

July 29, 1947.

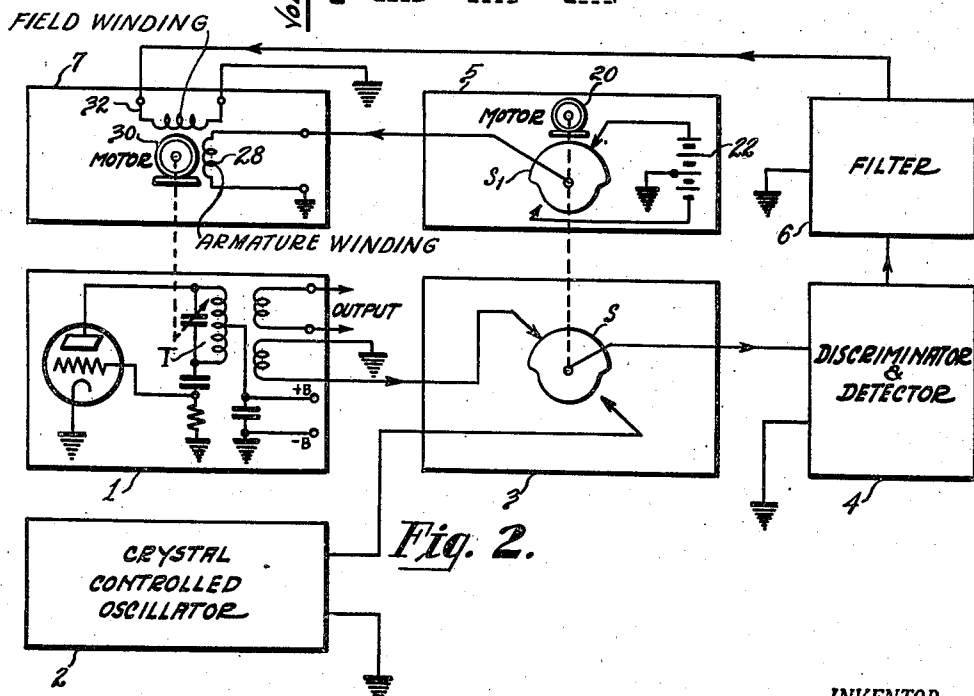
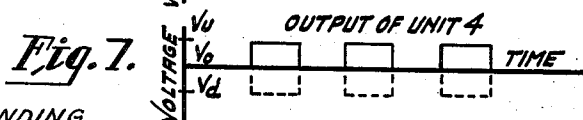
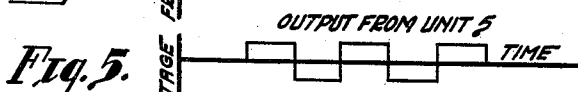
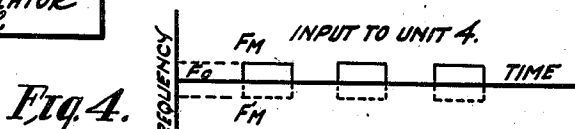
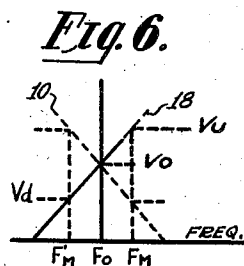
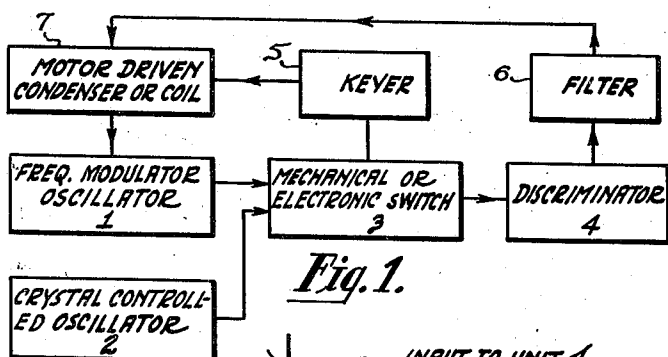
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2,424,833

FREQUENCY COMPARISON AND CONTROL CIRCUIT

Filed Oct. 18, 1944

2 Sheets-Sheet 1



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FREQUENCY COMPARISON AND CONTROL CIRCUIT

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2 Sheets-Sheet 2

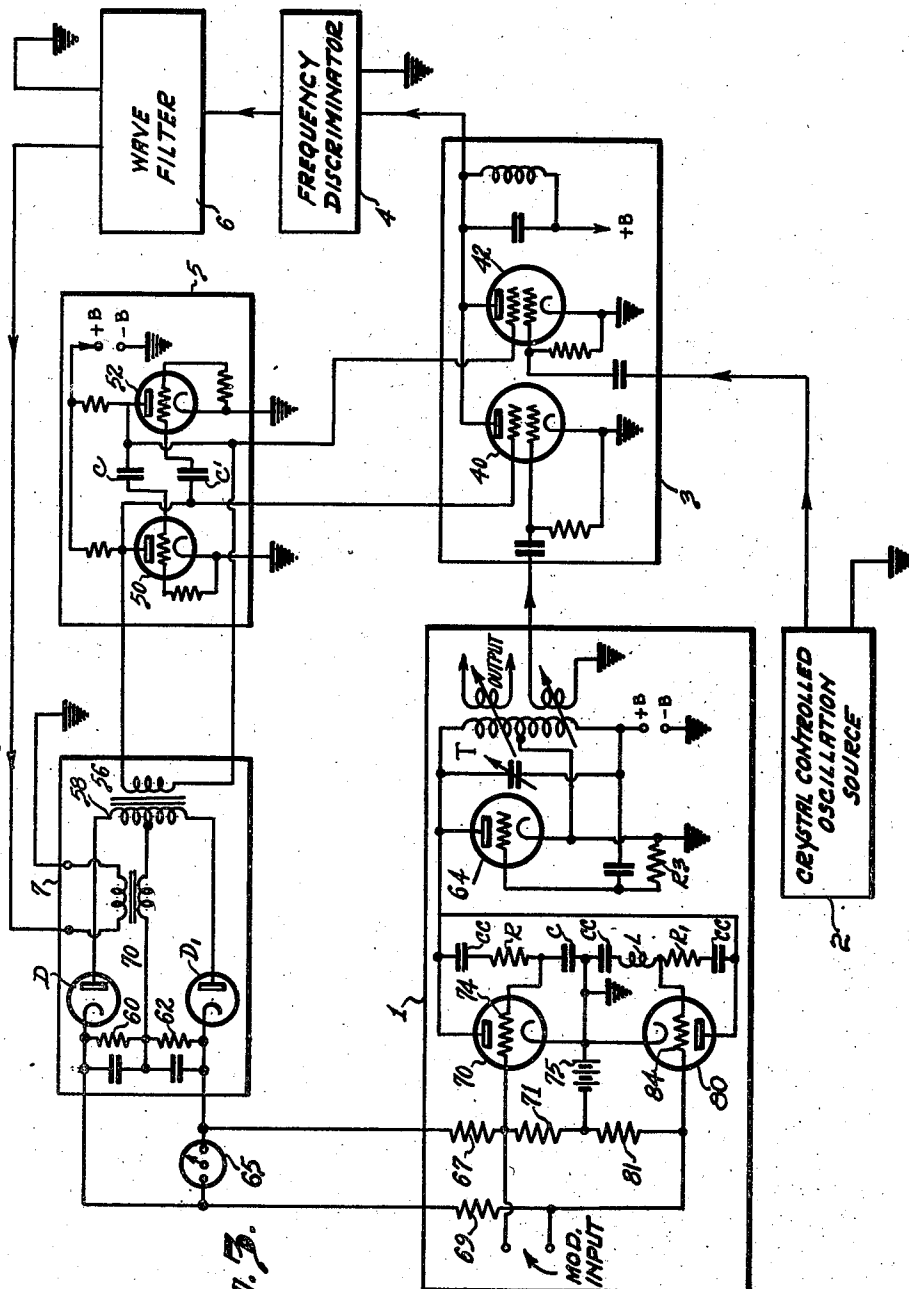


Fig. 3.

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2,424,833

FREQUENCY COMPARISON AND CONTROL
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Application October 18, 1944, Serial No. 559,189

14 Claims. (Cl. 250—36)

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This application relates to a method of and means for comparing the frequency of a source of wave energy the frequency of which may drift, with the frequency of wave energy of a substantially constant frequency, (standard source), and for producing current or energy which has a characteristic that changes when the frequency relation of the compared currents changes.

Such means are of wide use in the radio and allied arts. For example, it is often desirable to be able to check the operating frequency of a source of oscillations which may drift, and this application discloses an improved and simplified method and means for accomplishing this.

For example, in receivers of the heterodyne type, the received wave or the local oscillator may change in frequency so that the resulting I. F. frequency may not coincide with the tuning of the I. F. stages. In timing modulation systems usually an oscillation generator the frequency of which may be varied by the modulation is used. The oscillator may also drift in mean frequency of operation. In this application I show an improved, efficient and simplified means for comparing the frequency of oscillations from sources of this type with oscillations of substantially constant frequency to ascertain whether or not the frequency of the oscillations from the said sources are as intended.

This application also relates to methods of and means for ascertaining the relation of the frequency of a source of oscillations with respect to a standard source frequency and for producing currents or energy a characteristic of which depends on the relation of the frequency of the source to the standard source.

This application also relates to methods of and means for ascertaining the relation of the frequencies of two sources one of which is of fixed frequency, producing currents or energy characteristic of the deviations and direction of deviation of the variable source frequency from the fixed source frequency and for stabilizing or retuning the source the frequency of which may drift by means of the produced current or energy.

The broad general object of this invention is improved frequency comparison and control.

More in detail, the object of this invention is simplified, improved and efficient means for comparison of the frequencies of two sources of oscillations one of which is of substantially fixed frequency, and one which is of a frequency which may drift or vary slowly.

A further object of this invention is means for comparing the frequencies of two sources as

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described in the preceding paragraph, and simplified, improved and efficient means for deriving currents or energy characteristic of the frequency relation of oscillations from the two sources.

5 An additional object of this invention is means as described in the preceding paragraph, and simplified, improved and efficient means for using the derived currents or energy to correct the frequency of the oscillations the frequency of which may vary.

Other objects and the manner in which the same and the foregoing objects are attained will appear from the description which follows.

10 In describing my invention in detail, reference will be made to the attached drawings wherein Fig. 1 shows schematically and by block diagram the essential features of a frequency comparison and control circuit arranged in accordance with my invention, by means of which my improved method can be carried out. In Fig. 1, which is given merely by way of example, the oscillator the frequency of which may vary is designated as a frequency modulated oscillator of a frequency modulation system. The invention is equally applicable to oscillators used for other purposes, such as heterodyning oscillators of transmitters or receivers.

15 Figs. 2 and 3 each illustrate a preferred embodiment of my improved frequency comparison and control means. In Figs. 2 and 3, as in Fig. 1, certain of the apparatus and means used is shown merely by rectangle, since the same may be conventional and per se forms no part of the present invention. Other features are shown by simplified circuit diagram.

20 Figs. 4 to 7, inclusive, are curves used in describing the operation of the keyer in unit 5, the switching means in unit 3, the discriminator in unit 4, and the manner in which the frequencies of the two sources are compared, the nature of the current produced by such comparison, and the manner in which the same is used to retune the oscillator in unit 1.

25 As illustrated in Fig. 1, a timing modulated wave generator included in rectangle 1 is to be stabilized in operation so that its mean or average frequency is held substantially constant in the assigned band. A self-excited oscillator may be used here and may be modulated in frequency in any well known manner.

30 The unit 2 includes a source of oscillations of fixed frequency and, if desired, frequency multipliers to provide a stable output at the proper mean frequency of the modulated wave from

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unit 4. A crystal controlled oscillation generator is preferred in unit 2.

The unit 3 includes a device for alternately feeding the outputs of units 1 and 2 to a discriminator and detector in unit 4. The device in unit 3 may be either mechanical or an electronic switch which is keyed by the output of a keyer in unit 5. The keyer in unit 5 may comprise a wave generator providing a wave to key the switcher in unit 3, or may comprise mechanical means for providing keyed direct current at its output.

The current out of 5 may be of sine wave form or rectangular. In one example illustrated, the apparatus in 5 is a multi-vibrator oscillator of a well known type wherein sustained oscillations of square wave form such as illustrated in Fig. 5 are generated. These currents or voltages which may be below audibility or, if desired, above audibility, are fed to the unit 3 which herein is referred to as a switching stage. The function of the unit 3 is to permit output from the modulated non-stable oscillator 1, and output from the stable oscillation source 2 to be fed to the discriminator and detector in 4 alternatively for equal time periods set by the rate of recurrence of the current or oscillations from unit 5.

The object of this apparatus is to compare the mean frequency of the oscillations of the modulated generator in 1 with the frequency of the oscillations from the reference source in 2.

Assume that the mean frequency out of unit 1 is as desired. Then it is equal to the frequency of the source in 2 and the frequency of the oscillations fed alternatively by mechanical or electronic switch stage 3 to the discriminator in 4 are equal and say F_0 and represented by a straight line in Fig. 4. The output of a discriminator and detector in unit 4 will then be constant (F_0 Fig. 6) and represented by a straight line, say V_0 in Fig. 7. If, however, the mean frequency of the modulated oscillations out of unit 1 has varied and is say higher than the frequency of the oscillations from source 1, then as 3 is switched by the output of the keyer in unit 5 the input to the discriminator in unit 4 is first at frequency F_0 , Fig. 4, and then at frequency F_m (modulated oscillations out of unit 1); and back at F_0 . If the drift of the modulated source in unit 1 is in the opposite direction when this source is switched through, the pulses F'_m passed to unit 4 input are below the frequency F_0 , as shown by dotted lines in Fig. 4.

Now the output of the discriminator and detector changes, as illustrated in Fig. 6, and there is an increased output from unit 4 when the modulated oscillations have a mean frequency F_m above the frequency of the source in unit 2, and the stage 1 is feeding through to the input of the unit 4. The voltage at the detector output varies from V_0 to V_u , Fig. 7, as the stage 3 switches the input to the discriminator and detector in unit 4. The wave form at the output of unit 4 is then as illustrated by full lines in Fig. 7.

If the drift of the modulated source in unit 1 is in the opposite direction and say through the frequency F_0 of the reference source to a frequency F'_m , Figs. 4 and 6, then the output of the discriminator and detector in unit 4 drops to say V_a , Fig. 4, when the switch in 3 lets the output of the modulated oscillator 1 through. The wave form is then as shown by dotted lines and full lines in Fig. 7.

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Thus from the discriminator and detector in unit 4 I derive a voltage which is keyed from a base value an amount depending on the drift of the mean frequency of the modulated wave from unit 1, and in a direction depending upon the relation of this mean frequency to the frequency of the oscillations generated in unit 2. The discriminator and detector in unit 4 has a linear characteristic over the range of the frequencies which may be present at its input.

A filter circuit in unit 6 functions to remove the modulation present on the output of the frequency modulated oscillator in unit 1. The filter in 6 is not needed in cases where the tuning device used to stabilize the mean frequency of the modulated oscillator in unit 1 is not responsive to this modulation.

At the output of the filter in 6 then is obtained a square wave whose amplitude is proportional to the differences between the average frequency of the modulated oscillator in unit 1 and the frequency of the stabilized or fixed frequency output of unit 2. This square wave is plotted against time in Fig. 7, and is either in phase or out of phase with the output of the keying means in 5, depending upon whether the mean frequency of the oscillations out of 1 is higher or lower than the frequency of the stabilized oscillations out of unit 2, and on the phasing of the switcher in 3 and the discriminator characteristic in 4. For example, if Figs. 5 and 7 are compared, it will be seen that when the mean frequency of the oscillator unit 1 is above F_0 the wave output of the discriminator 4 and filter 6 shown in full lines in Fig. 7 is in phase with the keying voltage out of unit 5, shown in Fig. 5. When the mean frequency of the oscillator unit 1 is below F_0 then the keying voltage out of 5 and output of the discriminator 4, shown in dotted lines, Fig. 7, oppose.

It will also be apparent by reference to Fig. 6 that reversing the discriminator characteristic so that it is as shown by dotted line 10 therein instead of by full line 8, will reverse the output of the detector in unit 4 and filter in unit 6, as shown by dotted lines in Fig. 7. Note that this output now opposes in phase the output from unit 5, whereas the output of unit 4 shown in full lines is in phase with the output from unit 5. Obviously, by reversing the operation of the mechanical or electrical switch in unit 3 the same result can be obtained. Also by reversing the operation of the keying voltage or current out of the unit 5 will result in reversing the output of the discriminator 4 in filter 6. Any of these expedients then may be used to provide out of 6 for use in the tuning apparatus in 7 a voltage of a polarity such as to retune the oscillator in 1 in the proper direction to bring the mean frequency thereof in agreement with the frequency of the reference oscillations supplied from 2.

In any case, the square wave output from the filter 6 is either in phase (full lines, Figs. 5 and 7), or out of phase (dotted lines, Fig. 7; full line, Fig. 5), with the output of the keyer in 5 depending on whether oscillator 1 is higher or lower in frequency than oscillator 2, and this phase relation is such as will be seen in detail hereinafter to act through the unit 7 to properly tune the frequency modulated oscillator in 1 to restore equality between the frequencies fed through switcher stage 3 to unit 4.

The outputs of units 5 and 6 are combined, in one of a number of ways, to control the tuning of the oscillator in 1 to hold the same at the fre-

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quency of the reference oscillations produced by oscillator 2. One such device for retuning the oscillator in 1 is a variable capacitor or inductance in the oscillator circuit driven by a direct current motor whose field and armature are actuated by the outputs of the filter 6 and the keyer 5, respectively. The essential features of this arrangement have been shown in Fig. 2 of the drawings. This Fig. 2 also illustrates an embodiment of my invention wherein the keyer in the unit 5 and the switching means in the unit 3 are mechanical.

The oscillator in 1 may include an electron discharge device having a tank circuit T coupled with its anode and tuned by a motor driven condenser. Additional capacity not shown may be included in the circuit T. The oscillator may be frequency modulated in any known manner in accordance with control potentials. For example, reactance tube modulation as disclosed in Crosby patents No. 2,279,659, dated April 14, 1942, and No. 2,279,660, dated April 14, 1942, may be used. The mean frequency depends upon the tuning of T and the tuning of T depends upon rotation of the motor in 7. Output from the unit 1 in tank circuit T is supplied by way of a mechanical switch S in unit 3 to the unit 4 during a portion of a cycle of rotation of S, say half of a cycle of the rotation of the switch S. Output from the unit 2, i. e., oscillations of the reference frequency are supplied through the switch S in unit 3 for the remaining part of this cycle. The switch S is on a shaft which also carries a switch S₁ in the unit 5 and the switches S and S₁ are synchronized and may be driven by a motor 20 at say a sub or super-audible rate. The switch S₁ alternately applies direct current potentials of opposed polarity from the source 22 to the armature winding 28 of a direct current motor 30 in unit 7 driving a condenser in the tank circuit T.

When the switch S and S₁ are in the position shown high frequency current flows from the oscillator in 1 to the input of the discriminator in 4, and direct current flows from the positive end of source 22 in one direction through the armature winding 28 of the motor 30. When the switch motor 20 rotates the switches S₁ and S through a half cycle of rotation the input to the discriminator 4 is coupled to the output of the oscillator in 2 and the winding 28 of the motor 30 is coupled to the negative terminal of the source 22 so that current flows through this winding in an opposite direction. Relative movement of switches S and S₁ through half a cycle in either direction will change this relation so that the oscillations out of unit 1 are supplied to the input of 4 when the negative terminal of source 22 supplies current to the winding 28.

The output of the filter in 6 is supplied to the field winding 32 of the motor 30. When the sources in units 1 and 2 are of like frequency the output of the discriminator and detector is constant, i. e., there is no pulse output since the voltage is V₀ as illustrated in Fig. 7, the winding 32 is not energized, and the rotor of the motor 30 is stationary, so that the oscillation generator 1 operates at the same mean frequency as long as this condition is maintained. If the frequency of the unstable oscillator in 1 drifts below F₀ so that there is a pulse output from the discriminator and detector in 4 which has pulse peaks below V₀ to provide an output V_a, Fig. 7, in phase opposition to the output of unit 5 to winding 28, then the motor 30 is caused to operate in a direction such as to retune the tank circuit T in a

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proper sense to bring the frequency of the oscillator generator 1 back to the frequency of the oscillator generator 2. If the drift has been in the opposite direction so that the frequency of the generator in 1 is above F₀ the pulse peaks out of the detector are above V₀ at say V_b and the polarity of the current through the winding 32 is reversed with respect to the polarity of the current out of the unit 5 through winding 28, and the direction of the rotation of the motor 30 reverses to again tune T in a sense such as to bring the mean frequency of the oscillations generated in 1 to the frequency of the oscillations generated in 2.

In the embodiment of Fig. 3 the oscillation generator in unit 1 may be of the type wherein the tank circuit is associated with the output impedances of a pair of reactance tubes connected for modulation as described say in U. S. Patent #2,279,661. The balanced combining and rectifying system in unit 7 provides a differential output which in one direction increases the frequency of the oscillator in 1 and in the other direction decreases the frequency thereof.

The switching means in unit 3 may then comprise a pair of electron discharge devices 40 and 42 having their anodes tied together to supply input to the discriminator and detector in unit 4 from the unstable oscillator in 1 or the stable oscillator in 2. Tube 40, for example, has its input electrodes including its control grid coupled to the output of unit 1 while tube 42 has its input electrodes including its control grid coupled to the output of unit 2. The two tubes also include screening electrodes by means of which they are switched alternatively to pass and to block passage of excitation from unit 1 or 2 to unit 4.

The multi-vibrator tubes 50 and 52 in keyer 5 have their anodes connected through resistances to a positive source of potential the negative terminal of which is grounded and thereby connected to the cathodes of these two tubes. The control grids and anodes of the two tubes are cross-connected through coupling condensers and the anodes of the two tubes 50 and 52 are also connected to the screening grid electrodes of the switching tubes 40 and 42. The bias resistances between the control grids and cathodes of the tubes 50 and 52 and the condensers C and C' in the couplings between the anodes and control grids are such that the tubes 50 and 52 generate in a well known manner sustained oscillations of square wave form and of a sub-audible and super-audible frequency. In generating these oscillations the tubes are alternatively conductive so that the potentials on the anodes thereof rise and fall at the oscillation rate and pass from a value which is positive sufficiently to key tubes 40 and 42 to a conductive state to a value which is sufficiently less positive or negative to cut these tubes off. Thus in operation the tubes 40 and 42 are alternatively keyed on and off by keying of the screen grid potentials thereof. Then the discriminator circuit in 4 has as input oscillations from the source 1 or from the source 2 alternatively present.

The anodes of the tubes 50 and 52 are also connected to the opposite ends of the winding 56 so that the generated oscillations are set up in this winding to appear in the winding 58 and to be applied differentially to the diode detectors D and D₁. These diode detectors have their cathodes coupled in opposition by resistances 60 and 62 shunted by condensers of sufficient size to remove any voltages or current changes of modula-

tion frequency to prevent modulation of the frequency modulated generator in 1 by such changes super-impressed on the control potentials. The output of the filter 6 is supplied to a second transformer 70 having its secondary winding connecting the diodes D and D1 in parallel. The diodes D and D1 as connected compare and detect the phase relation of the outputs of units 5 and 6.

Inspection of this circuit will show that the voltages impressed from 56 on the diodes D and D1 are in phase and out of phase respectively, with the voltages impressed in parallel on these diodes by transformer 70. Moreover, the phase relation of the output at 56 and the output of unit 6 depends upon whether the mean frequency of the modulated oscillator in 1 is ahead or behind the frequency of the stabilized source in 2. Since the detector D and D1 outputs which appear across resistances 60 and 62 are differential the polarity of the output depends upon whether the mean frequency of the source to be controlled in unit 1 is ahead or behind the frequency of the standard source in unit 2. The term polarity as used here is not to mean that the cathode of one diode is negative when the cathode of the other diode is positive and vice versa. The term does mean, however, that if we assume that when the sources in 1 and 2 are in synchronism the cathodes of D and D1 are say positive small substantially equal amounts and the frequency of 1 then shifts the cathode of one diode say D will become more positive and the cathode of D1 will become less positive. If the shift in frequency of the source in 1 is in the opposite direction then the cathode of diode D would have become less positive and the cathode D1 more positive.

The potentials developed at the diode cathodes are proportional to the difference between the frequencies out of sources 1 and 2 and a meter 65 shunting resistances 60 and 62 may be calibrated to show not only this difference but also give sense indications, i. e., denote whether source 1 is of higher or lower frequency than source 2.

The potential appearing at the cathode end of resistances 60 or resistance 62 may be used to retune the oscillation generator in 1 in any desired manner. For example, either of these potentials may be applied as a control voltage to a single reactance tube associated with the tank circuit T to tune the same and make the necessary corrections. In the embodiment illustrated the potentials at the diode cathodes are applied differentially to two reactance tubes 70 and 80, described in detail hereinafter.

The phase relation of the voltages out of units 5 and 6 is made such, by one or the other of the means described hereinbefore, as to vary the effective reactance of the tubes 70 and 80 connected with the generator in 1 in a sense to bring the mean frequency of the oscillator 1 toward the frequency of the oscillator 2. In addition to the means described hereinbefore for properly relating the phase of the output 5 to the phase of the output of 6 to obtain frequency correction in the desired sense, it will be noted that the direction of tuning can also be reversed by reversing the polarity of either of the windings of transformers 56 and 70. The condensers 60 and 62 filter out the switching frequency components before they reach the reactance tubes and cause undesired modulations.

The reactance tube controlled oscillation generator in Fig. 1 may take many forms. For example, I may use frequency modulated oscillation generators of the nature disclosed in many

prior art patents, such as, for example, Crosby U. S. Patent #2,279,659, 2,279,660, 2,279,661 and 2,324,282.

In Fig. 3 I show a system substantially as disclosed in Fig. 2 of Crosby U. S. Patent #2,279,661. The generator comprises a tube 64 having an anode control grid and cathode regeneratively coupled by a tank circuit T for the production of oscillatory energy of frequency determined in part at least by the tuning of the tank circuit T. The generator has its grid supplied with direct current biasing potential by resistance R3 and its anode connected to a +B source. The negative terminal of this source and the cathode are grounded. The generator is coupled to the input of the unit 3, i. e., the switching stage, and has an output coupled as desired to any utilization circuit.

The reactance tubes 70 and 80 have their anodes tied together and connected to the anode end of tank circuit T. The cathodes of the reactance tubes are tied together for radio frequency potential and to the cathode of the oscillator tube 64 so that the reactive effect produced in these tubes 70 and 80 shunt a part at least of the tank circuit T. The phases of the radio frequency voltages on the anodes of these tubes are alike. The grid 74 of tube 70 obtains a radio frequency voltage shifted in phase about 90° by virtue of the action of phase shifting resistance R and phase shifting condenser C. The grid 84 of the tube 80 likewise is supplied a voltage shifted in phase about 90° with respect to the anode voltage of this tube by virtue of the action of phase shifting resistance R1 and inductance L. The condensers CC are merely coupling condensers and of little or no effect on the phasing of the voltages. Since tube 70 obtains its grid voltage by a capacitive reactive drop while the tube 80 obtains its grid 84 voltage from an inductive reactive drop the effective variable reactance of the plate circuits of the two tubes are of opposite sign, one being predominantly capacitive reactance, the other being predominantly inductive reactance. Since an increase in amplification decreases the effective inductance in the plate circuit of say tube 80, and increases the effective capacity in the plate circuit of tube 70, it can be seen that if the amplification of both tubes vary in the same direction the reactive effects tend to cancel. However, it can also be seen that if differential control is applied as disclosed here, an increase in the amplification of one tube while decreasing the amplification of the other tube causes the reactive effect to aid each other, thereby tuning the tank circuit T. The control potentials developed across resistances 60 and 62, which vary above and below about equal positive values as described hereinbefore, are fed to the control grids 74 and 84 by way of resistances 67 and 69 respectively. The grids 74 and 84 are biased negatively the proper amount by source 75 connected to the grids 74 and 84 by resistances 71 and 81 respectively. The source 75 and the resistances 67, 69, 71 and 81 are such that the differential potentials from diodes D and D1 change the respective tube 70 and 80 conductances the amount required to hold operation of the generator including tube 64 and tank circuit T at the proper, and substantially constant, mean frequency.

The modulation may be applied as desired as long as it is also differential in its effect on the tube reactances. It may be applied to the control grids as shown.

In the sake of simplicity I have used a discriminator and detector system in Fig. 4 having a single sloping characteristic as illustrated in Fig. 6. Obviously in practice I contemplate using a balanced discriminator circuit in order that amplitude variations on the currents supplied to the unit 4 will cancel out. For example, I may use a discriminator and detector of the off-tuned circuit type referred to in the art as the Conrad type discriminator. This discriminator may be substantially as disclosed in Conrad U. S. Patent #2,151,747, dated March 28, 1939. A preferred form of circuit for use here is disclosed in Seeley U. S. Patent #2,121,103, dated June 21, 1938, and in Crosby U. S. Patent #2,230,212, dated January 28, 1941.

If a filter is necessary in unit 6 it may be of the low pass type where a sub-audible keying rate is used in the unit 5 of Fig. 2, or a sub-audible multi-vibrator generator is used in unit 5 of Fig. 3. Then frequencies falling below the modulation band are passed. In case a super-audible rate of keying is used in Fig. 2 or a super-audible generator is used at 5 in Fig. 3, a high pass filter passing frequencies above the modulation frequencies may be used in unit 6.

I claim:

1. In a signalling system two sources of oscillations the frequency of one of which may drift with respect to the frequency of the other, reactance tube control means associated with said one source to control the frequency thereof, a discriminator and detector circuit, a switching circuit for alternatively connecting the outputs from said sources to said discriminator circuit at a selected rate to produce pulses of said rate when said one source drifts, of a phase depending on the direction of drift of the frequency of said one source, means for producing voltages of a frequency equal to said selected rate, means for combining said produced voltage with the output of said discriminator and detector circuit to obtain voltages of an amplitude determined by the extent of drift of the frequency of said one source, and means for controlling said tube reactance in accordance with said last mentioned voltages.

2. The method of comparing the frequency of a source of oscillations of unstable frequency with oscillations from a source of substantially the same and fixed frequency which includes these steps, producing current pulses recurring at a substantially constant rate, subjecting pulses of said oscillations of unstable frequency, recurring substantially at said constant rate, and alternatively occurring pulses of said oscillations of fixed frequency to a frequency demodulation action, to derive pulses the phase of which depends on the frequency of the unstabilized oscillations and pulses of fixed frequency, and combining said produced current pulses with said derived pulses to provide resultant potentials which vary from a base value in a direction depending on the frequency relation of the unstable oscillations and stable oscillations.

3. The method of comparing the frequency of a source of oscillations of unstable frequency with oscillations of substantially the same and fixed frequency which includes these steps, producing current pulses recurring at a substantially constant rate, subjecting pulses of said two oscillations recurring alternately at the same substantially constant rate to a timing demodulation action to derive pulses of current, of like pulse rate and timing, the phase of which depends on whether the frequency of the unstable oscilla-

tions is above or below the frequency of the oscillations of fixed frequency, and combining said produced current pulses with said derived pulses of current to provide resultant potentials which vary from a base value in a direction depending on the frequency relation of the unstable oscillations and stable oscillations.

4. The method of stabilizing the frequency of a source of oscillations of otherwise unstable frequency by means of oscillations of substantially the same and fixed frequency which includes these steps, producing current pulses recurring at a substantially constant rate, subjecting pulses of said two oscillations recurring alternately at the same substantially constant rate to a frequency discriminating and detecting action to derive pulses of current, of like pulse rate and timing, the phase of which depends on whether the frequency of the unstable oscillations is above or below the frequency of the oscillations of fixed frequency, combining said produced current pulses with said derived pulses of current to provide resultant potentials which vary from a base value in a direction depending on the frequency relation of the unstable oscillations and stable oscillations and controlling the frequency of said oscillations of unstable frequency in accordance with said resultant potentials.

5. The method of comparing the frequency of a source of oscillations of unstable frequency with oscillations from a source of substantially the same and fixed frequency which includes these steps, generating current pulses of substantially square wave form and of substantially constant frequency, alternately selecting pulses of oscillations from said two sources at a pulse rate equal to the pulse rate of said generated pulses and in synchronism therewith, detecting the selected pulses of oscillations to derive pulses of current, of like pulse rate and timing, the phase of which depends on whether the frequency of the unstable oscillations is above or below the frequency of the oscillations of fixed frequency, and combining said generated current pulses with said derived pulses of current to provide resultant potentials which vary from a base value in a direction depending on the frequency relation of the unstable oscillations and stable oscillations.

6. The method of stabilizing the frequency of a source of oscillations of unstable frequency by means of oscillations from a source of substantially the same and fixed frequency which includes these steps, generating current pulses of substantially square wave form and of substantially constant frequency, alternately selecting pulses of oscillations from said two sources at a pulse rate equal to the pulse rate of said generated pulses and in synchronism therewith, subjecting the selected pulses of oscillations to a timing demodulation action to derive pulses of current, of like pulse rate and timing, the phase of which depends on whether the frequency of the unstable oscillations is above or below the frequency of the oscillations of fixed frequency, combining said generated current pulses with said derived pulses of current to provide resultant potentials which vary from a base value in a direction depending on the frequency relation of the unstable oscillations and stable oscillations, and controlling the frequency of said oscillations of unstable frequency in accordance with the resultant potentials.

7. In apparatus for comparing the frequencies of oscillations from two sources the frequency of one of which may drift with respect to the fre-

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quency of the other, a discriminator and detector circuit, a switching circuit for alternatively connecting the outputs from said sources to said discriminator circuit at a selected rate to produce pulses of said rate when said one source drifts, of a phase depending on the direction of drift of the frequency of said one source, means for producing voltages of a frequency equal to said selected rate, and means for combining said produced voltage with the output of said discriminator and detector circuit to obtain voltages of an amplitude determined by the extent of drift of the frequency of said one source.

8. In frequency control apparatus two sources of oscillations the frequency of one of which may drift with respect to the frequency of the other, a discriminator and detector circuit, a switching circuit for alternatively connecting the outputs from said sources to said discriminator circuit at a selected rate to produce pulses of said rate when said one source drifts, of a phase depending on the direction of drift of the frequency of said one source, means for producing voltages of a frequency equal to said selected rate, means for combining said produced voltage with the output of said discriminator and detector circuit to obtain voltages of an amplitude determined by the extent of drift of the frequency of said one source, and means for retuning said one source of oscillations in accordance with said last mentioned voltages.

9. In apparatus for comparing the frequencies of oscillations from two sources the frequency of one of which may drift with respect to the frequency of the other, a frequency discriminator and detector circuit, a switching circuit for alternatively and at a selected rate connecting the said sources to said discriminator circuit to alternatively rectify oscillations from said sources to supply rectified output, means for producing output voltages of said selected rate, and a balanced rectifier system excited differentially by one of said outputs, and cophasially by the other of said outputs.

10. In apparatus for comparing the frequencies of oscillations from two sources the frequency of one of which may drift with respect to the frequency of the other, a frequency discriminator and detector circuit, a switching circuit for alternatively and at a selected rate connecting the outputs from said sources to said discriminator circuit to alternatively rectify the outputs of said sources to supply rectified output, means for producing voltages of said selected rate, and a balanced rectifier system excited differentially by the output of said discriminator and detector circuit, and cophasially by said produced voltages.

11. In apparatus for stabilizing the frequency of oscillations from an unstable generator, a generator of substantially the same and fixed frequency, a frequency discriminator and detector circuit, a switching circuit interposed between said generators and said discriminator for alternatively connecting said generators to said discriminator circuit to alternatively rectify the oscillations to supply rectified output, a pulse generator having two outputs, one of which is coupled to said switching circuit to operate the

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same, a balanced rectifier system excited by the output of said discriminator and detector circuit, and by the generated pulses, and a tuning control circuit connecting said balanced rectifier system to said unstable generator.

12. In apparatus for comparing the frequencies of oscillations from two sources the frequency of one of which may drift with respect to the frequency of the other, a discriminator and detector circuit, a switching circuit for alternatively connecting the outputs from said sources to said discriminator circuit at a selected rate to produce current pulses of said rate when said one source drifts, of a polarity depending on the direction of drift of the frequency of said one source, switching means for producing direct current voltages of a frequency equal to said selected rate, and a motor having two windings, one of which is coupled with said discriminator and detector and the other of which is coupled with said last mentioned means.

13. In frequency control apparatus, two sources of oscillatory energy the frequency of one of which may drift with respect to the frequency of the other, a discriminator and detector circuit, a switching circuit for alternatively connecting the output from said sources to said discriminator circuit at a selected rate to produce pulses of said rate when said source drifts, of a phase depending on the direction of drift of the frequency of said one source, a motor having two windings, means for producing voltages of a frequency equal to said selected rate and supplying the same to one motor winding, a coupling between said detector circuit and the other winding of said motor, and reactive means operated by said motor for controlling the frequency of the oscillatory energy of said one of said two first sources.

14. In apparatus for comparing the frequencies of oscillations from two sources, the frequency of one of which may drift with respect to the frequency of the other, a frequency discriminator and detector circuit, a switching circuit for alternatively and at a selected rate connecting the said sources to said discriminator circuit to alternatively rectify oscillations from said sources to supply rectified output, of a polarity depending on the relative frequencies of said two sources, a motor having two windings, means for producing direct current potentials recurring at said selected rate and applying the same to one of said motor windings, and a connection between the output of said detector and the other of said motor windings, the arrangement being such that the direction of rotation of said motor depends upon the polarity of said rectified output.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
1,647,270	Burton	Nov. 1, 1927
2,151,127	Logan et al.	Mar. 21, 1939
2,126,910	Moseley	Aug. 16, 1938
2,111,598	Marrison	Mar. 22, 1938