Oct. 22, 1935. W. S. HALSTEAD 2,017,858

DUPLEX FREQUENCY CONTROL AND MONITORING SYSTEM

Filed Oct. 8, 1932 3 Sheets-Sheet 1

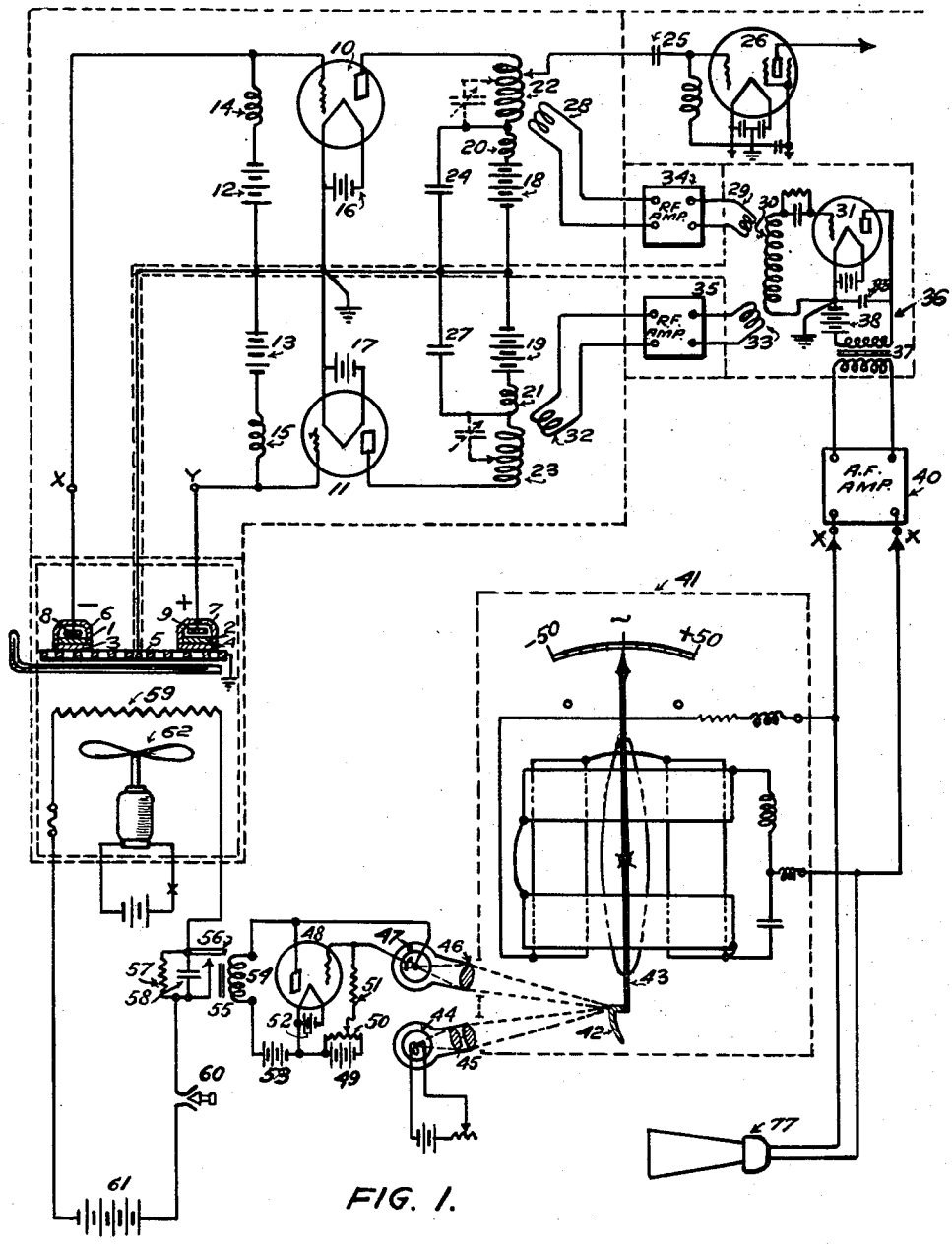


FIG. 1.

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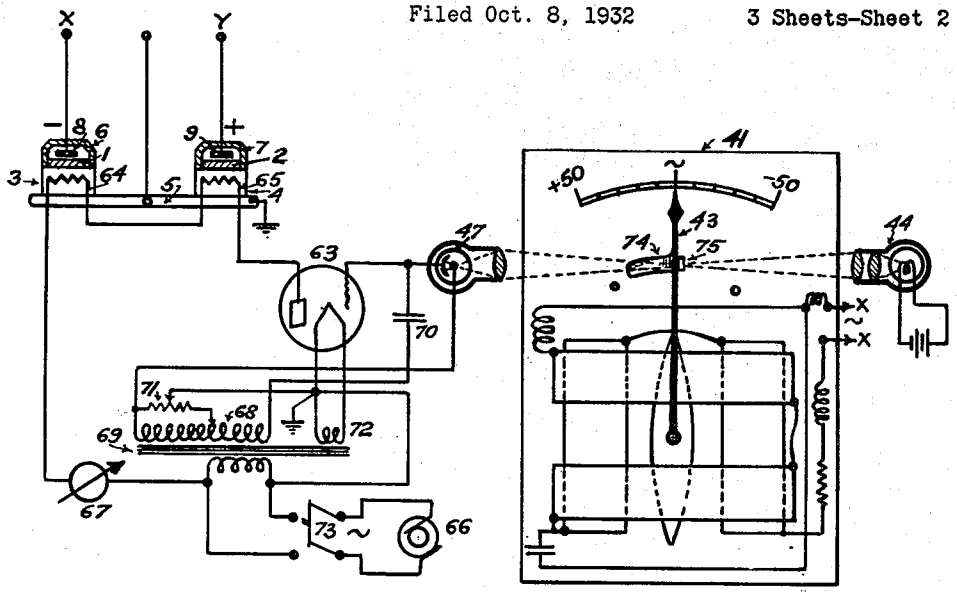


FIG. 2.

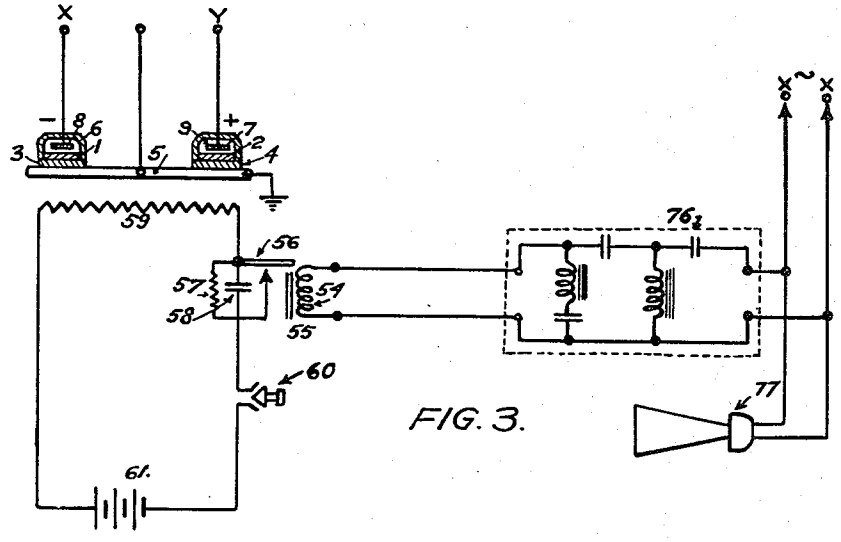


FIG. 3.

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DUPLEX FREQUENCY CONTROL AND MONITORING SYSTEM

Filed Oct. 8, 1932 3 Sheets-Sheet 3

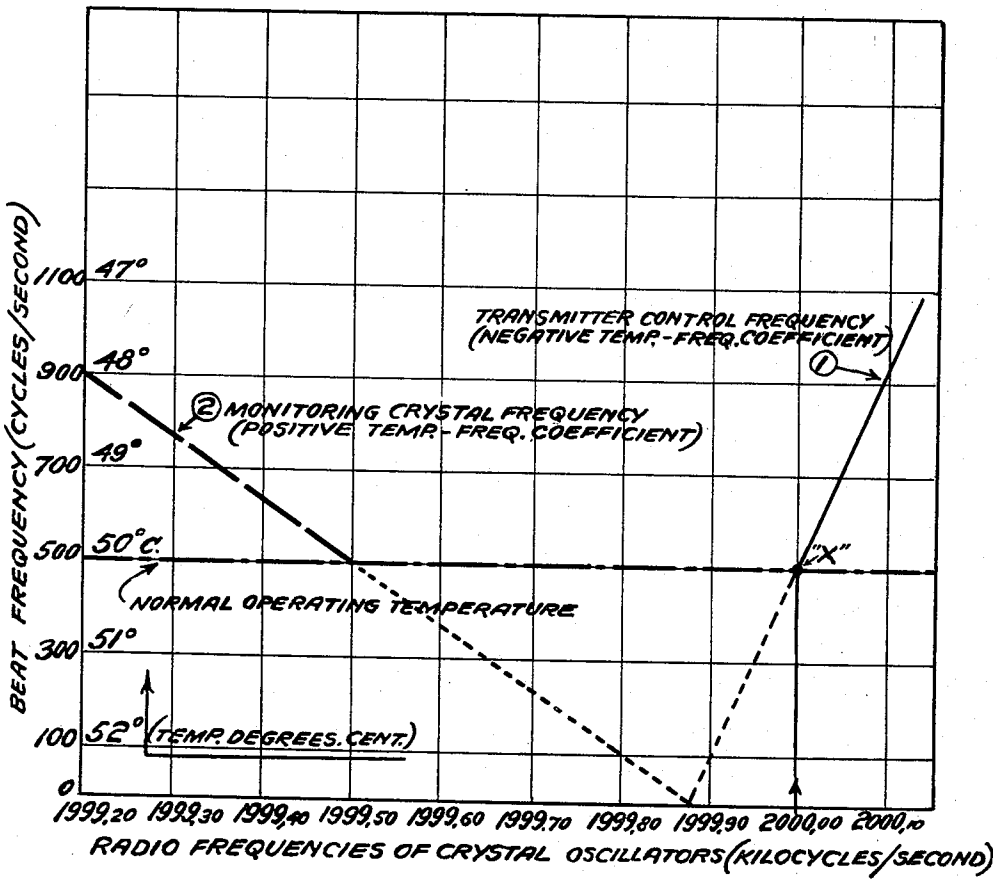


FIG. 4.

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2,017,858

DUPLEX FREQUENCY CONTROL AND MONITORING SYSTEM

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Application October 8, 1932, Serial No. 636,888

15 Claims. (Cl. 250—36)

(Filed but not issued under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates in general to the control or operation of electric circuits and is more particularly concerned with means for controlling the frequency of oscillating systems.

The invention is particularly applicable to radio transmission systems in which a piezo-electric crystal oscillator is employed to control the frequency of the emitted wave, and will therefore be described hereinafter with that type of radio frequency circuit in view; but it will be readily understood that this particularization constitutes no limitation on the invention, for other forms of oscillators, such as magnetostriction oscillators may be substituted for the piezo-electric frequency controlling crystals and the invention may also be employed in connection with other oscillating devices not directly associated with the radio art.

In prior applications of the piezo-electric crystal oscillator as a frequency control means for radio transmitters the degree of frequency stability of the emitted wave has been limited largely by the inability of mercury-column thermostats, or other devices with delicate moving elements responsive to temperature variations, through their associated relay-controlled heater circuits, to maintain the piezo crystal at a constant operating temperature over extended periods of time. Since very small changes in the temperature of the crystal are responsible for appreciable and increasingly objectionable variations in the frequency of the emitted signal, which ordinarily are not noticed by an operator unless suitable monitoring apparatus is employed, more accurate and reliable temperature control means which do not depend on moving thermo-responsive elements are desirable.

It is a primary object of the present invention to provide highly accurate means for obtaining a high degree of frequency stability in oscillating systems, without the use of thermostats or devices employing moving thermo-responsive elements.

It is a further object of this invention to provide means whereby the beat frequency between two oscillators of opposite temperature-frequency coefficients is employed as the frequency control means for both oscillators, one of which is connected as the frequency-determining portion of a radio transmitter.

Another object of this invention is to provide, with the same electrical frequency-control means, visual and audible indication of variations between the frequencies of the two oscillating systems.

It is still another object of this invention to provide additional means whereby temperature control of a piezo-electric crystal oscillator may be accomplished without either thermostats or relays.

According to the preferred embodiment of the present invention, these objects are accomplished by the generation of a variable audio-frequency beat signal whose variations in frequency are correlated with and dependent on variations in the joint temperature of two oscillating frequency-determining elements of opposite temperature-frequency coefficients, such as X- and Y-cut quartz arranged in the input circuits of two independent wave generators, one of which is employed as the frequency-determining portion of a radio transmitter. The beat signal, or control wave, is then employed to actuate frequency responsive and selective devices whose operation regulates the temperature of the two frequency-determining elements and thereby controls their respective frequencies.

In a selected application of this invention hereinafter described, one crystal, preferably of negative temperature-frequency cofficient, such as X-cut quartz, serves as the frequency-determining element of an oscillating circuit whose output is connected to the radio frequency amplifier of a radio transmitter. A portion of the output from the crystal oscillator circuit is supplied to a detector circuit whose input also carries radio frequency energy from the output of an independent monitoring crystal circuit whose frequency is determined by the second crystal, in this example of positive temperature-frequency coefficient such as provided by Y-cut quartz. Both crystals are jointly heated to a specified normal operating temperature at which the frequency difference between the frequencies of their associated oscillator circuits produces in the common detector circuit an audio-frequency beat signal, the frequency of which decreases towards zero beat as the temperature of the two crystals is increased beyond the specified normal operating temperature. The beat signal, which is the result of the frequency difference between the transmitter control circuit frequency and that of the monitoring crystal circuit is then employed to accomplish the following results: first, accurately regulate the degree of heat applied to the two crystals and thereby maintain within

small limits the emitted frequency variations of a radio transmitter; second, provide indication of variations of frequency of the transmitter-control crystal oscillator from the monitoring oscillator frequency by means of a precise visual frequency indicating device, such as a resonant frequency meter, and an audible frequency-change indicator such as a loud speaker connected to the input of the visual frequency-indicating device.

The invention will be more fully understood from the following detailed description of a present proposed embodiment thereof: reference for this purpose being made to the accompanying drawings, in which:

Figure 1 is a diagram of the frequency controlling portion of a radio transmitter having piezo-electric frequency-temperature control and monitoring means arranged in accordance with the invention.

Figure 2 is an alternate arrangement wherein the electro-magnetic relay-controlled crystal heater of Figure 1 is replaced by a space-discharge tube relay and associated crystal heater elements.

Figure 3 is a second alternate arrangement in which the resonant frequency meter with its associated photo-electric relay-control means and crystal heater as shown in Figure 1, is replaced by an electric wave filter.

Figure 4 is a diagram illustrating the frequency variations of the two crystal oscillators with changes in their temperature. Also, the diagram illustrates the corresponding beat frequency variation with identical changes in temperature.

Referring to the diagram of Figure 1, two piezo-crystals, 1 and 2, are mounted on lower electrodes 3 and 4, respectively, which are in turn mounted on a common perforated metallic plate or grille 5, connected to ground. Protective covers, 6 and 7, enclose crystals 1 and 2 respectively, and serve as supports for upper electrodes 8 and 9, respectively.

Crystal 1, the frequency-determining element of the transmitter proper is preferably of X-cut quartz, or tourmaline, possessing a negative temperature coefficient, i. e., its frequency of vibration decreases with an increase in temperature. Crystal 2, the monitoring frequency-determining element is preferably Y-cut quartz in which the temperature coefficient is positive, its frequency increasing with increase in temperature.

Upper electrodes 8 and 9, associated with crystals 1 and 2, respectively, are connected to the control elements of space discharge oscillators 10 and 11 respectively. Sources of negative grid potential 12 and 13, respectively, are connected between the grid and filament circuits of the two tubes 10 and 11, respectively, through radio frequency choke coils 14 and 15, respectively, for supplying the proper bias potentials to the two grids. Sources of E. M. F. 16 and 17 supply filament-heating current to the two oscillator tubes 10 and 11, respectively. Space current is supplied to tubes 10 and 11 from direct current sources of E. M. F. 18 and 19, respectively, through the radio frequency choke coils 20 and 21, respectively, and plate inductances 22 and 23, respectively. Inductance 22, in the plate circuit of oscillator tube 10, and radio frequency by-pass condenser 24 connected between the plate inductance and ground, complete the output circuit elements of the oscillating circuit of which crystal 1 is the frequency-determining portion.

Radio frequency energy is transferred from the output circuit of crystal oscillator tube 10 to the succeeding amplifier stages of the transmitter by coupling means such as condenser 25, connected between the plate end of inductance 22 and the control grid of the first radio frequency "buffer" amplifier 26.

Inductance 23, in the plate circuit of oscillator tube 11, and radio frequency by-pass condenser 27 connected between the plate inductance and ground, complete the output circuit elements of the monitoring circuit of which crystal 2 is the frequency-determining portion.

Coupling means such as coils 28 and 29 are employed to transfer a small amount of radio frequency energy from plate inductance 22 to the input circuit 30 of detector tube 31. Coupling means such as coils 32 and 33 also transfer a small amount of radio frequency power from the plate inductance 23 of oscillator tube 11 to the input circuit 30 of detector tube 31.

Isolating or "buffer" amplifiers 34 and 35 are inserted in the coupling circuits between the plate inductances 22 and 23, respectively, and the common grid circuit 30 of the detector tube 31 to prevent undesirable interaction between the two output circuits of the oscillators.

The plate circuit 36 of detector tube 31 is connected, through the primary windings of amplifying transformer 37 and source of plate current 38, to ground. A radio frequency by-pass condenser 39 is connected between the plate of detector tube 31 and ground. The secondary windings of amplifying transformer 37 are connected to audio frequency amplifier 40. The output terminals of the amplifier, shown at x—x, are connected to a tuned frequency-responsive device, such as a resonant frequency meter 41, provided with photoelectric means whereby the movement of the pointer of the frequency meter beyond a specified point on the meter scale controls the operation of the photoelectric circuit. A light-controlling medium, such as the curved reflecting element 42, is fastened to the pointer arm 43, of the frequency meter. In the arrangement shown in the diagram of Figure 1, light from a small incandescent lamp 44 is focused, by means of lens system 45, on the upper end of reflecting element 42 when the pointer arm is in the vertical position, as shown in Figure 1. The curvature of the reflecting element 42 is such that movement of the reflector to the left of the vertical position with increase in frequency above 500 cycles will not interfere with the passage of the beam of light from the lamp 44 through lens systems 45 and 46 to a photoelectric cell 47. However, any movement of the reflector 42 to the right of the vertical position with decrease in frequency below 500 cycles will immediately remove the reflecting surface from the incident light beam, thereby cutting off the light supply to the photoelectric cell. The light-sensitive cathode of photoelectric cell 47 is connected to the grid of a vacuum tube 48. The anode of photoelectric cell 47 is connected to the plate of vacuum tube 48, such connections producing an increase in current in the plate circuit of vacuum tube 48 with an increase in light received by the photoelectric cell. A source of grid potential 49, means for regulating the grid potential, such as potentiometer 50 shunting grid bias source 49, and a grid leak 51 connected in series between the moveable arm of the grid potentiometer and the grid, complete the elements of the input circuit of tube 48. Heating current for the cathode of

tube 48 is supplied from a source of E. M. F. 52. The plate current path includes in series connection, a source of E. M. F. 53 and windings 54 of an electric relay 55. The contacts of relay armature 56 are connected in parallel with resistor 57 and condenser 58, which elements are connected in series with crystal heater resistor 59, power switch 60, and a source of heater power 61. A motor-driven fan 62 provides means for securing proper heat distribution throughout the crystal oven. Audible indication of frequency change in the beat signal is provided by loud speaker 77, connected to the input of amplifier 40.

When read in connection with the diagram of Figure 1 and the foregoing description of the circuit parts, the operation of the duplex crystal control system is outlined as follows:

With the two crystal oscillator circuits in operative condition, switch 60 is closed thereby applying power to the heater element 59, common to both crystals. As the temperature of the transmitter frequency-control crystal, 1, increases its frequency of oscillation decreases since its temperature-frequency coefficient is negative. Conversely, as the temperature coefficient of monitoring crystal 2 is positive, its frequency increases directly with the temperature. With reference to Figure 4, assuming that transmitter-control crystal 1, of negative temperature coefficient, is ground to a 2000 kilocycle fundamental frequency at a specified normal operating temperature of 50 degrees centigrade, shown at "X", it will be seen that its frequency decreases towards 2000 kilocycles from a higher frequency as the temperature is increased. Monitoring crystal 2, of positive temperature coefficient, ground to a monitoring frequency 500 cycles below 2000 kilocycles at the specified normal operating temperature of 50 degrees centigrade, on the other hand approaches its monitoring frequency, 1999.50 kilocycles, from a lower frequency as shown by the broken line. It may be seen by further reference to the diagram that if the temperature of both crystals were permitted to rise several degrees above 50 degrees, the normal operating temperature, the frequencies of both crystals would coincide. This point of zero beat is illustrated in the diagram as the intersection of the two dotted lines, representing the convergence of the two frequencies towards a common frequency with unchecked temperature rise—a condition which is not permitted to exist in the operation of the circuits illustrated.

The radio-frequency coupling coils 28—29 and 32—33 connected between the output circuits of oscillator tubes 10 and 11 respectively, and the common grid input circuit 30 of detector tube 31 thus supply to detector tube 31 two frequencies both of which, as the temperature increases, approach a common zero beat frequency from opposite directions. The audio beat frequency in the plate circuit of the detector tube, resulting from the interaction of the two radio frequencies in the grid circuit, thus decreases towards zero beat as the radio frequencies of the two crystals draw closer together with increasing temperature, as may be seen by further reference to Figure 4 which also illustrates the approximate change of beat frequency with like temperature variations of the crystals. The audio beat signal is intensified by amplifier 40 and is then employed to actuate the resonant frequency meter 41. As long as the beat signal frequency is above 500 cycles the indicating pointer of the frequency meter is drawn to the right-hand portion of the indicating scale, in which position the reflecting element 42, carried by pointer arm 43, as previously outlined reflects light from lamp 44 to the photoelectric cell 47, thereby increasing the plate current of vacuum tube 48 which action closes relay 55, shunts resistor 57 and applies maximum heater current to the crystal heater element 59. The temperature of the crystals increases rapidly with application of full heater power thereby accelerating the decrease in beat frequency. When the beat frequency decreases slightly below 500 cycles the position of pointer arm 43 is such that it removes reflecting element 42 from the incident light beam from lamp 44. Photoelectric cell 47 receives no light, the plate current in vacuum tube 48 decreases, relay 55 opens and the current in the crystal heater element 59 is reduced. As a result, the temperature of the crystals drops, the beat frequency increases and the indicator pointer arm 43 again moves reflector 42 into the incident light beam, thereby closing relay 55, through the intermediary action of vacuum tube 48, which condition produces an increase in the heater current and a decrease in beat frequency. This cycle is repeated successively until the alternate application and reduction of full heater power soon maintains the average temperature and frequency within close limits.

It may be noted, by referring to Figure 4, that as the frequency of the oscillating circuit, determined by X-cut crystal 1, changes only 50 cycles, while the beat frequency changes 200 cycles, with one degree variation in temperature, the emitted frequency of the transmitter does not vary appreciably. At the same time, any undue frequency variations in beat frequency are visually and audibly indicated to the transmitter attendant. Failure or improper operation of any element in the system is indicated immediately by pronounced movement of the pointer of the frequency meter away from the normal vertical position.

In a modified form of the duplex crystal frequency-temperature control system, illustrated in Figure 2, the cathode of the photoelectric cell, 47, is connected to the grid of a vacuum tube or a gas-content tube such as a thyratron, 63, which is employed as an electronic relay in lieu of magnetic relay 55 of Figure 1. The plate of vacuum tube or thyratron 63 is connected through small heater elements 64 and 65, arranged in series and disposed directly beneath the lower electrodes of crystals 1 and 2, respectively, to a source of alternating E. M. F. 66. A milliammeter, 67 may be included in the plate circuit of tube 63 to give visual indication of the plate current. The anode of the photoelectric cell 47 is connected to one end of a secondary winding 68 of transformer 69, the other end of secondary winding 68 being connected through a condenser 70 to the grid of tube 63. A potentiometer 71 is disposed across a section of secondary winding 68 to vary the current flow through photoelectric cell 47. The mid-tap of the potentiometer is connected to one side of the filament of tube 63, which is also connected to one side of the primary winding of transformer 69. Current from transformer secondary 72 is employed to heat the cathode of tube 63. A power supply switch 73 is used to place the system in operative condition. The connections, as described, produce an increase in current in the plate circuit of vacuum tube 63 with an increase in the light received by the photoelectric cell. If a thyratron is used, the circuit connections are

such that no plate current flows until light is received by the photoelectric cell.

Frequency meter 41, connected to the output of amplifier 40 at "x—x", is similar to that of Figure 1, except that its circuit connections produce a movement of the pointer to the right with decrease in beat frequency. A modification of the light-control means illustrated in Figure 1, is employed in this arrangement. A light-shutter 74 is disposed on the pointer arm, 43, of frequency meter 40 so as to prevent the passage of a light beam from exciting lamp 44 through aperture 75 to photoelectric cell 47 when the pointer is to the right of the vertical position, corresponding to a decrease in beat frequency below 500 cycles.

The principle of operation of the circuit of Figure 2 is similar to that of the circuit previously described and illustrated in Figure 1. The movement of the pointer of the frequency meter to the right or left of the vertical position with decrease or increase in frequency controls the operation of the photoelectric cell so as to decrease or increase, respectively, the plate current flowing through crystal heater elements 64 and 65, thereby providing automatic temperature regulation of the crystals without the use of a thermostat or an electro-magnetic relay.

In the arrangement of Figure 3 a high-pass filter 76 is employed as a substitute for the resonant frequency meter 41 with its associated photoelectric cell 47 and amplifier 48 of Figure 1 to control operation of heater relay 55. The high-pass filter, which preferably is designed to cut off all frequencies below 500 cycles and pass without marked attenuation all frequencies above the 500 cycle cut-off frequency, is connected between the output "x—x" of the audio frequency amplifier 40, and the windings 54 of relay 55 of Figure 1.

In operation, the high-pass filter performs a function similar to that of the resonant frequency meter with its associated photoelectric circuit control means, namely, it acts as a frequency selective device which automatically closes relay 55 thus applying full current to the crystal heater element 59 when the beat frequency is above 500 cycles, and opens the relay, thereby reducing the current supply to the heater element when the beat frequency falls below 500 cycles.

It will be recognized that the illustrative systems described herein are capable of considerable modification and rearrangement without departing from the spirit and scope of the invention, and it is therefore to be understood that the following claims embrace all such modifications and equivalent arrangements as may fairly be construed to fall within the scope of the invention.

I claim:

1. In a frequency control and monitoring system employing oscillating circuits under control of frequency-determining resonators of opposite temperature frequency coefficients; common heating means for said resonators; means for producing resultant-wave oscillations of variable frequency, the frequency variations of said resultant wave being dependent upon the temperature changes of said resonators; means for amplifying said resultant wave oscillations; and resonant frequency-selective means for utilizing the frequency changes of the resultant wave to control the temperature of said resonators, and simultaneously to provide precise visual indication of the degree of frequency change in said resultant wave, including a resonant frequency meter having an indicating needle whose response to frequency variations controls the current flow through said common heating means thereby effecting temperature frequency control of said resonators.

2. In a frequency control system employing oscillating circuits under control of frequency-determining piezo-electric crystals of opposite temperature frequency coefficients; means for jointly heating said crystals; means for producing resultant wave oscillations of variable frequency, the frequency variations of said resultant wave being dependent upon the temperature changes of said crystals; means for amplifying said resultant wave oscillations; and resonant frequency responsive means for utilizing the frequency changes of the resultant wave to control the temperature of said crystals and simultaneously to provide precise visual indication of small frequency changes of said resultant wave, including a resonant frequency meter; an indicating needle on said meter for visually indicating frequency variations in cycles per second; a light-controlling element disposed on one extremity of said indicating needle; a light source; a photoelectric cell disposed so that said light-controlling element changes the amount of light received by said cell in response to frequency variations of the resultant wave; and an electron tube for amplifying the varying current flow through said photoelectric cell in response to light variations and associated resultant wave frequency variations, said electron tube being connected so that its anode current flows through said crystal heating means thereby providing temperature control of said crystals.

3. In a frequency control system employing oscillating circuits under control of frequency-determining resonators of unlike frequency temperature coefficients; electric heating means for changing the temperature of said resonators; means for producing resultant wave oscillations of variable frequency, the frequency variations of said resultant wave being dependent upon the temperature changes of said resonators; means for amplifying said resultant wave oscillations; and frequency selective means for utilizing the frequency changes of the resultant wave to control the temperature changes of said resonators and simultaneously to provide precise visual indication, in terms of cycles per second, of variations in the frequency of said amplified resultant wave, including a tuned electric filter; an electric relay connected to the output circuit of said filter, the armature of said relay being connected in series with said electric heating means and a source of electric power; and a resonant frequency meter connected to the input terminals of said electric filter.

4. In a frequency control and monitoring system employing oscillating circuits under control of frequency determining piezo-electric crystals of unlike temperature frequency coefficients; an electric heating means for changing the temperature of said piezo-electric crystals; means for combining the outputs of said oscillating circuits so as to produce resultant-wave oscillations of variable frequency, the frequency variations of the resultant wave being dependent upon the temperature of said piezo-electric crystals; means for amplifying said resultant wave oscillations; and resonant frequency-selective means for utilizing the frequency changes of said resultant wave to control the temperature of said piezo-electric crystals, and simultaneously to provide precise visual indication of variations in the frequency of said amplified resultant wave, including a

resonant frequency meter whose input circuit is connected to the output of said amplifying means; a movable indicating needle on said frequency meter for visually indicating frequency changes of said resultant wave; a source of light; a photoelectric cell; a light-aperture disposed on said frequency meter between said source of light and said photoelectric cell; a light-controlling shutter disposed on said indicating needle and in line with said light-aperture at a predetermined position of said indicating needle corresponding to a specific frequency value of said resultant wave; and an electric relay whose controlling circuit is connected to said photoelectric cell and whose controlled circuit is connected in series with said electric heating means for regulating the temperature of said piezo electric crystals.

5. In combination, two oscillating circuits, each controlled by frequency-determining resonators of opposite frequency-temperature coefficients; electric heating means disposed so as to jointly change the temperature of said resonators; a demodulator for combining the outputs of said oscillating circuits to produce a resultant wave whose frequency variations correspond to the frequency difference between said two oscillating circuits; an amplifier for increasing the wave energy of said resultant-wave; a resonant frequency meter connected to the output of said amplifier; an indicating needle on said frequency meter for visually indicating small variations in the frequency of said resultant-wave; a source of light; a photoelectric cell; an aperture disposed in said frequency meter between the source of light and the photoelectric cell; a shutter disposed on said indicating needle, said shutter being positioned in line with said aperture at a predetermined position of said needle, thereby controlling the passage of light rays from said source of light to said photoelectric cell in accordance with varying positions of said needle; and a space discharge tube connected to the output of said photoelectric cell; the output circuit of said tube being connected in series with said electric heating means and a source of electric power, thereby utilizing the current flow through said tube to vary the temperature of said resonators.

6. In combination, two oscillating circuits having frequency-determining piezo-electric resonators of unlike frequency-temperature coefficients; electric heating means disposed so as to jointly change the temperature of said resonators; a demodulator circuit for combining the output of said two oscillating circuits to produce a resultant wave whose frequency variations correspond to the frequency difference between said oscillating circuits; an amplifier for increasing the wave energy of said resultant wave; a resonant frequency-meter connected to the output of said amplifier; a movable needle on said frequency-meter for visually indicating small variations in the frequency of said resultant wave; a source of light disposed on one side of the face of said frequency meter; a photoelectric cell disposed on the opposite side of the face of said frequency meter; an aperture disposed in the face of said frequency-meter between the source of light and the photoelectric cell; a shutter disposed on said movable needle, said shutter being positioned in front of said aperture at a predetermined position of said needle; an electron tube having its input circuit connected to the photoelecric cell; and an electric relay having its windings connected to the output circuit of said electron tube, said relay also having its armature connected in series with said electric heating means and a source of electric power for effecting temperature control of said piezo-electric resonators.

7. In a frequency stabilizing and monitoring sytem, the combination of two oscillating circuits having frequency-determining resonators of unlike temperature frequency coefficients; electric heaters disposed so as to affect the temperature of said resonators; a demodulator circuit for combining the output of said two oscillating circuits, for producing a resultant wave whose frequency variations are the frequency differences of said two oscillating circuits; an amplifier for increasing the wave energy of said resultant wave; a resonant frequency-meter actuated by said amplified resultant wave to effect visual indication of frequency variations of said wave; a source of light; a photoelectric cell positioned to respond to variations of light intensity from said source, said variations being effected by the mechanical actuation of said frequency-meter by the resultant wave; and electrical means for translating the response of said photoelectric cell into variations in current in said electric heaters.

8. In a frequency stabilizing and visual frequency monitoring system, the combination of two oscillating circuits having frequency-determining piezo-electric crystals of opposite temperature-frequency coefficients, one of said oscillating circuits having a piezo-electric crystal of negative temperature frequency coefficient, the other of said oscillating circuits having a piezo-electric crystal of positive temperature-frequency coefficient; a radio frequency amplifier connected to the output circuit associated with said oscillator having a piezo-electric crystal of negative temperature-frequency coefficient; said radio frequency amplifier being connected to the power amplifier of a radio transmitter; a demodulator for combining the output of said oscillating circuits in the form of a resultant wave of audio frequency; and resonant frequency selective means for employing said resultant wave to effect temperature control of said piezo-electric crystals and simultaneously to provide visual indication of such control.

9. In a frequency stabilizing and visual monitoring system, the combination of two wave generators having frequency-determining crystals of unlike temperature-frequency coefficients; electric heater means for effecting changes in the temperature of said frequency-determining crystals; a demodulator for combining the wave energy from said wave generators in the form of a resultant wave of varying frequency, said varying frequency representing the frequency difference between the waves of said wave generators; an amplifier for increasing the wave energy of said resultant wave; a resonant frequency-meter connected to the output of said amplifier having a movable pointer-arm for visually indicating frequency changes of said resultant wave; a light source; a photoelectric cell disposed in the path of light rays from said light source; a shutter disposed on said movable pointer-arm for effecting control of the amount of light received from said light source by said photoelectric cell in accordance with variations in the frequency of said resultant wave; and an electron tube, the input circuit of said tube being connected to said photoelectric cell, for amplifying the variations in photoelectric current flowing through said photoelectric cell, and the output circuit of said tube being connected in series with said electric heater means and a source of electric power for effecting

changes in the temperature of said resultant wave in accordance with changes in the frequency of said resultant wave.

10. In a frequency stabilizing and monitoring system, the combination of two wave-generator circuits having frequency-determining crystals of unlike temperature-frequency coefficients; electric heater means for effecting changes in the temperature of said frequency-determining crystals; a demodulator for combining the wave energy from said two wave-generator circuits in the form of a resultant wave whose frequency variations are the frequency differences of said two wave-generator circuits; means for amplifying the wave energy of said resultant wave; a resonant frequency-meter connected to the output of said amplifier, said frequency-meter having a movable pointer-arm for visually indicating small frequency changes of said resultant wave; a mirror disposed on said pointer-arm; a source of light; a lens system for directing light rays from said source of light to said mirror; a photoelectric cell positioned in line with reflected rays of light from said mirror, said cell being so disposed as to receive said reflected rays of light only at definite predetermined positions of said pointer-arm corresponding to definite frequencies of said resultant wave; and an electronic amplifier whose input is connected to the output circuit of said photoelectric cell to effect amplification of the current flow through said photoelectric cell, the output circuit of said electronic amplifier being connected in series with said electric heater coils and a source of electric power for effecting changes in the temperature of said resultant wave in accordance with changes in the frequency of said resultant wave.

11. In a frequency control system employing oscillating circuits under control of frequency determining elements of unlike temperature-frequency coefficients; means for producing resultant wave oscillations of variable frequency, the frequency variations of said resultant wave being dependent upon the temperature changes of said frequency-determining elements; means for amplifying said resultant wave oscillations; and resonant frequency-selective means for utilizing the frequency changes of said amplified resultant wave oscillations to control the temperature of said frequency-determining elements, including a resonant frequency meter having a moving element whose actuation visually indicates definite frequency variations in terms of cycles per second; a source of light; a photoelectric cell; and means actuated by said moving element for varying the amount of light received from said light source by said photoelectric cell in accordance with variations in the frequency of said resultant wave oscillations, said photoelectric cell thereby effecting control of the temperature of said elements.

12. Means for producing a primary wave of substantially constant frequency and simultaneously effecting positive visual indication of variations in the frequency of said primary wave, comprising a primary wave generator whose oscillation frequency is controlled by a piezo-electric crystal having a negative temperature-frequency coefficient; a second wave generator whose oscillation frequency is controlled by a piezo-electric crystal having a positive temperature-frequency coefficient; electric heating means for varying the temperature of said crystals; means for producing a resultant wave whose frequency is the difference of the frequencies of the waves of said wave generators; means for amplifying said resultant wave; and resonant frequency selective means for employing said amplified resultant wave to control the temperature of said two piezo-electric crystals and simultaneously to effect visual indication of frequency variations of said resultant wave, including a resonant frequency meter having an indicating scale calibrated in cycles per second.

13. Means for producing an electric wave of substantially constant frequency and simultaneously effecting positive visual indication of variations in the frequency of said electric wave, comprising two wave generators having frequency-determining elements whose temperature coefficients are of opposite sign; means for jointly heating said frequency-determining elements; and resonant frequency selective means controlled by the difference of frequency of said wave generators to regulate the degree of heat influencing said frequency-determining elements, comprising an electric wave filter, and an electric relay selectively operated by said filter, said relay being arranged to control the temperature of said frequency-determining elements.

14. In a frequency control system employing oscillating elements whose respective frequencies of oscillation are under temperature control; heterodyne means for producing a resultant control wave whose frequency variations are dependent upon temperature variations of said oscillating elements; heating means for varying the temperature of said oscillating elements; and photoelectric means for limiting frequency variations of said control wave, including a resonant frequency meter having a movable frequency responsive member whose displacement controls the amount of light received by said photoelectric means, said frequency meter and said photoelectric means being operatively coordinated with said resultant control wave and said heating means.

15. In a frequency control and monitoring system for stabilization of the emitted wave of a radio transmitter, two wave generators having frequency-determining vibratile resonators of unlike temperature-frequency coefficients; a common source of heat for varying the temperature of said resonators; a demodulator for combining the waves from said generators in the form of a resultant wave representing the frequency difference between said waves from said generators; an amplifier for increasing the wave energy of said resultant wave; and resonant frequency selective means connected to the output of said amplifier for effecting control of the temperature of said vibratile resonators, including an electric wave filter whose input circuit is connected to the output of said amplifier and whose output circuit is connected to an electric relay, the operation of said relay effecting temperature control of said vibratile resonators.

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