Oct. 18, 1938. G. W. PIERCE 2,133,646

ELECTRICAL SYSTEM

Filed April 9, 1930

Fig. 1.

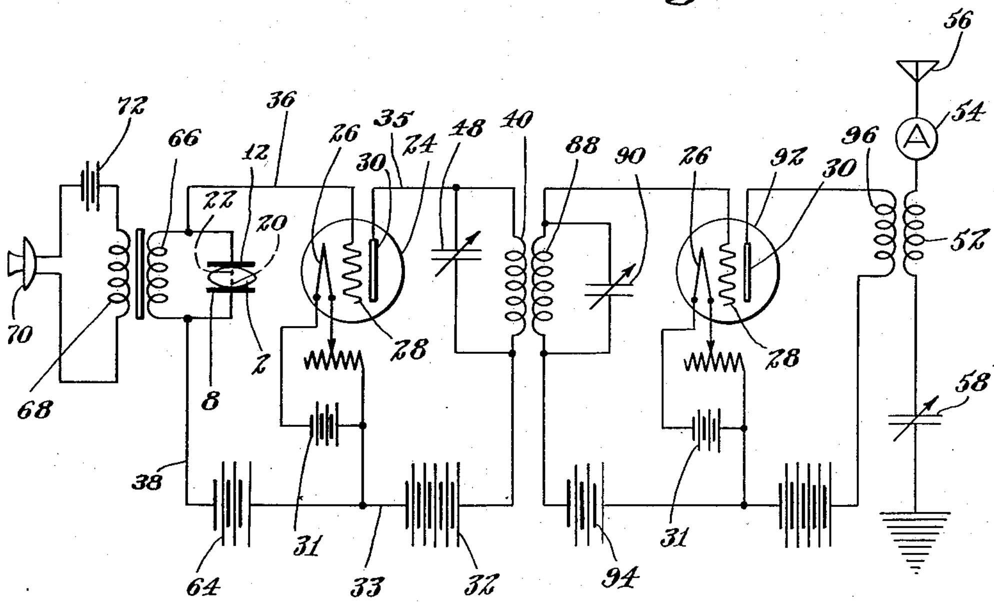
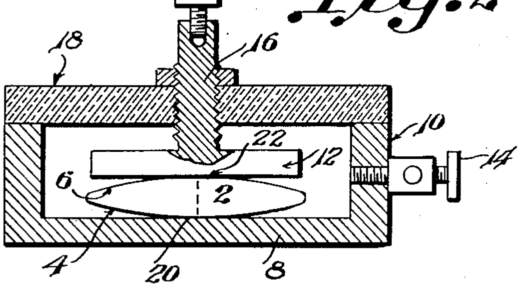


Fig. 2



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ELECTRICAL SYSTEM

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Continuation of application Serial No. 659,094, February 25, 1934. This application April 9, 1930, Serial No. 442,862

29 Claims. (Cl. 250—17)

The present invention relates to electrical systems, and more particularly to oscillatory systems controlled by electromechanical vibrators. From a more limited aspect, the invention relates to the transmission of intelligence. The present application is a continuation of a copending application, Serial No. 695,094, filed February 25, 1924.

Electromechanical vibrators of the type described in the said application have the property of executing mechanical vibrations under vibratory electrical stimulus; and, conversely, of developing electrical potentials as a result of their mechanical vibrations. Piezo-electric bodies,—such as a whole crystal or part of a crystal of quartz, Rochelle salt, tourmaline, and the like,—have long been known to possess this property. Such bodies possess at least one, and usually two or more, axes—known as the electrical axes of the body—that have definite orientations in the original crystal. When a potential gradient, with a component in the direction of an electric axis, is applied to such a crystal body, the body undergoes mechanical deformations; and conversely, when the crystal body is deformed, a potential gradient is established in the body. The action of the electric forces to cause mechanical displacement will be called "stimulation"; and the development of electromotive force by the displacement will be called "response". The crystal body is, in general, capable of two or more particular modes of mechanical vibration, of different frequency, that correspond to two or more of its dimensions. These mechanical and electrical effects are normally transitory, for the crystal body will not, of itself, persist in continuous vibration. As described in the said application, however, the crystal may be so connected into circuit as to render these effects oscillatory in character and persistent, the said circuit then producing oscillations at very nearly constant frequency. A novel electrical system is thus produced comprising an electric circuit that is not, in itself, capable of sustaining oscillations, and that is not, in itself, a source of alternating currents, in combination with an electromechanical vibrator that will not, in itself, persist in continuous vibration; the connections being such, however, that the resulting electrical system will sustain oscillations of a frequency determined, to a high degree of precision, by the frequency of one of the modes of mechanical vibration of the electromechanical body.

An object of the present invention is to provide a novel system for producing high-frequency or short-wave oscillations derived from and harmonically related to crystal-controlled oscillations of very nearly constant frequency.

Another object is to vary the harmonically related frequency.

A further object is to provide a novel radio transmitter for transmitting at high frequency and embodying such novel system.

In radio telegraphy, it is customary to transmit signals by means of electric waves with a frequency that is desired to be constant. In radio telephony and radio telegraphy, and in carrier-current systems where transmitting is effected by means of a carrier wave, also, the carrier frequency may be suppressed at the sending station, one side band alone being transmitted. In most cases it is important to maintain the oscillations of transmitters accurately constant; otherwise, the transmitting stations will interfere with each other. The more nearly constant their frequencies are, the more numerous may be the transmitting stations, without such interference.

Crystal-controlled oscillators are inherently very low-power devices, and this is particularly true in the case of high-frequency oscillators for which the controlling crystal must be very small and fragile. Transmitters, nevertheless, require high power. Another object of the present invention, therefore, is to provide an improved crystal-controlled system for transmitting electrical signals, particularly at a frequency harmonically related to the crystal frequency, to provide for an accurate control of the transmitting-station frequency, thereby to reduce interference to a minimum and to avoid the use of extremely small crystals.

Other and further objects of the invention will be explained hereinafter, and will be pointed out in the appended claims, it being understood that it is intended to cover in the appended claims all the novelty that the invention may possess.

In the accompanying drawing, Fig. 1 is a diagram of circuits and apparatus illustrating an operable embodiment of the invention; and Fig. 2 is a section of a modified form of mechanical-vibrator holder.

The radio transmitter of the present invention is illustrated as comprising a crystal-controlled master oscillator, a frequency multiplier coupled thereto, means for modulating the oscillations, and a radiating antenna or signal-transmission circuit.

As a setting to a description of the specific oscillator illustrated, reference will first be made to the electromechanical vibrator for determining the wave frequency. Though the vibrator is illustrated as of the piezo-electric type, the invention is not, in its broader aspects, limited to such a crystal body, but may employ any body or mechanism having like properties in itself, or like properties introduced by electric currents, electric polarization, magnetic fields, etc. At 2 is shown a piezo-electric body, which has one of its electrical axes approximately along the line 20—22, in the direction of the thickness of the crystal plate. This body may be of any desired form, as, for example, the lenticular shape illustrated and described in the above-mentioned application. It may be constituted of any suitable substance having sufficiently pronounced piezo-electric properties. Quartz is preferred, because of its durability and constancy. The term "electromechanical vibrator"—or, more simply, the term "vibrator"—will be employed hereinafter, in the specification and the claims, to denote any substance or arrangement, whether or not crystalline in character, that is endowed with the above-referred-to property of changing shape or dimensions under the action of an electric force or an electric current and of reacting on the electric circuits.

The oppositely disposed sides or surfaces 4 and 6 of the body 2 are provided with opposed conducting electrodes, terminals or plates 8 and 12, substantially perpendicular to an electric axis of the crystal, and arranged to act conjointly for stimulation and response. It is by means of these electrodes or terminals that the crystal is adapted to be connected into an electric circuit.

In Fig. 2, the electrode 8 is shown constituted of a flat bottom or base plate of a metal box, container or housing 10, within which the vibrator 2 is centrally located, as shown. The vertical side walls 11 of the housing 10 are integral with the base plate 8. The side or surface 4 is shown engaging the bottom or base plate 8. The opposite side or surface 6 contacts with, or is near to, the electrode 12 disposed in the housing 10 between the crystal and an insulating cover 18. The cover 18 may be constituted of hard rubber. The crystal is thus secured in the casing or housing 10 between the electrodes 8 and 12 without being in any way restricted, so that it is free to vibrate mechanically between the opposed electrodes 8 and 12 according to any of its modes or periods of natural vibration or any of its overtones of such modes of vibration. The electrode 8 is electrically connected to a binding post 14, and the plate 12 is electrically connected to a binding post 16. The binding post 14 is secured to a side wall 11, and the binding post 16 is suspended over the crystal 2. Electrical connection may be established between the two sides 4 and 6 of the crystal by means of conductors leading to the terminal binding posts 14 and 16 exterior of the housing. The binding post 16 may be in the form of a thumb screw, threaded through the cover 18, as shown, and secured to the electrode 12. The position of the electrode 12 may thus be shifted manually in parallel planes toward and away from the surface 6 of the crystal 2, to cause the electrodes 12 to approach the vibrator 2 more or less nearly, as desired, or into pressure contact with the vibrator 2, by screwing the binding post 16 in one direction or the other.

Being free to vibrate according to the desired mode of vibration, longitudinal or transverse, without restriction, and without interference with its vibrations, the crystal will vibrate without introducing variations in frequency, and the constancy of frequency is unaffected from error sources of this nature. I have found, however, that very minute variations of frequency of the order of one three-hundredth of one per cent may be introduced by bringing the electrodes more or less near to the piezo-electric vibrator. This is of importance in the final adjustment of such a vibrator, where extreme precision of frequency is required.

By means of this variable-capacity coupling between the crystal and the tuned circuit, the oscillator is thus capable of generating any wave within the limits of a predetermined band, and the period of the crystal may be increased or decreased by any desired amount so that the oscillator may sustain oscillations of any selected frequency within the predetermined band.

The illustrated oscillator comprises a multi-electrode vacuum or electron or electron-discharge tube 24, diagrammatically shown as provided with three sensitive elements or electrodes, namely, a cathode or filament 26, a plate or anode 30 and a grid 28 for controlling the transmission of current between the cathode and the anode. The master oscillator has an input circuit between or including the grid 28 and the cathode 26 and an anode or output circuit between or including the cathode 26 and the plate 30. The invention is not restricted to the use of this particular type of tube, but it will serve for illustrative purposes; it being understood, however, that the terms "plate" and "grid", as used herein, will include within their scope other sensitive elements of different types of tubes, and that the term "cathode" or "filament" will be employed, in the specification and the claims, to include any suitable means for rendering the space of the tube conducting,—exemplified in the drawing by the filament proper 26 connected to the filament-heating battery 31. A plate battery 32 is connected with the filament 26 by a conductor 33, and with the plate 30 by a conductor 35, and constitutes a source of energy for the plate 30. An element 40, shown in the form of an inductance coil, is connected between the battery 32 and the conductor 35.

The electrode 12 of the electro-mechanical vibrator is connected by a conductor 36 with the grid, and the other electrode 8 by a conductor 38 with the filament 26. A single crystal is thus shown, for illustrative purposes, as connected in the input circuit, between the filament 26 and the grid 30, but it may be connected between any two of the three tube electrodes, or have other locations, as explained in the said application. As is also explained in the said application, the mode of vibration depends somewhat on the points of connection of the vibrator in the circuit.

An impedance element 66, shown as the secondary winding of a modulation transformer, but which may be replaced by a resistor of high resistance with a new disposition of the hereinafter-described microphone 70, is connected in the grid circuit in parallel with the electrodes 8 and 12. The impedance element 66 may be constituted to give the grid a suitable potential about which its fluctuations occur. If desired, a biasing battery 64 may be employed to bias the grid 28 to a predetermined negative potential. The potential of the grid will then fluctuate about the biased value. Assuming the parameters of the circuit to be properly chosen to produce crystal-controlled oscillations, as by approximate adjustment of the various elements of the system, the system will oscillate with a frequency determined by the frequency of some resonant mode of mechanical vibration of the electromechanical vibrator; that is, the parameters of the system will have electrical characteristics such as to render the system oscillatory under the control of the vibrator at a substantially constant frequency that is stabilized and determined by some mode of mechanical vibration of the vibrator, substantially independent of the value of the element 40, and such as to render the system stably non-oscillatory when not under the control of the vibrator.

This system, therefore, which can not oscillate in the desired frequency ranges, in its stable condition, with the crystal absent, is thus combined with the vibrator to produce a self-oscillating master oscillator, under the control of the vibrator. The vibrator is stimulated by the oscillations to maintain it in vibration and responds to maintain the system in oscillation with a fixed period determined by the vibrator. It is the vibrator itself, therefore, that provides automatically, by its presence, all the necessary additional electrical parameters or constants, such as inductances and capacitances, and the right transfer of energy from one part of the system to another, to render the relations among the reactances proper for producing oscillations.

Even wide variation of the electric parameters of the system have but an exceedingly slight effect upon the frequency of the oscillations, except in certain cases where certain controlled changes may result in shifting the frequency from that of one mode to that of another distinct mode. As explained in the said application, the disturbing effects—such as those produced by changes of temperature, changes of mounting supports, changes of electrical constants and the like,—on the frequency of the oscillations usually amount to less than one one-hundredth of one per cent of the frequency.

For some purposes, the power of the system may be increased by electrical tuning of some element of the system into or near resonance with the frequency of the mechanical vibrations of the vibrator. To understand what is meant by the term "tuning", it will be recalled that, when a circuit exhibits inductive reactance for one band of frequencies, capacitive reactance for a second band of frequencies, and zero reactance for a particular frequency between these two bands, the circuit is said to be "tuned" or "resonant" at the said particular frequency. Alternatively, this may be stated in terms of the phase relation between the voltage across the circuit and the current through the circuit. When, at any particular frequency, a circuit that exhibits reactance at other frequencies exhibits an impedance that is a pure resistance at the said particular frequency, so that the said current and the said voltage are in phase, that circuit is said to be tuned or resonant at the said particular frequency.

An easy way of selecting suitable circuit parameters for oscillation controlled by any vibrational mode of the crystal is to tune the circuit elements. For example, the plate or output circuit of the tube 24 may be adjusted by means of the condenser 48, so as to obtain high-current output. Due to the action of the crystal in maintaining constant the oscillation frequency, such adjustments are not critical; oscillations will be generated for a wide range of values of the condenser 48 or of the coil 40. Alternatively, the coil 40 may be so chosen as to have suitable resonant properties without the use of a discrete condenser 48.

The crystal may be applied to other parts of the system; untuned elements, such as resistors, for example, or elements resonant to a frequency widely different from the oscillation frequency, may be used. The element 40, for example, may be replaced by any other proper type of electrical apparatus in which the oscillation power is developed. In attempting to obtain oscillations, of course, one would always select proper parameters; and tuning the circuits by means of the condenser 48 is one way of obtaining such proper parameters.

Electric circuits have heretofore been produced with parameters having electrical characteristics such as to render the system stably non-oscillatory in the absence of a tuned element of the system and such as to render the system oscillatory when the tuned element is connected with the system. One of the prior-art circuits, for example, comprised a tuned element in the grid circuit and another tuned element in the plate circuit, the grid and plate circuits being uncoupled except for the capacity coupling between the grid and the plate. Such circuits, as is well known, will not oscillate unless proper circuit elements are chosen. In the oscillator herein shown, one of the said tuned elements of the prior art may be replaced by the electromechanical vibrator in the grid circuit, for example, as illustrated in the drawing. As in the case of the prior-art circuits, oscillations will or will not be produced, depending upon whether proper circuit elements have been chosen; but when oscillations are established, they will be of the frequency of the vibrator and highly constant.

For high frequencies, it is necessary to use the period determined by a small dimension of the specimen, as by its thickness, and this must be of the order of one millimeter for a frequency of 3,000 kilocycles per second.

An oscillator of the type described is mechanically limited as to exceedingly high frequencies, therefore, through inability to produce a crystal of the requisite thinness, which at the same time will be mechanically strong enough to permit handling and use. According to the present invention, however, the requisite high frequency may be obtained by combining a frequency multiplier with a master oscillator having a crystal of not excessive thinness; specifically, as illustrated, by coupling the frequency multiplier to the output of the oscillator so as to receive oscillatory energy therefrom. Incidentally, the frequency multiplier serves also as a power amplifier to amplify the signal strength, the frequency multiplier being operated at a harmonic relationship to the fundamental (or a harmonic) frequency of the master oscillator, thus making it possible to transmit at an enhanced harmonic frequency of the crystal-controlled oscillations of the master oscillator. The frequency multiplier is shown as comprising a vacuum tube 92 and its circuits, as will now be described.

The winding 40 is shown coupled to or interlinked with a winding 88 that is shunted by a tuning condenser 90. The elements 88 and 90 may be tuned so as to select or pick off from the master oscillator one of the many harmonics of the fundamental frequency of vibration of the crystal 2. The grid or input circuit of the vacuum tube 92 in which the winding 88 is connected is biased by a battery 94 so as to impress a negative potential upon the grid 28 of the tube 92. A winding 96 is connected in the plate or output or anode circuit of the tube 92 and is coupled to a radiating antenna 56 through an antenna coil 52 that is connected, in series with a hot-wire ammeter 54, and through a variable condenser 58, to the ground. The antenna circuit constitutes an output or load circuit coupled to the output circuit of the frequency multiplier for receiving the increased or enhanced or amplified harmonic-frequency energy of the oscillations of the master oscillator.

The plate or output circuit of the tube 92, containing the coil 96, is tuned or made resonant by the condenser 58 to a harmonic of the frequency of the master oscillator, by virtue of its coupling to the circuit of the coil 52, which is connected to the antenna-to-ground capacity. This will be understood when it is reflected that the phase relation of the voltage across the coil 96 to the current that flows through it, at any given frequency, is in part determined by the adjustment of the condenser 58. At any given impressed frequency, therefore, there is a setting of the condenser 58 that brings the current in the coil 96 and the voltage across the coil 96 in phase. At this setting of the condenser 58, the anode circuit of the tube 92 is tuned to the impressed frequency. This frequency is practically the same as that to which the antenna circuit itself is resonant. For frequencies other than that to which the anode circuit is resonant, this anode circuit exhibits reactance and this reactance is either negative or positive, depending upon whether the frequency is higher or lower than the said resonant frequency.

By tuning the coil 52 through the medium of adjusting the condenser 58, therefore, the antenna circuit may be tuned so as to pick off a harmonic frequency of the oscillations in the circuit of the vacuum tube 24. The tube 92 and its circuits thus constitute a frequency multiplier. Any desired number of such amplifying units may be interposed between the master oscillator and the antenna to form an amplifier train without in any way departing from the present invention. Energy of the harmonic frequency in the output circuit thereof may be radiated through the antenna 56, or it may be amplified to other circuits in which it may be radiated or otherwise utilized. The crystal prevents variation in the frequencies of the currents of the tuned circuits of the master oscillator and, therefore, of the frequency multiplier also.

The vibrator 2 determines the frequency of oscillation of the master oscillating circuit comprising the vacuum tube 24. The master oscillator, which may be of, say, 5 watts, controls, through power amplification of the fundamental or a harmonic, the tube 92 that is adapted to yield an output of much higher power, say 50 watts, and so forth. Such a system has been successfully operated by me in practice over a considerable distance. I have constructed apparatus, according to the present invention, for fundamental frequencies ranging from 35 kilocycles per second to 3000 kilocycles per second. I have utilized harmonics of the device at frequencies of 20,000 kilocycles per second, corresponding to an electric wave of fifteen meters wave length. This range may undoubtedly be extended in both directions.

By gradually varying the air gap between the electrode 12 and the surface 6 of the crystal 2 to vary the frequency of the piezo-electric device 2, corresponding changes will be effected in the before-mentioned multiplied or harmonic frequency within predetermined limits. The same result may be brought about by means of other variable impedances. As explained in the said application, and also in application, Serial No. 549,830, filed July 10, 1931, other variable impedances than an air gap may be connected in series with the crystal. The frequency of the oscillations will be multiplied by a predetermined integer through the medium of the harmonic producer; and variation of the impedance will effect variations in the vibratory period of the crystal to produce variations in the frequency of the harmonics.

The crystal-controlled master oscillator, the frequency multiplier coupled thereto, and the radiating antenna having now been described, it remains to describe the means for modulating the oscillations in order that the harmonic-frequency energy appearing in the antenna or load circuit may bear signal modulations. This modulating means may take any desired form, and several forms, including a telegraph key, are described in the said application. According to the illustrated embodiment of the invention, however, the primary winding 68 of the modulation transformer is shown connected to the microphone 70, in circuit with a source of energy, shown as a battery 72.

The variations produced by the microphone modulate the carrier oscillations of the system; the modulated oscillations are impressed on the circuit 88, 90, which, as before stated, is tuned to a harmonic frequency of vibration of the crystal 2; the harmonically related oscillations are increased in amplitude by reason of the fact that the tube 92 acts both as an amplifier and a harmonic producer; and the modulated amplified oscillations of harmonic frequency are then transmitted to the antenna by the coils 96 and 52. The microphone 70 thus causes signal modulation of the energy of harmonic frequency to appear in the load circuit. The operation will be understood by persons skilled in the art without further description.

If the transmission is applied to a telephone line, the antenna-and-ground connections may be replaced by the well known connections to line wires.

Though the invention is illustrated in connection with a radio telephone, corresponding connections for transmitting by telegraph will be obvious to those skilled in the art. Both in telegraphy and telephony, the oscillations of the system will be kept at practically constant frequency by the vibrator, making it possible, for example, to use a very high frequency, with all the advantages flowing therefrom.

Modifications within the scope of the present invention will readily occur to persons skilled in the art. It is therefore desired that the above-described embodiment of the invention shall be regarded as illustrative of the invention, and not restrictive, and that the appended claims be construed broadly, except insofar as it may be necessary to impose limitations in view of the prior art.

What is claimed is:

1. In an oscillatory system, the combination of a plurality of electron tubes each having input and output circuits, said circuits interconnecting said tubes to form an amplifier train, one of said tubes being arranged for the generation of high-frequency oscillations, another of said tubes being arranged to multiply the frequency of said oscillations, and a piezo-electric crystal for controlling the frequency of the high-frequency oscillations.

2. An oscillatory system having, in combination, a vacuum tube having three electrodes, namely, a cathode, a grid and a plate, a source of energy, an output circuit including said plate and said cathode, an input circuit including said grid and said cathode, a piezo-electric crystal, means connecting the source in the first-named circuit and connecting the crystal with two of the electrodes to constitute an oscillatory system, the parameters of the system having electrical characteristics such as to render the system oscillatory under the control of the crystal at a substantially constant frequency determined by a mode of vibration of the crystal and such as to render the system stably non-oscillatory when not under the control of the crystal, a second vacuum tube having an input circuit and an output circuit, the input circuit of the second vacuum tube being arranged to receive oscillatory energy from the output circuit of the first-named vacuum tube, and means in a circuit of the second vacuum tube for enhancing a harmonic frequency of the oscillations of the first-named vacuum tube.

3. A frequency selector and amplification system comprising an electron tube for generating high frequency oscillations, a piezo electric crystal connected to said electron tube for stabilizing the frequency of said electron tube, circuits connected to the output of said electron tube for selecting a harmonic frequency of the fundamental frequency of said piezo electric crystal, and connections between the output circuit of said electron tube and another electron tube effecting an increase in amplitude of the harmonic frequency thus selected.

4. In a transmitter system, the combination of a signal transmission circuit, a piezo electric crystal element, an electron tube having input and output circuits, the input circuit of said electron tube connected to said piezo electric crystal element, said electron tube having means connected into its output circuit for selectively and independently sustaining a plurality of harmonics of the fundamental frequency of said piezo electric crystal element, an amplification system, a tuned circuit coupling said amplification system with said aforementioned means and adjustable to selectively amplify any one of the harmonic frequencies of said piezo electric crystal element selected and sustained by said aforementioned means, and connections between said amplification system and said transmission circuit for impressing the selected harmonic frequencies of increased amplitude upon said transmission circuit.

5. An oscillatory system having, in combination, a vacuum tube having an input circuit and an output circuit, a source of energy, an electromechanical vibrator, means connecting the source in the output circuit and the vibrator in the input circuit to constitute a self-oscillating system the frequency of the oscillations of which, when the system oscillates, will be substantially constant and determined by a mode of vibration of the vibrator, the electrical parameters of the system being such as to render the system stably non-oscillatory when not under the control of the vibrator, means for tuning the output circuit, a further circuit coupled to the output circuit, and means for tuning the further circuit to a hormonic frequency of the self-oscillating system.

6. An oscillatory system having, in combination, a vacuum tube having an input circuit and an output circuit, a source of energy, an electromechanical vibrator, means connecting the source in the output circuit and the vibrator in the input circuit to constitute a self-oscillating system the frequency of the oscillations of which, when the system oscillates, will be substantially constant and determined by a mode of vibration of the vibrator, the electrical parameters of the system being such as to render the system stably non-oscillatory when not under the control of the vibrator, means for tuning the output circuit, a second vacuum tube having an input circuit and an output circuit, the input circuit of the second vacuum tube being coupled to the output circuit of the first-named vacuum tube, means for tuning the input circuit of the second vacuum tube to a harmonic frequency of the self-oscillatory system, an antenna connected with the output circuit of the second vacuum tube, and means for tuning the output circuit of the second vacuum tube for maximum current.

7. In a signaling system, a multi-electrode tube having connected to the electrodes thereof a plurality of circuits, a piezo-electric crystal coupled to one of said circuits, a source of energy, means connecting the tube, the circuits, the source and the crystal together to constitute an oscillatory system, the parameters of the system having electrical characteristics such as to render the system oscillatory under the control of the crystal at a substantially constant frequency determined by a fundamental mode of vibration of the crystal and such as to render the system stably non-oscillatory when not under the control of the crystal, whereby substantially constant-frequency oscillations of a fundamental frequency are produced by said tube and circuits, an electron-discharge device having an input circuit and an output circuit, the input circuit of said device being tuned to a harmonic frequency, means for feeding energy from said tube oscillator to said harmonically tuned circuit, a load circuit, means for coupling said load circuit to the output circuit of said electron-discharge device, whereby energy of harmonic frequency is fed to said load circuit, and means for causing signal modulation of the energy of harmonic frequency appearing in said load circuit.

8. In a signaling system, a multi-electrode-tube oscillator having a frequency-controlling circuit including a piezo-electric crystal and a tuned output circuit, said tube oscillator producing oscillations of a fundamental frequency, an electron-discharge-device amplifier having a tuned input circuit and an output circuit, said tuned input circuit being tuned to a harmonic of the fundamental frequency of oscillation of said tube oscillator, a load circuit coupled to the output circuit of said electron-discharge-device amplifier, means for feeding energy from said tube oscillator to said harmonically tuned input circuit, whereby amplified harmonic frequency energy appears in said load circuit, and means for causing the harmonic-frequency energy appearing in said load circuit to bear signal modulations.

9. In a signaling system, the combination of a plurality of electron tubes each having input and output circuits, with the output circuit of one of said tubes interlinked with the input circuit of a succeeding tube, one of said tubes being arranged for the generation of high-frequency oscillations, a piezo-electric crystal for controlling the constancy of the high-frequency oscillations, another of said tubes being arranged to multiply the frequency of said oscillations, and means for modulating the oscillations of increased frequency thus developed.

10. In a signaling system, the combination of a plurality of electron tubes each having input and output circuits, with the output circuit of one of said tubes interlinked with the input circuit of a succeeding tube, one of said tubes being arranged for the generation of high-frequency oscillations, a piezo-electric crystal for controlling the constancy of the high-frequency oscillations, another of said tubes being arranged to multiply the frequency of said oscillations, means for impressing a negative potential upon the input circuit of said last mentioned tube, and means for modulating the oscillations of increased frequency.

11. In a signaling system, the combination of a plurality of electron tubes each having grid, filament and plate electrodes, input and output circuits interconnecting said electrodes, means interlinking the output circuit of one of said tubes with the input circuit of a succeeding tube, said first-mentioned tube having means for the generation of high-frequency oscillations, a piezo-electric crystal for controlling the constancy of the high-frequency oscillations, the next-adjacent tube having means for multiplying the frequency of the oscillations thus developed, means for increasing the amplitude of the oscillations thus developed, means for impressing a negative potential upon the grid electrode of said second-mentioned tube, and means for modulating the oscillations of increased frequency thus developed.

12. In a signaling system, the combination of a plurality of electron tubes each having grid, filament and plate electrodes, input and output circuits interconnecting said electrodes, means interlinking the output circuit of one of said tubes with the input circuit of a succeeding tube, said first-mentioned tube having means for the generation of high-frequency oscillations, a piezo-electric crystal for controlling the constancy of the high-frequency oscillations, the next-adjacent tube having means for multiplying the frequency of the oscillations thus developed, means for increasing the amplitude of the oscillations thus developed, and means for modulating the amplitude of oscillations of increased frequency.

13. The combination of an electron-discharge device comprising a grid, a cathode and an anode, an anode circuit connected between said cathode and anode, a single piezo electric element connected in circuit with said grid, and a second electron-discharge device provided with a grid circuit coupled to said anode circuit and with an anode circuit, one of the last-named circuits being tuned to a frequency which is a harmonic of the resonant frequency of said element.

14. The combination of a tuned circuit, an electron-discharge device provided with a cathode and anode connected in said circuit and with a grid for controlling the transmission of current between said cathode and anode, a single piezo electric element connected between said cathode and grid, a second electron discharge device provided with a grid circuit coupled to said tuned circuit and with an anode circuit, and means for tuning the grid circuit to a frequency which is a harmonic of the resonant frequency of said element.

15. An oscillator comprising a pair of electron-discharge devices provided with anode circuits and with grid circuits, means for tuning the circuits of one of the devices to a harmonic of the frequency of the circuits of the other device, means for coupling one of said anode circuits to one of said grid circuits, and a piezo-electric element connected in the other of said grid circuits for preventing variation in the frequencies of the currents in said tuned circuits.

16. A radio transmitter having, in combination, a vacuum tube having three electrodes, namely, a cathode, a grid and a plate, a source of energy, a circuit including said plate and said cathode, another circuit including said grid and said cathode, a piezo-electric crystal, means connecting the source in the first-named circuit and connecting the crystal with two of the electrodes to constitute a master oscillator, the parameters of the master oscillator having electrical characteristics such as to render the master oscillator oscillatory under the control of the crystal at a substantially constant frequency determined by a mode of vibration of the crystal and such as to render the master oscillator stably non-oscillatory when not under the control of the crystal, a frequency multiplier coupled to the master oscillator, means for modulating the oscillations, an output circuit coupled to the frequency multiplier, and a radiating antenna connected with the output circuit.

17. A radio transmitter having, in combination, a vacuum tube having three electrodes, namely, a cathode, a grid and a plate, a source of energy, a circuit including said plate and said cathode, another circuit including said grid and said cathode, a piezo-electric crystal having two electrodes only, means connecting the source in the first-named circuit, means connecting one of the crystal electrodes with one of the tube electrodes and the other crystal electrode with another tube electrode to constitute a master oscillator in which the two crystal electrodes will act conjointly for both stimulation and response, the parameters of the master oscillator having electrical characteristics such as to render the master oscillator oscillatory under the control of the crystal at a substantially constant frequency determined by a mode of vibration of the crystal, a frequency multiplier coupled to the master oscillator, means for modulating the oscillations, an output circuit coupled to the frequency multiplier, and a radiating antenna connected with the output circuit.

18. A radio transmitter having, in combination, a vacuum tube having three electrodes, namely, a cathode, a grid and a plate, a source of energy, a circuit including said plate and said cathode, another circuit including said grid and said cathode, a piezo-electric crystal, means connecting the source in the first-named circuit and connecting the crystal in the second-named circuit to constitute a master oscillator, the parameters of the master oscillator having electrical characteristics such as to render the master oscillator oscillatory under the control of the crystal at a substantially constant frequency determined by a mode of vibration of the crystal and such as to render the master oscillator stably non-oscillatory when not under the control of

the crystal, a frequency multiplier coupled to the master oscillator, means for modulating the oscillations, an output circuit coupled to the frequency multiplier, and a radiating antenna connected with the output circuit.

19. A radio transmitter having, in combination, a vacuum tube having three electrodes, namely, a cathode, a grid and a plate, a source of energy, a circuit including said plate and said cathode, another circuit including said grid and said cathode, a piezo-electric crystal, an impedance, means connecting the source in the first-named circuit and connecting the crystal and the impedance in parallel relation in the second-named circuit to constitute a master oscillator, the parameters of the master oscillator having electrical characteristics such as to render the master oscillator oscillatory under the control of the crystal at a substantially constant frequency determined by a mode of vibration of the crystal and such as to render the master oscillator stably non-oscillatory when not under the control of the crystal, a frequency multiplier coupled to the master oscillator, means for modulating the oscillations, an output circuit coupled to the frequency multiplier, and a radiating antenna connected with the output circuit.

20. A radio transmitter having, in combination, a vacuum tube having three electrodes, namely, a filament, a grid and a plate, a source of energy, a piezo-electric body, means connecting the source between the filament and the plate and the body with two of the electrodes to produce a master oscillator the frequency of the oscillations of which, when the master oscillator oscillates, shall be substantially constant and determined by a mode of vibration of the body, the electrical parameters of the master oscillator being such as to render the master oscillator stably non-oscillatory when not under the control of the body, the master oscillator having an input circuit connected between the filament and the grid and an output circuit connected between the filament and the plate, means for tuning the output circuit to a frequency determined by a fundamental mode of vibration of the body, a power amplifier having an input circuit and an output circuit, the amplifier input circuit being coupled to the output circuit of the master oscillator, means for tuning the power amplifier to a harmonic frequency of the master oscillator, means for modulating the oscillations, an output circuit coupled to the amplifier output circuit, and a radiating antenna connected with the output circuit coupled to the amplifier output circuit.

21. A radio transmitter having, in combination, a vacuum tube having an input circuit and an output circuit, a source of energy, a piezo-electric body, means connecting the source in the output circuit and the body in the input circuit to produce a master oscillator the frequency of the oscillations of which, when the master oscillator oscillates, will be substantially constant and determined by a mode of vibration of the body, the electrical parameters of the master oscillator being such as to render the master oscillator stably non-oscillatory when not under the control of the body, means for tuning the output circuit to a frequency determined by a fundamental mode of vibration of the body, a power amplifier having an input circuit and an output circuit, the amplifier input circuit being coupled to the output circuit of the master oscillator, means for tuning the power amplifier to a harmonic frequency of the master oscillator, means for modulating the oscillations, an output circuit coupled to the amplifier output circuit, and a radiating antenna connected with the output circuit coupled to the amplifier output circuit.

22. An oscillatory system having, in combination, an amplifying relay, a source of energy, an electromechanical vibrator, means connecting the relay, the source and the vibrator together to constitute an oscillatory system, the parameters of the system having electrical characteristics such as to render the system oscillatory under the control of the vibrator at a substantially constant frequency determined by a mode of vibration of the vibrator, and such as to render the system stably non-oscillatory when not under the control of the vibrator, a secondary circuit associated with the system, and means for adjusting the secondary circuit so as to take energy at a harmonic frequency from the system.

23. The combination of an oscillator of alternating current, a frequency multiplier coupled to said oscillator, a piezo-electric device for controlling the frequency of the oscillator, and means for gradually varying the frequency of the piezo-electric device to effect corresponding changes in the multiplier frequency.

24. A system for generating an alternating-current wave of a frequency within the limits of a predetermined band, comprising a source of oscillations, a frequency multiplier, means for connecting the multiplier to said source of oscillations to multiply the frequency thereof by a predetermined integer, and piezo-electric means for gradually varying and controlling the multiplier frequency.

25. The combination of an electrical oscillator, a harmonic producer for producing a harmonic of the frequency of said electrical oscillator, a piezo-electric device, means connecting the piezo-electric device with said electrical oscillator for determining the frequency thereof, and means for gradually varying the period of said piezo-electric device to vary the frequency of the harmonics.

26. The combination of an electrical oscillator, a harmonic producer for producing a harmonic of the frequency generated by said electrical oscillator, and a piezo-electric device connected with the oscillator for gradually varying the resultant frequency of the harmonic producer within predetermined limits.

27. The combination of an electrical oscillator, a harmonic producer for producing a harmonic of the frequency of said electrical oscillator, a piezo-electric crystal for determining the frequency of said electrical oscillator, and a variable impedance in series with said piezo-electric crystal, said impedance being varied to effect a corresponding variation in the vibratory period of said piezo-electric crystal to vary the frequency of the harmonics.

28. An oscillatory system having, in combination, an alternating-current circuit, an electromechancal vibrator connected with the circuit, means connecting the circuit with the vibrator to maintain the frequency of the circuit substantially constant, the electrical constants of the system being of such value and kind as will enable the vibrator to be the sole control of the frequency, an impedance in series with the vibrator, means for varying the impedance to vary the constant frequency, a second electric circuit, and means for transferring energy from the first-named circuit to the second circuit at a harmonic frequency.

29. An oscillatory system comprising a master oscillator having a tube provided with three electrodes, namely, a filament, a grid and a plate, a piezo-electric crystal, means connecting the crystal between the grid and the filament to maintain the oscillations of the system at the substantially constant frequency of a mode of vibration of the crystal, the electrical constants of the system being of such value and kind as will enable the vibrator to be the sole control of the frequency, an impedance in series with the vibrator, means for varying the impedance to vary the constant frequency, a secondary power circuit associated with said master oscillator, and means for transferring energy at a harmonically related frequency from the tube circuit to said power circuit.

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