Jan. 13, 1931. W. A. MARRISON 1,788,533

FREQUENCY CONTROL SYSTEM

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FIG. 1.

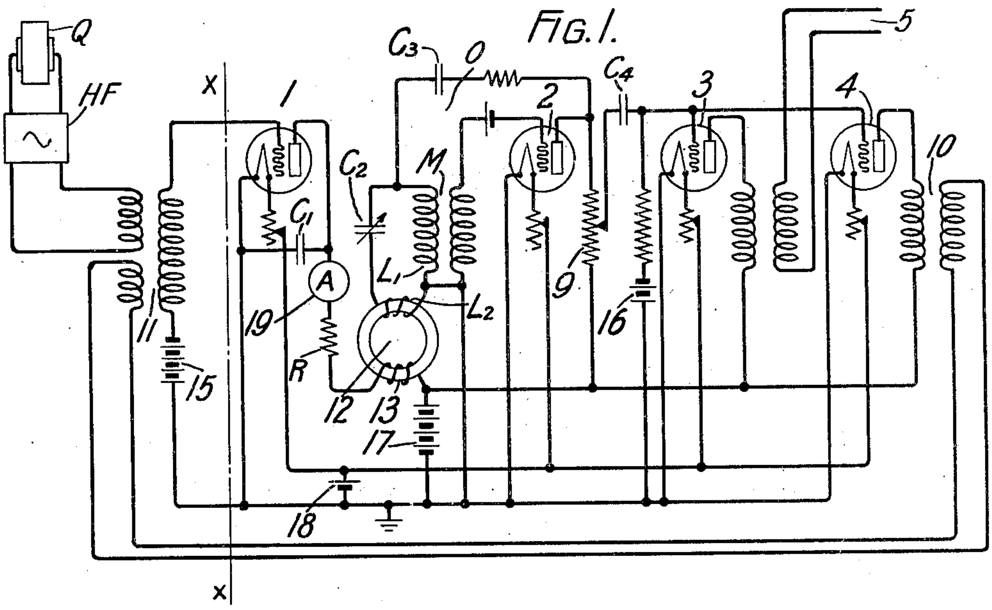

FIG. 1A

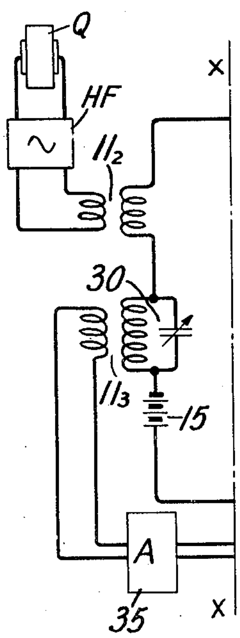

FIG. 5

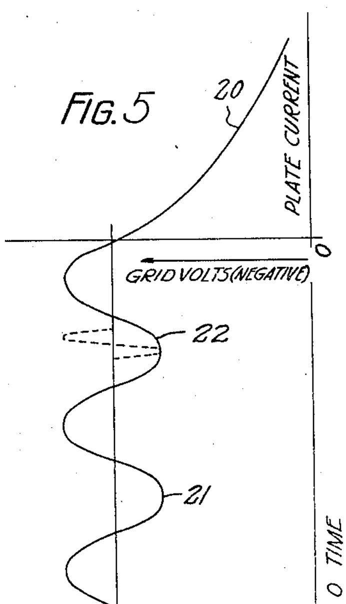

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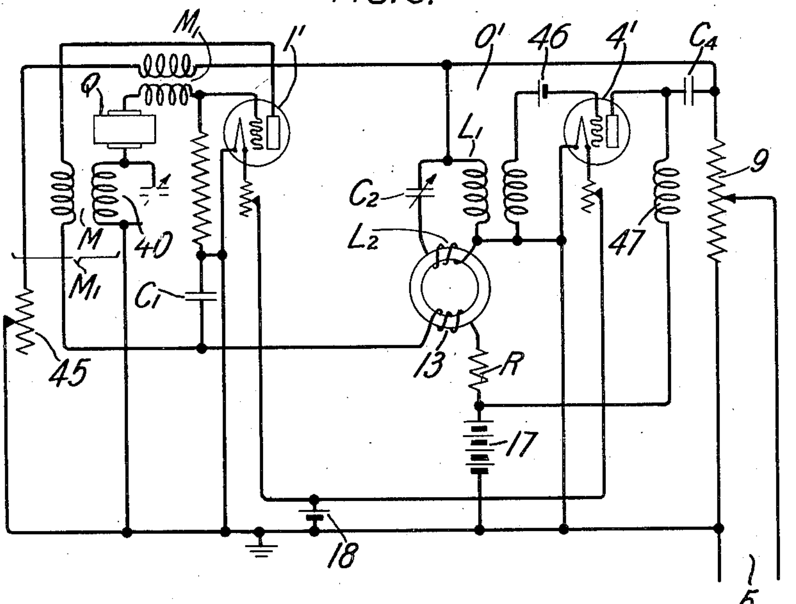
FIG. 6.



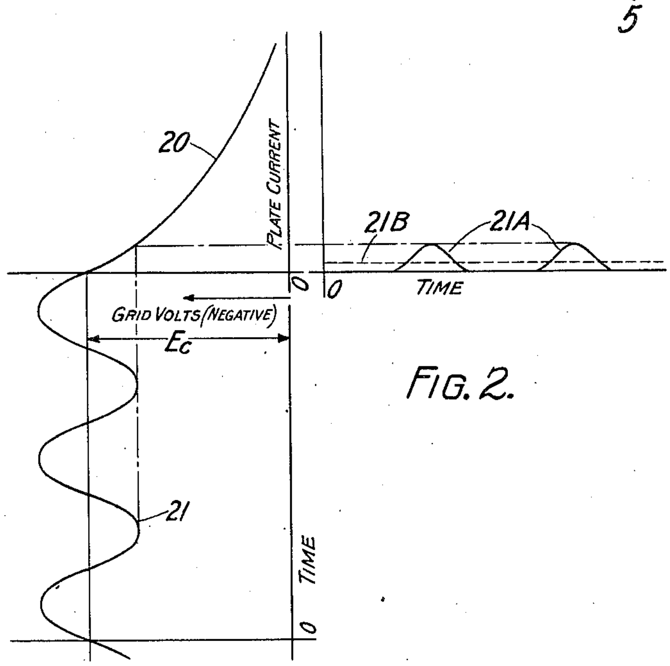


FIG. 2.

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FREQUENCY CONTROL SYSTEM

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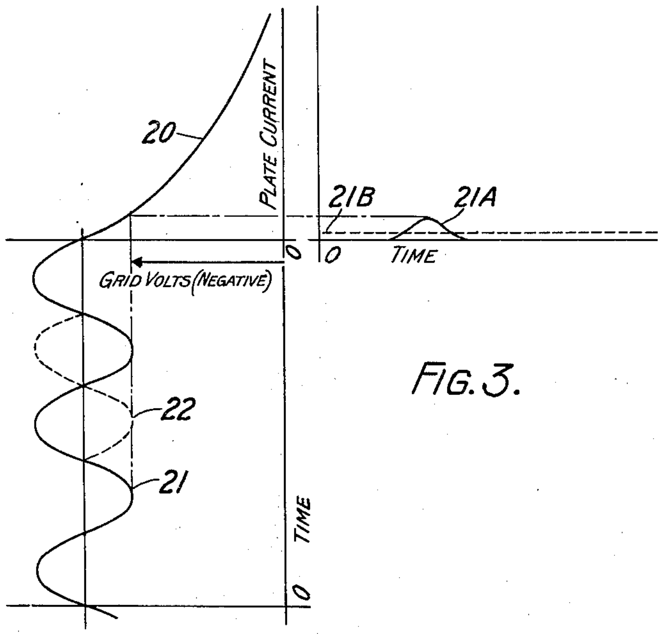

FIG. 3.

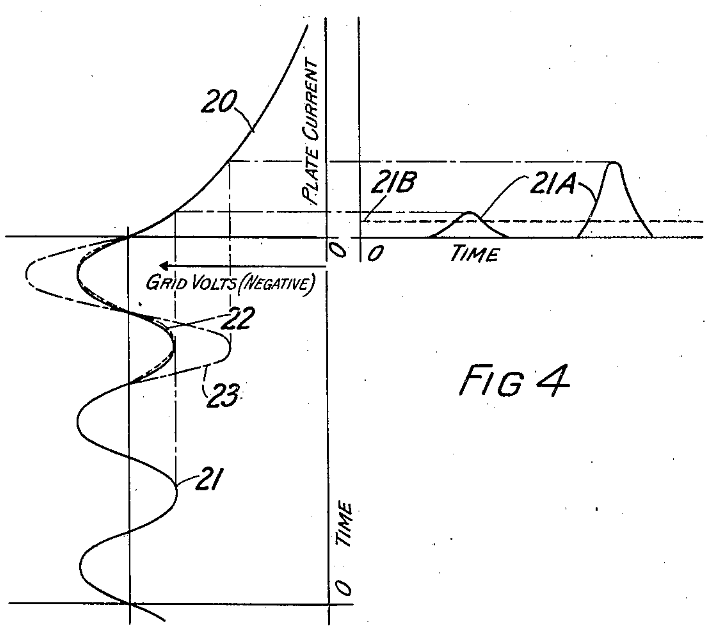

FIG 4

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Patented Jan. 13, 1931 **1,788,533**

UNITED STATES PATENT OFFICE

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FREQUENCY-CONTROL SYSTEM

Application filed March 28, 1927. Serial No. 178,937.

This invention relates to regulation, and especially to the control of electrical characteristics, as for example the frequency of electrical variations.

A specific form of the invention, which is shown in the accompanying drawing and which has been chosen merely for the purpose of illustration, is a system for maintaining the frequency of an electric space discharge oscillator constant at a value which is too low to be maintained fixed in the usual manner by means of a piezo-electric crystal of readily obtainable size.

In this form of the invention a master oscillator has its frequency maintained constant in the usual manner by a crystal, but at a multiple of the frequency to be ultimately obtained, and the constancy of the master oscillator frequency is utilized to maintain another oscillator at the desired constant frequency, which is a submultiple of the master oscillator frequency. To obtain the constancy of the frequency of the submultiple frequency oscillator, voltages derived from the master oscillator and the submultiple frequency oscillator are so combined in an electric space discharge modulator as to produce current the magnitude of which varies with their instantaneous phase relation. The current is caused to so control reactance in the tuned oscillation circuit of the submultiple frequency oscillator as to oppose any tendency of that oscillator to vary its frequency with respect to the frequency of the master oscillator and prevent the phase relation between the combining voltages from changing except by a small amount depending on the degree of control required. The maximum phase variation observed is about 180° at the frequency of the master oscillator.

It is not necessary that the controlled frequency be an integral submultiple or integral multiple of the controlling frequency. In fact, each of the embodiments of the invention specifically shown and described herein by way of example is a system for maintaining the frequency of an oscillator at any frequency which is a rational fraction of a given controlling frequency. The control is greatest when the fraction is l/n or n/l where n is a small integer, but is appreciable when the fraction is n/m, n and m both being integers.

In one form of the invention the controlled oscillator itself generates a voltage which is employed as one of the two combining voltages, and the master oscillator itself serves as the modulator for combining the voltages to produce the current which controls the tuning reactance of the submultiple frequency oscillator.

Fig. 1 is a circuit diagram of one form of the invention;

Fig. 1A is a circuit diagram of a modified form;

Figs. 2, 3, 4 and 5 show curves for facilitating explanation of the invention; and

Fig. 6 is a circuit diagram of another form of the invention.

Referring to Fig. 1, HF indicates the master oscillator which is assumed to generate a wave of frequency which is high as compared with the controlled frequency and specifically an integral multiple thereof although there may be any rational fractional relationship between the two frequencies. It may have its frequency maintained constant, as for example by a quartz crystal Q incorporated in the oscillator in a well known manner. An oscillator O of any standard type involving a tuned circuit (L_1, L_2 and C_2) may be used as the controlled, low frequency, source. An oscillator of a type disclosed in U. S. patent to Terry, 1,573,948, February 23, 1926, is shown, by way of example, having in addition only the controlling inductance L_2.

Elements 1, 2, 3 and 4 are electric space discharge tubes. Tube 1 is a modulator or rectifier tube giving a direct current output the amplitude of which varies with the phase relation of the inputs. Tube 2 is the low frequency oscillator tube. Tube 3 supplies energy to output circuit 5 at low frequency without reacting on the control circuit. Tube 4 is a harmonic producer. It is an amplifier with its operation so adjusted that, in conjunction with transformers 10 and 11, it feeds a narrow peaked wave to tube 1. The characteristics of the last tube should be chosen to suit any special case. When controlling a frequency about 1/5 of the given high frequency a Western Electric "V" tube (Code No. 102–D) with 9 volts "C" battery works very well. Preferably, some form of gain control device, as for example the interstage voltage divider 9, should be used to adjust the input to this tube, so that its space current will be cut off except during a sufficient portion of each cycle for production of the narrow, peaked wave just mentioned. For example, space current may be permitted to flow only during times corresponding to the small fractions of the positive half-cycles of the impressed wave in the neighborhood of the tops of these positive pulses. The function of such a harmonic producer may be conveniently conceived of as "forming" the subharmonic wave into an impulse wave of the same frequency.

The direct current output of tube 1 flows through one winding 13 on the magnetic cored control coil 12. The core of the coil may be of iron or permalloy, for example. Constants are so chosen that a small variation of this D. C. output causes the maximum change of inductance of the winding L_2 by virtue of the variable permeability of the core with magnetization.

The frequency of the low frequency oscillator is adjusted to be the submultiple desired by means of condenser C_2. It is then controlled by and kept in locked synchronism with the controlling input frequency. If something happens which tends to increase or decrease the frequency of the low frequency oscillator the change in D. C. produced thereby in tube 1 changes the inductance of winding L_2 just enough to compensate, the only effect on the output being a very slight phase shift with respect to the control frequency.

The condenser C_1 prevents high frequency current from reaching the control coil and therefore the low frequency amplifiers. The resistance R keeps the impedance of the circuit of the direct current winding of the magnetic cored control coil high so as to avoid any close approach to and inductively short-circuiting of the other winding by condenser C_1 and plate battery 17, and thus obtain the largest possible variation of inductance in winding L_2. The optimum condition may be determined with the help of meter 19. Condensers C_3 and C_4 are blocking condensers to prevent the voltage of the plate battery 17 from being connected to ground through the oscillating coil and from reaching the grids of tubes 3 and 4. The battery 18 supplies current for heating the filaments of all of the tubes. Batteries 15 and 16 supply steady negative potentials for the grids of tubes 1 and 3, respectively.

For the waves of the controlling and controlled oscillators of the system of Fig. 1, with their frequencies at, for example, 25,000 cycles and 5000 cycles, respectively, the pattern observed on a Braun tube is stationary, there being no "hunting" effects. The effect of varying the filament current or the voltage of battery 17 slightly is to cause a slight shift in phase, which results in maintaining the frequency constant. If operation of the system is stopped and started again, the control effect begins again immediately.

Important advantages of this form of frequency control are the great stability obtained and the ease and stability of adjustment. Moreover, a large output of the controlled frequency is obtained which is practically free from harmonics. If harmonics are desired they may be added in well known ways, as for example, by an additional electric space discharge tube modulator or harmonic producer. Only three tubes, 1, 2 and 4, are required. The functions performed by the different tubes are related in such a way that no interference will be introduced by operating the filaments from alternating current.

Preferably the constants of the system are so adjusted as to cause the control tube 1 to operate on the curved lower portion, shown in Figs. 2, 3 and 4, of its grid voltage-plate current characteristic 20. These figures are merely illustrative of the operation of the control tube for one condition of adjustment of the operating conditions of the system, chosen by way of example. The steady grid voltage E_c of battery 15 is shown as just sufficient to reduce the space current of tube 1 to zero when there is no variable input to the tube. The graph 21A in Fig. 2 represents instantaneous values of the plate current in the tube. This figure represents conditions when the only variable voltage on the grid is the high frequency voltage wave 21 in the secondary winding of transformer 11, due to the source HF. The graph 21A consists of one pulse of positive sign for each positive pulse of the voltage from HF. The graph 21B represents the average value of these pulses, which is the direct current that they produce in the winding 13 of the control coil. The instant chosen as the zero or reference instant of time is indicated by the zeros of the time scales.

Fig. 3 represents conditions when a voltage pulse 22 in phase opposition to wave 21 is received by the grid of tube 1 due to the wave from tube 4, it being assumed that the adjustments such as the setting of the gain control device 9 and the value given to the voltage of battery 16 are such that the amplitude of the pulse 22 is equal to the amplitude of wave 21 and the duration of the pulse is equal to one period of the wave 21 (although in reality the duration of the pulse usually would preferably be considerably less), and it being assumed that the pulse occurs during the second cycle of wave 21 from the arbitrary zero or reference point of time. Further, for the sake of simplicity the shape of the pulse is represented as though it were substantially the same as that of one cycle of wave 22, although in reality it usually would be somewhat narrower. With the frequencies of the oscillators HF and O in the ratio 5:1 as considered above, the pulse occurs every fifth cycle of the wave 21. Therefore, counting from the arbitrary zero or reference point of time, the pulses of graph 21A which in Fig. 2 correspond in time to the 2nd, 7th, 12th, 17th, 22nd, etc., positive half cycles of wave 21 will be absent from the graph 21A, under the conditions represented in Fig. 3; for the effect of such half cycles of wave 21 upon the grid of tube 1 is nullified by the effect of a negative half cycle of the pulse 22. Therefore, under the conditions represented in Fig. 3 the direct current 21B in winding 13 which is the average value of all of the current pulses in that winding, has only four-fifths of the value of the current 21B of Fig. 2.

Fig. 4 represents conditions when the voltage pulse 22 occurs later than in Fig. 3 by one half period of wave 21, so that the pulse is in phase with wave 21. Counting from the arbitrary zero or reference point of time, the pulses of graph 21A corresponding in time to the 2nd, 7th, 12th, 17th, 22nd, etc., positive half cycles of wave 21 will be augmented in the graph 21A, under the conditions represented in Fig. 4; for the effect of such half cycles of wave 21 upon the grid of tube 1 is augmented due to the fact that a positive half cycle of the pulse 22 shifts the operating point for the half cycle of wave 22 upwardly to steeper portions of the characteristic curve 20 and back again, or causes the grid voltage due to wave 21 and pulses 22 to have a resultant value indicated by curve 23. Therefore, under the conditions represented in Fig. 4 the direct current 21B in winding 13, which is the average value of all of the current pulses in that winding, is greater than the current 21B in Fig. 2 by an amount depending on the curvature of the characteristic curve 20 in the operating region.

Thus, Figs. 3 and 4 illustrate how the direct current, or the average value of all of the current pulses, in winding 13, can vary with the phase relation between the high frequency wave 21 and the pulses 22 fed to the grid of tube 1 by the harmonic generator 4. (This average value of current also depends upon the number of cycles of high frequency for each pulse 22 fed from the harmonic generator 4.) Variation of the phase relation and consequently of the direct current, occurs when the frequency of oscillator O tends to depart from a given value with relation to the frequency of the oscillator HF; and the variation of the direct current is such as to check this tendency. For example, the normal condition of operation of the system may be that the frequency of oscillator HF is at exactly 25,000 cycles/sec. and the frequency of oscillator O is at exactly 5000 cycles/sec., the phase difference between the inputs to the grid of tube 1 is between the differences shown in Figs. 3 and 4, the direct current in coil 13 has a value between the values shown in Figs. 2 and 4, and the coil 12 is operating on a portion of its magnetizing current-permeability curve of negative slope. Then if something causes the oscillator O to tend to increase its frequency, the pulses 22 advance slightly in phase with respect to wave 21, the direct current in winding 13 consequently decreases, the permeability of the core of coil 12 therefore increases, and the inductance of winding L_2 therefore increases to oppose the tendency of the frequency of oscillator O to increase, and the frequency of the voltage wave delivered to the output circuit 5 remains constant at 5000 cycles/sec. although this wave has advanced slightly in phase with respect to the wave of oscillator HF. The phase advance is less than a half-period of the oscillator HF. If something had caused the oscillator O to tend to decrease its frequency instead of to increase it, the correcting action of the system would have been opposite to that just described. Thus, the submultiple oscillator is kept in synchronism with the master oscillator and adjusts itself to such a phase relation to it that the rectified current from the control tube 1 suffices to change the inductance of the magnetic cored coil enough to adjust the frequency of the submultiple oscillator.

While Figs. 2, 3 and 4 amply illustrate the principle of operation of the invention, it is true, as has already been indicated, that a much greater sensitivity of response tends to result from the use of pulses which are of shorter duration than those assumed in Figs. 2, 3 and 4 and especially from the use of pulses which are of shorter duration than the half periods of the controlling waves. This condition is illustrated by Fig. 5 which assumes conditions which are exactly like those illustrated by Figs. 3 and 4 except only as to the duration of pulses. For simplicity, and because the figure is intended merely to illustrate an alternative type of pulse, the wave forms of the resultant rectified current are not shown. They may be plotted in exactly the manner disclosed in Figs. 3 and 4. It is evident that a control system of this type is more responsive than the simpler type illustrated by Figs. 3 and 4. For instance, the relative phase of the pulse need change only about 90° from the particular phase condition illustrated by the figure, which results in a maximum direct current in winding 13 as in the case of Fig. 4, to achieve a condition of minimum current. This result may not be approximated by the particular arrangement assumed by Figs. 3 and 4. The amount of controlling effect required depends upon the order of the submultiple and the constancy inherent in the circuits to be controlled.

The principle of the invention can be used to control harmonic frequencies instead of submultiple frequencies, by reversing the control process—that is, by having the oscillator which includes the coil 12 in its tuned frequency determining circuit the high frequency oscillator and having the oscillator which is connected in circuit as oscillator HF is connected in circuit in Fig. 1 the relatively low frequency oscillator.

The controlling effect in a system such as that of Fig. 1 can be increased if a band-pass filter or tuned circuit 30 to select and pass the high frequency component corresponding to the frequency of the wave from source HF, from the wave fed from tube 4, and preferably also an amplifier 35, be introduced in the low frequency circuit feeding tube 1, as indicated by way of example in Fig. 1A. In that figure transformers 11_2 and 11_3 replace the transformer 11 of Fig. 1. The portion of the system of Fig. 1A to the right of line X—X is the same as in the case of Fig. 1. Where, as in the case considered above, the ratio of the controlling and controlled frequencies is 5:1, the phase displacement required between these frequencies to produce a given variation in the direct current in winding 13 is approximately one-fifth as great in the case of Fig. 1A as in the case of Fig. 1. There results a greater effectiveness of control.

In the circuit of Fig. 1, one tube is used for each function. In some cases in the interest of simplicity it is preferable to operate with fewer tubes and make each tube perform more than one function.

The circuit of Fig. 6 will generate a submultiple of the natural frequency of the high frequency oscillator which, if desired, may have its frequency set by a piezo-electric crystal Q having the same natural frequency as the tuned circuit 40 of the oscillator. The oscillator comprises an electric space discharge tube 1′, operating on a non-linear part of the grid voltage-plate current characteristic. Because of this the oscillator functions also as a modulator or rectifier corresponding to the rectifier tube 1 of Fig. 1 and the space current will vary with the phase relation of the wave of the crystal oscillator and a wave fed to the grid of the oscillator through coupling M_1 as will now be described.

The controlled submultiple-frequency or low frequency oscillator O′ comprises an electric space discharge tube 4′ which also operates on a curved portion of its characteristic in order to impress harmonics of the low frequency on the grid of tube 1′ through a circuit comprising an adjustable resistance 45 and coupling M_1. Tube 4′ thus performs functions of both of the tubes 2 and 4 of Fig. 1, avoiding necessity for two tubes for performing these functions. This tube 4′ should have a large "C" battery 46, thereby making use of the lower part of the grid voltage-plate current characteristic. A retard coil 47 is included in the circuit which supplies direct space current from the plate battery 17 to tube 4′.

The operation of the system of Fig. 6 will be apparent without further description from the description, above, of the operation of the system of Fig. 1.

Although only two oscillator-modulators are shown in Fig. 6, the system may be extended by adding other such oscillator-modulators, each having its output circuit connected to the input circuit of the preceding one as the output circuit of tube 4′ is connected to the input circuit of tube 1′, so that each oscillator succeeding the first in the series will have its frequency controlled by the preceding oscillator as the frequency of oscillator 4′ is controlled by the frequency of oscillator 1′. Each oscillator of the series can thus have its frequency an exact submultiple of the frequency of the preceding oscillator. For example, the oscillators may have frequencies of 100,000, 10,000 and 1,000 cycles/sec., respectively, and the oscillators may have output circuits, respectively, each corresponding to circuit 5 but each receiving a wave of the frequency of the oscillator to which it is connected.

One field of use of the invention is the measurement of frequencies which are too high to be measured directly and which it may therefore be desirable to measure by a process involving one or more stages of downward frequency conversion. By employing this invention for the conversion, there is avoided any necessity for using entirely independent separate local sources, which introduce additional errors or uncertainties in the measurement.

What is claimed is:

1. In a method of frequency control, deriving from one of two waves periodic pulses individually of duration different from a half-period of the other wave, so combining the other wave with said pulses as to produce current of magnitude varying in accordance with the phase relation of the other wave to said pulses, and controlling the frequency of one of said waves in accordance with the magnitude of said current.

2. In a method of frequency control, deriving from one of two waves periodic pulses individually of duration different from a half-period of the other wave so combining the other wave with said pulses as to produce current of magnitude varying in accordance with the phase relation of the other wave to

said pulses, and so controlling the frequency of one of said waves in accordance with the magnitude of said current as to prevent phase change in said pulses measured by a time greater than one half period of said other voltage.

3. In a frequency control system, sources of voltage of relatively high and relatively low frequencies respectively, means for deriving from said relatively low frequency source a wave of narrow, peaked pulses of voltage each of duration less than a half cycle of the voltage of said relatively high frequency source, and means responsive to the relatively high frequency voltage and said pulses to control the frequency of said relatively low frequency source in accordance with the phase relation of the high frequency voltage to said pulses.

4. The method of controlling the ratio of the frequency of an electric generator to the frequency of a given wave, the frequency of which is otherwise independent of that of said generator, which comprises deriving from said generator an alternating current component whose frequency is commensurable with the frequency of the given wave but differing therefrom, so combining said waves as to produce a direct current which is steady when the phase relation is constant and which changes when the phase relation changes, and exerting on said generator an influence varying in accordance with said direct current and in such a direction as to prevent said generator from changing its frequency.

5. A system comprising a source of a wave of given frequency, an oscillator having a tuned frequency determining circuit for setting the frequency of said oscillator approximately at a rational fraction of said first frequency, an electric space discharge device responsive to waves from said oscillator for producing a narrow peaked wave of the frequency of said oscillator, a second electric space discharge device, means rendering said latter device responsive to said narrow peaked wave and the wave from said source to produce current of a magnitude depending on the phase relation between said two latter waves, and means responsive to said current for so controlling the natural period of said tuned circuit as to maintain the ratio of said first frequency and the frequency of said oscillator constant.

6. A frequency controlling system comprising a master oscillator, a piezo-electric crystal so connected to said oscillator as to maintain the frequency of said oscillator constant, a second oscillator having a tuned frequency determining circuit for setting the frequency of said second oscillator approximately at a rational submultiple of the frequency of said master oscillator, an electric space discharge device responsive to waves from said second oscillator for producing a narrow peaked wave of said submultiple frequency, a second electric space discharge device, means rendering said latter device responsive to said narrow peaked wave and the wave from said master oscillator to produce current of a magnitude depending on the phase relation between said two latter waves, and means responsive to said current for so altering the natural period of said tuned frequency determining circuit as to maintain the ratio of the frequency of said master oscillator and the frequency of said second oscillator constant.

7. A system comprising a master oscillator, an oscillator of a frequency which is a given rational submultiple of the frequency of said master oscillator, means for deriving, from said oscillators, voltages which have the same frequencies as said oscillators, respectively, and which have a phase relation varying in accordance with the tendency of the frequency of said submultiple oscillator to change its frequency with respect to the frequency of said master oscillator, means for so combining said voltages as to translate said variations of phase relation into direct current the value of which varies with said phase relation and is appreciable when the waves of said voltages are so related that a maximum instantaneous value of one occurs simultaneously with a zero instantaneous value of the other, a frequency determining inductance and capacity included in said submultiple-frequency oscillator, said inductance having magnetic material in its magnetic circuit, and means for causing said direct current to so vary the permeability of said material as to maintain the frequency of said submultiple-frequency oscillator exactly at said rational submultiple of the frequency of said master oscillator.

8. A frequency controlling system comprising a master oscillator and modulator, a second oscillator and modulator having its oscillation frequency a rational fraction of the oscillation frequency of said master oscillator, means for impressing a modulated wave from said second oscillator upon said first oscillator, and means responsive to a modulation product from said first oscillator to control the frequency of said second oscillator.

9. A frequency controlling system comprising an electric space discharge master oscillator, a piezo-electric crystal so connected to said oscillator as to maintain the frequency of said oscillator constant, a second electric space discharge oscillator having a tuned frequency determining circuit for setting the frequency of said second oscillator approximately at a rational submultiple of the frequency of said master oscillator, means causing said first oscillator to operate on a nonlinear portion of its input voltage-output current characteristic, means causing

said second oscillator to operate on the lower curved portion of its input voltage-output current characteristic, means for so impressing harmonics of said submultiple frequency from said second oscillator upon said first oscillator as to cause the space current of said first oscillator to vary with the phase relation of the crystal oscillator wave and the wave impressed upon the crystal oscillator from the second oscillator, and means responsive to said current for controlling the natural period of said tuned frequency determining circuit.

10. A system comprising a source of variations of given frequency, an oscillator having a tuned frequency determining circuit for setting the frequency of said oscillator approximately at a rational fraction of said first frequency, an electric space discharge device responsive to waves from said oscillator for producing a narrow peaked wave of the frequency of said oscillator, a second electric space discharge device, means rendering said latter device responsive to said narrow peaked wave and the wave of said source to produce current of a magnitude depending on the phase relation between said two latter waves, means responsive to said current for so controlling the natural period of said tuned circuit as to maintain the ratio of said first frequency and the frequency of said oscillator constant, a load circuit, and a unidirectionally transmitting device connecting said oscillator to said load circuit.

11. A method of achieving a fixed frequency relation between waves from two sources, which comprises deriving from the wave from one source an interrupted wave whose periodicity of interruption is the frequency of the wave from which it is derived, combining said interrupted wave with the wave from the other source so as to produce a direct current component of magnitude varying in accordance with the phase relation of the two combining waves, and controlling the frequency of the wave from one source in accordance with the magnitude of said current.

12. A frequency controlling system comprising an oscillator having a frequency determining inductance, a second oscillator, means responsive to a relative change of the frequencies of the waves from said oscillators for producing a direct current which varies in average amplitude as in accordance with such relative change, and means using said current for variably saturating said inductance and thereby controlling the frequency of the wave from the first oscillator so as to maintain any definite predetermined rational relation between the frequencies of the waves from said oscillators.

In witness whereof, I hereunto subscribe my name this 26th day of March, A. D. 1927.

WARREN A. MARRISON.

Certificate of Correction

Patent No. 1,788,533. January 13, 1931.

WARREN A. MARRISON

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, line 50, for "*l/n or n/l*" read 1/n or n/1; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 14th day of March, A. D. 1933.

[SEAL.]

M. J. MOORE,
Acting Commissioner of Patents.