

Nov. 3, 1925.

1,560,056

J. W. HORTON

SOURCE OF WAVES OF CONSTANT FREQUENCY

Filed May 1, 1923

4 Sheets-Sheet 1

Fig. 1.

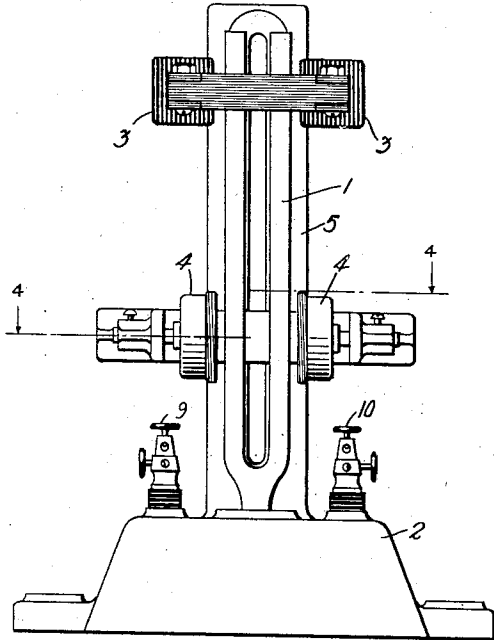


Fig. 2.

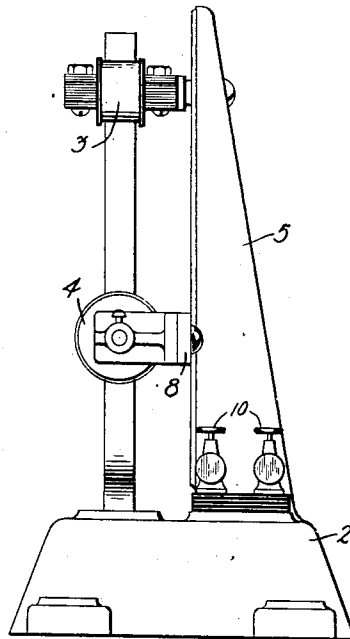


Fig. 3.

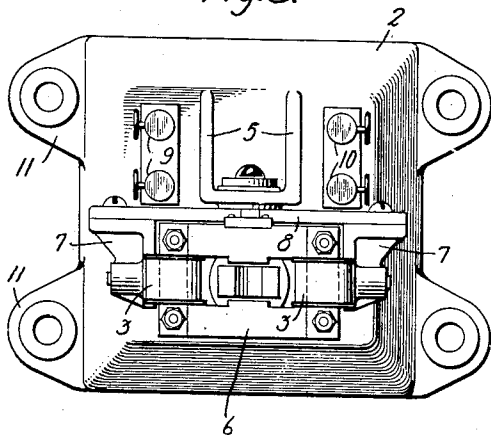
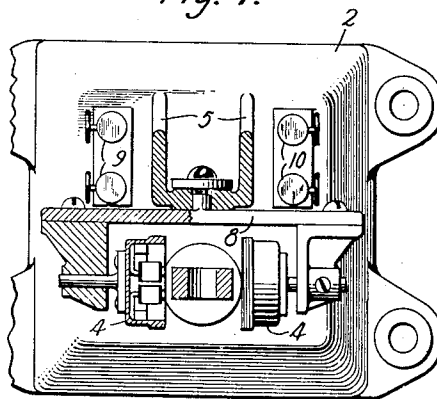


Fig. 4.



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4 Sheets-Sheet 2

Fig. 5

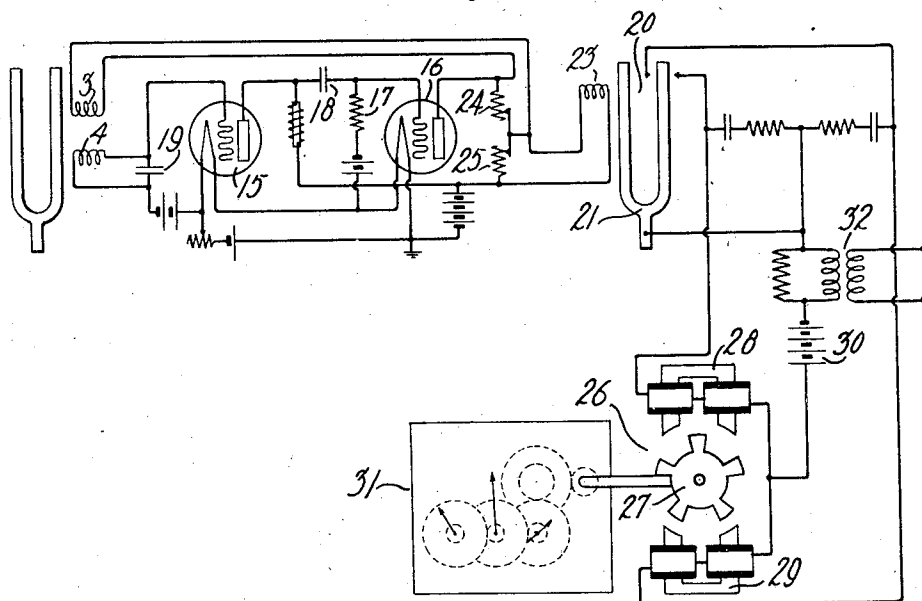
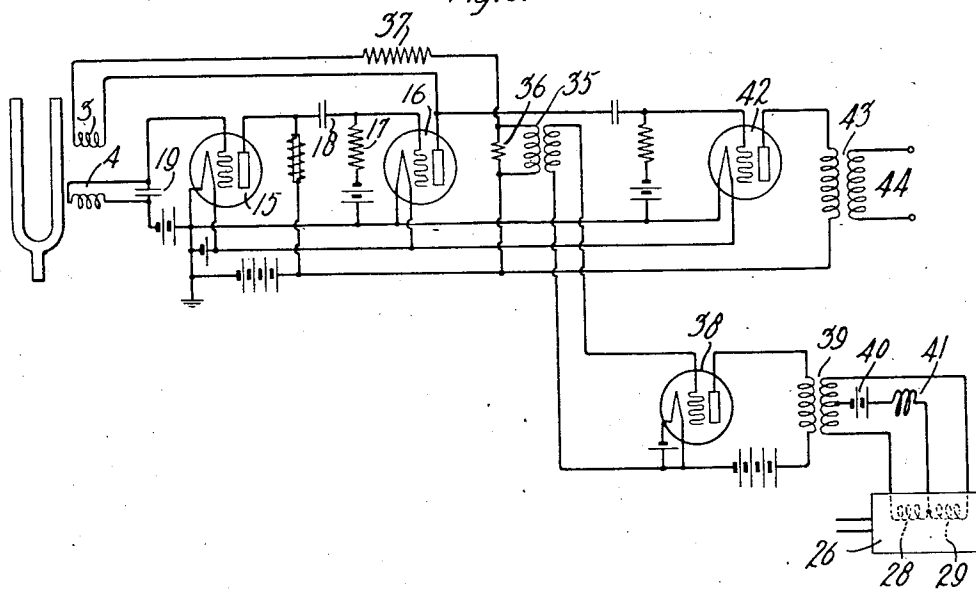


Fig. 6



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4 Sheets-Sheet 3

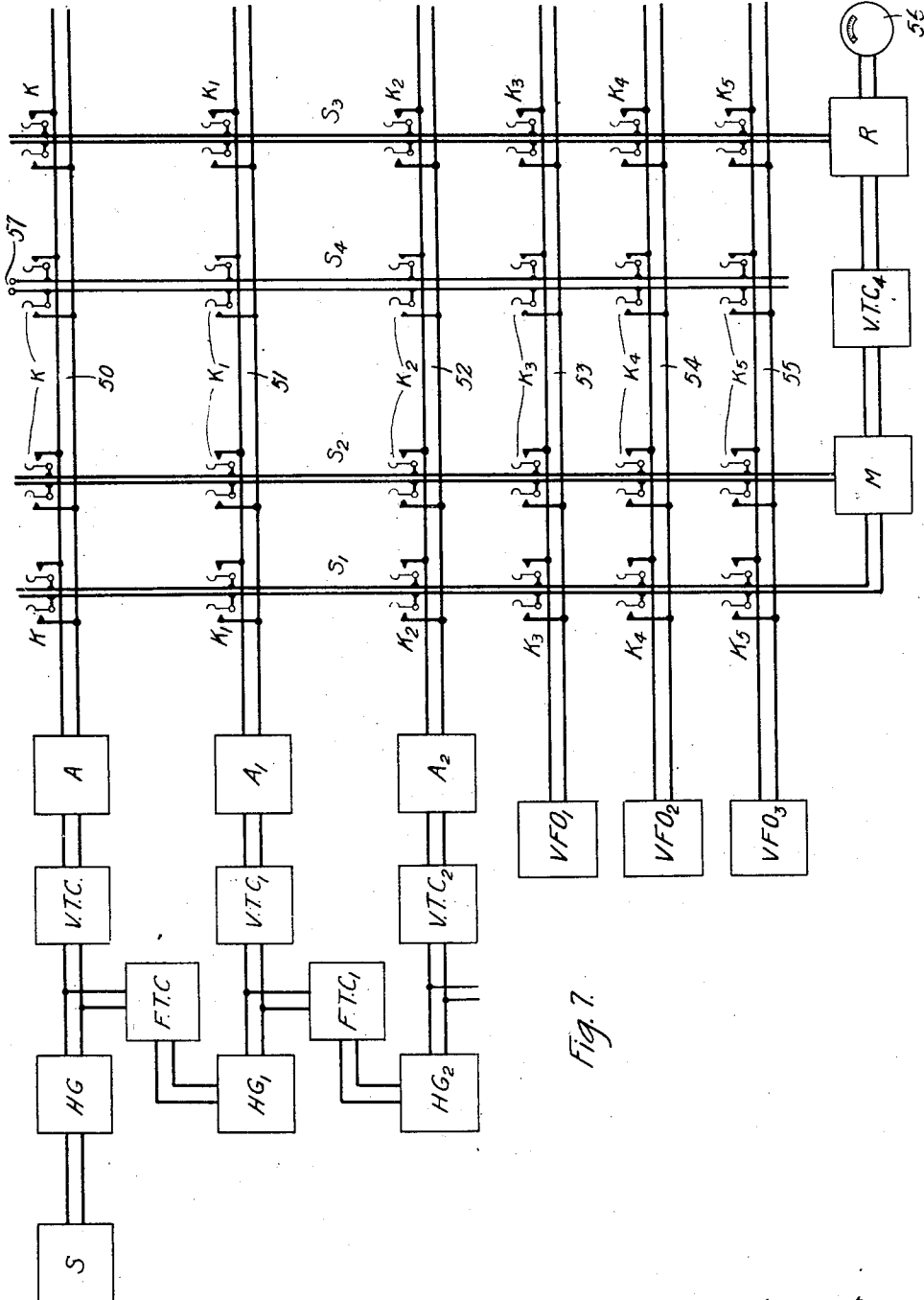


Fig. 7.

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4 Sheets-Sheet 4

Fig. 8.

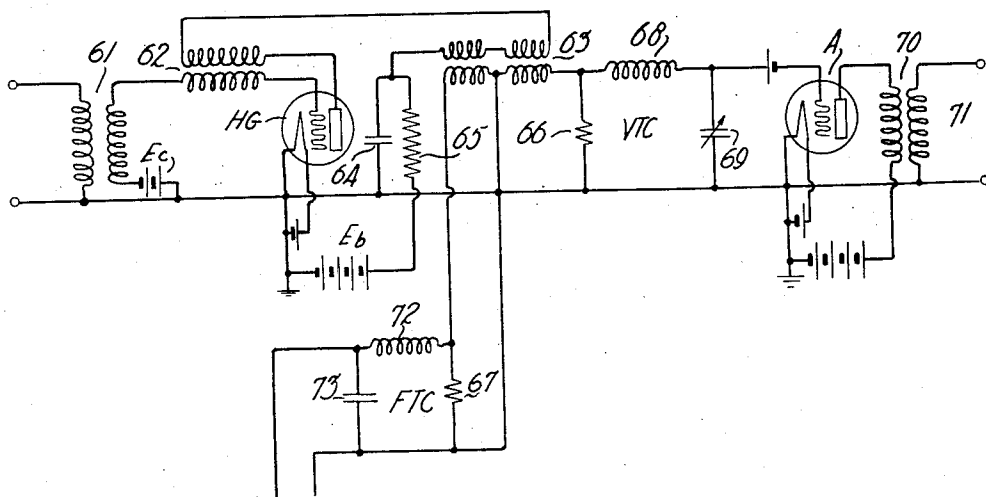
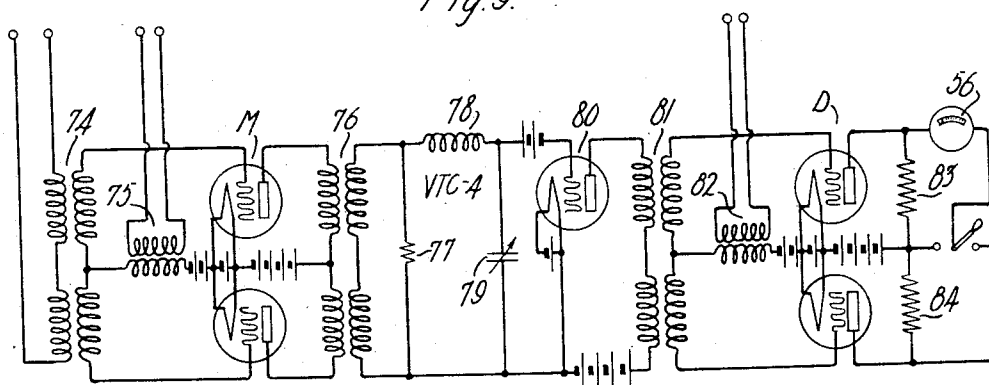


Fig. 9.



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UNITED STATES PATENT OFFICE.

JOSEPH W. HORTON, OF BLOOMFIELD, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

SOURCE OF WAVES OF CONSTANT FREQUENCY.

Application filed May 1, 1923. Serial No. 635,901.

To all whom it may concern:

Be it known that I, JOSEPH W. HORTON, a citizen of the United States of America, residing at Bloomfield, in the county of Essex, State of New Jersey, have invented certain new and useful Improvements in Sources of Waves of Constant Frequency, of which the following is a full, clear, concise, and exact description.

This invention relates to a source of waves of constant frequency.

The art of electrical communication has at its disposal such a wide variety of methods for the transmission of intelligence that it now employs alternating currents having frequencies which cover the entire range between a few cycles per second and several million. Refinements in these methods have reached a point where it is imperative that determinations of the frequency of any of these alternating currents may be made with an accuracy considerably higher than has been possible hitherto.

For example, in the field of radio broadcasting, it has already become necessary to establish a carefully planned assignment of wave lengths for the many stations now operating throughout the country. Great care must be exercised in maintaining these stations at their allotted frequency in order that the general scheme may be effective in preventing undue interference.

Recently introduced methods for multiplex telephony and telegraphy by means of carrier currents over wires have placed exceedingly rigorous limits on the frequency adjustments of certain types of apparatus. It is sometimes necessary to hold such circuits as oscillators and filters to within 0.1 percent of a given value under commercial operating conditions. It is, therefore, apparent that the calibrating devices used in the manufacture and maintenance of such circuits must be reliable to 0.01 percent and that the primary standard should be good to 0.001 percent.

Among the objects of the invention are:—

To produce a constant frequency source which may be employed as a primary frequency standard.

To produce an efficient driving means for an indicating device.

To produce efficient, accurate, and reliable

means for determining the frequency of an alternating current source.

To provide an efficient tuning fork relay and driving mechanism therefor.

To provide an efficient synchronous motor driven by alternating current.

To provide an improved harmonic generator system for producing an increased number of harmonics of the base frequency.

To provide improved coupling means for circuits.

In accordance with this invention, a tuning fork oscillation generator is sustained in vibration by means of amplified currents supplied by an amplifier coupling the driving and control magnets of the fork. The output of this generator drives a synchronous motor. The motor operates a clock which serves to count and indicate the frequency of the generator. Thus, the constancy of the primary generator frequency may be compared with another standard, such, for example, as the time signals broadcasted daily from Arlington.

The standard frequency source may be employed to calibrate other oscillation generators, wave meters and other apparatus, and to analyze and determine the frequency of alternating currents.

In order to have available for calibration and other frequency measurement purposes, many different frequencies, the primary source is arranged to feed into a harmonic generator system wherein are produced harmonics of the standard frequency upward of the thousandth harmonic.

Any two of the frequencies furnished by the harmonic producer system may be combined in a balanced modulator to produce components thereof which are equal to the sum and to the difference of the input frequencies. Thus practically any desired frequency may be obtained for frequency measuring and other purposes.

A frequency indicator coupled to a balanced detector is associated with the harmonic producer system and the modulator whereby, with the aid of suitable switching mechanism various forms of apparatus may be readily calibrated and the frequency of alternating currents easily and quickly determined.

A primary standard of frequency which

has a frequency of 100 cycles per second is well suited for calibrating apparatus and measuring the frequencies of circuits employed in the ordinary telephone system and in carrier current systems wherein the frequencies used are ordinarily not greater than 100,000 cycles per second.

However when calibrating apparatus and measuring the frequency of circuits employed in radio systems wherein frequencies of the order of several million are used, it is desirable that the base frequency supplied to the harmonic generator system be of a higher order than 100 cycles per second.

Such a higher base frequency may be obtained by employing the constant frequency tuning fork oscillation generator herein disclosed to drive a 1000 or 10000 cycle frequency bar which may serve to supply the base frequency to the first generator of the harmonic generator system.

While some of the features of this invention may be employed with particular advantage in frequency measuring systems and indicating mechanism control systems they may also be employed with advantage in other systems.

In the drawings:

Fig. 1 is a front elevation of the tuning fork oscillation generator which serves as the standard frequency source.

Fig. 2 is a side elevation of this generator.

Fig. 3 is a top plan of the generator.

Fig. 4 is a horizontal section on line 4-4 of Fig. 1.

Fig. 5 shows diagrammatically the tuning fork generator and its driving and control apparatus with a cycle counter coupled thereto and operated by a tuning fork relay controlled synchronous motor.

Fig. 6 shows diagrammatically the tuning fork generator and its driving and control apparatus with the indicating mechanism operated by alternating current supplied directly from the generator.

Fig. 7 shows the harmonic generator or producer system associated with a balanced modulator for obtaining alternating currents of frequencies other than those furnished directly by the harmonic producers and coupled to a balanced detector and indicator employed in measuring frequencies.

Fig. 8 shows diagrammatically one of the harmonic generators and the variable and fixed tuned circuits into which it feeds.

Fig. 9 shows diagrammatically the balanced modulator and the balanced detector and indicator coupled thereto.

Tuning fork generator.

The tuning fork generator as shown in

Figs. 1 to 4 inclusive, comprises a tuning fork 1, a driving magnet 3 and a controlling magnet 4.

In order that the energy loss in mounting the fork may be kept within a small value and that no variation in energy absorption occurs due to change in location, the fork is mounted on a heavy cast iron base 2. The fork is keyed into its socket and is clamped firmly by a nut (not shown) beneath the base 2.

The driving magnet, having two windings, is similar to the Eckhard tuning fork driving magnet described in Physical Review, vol. 17, April, 1921, pages 535 and 536. This magnet has a rectangular hollow core 6 within which the tines of the fork are positioned. The driving magnet is adjustably mounted on the upright 5.

The control magnet 4 comprises two suitable electromagnets such as the electromagnets of telephone receivers which are positioned on opposite sides of the fork near the base thereof. These magnets are adjustably mounted in brackets 7 so that the air gaps between the tines of the fork and the magnets may be varied. The brackets 7 are fastened to a bracket 8 adjustably mounted on the upright 5. Thus, the position of the control magnets 4 along the length of the fork may be varied.

Pairs of terminals 9 and 10 for the driving and control magnets are mounted upon but insulated from the base 2.

The base 2 is provided with apertured lugs 11 for the reception of fastening means for securing the base to a bench or other support.

The circuits for the driving and control magnets of the tuning fork generator are shown in Fig. 5.

The control magnet coupled to the fork 1 controls the action of the driving magnet through a two-stage amplifier comprising two three-electrode electronic amplifiers 15 and 16 connected in tandem by means of the usual bridged resistance 17 and series condenser 18.

The winding of the control magnet 4 is shunted by a condenser 19 is included in the input or grid circuit of the first amplifier 15. The winding of the driving magnet 3 is included in the output or plate circuit of the second amplifier 16. The output circuit of the amplifier 16 also includes the windings of a driving magnet 23 for the tuning fork relay 20. The windings of these driving magnets 3 and 23 are shunted by potentiometers 24 and 25 respectively, by means of which the amplitude of the current in these windings may be regulated.

The operation of the tuning fork generator will now be described. Assuming that the fork 1 is set into vibration mechanical

ly, such vibration is sustained by means of the control and driving magnets 4 and 3. Due to the coupling between the fork and the control electromagnet 4, the vibration of the fork sets up in the grid circuit of the amplifier 15, an alternating electromotive force which is impressed upon the grid. Thus, the potential of the grid is varied cyclically in accordance with the vibration of the fork and causes corresponding amplified variations in the current flowing through the windings of the driving magnets in the output circuit of amplifier 16. These cyclic variations of current through the windings of the driving magnets are in synchronism with the vibrations of the fork 1 and maintain the fork in vibration.

The condenser 19 shunted across the winding of the control magnet 4 serves to maintain the proper phase relation between the currents of the control and driving magnets and thus assists in maintaining the fork in vibration at the proper rate.

Since the driving magnet 23 of the tuning fork relay 20 is in series with the driving magnet 3, the fork 21 of the relay will be driven and maintained at the same rate of vibration as the tuning fork 1. These tuning forks 1 and 21 have the same fundamental frequency, for example, a frequency of 100 cycles per second, this frequency being chosen as a suitable frequency for the standard frequency source.

The tuning fork relay 20, provided with suitable contacts positioned upon opposite sides of one of its tines, drives a synchronous motor 26 consisting of the well known LaCour or phonic wheel 27 and operating magnets 28 and 29 therefor. The electrically driven fork 21 of the relay alternately supplies impulses from battery 30 or other source to the magnets 28 and 29 which cause the wheel 27 to rotate at constant speed in accordance with well known practice.

The wheel 27 of the motor makes one complete revolution for each five cycles and therefore 20 revolutions in a second, the generator delivering alternating current of 100 cycles per second. The shaft of the wheel 27 is connected through suitable gearing to the second hand of a clock 31 so that the second hand makes one complete revolution in one minute. The minute and hour hands of the clock are geared to the second hand in the usual manner.

The clock 31, therefore, serves as indicating mechanism by means of which the frequency of the generator may be counted.

The tuning fork oscillation generator in combination with the motor 26 and the intermediate tuning fork control relay 20 constitutes the operating mechanism of the clock 31.

Output current having a frequency of 100

cycles per second supplied for frequency measuring and calibrating purposes may be obtained at the terminals of the secondary winding of transformer 32.

The circuit organization of Fig. 6 differs from that of Fig. 5 principally in that the motor 26 is driven by alternating current supplied direct from the tuning fork generator.

The control magnets 4 and driving magnet 3 associated with fork 1 are coupled through amplifiers 15 and 16 connected in tandem as in Fig. 5. In Fig. 6, however, the output circuit of amplifier 16 has two branches, one of which contains the driving magnet 3 and a transformer 35 by means of which current from the generator is supplied for operating the motor 26. The other branch supplies current for measuring and calibrating purposes.

The primary winding of transformer 35 is shunted by a non-inductive resistance 36 of low value and is connected in series with a non-inductive resistance 37 of high value. Low resistance 36 substantially absorbs any reactions upon the output circuit due to changes of impedance in the secondary circuit of the transformer 35. Resistance 37 is high compared to the total resistance of the circuit so that any reactions thereon due to changes of impedance in the secondary circuit of the transformer 35 will not have an appreciable effect upon the impedance of the output circuit. The frequency of the generator fork 1 therefore will be substantially unaffected by changes of impedance in the circuit connected to the secondary of transformer 35.

The secondary winding of transformer 35 is connected to the input circuit of an amplifier 38 whose output circuit is connected to the primary winding of a transformer 39. The secondary winding of transformer 39 is connected in circuit with the windings of the motor magnets 28 and 29, and a source of current, such as a battery 40. This battery 40 serves to polarize the motor magnets 28 and 29. Amplified alternating current from the tuning fork oscillation generator supplied through amplifier 38 is superimposed upon the polarizing current in the motor magnet windings. Retardation coil 41 prevents the flow of this alternating current in the common branch of the motor magnet circuit. Thus, while the steady polarizing current flows through the windings in parallel, the alternating current during any particular half cycle flows through the windings in series and hence aids the polarizing current through one magnet and opposes the polarizing current through the other. The amplitudes of the alternating and polarizing currents are such that when these currents are aiding in one

magnet there is practically no current flowing in the other magnet. Consequently, the magnets are alternately rendered effective to cause the rotation of the wheel of the motor.

- 5 The motor may be connected to the clock or other indicating mechanism in the same manner as described in connection with Fig. 5.

10 The other branch of the output circuit of amplifier 16 is connected through an amplifier 42 and a transformer 43 to an outgoing circuit 44. From the terminals of the outgoing circuit 44 may be obtained alternating current of the frequency of 100 cycles, 15 for measuring and calibrating purposes.

The amplifiers 38 and 42 prevent changes of impedance in the output circuits thereof from reacting upon the tuning fork oscillation generator whereby such changes cannot affect the frequency of the generator.

20 Fig. 7 shows the harmonic generator system and means for combining the various frequencies produced thereby so as to obtain any desired intermediate frequency.

25 This harmonic generator system includes a plurality of harmonic generators, tuned circuits and amplifiers so related that practically any desired multiple of the base frequency may be obtained. A source of base frequency S feeds into a harmonic generator HG, whose output is connected to a variable tuned circuit VTC and a fixed tuned circuit FTC. This base frequency is preferably supplied by the source of constant frequency such as the tuning fork generator previously described. The harmonic generator and the tuned circuits are shown in detail in Fig. 8 to be described later. 40 VTC may be varied so as to obtain any one of the first nine harmonics produced by the harmonic generator HG. For the purpose of this application, the first harmonic is considered to be the frequency impressed upon the harmonic generator while each succeeding harmonic of the impressed frequency is considered to be the multiple thereof corresponding to the particular numbered harmonic. Thus the tenth harmonic has a frequency ten times the impressed frequency. The variable tuned circuit VTC feeds into an amplifier A which amplifies the current of the selected frequency and delivers such amplified current to the bus bars 50.

55 The fixed tuned circuit FTC is tuned to the tenth harmonic produced by the harmonic generator HG. Current of the tenth harmonic having a frequency ten times that of the current impressed upon the harmonic generator HG, selected by the tuned circuit FTC is delivered to the input circuit of a second harmonic generator HG₁. The harmonic generator HG₁ delivers the harmonics 65 produced therein to a variable tuned circuit

VTC₁ and to a fixed tuned circuit FTC₁. The variable tuned circuit VTC₁ is similar to the tuned circuit VTC and the constants thereof may be adjusted so as to select any one of the first nine harmonics produced by the generator HG₁. The selected harmonic may be amplified in amplifier A₁ and delivered to the bus bars 51.

The fixed tuned circuit FTC₁ is similar to the fixed tuned circuit FTC and is tuned 75 to the tenth harmonic produced by the generator HG₁. The tenth harmonic selected by this tuned circuit FTC₁ is impressed upon the input circuit of a third harmonic generator HG₂ which produces currents 80 having frequencies which are harmonics of the impressed frequency. By means of the variable tuned circuit VTC₂, any one of the first nine harmonics from the generator HG₂ may be selected and then amplified by 85 an amplifier A₂ and delivered to bus bars 52.

If desired, further harmonics of the base frequency supplied from the source S may be obtained by providing a fixed tuned circuit connected to the output of the harmonic generator HG₂, to select the tenth harmonic produced thereby and impress the same on another harmonic generator in the manner as explained above. 90

By employing a base frequency of 100 95 cycles per second, the input currents to the various generators will have the frequencies set forth in the table below and the frequencies which it is possible to have available upon the respective bus bars are the 100 first ten harmonics of the frequencies set forth.

Generator.	Frequency.	Bus bars.
HG.....	100	50
HG ₁	1000	51
HG ₂	10000	52

105 The harmonic generator system is incorporated in the measuring and calibrating system which also includes three variable frequency oscillators VFO₁, VFO₂ and VFO₃, a balanced modulator M, a variable tuned circuit VTC₄, a balanced rectifier R and meter 56. 115

The variable frequency oscillators may be of any well known type but preferably are of the type disclosed in my copending application Serial No. 555,286, filed April 18, 1922. The first two variable frequency oscillators VFO₁ and VFO₂ are adapted to supply currents of frequencies ranging from 100 to 10,000 cycles per second while the variable frequency oscillator VFO₃ is adapted to supply currents of frequencies 125 ranging from 1000 to 1100 cycles per second. The output circuits of these oscillators are connected to the bus bars 53, 54 and 55 respectively.

By means of the individual keys of 130

switches S_1 and S_2 any of the frequencies available on the bus bars may be impressed upon the input circuit of the modulator M, wherein two different impressed frequencies may be combined to produce in the output circuit thereof current components having frequencies equal to the sum and to the difference of the impressed frequencies.

Thus it is possible, in the system shown in Fig. 7, to obtain from the output of the modulator a very great number of frequencies for calibrating and measuring purposes.

The modulator output circuit is connected to the variable tuned circuit VTC_4 , the constants of which may be varied so as to select any frequency delivered thereto by the modulator. The frequency selected by this tuned circuit is delivered to a balanced rectifier R, in the output circuit of which is included the meter 56. By means of the individual keys of the switch S_3 , any one of the frequencies available on the bus bars may be connected directly to the balanced rectifier R. By means of the individual keys of switch S_4 any of the frequencies available on the bus bars may be connected with the terminals 57 to which a wave meter or other apparatus to be calibrated may be connected.

The four switches are similar in construction, each comprising a plurality of individual two-contact keys so arranged that when one key is depressed, it is locked in depressed position with the contacts thereof closed. The depression of another key of the same switch releases the previously depressed key which is thereupon restored to its normal position.

The harmonic generators, the variable and fixed tuned circuits and the amplifiers employed in the system are similar in construction, so a description of one of each will suffice.

Fig. 8 showing diagrammatically the details of the first set of the generator system will now be described.

The harmonic generator HG comprises a distortion producing electronic amplifier having a cathode, an anode and a control electrode or grid and the design of the harmonic generator HG is based on the principle that if the energy of any periodic wave is liberated during a small fraction of a cycle, the wave will contain a number of harmonics. The input or grid circuit of the harmonic generator includes a battery E_c which maintains the grid at a sufficiently negative potential to prevent the flow of current in the anode or plate circuit. The grid circuit also includes the secondary winding of transformer 61 whose primary may be coupled to the source S of the constant base frequency and the secondary winding of transformer 62 whose primary is in-

cluded in the plate circuit. The plate circuit also includes the primary winding of transformer 63, a condenser 64, a high resistance 65 and the usual plate battery E_B .

The capacity of condenser 64 and the resistance 65 are of such values that, during each negative half cycle of the alternating current impressed upon the grid circuit through the input transformer 61, condenser 64 is charged by current from battery E_B supplied through resistance 65 and during the succeeding positive half cycle the condenser discharges to effect the results to be hereinafter stated. Resistance 65 is of such a high value as to prevent the flow of current from the battery E_B through the plate circuit, such current being obtained from the charged condenser 64.

The operation of the harmonic generator may be explained briefly as follows: The plate potential for the harmonic generator is obtained from the condenser 64 which is charged to the potential of the battery E_B through the resistance 65. The potential of the battery E_c in the grid circuit is more than sufficient to prevent the plate from drawing current from the condenser 64. If now, a sine wave is impressed upon the terminals of the primary winding of the transformer 61 there is induced in the grid circuit a sine wave electromotive force which acts in series with the potential of the battery E_c . The amplitude of this sine wave is such that at some time during the positive half of the cycle, the negative potential on the grid is reduced to a point which permits the plate to draw current. As current flows from the condenser an electromotive force is induced in the secondary winding of the transformer 62. The windings of this transformer are so connected that this induced electromotive force tends to further reduce the negative potential on the grid. The action therefore builds itself up so that the space current increases very rapidly thus reducing the charge on the condenser 64 more rapidly than the battery E_B can replace it through the resistance 65. This finally results in a decrease in the space current due to the decrease in the potential across the condenser 64 which in turn immediately reacts to increase the negative grid potential thereby reducing the plate current still further. As soon as current to the plate becomes less than the current at which the battery charges the condenser 64 through the resistance 65, the potential across the condenser and therefore the potential acting in the plate circuit begins to increase. By this time, however, the grid is sufficiently negative to prevent the further flow of current to the plate. Thus, during a portion of the positive half cycle, current is permitted to flow from the condenser 64 to the plate while during the negative half

cycle and at the beginning and ending of the positive half cycle, the grid is maintained at such a negative potential that the plate can draw no current from the condenser 64. As the impressed sine wave passes through its cycle, it again reaches during the positive half cycle, a value at which current may flow in the plate circuit and, the condenser having acquired another charge during the negative half wave, the process is repeated. In this manner, the sine wave serves to release the charge on the condenser 64 through the primary winding of the transformer 63 at periodic intervals and in such a manner that the greater part of the energy is expended in a very small fraction of the cycle. In practice, it has been possible to adjust the harmonic generator of this type so that it will give 500 or more harmonics of the hundred cycle tuning fork generator.

The secondary winding of the transformer 63 is divided into two portions connected respectively across low resistances 66 and 67. A series circuit comprising an inductance 68 and a variable capacity 69 is shunted across the resistance 66. By adjusting the condenser 69, the circuit including the condenser and the inductance may be tuned so as to select any one of the first nine harmonics produced by the harmonic generator HG. In practice, the scale of the condenser 69 is calibrated to indicate directly the harmonics of the generator. The terminals of the variable condenser 69 are connected to the input or grid circuit of the amplifier A whose output circuit is coupled through a transformer 70 to an outgoing circuit 71.

The low resistance element 66 serves to couple the variable tuned circuit to the circuit incoming thereto and absorbs the reactions due to changes in impedance in the incoming circuit whereby the tuned circuit is substantially unaffected by such changes.

Resistance 67 of low value, is shunted by an inductance 72 and a fixed capacity 73 which form a tuned circuit tuned to the tenth harmonic produced by the harmonic generator HG. Resistance 67 serves the same purpose as resistance 66. The terminals of the resistance 67 are connected to the circuit including a portion of the secondary winding of the transformer 63, while the terminals of the condenser 73 are connected to the input circuit of the next succeeding harmonic generator of the harmonic generator system as indicated in Fig. 7.

The balanced modulator M, the variable tuned circuit VTC₄ and the balanced detector D with its meter 56 and the circuit relation thereof are shown diagrammatically in Fig. 9.

The balanced modulator M may be of any well known type but as illustrated is of the type disclosed in U. S. Patent to Carson, No. 1,343,307, granted June 15, 1920.

Any of the frequencies available on the bus bars of Fig. 7 may be impressed upon the balanced modulator M through either transformer 74 or transformer 75. As is well known, the frequencies impressed through transformer 74 on the input circuit appear in amplified form in the modulator output circuit while frequencies impressed through transformer 75 are balanced out in the output circuit.

The output circuit of the modulator M is coupled by means of transformer 76 to an outgoing circuit which in turn is coupled through low resistance 77 to the variable tuned circuit VTC₄ comprising inductance 78 and a variable condenser 79. Resistance 77 is similar to resistance 66 and 67 and serves a similar purpose. The terminals of condenser 79 are connected to the input circuit of an amplifier 80 whose output circuit is coupled to the detector input circuit through an input transformer 81. Thus, any of the frequencies selected by the tuned circuit VTC₄ and amplified by the amplifier 80 may be impressed upon the detector D.

The balanced detector D may be of any well known type but as illustrated includes two three-electrode space discharge tubes having their control electrodes connected to the opposite ends of the secondary winding of transformer 81. The mid-point of this winding is connected to the cathodes of the tubes by a path including the secondary winding of transformer 82. Any of the frequencies available upon the bus bars of Fig. 7 may be impressed upon the common branch of the detector input circuits. The anodes of the detector tubes are connected to separate terminals of resistances 83 and 84. A common mid-terminal of these resistances is connected to the two cathodes by a path including a space current battery. An indicating device such as a galvanometer 56 is adapted to be connected across the resistance 83 or across both resistances 83 and 84 by a suitable switch.

The balanced rectifier comprises two electronic valves connected in balanced relation. These valves have on the grids thereof a constant potential of such value that when there is no voltage impressed across either input transformer there is no plate current flowing in either valve. Should a voltage be impressed upon the input transformer 81, the potentials impressed upon the grid of the two valves will be such that they will alternately draw current from the plate battery. This will set up across the outer ends of resistances 83 and 84, an alternating potential having a frequency equal to that impressed upon the transformer. Since this voltage is symmetrical with respect to the meter, there will be no motion of the needle, unless the frequency is sufficiently low to be followed by the needle. Voltages im-

pressed upon the transformer 82 cause both valves to draw current from the plate battery during that portion of the wave which makes the total grid potential less negative than that of the grid battery. Under these conditions, there will be no difference of potential across the outer ends of the resistances 83 and 84. If, however, two voltages of nearly the same frequency are impressed upon the two input transformers they will not affect the two valves equally. At the instant when they are in such phase relation that their sum is effective on one valve, their difference is effective on the other. Under this condition, the bridge circuit composed of the two resistances and the two valves will be unbalanced and the needle of the meter will be deflected. As the phase relation changes so that the two voltages are 90° apart, the effect on the two valves becomes symmetrical and the needle of the meter will stand at its mid-zero position. As the phase continues to change, the resulting voltages will unbalance the bridge in the opposite direction and the deflection of the meter will be reversed. It is thus seen that the deflection of the meter indicates the phase difference between the two impressed voltages and may be used in determining the frequency difference between them so long as this difference is not too great to be followed by the needle. Because of the balanced arrangement of the input circuits of the rectifier D, the frequencies of the currents from two sources may be compared without any tendency on the part of one to influence the operation of the other.

If currents of the same frequency and of the same or different phase are impressed upon the respective input transformers of the rectifier, the direct current components of the currents in the plate circuits will flow through the meter and cause a constant deflection thereof which is a function of the relative phase of the impressed currents.

The constant deflection of the meter is therefore an indication that the frequency of the source being calibrated has been adjusted to identity with the frequency of a known current.

So long as there is a slight frequency difference between the two sources the needle will swing from side to side in synchronism with the change in phase between the two currents.

The primary winding of the modulator input transformer 74 is connected to the leads common to the keys of switch S₁, the primary winding of transformer 75 is connected to the leads common to the keys of switch S₂ and the primary winding of the detector input transformer 82 is connected to the leads common to the keys of switch S₃.

The operation of the calibrating and measuring system shown in Fig. 7 as used to obtain any desired multiple of the fundamental or base frequency can best be explained by a typical example. Given the problem of adjusting a frequency meter to determine the setting corresponding to a frequency, such, for example, as 78,100 cycles, the procedure is as follows: The variable tuned circuit VTC is adjusted to select 100 cycles from the output of the harmonic generator HG, the circuit VTC₁ is adjusted to select 8,000 cycles from the output of the harmonic generator HG₁, and the circuit VTC₂ is adjusted to select 70,000 cycles from the output of the harmonic generator HG₂. There is then available on the buses 50, 51 and 52 sinusoidal alternating currents having frequencies of 100, 8,000 and 70,000 respectively.

The first two of these currents, namely, those having frequencies of 100 and 8,000 cycles may be combined directly in the modulator M, the 100 cycle current being connected thereto by depression of key K of switch S₁ and the 8,000 cycle current being connected thereto by depression of key K₁ of switch S₂. In the output of this modulator there will be current components having frequencies equal to the sum and to the difference of the two impressed frequencies and also to the frequency of the particular component impressed upon the switch system S₂. Due to the balanced arrangement of the modulator valves, the 8,000 cycle current will be balanced out in the modulator output circuit, but currents having frequencies of 100, 7900 and 8100 will be delivered by the modulator to the tuned circuit VTC₄. The current component having a frequency of 8100 cycles may be selected from the output of the modulator by the variable tuned circuit VTC₄ and impressed upon the balanced rectifier R. The adjustment of this tuned circuit may be effected by throwing the meter switch indicated in Fig. 9 so that the meter 56 reads the current flowing in one side of the balanced rectifier only. Having adjusted this tuned circuit, the meter may be connected across both sides of the rectifier. One of the variable oscillators, VFO₁ may now be connected to the balanced rectifier by depression of key K₃ of the switch S₃. This oscillator may be adjusted to the frequency of the 8100 cycle component by varying its frequency until the frequency difference, as indicated by the rectified current meter, is reduced to zero.

By the provision of a second balanced modulator, it would, of course, be possible to combine therein the 8100 cycle current from modulator M and the 70,000 cycle current available on bus bars 52, so as to ob-

tain directly from this second modulator the desired 78,100 cycle current. Further similar extension of the system to obtain higher frequencies will be obvious to those skilled in the art.

It will be noted that this method of selecting the particular product of modulation, in which we are interested, directly from the output of the modulator, requires that the variable tuned circuit VTC₄ be able to select a given current component and suppress another current component having a frequency differing but little therefrom. This may be avoided if we proceed in the following manner: Connect the 100 cycle current to the modulator by depression of key K of switch S, and connect the meter of the rectifier R across one side only of the circuit. The variable tuned circuit VTC₄ may then be adjusted to approximately 100 cycles by varying the capacity thereof until a maximum deflection of the meter is obtained. Now connect the 8000 cycle current and the variable frequency oscillator VFO₁ to the two input circuits of the modulator M by the depression of the proper switch keys. Assuming that the calibration of the oscillator is known approximately, it may be set to have a frequency in the neighborhood of 8000 cycles. By varying its frequency over a limited range, it may be caused to pass through a frequency range including 7900 and 8100 cycles. When the oscillator is adjusted for either 7900 or 8100 cycles, one of the products of modulation will be a current having a frequency of 100 cycles. A maximum deflection on the meter will give an approximate indication of the frequency of this component. The two frequencies, 7900 and 8100 may be distinguished from each other by observation of the sign of the change in the frequency control element of the oscillator, in accordance with well known practice. The final adjustment of the oscillator to exactly 8100 cycles may now be completed by connecting the 100 cycle current on bus bars 50 to the rectifier input transformer 82 and then readjusting the oscillation until the low frequency component, resulting from modulation with the 8000 cycle current, has an identical frequency, as indicated by the constant deflection of the meter.

By repetition of either of the above described methods of procedure, the 70,000 cycle current available on bus bars 52 may now be combined with the 8100 cycle current available on the bus bars 53 (obtained from the previously adjusted oscillator VFO₁) the oscillator VFO₂ may be adjusted to a frequency of 78,100 cycles.

In general, there are two methods for obtaining a frequency equal to the sum or dif-

ference of two other frequencies. The first consists in modulating the two frequencies directly and adjusting some variable frequency device for zero beats with the frequency of the particular component desired. The second method consists in modulating the variable frequency device with the current from either of the sources of known frequency and adjusting it for zero beats with the frequency of the other.

As a result of the adjustments made as above described we have succeeded in determining the setting of the oscillator VFO₂ for a particular frequency. This is illustrative of the manner in which a variable frequency oscillator would be calibrated.

Having adjusted oscillator VFO₂ to the frequency of 78100 cycles, the frequency meter may now be calibrated. The 78100 cycle current now available on bus bars 54 is connected, by depression of key K₄ of switch S₄ to the frequency meter connected to terminals 57. The frequency meter may then be adjusted to give its characteristic indication. The calibration of other apparatus may, of course, be accomplished in a similar manner.

The variable frequency oscillator VFO₃ is provided for the purpose of obtaining frequencies other than multiples of 100 cycles. Variation of the frequency of this oscillator is effected by means of a continuously varying air condenser having an accurately graduated scale. Condenser settings corresponding to a number of frequencies such as 900, 1,000, 1,100 and 1,200 cycles may be obtained by comparison with the output of the harmonic generator system in the manner previously described. From these settings and the known relation between capacity and frequency, interpolations between these frequencies may be made with considerable accuracy. By suitably combining the current from this variable frequency oscillator with current from the harmonic generator system or from an oscillator, the frequency of which is accurately known, determinations of frequency may be made at any part of the frequency scale.

The invention set forth herein is, of course, susceptible of various other modifications and adaptations.

The invention claimed is:

1. The combination of an alternating current generator, a tuning fork relay having a fundamental frequency equal to the frequency of the generator and driven by current therefrom, and a work circuit coupled to the relay.

2. The combination of an alternating current generator, a tuning fork relay having a fundamental frequency equal to the frequency of the generator and driven by current therefrom, and a motor controlled by

the tuning fork relay and operated in synchronism with the generator.

3. The combination of an alternating current generator, a tuning fork relay having a fundamental frequency equal to the frequency of the generator, electromagnetic driving means for the tuning fork relay supplied with current from the generator, and a motor controlled by the relay so as to operate in synchronism with the generator.

4. The combination of a tuning fork oscillation generator, driving and controlling means for the generator fork, electronic amplifying means coupling the driving and controlling means, a tuning fork relay having the same fundamental frequency as the generator fork driven by current from the generator, and a motor controlled by the relay so as to operate in synchronism with the generator.

5. The combination of a tuning fork generator having driving and controlling magnets, an amplifier coupling the controlling and driving magnets, a synchronous motor driven by current supplied by the generator, and an amplifier coupling the generator and motor.

6. The combination of a tuning fork alternating current generator having driving and controlling magnets coupled by an amplifier, a synchronous motor having a rotatable inductor and polarized driving electromagnets therefor, and means including an amplifier to supply alternating current from the generator to the driving electromagnets to cause the inductor to rotate at a speed determined by the frequency of the alternating current.

7. The combination of a tuning fork alternating current generator having driving and controlling magnets coupled by an amplifier, a synchronous motor having a rotatable inductor and polarized driving electromagnets therefor, and means to supply alternating current from the generator to the driving electromagnets to cause the inductor to rotate at a speed determined by the frequency of the alternating current.

8. A harmonic generator system comprising a harmonic producer having input and output circuits, a source of base frequency current connected to the input circuit, a selecting circuit connected to the output circuit and variable to select any one of a plurality of the harmonics, a selecting circuit tuned to another harmonic and coupled to the output circuit, another harmonic producer having its input circuit connected to the last mentioned selecting circuit, and a second variable selecting circuit connected to the output circuit of the second harmonic producer.

9. A harmonic producer system comprising a first and a second electronic valve, each

having input and output circuits; a source of alternating current connected to the input circuit of the first valve; each valve being adapted, when overloaded by alternating current delivered to its input circuit, to produce currents the frequencies of which are harmonics of the frequency of the impressed current; a selecting circuit coupling the output circuit of the first valve to the input circuit of the second and tuned to one of the harmonics produced by the first valve; and a variable selecting circuit for each valve to select any one of a plurality of harmonics produced thereby.

10. A calibrating and frequency measuring system having in combination a harmonic producer according to claim 9, a plurality of variable frequency oscillation generators, a pair of bus bars connected to each generator and to each variable selecting circuit of the harmonic producer system, a balanced modulator, a balanced detector having a meter in its output circuit, a variable selecting circuit coupling the modulator and detector, and switching means to couple any two pairs of the bus bars to the input circuit of the balanced modulator and any other pair of the bus bars to the input circuit of the detector.

11. A calibrating and frequency measuring system having in combination a harmonic producer according to claim 9, a plurality of variable frequency oscillation generators, a pair of bus bars connected to each generator and to each variable selecting circuit of the harmonic producer system, a balanced modulator having two input coils and an output circuit, a balanced detector having two input coils and an output circuit, a meter in the detector output circuit, a variable selecting circuit coupling the modulator output circuit and one of the detector input coils, switching means to couple any two pairs of the bus bars to the modulator input coils and any other pair of the bus bars to other input coil of the detector, and switching means to connect the apparatus or circuit under test to any pair of the bus bars.

12. A calibrating and frequency measuring system having in combination, a harmonic producer according to claim 9, a plurality of variable frequency oscillation generators, a balanced modulator and a balanced detector, each having two input coils and an output circuit, a meter connected to the detector output circuit, a variable selecting circuit coupling the modulator output circuit and one of the detector input coils, switching means to connect to the modulator input coils any two frequencies produced by the harmonic generator system and the oscillator and to connect to the other input coil of the detector any other frequency produced in the system, and switching means to

connect any of the produced frequencies to apparatus under test.

13. A multiple frequency producing system having in combination a harmonic producer system according to claim 9, a balanced modulator having two input coils and an output circuit, means to connect to the input coils any two selected frequencies produced in the harmonic system, and a selecting circuit coupled to the output circuit and variable to select any desired frequency component of the products of modulation.

14. A harmonic producer system comprising a first and a second electronic valve, each of said valves having input and output circuits; a source of alternating current connected to the input circuit of the first valve; each valve being adapted, when overloaded by alternating current delivered to its input circuit, to produce currents of frequencies which are harmonics of the impressed frequency; a selecting circuit coupling the output circuit of the first valve to the input circuit of the second and tuned to the tenth harmonic produced by the first valve; and a variable selecting circuit for each valve to select any one of the first nine harmonics produced thereby.

15. A harmonic producer system comprising a plurality of electronic valves, each serving when overloaded by alternating current impressed thereon to produce currents of frequencies which are harmonics of the frequency of the impressed current, a source of alternating current impressed on the first harmonic producer valve, a plurality of selecting circuits connecting the harmonic producer valves in tandem and each tuned to the tenth harmonic produced by the preceding valve, and a variable selecting circuit for each harmonic producer valve to select any one of the first nine harmonics produced thereby.

16. A multiple frequency producing system having in combination the harmonic producer system according to claim 15, a balanced modulator having two input coils and an output circuit, means to connect to the input coils any two selected frequencies produced in the harmonic system, and a selecting circuit coupled to the output circuit and variable to select any desired frequency component of the products of modulation.

17. A calibrating and frequency measuring system having in combination the harmonic producer system according to claim 15, a plurality of variable frequency oscillation generators, a balanced modulator and a balanced detector each having two input coils and an output circuit, a meter connected to the detector output circuit, a variable selective circuit coupling the modulator circuit and one of the detector input coils, switching means to connect to the modulator input coils any two frequencies pro-

duced by the harmonic system and the oscillators and to connect to the other input coil of the detector any other frequency produced in the system, and switching means to connect any of the produced frequencies to apparatus under test.

18. Driving means for indicating mechanism provided with a driven shaft, a motor coupled to the driven shaft, and a tuning fork oscillation generator supplying operating current to the motor.

19. Driving means for indicating mechanism provided with a driven shaft, a motor coupled to the driven shaft, a tuning fork oscillation generator, and means for the motor responsive to current from the generator to drive the motor at a speed determined by the frequency of the generator current.

20. The combination of an input circuit, an output circuit, and means to couple said circuits comprising a non-inductive element, an inductive element and a capacity element connected to form a loop with the terminals of the non-inductive element connected to the input circuit and the terminals of the capacity element connected to the output circuit.

21. Means to couple an incoming to an outgoing circuit, comprising a loop including non-inductive, inductive and capacity elements connected in series, the non-inductive element being of low resistance with the incoming circuit connected across the terminals thereof, and the inductive and capacity elements forming a series circuit tuned to the frequency of the incoming currents with the terminals of the capacity element connected to the outgoing circuit.

22. The combination of incoming and outgoing circuits, a low resistance bridged across the former, a condenser bridged across the outgoing circuit, and an inductance connected in series with the condenser and forming therewith a circuit shunting the resistance and tuned to the frequency of the current to be transmitted from the incoming to the outgoing circuit.

23. The combination of incoming and outgoing circuits, a frequency selecting circuit capacitatively coupled to the outgoing circuit and including inductance and capacity tuned to the frequency to be selected, and a low resistance bridged across the incoming circuit and coupling the selecting circuit thereto.

24. The combination of incoming and outgoing circuits, and coupling means therefor comprising a low resistance bridged across the incoming line, a condenser bridged across the outgoing line, and an inductance between the resistance and condenser serially related to the circuits and forming with the condenser a frequency selective circuit.

25. A system for insuring the supply of

oscillations of a standard frequency comprising a source of substantially constant base frequency oscillations, means to produce desired harmonics of said oscillations to serve as standard frequency oscillations and a mechanical time indicator controlled by said base frequency oscillations and dependent

for its correct time indication upon their frequency.

In witness whereof, I hereunto subscribe 10
my name this 30th day of April A. D.,
1923.

JOSEPH W. HORTON.