Dec. 6, 1949 C. J. YOUNG 2,490,500

STABILIZED OSCILLATOR GENERATOR

Filed Dec. 28, 1946 3 Sheets-Sheet 1

Fig. 1

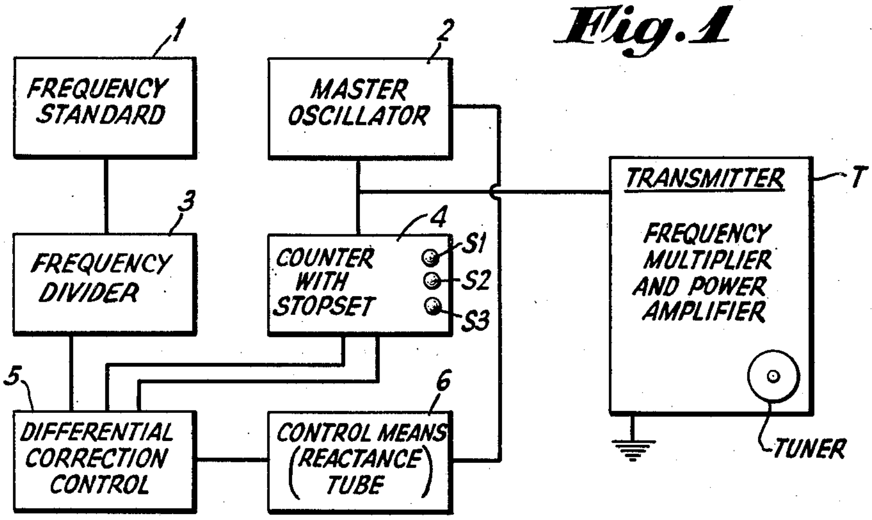
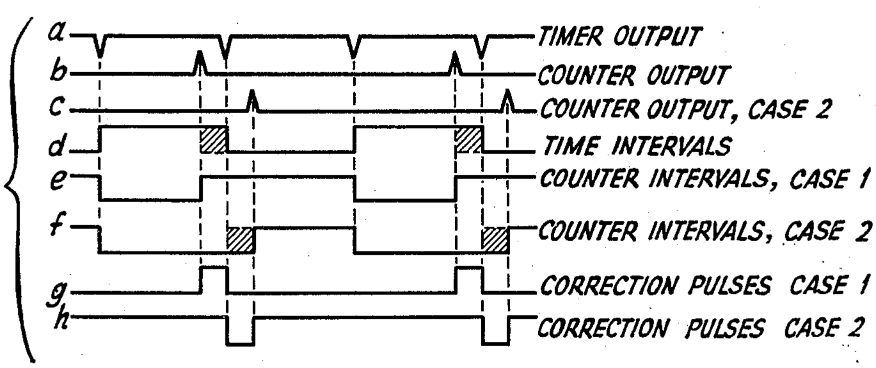


Fig. 2



WAVEFORMS

CASE 1 - MASTER OSCILLATOR FREQUENCY TOO HIGH
CASE 2 - MASTER OSCILLATOR FREQUENCY TOO LOW

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STABILIZED OSCILLATOR GENERATOR

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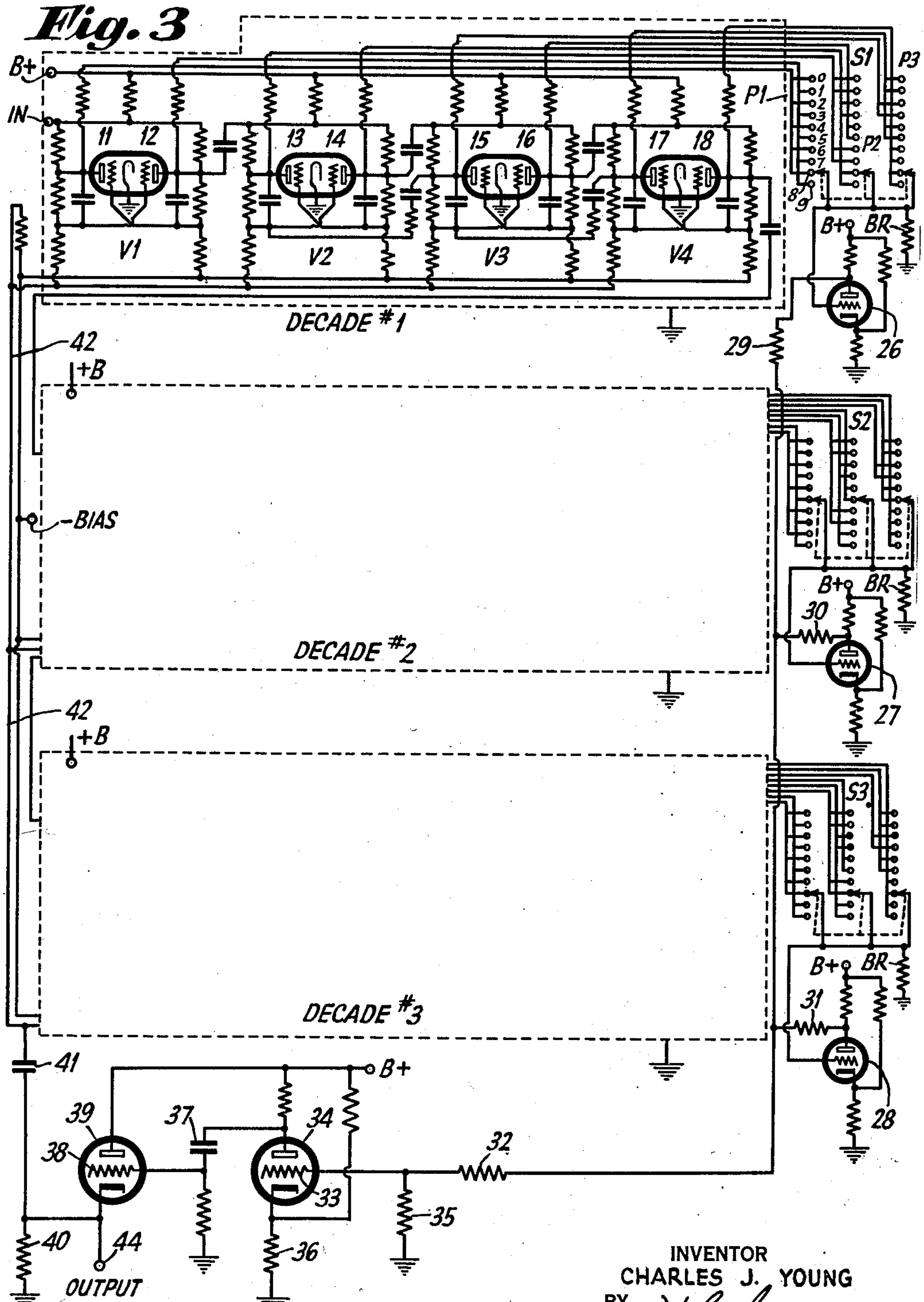
Fig. 3



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STABILIZED OSCILLATOR GENERATOR

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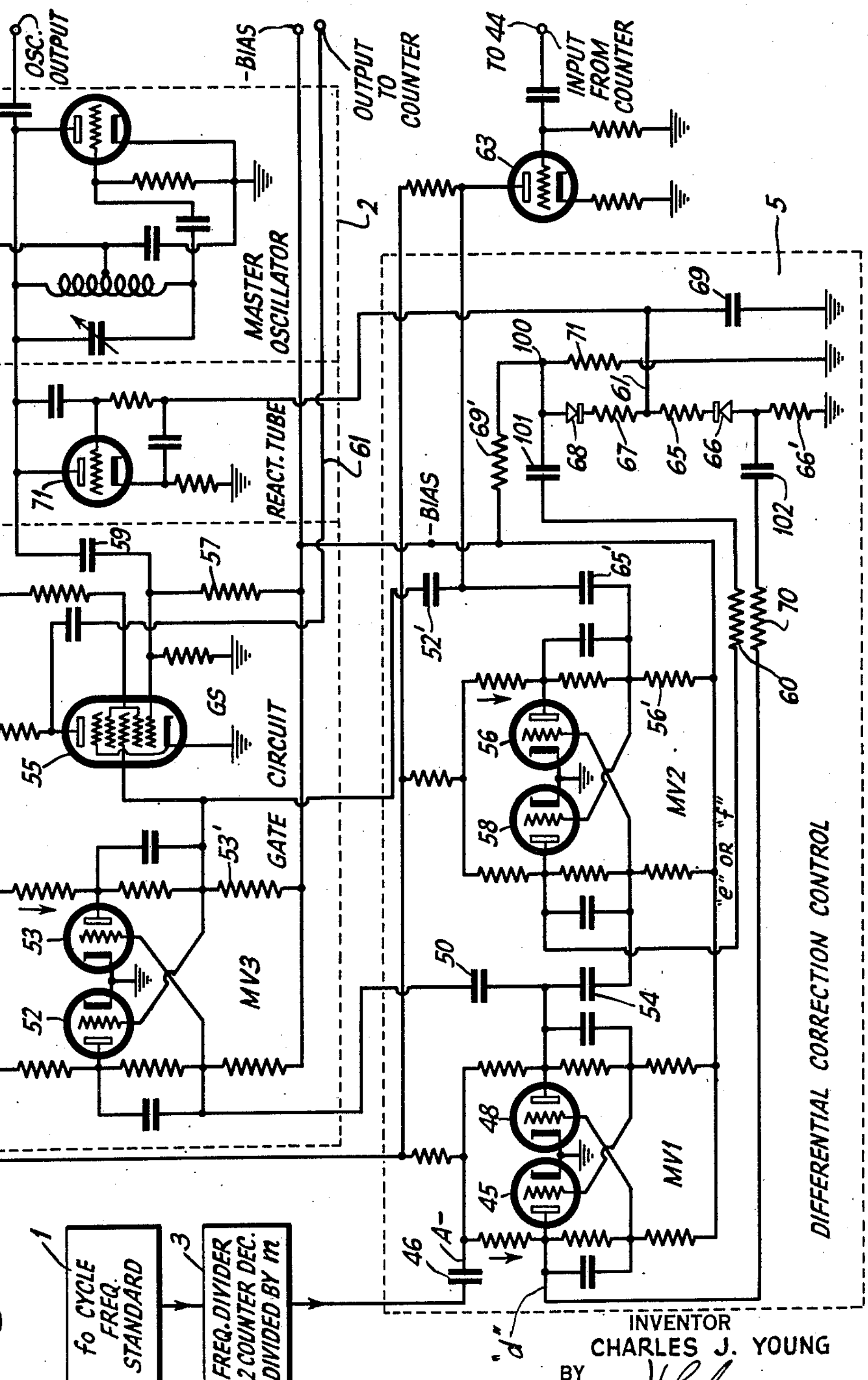
Fig. 4



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UNITED STATES PATENT OFFICE

2,490,500

STABILIZED OSCILLATOR GENERATOR

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Application December 28, 1946, Serial No. 719,035

14 Claims. (Cl. 250—36)

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This application relates to oscillation generators and in particular, a generator the frequency of operation of which is stabilized but can be changed to any frequency within a given wide range.

There is great need of a calibrated variable frequency master oscillator which can readily be set to any predetermined frequency within its range, with assurance that the output frequency will remain close to the desired preset frequency.

The general object of this invention is to provide oscillation generating means as outlined above for supplying to a transmitter or other utilization means, oscillations of any frequency within a given wide range.

A further object of the present invention is to provide oscillation generating means as described above and simple means for setting or selecting the chosen frequency.

A further object of the present invention is to provide oscillation generating and selecting means wherein the oscillations generated and of selected frequency are fixed in frequency with respect to an oscillator of standard fixed frequency such as a crystal oscillator.

An additional object of the present invention is to provide an oscillation generator as described above with simple and effective means for automatically correcting the frequency of operation of said oscillation generator should the same be improperly related in frequency to the frequency of the standard source thereby stabilizing the frequency of operation of the generator.

The above objects are attained as follows:

Oscillations from the standard frequency source are counted (divided in frequency) and used to establish time intervals of fixed and known duration and also to produce voltage of a duration measured by said time intervals. At the start of certain of the time intervals, a preset cycle counter is set into operation to count off a preset number of cycles of the oscillations generated and to stop. A voltage of duration measured by the counting time of the cycle counter is developed and the differential of said produced voltage and developed voltage is used to control the master oscillator frequency. Now if the frequency of the controlled oscillator is changed and a new and appropriate number set up on the counter, my system takes over to stabilize this new frequency of operation. Thus a series of frequencies related as desired may be generated. Such operation cannot be carried out in prior art systems using fixed frequency dividers.

In describing my invention in detail, reference

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will be made to the attached drawings wherein:

Fig. 1 illustrates by block diagram an oscillation generator in accordance with my invention for stable operation at any selected frequency of a wide range of frequencies.

Fig. 2 illustrates by voltage curves the operation of my system of Fig. 1, and of Fig. 4.

Fig. 3 illustrates details of one type of cycle counter circuit which is satisfactory for use in the unit 4 of Fig. 1, and

Fig. 4 illustrates details of the manner in which pulses, of fixed time separation, developed in unit 3 control the cycle counter of unit 4 and the differential correction apparatus of unit 5 which is also controlled by the counter to act through the reactance tube of unit 6 to stabilize the generator at any frequency selected for generation by setting the number of cycles counted and roughly adjusting the tuning condenser of the master oscillator.

Referring to Fig. 1, the master oscillator 2, which supplies the output for use in, for example, a transmitter T, is shown as controlled from a frequency standard 1. The frequency standard 1 may include a crystal oscillator. The basic control is obtained by comparing two time intervals, one measured by the standard oscillator 1 frequency, the other a measure of a preset number of cycles of the oscillations generated in unit 2. By way of example, it may be assumed that the frequency standard 1 operates at a frequency of 1000 cycles per second and the master oscillator 2 which may be set and/or tuned at any one of any desired number of frequencies, will, for purposes of illustration, be operated at 7580 cycles per second. To obtain the two short time intervals which are compared to obtain control energy for controlling the frequency of operation of oscillator 2, separate frequency dividers or time sensitive elements 3 and 4 are used. Element 3 is basically a fixed frequency divider which divides the frequency of the standard 1, in the case illustrated by 100. This means that the output of divider 3 will have a frequency of ten cycles per second. In the embodiment, described, the unit 3 is assumed to include a divider of the counting circuit type and supplying ten pulses per second as illustrated by line *a* of Fig. 2.

The second frequency divider or timer which is in unit 4 is in the embodiment described essentially an electronic counter with an adjustable stop set which stops the count thereof as set. A counter of this type is shown in Grosdoff U. S. application Ser. #580,446, filed March 1, 1945. It is the purpose of this counter in unit 4 to count off a predetermined number of cycles of operation of the master oscillator in unit 2 and at the end of this counting interval, to stop counting and produce an output pulse (lines *b* and *c* of Fig. 2). In my illustration of the oscillator, operating at 7580 cycles per second, assume that the counter is set at the value 758. This means that if the master oscillator unit 2 is operating exactly on a frequency of 7580 cycles per second, the interval of time which counter 4 will measure will be equal to the length of time passed during 758 cycles or $\frac{1}{10}$ second time intervals measured by divider 3. The start of operation of counter 4 coincides, with respect to time, with one of the pulses from counter 3, and counter 4 counts the preset number of cycles or pulses from the master oscillator of unit 2 and stops.

The differential correction control 5 compares the fixed intervals of time measured by the divider 3 with those measured by counter 4 and produces a corrective voltage, representing the difference of the intervals, which is applied to an oscillator frequency control means in unit 6 which may be, by way of illustration, a reactance tube per se well known in the art. Line *d* of Fig. 2 shows a voltage pulse measured by a standard interval of time obtained in the correction control unit 5 from the timer output pulses line *a* and lines *e* and *f* show the intervals produced in the correction control 5 by the output pulses from counter 4. The initiation of the intervals shown in lines *e* and *f* is produced by alternate pulses of line *a*, *a* here coming from the divider 3, while termination of the intervals shown in lines *e* and *f* is produced by the pulses of lines *b* and *c*, here coming from the counter 4. Two cases are illustrated by the wave forms; lines *b* and *e* illustrating case 1 where the oscillator in unit 2 is operating at too high a frequency and lines *c* and *f* illustrating case 2 where the oscillator in unit 2 is operating at too low a frequency. That is, in both cases, the oscillation generator in unit 2 is not operating at the frequency selected. To obtain the control voltage, the correction control circuit in unit 5 combines the voltage represented by line *d* with the voltage represented by line *e* or *f*. These combined voltages are shown as lines *g* or *h* for case 1 or for case 2 respectively. It will be noted that in line *g*, case 1, positive polarity pulses are shown and in line *h*, case 2, negative polarity pulses are shown. These pulses are applied, after averaging their value, through the reactance tube in unit 6 to control the frequency of the oscillator in unit 2 and the pulse polarity is such as to correct the frequency of the oscillator in 2 in the proper direction to reduce the correction voltage to zero or to adjust the oscillator in unit 2 to the correct point of operation. The relationship between the frequency of the standard in unit 1 and the master oscillator in unit 2 can be adjusted or set at any desired value by means of dial switches associated with the counter 4. In the case illustrated, the cycle counter dials are assumed to be set at 758 which would cause the master oscillator in unit 2 to operate at 7580 cycles per second. Adjusting the counter circuit in unit 4 changes the frequency of the oscillator as described above and its frequency may be changed practically continuously throughout a wide range merely by setting the counter as desired and then roughly returning the oscillator in unit 2 to the frequency set. The oscillatory energy as selected in frequency is supplied to the transmitter T for use as desired.

The standard frequency oscillator in rectangle 1 may be conventional and many oscillators appropriate for use here are known in the prior art and the same will not be described in detail herein. The same remarks apply to the apparatus in rectangle 3 wherein this apparatus is designated a timer. In practice, it takes the form of a frequency divider or a decade counter. The frequency divider may be of the counter type or any other approved type, many of which are known in the prior art. For example, a decade counter such as used in unit 4 described hereinafter may be used in unit 3. It is essential, however, that wave shaping be carried out in the timer to provide pulse output as shown in line *a*, Fig. 2. Many means are known in the prior art for shaping the waves as desired. For example, when the timer in unit 3 is a multivibrator, its output is of square wave form and may be supplied to a differentiating network to produce the peaks separated by the desired time intervals. A voltage differentiating network of this general type is shown in Fig. 1 of Max Mesner application #559,469, filed October 19, 1944. The counter circuit in unit 4 is as stated above in general like that of the above referred to Grosdoff application. Improvements and additions thereto have been made and the details of the counter circuit are illustrated in Fig. 3. The differential correction control circuit of unit 5 wherein the pulses are compared as to time intervals is illustrated in detail in Fig. 4. The reactance tube 6 and oscillator 2 may be conventional but in order to make my invention clear, have been included in Fig. 4 so that the manner in which the same and the correction control circuit etc., are connected in the system may be illustrated.

Referring to Fig. 3, three decade counter circuits are shown; more or less may be used. Decade 1 consists of multivibrator-like locking stages V1, V2, V3 and V4. These stages each have two positions of rest at one or the other of which they stay locked, when tripped thereto, until some applied voltage or current trips them again to lock them in the other position. In the embodiment shown, application of a negative voltage to the anodes and thence to the grids of the locking circuit tubes will reduce current in that tube drawing current and start the tripping action which switches the current through the other tube. Decades 2 and 3 are similar and to simplify the diagram have been illustrated by rectangles. Associated with each decade is a three-pole, ten-position switch. These switches are referred to as S1, S2 and S3, and the contacts thereof are coupled to the anodes of the locking circuit tubes whereat the potentials rise and fall depending on which tube of the pair is drawing current. For example, the anode of tube 11 of V1 is connected to alternate contacts of pole P1 of the three-pole switch S′. The anode of tube 12 of this stage is connected to the remaining contacts of this pole. The anodes of tubes 13, 14 and 16 of V2 and V3 are connected to staggered pairs of contacts of the second pole P2, etc. The basic details of each decade and how it operates is covered fully in Grosdoff, 580,446, referred to above and consequently, no detailed explanation will be given here. The decades count the incoming pulses from the master oscillator 2, these pulses being applied to the lead labeled Input of decade 1.

The basic purpose of the counter circuit is to produce output pulses after the counter decades have counted a predetermined number of master oscillator cycles or pulses. The start of the counting is controlled by a Gate circuit so labeled in

Fig. 4 as will be explained later. The development of the output pulses from the decades to be produced after the predetermined count has been reached is obtained by combining the proper voltages from the anodes of certain tubes in all three decades. This scheme is explained and is shown generally by Grosdoff 659,704, filed April 5, 1946. Using my illustration of a count of 758, switch S1 on decade 1 would be set at position 8 which is the units count, the switch S2 on decade 2 would be set on position 5 which is the tens count and switch S3 on decade 3 would be set on position 7 which is the hundreds count. The voltage pulses collected by the switches are combined by means of three vacuum triodes 26, 27 and 28. The tubes are in conventional circuits including grid biasing resistances BR connecting the switches to ground. This combination is produced by the connections of said switches to the control grids of these three tubes. The anodes of the tubes are connected together to produce a single pulse, which represents the sum of the collected pulses, and feeds the same by way of resistors 29, 30 and 31 and common resistor 32 to the grid 33 of a final combining tube 34. The tube 34 is connected in an amplifier stage with its grid grounded by a resistor 35 and its cathode grounded by a resistor 36 and its anode connected to the plus terminal of a direct current source. The anode of amplifier tube 34 is coupled by a capacitor 37 to the control grid 38 of an output tube 39, the purpose of which is to deliver the combined pulse to all of the tubes in all of the decades to trip the same back to their starting position for successive operation of the counter. This cathode follower stage also delivers this combined output pulse to the differential correction control circuit 5 of Figs. 1 and 4. To do this, the cathode load resistor 40 of this tube is coupled through a capacitor 41 to a lead 42 running to a common reset lead in each of the three decades and also to the lead 44 labeled Output which goes to the unit 5 of Figs. 1 and 4.

Referring to decade 1 which has its switch S1 set at position 8, it is noted that for each position of the switch, a different combination of voltages from the eight tubes of decade are used as explained in the Grosdoff application #580,-446. The voltage on the switch S1 as applied to the grid of tube 26 reaches a certain maximum positive value only when the count is at the value for which the switch position is set and the final desired output pulse applied to the grid of tube 34 is obtained only when the proper combination of voltages occurs simultaneously on the selected tubes of all three decades. For example, in decade 1 on the count of 8, the voltages selected by switch S1 are those at the anodes of tubes 11 and 14 and 18. This combination of three voltages raises the control grid of tube 26 above its cut-off point so that conduction is initiated in tube 26 and the potential on its anode and at resistor 29 falls. A similar action takes place in tubes 27 and 28 when the proper voltages are obtained by the settings on switches S2 and S3. When the final pulse which represents the final combination of voltages from the tubes 26, 27 and 28 is reached the voltage applied to the control grid of tube 34 is reduced (negative) to such a point that conduction in the tube 34 is cut off. This action occurs suddenly at the instant the decades of the counter reach the number or count for which the switches have been set. Also the tubes 26 and 27 may be made conductive several times during the process of the count, yet the combined voltage applied to the grid of tube 34 is never sufficiently negative to cut this tube off until the time occurs when tubes 26, 27 and 28 are simultaneously conductive, this point being when the counter has reached the predetermined count of adjustment.

At the instant when the counter produces its output pulse at the plate of tube 34, this output pulse is applied through the coupling tube 39 which is a cathode follower type of circuit to the output terminal 44 and also by way of condenser 41 to reset the decades of the counter back to the zero or starting position. This resetting function is accomplished by application of the output pulse, which is positive in polarity, to the grid circuits of all the tubes in the decades which draw current in the starting position.

As stated above, the oscillations or short pulses representative thereof are supplied from the oscillator to the input lead of the first decade counter, Fig. 3, and at the cathode end of load resistor 40 of tube 38 is produced the potential which resets the decade counters when they have finished counting the pre-set number, and, also the potential supplied to lead 44 which goes to the differential correction control unit 5 to terminate the time interval measuring the counting time. The potential, also, as will appear in detail hereinafter, operates to close a gate for the generated oscillations and to return locking stages to one condition of stability so that the cycle of operation may be completed and repeated.

The arrangement for accomplishing these purposes and other purposes is shown in Fig. 4. In Fig. 4, the dotted rectangle 5 includes the differential correction control and comprises in the embodiment shown, two multivibrator-type locking stages MV1 and MV2. The dotted rectangle 4 may include in addition to the counters shown in Fig. 3, a multivibrator-type locking stage MV3 controlled by the locking stage MV1 and also a gating stage GS controlled by the locking stage MV3. In practice, the gating stage may also peak the oscillations and may with its control stage MV3 be included in a separate unit here designated 4′. The showing of these connections is simplified in Fig. 1. The dotted rectangle 6 includes the reactance tube while the dotted rectangle 2 includes the master oscillator.

The pulses of line *a* are minus and are supplied by condenser 46 to the anodes and thence to the control grids of the pair of tubes in the locking circuit MV1 which is substantially conventional so that when the one tube is drawing current, the other tube is cut off and vice versa and the application of a negative pulse is ineffective on that tube having a negative grid but is effective on that tube having a positive grid to switch current therefrom to the other tube. The locking stage MV1 has its second tube 48 anode coupled by a condenser 50 to the control grid of the tube 53 in the locking stage MV3. The anode of tube 48 is also coupled by condenser 54 to the control grid of the tube 56 of the locking stage MV2. The anode of the tube 58 of locking stage MV2 is connected by a resistor 60 to the anode of a diode 68 and, by way of a resistor 67 and a connection 61, to a capacitor 69. This connection, as will be seen hereinafter, supplies the voltage pulses represented by line *e* or *f* of Fig. 2 which are a measure of the time it took the counter in 4 to count the preset number of cycles of oscillations generated by the master oscillator. To do this, stage MV2 is controlled by the said pulse which is amplified in tube 63 and fed by coupling condenser 65′ to the control grid of tube 58 of the stage MV2. The anode of tube 45 of the stage MV1 is also connected by resistor 70 to the anode of diode 66 and, by way of resistor 65 and connection 61, to the capacitor 69. The arrangement here is such that both of the voltages developed on the left end tubes of stages MV1 and MV2 are combined in 61 and applied to the diodes connected in opposed polarity. The anode of diode 66 is connected by differential resistors 65 and 67 to the cathode of the diode 68 so that the potential therein which represents the difference between the potentials of lines *d* and *e* or *d* and *f* appears across the condenser 69 which is supplied to the control grid of a reactance tube stage 71. The reactance tube stage is connected in a well known manner with the conventional oscillator in unit 2 to control its frequency of operation in accordance with the potential developed in 69.

The locking stage MV3 has the anode of its tube 53 coupled to the third grid of a gating stage tube 55. Note that the control grid of the tube 52 of this locking stage MV3 is also coupled by condenser 52′ to the anode of the amplifier stage tube 63, the grid of which is connected to the output lead 44 of the counter circuit output, Fig. 3.

The operation of the complete system will now be fully explained and reference will be made to Fig. 4.

In the initiation or starting condition of the circuit, the tube 45 of locking circuit MV1 and the tube 56 of locking circuit MV2 and the tube 53 of gate circuit locking stage MV3 are all in a state of conduction as indicated by the arrows adjacent their anode resistances. Their complementary tubes 48, 58 and 52 are non-conductive. The generated oscillations are continuously applied to the first grid of gate tube 55 which is biased negative by resistor 57. However, the gate tube 55 is in a state of non-conduction because of the negative direct current potential applied its number one grid and also to its number three grid by the negative anode by tube 53 of MV3. The bias is such that when the gate tube is opened very short pulses only of current flow to the anode in response to the applied oscillations. The timing pulses from timer 3 are applied to stage MV1 by the input condenser 46. The first pulse or initiating pulse which starts the system through a cycle of operation causes the states of conduction of tubes 45 and 48 to be reversed or exchanged and the second pulse from the timing circuits restores MV1 back to the starting position again. This operation of MV1 is illustrated by line *d* of Fig. 2 which shows that tube 45 is cut off and tube 48 remains continuously conductive, after being triggered for a length of time equal to the distance between the incoming pulses which is $\frac{1}{10}$ second for the illustration selected. At the same time that the first or initiating pulse is applied to the locking circuit MV1, the triggering of tube 48 to a conductive state sends a negative pulse by way of condenser 50 to stage MV3 in the gate circuit. It is the purpose of the gate circuit combined with gate tube 55 to pass peaks of the cycles of oscillation from the master oscillator 2 into the counter circuit of unit 4 so that the counter may count off a predetermined number of cycles as explained previously. To carry out this operation, the locking circuit MV3 controls conduction through gate tube 55. Normally, or in the absence of control, gate tube 55 is biased to cut-off because as shown above tube 53 is conductive and its anode is negative and holds the number three grid of tube 55 well below the cut-off point. If the initiating pulse from locking stage MV1 acts by virtue of the drop in potential on the anode of tube 48 to trigger stage MV3, this raises the potential of the anode of tube 53 and on the number three grid of tube 55 to the point where the gate is open. The cycles of energy, that is, peaks thereof, received from the master oscillator via condenser 59 are allowed to pass (amplified) through tube 55 and go out on lead 61 to the counter only when the gate is in the open position. At all other times, when the gate is closed, no pulse from the master oscillator is passed to the tube counter.

So far in my explanation of operation, MV1 has been turned on and the counting of oscillating cycles in the counter has been initiated. MV2 was also triggered, by the negative potential developed on the anode of tube 48 and applied by condenser 54 to the grid of tube 56, at the same instant when MV1 was originally triggered. Hence, tube 58 is also tripped to the state of conduction and tube 56 is cut off. No further action takes place in the system, except application of the potentials developed at the anodes of tube 45 and 58 to the diodes 66 and 68, until the counter of Fig. 3 has accumulated or counted off the pre-determined number of cycles that number being 758 in our illustration. When the counter has reached this count, its output pulse developed as explained previously will be applied by way of input triode 63 to perform two functions. The first function is to trigger the gate circuit GS to the off position to stop the flow of master oscillator output cycles to the counter. This is accomplished by application of the counter output pulse reverse by tube 63 to the grid of tube 52 (conductive) of locking stage MV3 by way of condenser 52′ which triggers it into its initial position with tube 53 conductive. This action then restores the cut-off bias on gate tube 55 thus stopping the flow of oscillator cycles to the counter. At the same time that the gate circuit is turned off, the negative potential swing at the anode of tube 63, caused by the pulse from the counter, passing through condenser 65, triggers the locking stage MV2 back into its initial or starting position with tube 58 cut off and tube 56 conductive. The operation of MV2 is illustrated by lines *e* and *f* of Fig. 2 for case 1 and case 2 as mentioned earlier. Considering case 1 of line *e*, it is noted that MV2 is restored to its initial condition prior to the time that MV1, as shown by line *d*, is returned to its initial condition. In other words, the interval of time measured by MV2, shown by line *e*, is shorter than the interval of time measured by MV1 or shown by line *d*. This difference in these two time intervals is due to and indicates the fact that the frequency of the master oscillator 2 is too high. This frequency being too high causes the counter in Fig. 3 to count off the predetermined number of cycles in an interval of time shorter than the standard interval of time measured by the timing pulses out of timer 3. If, now the master oscillator frequency here is too low, as indicated and illustrated by line *f* of case 2, then the interval of time determined by the locking stage MV2 as controlled by pulses from the counter would be greater than the standard interval of time of line *d*. Since the counter produces an output pulse, when a predetermined number of cycles has passed, different output pulses may occur earlier or later than the second pulse from the timer 3, which retrips stage MV1 and terminates the voltage pulse (line d), depending on whether the master oscillator frequency is higher than or lower than the correct value. When the master oscillator in unit 2 is exactly on the proper frequency, the output pulse from the counter of unit 4 occurs simultaneously with the second output pulse from the timer of unit 3.

To obtain a correct voltage for the oscillator to restore it to the correct frequency, a double diode circuit is used. In this circuit it will be noted that the two diodes 66 and 68 are connected in the direction of conduction between a point 100, held at a chosen negative voltage by divider resistances 69' and 71, and ground. Initially, therefore, the capacitor 69 may be charged to any voltage between 0 and the potential of point 100. Any tendency for the capacitor voltage to become positive, will be prevented by conduction from 69 through resistor 65, diode 66, and resistor 66' to ground; while any tendency to become more negative than point 100 will be prevented by conduction through diode 68 and resistor 67.

In operation, the voltage of the plate of tube 45 is represented by d in Fig. 2, while that of the plate of tube 58 is shown by e and f. These two voltages connected through resistors 70 and 60 respectively combine in lead 61 so that its voltage is as shown by g and h in Fig. 2. For the case of g the positive pulse passes through capacitor 101 and momentarily raises the potential on point 100. This causes conduction through diode 68 and resistor 67 to reduce the negative potential on capacitor 69 and thereby lower the bias on reactance tube 71 which lowers the frequency of master oscillator 6. On the other hand, in case 2, the negative pulses shown by h in Fig. 2 pass through capacitor 102 and make the diode 66 momentarily conductive to pass charge from capacitor 69 through resistor 65, thereby making the negative bias of tube 71 greater and thus increasing the frequency of the master oscillator.

The corrective action is an accumulative one due to the storage effect of capacitor 69. The more positive pulses arrive, the more positive becomes the bias voltage on tube 71 and the more the frequency of the master oscillator is reduced. As its frequency approaches the correct value the potential on capacitor 69 approaches a steady state and the length of the corrective pulses approaches zero.

The particular feature of this invention is that the master oscillator 2 may be adjusted readily and quickly to operate at any one of a large number of frequencies. These frequencies in the case illustrated all are integral multiples of the output frequency of the timer for if it was desired to change the output frequency from 7580, as mentioned before, to a new value, this would be accomplished by roughly turning the master oscillator to the new frequency and by setting up new positions of switch S1, S2 and S3 of the counter. When the new switch positions are selected, the corrective action already described takes place and the master oscillator 2 is adjusted to the new frequency automatically and held there by the correction action.

For example, if I let

f=the master oscillator frequency to be controlled

f_0=the standard reference frequency, preferably from a crystal oscillator

m=the division ratio applied to f_0

D=the division ratio preset in the counter which is excited by f, and

T=the duration of the comparison time interval

Then

$$\frac{1}{T}=\frac{f_0}{m}=\frac{f}{D}$$

or

$$f=D\frac{f_0}{m}$$

In my example, this becomes

$$7580=758\frac{1000}{100}$$

Obviously the 758 could be instantly reset to any other three figure number. The next preset master oscillator frequency would be, for example,

$$7590=759\frac{1000}{100}$$

If unit 4 included four decades instead of three and unit 3 divided by 1000 instead of 100, we could set for

$$7581=7581\frac{1000}{1000}$$

This emphasizes a valuable feature of my invention, namely that the decade dials of unit 4 can readily be made direct reading in master oscillator frequency, i. e. D stands for dial setting in the equation.

What is claimed is:

1. In apparatus for generating oscillations, the frequency of which may be adjusted and for stabilizing the frequency of the generated oscillations in combination, a source of oscillations of fixed frequency, a source of oscillations of controllable frequency, a voltage phase comparer and detector, a frequency divider coupling said source of fixed frequency to said phase detector, an adjustable frequency divider coupling said source of oscillations of controllable frequency to said phase detector and means for controlling the frequency of operation of said controllable source in accordance with a component resulting from phase detection of the divided frequencies in said phase detector.

2. The method of generating oscillations of substantially fixed frequency which may be changed through a wide range of frequencies which includes these steps, producing pulses separated by time intervals of fixed duration, recurring at a fixed rate per second, generating oscillatory energy of a frequency which may be controlled through a wide range, counting a preselected number of cycles of said generated energy, establishing time intervals measured by the time required to make said count, developing energy representative of the difference in duration of said first and second time intervals, and controlling the frequency of said generated oscillations in accordance with said developed energy.

3. The method of providing oscillatory energy of substantially fixed frequency which may be changed through a wide range of frequency which includes these steps, producing pulses separated by time intervals of fixed duration, recurring at a fixed rate, generating oscillatory energy of a frequency which may be controlled through a wide range, counting a preset number of cycles of said generated energy during a time interval of a length about equal to the length of one of said first time intervals, developing a potential

the magnitude of which is representative of the difference in duration of said first mentioned time interval and said second mentioned time intervals and the direction of variation of which indicates which of said two time intervals is longest and controlling the frequency of said generated oscillations in accordance with said developed potential to reduce said developed potential to about zero magnitude.

4. The method of generating oscillations of substantially fixed frequency NX which may be changed through a wide range of frequency (where N is a pre-selected number) which includes these steps, producing pulses separated by time intervals of fixed duration, recurring at a rate of N per second, generating oscillatory energy of a frequency which may be controlled through a wide range, counting X cycles of said generated energy, establishing other time intervals each starting about at the start of a different one of said first time intervals and of a duration equal to the time required to make said count, developing energy, the magnitude of which is representative of the difference in duration of said time intervals, and the polarity of which indicates which of said two developed intervals is longest and controlling the frequency of said generated oscillations in accordance with said developed energy to reduce said developed energy to about zero magnitude.

5. The method of providing oscillatory energy of substantially fixed frequency which may be changed through a wide range of frequency which includes these steps, producing pulses separated by time intervals of fixed duration, recurring at a fixed rate, generating oscillatory energy of a frequency which may be controlled through a wide range, counting a preset number of cycles of said generated energy during a time interval which starts about at the start of one of said first time intervals, devolping a direct current potential the magnitude of which is representative of the difference in duration of said first mentioned time interval and said last mentioned time intervals and the polarity of which indicates which of said two time intervals is longest and controlling the frequency of said generated oscillations in accordance with said developed potentional to reduce said developed potential to about zero magnitude.

6. The method of producing oscillatory energy of substantially fixed frequency which may be changed through a wide range of frequency which includes these steps, developing voltage peaks separated by time intervals of fixed duration, and recurring at a fixed rate per second, generating oscillatory energy of a frequency which may be controlled through a wide range, counting a preset number of cycles of the generated energy during a time interval starting about at the start of a time interval between two of said voltage peaks, producing a pulse of energy at the start and the end of said count, developing energy the duration of which is representative of the time duration between said voltage peaks, developing energy, the duration of which is representative of the time duration between said energy pulses, combining said developed energies to produce a resultant potential the magnitude of which indicates which of said two time intervals is longest and controlling the frequency of said generated oscillations in accordance with said developed resultant potential to reduce said developed potential to about zero magnitude.

7. The method of producing oscillatory energy of substantially fixed frequency which may be changed through a wide range of frequency which includes these steps, developing voltage peaks separated by time intervals of fixed duration, and recurring at a fixed rate per second, generating oscillatory energy of a frequency which may be controlled through a wide range, generating short electrical pulses in synchronism with said oscillatory energy, counting a preset number of pulses during a time interval starting about at the start of a time interval between two of said voltage peaks, producing a pulse of energy at the start and the end of said count, developing energy the magnitude of which is representative of the time duration between said voltage peaks, developing energy the magnitude of which is representative of the time duration between said energy pulses, combining said developed energies to produce a resultant potential the polarity of which indicates which of said two time durations is longest and controlling the frequency of said generated oscillations in accordance with said developed resultant potential to reduce said developed energy to about zero magnitude.

8. The method of providing oscillatory energy of substantially fixed frequency which may be changed through a wide range of frequency which includes these steps, producing pulses separated by time intervals of fixed duration, recurring at a fixed rate, generating oscillatory energy of a frequency which may be controlled through a wide range, counting selected groups of cycles of said generated energy, each group comprising a preset number of cycles, during time intervals which start about at the start of an alternate one of said first time intervals, developing a direct current potential the magnitude of which is representative of the difference in duration of said first mentioned time intervals and said last mentioned time intervals and the polarity of which indicates which of said two developed intervals is longest and controlling the frequency of said generated oscillations in accordance with said developed potential to reduce said developed potential to about zero magnitude.

9. The method of producing oscillatory energy of substantially fixed frequency which may be changed through a wide range of frequency which includes these steps, developing voltage peaks separated by time intervals of fixed duration, and recurring at a fixed rate per second, generating oscillatory energy of a frequency which may be controlled through a wide range, counting spaced blocks of the generated cycles, each of which blocks comprises a pre-selected number of cycles, during time intervals starting about at the start of the time intervals between alternate ones of said voltage peaks, producing a pulse of energy at the start and the end of each count, developing energy the magnitude of which is representative of the time duration between said voltage peaks, developing energy the magnitude of which is representative of the time duration between said energy pulses at the start and end of each count, combining said developed energies to produce a resultant potential the polarity of which indicates which of said two time durations is longest and controlling the frequency of said generated oscillations in accordance with said developed resultant potential to reduce said developed energy to about zero magnitude.

10. In apparatus for generating oscillatory energy of changeable frequency in combination, a source of oscillatory energy of controllable frequency, means for producing pulses separated by

predetermined fixed time intervals, a pre-set cycle counter coupled to said controllable oscillation generator and set in operation by said pulses for counting off a pre-set number of cycles of said oscillatory energy during time intervals which vary as the frequency of the energy varies, means for comparing the relative lengths of said time intervals and producing a potential the magnitude of which is a measure of the difference in duration of said intervals, and means for controlling the frequency of said oscillatory energy in accordance with said resultant to make said time intervals equal to thereby bring said potential about to zero.

11. In apparatus for generating oscillatory energy of changeable and known frequency in combination, a source of oscillatory energy of fixed frequency, a source of oscillatory energy of controllable frequency, means controlled by said fixed frequency source for producing pulses separated by fixed time intervals, a preset cycle counter set in operation by said pulses for marking off the intervals of time required by said oscillation generator to generate said preset number of cycles, means for producing a first voltage measured by said first time intervals, means for producing a second voltage measured by said second time interval, and means for controlling the frequency of said controllable source in accordance with the differential of said first and second voltages.

12. In apparatus for producing oscillatory energy the frequency of which may be changed through a wide range in combination, a source of oscillatory energy of fixed frequency, a source of oscillations of controllable frequency, a controllable reactance coupled to said last source, a frequency divider and wave shaper coupled to said first source to provide pulse energy of fixed frequency, a cycle counter which may be preset for the desired count and which includes means by which it is stopped at the end of said count, a coupling between said cycle counter and said controllable source, means coupling said cycle counter to said wave shaper to start operation thereof on the appearance of a pulse of said pulse energy, a first means excited by said pulse energy to develop voltage of a duration measured by the time between the energy pulses, a second means coupled to said wave shaper and to said counter for developing a voltage of a duration measured by said counting time, a combining circuit coupled to said first and second means for providing a potential the magnitude of which represents the differential of the voltages generated thereby and means for controlling the value of said reactance in accordance with said last named potential.

13. In apparatus for generating oscillatory energy of changeable and known frequency in combination, a source of oscillatory energy of fixed frequency, a source of oscillatory energy of controllable frequency, means controlled by said fixed frequency source for producing N pulses per second separated by predetermined fixed time intervals, a preset cycle counter set in operation by said pulses and excited by oscillations from said controllable source for producing an energy pulse after a time interval sufficient for said controllable oscillator to generate a preset number of cycles, means for producing a first voltage the duration of which is measured by said first time interval, means for producing a second voltage of opposed phase the duration of which is measured by said second time interval, and means for controlling the frequency of operation of said controllable oscillator in accordance with the differential of said produced voltages to thereby bring said controllable oscillator to a frequency per second equal to N times the number preset.

14. In apparatus for generating oscillatory energy of changeable frequency in combination, a source of oscillatory energy of fixed frequency, a source of oscillatory energy of controllable frequency, means controlled by said fixed frequency source for producing pulses separated by predetermined time intervals, a preset cycle counter coupled to said controllable oscillation generator and set in operation by individual ones of said pulses for producing an energy pulse after said controllable oscillator generates a preset number of cycles, means for producing a first voltage measured by said first time interval, means for producing a second voltage of opposed phase measured by said second time interval, means for combining said voltages to produce a resultant the magnitude of which is a measure of the difference in duration of said voltages and the polarity of which is determined by which voltage is of greatest duration, and means for controlling the frequency of said controllable voltage in accordance with said resultant to thereby bring said controllable oscillator to a frequency equal to the sum of number preset.

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

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Number	Name	Date
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