

Oct. 11, 1949.

K. H. DAVIS

2,484,611

FREQUENCY DIVIDER

Filed Dec. 19, 1946

2 Sheets-Sheet 1

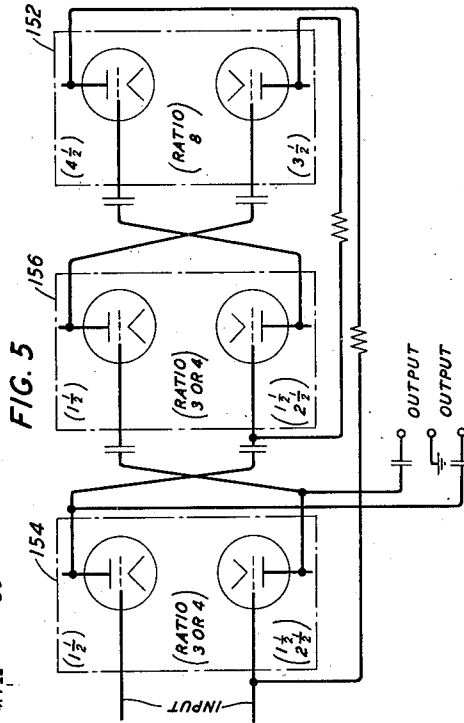
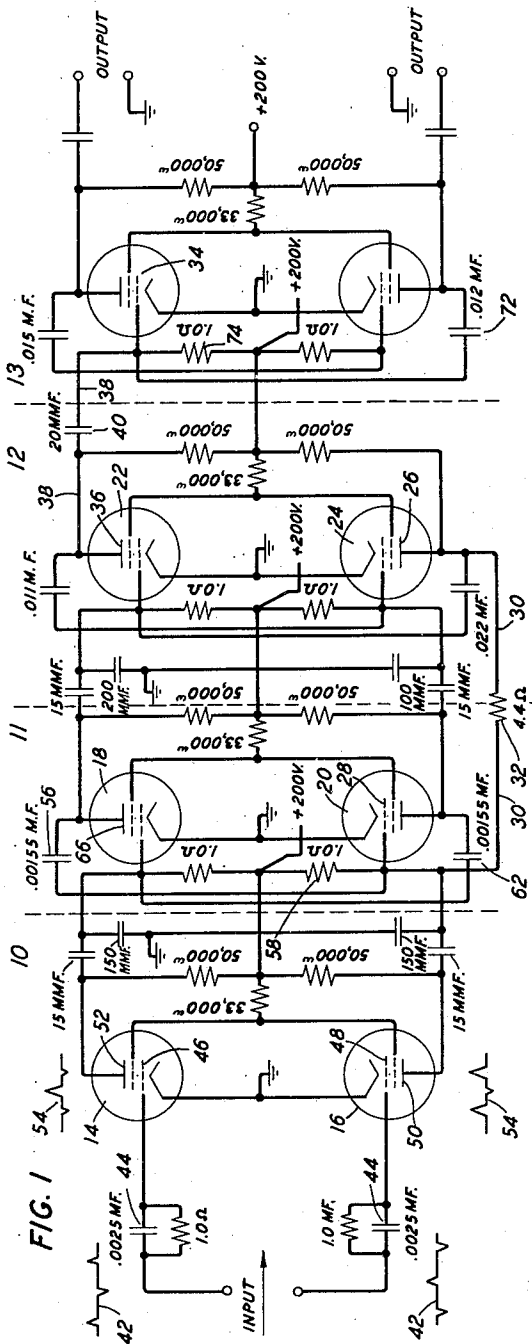
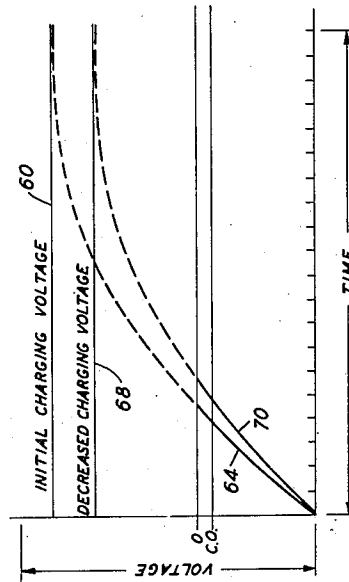


FIG. 2



INVENTOR
K. H. DAVIS
BY
Robert J. Fluskey
ATTORNEY

Oct. 11, 1949.

K. H. DAVIS

2,484,611

FREQUENCY DIVIDER

Filed Dec. 19, 1946

2 Sheets-Sheet 2

FIG. 3

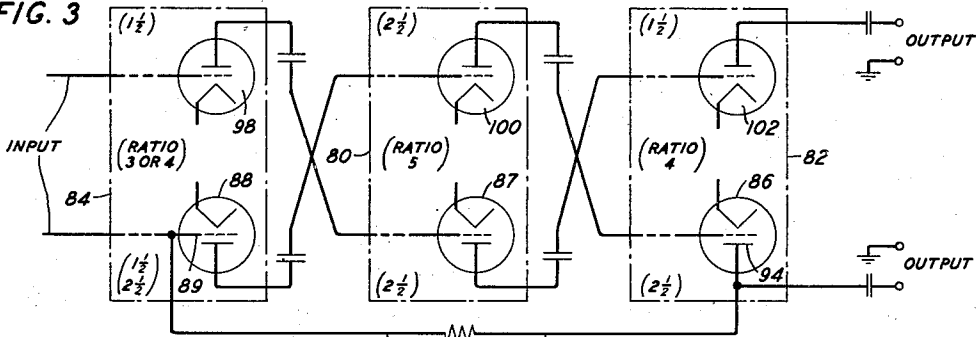


FIG. 4

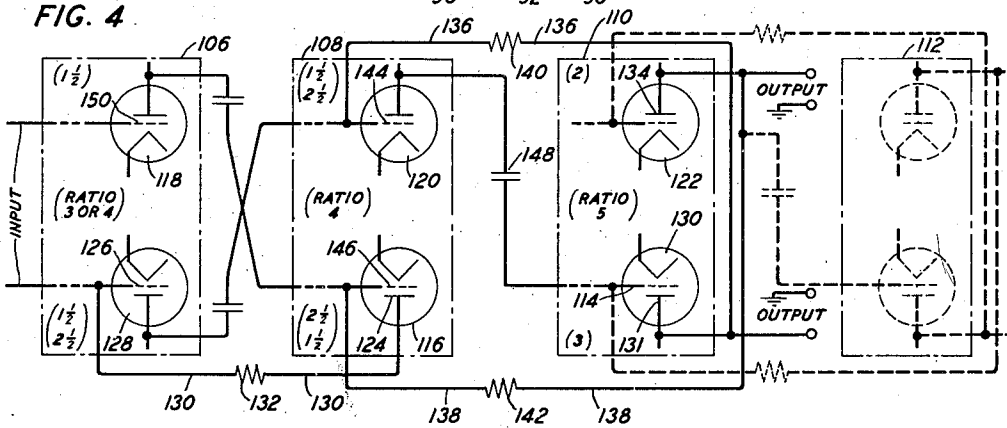
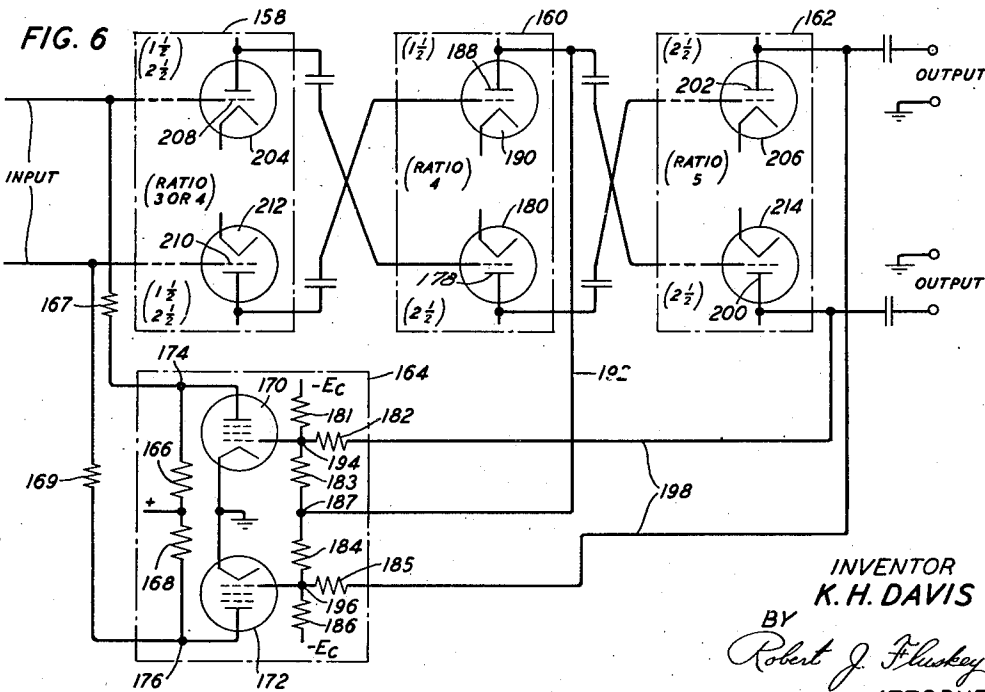


FIG. 6



INVENTOR
K. H. DAVIS

BY
Robert J. Fluskey
ATTORNEY

UNITED STATES PATENT OFFICE

2,484,611

FREQUENCY DIVIDER

Kingsbury H. Davis, Bernardsville, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application December 19, 1946, Serial No. 717,111

12 Claims. (Cl. 250—36)

1

This invention relates to alternating wave generators and particularly to such generators of the type known as relaxation oscillators.

The relaxation oscillator, particularly of the multivibrator type has had many applications in frequency dividing systems. The usual arrangements have employed single or tandem operations of multivibrators to reduce a higher control frequency to some one or more desired lower frequencies. These prior art systems have been limited to applications wherein the obtained divided frequency bears an integral relation to the original undivided control frequency. With these systems, whenever the desired frequency conversion does not present such an integral relation, the conversion must be effected through combined operations involving frequency division and frequency multiplication. Furthermore, prime number frequencies, which have cyclic variations numerically greater than a low limiting value are indivisible by these systems when the divided output is required to have an integral number of cyclic variations each second. This low limiting value has as a limit the numerical step-down ratio that may be practically realized in one stepdown operation.

This invention makes possible the direct conversion of an alternating electromagnetic force from a higher to a lower frequency value by a ratio which may be a prime number greater than the stepdown ratio obtainable in a single step-down operation.

The invention also makes possible frequency conversions wherein the divided output frequency bears a fractional relation to the original undivided frequency.

Electromagnetic waves having a large prime number of cyclic variations per second may, through the means provided by this invention, be converted to waves having fewer cyclic variations per second and having a frequency which is integrally related to the original frequency.

The manner in which these and other desirable results are accomplished, and the attendant advantages which may be realized through the use of the invention, will be more apparent from the following description considered in conjunction with the accompanying drawings in which:

Fig. 1 shows one embodiment of the invention for the reduction of frequency by a prime ratio;

Fig. 2 diagrammatically indicates the change in the exponentially rising voltage in the oscillator timing circuit caused by changing the voltage level to which the timing circuit charges;

Fig. 3 shows a variation of the arrangement of Fig. 1;

Fig. 4 shows an alternative arrangement to those shown in Figs. 1 and 3, and is one which may provide increased operating margins under certain conditions;

2

Fig. 5 shows an arrangement for securing a fractional frequency product, and;

Fig. 6 shows an embodiment of the invention in which the feedback voltage is alternately connected to the input circuits.

The invention utilizes the principle that a condenser in charging from a constant potential source through a constant resistance experience a voltage increase which follows the relation:

$$e = E \epsilon^{-\frac{t}{RC}}$$

where

e —the instantaneous voltage across the condenser

E —the constant value charging voltage

t —time the charging voltage E has been applied, and

RC —the resistance capacitance (time constant) of the circuit.

This is an exponential function which has its greatest slope at the start of the charging operation and which approximately maintains this slope for a small percentage of the total charging range. This substantially constant slope may be extended, to approximate a linear function, over a limited voltage range by the proper choice of the charging voltage E , and additionally the slope of the linear portion may be changed within narrow limits by the choice of the charging voltage E . In the usual prior art multivibrator oscillator circuit, this charging voltage is maintained at a substantially constant level and the oscillator has a characteristic natural time for reversals. Where the oscillator is to be synchronized to a submultiple frequency of a wave, this characteristic natural time of reversal is so selected that it is reversed by the last of a group of cycles of the synchronizing wave at a time just prior to its natural reversal time. The interval between reversals may be the same for both sides of the multivibrator, in which case the circuit is symmetrical and balanced, or it may be different for the two sides, in which case the circuit is unbalanced.

If a normally balanced multivibrator has its characteristic natural reversal time changed on one side only, it becomes an unbalanced unit; and experiences a change in the time required for its cyclic operation. However, if a normally balanced unit has its reversal times reciprocally changed on both sides, that is, one side increased by the same period that the complementary side is decreased, the unit becomes unbalanced; but there is no frequency change as the time required for its cyclic operation remains unchanged. Accordingly, the balance relations of a multivibrator oscillator partially disclose its operating characteristics and may be defined as a ratio of the non-conductive intervals of the respective sides

of the unit. During the following description this ratio is expressed in terms of input cycles.

The present invention employs the foregoing principles to control the oscillating characteristics of tandem operated multivibrator units. This control is effected through one or more voltages that are fed back from subsequent to preceding units in the tandem array to change either the balance ratio or the frequency of oscillation of the controlled unit. The multivibrator units that are to be thus controlled may be constructed in accordance with well-known principles covering the design of a unit having a specified natural time of reversal and a natural balance condition.

In Fig. 1 there is shown a circuit diagram of one tested embodiment of the invention that was successfully used to effect the stepdown ratio of 157 to 1, which ratio is a prime number. Although the described embodiment employs four stages, 16 to 13 inclusive, the actual stepdown, or division, is effected in stages 11 and 12. In Fig. 2 there is shown a diagrammatic representation of the variation in the time required for a resistance-capacity circuit to charge to a specified value when the charging voltage is changed. Reference will be made to this variation in describing the operation of the circuits of Figs. 1 and 3 to 6.

In the arrangement of Fig. 1, the vacuum tubes 14 and 16 perform a pulse inverting, amplifying and clipping function. This stage is helpful but not essential in the operation of this frequency dividing system. The vacuum tubes 18 and 20 with their associated resistance and capacitance circuit components form the multivibrator 11, which in this embodiment operates as a variable-ratio unit having a stepdown ratio of 15.7 to 1. The following stage 12 comprises vacuum tubes 22 and 24 together with the usual multivibrator resistance and capacitance circuit components, and operates at a 10 to 1 stepdown ratio with respect to the previous stage 11.

The plate or anode 26 of vacuum tube 24 is connected to the control grid 28 of the tube 20 in the preceding stage 11 through the interconnecting circuit 30 including resistor 32. Whereas the multivibrator 11 is a normally balanced unit, the multivibrator 12 is unbalanced in the ratio of $6\frac{1}{2}$ to $3\frac{1}{2}$, with the tube 22 remaining cut off for the longer period. Because the multivibrator 12 is unbalanced, the positive and negative portions of its output wave are unequal. In order to secure a symmetrical output wave, the balanced multivibrator 13 is operated at a 1 to 1 ratio. Control synchronizing pulses are supplied to only one of its control grids 34 from the plate or anode 36 of the preceding stage 12 by way of the interconnecting circuit 38 including the coupling condenser 40. The period of the uncontrolled side of the multivibrator 13 is made equal to one-half of the total control period, and the output from this stage 13 is balanced.

In operation, the input wave, the frequency of which is to be reduced, and which, though here shown as the pulses 42, may be pulses or cyclic variations, is applied through the coupling units 44 to the control grids 46 and 48 of the pulse inverter stage 10. The tubes 14 and 16 are so biased that they are normally in a saturated plate current condition, and the positive portion of the input pulse causes little or no reaction at the plates or anodes 50, 52. The negative portion of the pulse gives rise to a sharp positive plate voltage increase that is available as the positive pulses 54 for synchronizing the fre-

quency division circuit 11 in the usual well-known manner. Assume, for reference purposes, that the tubes 20, 22 are conducting current and tubes 18, 24 are cut off. As the multivibrator 13 acts only as a 1 to 1 ratio unit to balance the positive and negative portions of the output waves, its detailed cyclic operation is not believed necessary in this description. If the tube 24 is non-conductive, the positive voltage on its plate 26 is the same as the charging voltage to which the plate-grid coupling condenser 56 is returned by way of the grid resistor 58. This voltage is indicated in Fig. 2 by the horizontal line 60. Under these circumstances, the multivibrator 11 is balanced, and the condensers 56 and 62 in its timing circuits each charge along the exponential curve 64 (Fig. 2). If not limited by grid current, these charges would approach the charging voltage 60 in an asymptotic manner, as indicated by the dotted portion of the curve 64. In this condition, the multivibrator 11 operates at a 15 to 1 stepdown ratio with respect to the input frequency for $52\frac{1}{2}$ cycles of this input. At the completion of $52\frac{1}{2}$ input cycles, the tube 18 is just completing $3\frac{1}{2}$ operating cycles and is changing from a cut-off to a conducting state with the usual drop in voltage at its plate or anode 66. Multivibrator 12 is so proportioned that its tube 22 has been conducting during these $3\frac{1}{2}$ cycles of the preceding stage 11. By the usual normal multivibrator action, this tube 22 is now forced to cutoff by the start of conduction in its complementary tube 24, and a sharp drop occurs in the voltage level at the anode 26. At this instant the charging voltage to the condenser 56 is lowered from its previous positive voltage value 60 (Fig. 2) to some lower level 68 (Fig. 2), the exact value of which is determined by the voltage potential at the plate 26 of the tube 24 and the value chosen for the resistor 32. Under these changed circumstances, the condenser 56 charges along the exponential curve 70, which if not limited by grid current would become asymptotic to the lowered voltage level 68, whereas the condenser 62 associated with the control grid of the tube 18 continues to charge along its original curve 64. In this described, tested embodiment, the charging voltage was lower from about 200 volts to approximately 35 volts, which change was sufficient to increase the cut-off period of the tube 20 by an interval equivalent to one complete input cycle. Under these revised conditions, the tube 20 is cut off for $8\frac{1}{2}$ cycles of the input frequency, tube 18 is cut off for $7\frac{1}{2}$ input cycles, and the multivibrator operates at a stepdown ratio of 16 to 1 with respect to the input cycles. This condition continues for the conduction period of the tube 24, which in this tested embodiment was for the interval during which the preceding stage 11 performed $6\frac{1}{2}$ cyclic operations, and the input frequency performed $104\frac{1}{2}$ cyclic variations. From the foregoing it will be observed that the multivibrator 12 experienced one complete cycle of operation while the input cycle of the tubes 14, 16 were receiving 157 input cycles of the original wave 42. In the tested embodiment this input frequency was 9420 cycles per second and the desired reduced frequency was 60 cycles per second. As previously stated, the output from the multivibrator 12 is unbalanced in the ratio of $6\frac{1}{2}$ to $3\frac{1}{2}$, therefore, the multivibrator 13 is synchronized by pulses from only anode 36 of the tube 22 to secure a balanced output. The uncontrolled side of this unit 13 has the values of its

5

capacitance 72 and resistance 74 so proportioned that its natural oscillating period is equivalent to one-half of the period required for one complete cycle of the preceding stage 12.

In the frequency dividing system of Fig. 3, three multivibrator units are utilized to provide increased stepdown ratios. For the sake of simplicity, this and the following figures of the drawing are in block schematic form, and do not indicate the usual multivibrator circuit components as they are not necessary for a complete understanding of the operation of the invention. Though not indicated, each multivibrator includes suitable timing circuits interconnecting the anodes and grid circuits of the opposed sides in the usual manner. Also, for simplicity the operation of each of the circuits of Figs. 3, 4 and 6 will be explained on the basis that they are functioning at a stepdown ratio of 67 to 1. This ratio is selected as a convenient one for explanatory purposes, and does not represent the maximum stepdown capabilities of such systems, since this is a matter that is controlled by the usual limitations experienced in multivibrator design and operation.

In its general operation, the circuit of Fig. 3 resembles the circuit of Fig. 1, notwithstanding the physical differences in the voltage feedback circuit. In this embodiment it will be noted that the coupling paths between units are crossed; that is, the plate of the bottom tube is coupled to the control grid of the top tube of the following unit. This particular configuration has no operating significance, but is merely a convention that is here adopted to aid in the explanation of the circuit operation, since all top tubes may be considered as conducting elements at the start of the reference period.

In designing such a stepdown system, the first consideration is to select the normal operating ratios and balance conditions for the individual units. One method by which this selection may be made is illustrated in the following illustrative calculation for a ratio of 67 to 1. By inspection, the ratios 3, 4 and 5 form a close approximation of the desired result. Selecting 5 as the stepdown factor for the middle unit 80 and dividing 67 by this figure gives a result of 13%. This unit 80 may operate with an unbalance ratio of 2 to 3 if the unit is to be controlled on one side only. Because push-pull synchronization is to be employed, this may be changed to a balanced ratio of $2\frac{1}{2}$ to $2\frac{1}{2}$ without affecting the circuit operation. Selecting the stepdown ratio of 4 for the unit 82, and dividing the above-obtained 13 thereby, a quotient of $3\frac{1}{4}$ is obtained, which indicates that the unit 82 should operate at a ratio of 4 to 1 with unbalanced periods of 1 and 3 if it is to be operated with synchronizing pulses on only one control grid; or with periods of $1\frac{1}{2}$ and $2\frac{1}{2}$ if push-pull control is used, as shown. From the foregoing, it is determined that the system will comprise three multivibrator stages 80, 82, 84, the first of which may be a variable ratio unit operating at a stepdown ratio of 3 to 1 for a portion of the time, and at a ratio of 4 to 1 for the remainder of the time. If, as in this case, the unit 84 is to operate at an odd ratio, the unit may be balanced with non-conduction periods of $1\frac{1}{2}$ on each side until the voltage feedback occurs, at which time the controlled side will be increased to a $2\frac{1}{2}$ period. If the unit would normally operate at an even ratio of stepdown, the sides may normally be unbalanced, say $2\frac{1}{2}$ to $1\frac{1}{2}$, and become shifted to a balanced condition of $2\frac{1}{2}$ input

6

cycles for each side. The second unit 80 may have a ratio of 5 with balanced conducting periods, and the last unit 82 may have a ratio of 4 with conduction periods of $1\frac{1}{2}$ and $2\frac{1}{2}$, for push-pull control. These values are shown parenthetically in the block schematic diagrams. To effectuate the voltage feedback, the plate or anode 94 of the vacuum tube 86 is coupled to the control grid 89 of the vacuum tube 88, of the first unit 84, through the conduction path comprising the conductor 90 and resistor 92. All of the multivibrator units may be designed in accordance with the usual principles well known in this art, and preferably with the control grid circuits returned to the same positive voltage level as is used for the plate voltage supply. The magnitude of the feedback resistor 92 is so selected that when saturation current flows in the plate-cathode path of the vacuum tube 86 and the positive voltage potential at the plate 94 is lowered to its low limit, the charging voltage for the plate-grid coupling condenser (not shown) associated with the control grid 89 of the vacuum tube 88 is lowered from the level 60 to the level 68 (Fig. 2); and this change is sufficient to lengthen the non-conductive period of the controlled tube 88 by an interval equal to the desired number of input cycles. In this example, the desired interval is equivalent to one cycle of the input frequency.

The operating cycle of this Fig. 3 system may be visualized as follows. At the start of the reference period, tubes 98, 100 and 102 are conducting, and the complementary tubes 86, 87 and 88 are cut off. Unit 84 functions at a 3 to 1 stepdown ratio for $37\frac{1}{2}$ input cycles during which interval the unit 80 completes five reversals, or $2\frac{1}{2}$ cycles. At the end of this period, unit 82 reverses its conduction state since its tube 86 has a cut-off period that is equal to $2\frac{1}{2}$ cycles of the unit 80. The consequent drop in the level of the positive voltage at the anode 94 is fed back through the conductive path 90, 92 to the control grid 89 of tube 88 which has just started a conductive period. This lowered charging voltage has no effect on the conductive period of this tube, however, it extends the next cut-off period from its previous interval equivalent to $1\frac{1}{2}$ input cycles to a new interval which is equivalent to $2\frac{1}{2}$ input cycles. As there has been no change in the circuit of the tube 98, the multivibrator 84 operates at a 4 to 1 stepdown ratio, with the tube 98 being cut off for $1\frac{1}{2}$ cycles, and the complementary tube 88 being cut off for $2\frac{1}{2}$ cycles. The multivibrator 82 has now shifted to the condition of cutoff for tube 102, where it will remain for $1\frac{1}{2}$ cycles of the preceding unit 80. After $1\frac{1}{2}$ cycles of unit 80, during which time the tube 88 has experienced seven cut-off periods, and the multivibrator unit 84 has operated at a 4 to 1 stepdown ratio for $29\frac{1}{2}$ input cycles, the tube 102 again starts conduction. Tube 86 is again cut off, with an attendant positive voltage increase at its anode 94, and the control grid 89 of vacuum tube 88 is again returned to its original positive charging voltage level 60 (Fig. 2), to complete the cycle. During this described interval 67 cycles of the input wave have been impressed on the input unit 84.

In order to realize optimum operating margins in the above-described arrangement, it is preferable that the change in the control voltage occur at, or near, the start of a conduction period of the controlled tube. When this procedure is followed, it is apparent that the arrangement of

Fig. 3 is not limited to the single intermediate unit 80, as shown, but as many units may be added as will permit the assembly to complete its reversal and feed back the lowered voltage to the controlled tube before that tube becomes cut off.

In Fig. 4 there is indicated an alternative arrangement which eliminates any delay attendant upon serially reversing several intermediate units. In this arrangement, the variable-ratio multivibrator unit 106 is controlled from the next adjacent unit 108, which is in turn controlled by a subsequent unit 110. Whereas the first unit 106 is changed in its stepdown ratio by the feedback voltage, the second unit 108 maintains its stepdown ratio but is changed in its balance arrangement by the voltage control from the subsequent stage 110. If desirable, additional multivibrator units may be added to control the balance of the preceding balance controlling unit without introducing additional delay in the ratio-changing control between the first two units 106 and 108. This latter arrangement is indicated by the unit 112 and its connections as shown in dotted lines in Fig. 4.

The stepdown ratios and balance relations of the individual multivibrator units are chosen in the same manner described for the arrangement of Fig. 3. For example, for a 67 to 1 stepdown ratio, the unit 110 would have a ratio of five with an unbalance of 2 to 3, since in this arrangement it is preferably operated with control pulses on only one grid 114. The ratio controlling unit 108, although now in an intermediate physical position, continues to operate at a 4 to 1 stepdown ratio. Whereas, in the arrangement of Fig. 3 the corresponding unit 82 had a fixed unbalance of $1\frac{1}{2}$ to $2\frac{1}{2}$, unit 108 now operates at this unbalance for three-fifths of a cycle of the succeeding unit, and is then changed to an unbalance of $2\frac{1}{2}$ to $1\frac{1}{2}$ for the remainder of its cycle. As previously described, the variable ratio unit 106 operates at a 3 to 1 ratio for a portion of the time, and at a 4 to 1 ratio for the remainder of the complete cycle of operations. In the previously described arrangement, the controlled tube 88 added the same number of extra input cycles each time the voltage was lowered at the anode 94 of the controlling tube 85. In the embodiment of Fig. 4, it should be noted that the controlling tube 116 has the lowered anode voltage for variously $1\frac{1}{2}$ or $2\frac{1}{2}$ cycles of the variable-ratio unit 106. Notwithstanding this difference, the same number of extra input cycles are added during the complete stepdown cycle, so that the overall effect is a 67 to 1 reduction in the input frequency.

The sequence of reversals may be visualized from the following, if it is assumed that the cycle of operation is started just as each of the upper tubes 118, 120, 122 starts its conductive period. Initially, the multivibrator 106 reverses for each $1\frac{1}{2}$ cycles of input frequency. After $2\frac{1}{2}$ such reversals the succeeding unit 108 reverses so that the tube 116 conducts, and the lowered voltage at its plate 124 is fed back through the conductive path 130, 132 to the control grid 126 as the tube 128 starts its conductive period. This condition maintains for $1\frac{1}{2}$ cycles of the unit 106 during which time the tube 128 is cut off once, and adds one input cycle by operating at a 4 to 1 instead of a 3 to 1 stepdown ratio. At the end of this period, the multivibrator unit 108 reverts to its original condition. This process is repeated three times, during which time the unit 106 completes nine cycles at a 3 to 1 stepdown rate and three cycles at a 4 to 1 stepdown rate. At about

the end of this period, or slightly after the start of the succeeding period, the balance controlling unit 110 changes so that the lower tube 130 is conducting, with a lowered potential at its plate or anode 134, and the upper tube 122 is cut off with increased potential at its plate or anode 134. By way of the conductive paths comprising conductors 136 and 138 and resistors 140 and 142, these voltage changes are applied to the control grids 144 and 146 of the preceding unit 108. The unit 108 is suitably designed for balanced operation when the multivibrators conventional grid condenser-resistors (not shown) are returned to equal voltage potentials. The values of resistors 140 and 142 are so selected that the cutoff period of their associated tube 116 or 120 is extended by one cycle of the unit 106 when the voltage at the anode 134 or 134 is lowered to its minimum value by plate current conduction. These revised voltage conditions reverse the unbalance relation within the multivibrator unit 108 so that the tube 116 now conducts, with lowered voltage at its plate or anode 124 for $2\frac{1}{2}$ cycles of the first unit 106. During this time, the tube 128 is cut off twice and adds one cycle of the input frequency during each cut-off period. This condition persists for two complete cycles of the unit 108, after which time the tube 120 is becoming conductive delivers a negative pulse through the coupling condenser 148 to the grid 114 of the saturated tube 130. In known manner, this negative pulse is inverted and delivered through the conventional multivibrator plate-control grid coupling (not shown) to start conduction in the upper tube 122 of the balance controlling stage 110. This completes the operating cycle during which 67 cycles of the input wave have been applied to the control grids 126, 150 of the variable-ratio unit 106.

The above-described arrangement may have, if desired, additional dividing stages as indicated by the dotted line unit 112. As in the case of the balance controlling unit 110, the added stages may be controlled by pulses on only one control grid and be unbalanced by whole number ratios. If desired, a balanced unity-ratio unit may be operated from the last stage to provide an output wave having equal period positive and negative portions.

The arrangement indicated in Fig. 5 illustrates one method of employing the principles of this invention to secure a true fractional reduction in frequency. This arrangement employs one fixed unbalance stage 152 and two variable-ratio stages 154 and 156, with the desired output being taken from the plate-cathode circuits of the first unit 154. The circuit of Fig. 5 is designed for a stepdown ratio of $3\frac{10}{29}$ and in effect employs two systems, one comprising the units 152 and 156 which cooperatively effect a 29 to 1 stepdown ratio in the previously described manner. The second portion of the system comprises the unit 154 and the combined effect of the two units 152, 156. In the manner previously described, the first unit operates at a 3 to 1 stepdown ratio for $\frac{19}{29}$ of the complete cycle and at a 4 to 1 ratio for $\frac{10}{29}$ of the cycle.

In each of the foregoing examples, the ratio-changing voltage feedback connection has been in fixed relation to one of the control grid circuits of a preceding stage. This is not an essential arrangement as is shown by the circuit of Fig. 6, which illustrates one method of obtaining the desired frequency reduction by alternately applying the feedback voltage to one and then the

other control grid of the variable-ratio multivibrator unit 158. In the arrangement of Fig. 6, the multivibrator units 158, 160, 162 are conventionally designed units with normal balanced or unbalanced conditions as may be desired. The ratio and balance characteristics may be selected in accordance with the previously described method. Assuming a 67 to 1 stepdown ratio to be desired, the last unit 162 might preferably operate at a 5 to 1 ratio with balanced cut-off periods. The preceding unit 160 might operate at a 4 to 1 ratio, using cut-off periods of $1\frac{1}{2}$ and $2\frac{1}{2}$ cycles of the preceding stage 158 which necessarily then must operate at a 3 to 1 and a 4 to 1 rate.

The gating circuit 164, shown only in simplified schematic form, serves as a relay to effect the switching of the control voltage from one control grid circuit to the other control grid circuit of the unit 158. The plate resistors 166, 168 are so chosen that, for saturated plate-cathode current conditions in the tubes 170, 172, the voltage potentials available at the points 174, 176 are the same as the potential at the plate or anode 179 during the conduction interval of the tube 180. Resistors 167, 169 are provided in the conductive paths connecting the voltage points 174, 176 to the control grid elements 208, 210 in accordance with the previously explained principle. The same positive plate voltage supply may be used for the gate tubes 170, 172 as is used for the multivibrator units 158, 160, 162. A voltage dividing network, comprising resistors 181 to 186 inclusive, is provided in the control grid circuits of the gating tubes 170, 172. The midpoint 187 of this network is connected to the plate or anode 188 of the multivibrator tube 190 by the conductive path 192. The symmetrically located intermediate points 194, 196 are respectively connected by way of the conductive paths 198 to the plates or anodes 200 and 202 of tubes 206 and 214. Suitable grid voltage sources, designated $-E_c$, are provided to cause the tubes 170, 172 to be non-conductive at all times except when the combined voltage potentials at the anode 188 and either one of the anodes 200, 202 are at their maximum values. In this manner, the tubes 170, 172 never conduct current simultaneously, since the anodes 200, 202 are never at maximum plate potential at the same time.

The operation of this circuit may best be visualized if, as a reference time, it is assumed that the upper tubes 190, 204, 206 have just started their conductive cycles, and the non-conductive period of each half of each multivibrator unit is as shown parenthetically at the upper and lower left corners of the units 158, 160, 162 on the drawing. Because tube 190 is conductive, the voltage potential at its anode 188 is low, both of the gating tubes 170, 172 are non-conductive, and the full positive plate voltage potential is available at the voltage points 174, 176. Under these circumstances, the first unit 158 operates as a balanced 3 to 1 unit for $2\frac{1}{2}$ cycles, corresponding to $7\frac{1}{2}$ cycles of the input wave; then the multivibrator unit 160 reverses its operation, and the voltage potential at the anode 188 rises to its maximum value. At this same time, the unit 162 is conductive in its upper tube 206, with lowered potential at its anode 202, and is cut off in its lower tube 214, with full positive plate voltage at the anode 200. These voltage relations condition the gate tube 170 for current conduction which results in lowered voltage potential at the voltage point 174. As explained in the previously

described cases, the resistor 167 together with the usual grid charging resistor (not shown) in the circuit of the control grid 208 form a voltage dividing network. Acting through this network, the lowered potential at the voltage point 174 changes the charging voltage in this grid circuit and increases the cut-off period of the tube 204 from $1\frac{1}{2}$ to $2\frac{1}{2}$ cycles of the input wave. The lowered voltage continues for $6\frac{1}{2}$ cycles of the input wave, during which interval the unit 158 completes $1\frac{1}{2}$ cycles of operation; after which the multivibrator unit 160 again reverses to its original condition, current conduction is interrupted in the gate tube 170, and the multivibrator unit 158 again reverts to a balanced 3 to 1 stepdown ratio unit. This series of operations is repeated for a total of $2\frac{1}{2}$ cycles of the unit 160, corresponding to $35\frac{1}{2}$ cycles of the input frequency wave, at which time the multivibrator unit 162 reverses its operation so that the voltage potential at the anode 202, and at the point 196 on the voltage dividing network, are at their maximum values. At this same time, the potential at the anode 188 is at maximum, as the tube 190 is cut off, and saturation current flows in the plate circuit of the gate tube 172 to lower the voltage at the voltage point 176 and at the control grid 210 of the tube 212. This tube 212 has just started a conductive period, and will experience only one cut-off period in the next $1\frac{1}{2}$ cycles, during which interval it can add an additional input cycle. Then, the multivibrator unit 160 again reverses its operation, and the gate tube 172 is cut off by the lowered voltage potential at the anode 188. This cycle of operation continues for $2\frac{1}{2}$ cycles of unit 160, during which time the input unit 158 has had $31\frac{1}{2}$ cycles of the input wave applied to its control grids 208, 210. Throughout this entire operation, the multivibrator unit 162 has performed one complete operating cycle, while 67 cycles of the input frequency have been impressed on the input unit 158.

Although the invention has been described in connection with frequency division systems, it is apparent that the field of its application is not so confined. This disclosure will suggest to others skilled in the art equivalent means for practicing the invention.

What is claimed is:

1. An alternating wave generator comprising a plurality of periodic devices, each of said devices comprising an oscillator having input and output connections and a natural free-running period of oscillation, a conductive path including a series capacitive impedance interconnecting at least one output connection of a preceding oscillator and one input connection of the succeeding oscillator, and means responsive to the operation of said succeeding oscillator for changing the natural free-running period of oscillation of said preceding oscillator.

2. An alternating wave generator according to claim 1 in which the means responsive to the operation of said succeeding oscillator comprises a direct-current conductive circuit including a series connected resistor unit interconnecting an output connection of said succeeding oscillator and an input connection of said preceding oscillator.

3. An alternating wave generator comprising a plurality of multivibrator oscillators, each of said oscillators having plate-cathode and control grid-cathode circuits, and each side of each oscillator having a natural ratio between its free-running

conductive and non-conductive intervals, capacitive elements connecting the plate-cathode circuits of a first oscillator unit to the control grid-cathode circuits of a second oscillator unit, at least one capacitive element interconnecting at 5 least one plate-cathode circuit of said second oscillator unit to at least one control grid-cathode circuit of a third oscillator unit, means responsive to the oscillations of said third oscillator unit for changing the natural ratios between the said 10 free-running conductive and non-conductive intervals of said second oscillator unit, and means responsive to the oscillations of said second oscillator unit for changing the natural ratios between the free-running conductive and non-conductive intervals of said first oscillator unit.

4. An alternating wave generator in accordance with claim 3 in which the means for changing the natural ratios between the free-running conductive and non-conductive intervals of said second oscillator is a plurality of conductive paths each including a series impedance element connecting each plate-cathode circuit of said third oscillator unit to one of the control grid-cathode circuits of said second oscillator unit, and said means responsive to the oscillations of said second oscillator unit for changing the natural ratios between the free-running conductive and non-conductive intervals of said first oscillator unit comprises a direct-current conductive path including a series impedance element connecting the plate-cathode circuit of one side of said second oscillator unit to one control grid-cathode circuit of said first oscillator unit.

5. An alternating wave generator comprising at least two tandem-connected multivibrator oscillators, each including a pair of vacuum tubes each having a plate, a cathode and a control grid, plate-cathode and control grid-cathode circuits for each vacuum tube, a capacitive element connected between the plate-cathode circuit of each vacuum tube and the control grid-cathode circuit of the other tube, at least one conductive path containing a series connected capacitance connecting the plate-cathode circuit of a vacuum tube in one of the tandem-connected oscillators to the control grid-cathode circuit of one of the vacuum tubes in the next succeeding oscillator unit, and a direct-current conductive circuit containing a series resistor connecting one of the plate-cathode circuits of said next succeeding oscillator unit to one of the control grid-cathode circuits of said preceding oscillator unit.

6. In a frequency dividing system comprising a plurality of multivibrator oscillator units in tandem connection, each of said units having a natural free-running frequency of oscillations and comprising plate-cathode and control grid-cathode circuits, input means connected to the control grid-cathode circuits of the first of said tandem-connected units and output means connected to the plate-cathode circuits of one of the succeeding connected units, conductive paths including serially-connected impedance elements connecting the plate-cathode circuits of each preceding oscillator unit to the control grid-cathode circuits of each succeeding connected oscillator unit, and direct-current conductive means responsive to alternations in one of said succeeding oscillator units for controlling the frequency of oscillation of said first-connected unit.

7. A frequency dividing system in accordance with claim 6, the said means for controlling the frequency of oscillation of said first-connected unit comprising a direct-current conductive path

including a serially-connected impedance element connecting one control grid-cathode circuit of said first-connected oscillator unit to one plate-cathode circuit of a non-adjacent succeeding connected oscillator unit.

8. In a frequency dividing system for the production of an output wave whose cyclic variations bear a fractional ratio relation to the cyclic variations of the input wave, said system comprising at least initial, intermediate and other multivibrator oscillator units in tandem connection, each oscillator having a natural free-running frequency of oscillation, each such unit comprising two plate-cathode and two control grid-cathode circuits, one of said multivibrator units having input terminals connected to its control grid-cathode circuits for the introduction of the wave the frequency of which is to be divided, and one of the said units having output terminals connected to its plate-cathode circuits for the delivery of the fractional ratio output wave, conductive paths including serially-connected impedance elements connecting the plate-cathode circuits of each preceding oscillator unit to the control grid-cathode circuits of each succeeding arranged oscillator unit, means responsive to the oscillations in said succeeding arranged multivibrator oscillator units for changing the frequency of oscillation of said intermediately arranged oscillator unit from its natural value to a different value, and means responsive to the oscillations in said succeeding arranged multivibrator oscillator unit for changing the free-running frequency of oscillation of the said initially arranged oscillator unit from its natural to a different value.

9. A frequency dividing system in accordance with claim 8 wherein said means for changing the frequency of oscillation of the intermediate oscillator unit comprises a direct-current conductive path including a serially-connected impedance connecting one plate-cathode circuit of said succeeding arranged oscillator unit to one control grid-cathode circuit of said intermediate oscillator unit, and said means for changing the frequency of oscillation of said initially arranged oscillator unit comprises a conductive path including a serially-connected impedance connecting a control grid-cathode circuit of said initial oscillator unit to the other plate-cathode circuit of said succeeding arranged oscillator unit.

10. In a frequency dividing system employing an alternating wave generator comprising at least three multivibrator oscillator units in tandem connection, each such unit having a natural oscillatory frequency and a natural balance ratio and comprising plate-cathode and control grid-cathode circuits, the first one of said oscillator units having input terminals connected to its control grid-cathode circuits for connection to the source of the wave the frequency of which is to be divided, output terminals connected to the plate-cathode circuits of one of said oscillator units, the plate-cathode circuits of each preceding unit being capacitively coupled to the control grid-cathode circuits of the next succeeding unit, means responsive to the oscillations of one of said oscillator units for changing the frequency of oscillation of the said first one of said units, and means responsive to the oscillations of the third of said oscillators for alternately reversing the balance ratio of the second oscillator unit.

11. A frequency dividing system which comprises a pair of multivibrator oscillator units in

tandem connection, each of said oscillator units having a natural free-running frequency of oscillation, and each one comprising plate-cathode and control grid-cathode circuits, input means connected to the control grid-cathode circuits of the first of said tandem connected units and output means connected to the plate-cathode circuits of the succeeding unit, an impedance element interconnecting each plate-cathode circuit of said first unit to a respective one of the control grid-cathode circuits of the succeeding unit, and a resistive connection between one plate-cathode circuit of said succeeding unit and a control grid-cathode circuit of said first unit whereby the frequency of oscillation of said first unit is decreased during intervals when said succeeding unit is conducting current in its plate-cathode circuit connected to said resistive connection.

12. A frequency dividing system which comprises a first and a second multivibrator oscillator unit in tandem connection, each of said units comprising a pair of electron discharge circuit elements each of which comprises a plate electrode, a cathode electrode and a control grid-electrode, said plate electrodes being resistively connected to the positive terminal of a potential source, said cathode electrodes being connected to the negative terminal of said source, a serially connected capacitor-resistor circuit connected between the plate electrode of each of said elements and a source of positive potential, the control grid-electrode of each of said elements being attached to the junction of the capacitor-re-

sistor connected to the plate electrode of its conjugate element, the plate electrodes of said first unit being connected to a respective one of said control grid-electrodes of said second unit, input terminal means connected to said first oscillator unit for supplying to said unit a train of waves the frequency of which is to be divided, output terminal means connected to said second unit for the delivery of said divided frequency, and a direct-current conductive impedance element connected at its one end to a plate electrode of said second unit and connected at its other end to a junction point of one of said serially connected capacitor-resistor combinations, whereby said impedance element and said resistor form a voltage dividing circuit to which one control grid-electrode of said first unit is connected at an intermediate point.

KINGSBURY H. DAVIS.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,407,320	Miller	Sept. 10, 1946
2,410,156	Flory	Oct. 29, 1946
2,416,095	Gulden	Feb. 18, 1947

OTHER REFERENCES

Grosdoff, "Electronic Counters," RCA Review, September 1946, vol. 7, No. 3, pp. 438-447.