

Nov. 28, 1933.

R. N. HARMON

1,936,789

FREQUENCY MULTIPLIER

Filed Aug. 15, 1929

2 Sheets-Sheet 1

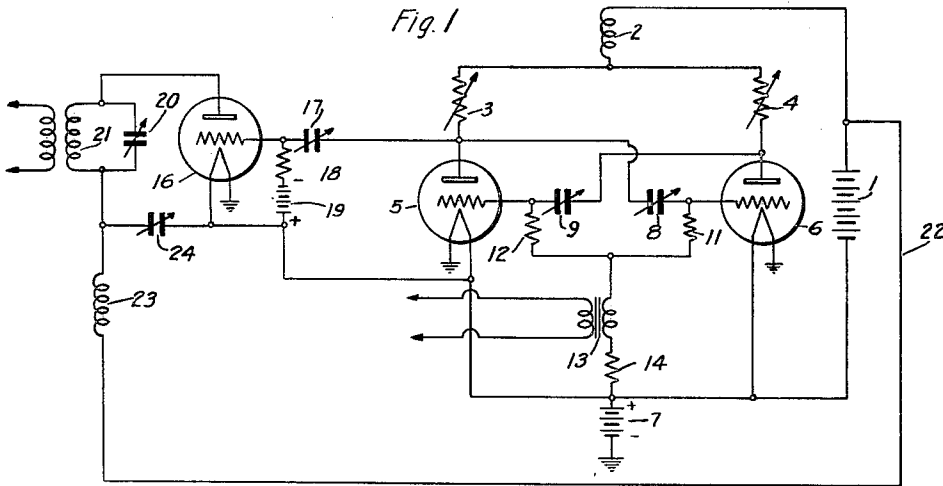


Fig. 2

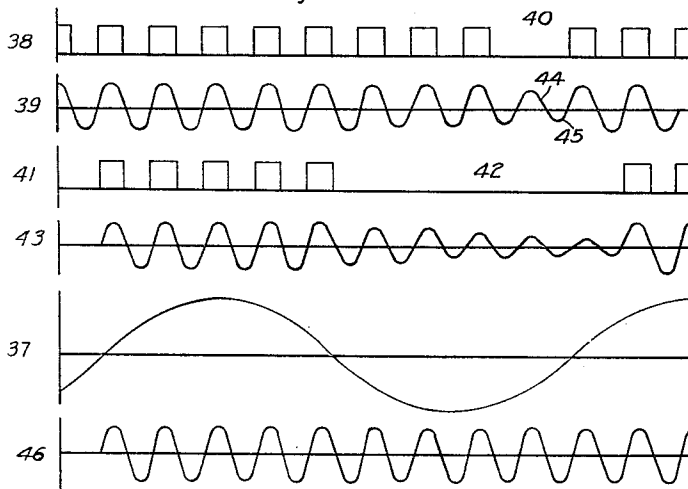
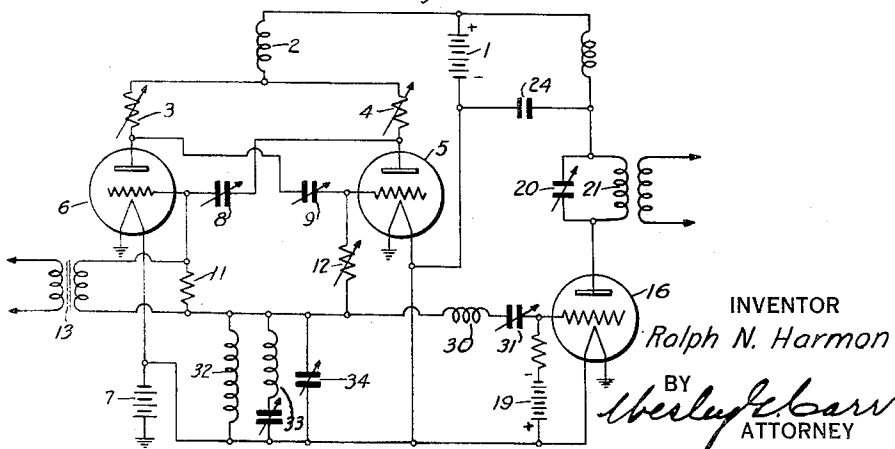


Fig. 3



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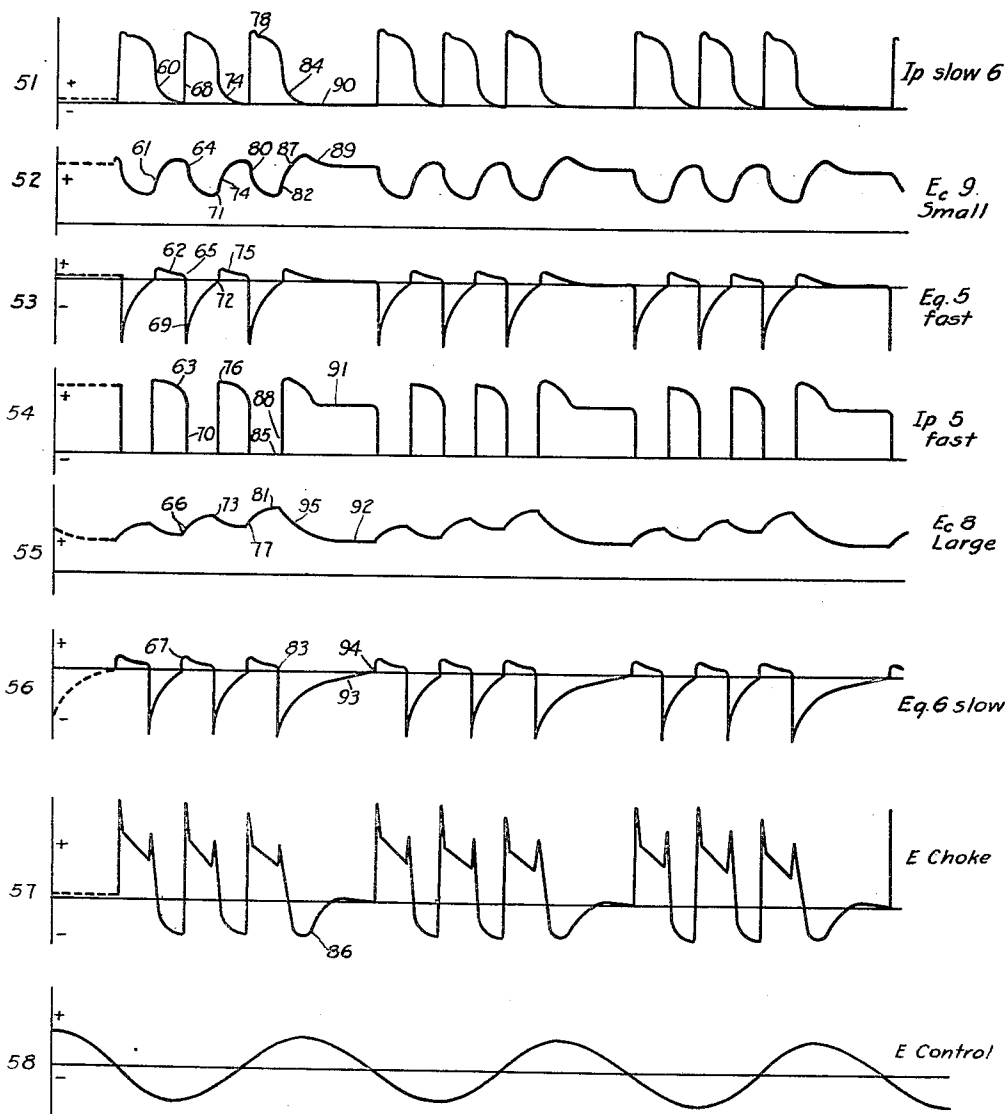


Fig. 4.

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1,936,789

FREQUENCY MULTIPLIER

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Application August 15, 1929. Serial No. 386,185

5 Claims. (Cl. 250—36)

This invention relates to frequency multipliers and particularly to an adaptation of the multivibrator by means of which one harmonic may be made to predominate strongly over the
5 others.

It is an object of my invention to produce, from a low frequency, a higher frequency having a fixed ratio thereto, whereby, if the low frequency be maintained constant, the high frequency will also be constant.

It is a further object of my invention to provide an arrangement by which a constant high frequency may be impressed and a low frequency will be delivered, which will be of constant value
15 so long as the high frequency remains fixed. The low frequency will be a submultiple of the impressed frequency and will be suitable for driving synchronous motors, such as are now frequently used for operating clocks.

It is a further object of my invention to provide means for obtaining a selected harmonic of the fundamental with a fewer number of tubes than have heretofore been required for that purpose.

It is a further object of my invention to provide a multivibrator in which the adjustments required are not critical.

Other objects of the invention and details of the construction will be understood from the following description and accompanying drawings, in which:

Figure 1 is a diagram of the circuits and apparatus;

Fig. 2 embodies a plurality of curves which
35 will be used to describe the results obtained;

Fig. 3 is a diagram of circuits and apparatus illustrating a modification, and

Fig. 4 embodies curves by means of which the operation of the device will be explained.

The multivibrator is a term introduced by Abraham and Bloch to describe an arrangement of tubes equipped with the usual resistance-capacity coupling, in which the output of the last tube is coupled to the input of the first tube.
45 I have introduced new features into this arrangement, but the invention will be best understood from a description of the whole multivibrator including them.

Referring to Fig. 1, the B-battery 1 is connected, through the inductor 2, to the resistors 3 and 4 and, through them, to the plates of the vacuum tubes 5 and 6. The filaments of these plates are connected together and to ground and are energized by the A-battery 7 in the usual
55 way.

An adjustable condenser 8 is connected between the plate of the tube 5 and the grid of the tube 6, and a similar condenser 9 is connected between the plate of the tube 6 and the grid of the tube 5.

A resistor 11 constitutes the grid leak for the tube 6, and a resistor 12 for the tube 5. The two grid leaks are connected to the filaments through the secondary of a transformer 13 and an additional resistor 14.

The portion of Fig. 1 thus far described constitutes the multivibrator. The features thereof which I have invented include the addition of the inductor 2 and such selection of values for condensers 8 and 9 and resistors 3, 4, 11 and 12 that the time constants of the circuits including the condenser 9 shall be much shorter than the time constants of the circuits including the condenser 8. This is accomplished either by making condenser 9 considerably smaller than condenser 8 or by making resistors 4 and 12 considerably smaller than resistors 3 and 11, or both of these expedients.

The input to the multivibrator is the primary of the transformer 13. I have provided an output by connecting the plate and filament of the tube 5 to the grid and the filament of an amplifier tube 16. The connection includes a stopping condenser 17 which may be adjustable. A resistor 18 and, if desired, a C-battery 19 constitute the grid-leak path of the tube 16.

The output circuit of the tube 16 preferably contains a parallel-resonant circuit, including an adjustable condenser 20 and the primary of a transformer 21, the secondary of which constitutes the final output.

B-battery potential is supplied to the tube 16 over a connection 22 from the positive side of the battery 1, through a choke coil 23, to the parallel-resonant circuit. A connection from the parallel-resonant circuit to the filament, for the high-frequency, is provided by the condenser 24.

In Fig. 3, the corresponding parts are similarly numbered. In order to illustrate that the input transformer does not have to be connected to the common lead for both tubes 5 and 6, Fig. 3 shows the output from the transformer 13 connected across the resistor 11.

In order to ensure greater purity in the output from the tube 16, the connection to the grid thereof, instead of being over a single condenser 17, is over a filter. To illustrate further variations which are possible, the connection, instead of being from the plate and filament of
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tube 5, is from the grid and the filament thereof. The filter includes the inductor 30 and condenser 31 in series which together are tuned to the desired harmonic. The inductor 32, the series-tuned circuit 33 and the condenser 34 illustrate possible shunts for removing undesired frequencies.

When a voltage, such as is illustrated by the curve 37 in Fig. 2, is impressed upon the primary of the transformer 13, a voltage like that illustrated in curve 38 of Fig. 2 is obtained in the output from the tube 5 which gives rise, in the transformer 21, to a voltage represented by the curve 39. It will be observed that the curve 38 has a square-wave-form of uniform character except that, at the point 40, a single wave has been omitted.

The omission of a single cycle of the high-frequency, square-wave-form potential corresponds to the adjustment in which the time constant of the condenser 9 is nearly equal to the time constant of condenser 8. If these time constants are less nearly equal, the potential delivered by the tube 5 will be similar to that shown in curve 41, and the period during which the square-wave-form pulses will not be delivered is greater, as illustrated at 42. The curve 43 illustrates the potential which will be delivered by the transformer 21 under these circumstances. It will be observed that a decrement shown by curve 43 occurs, beginning at the beginning of the period represented at 42 and continuing throughout this period. At the end of the period, the amplitude returns to its original value. A similar but much less conspicuous decrement is illustrated by curve 39 and may be observed by noticing that the peak 44 is not as high as its neighboring peaks and the trough 45 is not as deep as the neighboring troughs.

If, instead of a voltage corresponding to curve 37 being impressed upon the input of transformer 13, a voltage having the frequency of curve 39 is impressed thereon, as represented by the curve 46, the output at the transformer 21 may be made to very closely resemble curve 37. When this is done, the only readjustment of the constants of the apparatus required is in the parallel-resonant circuit 20—21 which must now be changed to a low frequency.

These results have been obtained experimentally. I am not prepared to state with certainty the explanation of them, but I have discovered that, if the inductor 2 be omitted but a control voltage be impressed at the transformer 13, a very much more critical adjustment of the condensers and resistors is required in order to produce the results described. If the inductor 2 be omitted and no controlling voltage be impressed at the transformer 13, the apparatus will give rise to a square-wave-form, high-frequency potential in the output of the tube 5 which may be controlled, to some extent, by adjustment of the ratio between the time constants of the two condensers, but under these circumstances, the adjustment is exceedingly critical, many harmonics will be present and the interruptions to high frequency, represented at 40 and 42, will not occur.

When the controlling voltage is impressed through the transformer 13 and the inductor 2 is omitted, similar results may be obtained by inserting an inductor in the connection between resistor 3 and the plate of the tube 5 or between the resistor 4 and the plate of the tube 6, but, by inserting an inductor in each of these places,

the result is far less stable. It is also possible to obtain these results by inserting an inductor between the resistor 12 and the filament connection or between the resistor 11 and the filament connection, but, if inserted in both of these places, the result is far less stable. To insert an inductor in the common connection from both resistors 11 and 12 to the filaments is equivalent to inserting it at the point 2 illustrated. It is then merely at the other end of the same circuits.

I have no satisfactory knowledge of the reason why the inductor, when inserted as described, produces the results I have stated. The following detailed description of the course of events is the best explanation I am, at present, able to offer, but I am aware that complete analysis of the operations may show this explanation to be incorrect.

Attention is called to an article beginning at page 259 of the *Philosophical Transactions of the Royal Society of London*, vol. 224, November 13, 1924, by D. W. Dye and to an article in the *Annals de Physique*, No. 9, Series XII, page 237 (1919). In the French article, beginning at page 252, the construction, and an analysis of the operation, of the multivibrator is given. Attention is also called to *Radio Engineering Principles* by Lauer & Brown, edition of 1928, beginning on page 208. This section describes a multivibrator and gives a brief analysis of its action. It will be noted, from the teaching of these articles, that the tubes 5 and 6 are "worked hard". That is to say, each time that the grid changes potential, the change is greater than the straight-line part of the tube characteristic.

The analysis about to be given here differs from those in the articles just cited, because the time constants of the condensers are unequal in the structure here proposed and are equal in the structures analyzed in the articles. There is a further difference which results from the presence of the inductance.

Oscillographic observations show that the tubes 5 and 6 are alternately conductive and non-conductive, because of the grid potential changing past the cut-off point. Curves, which have been prepared from the oscillographic observations, are represented in Fig. 4. Curve 51 represents the plate current through the tube 6. Curve 52 represents the charge upon the condenser 9. Curve 53 represents the potential of the grid in tube 5. Curve 54 represents the plate current through the tube 5. Curve 55 represents the charge upon the condenser 8. Curve 56 represents the grid potential of the tube 6. Curve 57 represents the potential across the inductor 2. The part of this curve above the zero line represents potentials directed upward in the inductor as it is represented in Fig. 1. Curve 58 represents the potentials impressed through the transformer 13.

The moment at which the tube 6 changes from a conductive and approaches a non-conductive condition is represented by the point 60 in curve 51 of Fig. 4. A consequence, although not all of the consequences, of the change of current through tube 6, is that the potential of the plate of tube 6 rises, because the potential drop across the resistor 4 approaches zero. Because the plate potential of the tube 6 is increased, the condenser 9 will receive a charge from the battery 1 over the circuit 1, 2, 4, 9, 12, 13, 14 and return. The increase in charge upon condenser 9 is represented by the upward trend at 61 of curve 150

52 of Fig. 4. The charging current for the condenser 9 flows downward in the resistor 12, as the diagram is drawn. Therefore, the grid of the tube 5, which is connected to the upper terminal of this resistor, is at a positive potential relative to the filament of this tube, which is connected to the lower end of said resistor. This is indicated by the fact that the portion 62 of curve 53 is above the zero line.

The tube 5 becomes conductive because its grid is positive. At the same time, there is some current flow from the grid to the filament in this tube and, therefore, the charging circuit for the condenser 9 includes the grid-filament path in tube 5 in parallel with the resistor 12. The current drawn by the plate of tube 5 during this time is represented at 63 of curve 54.

The condenser 9 will continue to charge during the time fixed by its capacity and the resistance of the charging circuit. The conditions just described, namely, tube 6 non-conductive and tube 5 conductive, will continue until the charging of the condenser 9 is completed.

When the condenser 9 is completely charged, as indicated at 64 of curve 52, no more current will flow in the charging circuit. The drop over the resistor 12, therefore, becomes zero, and the potential of the grid of tube 5 will fall, as shown at 65 of curve 53.

Even though the potential of the grid does not fall below the cut-off point for the tube, it falls enough to cause a diminution in the current through the tube 5. Diminution in this current causes an increase in the plate potential of the tube 5. The increased potential is impressed upon the condenser 8 and this condenser, therefore, begins to charge as shown at 66 of curve 55.

That the condenser 8 was, at this moment, either completely or partially discharged, is a consequence of the fact that the tube 5 had been conductive during the period that condenser 9 was charging. The discharge circuit for the condenser 8 was through the tube 5 to ground and from the ground through elements 14, 13 and 11.

The charging circuit for the condenser 8 is from the battery 1 through elements 2, 3, 8, 11, 13, 14 and return. The direction of the charging current for the condenser 8 is downward through the resistor 11 and, therefore, the grid of the tube 6 becomes positive relative to the filament, as soon as the charging of condenser 8 begins. This is represented at 67 of curve 56. This results in tube 6 drawing current as shown at 68.

The tube 6, being conductive, opens a discharge path for the condenser 9. The discharge current flows through the tube 6 to the ground and from the ground, through elements 14, 13, and 12, to the condenser. Since the discharge current is upward through the resistor 12, the grid of the tube 5 becomes negative relative to the filament and the tube 5 becomes non-conductive. Moreover, as there is substantially no inductance in the discharge path, the change in potential of the grid of tube 5 is abrupt, as shown at 69 of curve 53.

It should be noted that the consequence of the small decrease in current through the tube 5 which resulted from the cessation of charging current for the condenser 9 causes an abrupt termination of all current through said tube 5 as shown at 70 of curve 54.

The condition, tube 6 conductive and tube 5 non-conductive, will continue until the condenser 9 discharges. During this time, the condenser 8

is receiving a charge. This will be added to the charge which remained in the condenser 8 at the moment of change in conditions, represented at 66 of curve 55. The condenser 8 will not have been completely discharged because its time constant is slower than the time constant of condenser 9. The change from discharging to charging was brought about by the completion 64 of the charge upon condenser 9, which happened before the discharge of condenser 8 was completed.

The period now under consideration will continue until the condenser 9 has completed its discharge, as indicated at 71 of curve 52. When this discharge is completed, discharge current will cease to flow over the resistor 12. The potential of the grid of tube 5 will, therefore, rise from a negative value to zero, as indicated at 72 of curve 53, and the tube will again become conductive. As soon as this happens, the condenser 8 will begin to discharge through the tube 5, as indicated at 73 of curve 55. The tube 6 will, thereupon, become non-conductive, the plate potential across the tube thus will rise, and the condenser 9 will begin to charge, as indicated at 74 of curve 52. When the condenser 9 begins to charge, the grid of the tube 5 will become positive, as indicated at 75 of curve 53, and the tube will become even more conductive. All of the changes just noted are abrupt because no inductance is involved in any of them. The current through the tube 5, therefore, rises abruptly from zero to its maximum value, as indicated at 76 of curve 54.

Conditions are now as they were at the beginning of this analysis except that the charge upon condenser 8 is somewhat greater than at first. Operations will repeat themselves in this way until the charge upon the condenser 8 has increased sufficiently to require less time for the completion of the charge than is required for the discharge of condenser 9.

Consider the moment when the condenser 8 begins to receive charging current after the charge which has been accumulated therein is nearly sufficient to fill it, as indicated at 77 of curve 55. At that moment, the tube 6 is conductive, as indicated at 78 of curve 51, and the condenser 9 is discharging, as indicated at 80 of curve 52, but the condenser 8 completes its charge, as indicated at 81 of curve 55, before the condenser 9 has completed its discharge, as indicated at 82 of curve 52. When this happens, the charging current through the resistor 11 falls to zero. The potential of the grid in tube 6, therefore, becomes zero, as indicated at 83 of curve 56, and the tube, while still conducting, draws less current than before, as indicated at 84 of curve 51. Tube 5 is, at this moment, in a non-conducting condition, as indicated at 85 of curve 54. The total current drawn through inductor 2, therefore, diminishes.

The diminution produces an electromotive force downward in the inductor 2, as represented in the diagram at 86 of curve 57. The increase in plate potential across the tube 6, which result from diminution in the drop through resistor 4, is added to the electromotive force from the inductor 2, and the increase in plate potential across the tube 6 is, therefore, greater than heretofore. The charging effect upon the condenser 9 is, therefore, greater. This condenser charges, not only to a higher potential, but more rapidly, as indicated at 87 of curve 52. The tube 5, therefore, becomes conductive, as indicated at 88 of

curve 54, and, if anything, more abruptly than before.

The extra rise in plate potential upon the tube 6 was temporary. The effect of the inductor 2 disappears, and the higher potential to which the condenser 9 had been charged soon exceeds the potential impressed upon the plate of the tube 6. The condenser 9 will, therefore, discharge, but not through the tube 6. It will discharge over the path from 9 to 4, 2, 1, 14, 13, and 12, until the potential of the condenser 9 falls to the potential impressed by the battery 1 as indicated at 89 of curve 52.

Since the condenser 9 discharges over a path including the battery 1, the potential producing the discharge current is only the difference between the battery potential and the potential to which the condenser 9 charged. This difference is small. Consequently, the rate of discharge is slow. The current through the resistor 12 is, therefore, small, and the grid of the tube 5, although it becomes negative, does not become sufficiently negative to render the tube non-conducting.

Since the time during which the condenser 9 is discharging is brief, as may be seen by observing, at 89 of curve 52, that the portion of the curve which slopes downward is short, the slightly negative potential of the grid was not caught by the oscillograph, which is the reason why it is not exhibited by curve 53.

When the potential of the condenser 9 has fallen to that impressed by the battery, it will not continue to discharge over the path last traced, because of the opposing potential of the battery. It will not discharge over the path through tube 6, because this tube is, at this time, non-conductive (90 of curve 51). The charge of condenser 9 will, therefore, remain steady, and there will be zero current through the resistor 12. Consequently, the tube 5 will be somewhat conductive (91 of curve 54) and the condenser 8 will discharge (92 of curve 55), thereby maintaining the grid of tube 6 negative (93 of curve 56) and tube 6 non-conducting until the condenser 8 is completely discharged.

When the condenser 8 is completely discharged, the potential of the grid of tube 6 becomes zero (94 of curve 56). This tube begins to conduct. The condenser 9 can, therefore, discharge, and the cycle of operations repeats.

It will appear upon study of the foregoing analysis that one really significant action of the inductor 2 is to bring to pass that, during a short time, condensers 9 and 8 are both discharging, (compare 89 of curve 52 with 95 of curve 55). This changes the control from the fast condenser to the slow condenser, and the high-frequency pulses will not appear until the slow condenser has discharged.

There are many peculiarities of the electromotive force across the inductor 2 shown by curve 57 beside the one just mentioned, but this one alone produces a significant result. For this reason, the other peculiarities are not described in detail. The several sharp peaks correspond to moments when the total of the current in the tubes 5 and 6 is increasing. The portions of curve 57 which fall below the zero line correspond to times when this total is decreasing.

Tubes continue to be conductive after their grid potential has become negative. It is not until the grid has become several volts negative that the current is cut off entirely. This is the explanation of the fact that curve 51 slopes

downward at 74 at the same time that the curve 54 slopes downward at 76 and this accounts for the negative portion of curve 57 vertically in alignment with 74 and 76.

The portion of curve 57 immediately to the left of the point 86 is explained in the same way but, by considering the points on curves 57 and 54 vertically in alignment with 86, it will be seen that the portion of curve 51 between 84 and 90 slopes downward, while the portion of curve 54 at 91 is horizontal. The decrease in total current is, therefore, very small, and the portion of curve 57 to the right of 86 will rise rapidly towards the zero line.

The time constants of the two condensers are so adjusted that the ratio between them is, as nearly as possible, an integer. If this adjustment is inexact, the condenser 8 may complete the last step in its charging action somewhat too soon, but the inductance 2 will produce the effect described. Consequently, the presence of the inductor makes the adjustment of the resistors and condensers non-critical.

The transformer 13 may be so designed that its leakage inductance combines with the distributed capacity of the secondary to constitute the equivalent of a parallel-resonant circuit in the common conductor between the grid leads and the filaments. When such parallel-resonant circuit or its equivalent is present, the adjustments in the multivibrator are much less critical, even though the inductance 2 be made much smaller than otherwise.

The control electromotive force introduced through transformer 13, by impressing an extra electromotive force upon the condenser 9 and thereby causing it to charge above the potential impressed by the battery, can produce the same result as the inductor 2, but, under these circumstances, the adjustment must be much more carefully made to ensure the correct functioning of the apparatus. If both the transformer 13 and the inductor 2 be omitted, it is not possible, even with the most careful adjustment, to obtain the regular and periodic intermissions of the high frequency which can be obtained with my invention.

In one specific embodiment of my invention, the tubes used for tubes 5 and 6 are those known by the market name UX-210, in which the internal impedance from plate to filament when the grid is at zero potential is some 4500 ohms, and the minimum impedance when the grid is strongly positive is some 250 ohms. In these tubes, when the grid is positive relative to the filament, the impedance of the grid-filament space is some 840 ohms and, when the grid is zero, it is some 6500 ohms.

In the particular embodiment of my invention just mentioned, the inductor 2 has an inductance of five henries, the resistors 3 and 4 are each approximately 11,000 ohms, the condenser 9 is .015 microfarads and the condenser 8 is .3 microfarads. The resistors 11 and 12 were each made of a fixed resistance of 50,000 ohms combined with an adjustable resistance of 10,000 ohms. The battery 1 was 250 volts, the battery 7 was 7½ volts and the transformer 13 was a step-down transformer from 110 volts to 8 volts, the secondary of which was of very low inductance having only a few turns.

I have given these dimensions because I am, at present, unable to state a complete theory of the operation, but I have not intended them as a limitation. Many variations in the structure of

the device will occur to those skilled in the art, and no limitation is intended except such as may be required by the prior art and indicated by the accompanying claims.

5 I claim as my invention:

1. A multivibrator comprising a plurality of electronic devices having output circuits and control electrodes, control circuits having resistance and embodying said control electrodes, condensers of unequal capacities coupling said output circuits with said control circuits whereby said control circuits including their respective condensers have substantially unequal time characteristics, and an inductor in said multivibrator for stabilizing the operation of said condensers.

2. A multivibrator comprising a plurality of electronic devices having output circuits and control electrodes, control circuits having resistance and embodying said control electrodes, condensers of unequal capacities coupling said output circuits with said control circuits whereby said control circuits including their respective condensers have substantially unequal time characteristics, and an inductor in said multivibrator located symmetrically with respect to the circuits embodying said electronic devices.

3. In combination, a pair of vacuum tubes, each having input circuits and output circuits having resistance therein, the output circuit of each tube being coupled by a capacitor to the input circuit of the other, the time-constant of

one of said circuits including its coupling capacitor being an integral multiple of the time-constant of the analogous circuit including the other coupling capacitor, and means for stabilizing the time constants of said circuits.

4. In combination a pair of vacuum tubes, each having input circuits and output circuits having resistance therein, the output circuit of each being coupled by a capacitor to the input circuit of the other, the time-constant of an input circuit including its coupling capacitor being an integral multiple of the time-constant of the other input circuit including the other coupling capacitor and an inductor common to the output circuits of both tubes for stabilizing the time constants of said circuits.

5. In a multivibrator comprising a pair of electron discharge devices each having an input and output circuit having resistance therein, a plurality of coupling condensers, one of said condensers coupling the output circuit of one tube with the input circuit of the other tube, the other of said condensers coupling the remaining output circuit with the remaining input circuit, a resistance connected in circuit with at least one of said condensers, the time constant of the circuit including one condenser being materially greater than the time constant of the circuit including the other condenser.

RALPH N. HARMON.

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70	145
75	150