MULTIVIBRATOR WITH CATHODE STABILIZED BY A CAPACITOR

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This invention relates to stabilized multivibrators, and particularly to monostable and astable multivibrators wherein a cathode is stabilized by means of a capacitor connected thereto.

An astable multivibrator comprises a pair of inter-coupled electron discharge device electrode structures so arranged as to generate a substantially square output wave having a predetermined duration following the application to the multivibrator of a trigger pulse. The duration of the output square wave is determined by a timing circuit which usually consists of a timing capacitor and a timing resistor in the circuit coupling the plate of the first multivibrator electrode structure to the grid of the second multivibrator electrode structure. These electrode structures may be located within the same or separate evacuated envelopes to form one or two vacuum tubes. The first tube is normally cut-off and the second tube is normally conducting. The trigger pulse reverses the conditions of conduction as a result of which the second tube remains conducting for a period of time determined by the time constant of the timing circuit. An astable multivibrator includes two timing circuits, one between an output electrode of the first tube and an input electrode of the second tube, and another timing circuit between an output electrode of the second tube and an input electrode of the first tube. An astable multivibrator shifts back and forth between its two conductive states at times determined by the time constants of its two timing circuits. An astable multivibrator is free running but it may be synchronized by the application of a synchronizing pulse wave thereto.

In my copending application Ser. No. 343,623, filed March 20, 1953, now Patent No. 2,857,512, issued October 21, 1958 on a Monostable Multivibrator, there is described and claimed a cathode-stabilized multivibrator including a diode connected from a cathode of one of the tubes to a point of reference potential. The circuit of the copending application provides an output wave, the characteristics of which are unaffected by changes in the tubes, by variations in the values of most of the circuit components, and by changes in the power supply voltages. The multivibrator of the copending application is a monostable multivibrator responsive to trigger pulses, and the multivibrator operates in the desired stable manner regardless of the spacing of successive trigger pulses. According to this present invention, the need for a diode is eliminated and a capacitor is used to provide stabilized operation when the monostable multivibrator is receptive to a periodic trigger pulse wave. In the case of an astable multivibrator, the cathode of one of the tubes is stabilized by means of a capacitor for operation at a repetition rate determined by the timing circuits on the multivibrator. It is therefore a general object of this invention to provide an improved stabilized periodically operated multivibrator which is simpler and more reliable than those previously known.

It is another object to provide an improved multivibrator which is relatively unaffected by changes in the
a more positive (actually less negative) voltage on plate 29. Since plate 29 is directly connected to grid 22 of tube V1, tube V1 is rendered conductive and the potential on the plate 12 of tube V1 drops. The drop in potential is coupled thru capacitor 24 to grid 25 of tube V2 and V2 is brought to cut-off following the application of the negative trigger pulse for a period of time determined by the time constant of the RC timing circuit including resistor 27 and capacitor 24. The potential on grid 25 of tube V2 rises exponentially toward ground potential as capacitor 24 charges up due to current flowing from B+ thru resistor 14, capacitor 24 and resistor 27. When the potential on grid 25 reaches the cut-off potential, tube V2 starts conducting. The resulting potential drop on the plate 29 of tube V2 is connected to the grid 22 of tube V1 causing tube V1 to be cut-off, in turn causing tube V2 to conduct more heavily, all in a rapid regenerative manner. The foregoing cycle of operation is then repeated upon application to terminal 10 of the next following negative trigger pulse.

The voltage waveforms at various identified points in the circuit are shown in Fig. 2. It will be noted that the voltage on the plate of tube V1 is at B+ potential when the tube is cut-off and the potential drops to about 158 volts when the tube is conductive. The cathode of tube V1 is maintained at about 2 volts above ground at all times by the action of the storage capacitor 28. The plate of tube V2 is returned to ground thru resistor 23 and therefore the plate of tube V2 is at ground potential when tube V2 is cut-off and is at a lower potential when tube V2 is conductive. The grid of tube V1 is directly connected to the plate of tube V2, so that the voltage waveforms thereon are the same. When tube V2 is conducting, the potential on the grid of tube V2 is practically the same as the potential on the cathode, which potential is −70 volts from source terminal 17. The negative pulse applied from the plate of tube V1 to the grid of tube V2 drives down the voltage on the grid of tube V2. The voltage rises exponentially toward ground potential as timing capacitor 24 charges up by current flow in the circuit including timing resistor 27.

The multivibrator circuit of Fig. 1 differs from prior art multivibrator circuits in the use of the storage capacitor 28 and the cathode resistor 16, and in the manner of cross-coupling the multivibrator tubes V1 and V2. Following the input trigger pulse, the multivibrator provides an output pulse having a width which does not vary from the predetermined value as the tubes age, when a new tube is substituted in the circuit, or when the power supply voltages vary. The reason why the construction provides the highly stabilized operation are set forth below.

As is set forth on page 190 of vol. 19, “Wavesforms” of the M.I.T. Radiation Laboratory Series, the duration of the output square wave of a monostable multivibrator is in accordance with the formula:

\[ T = \text{proportional to} \frac{1}{E_{c}} \left( \frac{E_{b} - E_{c}}{E_{c} - E_{a}} \right) \]

where \( E_{a} \) is the initial voltage from which the timing waveform begins, \( E_{c} \) is the ultimate voltage which the timing waveform would reach if it were permitted to do so, and \( E_{b} \) is the critical voltage or cut-off voltage of tube V2 at which the transition occurs to terminate the output square wave. In the circuit of Fig. 1, \( E_{b} \) is fixed at zero volts for ground potential by reason of timing resistor 27 being returned to ground. The above formula may therefore be simplified as follows:

\[ T = \text{proportional to} \frac{1}{E_{c}} \left( E_{b} - E_{c} \right) \]

If \( E_{a} \) and \( E_{c} \) are maintained at constant values despite changes in the conductivity of the tubes with age and despite differences between tubes which may be sub-

stituted in the circuit, then the duration of the output square wave will remain constant. This ideal is approached in the circuit of this invention because \( E_{c} \) is equal to approximately \( 2E_{c} \) plus the voltage difference between cathode 15 and grid 22 of tube V1 when the tube is cut-off. This voltage difference is small compared with \( 2E_{c} \) that even large changes in the voltage difference have a negligible effect on the voltage \( E_{c} \). This advantageous condition results from the construction wherein a cathode resistor 16 is connected in series with each cathode. Therefore, the negative terminal 17 of the source of voltage \( E_{c} \). Resistor 16 is effective when tube V1 is conducting. Storage capacitor 20 is charged to +2 volts when tube V1 is conducting, and the time constant of the circuit including capacitor 20 and resistor 16 is long compared with the period between trigger pulses. Storage capacitor 20 maintains cathode 15 at a constant potential of about 2 volts above ground and prevents the cathode of tube V1 from going negative when tube V1 is cut-off. Therefore, only a moderate voltage drop developed across resistor 23 by the action of tube V2 is needed to cut tube V1 off.

The value of \( E_{c} \) in the circuit of Fig. 1 is equal to \( 2E_{c} \) plus the voltage difference between the cathode 15 and grid 25 of tube V2 when the tube just begins conducting. This voltage difference is small compared with \( E_{c} \) and it usually varies only plus or minus one volt in different tubes of the same type. Therefore, tube changes have a negligible effect on the value of \( E_{c} \). Furthermore, small changes in the voltage \( E_{c} \) will cause changes in the time at which tube V2 shifts from the non-conductive condition to the conductive condition. The effect of these changes are minimized by making the timing waveform steep where it intersects the cut-off voltage \( E_{c} \) so that the changes have very little effect on the time at which the transition takes place. This is done by making \( E_{c} \) a large percentage of \( E_{b} \). In Fig. 1, \( E_{c} \) is about 50% of \( E_{b} \) when plate resistor 14 equals cathode resistor 16. The effects of tube changes on \( E_{c} \) and \( E_{c} \) and consequently on the duration of the output square wave can be further minimized by the use of tubes V1 and V2 which have a high amplification factor.

Changes in the negative bias voltage \( E_{b} \) from the terminal 17 of the source have very little effect on the duration of the output square wave because the changes in \( E_{b} \) change both \( E_{a} \) and \( E_{c} \) in such a manner that the ratio \( E_{a}/E_{b} \) in the formula above remains practically constant. Changes in the B+ voltage have no effect on tube V2. Changes in the B+ voltage have a small percentage of the total voltage of the B+ voltage plus the \( E_{c} \) applied across the circuit of tube V1. The effect of cathode resistor 16 is to stabilize the current which flows thru tube V1 thereby maintaining at a relatively constant value the voltage change produced on the plate 12 when the tube goes from the cut off to the conducting condition.

The circuit of Fig. 1 imposes no limitations of any consequence on the sizes of plate resistor 14 and plate resistor 23. Therefore, these resistors may be made as small as is necessary to provide the desired speed of operation in the transitions between the two conditions of the circuit.

Fig. 1 of the drawing includes the values of circuit components given by way of example to illustrate a circuit operating in the described manner with a trigger pulse wave having 900 pulses per second. The negative going output pulses had a duration of 950 microseconds, leaving a period of 160 microseconds between output pulses.

Fig. 3 shows a modified circuit differing from that shown in Fig. 1 in that a source of negative potential is not required. Corresponding circuit elements in Fig. 3 are given the same numeral they bear in Fig. 1. It will
be noted that in Fig. 3, the cathode 28 of tube V2 is connected directly to ground, and the cathode resistor 32 of tube V4 also is connected to ground. The potential on the plate 29 of tube V2 and the grid 22 of tube V1 is referenced to an intermediate voltage (about 70 volts) between the B+ voltage and the voltage on the cathode 28 of tube V2. This intermediate voltage reference is established by the voltage divider action of plate resistor 33 and the resistor 23 connected in series between B+ and ground.

The multivibrator circuit of Fig. 3 operates in the highly stabilized manner exactly the same as that described in connection with Fig. 1. The circuit of Fig. 3 is even more stable in the face of variations in the B- and ground-supply voltage. This is because all voltage levels are proportional to the one B+ voltage and changes tend to cancel out. The circuit of Fig. 3 has one practical disadvantage compared with the circuit of Fig. 1 in that the storage capacitor 20 in Fig. 3 normally carries a charge equal to 70 volts, whereas the storage capacitor 20 in Fig. 1 carries a voltage charge of only 2 volts. Therefore, the capacitor 29 in Fig. 3 must be capable of carrying a larger voltage charge.

Fig. 4 shows the voltage waveforms on identified electrodes with respect to the circuit of Fig. 3. It will be noted that the waveforms of Fig. 4 are similar to those shown in Fig. 2, the difference being due to the use in the circuit of Fig. 3 of a single high voltage power source. Fig. 5 shows an astable or free running multivibrator circuit which is the same as the circuit shown in Fig. 1 except that the grid resistor 23 in Fig. 1 is replaced by an inductor 35 and a capacitor 36 connected in shunt to constitute a ringing circuit. A damping diode 37 is also connected in shunt with inductor 35 and capacitor 36 to cut-off the positive half cycles of oscillations in the ringing circuit. Diode 37 is represented by a symbol including an arrow pointing in the direction which current can flow (as contrasted with the direction in which electrons can flow). At the end of the timing cycle determined by capacitor 24 and resistor 27, tube V2 is again rendered conductive, and a surge of plate current passes from ground thru the ringing circuit and thru tube V2 to the source of —70 volts. This surge of plate current starts an oscillation in the ringing circuit having a period determined by the values of inductor 35 and capacitor 36. The initial half-cycle of the resulting oscillation is a negative going wave as shown in Fig. 6. The following positive going half-cycle of the oscillation is prevented by conduction thru the damping diode 37. Therefore, after a negative half-cycle of oscillation in the ringing circuit, the potential on the grid 22 of tube V1 is such that the plate 29 of tube V2 returns to ground potential. During this negative half-cycle, tube V1 is cut-off and tube V2 is conductive. Capacitor 20 maintains the cathode 15 of tube V1 at a constant potential of about 2 volts above ground. At the end of the half-cycle of oscillation in the ringing circuit, the grid 22 of tube V1 returns to ground potential and tube V1 starts to conduct. In the meantime, when tube V1 was cut-off, timing capacitor 24 was recharged so that after tube V1 becomes conductive, a new timing cycle is initiated. It is thus apparent that the ringing circuit 35, 36 determines the period of time that tube V1 is cut-off and the timing circuit 24, 27 determines the time during which tube V2 is cut-off. A trigger pulse wave could be applied thru capacitor 24 to the grid 25 of tube V2 to synchronize the operation of the free running multivibrator with the trigger pulse wave.

Fig. 5 includes the values of circuit components which were found to provide the desired stabilized operation with a period of 31.75 micro-seconds and with positive pulses on the plate of tube V1 having a duration of 2.5 micro-seconds. For the values of circuit elements shown, it was found that tubes could age to the point where they provided only one-half their normal emission of electrons and yet the frequency varied only plus or minus 2% from the value for which the circuit was designed.

All of the circuits shown in Figs. 1, 3 and 5 are relatively unaffected in their operation by changes in supply voltage, changes in the vacuum tubes and changes in or manufacturing tolerances of most of the circuit elements. The stabilized operation results from the use of a relatively large degenerative cathode resistor 16 in the circuit of tube V1, the use of storage capacitor 20 connected to the cathode 15 of tube V1 to maintain the potential thereon substantially constant, and the manner of coupling the plate of tube V2 to the grid of tube V1 so that a moderate voltage transition on the plate of tube V2 causes tube V2 to render tube V1 cut-off.

What is claimed is:

1. A stabilized multivibrator comprising first and second electron current devices each having an emitting electrode, a control electrode, and a collecting electrode, a timing capacitor coupled between said collecting electrode of said first device and said control electrode of said second device, a direct connection between said collecting electrode of said second device and said control electrode of said first device, a point of reference potential, means for applying a unidirectional potential that is positive with respect to said point of reference potential to said collecting electrode of said first device, means for applying a synchronizing pulse wave to said multivibrator to control the frequency of operation thereof, a first resistor connected at one end to said emitting electrode of said first device, means for applying a unidirectional potential that is negative with respect to said point of reference potential to the other end of said first resistor and to said emitting electrode of said second device, a second resistor connected between said control electrode of said first device and said point of reference potential, and a storage capacitor coupled between said emitting electrode of said first device and said point of reference potential, the time constant of said storage capacitor and said first resistor being at least fifteen times the period of said synchronizing pulse wave.

2. A stabilized multivibrator comprising first and second electron current devices each having an emitting electrode, a control electrode, and a collecting electrode, a timing capacitor coupled between said collecting electrode of said first device and said control electrode of said second device, a direct connection between said collecting electrode of said second device and said control electrode of said first device, a first resistor connected at one end to said emitting electrode of said first device, means for applying a unidirectional potential that is positive with respect to said point of reference potential solely to the other end of said first resistor, means for applying a synchronizing pulse wave to said multivibrator to control the frequency of operation thereof, a second resistor connected at one end to said emitting electrode of said first device, means for applying a unidirectional potential that is positive with respect to said point of reference potential solely to the other end of said second resistor and to said emitting electrode of said second device, an impedance element coupled between said control electrode of said first device and said point of reference potential, the time constant of said storage capacitor and said second resistor being at least fifteen times the period of said synchronizing pulse wave.

3. A stabilized multivibrator comprising first and second electron current devices each having an emitting electrode, a control electrode, and a collecting electrode, a timing capacitor coupled between said collecting electrode of said first device and said control electrode of said second device, a direct connection between said collecting electrode of said second device and said control electrode of said first device, a first resistor connected at one end to said emitting electrode of said first device, means for applying a unidirectional potential that is positive with respect to said point of reference potential solely to the other end of said first resistor, means for applying a synchronizing pulse wave to said multivibrator to control the frequency of operation thereof, a second resistor connected at one end to said emitting electrode of said first device, means for applying a unidirectional potential that is positive with respect to said point of reference potential solely to the other end of said second resistor and to said emitting electrode of said second device, an impedance element coupled between said control electrode of said first device and said point of reference potential, the time constant of said storage capacitor and said second resistor being at least fifteen times the period of said synchronizing pulse wave.
to said collecting electrode of said first device, a point of reference potential, means for applying a unidirectional potential that is positive with respect to said point of reference potential solely to the other end of said first resistor, means for applying a synchronizing pulse wave to said multivibrator to control the frequency of operation thereof, a second resistor connected at one end to said emitting electrode of said first device and said point of reference potential, a third resistor coupled between said control electrode of said second device, an impedance element coupled between said control electrode of said first device and said point of reference potential, and a storage capacitor coupled between said emitting electrode of said first device and said point of reference potential, the time constant of said storage capacitor and said second resistor being at least fifteen times the period of said synchronizing pulse wave.

4. A multivibrator as defined in claim 3, wherein said impedance element is a resistor.

5. A multivibrator as defined in claim 3, wherein said impedance element comprises a rectifier element, a capacitor, and an inductor connected in parallel with each other.

6. A stabilized multivibrator comprising first and second electron current devices each having at least an emitting electrode, a control electrode, and a collecting electrode, a timing capacitor coupled between said collecting electrode of said first device and said control electrode of said second device, a direct connection between said collecting electrode of said second device and said control electrode of said first device, a first resistor connected at one end to said collecting electrode of said first device, a point of reference potential, means for applying a unidirectional potential that is positive with respect to said point of reference potential solely to the other end of said first resistor, means for applying a synchronizing pulse wave to said multivibrator to control the frequency of operation thereof, a second resistor coupled between said emitting electrode of said first device and said point of reference potential, an impedance element coupled between said control electrode of said first device and said point of reference potential, a direct connection between said emitting electrode of said first device and said point of reference potential, and a storage capacitor coupled between said emitting electrode of said first device and said point of reference potential.

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