SECTION 8

MULTIVIBRATOR CIRCUITS

PART A. ELECTRON-TUBE CIRCUITS

ASTABLE (FREE-RUNNING) MULTIVIBRATORS.

The term **astable multivibrator** refers to one class of multivibrator or relaxation-oscillator circuits that can function in either of two temporarily stable conditions and is capable of rapidly switching from one temporarily stable condition to the other. The astable multivibrator is frequently referred to as a free-running multivibrator. It is basically an oscillator consisting of two stages coupled so that the input signal to each stage is taken from the output of the other. Thus the circuit becomes free-running because of the regenerative feedback, and the frequency of operation is determined primarily by its coupling-circuit constants rather than by an external synchronizing voltage.

The frequency of operation for an astable multivibrator can be as low as one cycle per minute or as high as 100 kilocycles per second, depending on the circuit design.

The output of the astable multivibrator is usually nearly rectangular in form. A symmetrical output results when the R-C time constants of the coupling circuits are made equal. Rectangular pulses of almost any desired width (time duration) can be obtained by proportioning the R-C time constants of the coupling circuits with respect to one another; the resulting pulse output is unsymmetrical since the R-C time constants of the coupling circuits are no longer equal.

The operating frequency of the astable multivibrator can be changed by switching values of R or C, or both R and C, in the coupling circuits to alter the time constants. For example, a multivibrator designed to operate at 800 pps can be changed to a lower frequency, such as 400 pps, by simply switching additional capacitors into the circuit in parallel with the existing coupling capacitors to lower the repetition frequency.

The frequency stability of the multivibrator is somewhat better than that of the typical blocking oscillator. However, a disadvantage of the multivibrator is that its output impedance is essentially equal to the plate-load resistance and this resistance must be relatively high in order to obtain good frequency stability. Also, the negative-going waveform is generated at a much lower impedance than the positive-going waveform. Because a changing load will also affect the frequency stability, the output is sometimes fed to a cathode follower, in order to isolate the load from the multivibrator plate circuit. In some instances the desired output from the multivibrator is a differentiated waveform, and this waveform, in turn, is applied to the cathode follower; in this circuit configuration the load will have the least effect upon the multivibrator frequency stability.

TRIODE PLATE-TO-GRID COUPLED ASTABLE MULTIVIBRATOR.

APPLICATION.

The plate-to-grid coupled astable multivibrator produces a square-wave output for use as trigger or timing pulses.

CHARACTERISTICS.

Free-running oscillator; does not require trigger pulse to produce oscillations.

Operating frequency is determined primarily by the R-C time constants in the feedback (plate-to-grid) coupling circuits and by applied voltage.

Frequency stability of 3 percent can be obtained.

Input trigger pulses may be applied to the circuit for synchronization to produce a stable output; it may be synchronized at the trigger-pulse frequency or integral submultiples thereof.

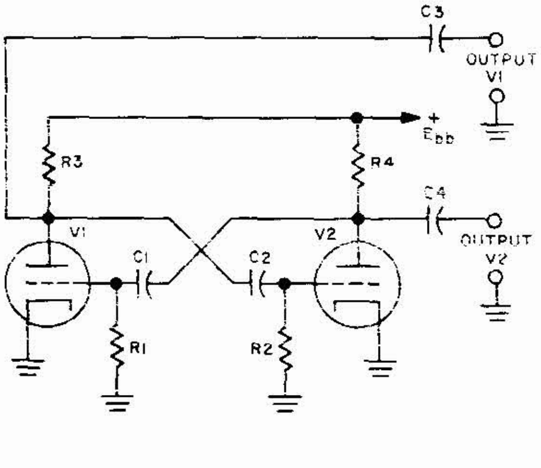
Symmetrical square- or rectangular-wave output is produced when the R-C time constants of the grid circuits are equal. Unsymmetrical output is produced when the R-C time constant of one grid circuit is purposely made several times greater than that of the other; for this condition the two tubes are cut off for unequal periods of time.

Output impedance is essentially equal to plate-load impedance.

CIRCUIT ANALYSIS.

General. The free-running plate-to-grid coupled multivibrator is a basic astable multivibrator. The circuit is fundamentally a two-stage R-C coupled amplifier with the output of the second stage coupled to the input of the first stage. Thus the output signal is fed back in the proper phase to reinforce the input signal; as a result, sustained oscillations occur.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a basic free-running multivibrator circuit. Electron tubes V1 and V2 are identical-type triode tubes; although the accompanying schematic illustrates two separate triodes, a twin-triode is frequently used in this circuit. Capacitor C1



Triode Plate-to-Grid Coupled Astable Multivibrator provides the coupling from the plate of V2 to the grid of V1; capacitor C2 provides the coupling from the plate of V1 to the grid of V2. Resistors R1 and R2 are the grid resistors for V1 and V2, respectively; resistors R3 and R4 are the plate-load resistors for V1 and V2, respectively.

Capacitor C1 and resistor R1 form an R-C circuit to determine the discharge time constant in the grid circuit of V1; capacitor C2 and resistor R2 determine the discharge time constant in the grid circuit of V2.. Output pulses can be taken from the plate of either or both electron tubes. Capacitors C3 and C4 are the output coupling capacitors for V1 and V2, respectively.

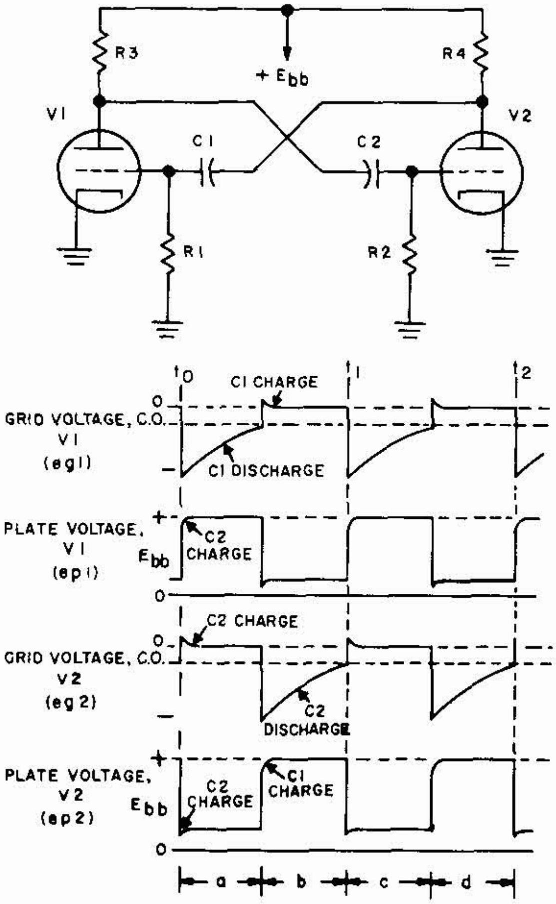
When voltage is first applied to the circuit, the grids of both tubes are at zero bias and plate current starts to flow through plate-load resistors R3 and R4. Also, capacitors C1 and C2 begin to charge when the applied voltage appears at the plate of each tube. If the constants of both stages of the circuit are alike, the currents through both tubes may at first be nearly equal. In practice, the symmetrical free-running multivibrator component values are held to close tolerances in order to obtain good frequency stability; the value of coupling capacitors C1 and C2 are at least 2 percent tolerance, grid resistors R1 and R2 are 1 percent tolerance, and plate-load resistors R3 and R4 are usually 5 percent tolerance. However, in spite of the close tolerances of the components, there will always be some slight difference in the two currents. This small difference in tube currents will cause a further unbalance, resulting in a regenerative action which rapidly switches the circuit to a condition wherein one tube is conducting maximum current and the other is cut off.

For example, if initially the current through tube V1 should be slightly greater than that through V2, the voltage drop across plate-load resistor R3 will be greater than the drop across resistor R4. This results in a lower plate voltage for V1. This decrease in plate voltage is coupled through coupling capacitor C2 to the grid of V2 as a negative-going instantaneous grid voltage which reduces the plate current of V2. When the current through V2 is decreased, the current through plate-load resistor R4 is also decreased; therefore, the voltage drop across resistor R4 decreases, resulting in a rise in the plate voltage of V2. This increase in plate voltage is coupled through coupling capacitor C1 to the grid of V1 as a positive-going instantaneous grid voltage which increases the plate current of V1. The drop across plate-load resistor R3 increases, the plate voltage of V1 decreases, and as before, the decrease in the plate voltage of V1 is coupled to the grid of V2 as a negative-going voltage. The regenerative switching action just described continues rapidly until V2 is cut off and V1 is at maximum conduction.

In order to cut off plate current in V2, the grid of V2 must be driven negative beyond the cutoff voltage. The negative grid voltage results from a charge on coupling capacitor C2. Since this charge leaks off through grid resistor R2, the grid voltage at V2 does not remain in a negative condition but starts to return to zero as C2 discharges through R2 and the cathode-to-plate conduction resistance of V1.. When C2 discharges sufficiently and the grid voltage cutoff point is reached, plate current once again starts to flow through V2, initiating another switching action similar to the first action described. However, this time as V2 conducts, coupling capacitor C1 discharges through grid resistor R1 to cut off the plate current in V1, and the switching action ends with V1 cut off and V2 at maximum conduction. Here again, the negative charge existing on coupling capacitor C1 must discharge through grid resistor R1 and tube V2 before the grid voltage cut off point is reached and V1 can conduct to initiate another switching action. The switching action repeats continuously with first one tube and then the other tube conducting.

For the following discussion of circuit operation, refer to the accompanying illustration which shows a simplified schematic and waveforms for a symmetrical free-running multivibrator.

At time t_o (start of time interval **a**) on the waveform illustration, the grid of V1 (e_{g1}) has been driven negative to



Theoretical Waveforms for a Symmetrical Free-Running Multivibrator

cut off the tube, and, as a result, the plate voltage of V1 (e_{p1}) has risen rapidly to approach the supply-voltage value (E_{bb}). Coupling capacitor C2 is quickly charged through the low cathode-to-grid internal resistance of V2 and the plate-load resistor, R3. The voltage waveform at the plate of V1 (e_{p1}) is rounded off, and the waveform at the grid of V2 (e_{g2}) has a small positive spike of the same time duration as a result of the charging of coupling capacitor C2. Since at this time the grid of V2 is slightly positive, V2 conducts heavily and the plate voltage of V2 (e_{p2}) drops to a minimum. Note that the plate voltage waveform (e_{p2}) exhibits a small negative spike of the same time duration as the positive spike on the grid waveform (e_{g2}).

While coupling capacitor C2 is being charged, coupling capacitor C1 (previously charged) discharges through grid resistor R1 and through the conduction resistance of V2. Capacitor C1 cannot change its charge immediately; therefore, it produces a negative voltage (e_{g1}) across grid resistor R1, which decays at an exponential rate (toward zero) as capacitor C1 discharges. The rate of discharge is determined primarily by the R-C time constant of R1 and C1. Although the conduction resistance of V2 is included in the discharge path of C1, the resistance is small as compared with the resistance of R1, and can therefore be neglected.

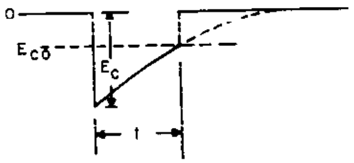
When the negative voltage (e_{g1}) produced across grid resistor R1 decreases near the end of time interval **a** and reaches cutoff, V1 immediately conducts and the plate voltage of V1 (e_{p1}) drops to a minimum; the circuit now switches to the other condition with V2 cut off by the discharge of capacitor C2 through grid resistor R2. This condition is shown on the waveform illustration as the start of time interval **b**. Coupling capacitor C2 discharges through grid resistor R2 and through the conduction resistance of V1. The rate of discharge is determined primarily by the R-C time constant of R2 and C2. (The conduction resistance of V1 is small and can be neglected.)

When the negative voltage (e_{g2}) produced across grid resistor R2 decreases near the end of time interval **b** and reaches cutoff, V2 immediately conducts and the plate voltage of V2 (e_{p2}) drops to a minimum; the circuit now switches to the other condition with V1 cut off by the discharge of capacitor C1 through grid resistor R1. This condition is shown on the waveform illustration as the termination of interval **b** at time t_1.

In the discussion of circuit operation given above, the multivibrator was assumed to be a symmetrical (or balanced) multivibrator; that is, coupling capacitors C1 and C2 are equal, resistors R1 and R2 are equal, and plate-load resistors R3 and R4 are also equal. Therefore, the discharge time constants of R1 and C1 and of R2 and C2 are equal. Also, the time intervals (**a**, **b**, **c**, and **d**) between the switching actions are equal to one another. To obtain a pulse output which is unsymmetrical (asymmetrical or unbalanced), it is necessary to proportion the time constants in the coupling circuits so that one tube remains cut off for only a short period of time while the other is cut off for a much longer period. For example, if the time constant of R1 and C1 is made short compared to the time constant of R2 and C2, then V1 will be cut off for a short period of time while V2 will be cut off for a longer period. Thus, the time intervals **a** and **c**, shown on the waveform illustration will be short while time intervals **b** and **d** will be long.

The time interval for either output pulse may be approximated if the voltage change across the coupling capacitor, the R-C time constant of the discharge path, and the cutoff voltage of the tube are known. The approximate time interval, t, for the capacitor to discharge to cutoff may be determined by use of the following formula:

$$t \cong 2.30\,RC\,\log\frac{E_c}{E_{co}}$$



where:
t = time interval to discharge to cutoff (seconds)
E_c = maximum voltage change across capacitor
E_{co} = negative cutoff value for tube
R = resistance of grid resistor (megohms)
C = capacitance of coupling capacitor (μf)

If the grid resistor, R, is returned to a positive voltage source, such as the plate-supply voltage (E_{bb}), the formula becomes:

$$t \cong 2.30\,RC\,\log\frac{E_{bb}+E_c}{E_{bb}+E_{co}}$$

where: E_{bb} = plate-supply voltage

The natural operating frequency (cycles) of the oscillator, f_o, may be calculated from the following formula:

$$f_o = \frac{1}{t_1 + t_2}$$

where:
t_1 = time interval to discharge to cutoff for V1 grid circuit.
t_2 = time interval to discharge to cutoff for V2 grid circuit.

The free-running multivibrator may be synchronized with a stable external source to force the period of multivibrator action to be exactly the same as the synchronizing source. In this case the multivibrator is called a **driven** multivibrator. Synchronizing signals, when used, are applied to the grid of one multivibrator tube if the impedance of the synchronizing source is high, or to the cathode if the impedance of the source is low. In either case, the frequency of the synchronizing signal must be slightly higher than the natural operating frequency of the multivibrator so that the synchronizing pulse occurs just prior to the time that normal switching action would occur.

The output of the multivibrator is taken from either or both plate circuits through an output-coupling capacitor

(C3 or C4). In cases where it is desired to minimize the effect of a varying load impedance on the multivibrator frequency stability, a cathode follower is used for isolation.

FAILURE ANALYSIS.

No Output. Assuming that the multivibrator is a free-running type and no synchronizing signal is applied, the applied plate and filament voltages should be measured to determine whether they are within specified values. If either coupling capacitor C1 and C2 should become leaky or shorted, a positive potential will be present on the grid of the associated tube and, as a result, the tube will conduct heavily; the other tube will also conduct heavily, since it will be at zero bias. A similar condition could exist if either coupling capacitor C1 or C2 should open; in this case the feedback necessary to sustain oscillations cannot occur and both tubes will conduct heavily because the grids are at zero bias. If the circuit is in a nonoscillating condition, the voltage at each plate should be measured to determine whether plate-load resistor R3 or R4 is open. If either is open, there will be no plate voltage present on the associated plate; also, the other tube will conduct heavily because of zero bias, and its plate voltage will be low. If either output coupling capacitor (C3 or C4) should become leaky or shorted, the input resistor of the following stage can form a voltage divider which also includes the associated plate-load resistor (R3 or R4). If the input resistor of the following stage is returned to ground or to a negative potential, voltage-divider action may reduce the voltage available at the plate of the multivibrator to the point where oscillations will cease; also, the additional current through the plate-load resistor (R3 or R4) may cause the resistor to burn out.

Incorrect Frequency or Pulse Width. The critical components governing the frequency and pulse width of the multivibrator are those in the coupling circuits. Any change in components governing the R-C discharge time constant will directly affect frequency and pulse width; a change in capacitor C1 or C2 or resistor R1 or R2 will have the greatest effect. A change in the value of plate-load resistor R3 or R4 will affect the amplitude of the output, and it will also have an effect upon the frequency, but not nearly as much as the components mentioned above.

A drift in frequency of the free-running multivibrator will generally occur if the applied plate voltage should change approximately 10 percent from the specified value; also, some frequency drift may occur if the filament voltage should drop below the specified value.

In a practical circuit, where the multivibrator is free-running and is not synchronized from an external source, means may be provided to adjust the applied plate voltage or to adjust the value of resistance in each grid circuit. This provision enables the circuit to be adjusted to the correct frequency and pulse width, and compensates for differences in individual tube characteristics when a tube substitution has been made.

If either output coupling capacitor (C3 or C4) should become leaky or shorted, the voltage-divider action which can occur may reduce the amplitude of the output waveform and cause the multivibrator to operate at a higher frequency, since the grid capacitor (C1 or C2) discharge time is dependent upon the amount of change in capacitor voltage. The operation of the following stage may also be affected by the change in grid-bias voltage resulting from the voltage-divider action.

PENTODE ELECTRON-COUPLED ASTABLE MULTIVIBRATOR.

APPLICATION.

The pentode electron-coupled astable multivibrator produces a square-wave output for use as trigger or timing pulses.

CHARACTERISTICS.

Free-running oscillator; does not require trigger pulse to produce oscillations.

Operating frequency is determined primarily by the R-C time constants in the feedback (screen-to-grid) coupling circuits and by the applied screen voltage.

Frequency stability of 3 percent can be obtained. Input trigger pulses may be applied to the circuit for synchronization to produce a stable output; the circuit may be synchronized at the trigger-pulse frequency or integral submultiples thereof.

Symmetrical square- or rectangular-wave output is produced when the R-C time constants of the grid circuits are equal. Unsymmetrical output is produced when the R-C time constant of one grid circuit is purposely made several times greater than that of the other; for this condition the two tubes are cut off for unequal periods of time.

Output is obtained from either plate circuit (or both). Changes in load have minimum effect upon multivibrator frequency because load is isolated from pentode screen (multivibrator plate) circuit by electron-stream coupling and suppressor-grid action of tube.

CIRCUIT ANALYSIS.

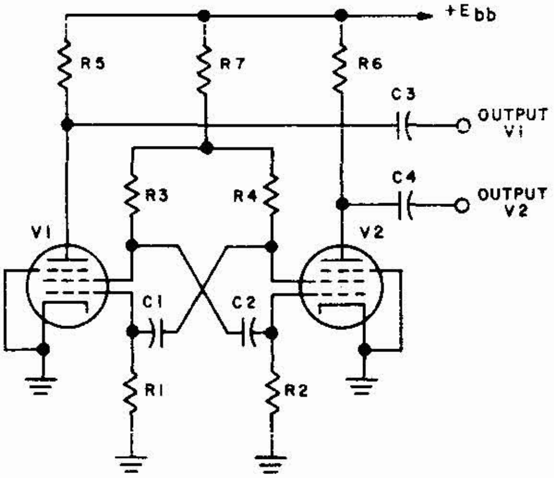
General. The pentode electron-coupled multivibrator is basically a free-running (triode) plate-to-grid-coupled multivibrator using the screen grids of sharp cutoff, pentode-type tubes as plates for the multivibrator switching function. The circuit is fundamentally a two-stage R-C amplifier with the output (screen grid) of the second stage coupled to the input of the first stage. The screen grid of each tube functions in the oscillator circuit as though it were the plate of a triode. Thus, the output signal from the screen grid is fed back in the proper phase to reinforce the input signal; as a result, sustained oscillations occur. The output, taken from the plate-load resistor, is coupled to the multivibrator oscillatory circuit through the electron stream of the pentode tube.

Circuit Operation. The accompanying circuit schematic illustrates two pentode electron tubes in a basic free-running multivibrator circuit. Electron tubes V1 and V2 are identical sharp cutoff, pentode-type tubes. Capacitor C1 provides the coupling from the screen grid of V2 to the grid of V1; capacitor C2 provides the coupling from the screen grid of V1 to the grid of V2. Resistors R1 and R2 are the grid resistors for V1 and V2, respectively; resistors R3 and R4 are the screen resistors for V1 and V2. Resistors R5 and R6 are the plate-load resistors for V1 and V2, respectively.

Resistor R7 is a series voltage-dropping resistor which is common to both screen -grid circuits.

Capacitor C1 and resistor R1 form an R-C circuit to determine the discharge time constant in the grid circuit of V1; capacitor C2 and resistor R2 determine the discharge time constant in the grid circuit of V2.

Output pulses can be taken from the plate of either or both electron tubes. Capacitors C3 and C4 are the output coupling capacitors for V1 and V2, respectively.



Pentode Electron-Coupled Astable Multivibrator

The switching action of the electron-coupled multivibrator is similar to that of the triode plate-to-grid-coupled multivibrator circuit, previously described in this section.

When voltage is first applied to the circuit, the grids of both tubes are at zero bias and both plate and screen currents start to flow; the plate currents pass through plate-load resistors R5 and R6, and the screen currents pass through resistors R3 and R4 and through the common voltage-dropping resistor, R7. Also, capacitors C1 and C2 begin to charge when the applied voltage appears at the screen of each tube. The currents through both tubes may be equal at first; however, in spite of the close tolerances of the components in the control-grid and screen-grid circuits, there will always be some slight difference in the total currents of the tubes. The difference in screen-grid currents will cause a further unbalance, resulting in a regenerative action which rapidly switches the circuit to a condition wherein one tube is conducting maximum screen and plate currents and the other is cut off.

For example, if initially the total plate and screen current through tube V1 should be slightly greater than that through V2, the voltage drop across screen resistor R3 will be greater than the drop across screen resistor R4. This results in a lower screen voltage for V1. This decrease in screen voltage is applied through coupling capacitor C2 to the grid of V2 as a negative going instantaneous grid voltage which reduces the plate and screen currents of V2. When the screen current of V2 is decreased, the current through screen resistor R4 (and resistor R7) is also decreased; therefore, the voltage drop across resistor R4 decreases, resulting in a rise in the screen voltage of V2. This increase in screen voltage is fed through coupling capacitor C1 to the grid of V1 as a positive-going instantaneous grid voltage which increases the screen current of V1. The voltage drop across screen resistor R3 increases as the screen current increases, the screen voltage of V1 decreases, and, as before, the decrease in the screen voltage of V1 is applied to the grid of V2 as a negative-going voltage. Note that as the screen current of V1 increases the screen current of V2 decreases. Since the screen currents of V1 and V2 flow through dropping resistor R7, the voltage (with respect to ground) at the junction of resistors R3, R4, and R7 remains essentially constant throughout the entire period of oscillation.

The regenerative switching action just described for the screen-grid to control-grid coupling of the pentode multivibrator circuit continues rapidly until V2 is cut off and V1 is at maximum conduction. In order to cut off plate and screen current in V2, the grid of V2 must be driven negative beyond the cutoff voltage. The negative grid voltage results from a charge on coupling capacitor C2. Since this charge leaks off through grid resistor R2, the grid voltage at V2 does not remain in a negative condition but starts to return to zero as C2 discharges through resistor R2 and the conduction resistance (cathode to screen grid) of V1. When capacitor C2 discharges sufficiently and the grid voltage cutoff point is reached, the plate and screen currents once again start to flow through V2, initiating another switching action similar to the first action described. However, this time as V2 conducts, coupling capacitor C1 discharges through grid resistor R1 to cut off the plate and screen currents in V1, and the switching action ends with V1 cut off and V2 at maximum conduction. Here again, the charge existing on coupling capacitor C1 must discharge through grid resistor R1 and tube V2 before the grid voltage cutoff point is reached and V1 can conduct to initiate another switching action.

In a sharp cutoff pentode tube, as long as the plate voltage is greater than the applied screen voltage, the plate current in the tube depends largely upon the screen voltage rather than upon the value of the applied plate voltage. The screen grid is made positive with respect to the cathode and therefore attracts electrons from the cathode; however, most of the electrons attracted by the screen pass on through the screen grid and reach the plate. It is this flow of electrons to the plate that couples the multivibrator action to the plate circuit, from which the output waveform is obtained. The term **electron coupled** refers to this method of coupling within the tube.

The fact that plate current is largely independent of applied plate voltage makes it possible to produce the desired output waveform in the plate circuit since the positive potential existing on the screen will control the number of electrons arriving at the plate. Furthermore, the plate and screen currents are controlled by the action of the control grid; therefore, when the tube is at maximum conduction and plate current flows through the plate-load resistor, the voltage drop across the plate-load resistor is also maximum and the plate voltage of the tube is minimum. When the tube is cut off, the plate voltage is at maximum. Thus, the voltage at the plate of the tube is determined by the coupling of the electron stream to the plate circuit, and this, in turn, is governed by the switching action of the multivibrator oscillatory circuit (control and screen grids). The suppressor grid acts to shield the screen from the plate and prevents changes in loading from affecting the oscillatory circuit; therefore, the frequency of the multivibrator is reasonably independent of changes in output loading.

Like the triode plate-to-grid-coupled multivibrator, described previously in this section, the proportioning of the R-C time constants of the coupling circuits (R1C1 and R2C2) determine whether the output waveform will be symmetrical or unsymmetrical.

The output waveform is taken from either or both plate circuits and coupled to the load through an output-coupling capacitor (C3 or C4).

FAILURE ANALYSIS.

No Output. Assuming that the multivibrator is a free-running type and no synchronizing signal is applied, the plate, screen, and filament voltages should be measured to determine whether they are within specified values. If either coupling capacitor C1 or C2 should become leaky or shorted, a positive potential will be present on the grid of the associated tube, and, as a result, the tube will conduct continuously; the other tube will also conduct, since it will be at zero bias. A similar condition could exist if either coupling capacitor C1 or C2 should open; in this case, the feedback necessary to sustain oscillations cannot occur, and both tubes will conduct continuously because the grids are at zero bias. If this circuit is in a nonoscillating condition, the voltage at each screen grid should be measured to determine whether screen resistor R3 or R4 is open. If either is open, there will be no screen voltage present on the associated screen grid, and the tube will be cut off; also, the other tube will conduct continuously because of zero bias, and its plate and screen voltages will be low. Furthermore, if resistor R7 should open, there will be no voltage at either screen grid, and both tubes will be cut off.

Note that, if a plate load resistor (R5 or R6) should open, the multivibrator oscillatory circuit (control and screen grids) may function normally, but no output waveform will be obtained from the tube associated with the open plate-load resistor.

Incorrect Frequency or Pulse Width. The critical components governing the frequency and pulse width of the multivibrator are those in the coupling circuits. Any change in components governing the R-C discharge time constant will directly affect frequency and pulse width; a change in capacitor C1 or C2 or resistor R1 or R2 will have the greatest effect. A change in the value of screen resistor R3 or R4 or dropping resistor R7 will also have an effect upon the frequency and pulse width, but not nearly as much as the coupling components mentioned above.

In a practical circuit, where the multivibrator is free-running and is not synchronized from an external source, means may be provided to adjust the applied screen voltage or to adjust the value of resistance in each control-grid circuit. This provision enables the circuit to be adjusted to the correct frequency and pulse width and compensates for differences in individual tube characteristics when a tube substitution has been made.

Reduced Output. A reduction in output amplitude is generally caused by a defective tube; however, it can also be caused by a decrease in the applied plate voltage or an increase in the resistance of the associated plate-load resistor (R5 or R6). A similar condition can also result from a change in the value of the applied screen voltage; however, in this case the multivibrator frequency will probably be affected before a noticeable change in output occurs.

If either output coupling capacitor (C3 or C4) should become leaky or shorted, the input resistor of the following stage can form a voltage divider which also includes the associated plate-load resistor (R5 or R6). If the input resistor of the following stage is returned to ground or to a negative potential, voltage-divider action may reduce the voltage available at the plate of the multivibrator and reduce the amplitude of the output waveform; also, the additional current through the plate-load resistor (R5 or R6) may cause the resistor to burn out. Furthermore, the operation of the following stage may also be affected by the change in grid-bias voltage resulting from the voltage-divider action.

TRIODE CATHODE-COUPLED ASTABLE MULTIVIBRATOR.

APPLICATION.

The triode cathode-coupled astable multivibrator produces a square- or rectangular-wave output for use as trigger or timing pulses.

CHARACTERISTICS.

Free-running oscillator; does not require trigger pulse to produce oscillations.

Operating frequency is determined primarily by the R-C time constant in the grid circuit and by the applied voltage.

Frequency stability is rather poor when unsychronized; however, stability is good when synchronized by an external timing pulse.

Circuit may be synchronized at the timing-pulse frequency or integral submultiples thereof.

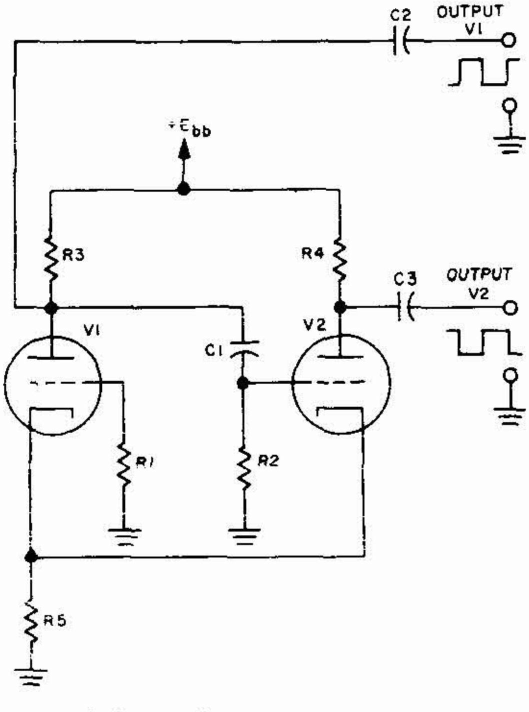
Either a symmetrical square- or rectangular-wave output or an unsymmetrical output may be produced by changing circuit constants or voltages.

Output impedance is essentially equal to plate-load impedance.

CIRCUIT ANALYSIS.

General. The triode cathode-coupled astable multivibrator is functionally similar to the basic Triode Plate-to-Grid-Coupled Astable Multivibrator discussed at the beginning of Section 8 of this Handbook. R-C coupling is provided from the plate of V1 to the grid of V2, as in the basic *plate-to-grid-coupled circuit, but in this instance the* coupling from V2 to V2 is direct, being affected in the cathode circuit through a common cathode resistor; the R-C coupling (in the basic circuit) from the plate of V2 to the grid of V1, is therefore, omitted. A variation of this cathode-coupled circuit uses separate cathode bias resistors, with V2 coupled to V1 through a capacitor rather than directly. Output signals can be taken from the plate of either or both electron tubes, as in the basic plate-to-grid-coupled circuit configuration.

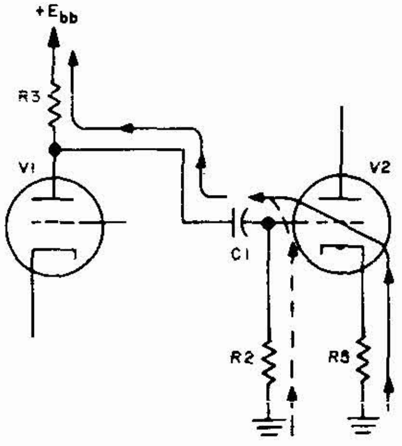
Circuit Operation. The accompanying circuit schematic *illustrates two triode electron tubes in a basic cathode-*coupled astable (free-running) multivibrator circuit employing direct coupling in the cathode circuit. Electron tubes V1 and V2 are identical-type triode tubes; although the schematic illustrates separate triodes, a twin-triode is frequently used in this circuit. Capacitor C1 provides the coupling from the plate of V1 to the grid of V2. Resistors R1 *and R2 are the grid resistors of* V1 and V2, *respectively*; resistors R3 and R4 are the plate-load resistors of V1 and V2, respectively. Resistor R5 is the common cathode-coupling and bias resistor coupling V2 to V1.



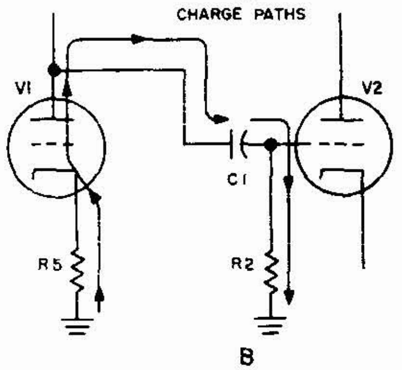
Triode Cathode-Coupled Astable Multivibrator
(Direct Coupling)

Capacitors C2 and C3 are the output coupling capacitors for V1 and V2, respectively.

Capacitor C1 and resistor R2 form and R-C circuit establishing the time constant in the grid circuit of V2. *The initial charge path for capacitor* C1 is from its left side through V1 plate-load resistor R3 and the plate supply voltage to ground, then through cathode resistor R5 and the low (approximately 1K) cathode-to-grid conduction resistance of V2 to the right side of C1, as illustrated by the solid-line path in part A of the following simplified schematic diagram. When the conduction through V2 decreases, and the grid of V2 no longer draws current, the charge path for C1 is completed through grid resistor R2, as illustrated by the dotted-line pathe in the same diagram. For all practical purposes, C1 charge completely during the time that V2 conducts; the amount of charge via R2 is negligible. Part B of the diagram shows the discharge path for capacitor C1 to be through grid resistor R2, *common cathode resistor* R5, *and the low cathode-to-*plate conduction resistance of V1. The time constant of the charge path and the cutoff voltage level of V1 determine the length of time that V1 is cutoff; the time constant of the discharge path and the cutoff voltage level of V2 determine the length of time that V2 is cutoff.



A
CHARGE PATHS



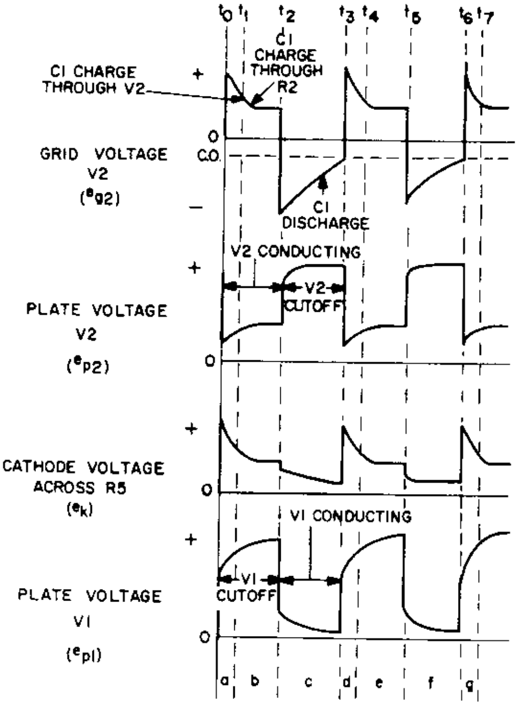
B
DISCHARGE PATH

Charge and Discharge Paths for Capacitor C1

If the time constants for the charge and discharge of C1 are equal, a symmetrical square-wave output is produced *by the circuit; by making the charge and discharge* R-C time constants different, the circuit produces an asymmetrical, or unsymmetrical, rectangular-wave output.

Although the conduction resistance of V1 and the resistance of cathode resistor R5 are in the discharge path, their resistance value is small as compared with that of R2, and are, therefore, neglected in the discharge path time-constant calculations.

For the following discussion or circuit operation, refer to the preceding illustrations in addition to the accompanying illustration which shows the theoretical waveforms for a symmetrical triode cathode-coupled astable multivibrator employing direct coupling between the cathodes. When voltage is first applied, the grids of both tubes are at zero bias and plate current begins to flow through plate-load resistors R3 and R4. When voltage is applied to the plate of V1, capacitor C1 begins to charge along the path previously outlined. As C1 charges, the grid of V2 becomes positive. Since there is no coupling capacitor from the plate of V2 to the grid of V1, the voltage at the plate of V2 has no effect on the conduction of V1. The plate current of V2 flowing through cathode resistor R5 makes the voltage at the top of the resistor positive with respect to ground. This voltage is a bias voltage os sufficient amplitude to cut off conduction of V1 and still permit V2 to conduct, since at this time the grid of V1 is at ground (zero volts) and the grid of V2 is at a positive potential. Thus, the initial conditions of circuit operation are established; that is, V2 is conducting and V1 is cut off.



Theoretical Waveforms for Symmetrical Cathode-Coupled Astable Multivibrator (Direct Coupling)

The foregoing multivibrator action is summarized at time t_0 (start of time interval **a**) on the waveform illustration. Note that the grid of V2 (e_{g2}) is driven positive, causing heavy conduction through this tube. At the same instant, the plate voltage of V2 (e_{p2}) decreases (is negative-going) as a result of plate current through plate-load resistor R4. Also, the same plate current, flowing through common cathode resistor R5, produces a positive voltage (e_k) which provides a bias sufficient to cut off V1 and cause the plate voltage (e_{p1}) of this tube to approach B+. The positive-going voltage at the plate of V1 is instantaneously coupled through capacitor C1 to the grid of V2, driving this grid still further positive. All of the action described is instantaneous and cumulative, so that the high positive potential on the grid of V2 causes this tube to conduct heavily while V1 is cut off.

With V1 cut off, its plate voltage is at B+, and capacitor C1 charges toward this value. The waveform at the plate of V1 (e_{p1}) is rounded off, and the waveform at the grid of V2 (e_{g2}) has a small positive spike of the same time duration as a result of the charging of capacitor C1. Since at this time V2 is conducting, its plate voltage (e_{p2}) drops. Note that the plate-voltage waveform has a small negative spike of the same time duration as the positive spike on the grid waveform.

As capacitor C1 charges, electrons are accumulated on its right side; this accumulation of electrons is a negative charge which acts in opposition to the positive potential on the grid of V2, in effect causing this potential to decrease from its most positive excursion. This is illustrated during time interval **a** (between t_0 and t_1), where the rapid charging of C1 is represented by the steep portion of the V2 grid voltage (e_{g2}) waveform. Note that during the rapid charge time of C1 the positive voltage on the grid of V2 decreases until, at t_1, it is equal to the voltage (e_k) across common cathode resistor R5. At this instant the grid of V2 ceases to draw current. However, C1 continues to charge, but at a slower rate through grid resistor R2, which is much larger in value than the total resistance in the "fast" charge path. This change in the R-C time constants of the charging paths of C1 accounts for the abrupt change in the voltage waveforms at t_1.

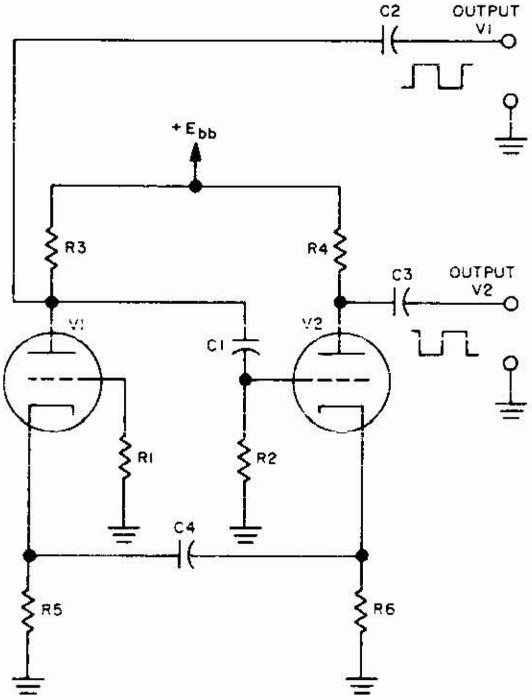
During time interval **b** (from t_1 to t_2), capacitor C1 continues to charge slowly and the grid voltage of V2 decreases slowly; this causes a reduction in the plate current of V2, which results in a decreasing voltage drop across common cathode resistor R5. This action continues until the voltage drop across resistor R5 decreases to the level where tube V1 is no longer held below cutoff. In other words, since the bias on tube V1 is determined by the cathode voltage (e_k), V1 remains cut off so long as the cathode voltage is positive with respect to ground by more than the cutoff voltage (bias) of V1. When the cathode voltage drops to the level of the V1 cutoff voltage, as at t_2 on the cathode voltage (e_k) waveform, V1 conducts and rapidly cuts off V2 because the large negative-going signal at its plate is coupled through capacitor C1 to the grid of V2. Thus, the first switching action occurs; that is, V2 is cutoff and V1 is conducting.

When tube V1 is conducting, capacitor C1 discharges through grid resistor R2, common cathode resistor R5, and the plate resistance of V1. The grid voltage of V2 approaches cutoff as capacitor C1 discharges; this is illustrated by the V2 grid voltage (e_{g_2}) waveform during time interval **c** (between t_2 and t_3). At t_3 the grid voltage of V2 just reaches the cutoff level, permitting this tube to conduct. When the plate current of V2 increases, the voltage across common cathode resistor R5 (waveform e_k) also increases (goes positive); this increases the bias on V1 and thereby reduces the conduction of V1. The decreasing plate current of V1 produces a positive-going signal across its plate-load resistor, R3, which, in turn, is coupled through capacitor C1 to the grid of V2, causing this grid to become highly positive. In addition to increasing the plate current of V2, the positive grid voltage again causes grid current flow and charges capacitor C1. Thus, the second switching action occurs and the cycle is now complete as the initial conditions once again are reached; that is, V2 is conducting and V1 is cutoff.

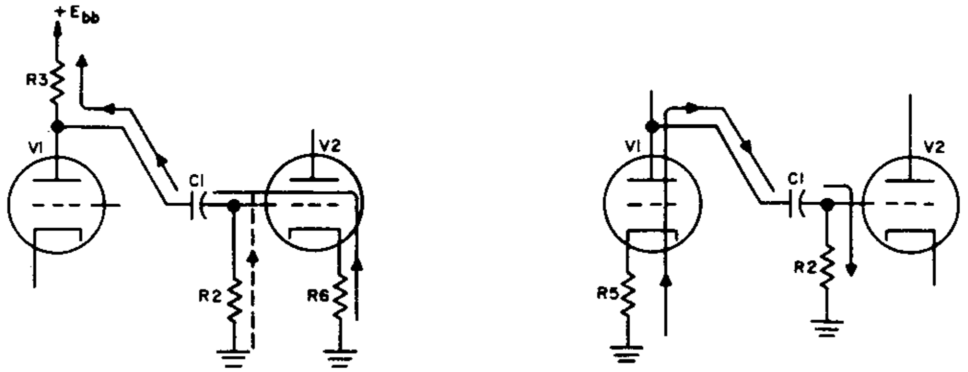
In the preceding discussion the multivibrator was considered to be a symmetrical type; that is, the periods for conduction and cutoff of the tubes are equal. An asymmetrical, or unbalanced, output can be obtained by having V2 cutoff for a longer period than V1. Adjusting the value of the cathode resistance will permit this to happen, since it is the bias voltage developed across the common cathode resistor that determines when V1 begins conduction. In this case, the combined time intervals of **a** and **b** will be less than time interval **c**.

Another configuration of a triode cathode-coupled astable multivibrator is the circuit shown in the accompanying schematic diagram. This circuit is identical to the basic common-cathode-resistor-coupled circuit just discussed, except that the feedback from V2 to V1 now is by capacitive coupling through C4 between the two cathodes. Although the same switching action occurs between the two tubes and the cutoff time of V2 is still determined by the discharging of capacitor C1 through grid resistor R2, the cutoff time of V1 in this instance is determined by the charging of capacitor C4 through its cathode resistor, R5. (Note that this circuit differs from the basic common-cathode-resistor-coupled multivibrator in that, in addition to capacitive coupling between cathodes, separate cathode resistors are used.)

The charge and discharge paths for capacitors C1 and C4 are depicted in the following illustration. Note that capacitor C1 (parts A and B of the illustration) the paths are the same as in the direct-coupled circuit just discussed, except that the cathode resistor through which capacitor C1 now charges initially is R6. The charge path for capacitor C4 (part C of the illustration) is from its right side through the low cathode-to-plate conduction resistance of V2, plate-load resistor R4, and the plate-supply voltage to ground, then through V1 cathode resistor R5 to its left side. Part D of the illustration shows the discharge path for capacitor C4 to be from its left side through the low cathode-to-plate conduction resistance of V1, plate-load resistor R3, and the plate-supply voltage to ground, then through V2 cathode resistor R6 to its right side.

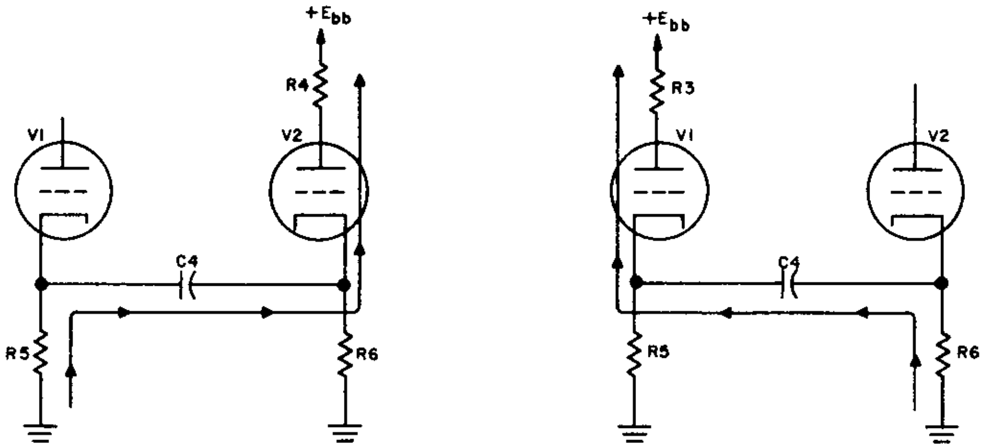


Triode Cathode-Coupled Astable Multivibrator (Capacitive Coupling)



A. CAPACITOR C1 CHARGE PATHS

B. CAPACITOR C1 DISCHARGE PATH



C. CAPACITOR C4 CHARGE PATH

D. CAPACITOR C4 DISCHARGE PATH

Charge and Discharge Paths for Capacitors C1 and C4 of Capacitive-Coupled Multivibrator

The free-running frequency of the output signal is determined primarily by the values of R-C time constants R2-C1 in the grid of V2 and R5-C4 in the cathode circuit, and by the value of the applied voltage. The symmetry of the square-wave output signals depends upon the degree of balance between the two tubes and their associated circuit components.

Consider now the operation of the astable multivibrator being discussed. When voltage is first applied to the circuit, the grids of both tubes are at zero bias, and plate current begins to flow through plate-load resistors R3 and R4. Also, capacitor C1 begins to charge by drawing grid current through resistor R2 and tube V2, making the grid of this tube positive. The plate current of V2 flowing through cathode resistor R6 makes the voltage at the top of the resistor more positive with respect to ground. This positive voltage swing is coupled through capacitor C4 to the cathode of V1, where it acts as a bias voltage to hold V1 cutoff. At this instant, capacitor C4 begins charging through resistor R5 toward the positive voltage at the top of resistor R6. The positive voltage at the top of R5 holds V1 cut off until C4 reaches the approximate potential across R6. At this time, the decrease in current through R5 decreases the bias on V1 and allows it to conduct, thereby causing the multivibrator switching action. That is, conduction of V1 causes the voltage at the V1 plate to decrease, and this negative-going voltage is coupled through capacitor C1 to the grid of V2, where it drives the grid negative and cuts off V2.

When V2 is cutoff, capacitor C1 discharges through R2, R5, and V1. Also, the voltage on the cathode of V2 decreases (becomes less positive); this negative going voltage is coupled through capacitor C4 to the cathode of V1. Since V1 is already conducting the negative-going signal merely aids its conduction. However, the plate current of V1 flowing through cathode resistor R5 produces a positive voltage at the top of this resistor. Capacitor C4 now discharges through V1, plate-load resistor R3, and cathode resistor R6. As capacitor C4 discharges, the voltage at the top of resistor R6 decreases (becomes less positive) because of the accumulation of electrons on the right side of capacitor C4. When the combination of the

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voltage on the grid of V2 (becoming less negative as capacitor C1 discharges through resistor R2) and the voltage on its cathode (becoming less positive as capacitor C4 discharges through resistor R6) decreases sufficiently, V2 again conducts. The switching action repeats continuously with first one tube and then the other tube conducting.

The output of the multivibrator is taken from either or both plate circuits through output coupling capacitor C2 or C3. In cases where it is desired to minimize the effect of varying load impedance on the frequency stability of the multivibrator, a cathode follower is used for stability.

The triode cathode-coupled astable multivibrator, like the plate-to-grid-coupled type, may be synchronized with a stable external source to force the period of the multivibrator action to be exactly the same as that of the synchronizing source. The frequency of the synchronizing signal must be slightly higher than the natural operating frequency of the multivibrator so that the synchronizing pulse occurs just prior to the time that normal switching action would occur.

FAILURE ANALYSIS.

No Output. Assuming that the multivibrator is a free-running type and no synchronizing signals are applied, the plate and filament voltages should be measured to determine whether they are within the specified values. If coupling capacitor C1 should become leaky or shorted, a positive potential will be present on the grid of V2 and, as a result, tube V2 will conduct heavily; V1 will remain cutoff because of the high positive potential (bias) on its cathode as a result of the heavy conduction of V2. If the circuit does not oscillate, measure the voltage at each plate to determine whether plate-load resistor R3 or R4 is open. If either resistor is open, there will be no voltage on the associated plate; also, the other tube will conduct heavily and, as a result of the heavy conduction, its plate voltage will be low.

In the common-cathode-resistor-coupled circuit configuration, if cathode resistor R5 were to open there would be no output because neither tube would conduct, and the plate voltage of both tubes would be at B+. In the capacitive-coupled-cathode circuit configuration, if cathode resistor R5 or R6 were to open only the associated tube (V1 or V2, respectively) would not conduct. If coupling capacitor C4 were to open there would be no feedback from V2 to V1, and thus no output from the multivibrator.

Reduced Output. A reduction in the output amplitude is generally caused by a defctive tube; however, it can also be caused by a decrease in the applied plate voltage or an increase in the resistance of the associated plate-load resistor, R3 or R4. If either output coupling capacitor, C2 or C3, should become leaky or shorted, the input resistor of the following stage can form a voltage divider which also includes the associated plate-load resistor, R3 or R4. If the input resistor of the following stage is returned to ground or to a negative potential, voltage-divider action may reduce the voltage available at the plate of the multivibrator and reduce the amplitude of the output waveform; also, the additional current through the plate load resistor, R3 or R4, may cause the resistor to burn out. Furthermore, the operation of the following stage may also be affected by the change in grid-bias voltage resulting from the voltage-divider action.

Incorrect Frequency or Pulse Width. The critical components governing the frequency and pulse width of the multivibrator are those in the coupling circuits. Any change in the components governing the grid or cathode R-C time constants will directly affect the frequency and pulse width; a change in the R-C combinations of R2-C1 or R5-C4 will have the greatest effect. A change in the value of plate-load resistor R3 or R4 will affect the amplitude of the output; it will also have an effect on the frequency, but not nearly so much as the components mentioned above.

If the plate-supply voltage, +Ebb, should change approximately 10 percent from the specified value, a drift in frequency will generally occur; some frequency drift may also occur if the filament voltage should drop below the specified value.

In a practical circuit, where the multivibrator is free-running and not synchronized from an external source, a variable resistor may be provided to adjust the applied plate voltage or to adjust the value of resistance in each grid circuit. This provision enables the multivibrator to be adjusted to the correct frequency and pulse width, and permits adjustment to compensate for differences in individual tube characteristics when a tube substitution is made.

If either output coupling capacitor (C2 or C3) should become leaky or shorted, the voltage-divider action which can occur may reduce the amplitude of the output waveform and cause the multivibrator to operate at a higher frequency, since the grid capacitor (C1) discharge time is dependent upon the amount of change in capacitor voltage.

BISTABLE (START-STOP) MULTIVIBRATORS.

The term **bistable multivibrator** refers to one class of multivibrator or relaxation oscillator circuits that can function in either of two stable states and is capable of switching rapidly from one stable state to the other upon the application of a trigger pulse. In the strict sense of the word, the bistable multivibrator is not an oscillator; rather, it is a circuit having two conditions of stable (bistable) equilibrium and requiring two input triggers to complete a single cycle. The operation of the bistable multivibrator is dependent upon the timing-control action involved in the transfer of conduction from one tube to the other, initiated by an input trigger pulse of proper polarity and sufficient amplitude. Because there is a sudden reversal (or "flopping") from one stable state to the other, the bistable multivibrator is frequently referred to as a **flip-flop** circuit.

The bistable multivibrator produces an output pulse, more commonly called a "gate", having fast rise and fall times and extreme flatness on top. To generate this type of waveform the circuit requires one trigger pulse for turn-on (start) and another trigger pulse for turn-off (stop), thus generating a "step" function for each input trigger. When the trigger pulses are of constant frequency and are applied at long time intervals (low frequency), the gates generated are wide. On the other hand, when the trigger pulses are of constant frequency and are applied at short time intervals (high frequency), the gates generated are narrow. In all cases, however, two input trigger pulses are required to complete one cycle of operation, resulting in an output gate frequency one-half that of the input trigger frequency.

Although the turn-on and turn-off input trigger pulses (which can be applied from different sources as well) can be of either positive or negative polarity, a negative trigger is preferred. A reason for this requirement is that if a tube is biased far beyond cutoff, a high-amplitude positive pulse is required to drive the tube from cut off into conduction. On the other hand, a low-amplitude negative pulse will immediately cut off conduction of a tube. In addition, the circuit used to generate a low-amplitude pulse requires less power.

The rectangular-gate output of the bistable multivibrator can be either positive or negative in polarity. Each gate is formed by the combination of positive and negative step functions produced by turning the multivibrator on and off. The negative-going step is inherently faster (0.7 microsecond) than the positive-going step (2.5 microseconds). When connecting other circuits to the bistable multivibrator output, precautions should be taken so as to prevent the shunting capacitance from causing undersirable effects on the rise and fall times of the step function.

TRIODE ECCLES-JORDAN (FLIP-FLOP) MULTIVIBRATOR.

APPLICATION.

The triode Eccles-Jordan (flip-flop) multivibrator produces a square- or rectangular-wave output for use as gating or timing signals, or for on-off switching operations in binary counter circuits.

CHARACTERISTICS.

Circuit assumes one of two stable states: one tube normally conducting with the other tube normally cut off, and vice versa.

Requires two input triggers to complete one cycle of operation; the circuit assumes a stable state upon completion of each half-cycle of operation.

For a constant-frequency input, the output frequency is one-half that of the input trigger frequency.

Input triggers can be either positive or negative; positive trigger affects normally cut-off tube, and negative trigger affects normally conducting tube.

Symmetrical triggering occurs when the same trigger pulse is applied simultaneously; unsymmetrical triggering occurs when triggers are applied separately.

Symmetrical or unsymmetrical output gate depends on timing sequence of input trigger pulses; input triggers from different sources (turn-on and turn-off triggers) produce unsymmetrical gate output.

Plate-to-grid feedback coupling is direct (through resistors), with bypass capacitors used to speed up switching from one stable state to the other.

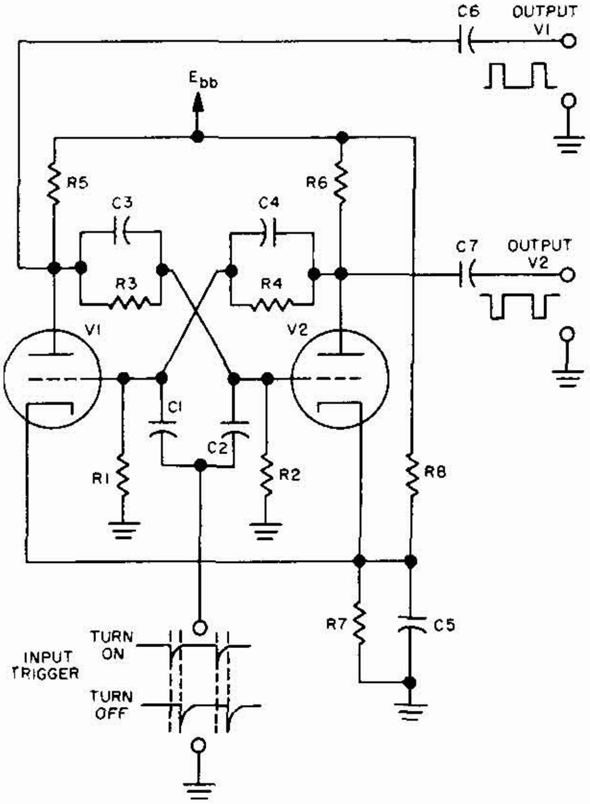
Circuit can be made to assume the same stable state whenever voltages are applied by incorporating a definite imbalance within the circuit or by using a manually controlled "reset" signal.

Tubes can be grid-biased by connecting to negative supply, or cathode-biased by connecting cathodes through voltage divider to positive supply.

CIRCUIT ANALYSIS.

General. The triode Eccles-Jordan (flip-flop) multivibrator is capable of producing a square- or rectangular-wave output pulse (gate) in response to two input triggers. This type of multivibrator has two stable (bistable) states – one tube is normally conducting while the other tube is normally held cut off – and will function for only one-half cycle upon the application of an input trigger. Feedback from the plate of one tube to the grid of the other is direct through a coupling resistor bypassed with a capacitor, whose function is to reduce or eliminate the effects of tube interelectrode capacitance. Because two input triggers (turn-on and turn-off) are required to complete one cycle of operation, the output-gate frequency of the bistable multivibrator is one-half the input trigger frequency. The output gate length is determined by the time interval of the turn-on and turn-off input trigger. Output signals can be taken from the plate of either or both electron tubes.

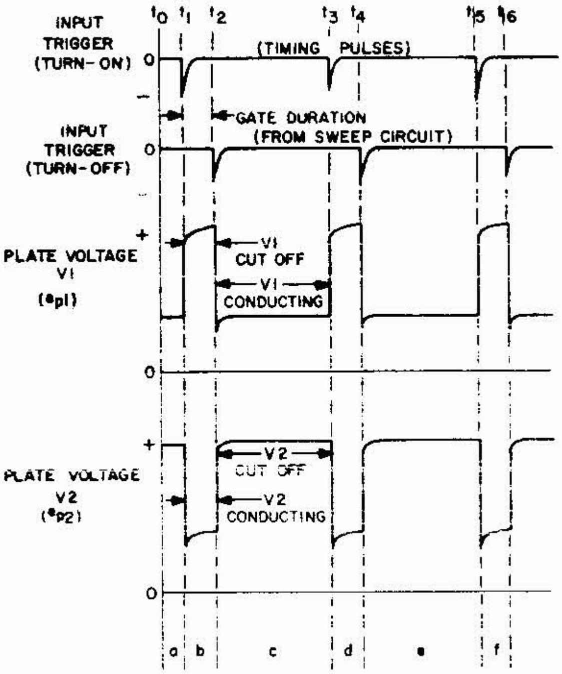
Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in the basic Eccles-



Triode Eccles-Jordan (Flip-Flop) Multivibrator

Jordan multivibrator circuit. Electron tubes V1 and V2 are identical-type triode tubes; although the accompanying schematic illustrates two separate triodes, a twin-triode is frequently used in this circuit. Resistors R1 and R2 are the grid resistors for V1 and V2, respectively. Resistor R3 provides the direct coupling from the plate of V1 to the grid of V2, and resistor R4 provides the direct coupling from the plate of V2 to the grid of V1. Feedback resistors R3 and R4 are bypassed with capacitors C3 and C4, respectively. These capacitors permit faster switching action from one tube to the other by reducing the effects of tube interelectrode capacitance. Resistors R5 and R6 are the plate-load resistors for V1 and V2, respectively. Capacitors C1 and C2 are the input-trigger coupling capacitors for V1 and V2, respectively; they provide symmetrical triggering. Capacitors C6 and C7 are the output-gate coupling capacitors for V1 and V2, respectively. Operating bias for this bistable multivibrator, which is cathode-biased, is determined by the combination of the cathode and respective grid circuit voltage dividers. The cathode circuit voltage divider consists of common cathode resistor R7, bypassed with capacitor C5, and resistor R8; the voltage divider for the grid circuit of V1 consists of resistors R1, R4, and R6, and the voltage divider for the grid circuit of V2 consists of resistors R2, R3, and R5.

Consider now the operation of the triode Eccles-Jordan (flip-flop) multivibrator by referring to the preceding circuit illustration and the accompanying illustration of the idealized theoretical waveforms. Also, in order to more fully analyze the timing sequence, assume that the circuit under consideration is for a radar application wherein it is desirable to have the gate length controlled by the display circuit. Thus, the radar sweep circuit provides the turn-off trigger to return the multivibrator to its initial stable state.



Theoretical Waveforms for Triode Eccles-Jordan (Flip-Flop) Multivibrator

When voltage is first applied to the circuit, there is a slight conduction through both tubes. Because of the inherent imbalance of the circuit, however, one tube will conduct slightly more than the other. For example, if initially the current through V1 should be slightly greater than that through V2, the voltage drop across plate-load resistor R5 will be greater than the drop across plate-load resistor R6. This results in a lower plate voltage for V1, which is applied through resistor R3 to the grid of V2, thus causing the voltage at this grid to become more negative and reduce the current through V2. When the plate current through V2 is reduced, the current through plate-load resistor R6 likewise is reduced; therefore, the voltage drop across resistor R6 decreases, resulting in a rise in the plate voltage of V2. The positive-going plate voltage of V2 is applied through resistor R4 to the grid of V1, making this grid more positive. The regenerative action just described continues rapidly until V2 is cut off and V1 is at maximum conduction. Thus, the circuit is in one of its two stable states of equilibrium, as represented by time interval **a** on the waveform illustration. Note that the output at the plate of V1 is at its most negative excursion (V1 is conducting) while the output at the plate of V2 is positive (V2 is cut off). Since there is no internal R-C time constant timing circuit to drive the nonconducting tube out of cutoff, the circuit remains in this stable condition until an input trigger pulse is applied.

Assume now that a negative trigger pulse of sufficient amplitude is applied simultaneously to both grids through input capacitors C1 and C2. This trigger pulse, which is the turn-on input trigger from the radar timing circuits, is applied at t_1 as illustrated on the waveform diagram. Because V2 is already cut off, the input trigger has little effect on this tube; however, the same negative trigger pulse drives the grid of V1 below cutoff, causing this normally conducting tube to decrease conduction. As soon as V1 reduces conduction, its plate voltage rises toward the plate-supply voltage, +Ebb. The positive-going signal at the plate of V1 is now coupled through resistor R3 and applied to the grid of V2, driving V2 into conduction. Thus, at instant t_1 a switching action occurs; V2 now conducts heavily, as indicated by the waveform at its plate, and V1 is cutoff. The multivibrator remains in this condition, which is its second stable state as depicted by time interval **b**, until another trigger is applied.

When the desired gate duration is attained, the negative turn-off trigger from the radar sweep circuits is applied (at t_2) and the gate is terminated. The negative-going turn-off trigger cuts off conduction of V2 and causes a switching action that returns the multivibrator to its original stable state, in which V1 is conducting and V2 is cut off. The circuit remains in this condition (time interval **c**) until another negative trigger from the radar timing circuits is applied at t_3.

Close examination of the waveform illustration reveals that the length of the output gates is determined by the time interval between the turn-on and turn-off triggers. If the frequency of the turn-off trigger is made lower, the time interval between the triggers will increase; hence, the gate length will likewise increase. Conversely, the gate length will drecrease if the turn-off trigger frequency is increased. Thus, the bistable multivibrator provides a positive or negative gate output in response to a timing (turn-on) input trigger pulse, with the gate being terminated by a turn-off trigger pulse. If a single constant-frequency trigger is used for both the turn-on and turn-off functions, the circuit will produce a symmetrical square-wave output having a frequency one-half that of the input-trigger frequency.

In the symmetrical-input bistable multivibrator being considered, positive input trigger pulses of sufficient amplitude can also be used to initiate the switching action between tubes V1 and V2. When the positive trigger pulse is applied simultaneously to the grids of the tubes, there will be no effect on the operation of the conducting tube. However, the plate current of the cut-off tube will be increased, causing its plate voltage to fall. The fall in plate voltage, when coupled to the grid of the conducting tube, drives this tube into cutoff.

Although it is true that either negative or positive input trigger pulses can cause the switching action to occur, triggering with negative pulses is preferred. For example, if the cut-off tube is biased with a high negative potential, a high-amplitude positive pulse is required to drive the tube into conduction, and only the most positive portion of the pulse has any effect. On the other hand, a low-amplitude negative pulse applied to the conducting tube immediately drives this tube into cutoff, causing an instantaneous switching action.

FAILURE ANALYSIS.

No Output. The input trigger should be checked with an oscilloscope to determine whether it is being applied to the circuit and whether it is of the proper polarity and amplitude. Lack of an input trigger at the grid of V1 or V2 can be due to an open coupling capacitor, C1 or C2, or to failure of the external input-trigger source.

Failure of the plate voltage supply, + Ebb, will disrupt the operation of the circuit, as will an open cathode circuit. With tubes (or a single twin-triode tube) installed in the circuit, the filament and plate voltages should be measured, as well as the bias voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether plate-load resistor R5 or R6 and cathode-bias resistor R7 or R8 is open. If coupling resistor R3 or R4 is open there will be no feedback signal to cause the multivibrator switching action. If bypass capacitor C3 or C4 is open feedback will still occur, but the interelectrode capacitance of the tube may cause undesirable effects on the wavefront of the feedback signal. An open output coupling capacitor, C6 or C7, will prevent the output-gate signal from reaching the following stage.

Reduced Output. A reduction in output is generally caused by a defective tube; however, it can also be caused by a decrease in the applied plate voltage or an increase in the resistance of the associated plate-load resistor, R5 or R6. A leaky or shorted output coupling capacitor, C6 or C7, will form a voltage divider with the input resistor of the following stage. If the input resistor of this following stage is returned to ground or to a negative supply, the voltage at the plate of both V1 and V2 will be reduced, and the operation of the following stage will be upset by the change in voltage applied to its grid. Also, the additional current through plate-load resistor R5 or R6 may cause the resistor to burn out.

Incorrect Frequency or Gate Width. The triode Eccles-Jordan (flip-flop) multivibrator has no components governing the frequency or width of its output-gate signal; these are both governed by the input triggers applied to the circuit. Therefore, any change in the output-gate frequency or width is a result of improper operation of the turn-on and/or turn-off trigger generating circuits.

PENTODE ECCLES-JORDAN (FLIP-FLOP) MULTIVIBRATOR.

APPLICATION.

The pentode Eccles-Jordan (flip-flop) multivibrator produces a square- or rectangular-wave output for use as gating or timing signals, or for on-off switching operations in binary counter circuits.

CHARACTERISTICS.

Circuit assumes one of two stable states: one tube normally conducting with the other tube normally cut off, and vice versa.

Requires two input triggers to complete one cycle of operation; the circuit assumes a stable state upon completion of each half-cycle of operation.

For a constant-frequency input, the output frequency is one-half that of the input trigger frequency.

Input triggers can be either positive or negative; positive trigger affects normally cut-off tube, and negative trigger affects normally conducting tube.

Symmetrical triggering occurs when the same trigger pulse is applied simultaneously; unsymmetrical triggering occurs when triggers are applied separately.

Symmetrical or unsymmetrical output gate depends on timing sequence of input trigger pulses; input triggers from different sources (turn-on and turn-off triggers) produce unsymmetrical gate output.

Plate-to-suppressor grid feedback coupling is direct (through resistors), with bypass capacitors used to speed up switching from one stable state to the other.

Circuit can be made to assume the same stable state whenever voltages are applied by incorporating a definite imbalance within the circuit or by using a manually controlled "reset" signal.

Tubes can be grid-biased by connecting to negative supply, or cathode-biased by connecting cathodes through voltage divider to positive supply.

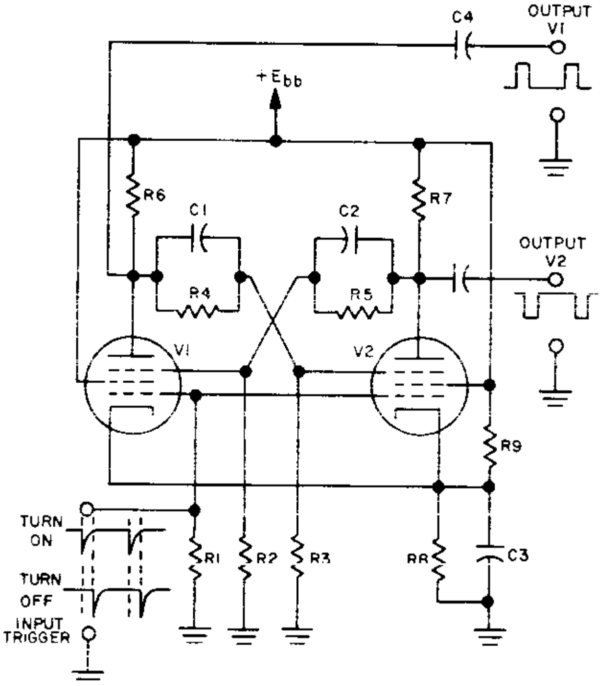
CIRCUIT ANALYSIS.

General. The pentode Eccles-Jordan (flip-flop) multivibrator is capable of producing a square- or rectangular-wave output pulse (gate) in response to two input triggers. The circuit has two stable (bistable) states – one tube is normally conducting while the other tube is normally held cutoff. Like the triode Eccles-Jordan multivibrator, discussed earlier in this Section of the Handbook, the circuit operation is controlled by the application of an input trigger pulse which causes the conduction to switch from one tube to the other. Thus, the multivibrator will function for only one-half cycle upon the application of each input trigger. Feedback from the plate of one tube to the suppressor grid of the other is direct through a coupling resistor bypassed with a capacitor, whose function is to reduce or eliminate the effects of tube interelectrode capacitance.

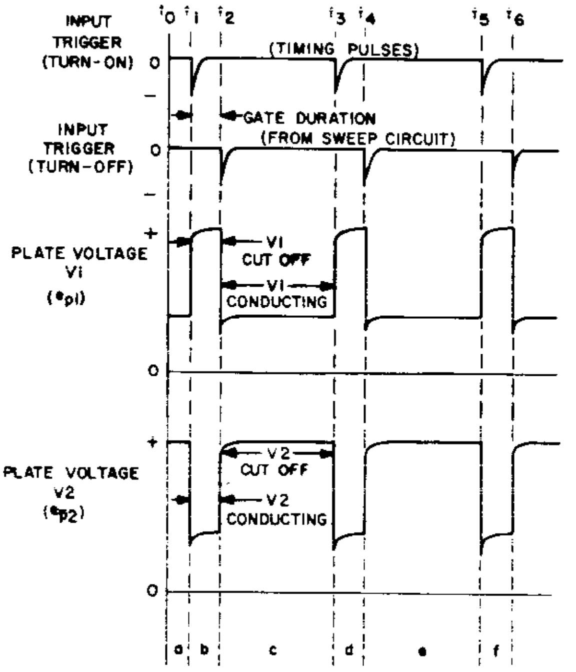
The feedback connection to the opposit suppressor grid, instead of the control grid, frees the control grid for application of the trigger pulses. Because two input triggers (turn-on and turn-off) are required to complete on cycle of operation, the output-gate frequency of the bistable multivibrator is one-half the input trigger frequency. The output gate length is determined by the time interval of the turn-off input triggers. Output signals can be taken from the plate of either or both electron tubes.

Circuit Operation. The accompanying circuit schematic illustrates two pentode electron tubes in an Eccles-Jordan bistable multivibrator configuration. Electron tubes V1 and V2 are identical sharp cutoff pentode-type tubes. Resistor R1 is a common grid resistor for both tubes. Resistors R2 and R3 are the suppressor grid resistors for V1 and V2, respectively. Resistor R4 provides direct-coupled feedback from the plate of V1 to the suppressor grid of V2; resistor R5 provides direct-coupled feedback from the plate of V2 to the suppressor grid of V1. Feedback resistors R4 and R5 are bypassed with capacitors C1 and C2, respectively. These capacitors permit faster switching action from one tube to the other by reducing the effects of tube interelectrode capacitances. Resistors R6 and R7 are the plate-load resistors for V1 and V2, respectively; the screen grids are tied directly to the supply voltage, +Ebb. Suppressor grid voltage for V1 is obtained from a voltage divider consisting of resistors R2, R5, and R7; suppressor grid voltage for V2 is obtained from a voltage divider consisting of resistors R3, R4, and R6. Capacitors C4 and C5 are the output coupling capacitors for V1 and V2, respectively. Operating bias for this bistable multivibrator, which is cathode-biased, is obtained from a voltage divider consisting of common cathode resistor R8, bypassed with capacitor C3, and resistor R9. A comparison of the pentode and triode Eccles-Jordan multivibrator circuits reveals their similarities and differences.

Consider now the operation of the pentode Eccles-Jordan multivibrator by referring to the preceding circuit illustration. Since the output-gate waveforms of the pentode circuit are similar to those of the triode Eccles-Jordan multivibrator presented earlier in this Section of the Handbook, reference to the triode circuit waveforms can be made for this pentode circuit as well. The waveforms are reproduced in the accompanying figure for convenience.



Pentode Eccles-Jordan (Flip-Flop) Multivibrator



Theoretical Waveforms for Pentode Eccles-Jordan (Flip-Flop) Multivibrator

When voltage is first applied to the circuit, there is a slight conduction through both tubes. However, because of the inherent imbalance of the circuit, one tube will conduct slightly more than the other. For example, if initially the current through V1 should be slightly greater than that through V2, the voltage drop across plate-load resistor R6 will be greater than the drop across plate-load resistor R7. This results in a lower plate voltage for V1, which is applied through resistor R4 to the suppressor grid of V2. The negative-going signal on the V2 suppressor grid reduces the plate current of this tube, thus reducing the current through plate-load resistor R7 and causing a voltage rise at the plateof V2. This positive-going voltage is coupled through resistor R5 to the suppressor grid of V1, further increasing the plate current of V1. Suppressor grid current flows at a slight positive suppressor grid voltage, but decreases at a high positive suppressor grid voltage, such as when the positive-going signal is applied from the plate of V2. The plate current of V1 increases further, and a regenerative action occurs instantaneously to drive V1 into heavy conduction and V2 into cutoff. Thus, the multivibrator is in one of its stable states, as depicted during time interval **a** in the waveform illustration referenced previously. Since there is no internal R-C time constant timing circuit to drive the nonconducting tube out of cutoff, the circuit remains in this stable state until a timing pulse is applied to the control grids to cause the switching action.

Assume now that a negative trigger pulse of sufficient amplitude is applied simultaneously to both control grids. The trigger pulse, applied at t_1, has little effect on the operation of V2 since this tube is already cut off. However, the same negative trigger drives the grid of V1 below cutoff, causing this tube to reduce conduction. As soon as V1 reduces conduction, its plate voltage rises toward the plate supply voltage, +Ebb. The positive-going signal at the plate of V1 is now coupled through resistor R4 and applied to the suppressor of V2 driving V2 into conduction. Thus, at instant t_1 a switching action occurs, with the result that V2 now becomes the conducting tube and V1 is cut off. Thus, the circuit is in the second of its two stable states, as depicted during time interval **b**. The multivibrator remains in the condition wherein V2 is conducting and V1 is cut off until the next negative trigger pulse is applied to cause another switching action.

When the desired gate duration is attained, the negative turn-off trigger is applied (at t_2) and the gate is terminated. The negative-going turn-off trigger cuts off conduction of V2 and causes a switching action that returns the multivibrator to its original stable state wherein V1 is conducting and V2 is cut off. The circuit remains in this condition (time interval **c**) until another negative trigger from the timing circuits, the turn-on trigger, is applied at t_3.

As in the triode Eccles-Jordan multivibrator, the length of the output gates of the pentode configuration is determined by the time interval between the turn-on and turn-off triggers. The gate length will increase if the turn-off trigger frequency is decreased; conversely, the gate length will decrease if the turn-off trigger frequency is increased. If a single constant-frequency trigger is used for both the turn-on and turn-off functions, the circuit will produce a symmetrical square-wave output having a frequency one-half that of the input-trigger frequency.

Although positive trigger pulses could be used to "drive" the pentode Eccles-Jordan bistable multivibrator, negative trigger pulses are preferred; a small-amplitude negative pulse when applied to the conducting tube will immediately drive this tube into cutoff to cause an instantaneous switching action. The output of the multivibrator is taken from either or both plate circuits through an output coupling capacitor (C4 or C5). A cathode follower should be used couple the positive gate output to a circuit that requires grid current, since the multivibrator may occasionally fail.

FAILURE ANALYSIS.

No Output. The input trigger should be checked with an oscilloscope to determine whether it is being applied to the circuit and whether it is of the proper polarity and amplitude. Lack of an input trigger at the grid of V1 or V2 can be due to failure of the external input-trigger source or to the coupling from the trigger source to the multivibrator.

Failure of the supply-voltage source, +Ebb, will disrupt the operation of the circuit, as will an open cathode circuit. With tubes installed in the circuit, the filament, plate, screen grid, and suppressor grid voltages should be measured, as well as the bias voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether any of the respective electrode resistors are open (resistors R2 through R9). If coupling resistor R4 or R5 is open, there will be no feedback signal to affect the multivibrator switching action; in addition, the d-c operating potential from the associated suppressor grid will be removed. If bypass capacitor C1 or C2 is open, feedback will still occur, but the interelectrode capacitance of the tube may cause undesirable effects on the wavefront of the feedback signal. An open output coupling capacitor, C6 or C7, will prevent the output-gate signal from reaching the following stage.

Reduced Output. A reduction in output is generally caused by a defective tube; however, it can also be caused by a decrease in the applied voltage or an increase in the resistance of the associated plate-load resistor, R6 or R7. A leaky or shorted output coupling capacitor, C4 or C5, will form a voltage divider with the input resistor of the following stage. If the input resistor of this following stage is returned to ground or to a negative supply, the voltage at the plate, screen grid, and suppressor grid of both V1 and V2 will be reduced, and the operation of the following stage will be upset by the change in voltage applied to its grid. Also, the additional current through the resistors associated with the electrodes mentioned previously may cause the resistors to burn out.

Incorrect Frequency and Gate Width. The pentode Eccles-Jordan (flip-flop) multivibrator has no components governing the frequency or width of its output-gate signals; these are both governed by the input triggers applied to the circuit. Therefore, any change in the output-gate frequency or width is a result of improper operation of the turn-on and-or turn-off trigger generating circuits.

MONOSTABLE (ONE-SHOT) MULTIVIBRATORS.

The term **monostable multivibrator** refers to one class of multivibrator or relaxation oscillator circuits that function in a stable condition until the application of a trigger pulse. At this time the circuit switches rapidly and goes through one complete cycle of operation, after which it reverts to its original stable condition, in which it remains until the application of another trigger pulse. The monostable (or **one-shot**) multivibrator is essentially a two-stage resistance-capacitance-coupled amplifier, and not an oscillator in the strict sense of the word, with one tube normally cut off and the other tube normally conducting. The one-shot multivibrator operates in much the same manner as the free-running, or astable, type discussed earlier in Section 8 of this Handbook, except that this circuit requires an input trigger to initiate the multivibrator action and produce the output signal.

The monostable multivibrator produces a square- or rectangular-wave output pulse, more commonly called a "gate", having fast rise and fall times and extreme flatness on top; the pulse is produced only in response to an input trigger. The output frequency is determined by the frequency of the input trigger, and the duration of the gate length is determined by the circuit design. The one-shot multivibrator can be used at pulse-repetition rates from zero to maximum which is determined by the gate length and the R-C time constant of the circuit. A nominal range of gate time duration is from 30 to 2500 microseconds, which will accommodate trigger pulses in the range of 200 to 2000 pps.

In applications requiring different gate lengths, the gate-determining components can be switched in value to produce the desired gate length! Also, the monostable multivibrator may supply both positive and negative gates to as many as four branches. A precaution is that the positive-gate output should not be applied to a circuit requiring grid current as the multivibrator may occasionally fail; the use of a cathode follower or buffer circuit will eliminate this disadvantage. Because the monostable multivibrator is not well suited for controlling the gate length with a turn-off trigger pulse, a bistable multivibrator should be used when this type of control is desired.

Although the output from the monostable multivibrator is sometimes differentiated to provide a pulse either at the leading edge or the trailing edge of the gate waveform, in most cases only the leading edge of the waveform must be extremely fast; the trailing edge is usually not used for critical timing applications. A negative-going leading edge is used whenever possible since such a gate can be obtained rather easily from any tube electrode except the cathode. In addition, a negative gate at the plate of a multivibrator tube will always be generated at a lower impedance than a positive gate at the same plate.

A fast positive-going leading edge can be obtained on the plate of one tube of the multivibrator only if direct coupling is provided to the control grid of the opposite tube. Even in this case, caution should be used to ensure that the value of the associated speed-up capacitor is just enough to match the input capacitance of the opposite tube; if the value of this capacitor is too large, the voltage rise on the plate will be delayed. An output gate with a fast positive-going leading edge may be obtained from the plate of a cathode-coupled monostable multivibrator, since this circuit has a free plate not involved directly in the circuit multivibrator action. A fast positive-going leading edge at a decreased amplitude can be obtained at the cathode of the multivibrator tube that is normally cut off.

TRIODE PLATE-TO-GRID-COUPLED MONOSTABLE MULTIVIBRATOR

APPLICATION.

The triode plate-to-grid-coupled monostable multivibrator produces a square-wave or rectangular-wave output for use as gating or timing signals.

CHARACTERISTICS.

Circuit assumes a stable state in which one tube normally conducts and the other tube is normally cut off.

Requires an input trigger to cause circuit operation; circuit returns to stable state upon completion of one cycle of operation.

Input trigger can be either negative or positive; negative trigger affects tube that is normally conducting, and positive trigger affects tube that is normally cut off.

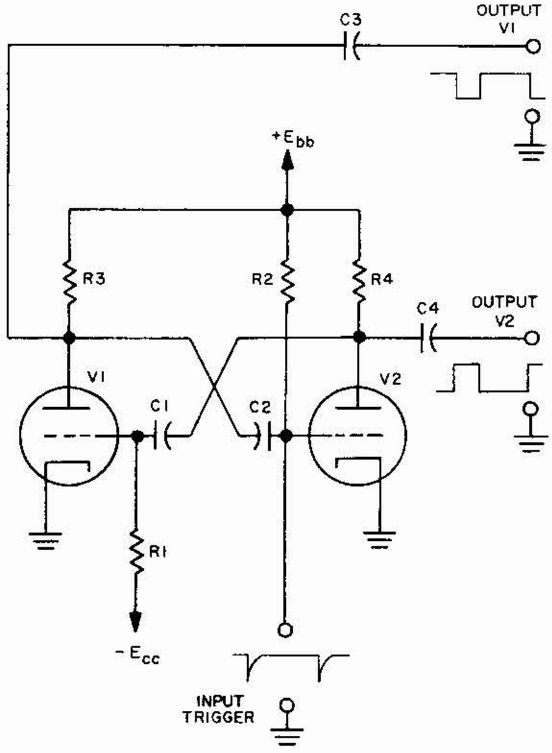
Produces square-wave or rectangular-wave output gates of both positive and negative polarity in response to an input trigger.

Output gate length is determined by R-C time constant in grid circuit and by the applied voltage; output frequency is determined by input trigger frequency.

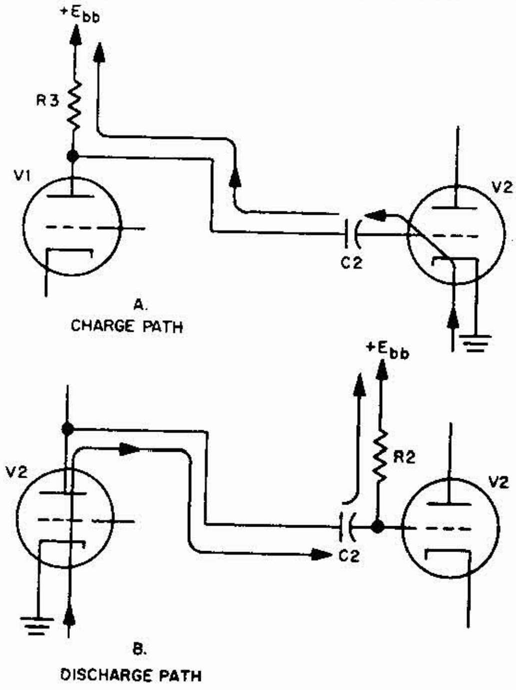
CIRCUIT ANALYSIS.

General. The triode plate-to-grid-coupled monostable multivibrator is a two-stage resistance-capacitance-coupled amplifier capable of producing a square-wave or rectangular-wave output pulse (gate) in response to an input trigger. The monostable multivibrator has only one stable state, in which one tube normally conducts while the other tube is normally cut off, and will function for only one complete cycle upon the application of the input trigger. To achieve the stable condition, the grid of the normally conducting tube is usually returned to B+, while the grid of the tube that is normally cut off is returned to ground or to a negative voltage source. Feedback from the plate of one tube to grid of the opposite tube is through R-C coupling. Because the monostable multivibrator operates for only one cycle in response to an input-trigger pulse, the output frequency of this circuit is dependent upon the input trigger frequency; the output gate length is determined by the R-C time constant of the plate-to-grid feedback network and the applied voltage. Output signals can be taken from the plate of either or both electron tubes.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a plate-to-grid-coupled monostable multivibrator configuration. Electron tubes V1 and V2 are identical-type triode tubes; although the accompanying schematic illustrates two separate triodes, a twin-triode is frequently used in this circuit. Capacitor C1 provides coupling from the plate of V2 to the grid of V1, and capacitor C2 provides coupling from the plate of V1 to the grid of V2. Resistor R1 returns the grid of V1 to the negative voltage (bias) supply, -Ecc, and resistor R2 returns the grid of V2 to the positive voltage supply, +Ebb. Resistors R3 and R4 are the plate-load resistors for V1 and V2, respectively. Capacitors C3 and C4 are the output coupling capacitors for V1 and V2, respectively. The tube that is normally cut off is V1, and the tube that is normally conducting is V2.



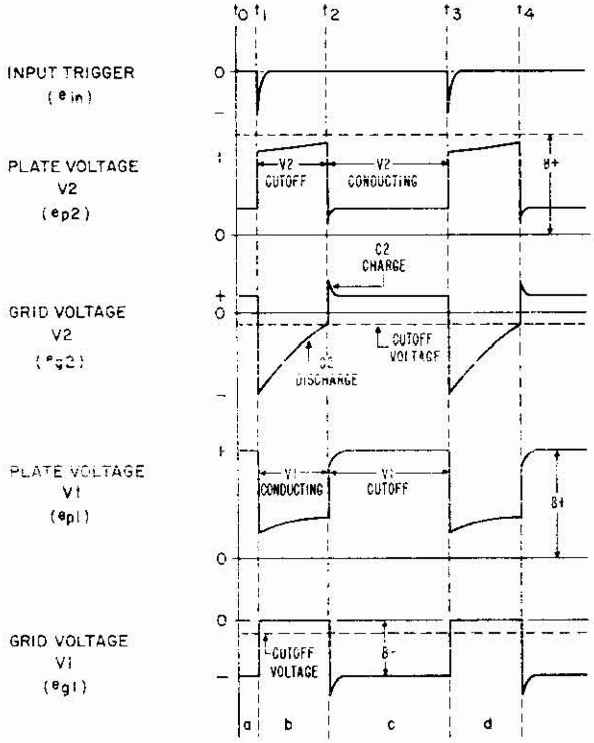
Triode Plate-to-Grid-Coupled Monostable Multivibrator



Charge and Discharge Paths for Capacitor C2

The following simplified schematic diagram illustrates the charge and discharge paths for feedback capacitor C2. The cutoff time of V2 is determined by the discharge of capacitor C2 through resistor R2 toward the positive voltage supply, +Ebb. Although the conduction resistance of V1 is included in the discharge path of C2, it is small as compared with the resistance of R2, and can therefore be neglected. The cutoff time of V1 is determined by the period of the input trigger pulse. If the R2-C2 time constant is made exactly one-half the period of the trigger pulse, the multivibrator produces a symmetrical square-wave output; if the R2-C2 time constant is made longer or shorter than one-half the trigger pulse period, an asymmetrical rectangular-wave output is produced.

Consider now the operation of the triode plate-to-grid-coupled monostable multivibrator by referring to the preceding circuit illustrations and the accompanying illustration of the idealized theoretical waveforms. When voltage is first applied, V2 goes into conduction and V1 cuts off. This action results from the fact that the grid of V2 is returned through resistor R2 to a positive voltage, while the grid of V1 is returned through resistor R1 to a negative voltage. Thus, at time t_0 (start of time interval **a**) on the waveform illustration, the grid voltage of V2 (e_{g_2}) is slightly positive, causing conduction through V2, and a decrease in its plate voltage (e_{p_2}). The negative-going voltage at the plate of V2 is coupled through capacitor C1 to the grid of V1, thus aiding in cutting off this tube (waveform e_{g_1}). Also, at t_0, coupling capacitor C2 charges through the low cathode-to-grid internal resistance of V2 (approximately 1K) and the V1 plate-load resistor, R3. The voltage at the plate of V1 is represented by the e_{p_1} waveform. At t_0, then, the plate-to-grid-coupled monostable multivibrator assumes its



Theoretical Waveforms for Triode Plate-to-Grid-Coupled Monostable Multivibrator

monostable multivibrator assumes its stable state, in which stable state, in which V2 normally conducts and V1 is normally cut off; the circuit remains in this condition until a trigger pulse is applied.

Assume now that a negative trigger pulse of sufficient amplitude to cut off the tube is applied directly to the grid of V2. The effect of this trigger pulse (ein, applied at t_1) is to drive V2 into cutoff. As a result of the decreased conduction through V2, the plate voltage of V2 (ep_2) rises toward the supply voltage, and the positive-going signal is coupled through capacitor C1 to the grid of V1, thus raising the grid voltage (eg_1) above cutoff and driving V1 into conduction. The plate voltage of V1 (ep_1) decreases, and the negative-going signal is coupled through capacitor C2 to the grid of V2 to drive V2 further into cutoff. Thus, at t_1 a switching action occurs and the multivibrator is in a "temporary" stable state in which V1 conducts and V2 is cutoff.

During this temporary stable state (time interval **b**), capacitor C2 discharges through resistor R2 toward the potential of the positive voltage supply. This causes the grid voltage of V2 (eg_2) to rise toward the potential of the positive voltage supply until the point is reached where the grid voltage of V2 can no longer hold the tube cut off. At that instant, t_2, V2 once again conducts and the negative-going signal at its plate is coupled through capacitor C1 to the grid of V1 which again cuts off V1. The voltage waveform at the plate of V1 (ep_1) is rounded off, and the waveform at the grid of V2 (eg_2) has a small positive spike of the same time duration as a result of the charging of coupling capacitor C2 when V2 again conducts. The plate voltage waveform of V2 (ep_2) has a small negative spike at the same time duration as the positive spike on the V2 grid voltage waveform (eg_2). Hence, at t_2, the multivibrator reverts to its original stable condition, in which V2 conducts and V1 is cut off; the circuit remains in this condition (time interval **c**) until another negative trigger pulse is applied at t_3.

Close examination of the waveforms reveals that the monostable multivibrator goes through one complete cycle of operation for each input trigger pulse. Also, the time of application of the trigger pulse determines when V1 is driven into conduction, and the R-C time constant of R2-C2 and the applied voltage determine when V2 is driven into conduction. Thus, the monostable multivibrator output frequency is determined by the input trigger frequency, and the output gate width is determined by the discharging of capacitor C2 through resistor R2 toward the potential of the positive voltage supply.

A negative trigger pulse applied to the grid of the normally conducting tube, as was done in this case, is not the only method by which the multivibrator circuit can be triggered. A negative trigger pulse applied directly to the plate of V1 and coupled through capacitor C2 to the grid of V2 serves the same purpose. A positive trigger pulse applied directly to the plate of V2 or to the grid of V1 will also trigger the circuit. In some practical-circuit applications, a positive trigger is applied to the grid of a "trigger-inverter" stage whose plate is connected in parallel with the plate of V1; the inverted trigger is then coupled through capacitor C2 to the grid of V2 as a negative trigger pulse. In any event, a cycle of multivibrator operation is initiated by driving the normally conducting tube into cutoff, or by driving the tube that is normally cut off into conduction.

FAILURE ANALYSIS.

No Output. The input trigger should be checked with an oscilloscope to determine whether it is being applied to the circuit and whether it is of the proper polarity and amplitude. Lack of an input trigger at the grid of V2 can be due to failure of the external input-trigger source.

Failure of the positive voltage supply, +Ebb, will disrupt the operation of the circuit, as will an open cathode circuit. With tubes (or a single twin-triode tube) installed in the circuit, the filament and plate voltages should be measured, as well as the grid bias voltage, to determine whether the applied voltages are within tolerance and whether plate-load resistor R3 or R4 or grid-bias resistor R1 or R2 is open. If coupling capacitor C1 or C2 opens, there will be no feedback signal to effect the multivibrator switching action. An open output coupling capacitor, C3 or C4, will prevent the output-gate signal from reaching the following stage.

Reduced Output. A reduction in output is generally caused by a defective tube; however, it can also be caused by a decrease in the applied plate voltage or an increase in the resistance of the associated plate-load resistor, R3 or R4. A leaky or shorted output coupling capacitor, C3 or C4, will form a voltage divider with the input resistor of the following stage. In this input resistor is returned to ground or to a negative voltage supply, the voltage at the plate of both V1 and V2 will be reduced, and the operation of the following stage will be upset by the change in voltage applied to its grid. Also, the additional current through plate-load resistor R3 or R4 may cause the resistor to burn out.

Incorrect Frequency or Gate Width. The plate-to-grid-coupled monostable multivibrator has no components governing the frequency of its output-gate signal; this frequency is governed by the input trigger applied to the circuit. Therefore, any change in the output-gate frequency is a result of improper operation of the trigger generating circuits. A change in the output-gate width, however, will result if there is a change in the value of either resistor R2, capacitor C2, or the applied voltage. A change in the resistance or capacitance of the R2-C2 timing control circuit will have the greatest effect on the gate width; changes in the applied voltage will affect the gate width to a lesser degree.

TRIODE COMMON-CATHODE-RESISTOR-COUPLED MONOSTABLE MULTIVIBRATOR.

APPLICATION.

The triode common-cathode-resistor-coupled monostable multivibrator produces a square-wave or rectangular-wave output for use as gating or timing signals.

CHARACTERISTICS.

Circuit assumes a stable state, in which one tube normally conducts and the other tube is normally cut off.

Requires an input trigger to cause circuit operation; circuit returns to stable state upon completion of one cycle of operation.

Input trigger can be either negative or positive; negative trigger affects tube that is normally conducting, and positive trigger affects tube that is normally cut off.

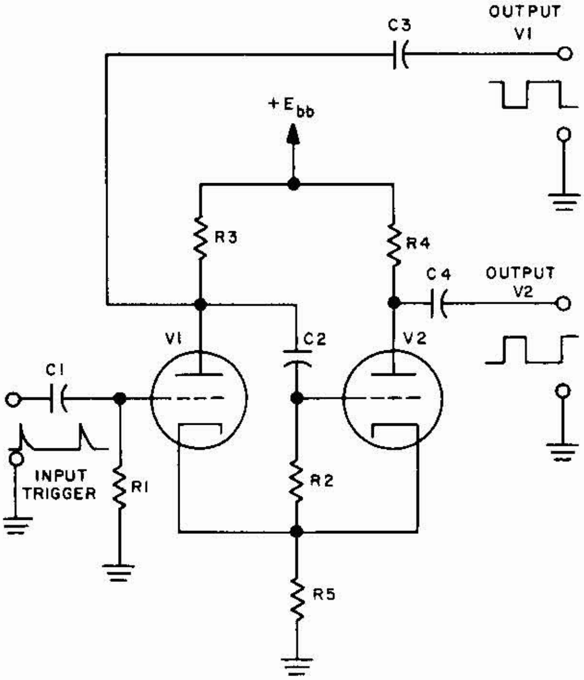
Produces square-wave or rectangular-wave output gates of both positive and negative polarity in response to an input trigger.

Output gate length is determined by R-C time constant in grid circuit and by the applied voltage; output frequency is determined by input trigger frequency.

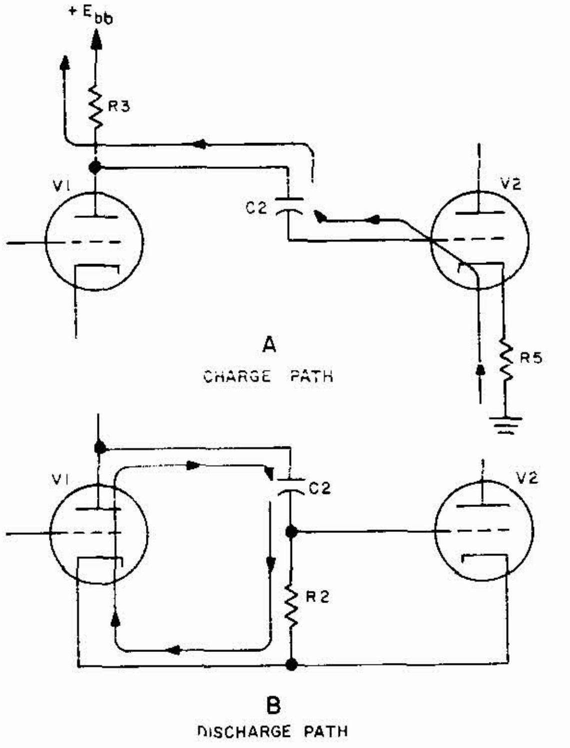
CIRCUIT ANALYSIS.

General. The triode common-cathode-resistor-coupled monostable multivibrator is functionally similar to the Triode Plate-to-Grid-Coupled Monostable Multivibrator discussed previously in Section 8 of this Handbook. The circuit has only one stable state, in which one tube normally conducts while the other tube is normally cut off, and will function for only one complete cycle upon the application of an input trigger pulse. To achieve the stable condition, the grid of the normally conducting tube is usually returned to its cathode or to B+ while the grid of the tube that is normally cut off is returned to ground or to a negative voltage (bias) supply. R-C coupling is provided from the plate of V1 to the grid of V2, but the coupling from V2 to V1 is effected across a common cathode resistor. Because the monostable multivibrator operates for only one cycle in response to an input trigger pulse, the output frequency of this circuit is dependent upon the input trigger time constant of the grid circuit and by the applied voltage. Output signals can be taken from the plate of either or both electron tubes.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a common-cathode-resistor-coupled monostable multivibrator configuration. Electron tubes V1 and V2 are identical-type triode tubes; although the accompanying schematic illustrates two separate triodes, a twin-triode is frequently used in this circuit. Capacitor C1 is the input coupling capacitor for application of a positive trigger to the grid of V1. Capacitor C2 provides coupling from the plate of V1 to the grid of V2. Resistor R1 returns the grid of V1 to ground, and resistor R2 returns the grid of V2 to the common cathode connection. Resistors R3 and R4 are the plate-load resistors for V1 and V2, respectively. Resistor R5 is the common cathode bias and coupling resistor for coupling from V2 to V1. Capacitors C3 and C4 are the output coupling capacitors for



Triode Common-Cathode-Resistor-Coupled Monostable Multivibrator



A

CHARGE PATH

B

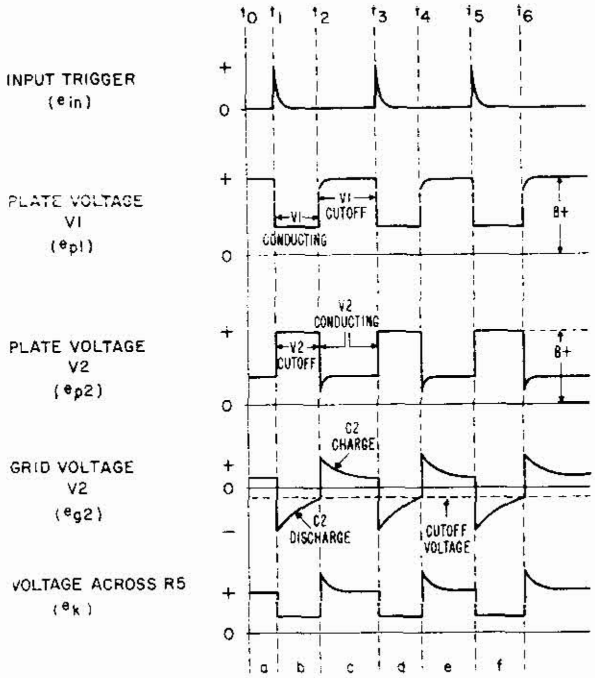
DISCHARGE PATH

Charge and Discharge Paths for Capacitor C2

V1 and V2, respectively. The tube that is normally cut off is V1, and the tube that is normally conducting is V2.

The following simplified schematic diagram illustrates the charge and discharge paths for capacitor C2. The cutoff time of V2 is determined by the discharge of capacitor C2 through resistor R2. Although the conduction resistance of V1 is included in the discharge path of C2, it is frequency; the output gate length is determined by the R-C small as compared with the resistance of R2, and can therefore be neglected. The cutoff time of V1 is determined by the period of the input trigger pulse. If the R2-C2 time constant is made exactly one-half the period of the trigger pulse, *the multivibrator produces a symmetrical square-wave output;* if the R2-C2 time constant is made longer or shorter than one-half the trigger pulse period, an asymmetrical rectangular-wave output is produced.

Consider now the operation of the triode common-cathode-resistor-coupled monostable multivibrator by referring to the preceding circuit illustrations and the accompanying illustration of the idealized theoretical waveforms. When voltage is first applied, V2 goes into conduction and V1 cuts off. This action results from the fact that the grid of V2 is returned through resistor R2 to the cathode, initially placing this grid at the same potential as the cathode, and thus allowing V2 to conduct heavily. The plate current flow of V2 through common cathode resistor R5 makes the voltage at the top of the resistor positive with respect to ground, producing a bias voltage of sufficient amplitude to hold V1 cut off (since its grid is returned to ground through resistor R1), and still permit V2 to conduct. Thus, at time t_0 (start of time interval a) on the waveform illustration, the grid voltage of V2 (e_{g_2}) is slightly positive, causing conduction through V2; as a result, the plate voltage (e_{p_2}) of V2 decreases because of plate current flow through plate-load resistor *R4. Also, as a result of V2 plate current,* there is a positive voltage (e_k) developed across common cathode resistor R5, which provides the bias to cut off V1. The positive-going voltage at the plate of V1 (e_{p_1}) is coupled through capacitor C2 to the grid of V2, driving the grid further positive. Also, at t_0, coupling capacitor C2 charges through the low cathode-to-grid internal resistance of V2 (approximately 1K) and the plate-load resistor, R3, of V1. At t_0, then the common-cathode-resistor-coupled monostable multivibrator assumes its stable state, in which V2 normally conducts and V1 is normally cut off; the circuit remains in this condition until a trigger pulse is applied.



Theoretical Waveforms for Triode Common-Cathode-Resistor-Coupled Monostable Multivibrator

Assume now that a positive trigger pulse of sufficient amplitude to cause the tube to conduct is applied to the *grid of V1 through coupling capacitor C1. The effect of* this trigger pulse (e_{in}, applied at t_1) is to drive V1 into conduction, thus causing an increase in current through V1 and a decrease in the plate voltage (e_{p_1}) of V1. This negative-going voltage is applied instantaneously through capacitor C2 to the grid of V2, driving the grid voltage of V2 (e_{g_2}) below cutoff. When the V2 plate current ceases, the voltage drop (e_k) across cathode resistor R5 decreases to the level where it decreases the bias on V1, permitting this tube to conduct more heavily. Thus, at t_1, a switching action occurs and the multivibrator is in a "temporary" stable state, in which V1 conducts and V2 is cut off.

During this temporary stable state (time interval **b**), capacitor C2 begins to discharge, causing the grid voltage of V2 (e_{g_2}) to become less negative. The discharge path of C2 is downward through grid resistor R2 and then upward through the low cathode-to-plate conduction resistance of V1. At this time V1 alone is conducting; its plate current is limited by its own cathode bias, which is not sufficient to cut off V1. As the voltage (e_{g_2}) on the grid of V2 becomes less negative, because of the discharging of capacitor C2, it soon reaches the point, at t_2, where is is no longer of sufficient amplitude to hold V2 in cutoff. Consequently, V2 once again conducts, and the flow of V2 plate current through common cathode resistor R5 increases the voltage drop (e_k) across this resistor, again increasing the bias of V1 and reducing the flow of plate current through V1. As the conduction through V1 decreases, the plate voltage (e_{p_1}) of V1 rises toward the potential of the positive voltage, supply, +Ebb. The positive-going signal at the plate of V1 is coupled through capacitor C2 to the grid of V2, driving this grid positive (waveform e_{g_2}, at t_2). Thus, capacitor C2 stops discharging and again begins charging. The voltage waveform at the plate of V1 (e_{p_1}) is rounded off, and the voltage waveform at the grid of V2 (e_{g_2}) has a small positive spike of the same time duration, as a result of the charging of coupling capacitor C2 when V2 again conducts. The plate voltage waveform of V2 (e_{p_2}) has a small negative spike, and the voltage waveform across common cathode resistor R5 (e_k) has a small positive spike of the same time duration as the positive spike on the V2 grid voltage waveform (e_{g_2}). Hence, at t_2, the multivibrator reverts to its original stable condition in which V2 conducts and V1 is cut off; the circuit remains in this condition (time interval **c**) until another positive trigger pulse is applied at t_3.

Close examination of the waveforms reveals that the monostable multivibrator goes through one complete cycle of operation for each input trigger pulse. Also, the time of application of the trigger pulse determines when V1 is driven into conduction, and the R-C time constant of R2-C2 and the applied voltage determine when V2 is driven into conduction. Thus, the monostable multivibrator output frequency is determined by the input trigger frequency, and the output gate width is determined by the discharging of capacitor C2 through resistor R2 toward the potential of the positive voltage supply.

A positive trigger pulse applied to the grid of the tube that is normally cutoff, as was done in this case, is not the only method by which the multivibrator circuit can be triggered. A negative trigger pulse applied directly to the cathode of V1 or applied to the grid of V2 and coupled to the cathode of V1 through the cathode-follower action of R5 serves the same purpose. In some practical-circuit applications, a positive trigger is applied to the grid of a "trigger-inverter" stage whose plate is connected in parallel with the plate of V1; the inverted trigger is then coupled through capacitor C2 to the grid of V2 as a negative trigger pulse. In any event, a cycle of multivibrator operation is initiated by driving the normally conducting tube into cutoff, or by driving the tube that is normally cut off into conduction.

FAILURE ANALYSIS.

No Output. The input trigger should be checked with an oscilloscope to determine whether it is being applied to the circuit and whether it is of the proper polarity and amplitude. Lack of an input trigger at the grid of V1 can be due to an open coupling capacitor, C1, or to failure of the external input-trigger source.

Failure of the positive voltage supply, +Ebb, will disrupt the operation of the circuit, as will an open cathode circuit. With tubes (or a single twin-triode tube) installed in the circuit, the filament and plate voltages should be measured, as well as the bias voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether plate-load resistor R3 or R4 or cathode bias resistor R5 is open. If coupling capacitor C2 opens, there will be no feedback signal to effect the multivibrator switching action. An open output coupling capacitor, C3 or C4, will prevent the output-gate signal from reaching the following stage.

Reduced Output. A reduction in output is generally caused by a defective tube; however, it can also be caused by a decrease in the applied voltage or an increase in the resistance of the associated plate-load resistor, R3 or R4. A leaky or shorted output coupling capacitor, C3 or C4, will form a voltage divider with the input resistor of the following stage. If the input resistor of this following stage is returned to ground or to a negative voltage supply, the voltage at the plate of both V1 and V2 will be reduced, and the operation of this following stage will be upset by the change in voltage applied to its grid. Also, the additional current through plate-load resistor R3 or R4 may cause the resistor to burn out.

Incorrect Frequency or Gate Width. The common-cathode-resistor-coupled monostable multivibrator has no components governing the frequency of its output-gate signal; this frequency is governed by the input trigger applied to the circuit. Therefore, any change in the output-gate frequency is a result of improper operation of the trigger-generating circuits. A change in the output-gate width, however, will result if there is a change in the value of either resistor R2, capacitor C2, or the applied voltage. A change in the resistance or capacitance of the R2-C2 timing control circuit will have the greatest effect on the gate width; changes in the applied voltage will affect the gate width to a lesser degree.

PHANTASTRON MULTIVIBRATOR.

APPLICATION.

The *phantastron* multivibrator is used to generate a rectangular-wave output having extreme linearity and accuracy, for use as gating or timing signals.

CHARACTERISTICS.

Operation is similar to that of a *monostable multivibrator*.

Pulse width or delay varies linearly with the applied control voltage.

Requires an electron tube of the pentode or pentagrid type.

Circuit operation turn-on is by application of negative trigger to the plate, or positive trigger to the suppressor, of a pentode or the additional control grid of a pentagrid tube; turn-off is automatic by internally generated waveform.

Output can be taken from the cathode, screen, or plate, and may be either positive or negative, as selected.

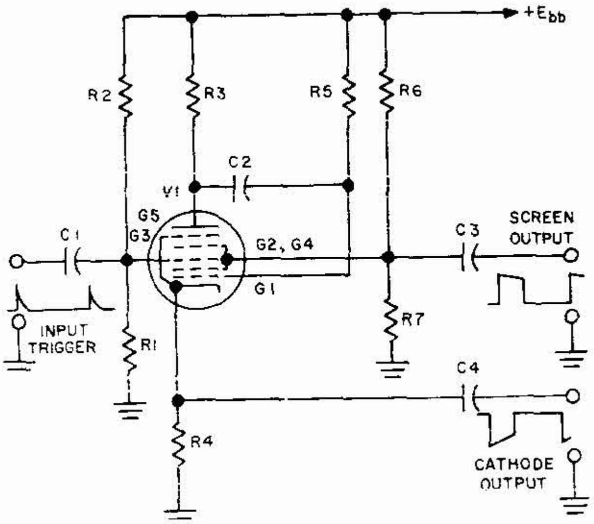
Provides either a low-impedance or high-impedance output, as determined by output connections.

CIRCUIT ANALYSIS.

General. The phantastron circuit is considered to be a relaxation oscillator similar to the multivibrator in operation; the screen-coupled and cathode-coupled phantastron circuits are analogous to the plate-to-grid-coupled and cathode-coupled monostable multivibrators, respectively. A difference in the operation of the circuits is that the monostable multivibrator derives its timing from an exponential waveform developed by an R-C network, whereas the phantastron uses a basic Miller-type sweep generator to produce a linear timing waveform. The phantastron is usually turned on by the application of a gating or trigger pulse, and is turned off automatically by an internally generated waveform. Both a positive and a negative rectangular-wave output with well-defined leading edges may be obtained from the phantastron, depending on the output connections.

For a thorough analysis of Miller circuit operation, and the operation of the screen-coupled, cathode-coupled, and fast-recovery pentode phantastron circuits, refer to Section 20 of this Handbook.

Circuit Operation. The accompanying schematic illustrates a pentagrid tube (type 6SA7 or equivalent) in a cathode-coupled phantastron multivibrator configuration. Although the schematic illustrates a pentagrid tube, a sharp-cutoff pentode, such as the 6AS6 or its electrically equivalent premium-type miniature 5725 or subminiature 5636, could be used as well, provided that the necessary circuit modifications are incorporated as illustrated and described in Section 20 of this Handbook.

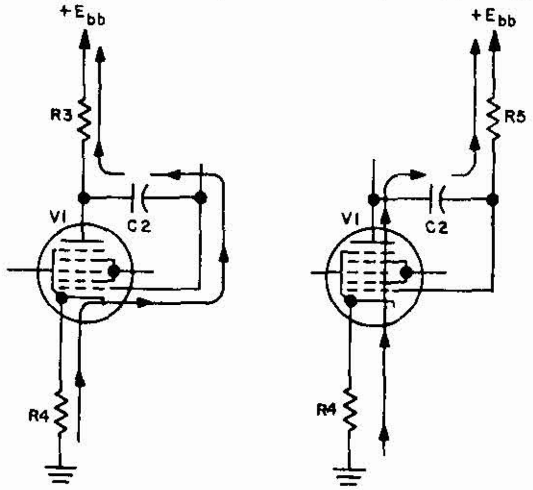


Pentagrid Phantastron Multivibrator

The functions of the electrodes of the pentagrid tube used in this circuit are as follows: Grid 1, which is the control grid, controls the total tube (cathode) current. Grids 2 and 4, connected internally, act as the screen grid. The cathode, the control grid (grid 1), and the screen grid (grids 2 and 4) correspond to the normally conducting tube of the cathode-coupled monostable multivibrator. (*For analysis of* Triode Common-Cathode-Resistor-Coupled Monostable Multivibrator operation, refer to the applicable discussion given earlier in Section 8 of this Handbook.) Grid 3, which is additional control grid, controls the division between screen and plate current; a negative voltage on this grid reduces plate current and increases screen current; a positive voltage has the opposite effect. Also, grid 3 has the effect of changing the cathode current, since some of the electrons returned toward the cathode by its action pass through the screen grid and reduce the space charge near the cathode, thereby causing the increase of screen current to be less than the corresponding decrease in plate current. Grid 5, connected internally to the cathode, is suppressor grid. The cathode, the additional control grid (grid 3), *and* the plate correspond to the normally cutoff tube of the cathode-coupled monostable multivibrator.

The circuit components of the pentagrid-tube phantastron multivibrator serve the following functions: Resistors R1 and R2 form a voltage divider from the positive voltage supply (+Ebb) to ground, setting the bias level of grid 3 and thereby initially holding plate current cut off. Resistor R3 is the plate-load resistor. The cathode-bias resistor, R4, also serves as the *cathode-load* resistor. Resistors R6 and R7 form a voltage divider from the positive voltage supply (+Ebb) to ground, setting the operating voltage level of the screen grid. Resistor R5 returns the control grid to the positive voltage supply, setting the bias level that initially permits the screen grid to conduct heavily. Operation of the circuit occurs at the rate determined by the discharge of feedback capacitor C2 through resistor R5; in some circuits this grid-return resistor, which usually has a value exceeding 1 megohm, is made variable to set the maximum delay or pulse width of the output gate. Capacitor C2 also provides feedback from plate to grid to allow rapid response to any changes in the plate voltage. Capacitor C1 couples the input trigger to grid 3; this trigger initiates (or turns on) the phantastron action. Capacitors C3 and C4 are the output coupling capacitors for the screen grid and cathode, respectively; a positive gate is obtained from the screen grid, and a negative gate from the cathode. If desired, a linear sawtooth waveform can be obtained from the plate of the phantastron circuit.

The following simplified schematic diagram shows the charge and discharge paths for capacitor C2. The charge path (part A of the illustration) is from ground through cathode resistor R4, the low cathode-to-grid conduction resistance of V1, to the right side of the capacitor, and then from the left side of the capacitor through plate-load resistor R3 and the positive voltage supply back to ground. This path causes capacitor C2 to charge at an exponential rate during the time that plate current is cut off and the tube is drawing heavy screen current and only slight control grid current. The discharge path (part B of the illustration) for capacitor C2 is from its right side through grid-bias resistor R5 and the positive voltage supply (+E_{bb}) to ground, and then from ground through cathode resistor R4 and the low cathode-to-plate conduction resistance of V1 to the left side of the capacitor. This path causes capacitor C2 to discharge at a linear rate during the time that screen current is low (near cutoff) and the tube is drawing heavy plate current. The linear discharge of capacitor C2 results from the Miller effect of tube V1, producing a much longer discharge circuit than could be obtained from R5-C2 alone.



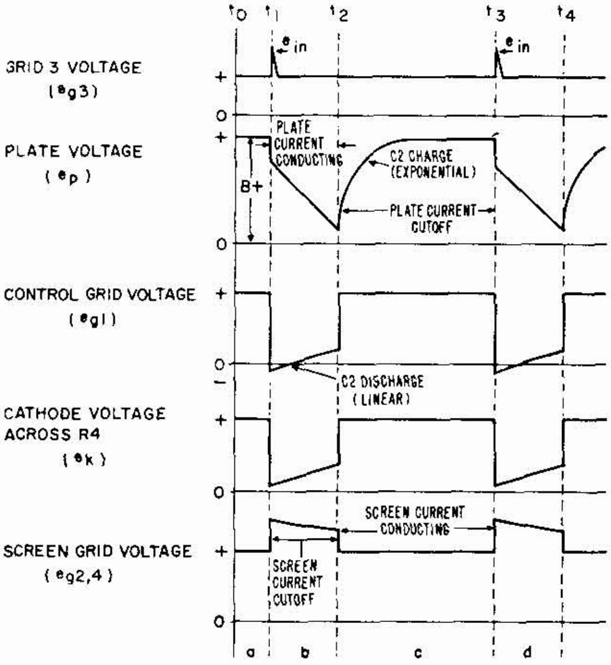
A
CHARGE PATH
(EXPONENTIAL)

B
DISCHARGE PATH
(LINEAR)

Charge and Discharge Paths for Capacitor C2

That is, although the discharge rate of capacitor C2 is determined by the time constant of R5-C2, the discharge capacitance is not the value of C2 alone, but is effectively the value of C2 times the quantity unity plus the gain of V1 (1 + A), which is the Miller effect.

The operation of the phantastron multivibrator can be more easily understood by referring to the preceding circuit illustrations and the accompanying waveform illustration during the following discussion. When voltage is first applied, the plate section of the tube is in cutoff and there is heavy screen grid current. The conduction of screen current is a result of the operating voltage on this electrode, as determined by voltage divider resistors R6 and R7. The voltage is sufficiently positive to attract electrons emitted by the cathode as a result of the positive bias on the control grid (positive voltage return to B+ through resistor R5); this permits the flow of cathode current at this time. In addition to permitting heavy screen current, the positive control grid draws current and charges capacitor C2 through the path described previously. The total screen and control grid current through cathode-bias resistor R4 produces a voltage drop across this resistor. Comparison of the e_k and e_{g3} waveforms reveals that the positive potential at the top of resistor R4 is now greater than the positive potential at grid 3, which is obtained from the action of voltage divider resistors R1 and R2. A bias voltage is therefore established between grid 3 and the cathode; this bias is sufficient to cut off plate current, while having no effect on screen or control grid current. Because there is no plate current, the plate potential is maximum positive (at B+), as



Theoretical Waveforms for Pentagrid Phantastron Multivibrator

depicted by the ep voltage waveform during time interval **a**. Notice, also, during time interval **a**, that the screen voltage ($e_{g_{2,4}}$) is at a minimum as a result of heavy screen current, the cathode voltage (ek) is positive, and the control grid voltage (e_{g_1}) is positive because the positive-going signal at the plate is fed back through capacitor C2. This, then, is the stable state of the phantastron multivibrator; the circuit remains in this condition (heavy screen current and plate current cut off) until a positive trigger pulse is applied to grid 3 at t_1.

When the positive trigger (ein) is applied through capacitor C1 to grid 3, it overcomes the bias on this grid and permits plate current to flow. This current, in turn, causes an immediate drop in the plate voltage developed across plate-load resistor R3. The negative-going signal at the plate is coupled through capacitor C2 to the control grid, where it drives the grid sufficiently negative to reduce the total cathode current. Since the total cathode current is reduced, the screen current is also reduced; thus a positive-going voltage is produced at the screen grid. Through cathode-follower action, the negative-going signal at the control grid is coupled to the cathode, where it reduces the bias between the cathode and grid 3. With a decrease in this bias voltage there is an increase in plate current, resulting in a further drop in plate voltage. The action just described is cumulative and instantaneous, so that when the positive trigger is applied to grid 3 at t_1, there is an immediate increase in plate current and a sharp fall in plate voltage, a decrease in screen current and a sharp increase in screen voltage, a decrease in total cathode current and sharp decrease in cathode voltage, and the control grid is driven negative. All of the voltage relationships are depicted at t_1 on the waveform illustration.

The fact that the plate current increases while the cathode current decreases is possible because the screen current is now decreasing. Therefore, the rise in plate current results from the fact that the plate draws current which had previously gone to the screen grid. That is, the bias between the cathode and grid 3 is decreasing, which is a regenerative action, causing the plate current to increase. Simultaneously, the bias between the cathode and control grid is increasing, which is a degenerative action, causing the total tube current (and screen grid current) to decrease. The screen grid current is only reduced—not cut off completely; if it were cut off completely, the plate current would also be cut off and circuit would not function. Hence, there must be a point were the regenerative and degenerative effects are equal and the current stabilizes for an instant. This is the instant (at t_2, when the sharp drop in plate voltage ceases) at which capacitor C2 begins its linear discharge action.

As capacitor C2 discharges during time interval **b**, it loses electrons from its right side, in effect making this side of the capacitor (and the control grid as well) more positive to reduce the bias between the control grid and the cathode. The reduction in control grid bias permits a heavier flow of plate current through the tube, which gradually raises the voltage drop across cathode-bias resistor R4 (ek waveform) and lowers the plate voltage (ep waveform), as illustrated during time intervals **b**. The rate of change in tube current is governed by the discharge rate of capacitor C2 through resistor R5. Thus, in discharging, the control grid side of capacitor C2 gradually becomes more positive, causing an increase in plate current that produces a constant decrease in plate voltage. The positive voltage increment on the control grid is always slightly greater than the negative-going plate signal it produces; therefore, the the grid potential gradually rises and the plate potential gradually drops, as depicted by the respective grid (e_{g_1}) and plate (ep) waveforms during time interval **b**.

An important characteristic of this circuit is the extreme linearity of the rate of change in the plate voltage and grid voltage during time interval **b**. The positive-going grid increases tube conduction, thereby decreasing the internal resistance of the tube. A decreasing resistance in series with a capacitor results in a linear voltage discharge of the capacitor, instead of the exponential discharge obtained when a fixed value of resistance is in series with a capacitor. The phantastron plate voltage during time interval **b** is, therefore, a linear downward-sloping voltage, and the grid voltage is a linear upward-sloping voltage.

The action described during time interval **b** continues until the plate voltage becomes so low (only a few volts) that the tube can no longer amplify the changes in plate voltage. At this instant, t_3, capacitor C2 stops discharging and the control grid is rapidly driven positive, causing the tube current to increase at a very fast rate. The rapid rise of current through cathode-bias resistor R4 produces a high positive potential on the cathode, which, in relation to the positive potential at grid 3, is a bias sufficient to cut off plate current. Since the total tube current is increasing at this instant, the additional current must flow in the screen grid circuit. The action now occuring is regenerative; as the plate voltage goes positive because of plate-current cutoff, the control grid goes positive and causes an increase in tube current, which produces a higher voltage drop across resistor R4 to increase the bias on grid 3 and further cut off plate current. Thus, the phantastron multivibrator has returned to its original stable state of plate current cutoff and maximum screen grid current, as illustrated during time interval **c**, until the next trigger pulse at t_4 again causes a cycle of phantastron action. Before the phantastron is ready for the next cycle of operation, however, capacitor C2 must charge through the relatively long exponential R-C time constant circuit of R3-C2. Because of the relatively slow recharging of C2, a long period must pass after completion of the phantastron gate before the application of the next trigger pulse. The long charge time of C2 is depicted on the plate voltage (ep) waveform during time interval **c**.

As mentioned previously, when the phantastron is triggered (turned on) there is a sudden drop in the screen current. This produces on the screen grid a positive-going voltage with a steep leading edge ($e_{g_{2,4}}$ waveform). As the tube current gradually increases, producing the linear drop in plate voltage, the screen current increases in the same manner, but by a much smaller amount. The screen waveform will therefore decrease linearly by a small amount until the point of plate-current cutoff (described previously) is reached. At the instant of plate-current cutoff, the screen current increases sharply, causing a sharp drop in screen voltage, as depicted by the trailing edge of the $e_{g_{2,4}}$ voltage waveform; this is the positive-gate output waveform coupled through capacitor C3 to the screen output terminals. The resultant negative-gate output, e_k, taken across cathode resistor R4, is coupled through capacitor C4 to the cathode output terminals. This negative-gate waveform also has steep leading and trailing edges, with the flat portion falling off in amplitude at a linear rate.

From the circuit action just described, it is evident that changing the value of the applied voltage will determine the point, and the time, at which the plate voltage "bottoms", with respect to the time of application of the input trigger. Changing the value of either feedback capacitor C2 or grid resistor R5 will also affect the pulse width by controlling the rate of discharge of capacitor C2. For example, increasing the value of either resistor R5 or capacitor C2 will increase their R-C time constant, thereby causing capacitor C2 to discharge more slowly and increase the width of the delay gate. A decrease in the value of either resistor R5 or capacitor C2 will have the opposite effect on the width of the delay gate. In some phantastron circuits the grid resistor, R5 in this case, is made variable so as to control the maximum width of the delay gate.

Variations of the phantastron multivibrator include separate diodes for input trigger application and clamping the plate voltage at a predetermined level, and a cathode follower in the charging circuit of feedback capacitor C2. The diode in the input trigger circuit acts as a trigger injector and also as a disconnecting diode to effectively isolate the trigger circuit after the phantastron action has started. The "plate-voltage catching", or clamping, diode establishes the maximum level of plate voltage, and, since the turnoff level is fixed, effectively controls the time during which the phantastron produces the linear delay gate. The cathode follower is added to reduce the time required for recharging the feedback capacitor, C2 in this case, between gates; the plate circuit of the pentagrid tube merely raises the grid voltage of the cathode follower, and conduction through this tube charges the capacitor at a much faster rate than through the normal plate-load-resistor charge path. The latter type of circuit is known as a "fast-recovery phantastron". All the variations in phantastron circuitry mentioned in this paragraph are described in more detail in Section 20 of this Handbook; refer to that Section of additional information.

FAILURE ANALYSIS.

No Output. The input trigger should be checked with an oscilloscope to determine whether it is being applied to the circuit and whether it is of the proper polarity and amplitude. Lack of an input trigger at the additional control grid (grid 3) can be due to an open input coupling capacitor, C1, or to failure of the external input-trigger source. It is also possible for excessive bias to make the circuit inoperative because the input trigger amplitude is not sufficient to overcome the bias and initiate the phantastron action. Such a condition is indicated when an input trigger can be seen with an oscilloscope on grid 3 of the pentagrid tube and voltage appears on all tube elements, but either the control grid or cathode voltage is higher than normal. This is most likely to occur when a negative voltage source is used with a common bleeder network to obtain the bias (as in a screen-coupled circuit). Since this cathode-coupled pentagrid circuit develops its own bias, an excessive current drain or short-circuit condition would be needed to increase the bias to the nonoperating point.

Failure of the positive voltage supply, $+E_{bb}$, will disrupt the operation of the circuit, as will an open cathode circuit. With a tube installed in the circuit, the filament, plate, screen, and grid 3 voltages should be measured, as well as the bias voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether an associated electrode resistor is open. If feedback capacitor C2 is open, there will be no feedback signal to promote the phantastron action. An open output coupling capacitor, C3 or C4, will prevent the output-gate signal from reaching the following stage.

Reduced Output. A reduction in output is generally caused by a defective tube; however, a low screen gate output can also be caused by a decrease in applied voltage or a change in resistance value in the screen circuit. Low cathode gate output indicates low cathode current, which is the sum of all tube element currents, and thus may be caused by any one of numerous conditions (decreased tube conductance, reduce plate or screen voltage, etc). Usually, a voltage check will locate the defective circuit and component. A leaky or shorted output coupling capacitor, C3 or C4, will form a voltage divider with the input resistor of the next stage. If the input resistor of this next stage is returned to ground or to a negative supply, the voltage at the screen grid or cathode will be reduced, and the operation of the stage will upset by the change in voltage applied to its grid.

Distorted or Unstable Output. Distortion is indicated by a nonlinear waveform or an inaccurate time delay. Linearity and accuracy of the output gate waveform development is the basic property of this circuit, with the controlling elements being the applied d-c control voltage and the R-C time constant in the feedback circuit. Control voltage trouble may occur when the circuit uses a separate external control voltage from a separate power supply, since power supply fluctuations can easily change the operating level and, therefore, the gate duration. A change of time constant due to changes in circuit values or to feedback capacitor failure or leakage will change the rate of operation and hence the gate length; this should be most noticeable for the longer gate lengths. False triggering due to pickup of noise or stray pulses in the control cabling (on remote units) may affect both the turn-on and turn-off of the gate. This instability, or jitter, can also be caused by power supply fluctuations. An oscilloscope waveform check at each electrode is usually the best method of checking for the cause of the jitter, which can then be traced to its source.

Incorrect Frequency. The phantastron multivibrator has no components governing the frequency of its output gate signal; this frequency is governed by the input trigger applied to the circuit. Therefore, any change in the output gate frequency is a result of improper operation of the trigger generating circuits.

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PART B. SEMICONDUCTOR CIRCUITS

ASTABLE MULTIVIBRATORS.

The term **astable multivibrator** refers to a class of multivibrator or relaxation-oscillator circuits that can function in either of two temporarily stable conditions and is capable of rapidly switching from one temporarily stable condition to the other. The astable multivibrator is frequently referred to as a **free-running multivibrator.** It is basically an oscillator consisting of two stages coupled so that the input signal to each stage is taken from the output of the other. One stage conducts while the other is cut off until a point is reached at which the stages reverse their conditions; that is, the stage which had been conducting cuts off, and the stage that had been cut off conducts. Thus, the circuit becomes free-running because of the regenerative feedback, and the frequency of operation is determined primarily by its coupling-circuit constants rather than by an external synchronizing pulse.

Most transistor multivibrator circuits are counterparts of multivibrator circuits using electron tubes. For example, the collector-coupled transistor multivibrator is analogous to the plate-to-grid coupled electron-tube multivibrator; the emitter-coupled transistor multivibrator is analogous to the cathode-coupled electron-tube multivibrator. Another form of transistor astable multivibrator circuit which is used primarily to convert low-voltage dc to high-voltage ac for rectification, is discussed in the DC-TO DC-CONVERTER circuit given in Section 4, Part B, Power Supplies.

The frequency of operation for an astable multivibrator is determined by the design of the circuit, and depends primarily upon the discharge time constants of the coupling circuits, the supply voltage, and the characteristics of the transistors themselves. Typical repetition frequencies for transistorized multivibrators range from 400 cycles per second to as high as 200 kilocycles per second.

The frequency of the multivibrator can be controlled by changing the value of the time constants in the coupling circuits if a large change in frequency is desired. If a small change in frequency is desired, the frequency can be controlled by changing the base-to-emitter voltage. Many multivibrators use separate power supplies for the base and collector elements; however, in those cases where frequency stability is extremely important, and the frequency is to remain fixed, the circuit is usually operated with a single supply.

The output waveform of the [illegible] multivibrator is commonly a square wave; a square-wave, or symmetrical, output results when the time constants of the coupling circuits are made equal. It is not always necessary that the time constants be made equal; for example, when an unsymmetrical pulse output waveform is desired, the time constants of the coupling circuits are purposely made unequal (some change in applied voltages may also be necessary). However, there are practical limitations to the proportioning of time constants of the coupling circuits to obtain an unsymmetrical output; the circuit may fail to oscillate when power is applied if extreme differences exist in the time duration for the [illegible] of the transistors.

The most common astable multivibrator circuit is the common-emitter configuration; therefore, the output waveform is taken from the collector circuit. If the waveform is symmetrical, the output can be taken from the collector circuit of either transistor; if the waveform is unsymmetrical, the output is taken from the collector circuit which provides the desired waveform. Since most astable multivibrator circuits function similarly, only a basic free-running multivibrator is discussed in the paragraphs to follow.

BASIC FREE-RUNNING ASTABLE MULTIVIBRATORS.

APPLICATION.

The free-running astable multivibrator circuit is a basic circuit. It is [illegible] used to produce a square-wave output for use as a trigger or timing pulse in electronic equipments; this basic circuit, when modified for application to switching circuitry, is representative of a class of circuits which perform computer logic functions (counters, shift registers, and memory circuits), control functions (relay driver circuits), and a variety of similar applications in radar and communications systems.

CHARACTERISTICS.

Free-running oscillator; does not require a trigger pulse to produce oscillations.

Operating frequency is determined primarily by the time constants in the feedback (collector-to-base) coupling circuits and by the applied voltage.

Symmetrical square-wave or rectangular-wave output is produced when the time constants of the coupling circuits are equal. *Unsymmetrical output* is produced when the time constant of one coupling circuit is purposely made several times greater than that of the other; for this condition the transistors are cut off or conducting for unequal periods of time.

Output taken from collector of either transistor in common-emitter circuit configuration.

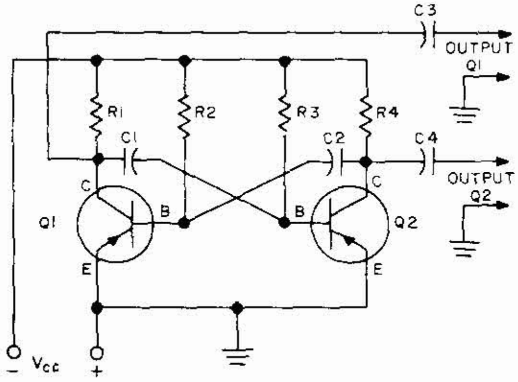
Output impedance is very low when transistor is in conducting (on) state; output impedance is approximately equal to collector load resistance when transistor is in cutoff (off) state.

CIRCUIT ANALYSIS.

General. The free-running collector-coupled multivibrator [illegible] a basic multivibrator. The circuit is fundamentally a two-stage, R-C-coupled, common-emitter amplifier, with the output of the second stage coupled to the input of the first stage. Since the signal in the collector [illegible] emitter amplifier is reversed in phase with respect to the input to the base, a portion of the collector output of each stage is fed to the base electrode of the other stage. Thus, the output signal from each stage is fed back in the proper phase to reinforce the input signal on the base electrode of the other stage; as a result of this regenerative feedback, sustained oscillations occur.

The collector-coupled, common-emitter multivibrator circuit described in the following paragraphs is analogous to the plate-to-grid-coupled electron-tube multivibrator circuit presented earlier in this section of the handbook.

Circuit Operation. The accompanying circuit schematic illustrates two transistors in a basic free-running multivibrator circuit.

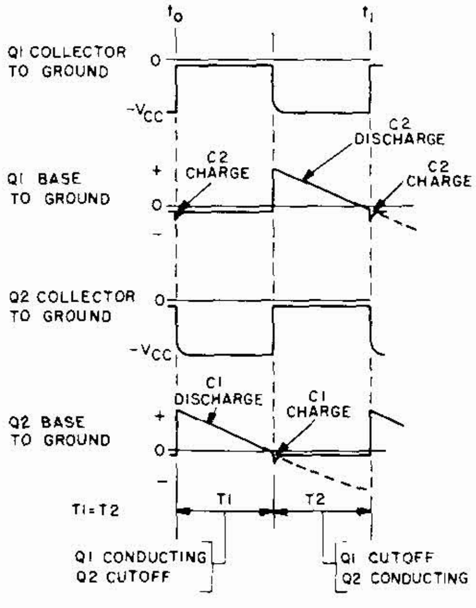


Basic Free-Running Astable Multivibrator Using PNP Transistors

Transistors Q1 and Q2 are identical PNP transistors used in a common-emitter circuit configuration; either junction or point contact transistors may be used in this circuit. Resistors R1 and R4 are the collector load resistors for Q1 and Q2, respectively; R2 and R3 are the base-biasing resistors for Q1 and Q2, respectively. Capacitor C1 provides the coupling from the collector of Q1 to the base of Q2; capacitor C2 provides the coupling from the collector of Q2 to the base of Q1. Capacitor C1 and resistor R3 form an R-C circuit to determine the discharge time constant for the base of Q2; capacitor C2 and resistor R2 determine the discharge time constant for the base of Q1. Capacitors C3 and C4 are the output coupling capacitors for Q1 and Q2, respectively. An output waveform can be taken from the collector element of either transistor, or output waveforms can be taken from the collector elements of both transistors.

The common-emitter configuration illustrated uses a single-battery power source, Vcc. Forward bias for the base of transistor Q1 is obtained through the low-resistance emitter-base junction, which is in series with resistor R2 across the voltage source, Vcc; since the base of Q1 is placed at a negative potential with respect to its emitter, the required forward bias for the PNP transistor is thereby established. In a like manner, forward bias for the base of transistor Q2 is obtained through the emitter-base junction and resistor R3. When voltage is first applied to the multivibrator, the current which flows in each collector load resistor, R1 and R4, is determined by the effective resistance offered by transistors Q1 and Q2 for a given value of base-bias voltage.

The multivibrator circuit shown in the schematic appears to be a balanced (or symmetrical) circuit, since each R-C-coupled stage is identical to the other; however, in spite of the use of close-tolerance components, there will always be minor differences in circuit resistances and in junction resistances within the transistors themselves. (A balanced circuit is assumed here and not necessarily a multivibrator designed for unsymmetrical output.) As a result of this inherent unbalance, the initial collector current (resulting from the forward-bias conditions set up by the emitter-base junction resistances and bias resistors R2 and R3) for each transistor is different, and the immediate effect produced by regenerative action between the coupled stages is that one transistor conducts while the other is cut off. For the purpose of this explanation, assume that initially more collector current flows through transistor Q1 than through transistor Q2; thus, as the collector current of Q1 increases, the voltage at the collector of Q1 decreases with respect to its emitter, or ground. In other words, the collector of Q1 becomes less negative and this, in effect, acts as a positive-going pulse, which is coupled through capacitor C1 to the base of transistor Q2. The positive-going pulse at the base of Q2 makes the base positive with respect to its emitter (ground) and, as a result, Q2 approaches cutoff. The collector current of Q2 decreases because of the reverse-bias action, and the voltage at the collector of Q2 increases, and approaches the supply voltage, −Vcc. In other words, the collector of Q2 becomes more negative and this, in effect, acts as a negative-going pulse, which is coupled through capacitor C2 to the base of transistor Q1. The negative-going pulse at the base of Q1 places the base negative with respect to its emitter (ground), and the collector current of Q1 is further increased because of the forward-bias action. This regenerative process continues until Q1 is driven into saturation (as a result



Theoretical Waveforms for a Symmetrical Free-Running Multivibrator (Using PNP Transistors) of increased forward-bias), and Q2 is cut off (as a result of the reverse-bias conditions).

For the following discussion of circuit operation, refer to the circuit schematic shown previously, and also to the waveforms shown in the accompanying illustration.

Assume that transistor Q1 is conducting and has just reached saturation. When Q1 is at saturation, its collector current no longer increases but rather becomes a constant value (see Q1 collector waveform for period T1); therefore, there is no further change in collector voltage to be coupled through capacitor C1 to the base of transistor Q2. The voltage at the base of Q1 is only a few tenths of a volt negative, and, as a result, capacitor C2 quickly charges (see Q1 base waveform for period T1) through the low resistance of R4 to a potential which is approximately equal to - Vcc. Since the collector voltage at Q1 (Q1 is conducting heavily) is at nearly ground potential, capacitor C1 (previously charged) starts discharging (see Q2 base waveform for period T1) at a rate which is equal to the time constant R3C1, through transistor Q1, the voltage source, and resistor R3.

As capacitor C1 discharges, the voltage at the base of Q2 becomes less and less positive (negative-going) until a point is reached where reverse bias is no longer applied and Q2 is able to conduct (as shown in the Q2 base waveform at the end of period T1).

When the base of Q2 returns to a forward-bias condition, Q2 begins to conduct and its collector current begins to flow through load resistor R4. As the collector voltage at Q2 drops (see Q2 collector waveform for period T2), a changing (positive-going pulse) voltage is coupled through capacitor C2 to the base of transistor Q1. The voltage at the base of Q1 is only a few tenths of a volt negative, and, as a result of the charge on capacitor C2, reverse bias is applied to the base of Q1. Transistor Q1 is driven to cutoff, and the collector voltage of Q1 rises (see Q1 collector waveform for period T2). This rise, coupled through C1, will drive the base of Q2 further into the forward-bias condition. The voltage at the base of Q2 is only a few tenths of a volt negative, and the collector voltage at Q1 is approximately -Vcc; as a result, capacitor C1 quickly recharges (see Q2 base waveform for period T2) through the low resistance of R1 to a potential which is approximately equal to -Vcc. Since the collector voltage at Q2 (Q2 is conducting heavily) is at nearly ground potential (see Q2 collector waveform for period T2), capacitor C2 (previously charged) starts discharging at a rate which is equal to the time constant R2C2, through transistor Q2, the voltage source, and resistor R2.

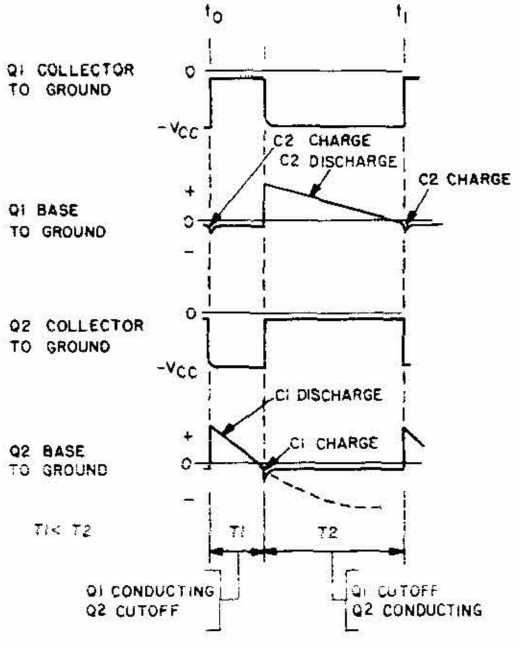
As capacitor C2 discharges (see Q1 base waveform for period T2), the voltage at the base of Q1 becomes less and less positive (negative-going) until a point is reached where reverse bias is no longer applied, and Q1 is able to conduct.

When the base of Q1 begins to conduct, collector current begins to increase through load resistor R1. As the voltage drops at the collector of Q1 a changing (positive-going pulse) voltage is coupled through capacitor C1 to the base of transistor Q2 to initiate another cycle of operation.

For each half-cycle of operation, whenever a changeover of the multivibrator takes place one of two actions occurs: in one case capacitor C1 recharges through load resistor R1 and the base-emitter junction of Q2 to the value of the supply voltage, Vcc, while capacitor C2 discharges through the series circuit consisting of transistor Q2, the voltage source, and resistor R2; in the other case, capacitor C2 recharges through load resistor R4 and the base-emitter junction of Q1 to the value of the supply voltage, Vcc, while capacitor C1 discharges through the series circuit consisting of transistor Q1, the voltage source, and resistor R3.

The discharge times of capacitors C1 and C2 are relatively long as compared with their charge times; thus, the capacitor which is charging reaches its final potential long before the other capacitor has completely discharged. This action can be clearly seen if the Q1 and Q2 base waveforms in the illustration are compared for periods T1 and T2.

The waveforms shown in the preceding illustration are for a symmetrical multivibrator, and the output taken from the collector of either transistor is a square wave. The waveforms shown in the accompanying illustration are for an unsymmetrical multivibrator, and the output waveforms have unequal time durations. The general circuit operation is identical with that of the symmetrical multivibrator; however, the on and off times, or charge and discharge times, are different since different R-C values are used.



Theoretical Waveforms for an Unsymmetrical Free-Running Multivibrator (Using PNP Transistors)

FAILURE ANALYSIS.

No Output. An open-circuited, short-circuited, or overbiased condition, as well as a defective transistor, can cause lack of output. The transistor element voltages can be checked against their proper values to determine the defective component. With the circuit in the non-oscillating condition, a check of the voltages at the collector of each transistor will reveal whether load resistor R1 or R4 is open. If either resistor is open, there will be no collector voltage on the associated transistor; also, the other transistor will conduct heavily because of the reduced bias (the circuit is inoperative), and its collector voltage will be low. (In this case the collector resistor can burn out.) If coupling capacitor C1 or C2 is leaky or shorted, the collector resistor of one transistor will be shunted across the base resistor of the other transistor, and the fixed bias on the base of the transistor to which the defective capacitor is connected, will be increased. If the increase in bias is sufficient, the transistor will be rendered inoperative. (Under certain conditions, an unsymmetrical output can occur.) Also, if coupling capacitor C1 or C2 is open, or if resistor R3 or R4 is open, the circuit will be rendered inoperative, since the R-C circuit resistance will be infinite. If output capacitor C3 or C4 is open, the circuit will operate at a slightly different frequency because of load changes, but no output will be observed.

Incorrect Frequency and Pulse Width. The critical components governing the frequency and pulse width of the multivibrator are those in the coupling circuits. Any change in the components governing the R-C discharge time constant will directly affect the frequency and pulse width. A change in value of coupling capacitor C1 or C2 or in the base resistance R2 or R3 will have the greatest effect. Although a change in the value of collector resistor R1 or R4 will affect the frequency and pulse width, it will have a greater effect on the output amplitude of the waveform.

A 10 percent variation in the collector voltage may cause some frequency drift. However, in practical circuits where the multivibrator is unsynchronized and free-running, adjustments are usually provided to adjust the collector voltage or the base resistance (usually the latter). In this manner the circuit can be set to the correct frequency and pulse width, and can be compensated for the difference in transistor characteristics when a replacement is made.

If output coupling capacitor C3 or C4 is leaky or shorted, the voltage divider action which can occur through the base resistance of the next stage may reduce the amplitude of the output waveform and cause the multivibrator to operate at a higher frequency. This is true because the discharge time in the base circuit is dependent on the amount of change in the voltage applied to the capacitor. Another effect can be a change in the operation of the following stage caused by the bias voltage resulting from this voltage divider action.

If this following stage employs a PNP transistor, the forward bias on the transistor will be increased, with a resultant increase in collector current. The excessive collector current may cause burnout of the collector resistor or the transistor, depending on the ratings of those parts. If the stage employs an NPN transistor the bias will be reversed and cutoff may occur.

BISTABLE MULTIVIBRATORS.

The term **bistable multivibrator** refers to one class of multivibrator or relaxation oscillator circuits that can function in either of two stable states, and is capable of switching rapidly from one stable state to the other upon the application of a trigger pulse. In the strict sense of the word, the bistable multivibrator is not an oscillator; rather, it is a circuit having two conditions of stable (bistable) equilibrium and requiring two input triggers to complete a single cycle. That is, the bistable multivibrator is initially at rest in either one of two stable states; when triggered by an input pulse, the circuit switches to the second stable state, where it remains until triggered by another pulse. Thus, the operation of the semiconductor bistable multivibrator is dependent upon the timing-control action involved in the transfer of conduction from one transistor to the other, initiated by an input trigger pulse of proper polarity and sufficient amplitude. Because there is a sudden reversal (or "flopping") from one stable state to the other, the bistable multivibrator is frequently referred to as a **flip-flop** circuit.

Most semiconductor multivibrator circuits are counterparts of multivibrator circuits using electron tubes. For example, the basic transistor bistable multivibrator is analogous to the triode electron tube Eccles-Jordan bistable multivibrator. In both cases, the bistable multivibrator produces an output pulse, more commonly called a "gate", having fast rise and fall times and extreme flatness on top. To generate this type of waveform, the circuit requires one trigger pulse for turn-on (start) and another trigger pulse for turn-off (stop), thus generating a "step" function for each input trigger. When the trigger pulses are of constant frequency and are applied at long time intervals (low frequency), the gates generated are wide. On the other hand, when the trigger pulses are of constant frequency and are applied at short time intervals (high frequency), the gates generated are narrow. In all cases, however, two input trigger pulses are required to complete one cycle of operation, resulting in an output gate frequency one-half that of the input trigger frequency.

The rectangular-gate output of the bistable multivibrator can be either positive or negative in polarity. Each gate is formed by the combination of positive and negative step functions produced by turning the multivibrator on and off, that is, driving the transistor from cutoff to saturation, and vice versa.

When a transistor is operating in the saturation region, a phenomenon known as **minority carrier storage** occurs. Because the collector-base voltage is limited in its excursion by the resistance in the collector circuit, the collector cannot accept all of the minority carriers injected by the emitter, and, as a result, an excess of minority carriers is built up in the base region. In a PNP transistor that is in a state of saturation, an excess of holes is built up in the base; before the transistor can be turned off, this excess must be removed. Thus, the turn-off operation is a function of the amount of minority carrier storage. Minority carrier storage is one limiting factor in the switching speed of the multivibrator; other factors that limit the switching speed are the operating level of the transistors, collector capacitance, and external circuit elements.

Minority carrier storage can be prevented by limiting the excursion of the collector voltage of a switching stage to an area outside the saturation region of the transistor. In this case, the collector current is not limited by the collector circuit resistance, but rather by the maximum current limitation of the transistor. This is the basis of operation of the "nonsaturating multivibrator"; this circuit is discussed in detail later in this section, as are several other semiconductor bistable multivibrator circuits and bistable multivibrator triggering techniques.

BASIC FLIP-FLOP MULTIVIBRATOR.

APPLICATION.

The basic flip-flop multivibrator produces a square-or rectangular-wave output for use as gating or timing signals in radar sets. It is also used in switching-circuit applications, and for computer logic operations which include counting, shift-registers, clock pulses, and memory circuitry. This circuit is often used for relay-control functions, and for a variety of similar applications in radar and communications systems.

CHARACTERISTICS.

Circuit assumes one of two stable states: one transistor normally conducts while the other transistor is cut off, and vice versa.

Requires two input triggers to complete one cycle of operation; the circuit assumes a stable state upon completion of each half-cycle of operation.

For a constant-frequency input, the output frequency is one-half that of the input trigger frequency.

Input triggers can be either positive or negative (positive trigger may be applied to base of conducting transistor, and negative trigger may be applied to base of cut-off transistor in common-emitter circuit configuration).

Symmetrical triggering occurs when the same trigger pulse is applied simultaneously; unsymmetrical triggering occurs when triggers are applied separately.

Symmetrical or unsymmetrical output gate depends on timing sequence of input trigger pulses; input triggers from different sources (turn-on and turn-off triggers) produce unsymmetrical output gate.

Collector-to-base feedback coupling is direct (through resistors), with bypass capacitors used to speed up switching from one stable state to the other.

Circuit can be made to assume the same initial stable state whenever voltages are applied by incorporating a definite imbalance within the circuit, or by using a manually controlled "reset" signal.

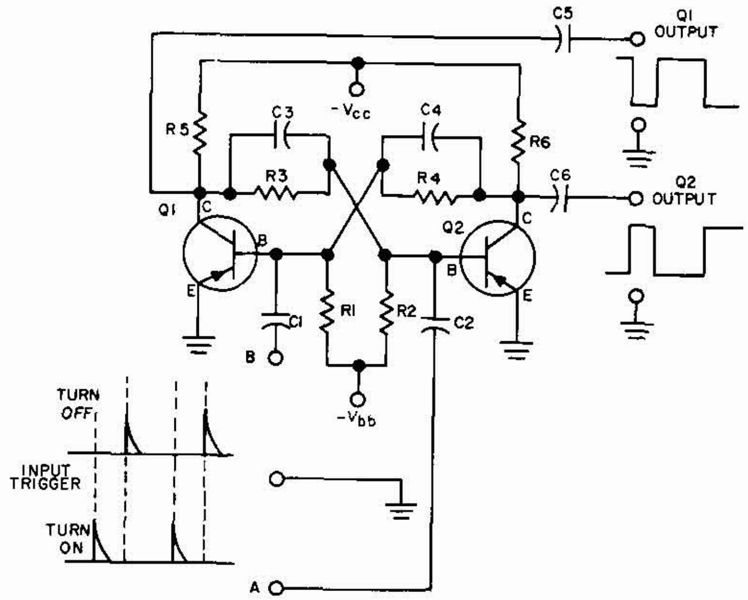
Output is taken from collector of either transistor in common-emitter circuit configuration.

Output impedance is low when transistor is in conducting (on) state; output impedance is approximately equal to collector load resistance when transistor is in cutoff (off) state.

CIRCUIT ANALYSIS.

General. The basic flip-flop multivibrator is capable of producing a square- or rectangular-wave output pulse (gate) in response to two input triggers. This type of multivibrator has two stable (bistable) states – one transistor is normally conducting while the other transistor is normally held cut off – each one functions for only one-half cycle when triggered. Feedback from the collector of one transistor to the base of the other is direct through a coupling resistor bypassed by a capacitor. The capacity shunts the high-frequency components of the pulse from collector to base around the coupling resistor so that the rapid change taking place at one collector is coupled, with minimum attenuation, to the base of the other transistor. Because two input triggers (turn-on and turn-off) are required to complete one cycle of operation, the output gate frequency of the flip-flop multivibrator is one-half the input trigger frequency. The output gate length is determined by the time interval between the turn-on and turn-off triggers. Output signals are taken from the collector of either or both transistors in the common-emitter circuit configuration.

Circuit Operation. The accompanying circuit schematic illustrates two transistors in a basic flip-flop multivibrator circuit. Transistors Q1 and Q2 are identical PNP transistors used in a common-emitter circuit configuration; either junction or point-contact transistors may be used in this circuit. Resistors R1 and R2 are the base-biasing resistors for Q1 and Q2, respectively. Resistor R3 provides the direct coupling from the collector of Q1 to the base of Q2, and resistor R4 provides the direct coupling from the collector



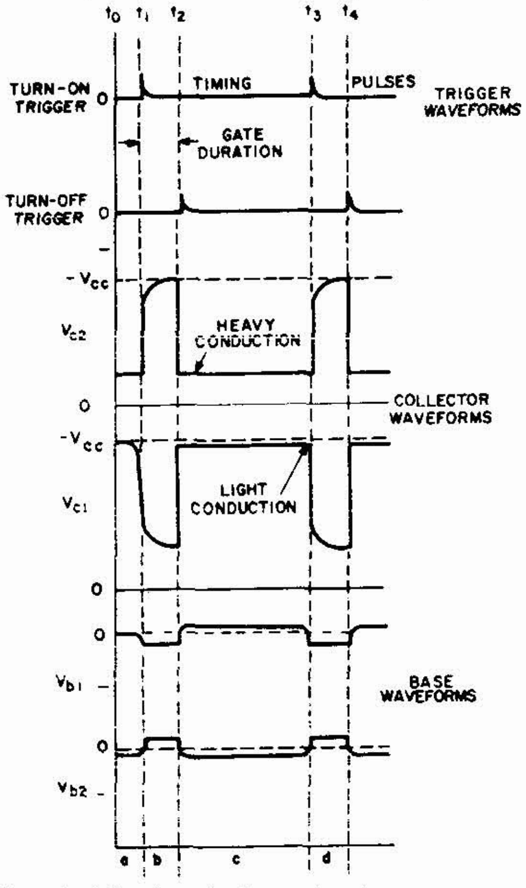
Basic Flip-Flop Multivibrator Using PNP Transistors

of Q2 to the base of Q1. Feedback resistors R3 and R4 are bypassed with capacitors C3 and C4, respectively; these capacitors permit faster switching action from one transistor to the other. Resistors R5 and R6 are the collector-load and output resistors for Q1 and Q2, respectively. Capacitors C1 and C2 are the input trigger coupling capacitors for Q1 and Q2, respectively; they provide unsymmetrical triggering. Capacitors C5 and C6 are the output-gate coupling capacitors for Q1 and Q2, respectively. An output waveform can be taken from the collector element of either transistor, or output waveforms can be taken from the collector elements of both transistors simultaneously.

Fixed bias for the PNP transistors of this flip-flop multivibrator is obtained from two separate d-c voltage sources via voltage-divider networks. Resistors R1, R4, and R6 form one voltage divider between the positive d-c (+V_{BB}) and negative d-c (-V_{CC}) supply voltages. The resistor values are selected so that the voltage at the top of R1 is negative with respect to the grounded P-type emitter of Q1; thus, the emitter of Q1 is forward biased with respect to the N-type base. Another voltage divider, consisting of resistors R2, R3, and R5 between the positive and negative supply voltages, forward biases the emitter of Q2 in the same manner. That is, the voltage at the top of R2 (at the N-type base of Q2) is negative with respect ot the P-type emitter of Q2. Because of the voltage-divider action, the voltage at the collector of each transistor is more negative than the voltage at its base; thus, the collector-base junction of each PNP transistor is reverse biased.

When voltage is first applied to the circuit, the current which flows in each collector load resistor (R5 and R6) is determined by the effective resistance offered by transistors Q1 and Q2 for a given value of base-bias voltage. Although the multivibrator shown in the schematic appears to be a balanced circuit, and in spite of the use of close-tolerance components, there is always minor differences in internal resistance within the transistors. As a result of this inherent imbalance, the initial collector current (resulting from the forward-bias conditions set up by the emitter-base junction resistances and bias resistors R1 and R2) for each transistor is different, and the immediate effect produced by regenerative action between the coupled stages is that one transistor conducts while the other is cut off.

For the purpose of this explanation, assume initially that more collector current flows through transistor Q1 than through transistor Q2; thus, as the collector current of Q1 increases, the negative voltage at the collector of Q1 decreases with respect to its emitter, or ground. Thus, the collector of Q1 becomes less negative and this, in effect, acts as a positive-going pulse, which is directly coupled through resistor R3 to the base of transistor Q2. The positive-going pulse at the base of Q2 makes the base positive with respect to the emitter (ground) and, as a result, Q2 is reverse-biased and approaches cutoff. The collector current of Q2 decreases because of the reverse-bias action between its base and emitter, and the voltage at the collector of Q2 increases, rising towards the value of the supply voltage. In other words, as the collector of Q2 becomes more negative a negative-going pulse is developed across R6, which is directly coupled through resistor R4 to the base of transistor Q1. The negative-going pulse at the base of Q1 makes the base negative with respect to its emitter (ground), and increase the forward bias on the base, causing the collector current of Q1 to further increase. This regenerative process continues until Q1 is driven into saturation (as a result of the increased forward-bias), and Q2 is cut off (as a result of the increased reverse-bias). Thus, with the initial application of d-c power, one transistor is turned on while the other is cut off, and each transistor is then held in this particular state of operation by the feedback from the other transistor until the off-trigger arrives.



Theoretical Waveforms for Basic Flip-Flop Multivibrator (Using PNP Transistors)

For the following discussion of basic flip-flop multivibrator circuit operation, refer to the preceding circuit schematic and the accompanying illustration of the idealized theoretical waveforms. Assume that transistor Q1 has been initially turned on and is conducting heavily in a saturated state, while transistor Q2 remains cut off. Thus the circuit is resting in one of its two stable states of equilibrium as discussed above. The initial turn-on period is represented by time interval **a** on the waveform illustration, while the steady state conducting condition of Q1 is represented by time interval **b**. Therefore, the output at the collector of Q1 is at its most positive excursion, while the output at the collector of Q2 is at its most negative excursion (Q2 is cutoff). Since there is no internal time constant circuit provided to permit the nonconducting transistor to be automatically raised above cutoff (the fixed bias network ensures that it is held below cutoff), the circuit remains in this stable condition until a positive off-trigger is applied Q1.

At time t_2, the positive turn-off trigger is applied to terminal B, and the base of Q1 is instantaneously driven below cutoff. Collector current flow through Q1 reduces, and heavy collector current flow through Q2 develops a positive-going output voltage across R6, which is also applied through R4 and C4 to reverse bias the base of Q1. This additional reverse-bias quickly causes Q1 collector current to cease, and the collector voltage rises quickly towards the supply value, producing a negative-going output through C5. At the same time, this negative-going collector voltage is fed back through R3 and C3 to the base of Q2 as a forward bias. This continuous feedback action of reverse bias on Q1 and forward bias on Q2 continues until the collector voltage on Q2 bottoms, or saturation is reached. The circuit now rests in its second stable state, (during time interval **c**) with Q1 non-conducting while Q2 conducts heavily. The switching action is speeded up by capacitors C3 and C4 which allow the instantaneous changes to be immediately applied to the associated base element to produce the steep leading and trailing edges of the waveform. The circuit remains in this condition (time interval **c**) until another turn-on trigger of positive polarity is applied to terminal A.

At time t_3, the positive turn-on trigger is applied to C2 and the base of Q2 which is forward biased and heavily conducting. The instantaneous positive bias produced by the input signal cancels the existing forward bias and reverse-biases Q2, stopping collector current flow. As the collector current of Q2 ceases, the collector voltage of Q2 rises towards that of the supply and produces a negative-going output signal. Meanwhile, this negative output voltage is also fed back to the base of Q1 through feedback resistor R4 which is bypassed by C4. The instantaneous negative swing through C4 quickly drives the base of Q1 in a forward-biased direction, and causes Q1 to conduct. As Q1 conducts, an output voltage of positive-going polarity is developed across R5, and is fed back through R3, bypassed by C3, to the base of Q2 driving it still further towards cutoff. Thus Q2 is held cut off, while Q1 once again conducts heavily near saturation. This is the starting condition and the other stable operating point (time interval **d** on the waveform).

Close examination of the waveform illustration reveals that the length of the output gates is determined by the time interval between the turn-on and turn-off triggers. If the frequency of the turn-off trigger is made lower, the time interval between the triggers will increase; hence, the gate length will decrease if the turn-off trigger frequency is increased. Thus, the bistable multivibrator provides a positive or negative output gate in response to a timing input (turn-on) trigger pulse, with the gate being terminated by a turn-off trigger pulse. If a **single** constant-frequency trigger is used for both the turn-on and turn-off functions, the circuit produces a **symmetrical** square wave output, with a frequency one-half that of the trigger frequency. A single pulse can be used for triggering because either the leading or the trailing edge of the trigger can be used. When conducting, and the leading edge is applied, a positive trigger operates to reverse bias the conducting transistor while the feedback causes the nonconducting transistor to be turned on. Conversely, if the trailing edge of the trigger pulse is applied to the nonconducting transistor, it produces a forward-biased condition and starts the transistor conducting, while feedback from the transistor produces a reverse bias to stop the first transistor from operating. This action is true as long as the trigger is a sharp pulse of short duration. If of long duration, an unsymmetrical output will be produced.

In the symmetrical-input bistable multivibrator under discussion, negative trigger pulses of sufficient amplitude can also be used to initiate the switching action between transistors Q1 and Q2. When the negative pulse is applied simultaneously to the base of the transistors, there will be no effect on the operation of the conducting tube. However, the collector current on the cut-off transistor will be increased, causing the collector voltage to decrease. The decrease in collector voltage when coupled to the grid of the nonconducting transistor drives this transistor into full conduction. In turn, feedback through this newly turned on transistor biases off the originally conducting transistor.

Although it is true that either negative or positive input trigger pulses can cause the switching action to occur, triggering with positive pulses is preferred. For example, if the cut-off transistor is biased with a highly positive potential, a high-amplitude negative pulse is required to drive it into conduction, and only the most negative portion of the pulse has any effect. On the other hand, a low amplitude positive pulse applied to the conducting transistor immediately drives this transistor into cutoff, causing a relatively instantaneous switching action.

FAILURE ANALYSIS.

No Output. The input trigger should be checked with an oscilloscope to determine whether it is being applied to the circuit, and whether it is of the proper amplitude and polarity. Lack of an input trigger at the base of Q1 or Q2 can be due to an open coupling capacitor, C1 or C2, or to failure of the external input-trigger source. If the input signal does not appear on the base side of the capacitor use an in-circuit capacitance checker to check C1 or C2 for proper capacitance or an open circuit.

Failure of the base bias or collector bias supply will disrupt operation of the circuit as would an open feedback circuit. Use a voltmeter to check the base bias, collector, and supply voltages. Normal voltage indications on these elements also indicates that neither R1 nor R2 is open and, likewise, R3 and R4 also. If either C3 or C4 is shorted, the circuit will still operate as a direct-coupled unit and operation will be somewhat slowed up, but an output will still be obtained. If normal signals appear on the collectors but not at the output, coupling capacitor C5 or C6 is probably open. Use an in-circuit capacitance checker to verify the capacitance value and to check for an open or shorted condition.

Reduced Output. A reduction of output is usually caused by low collector voltage, improper bias, or a defective transistor. A change in the resistance of the associated collector-load resistor R5 or R6 will also affect the output amplitude. Check the resistance with an ohmmeter. A leaky or shorted output coupling capacitor, C5 or C6, will form a voltage divider with the input resistor of the following stage. If the input resistor of the following stage is returned to ground or to a bias supply, the collector voltage on either Q1 or Q2 will be changed and operation of the following stage will be upset by the change in voltage on its grid. In addition, this may possibly cause additional collector current flow through collector resistor R5 or R6 and may cause the resistor to burn out.

Incorrect Frequency or Gate Width. The basic flip-flop multivibrator has no parts governing the frequency or width of the output gate signal; these are both governed by the input triggers applied to the circuit. Therefore, any change in the output-gate frequency or width is a direct result of improper operation of the turn-on and/or turn-off trigger generating circuits.

DIRECT COUPLED (OR BINARY) MULTIVIBRATOR.

APPLICATION.

The direct-coupled (or binary) multivibrator produces a square or rectangular output waveform primarily for use in computer circuit and switching operations such as computer logic, counting and shift register operations, clock pulse generation and memory circuit.

Because of its simplicity is also serves a variety of similar applications in radar and electronic equipments.

CHARACTERISTICS.

Usually employs self bias.

Provides two outputs (one is the inverse of the other).

Requires a turn-off or reset trigger to change state.

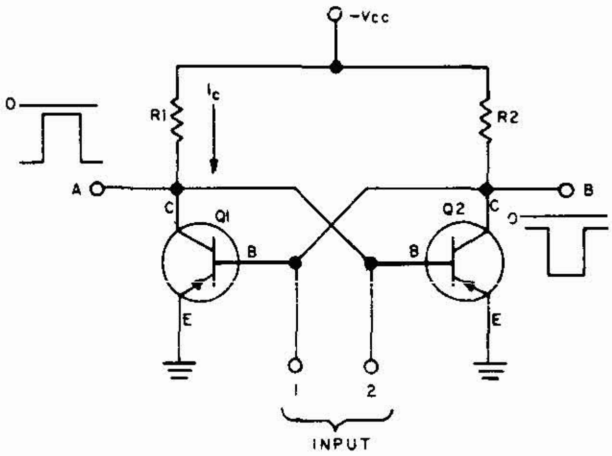
Requires a minimum number of parts.

Operates at low levels (10-15 millivolt input controls 200-300 millivolt output).

CIRCUIT ANALYSIS.

General. The d-c coupled or binary (count-by-two circuit) multivibrator offers design simplicity and a minimum of parts which leads to its frequent use in logic circuitry. It is basically, a bistable multivibrator with two states of stable operation. In the on-state, one transistor continuously conducts while the other remains cut off. In the off-state, the previously conducting transistor is cut off and the previously nonconducting transistor is switched on. The change of state is accomplished only by a separate trigger. There is no R-C timing network to permit automatic charge or discharge to control the switching rate. Design is usually such that the conducting transistor operates in a saturated condition. Thus the base voltage is higher than the emitter and the collector voltages, and all element voltages are low in value with only a fraction of a volt difference between them. Consequently, the conducting transistor has a low value of dissipation, and the output is also low. As a result, the d-c multivibrator usually requires a stage of external amplification if other transistors are to be driven by it. When operated as a saturated flip-flop it requires a higher turn-off power than that of the non-saturating type (discussed later in this section of the Handbook). Since no emitter resistors are used, the circuit is somewhat sensitive to temperature changes above 60 degrees Centigrade.

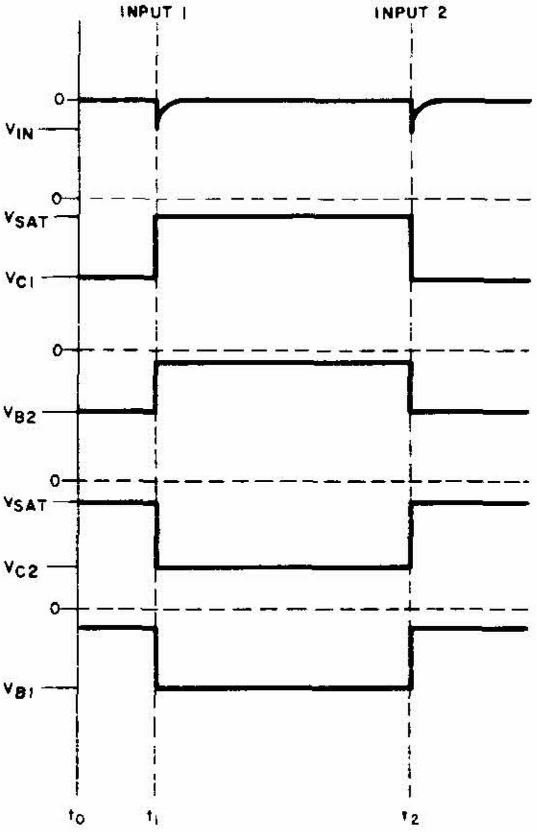
Circuit Operation. The accompanying schematic illustrates a basic d-c flip flop.



Basic PNP Direct-Coupled (Binary) Flip Flop

Note that only two resistors (R1 and R2) are used, which serve both as collector resistors and as feedback resistors, and across which the output is developed. For simplicity, the control trigger circuitry is not shown.

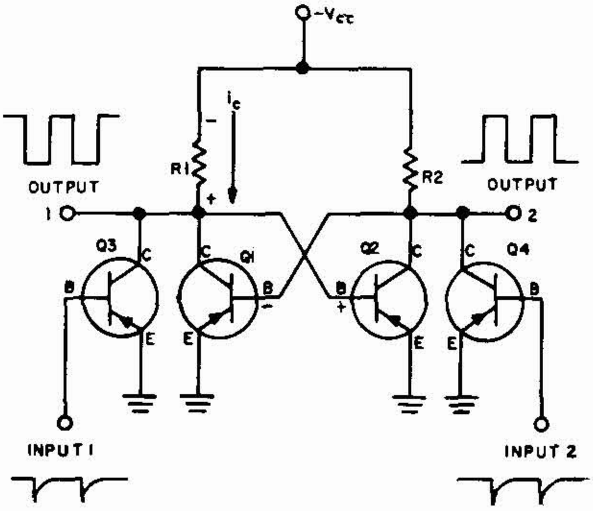
Initially a forward bias is applied to both transistors by connecting the base of Q1 and Q2 to R2, and R1, respectively (the negative supply voltage through the resistor places a forward negative bias on the transistor). In the absence of a trigger pulse both transistors tend to conduct. However, the first one to establish a flow of collector current produces a positive-going collector swing which is applied to bias the opposite transistor below cutoff. Because of the inherent slight difference in base resistance between similar transistors, one transistor will always conduct more heavily than the other. Assume for the sake of discussion that Q1 is conducting and Q2 is driven to cutoff. Since this circuit operates at collector saturation, a heavy current flows from the supply through resistor R1, and transistor Q1 to ground. The flow of I_c as shown on the schematic produces a positive voltage drop across R1. This positive-going voltage is fed back directly to the base of Q2 as a reverse bias which immediately stops conduction through Q2. The heavy flow of I_c drops the collector voltage of Q1 to almost zero (it is saturated). Meanwhile, since Q2 stops conducting its collector voltage rises to nearly the full negative supply value. Since the base of Q1 is connected to the collector end of R2, this negative-going feedback voltage is applied to the base of Q1 as a large forward bias. The base voltage on Q1 is now higher than that of the collector, and since the emitter is grounded and effectively at zero potential, the base voltage is also higher than the emitter. Thus the base voltage is the dominating voltage which holds Q1 conducting until a turn-off trigger arrives. The circuit is now operating between intervals t_1 and t_2 as shown on the accompanying waveform illustration.



Typical Waveforms

At time t_2 the turn-off trigger arrives, and a negative input pulse is applied via input 2. Consequently, the negative input on the base drives Q2 in a forward direction (the *small saturation voltage fed from the collector of Q1 is* easily overcome by the negative input pulse), and Q2 conducts. Immediately, current flow through R2 causes a positive swinging voltage to be applied to the base of Q1, stopping conduction through R1. As conduction ceases through R1 the collector voltage of Q1 rises towards the full negative supply value, and feeds back an increasing negative voltage to the base of Q2. Thus, Q2 is quickly switched into conduction while Q1 is turned-off. At time t_2 the second stable state is accomplished, and now the circuit awaits another turn-off trigger at time t_3. This is merely a repeat of the sequence of operation at time t_1. Namely, a negative trigger is applied to input 1 which drives the base of Q1 in a forward direction, causes collector current flow through R1 and feeds back a positive-going voltage to the base of Q2 causing it to stop conducting. Instantaneously, the collector voltage of Q2 rises towards the negative supply value, and drives the base of Q1 into heavy conduction. The circuit is now resting in the initial state, with Q1 conducting heavily and Q2 cut off.

The circuit schematic of a practical binary multivibrator is shown in the accompanying illustration, with control circuitry. Except for the operation of transistors Q3 and Q4, circuit operation is identical and corresponding parts are labelled identically so that the discussion above applies.



Typical PNP Binary Multivibrator

Transistor Q3 and Q4 merely act as switches, when a negative trigger is applied to their base they conduct, and when no trigger is present they are held nonconducting. The control transistor connected to the conducting multivibrator transistor is held at cutoff by the low saturation voltage of the collector to which it is connected, while the other is held cutoff by the high reverse bias at the non-conducting collector. Since their emitters are connected directly to ground, when triggered, they develop a shut-off pulse which stops the conducting transistor from operating and causes the switching. For example, assume Q1 heavily conducting, with its base held negative by the feedback from R2. Q4 is resting reverse biased awaiting the control trigger. When the negative control trigger (input 2) arrives, the base of Q4 is driven negative and this forward bias causes the transistor to conduct through R2. Flow of collector current in Q4 develops a positive swinging pulse across R2 and drives the base of Q1 positive to cutoff. Thus Q1 is stopped from conducting. Transistor Q3 operates similarly, assuming Q2 conducting and Q1 cut off, the negative input to Q3 (input 1) causes collector conduction and produces a positive pulse across R1, thereby driving Q2 base positive to cutoff, and switching Q1 into conduction by the feedback developed as the collector of Q2 rises towards the negative supply at cutoff.

FAILURE ANALYSIS.

Partial or No Output. A no-ouptup condition can only be caused by a lack of bias voltage because of a blown fuse or defect in the supply, or because both transistors Q1 and Q2 or load resistors R1 and R2 are defective. If either Q1 or Q2 is operable and either R1 or R2 is not open, a single unswitched output will be obtained, since the circuit has two states of operation. First check the supply voltage with a high resistance voltmeter to ascertain that a blown fuse or defective power supply is not at fault. Then check the collector voltage to ground. Transistors Q1 and Q3 will show either a high negative voltage or practically zero voltage depending on whether or not Q1 is conducting, while Q2 and Q4 will produce exactly the opposite indication under normal operation. If both Q1 and Q2 indicate either a low voltage or a high voltage, one or both of the transistors is at fault. Use an in circuit transistor checker to locate the defective one. In the absence of a transistor checker use an ohmmeter, and check the forward and reverse resistance of the emitter and collector junctions with the bias removed. The forward resistance should be considerably lower than the reverse resistance. Replace any defective transistors with known good ones. Since control transistors Q3 and Q4 shunt the multivibrator transistors, if defective, the output will also be shunted to ground. If inoperative, there will still be a single output and the stage will not change state. If they are simultaneously shorted, there will be no output and both Q1 and Q2 collector voltage will be almost zero. If only one is shorted there still will remain a single output which cannot be switched by application of an input trigger.

Reduced Output. A reduced output is usually caused by low collector voltage, improper bias, or a defective transistor. Any change in the resistance of collector load resistors R1 or R2 will also affect the output amplitude. Use a high resistance voltmeter to check the supply and collector voltages, and measure the resistance of R1 and R2 with an ohmmeter. If the voltages are normal and both R1 and R2 are of proper value the transistor must be at fault. Check the beta of both transistors with an in-circuit checker to determine which has a loss of gain, or use an oscilloscope to locate the low output waveform and associated transistor.

Incorrect Frequency or Gate Width. The direct-coupled multivibrator has no parts governing the internal frequency or width of the output gate signal; these are solely controlled by the input triggers applied to the circuit. Therefore, any change in output gate frequency or width can only be a direct result of improper operation of the turn-on or turn-off trigger generating circuits, not the multivibrator.

SQUARING MULTIVIBRATOR CIRCUIT.

APPLICATION.

The squaring multivibrator, also known as the Schmitt trigger or emitter-coupled bistable multivibrator, is primarily used to supply a square or rectangular output when triggered by a sine-wave, sawtooth, or other irregularly shaped waveforms.

CHARACTERISTICS.

May be self or fixed biased.

Has two stable (bistable) states of operation (one transistor conducts while the other is cut off, and vice versa).

Provides a symmetrical output gate regardless of input waveform.

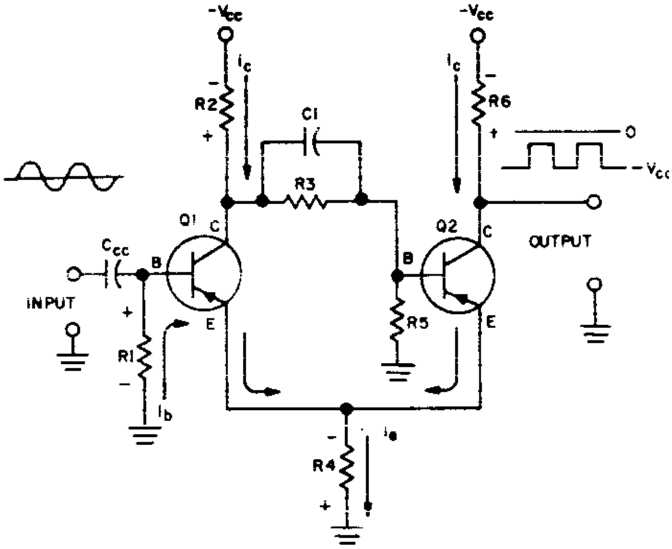
Collector to base feedback provides one switching path, while common emitter coupling feedback provides the other switching path.

Uses common emitter configuration.

CIRCUIT ANALYSIS.

General. The Schmitt circuit differs from the conventional bistable multivibrator circuit in that one of the coupling (feedback) networks is replaced by a common emitter resistor (the equivalent of cathode coupling in the electron tube). The additional regenerative feedback developed by the common emitter-feedback coupling arrangement provides quicker action and straighter leading and trailing edges on the output waveform than in other multivibrators. Because of the relatively instantaneous switching action of this arrangement, the waveform of the input trigger has no effect on the output so that essentially square-wave output signals are always produced.

Circuit Operation. The schematic of a typical Schmitt type squaring circuit is shown in the accompanying illustration.

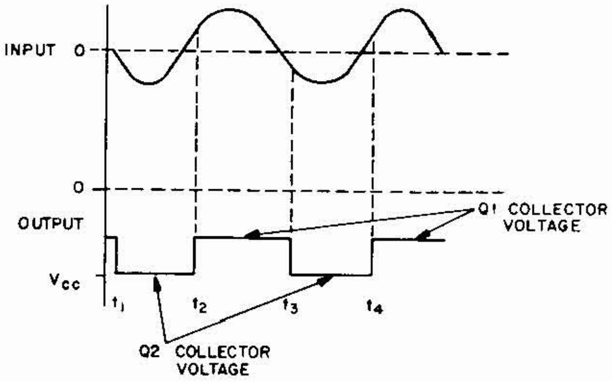


PNP Squaring Multivibrator

Transistor Q2 is the initially conducting transistor, which is supplied with forward base bias by resistor network R2, R3, and R5 connected as a voltage divider between the negative voltage supply and ground. Capacitor Ccc and base resistor R1 form a conventional R-C input coupling circuit. Resistor R4 is the feedback (coupling) resistor which is common to both emitters, and R6 is the collector resistor of Q2 across which the output waveform is developed. Capacitor C3 bypasses feedback resistor R3 to help speed up switching action.

Initially, transistor Q2 conducts heavily because of the large forward bias supplied by the voltage divider consisting of collector resistor R2, feedback resistor R3, and base resistor R5, series-connected between the negative supply and ground. A reverse collector bias is applied Q1 through R2, and a reverse emitter-bias is developed across the common emitter resistor R4 by Q2 current flow. Base current flow through R1 is also in a direction which produces a reverse base bias on Q1, so that Q1 cannot conduct until triggered. Thus, Q1 remains cutoff, while Q2 conducts. With Q2 conducting, a positive-going output voltage is developed across collector resistor R6 which lowers the effective collector voltage of Q2 to almost zero. No output coupling capacitor is shown since the circuit may be direct coupled to the following driver stage, if desired.

Assume now a sine-wave input signal is applied to Ccc. During the positive half-cycle of operation the positive input voltage applied across R1 keeps Q1 reverse-biased so that it cannot conduct. Since in this condition the output is developing a positive signal similar to that through initial conduction, as explained previously, it is evident that the input and output are in phase. When the input signal swings negative during the opposite half-cycle of operation, a negative voltage appears across R1 as Ccc discharges. The base of Q1 is thereby driven negative and forward biased, starting collector current flow through R2. The direction of electron flow is such that the collector end of R2 becomes positive (as marked on the schematic), and this instantaneous positive swing is coupled through C1 to the base of Q2, appearing as a positive reverse bias which instantly stops current flow through Q2. The reduction of collector current flow through R6 produces a voltage of opposite polarity to that shown on the schematic, that is a negative output voltage, as the collector of Q2 rises towards the supply voltage (time t_1 to t_2 on the waveform illustration).



Typical Input and Output Waveforms

Although R3 connects the collector of Q1 to the base of Q2, and any voltage appearing on the collector of Q1 will also eventually appear on Q2 base, a speed up of this action is obtained by bypassing R3 with capacitor C1. Thus, the high frequency components of the collector signal are not slowed up by the resistance of R3 so that switching action is faster than without C1.

Consider now the effect of the common coupling resistor (R4) in the emitter circuit. Initially the heavy current through Q2 produced a negative drop across R4, as marked on the schematic. This negative emitter bias which is degenerative, because no bypass capacitor is employed, also tends to prevent Q2 current flow. However, the base bias of Q2 is much larger and the degenerative emitter voltage produced across R4 has little effect on Q2 collector current flow. However, Q1 is already at cutoff, and this additional negative emitter bias ensures that it remains so until sufficient base input is applied (on the next half-cycle) to overcome this reverse bias.

With the collector current flow of Q2 reducing, the degenerative voltage developed across R4 also reduces, which is the same as applying an increasing positive voltage between emitter and ground. Thus, while the base of Q1 is driven in a forward-biased direction by the input signal, a regenerative feedback is developed in the emitter circuit by the reduction of Q2 current flow. Consequently, transistor Q1 is quickly driven into heavy conduction near saturation. The resulting instantaneous positive swing developed across R2 is instantly applied through C1 to the base of Q2, and quickly drives Q2 to cutoff. The circuit now rests in its second stable state (interval t_1 to t_2) until another trigger arrives to drive Q2 into conduction and cut off Q1.

When the input signal again swings in a positive direction (time interval t_2), the positive voltage appearing across R1 causes a reverse bias to be applied Q1 base and reduce collector current flow through R2; this produces a negative swinging voltage across R2, which is applied to the base of Q2 through capacitor C1. The negative swing forward-biases Q2 and starts it conducting, and develops a positive-going voltage swing across R6 to provide an inphase output voltage. Simultaneously, the increased negative emitter (reverse) bias developed across feedback resistor R4 further stops conduction in Q1. This regenerative feedback action quickly drives Q2 to collector saturation and Q1 to cutoff, whereupon the rising negative collector voltage of Q1 applied tobase of Q2 through C1 and R3 holds Q2 strongly conducting despite the degenerative emitter voltage developed across R4 (time interval t_2 to t_3). This is the initial order of conduction and the transistor awaits the next trigger (at time t_3) to turn off Q2 and turn on Q1. Because of the extreme regenerative action of the emitter-coupled circuit, once started, the switching action is quickly accomplished, and the shape of the input trigger has no effect in determining the output waveform. Cutoff and turn-on is sharp and the sides of the waveform are steep. The width of the output waveform like the other bistable multivibrators is controlled by the difference in time between the off and on pulses. When symmetrical and equal a true square wave is produced.

FAILURE ANALYSIS.

Constant or No Output. Lack of supply voltage, an open common emitter resistor, or defective transistors are about the only three items which can cause a no output condition, since at least one steady output can always be obtained if any voltage is present. Check the supply voltage with a high resistance voltmeter to make certain that a blown fuse or defective supply are not at fault. Since R4 connects both transistors to ground and they are reverse collector biased, no conduction will occur if R4 is open, and a steady negative output will be obtained. A zero emitter to ground voltage reading will indicate that R4 should be replaced. If a steady positive, or near zero but constant voltage is obtained, Q1 is probably defective and should be replaced with a known good transistor. On the other hand if Q2 is shorted the same indication would occur. Likewise, if Q2 is open a steady negative output voltage would be obtained through R6. It is evident that it is rather difficult because of the feedback and direct connections in this type of circuit to obtain a specific indication which conclusively points to only one cause of trouble. Therefore, a simple voltage check plus a resistance analysis of the few parts involved should quickly locate the defective component. If the voltage and resistance are correct but an unswitchable steady output is still obtained, check that an input trigger is being received on both sides of coupling capacitor Ccc, using an oscilloscope.

Reduced Output. A reduced output can occur because of low supply voltages, improper bias voltage, or defective transistors. Check the supply and bias voltage with a high resistance voltmeter. Use an incircuit transistor checker, or check for a low forward-resistance and a high reverse-resistance with an ohmmeter.

Incorrect Pulse Width or Frequency. Like the other bistable multivibrators, an effect on frequency or pulse width is controlled by the time difference between the on-

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and off-triggers. Thus any faulty operation of this type is due solely to defects in the trigger generating circuits and not the multivibrator.

SATURATING MULTIVIBRATOR.

APPLICATION.

The saturating multivibrator is used to supply a rectangular gate, or trigger, in radar and control applications, and in the logic switching circuits of computers and similar devices.

CHARACTERISTICS.

Usually uses fixed bias.

Provides two outputs simultaneously, one the inverse of the other. Requires a turn-on or turn-off trigger to change state.

Has two (bistable) stable states (one transistor conducts while the other remains cut off and vice versa).

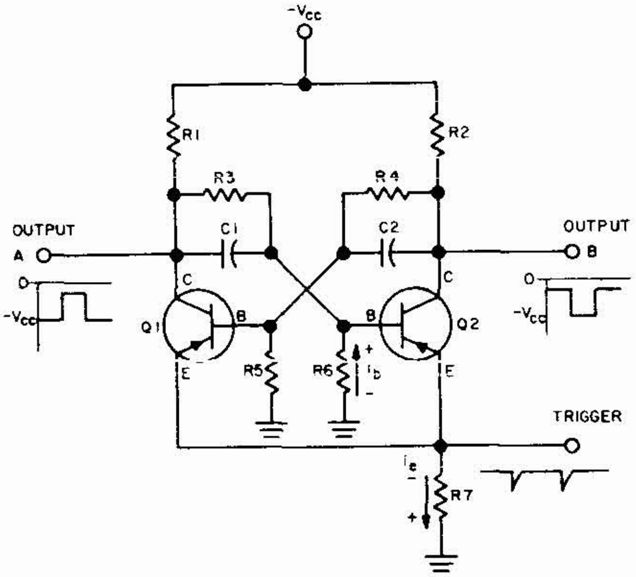
Output power is considerably lower than that of the nonsaturating type.

Operating speed is slower than the nonsaturating multivibrator.

CIRCUIT ANALYSIS.

General. In the saturating multivibrator, the emitter and collector voltages are lower than the base voltage and there is only a few tenths of a volt difference between them. Consequently, it takes more driving power in this saturating circuit, as compared with the nonsaturating circuit, to drive the stage out of saturation (a larger trigger is required). The output voltage is also less. Thus, while a certain amount of stability may be imparted by saturated operation the gain and speed suffer. The gain is limited by the low saturation voltages, and the speed by the amount of time required to obtain hole dispersion (the extremely heavy saturation current injects extra holes in the base, which require a finite recovery time to remove them). As a result, the saturated circuit is used where its simplicity makes it more economically feasible than the non-saturating type.

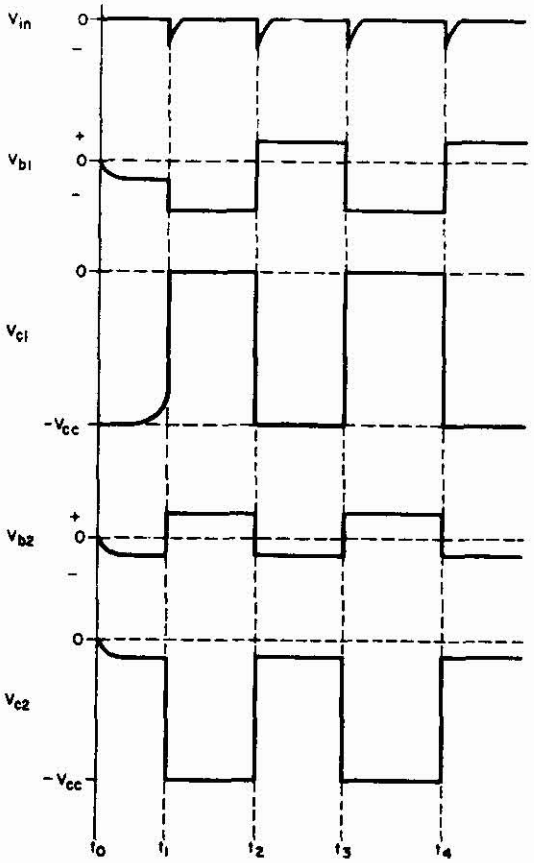
Circuit Operation. The schematic of a typical saturated multivibrator is shown in the accompanying illustration.



Saturated PNP Multivibrator

Fixed bias is applied by a voltage divider arrangement, consisting of R1, R3, and R6 for transistor Q2, and R2, R4, and R5 for Q1, connected between the negative supply and ground. Feedback resistors R3 and R4 are bypassed by capacitors C1 and C2, respectively, to speed up response. An output is taken from each collector, and the input trigger is applied across emitter resistor R7, which is common to both transistors. This circuit arrangement is that of the conventional bistable multivibrator arranged for common emitter triggering.

In the quiescent condition, with no trigger applied, both transistors conduct immediately when the supply voltage is applied, since they are both forward biased through voltage dividers to the negative supply. Although the circuit is symmetrical, that is, the collector, feedback, and base resistors are all of equal values to minimize any unbalance, there still exists a slight difference in base resistance between transistors of the same types. Thus, one transistor always tends to conduct more heavily than does its counterpart, and through feedback from the collector to the opposite base drives the associated transistor to cutoff, and itself to full conduction. Assume for the sake of discussion the normally-on transistor is Q1, while Q2 is the normally-off transistor. From time t_0 to t_1 (as shown on the accompanying waveform illustration) the initial conduction is established as previously explained, so that at time t_1 transistor Q1 is conducting while Q2 is cutoff. Since the turn-off input trigger at this time is stopping Q2 there is no effect and the circuit rests in its initially-on state until time t_2.



Typical Waveforms

During the interval from t_1 to t_2 a continuous positive (reverse) bias exists at the base of Q2 due to base current flow from ground through R6, producing a voltage drop of the polarity shown on the schematic (this current is actually produced by reverse collector current I_{ceo}). Thus, with reverse base bias and a reverse collector bias, Q2 remains cut off until the next turn-on trigger arrives. Since no collector current flows through R2 the collector of Q2 rises towards the value of the negative supply voltage and drives Q1 base in a forward-biased direction, causing heavy conduction through Q1. The heavy collector current drops the voltage across R1 to almost zero, and a positive-going output is produced at A, while a negative output from Q2 is produced at terminal B. Once saturated, the collector voltage of Q1 is less than the base voltage fed back from Q2. With high current but low voltage, the power dissipation of the transistor is well within ratings (one advantage of saturated operation is the low collector dissipation involved). They heavy emitter current flow through the common, emitter-coupling resistor R7 places a large degenerative voltage on the emitter of Q2 which effectively reverse-biases Q2. Thus Q2 is held in its off-state, regardless of whether or not the off period is long enough for C1 to discharge. The only effect on operation that C1 has is that of speeding up the switching operation by shunting the high frequency transients around R3 to help speed up turn-on, or turn-off, switching action.

When the negative trigger is applied at t_2 the emitter of Q1 is driven negative, which is the same as driving the base positive to reverse bias the transistor. Since transistor Q2 is already reverse-biased, this trigger has no effect on Q2, only on Q1. Consequently, the collector and emitter current of Q1 is reduced. This reduction of collector current produces a negative-swinging voltage across collector resistor R1, and through C1 to the base of Q2. The instantaneous negative swing applied to the base of Q2 drives Q2 in a forward-biased direction, and causes collector current flow through collector resistor R2. The voltage drop across R2 produced by the increasing collector current reduces the collector voltage, effectively producing a positive-swinging voltage at the collector, which is fed back through capacitor C2 to the base of Q1. The positive-swinging voltage drives the base of Q1 instantaneously in a reverse-biased direction and causes a further drop in collector current. The regenerative feedback action continues smoothly and quickly until Q2 is driven into collector saturation (collector voltage bottoms), while Q1 is cut off. While this regenerative feedback and switching action occurs, a degenerative voltage is developed across common resistor R7 in the emitter circuits of both transistors. Although this degenerative emitter voltage normally is of such polarity as to oppose the increase of current, it is not of as great an amplitude as the feedback voltage developed across R5 which is driving Q1 to cutoff, or the feedback voltage developed across R1 which is driving Q2 into conduction. It does, however, aid in obtaining collector current cut off on Q1 since the transistor is already being driven in that direction. and eventually reaching saturation. Because the heavy collector saturation current of Q1 produces extra holes in the base of Q1, transistor Q1 does not stop conduction immediately when its base voltage is driven positive and base current flow is stopped. But instead, the collector current continues to flow for a finite interval, even though there is no forward bias on Q1, until the holes are removed from the base of Q1 and cut-off prevails. With no collector current flow, the collector of Q1 rises in a negative direction towards the full supply voltage, and a negative output is produced at terminal A. Meanwhile, as Q2 conducts heavily saturated, the collector current is almost zero, and a positive output voltage is produced at terminal B by the voltage drop across collector resistor R2 of Q2. Conditions are now exactly opposite the original state and Q2 rests in the on-state (interval t2 to t3), while Q1 rests in the cutoff state awaiting a negative turn-on trigger at time t3.

When the turn-on trigger arrives at time t3, the emitter of Q1 and Q2 is driven negative. Since Q1 is already in a non-conducting state the trigger cannot further stop conduction so it has no effect on the operation of Q1. However, the trigger does drive Q2 in a reverse-biased direction (a negative emitter trigger has the same effect as a positive base trigger), and causes a reduction of collector current flow through R2. Immediately a negative-swinging voltage is developed across R2 and applied through C1 to the base of Q1, which drives Q1 in a forward direction towards saturation. The increasing collector current flow through R1, again produces a positive-swinging collector voltage which is applied through C1 to the base of Q2, further driving Q2 in a reverse biased direction and further reducing collector current flow. This regenerative switching action is smooth, continuous and relatively fast so that except for a slight delay caused by hole storage, as explained previously for the opposite condition of conduction in Q1, the switching is considered to be almost instantaneous. When Q1 reaches saturation and Q2 is completely cutoff, minimize hole storage time and produce speedy operation, even as high as 20 megacycles. Thus, the tendency is to use saturated circuitry generally for its simplicity and economy. Non-saturated circuits are usually only used when output power requirements call for more power than can be produced with saturated circuits.

FAILURE ANALYSIS.

General. When making voltage checks use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low voltage ranges. Be careful also to observe proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

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Partial or Steady Output. Failure of one half of the circuit to operate will produce a partial output in the form of a steady single polarity output. Failure of the supply voltage, or emitter resistor R7, are about the only two possibilities of obtaining no output at all. Because of the feedback connections it becomes rather difficult to isolate the trouble by symptom along. It is quicker to make a voltage check and determine if the supply voltage is present, and that no fuse or power supply is at fault. Then use an ohmmeter to the stage again rests in the original conducting state awaiting a turn-on trigger for Q2 to change operation (interval t3 to t4). Meanwhile, a positive output is developed across R2 and applied output terminal B, while a negative output is developed across R1 and applied to terminal A.

Practically all the non-clamped multivibrators are of the saturated type, since clamping the waveform to operate within the normal operating region of the transistor when used as an amplifier is necessary. As long as the base drive is allowed to draw collector current until the transistor collector voltage bottoms, saturation will always occur. Therefore to produce the unchanging steady current represented by the flat top of the output pulse there must be no further change of collector current. In the simple multivibrator this is achieved by collector current saturation, and in the more complicated types of multivibrators by clamping diodes. At the time transistors were first discovered and applied to this type of circuit, hole storage time effects caused a serious limitation in the speed of operation at which practical multivibrators could be made to operate. At the present state of the art, however, special switching transistors have been developed which check for continuity and proper resistance values to locate the defective part.

If either collector resistor R1 or R2 is open, no collector voltage will appear on the associated transistor, Q1 or Q2, respectively, and the bias voltage divider will be open. Therefore, the other transistor will be effectively cutoff biased by the floating base, and the normal reverse collector bias. With no conduction, a single negative output will be produced while the other output will be zero due to the open collector circuit. In the event emitter resistor R7 which is common to both transistors opens, there will be no flow of current through either transistor, but a negative output will appear at both output terminals since the transistors will, in effect, operate as if both were biased to cutoff. Thus, both collector voltages will rise to the full value of the supply. Therefore, if either transistor fails, or both fail, a negatime output will be produced.

Normal voltage indications on the base and collector elements of the transistors usually indicates that any associated series resistors have continuity and proper value. However, it is just as easy to check the resistance of each resistor with an ohmmeter because of the few parts involved. Since it is important to check that the proper polarity and amplitude of input trigger exists and that it is present, use an oscilloscope to observe the waveforms. When the waveforms are improper or missing it locates the general area of the trouble, which must then be further localized by voltage and resistance checks.

Reduced Output. A reduced output is usually caused by low collector voltage, improper bias, or a defective transistor. A change in the associated collector load resistor, R1 or R2, will also affect the output amplitude. Use an oscilloscope to observe the waveforms and determine where the reduced amplitude exists. Then check for proper bias and collector voltage in that portion of the circuit, and make certain that the collector resistance is normal. If normal voltages are present and the collector resistance is within tolerance, and a low output amplitude still exists, it must be because of reduced transistor current. Replace the doubtful transistors with known good ones.

Incorrect Frequency or Gate Width. Since the multivibrator has no parts which govern the frequency or width of the output signal, these are both governed by the input triggers' applied to the circuit. Hence, any change in these parameters must be the direct result of improper operation of the turn-on or turn-off trigger generating circuits.

NONSATURATING MULTIVIBRATOR.

APPLICATION.

The nonsaturating multivibrator is used to supply a rectangular gate or trigger in radar and control equipments, and in the logic switching circuits of computers and similar devices. Particularly where a large power output is required.

CHARACTERISTICS.

Usually uses fixed bias.

Provides two simultaneous outputs, one is the inverse of the other.

Requires a turn-on or a turn-off trigger to change state.

Has two stable operating states (bistable).

Output frequency is one-half that of the trigger frequency.

Output power is greater than that of the saturating type.

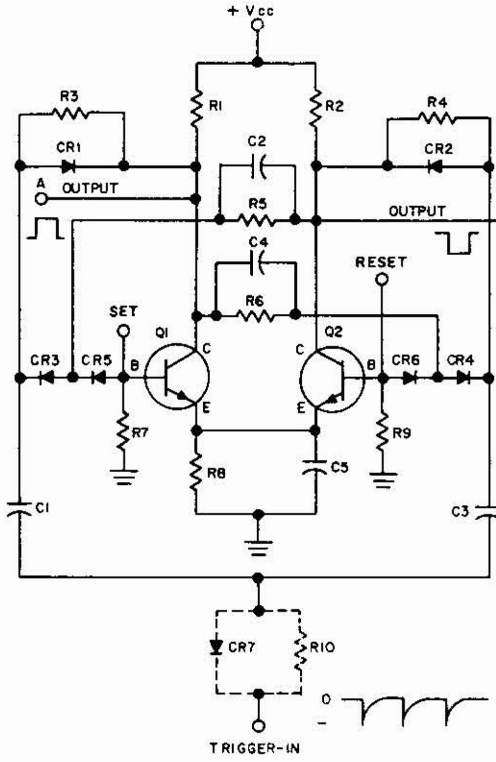
Operating speed is faster than the saturating multivibrator.

Uses clamping diodes to prevent saturation effects.

CIRCUIT ANALYSIS.

General. The nonsaturating multivibrator uses clamping diodes to stop collector saturation, and steering diodes to make certain the proper trigger is received, thus avoiding false triggering. In the circuit discussed below breakdown diodes are also used to prevent forward biasing of the collector which would cause saturation. Consequently, the transistors operate in the normal operating region (over the linear portion of their transfer curve). Basically the circuit is that of a conventional emitter-coupled bistable multivibrator, with the steering, clamping, and breakdown diodes added.

Circuit Operation. The schematic of a typical nonsaturating multivibrator is shown in the accompanying illustration.

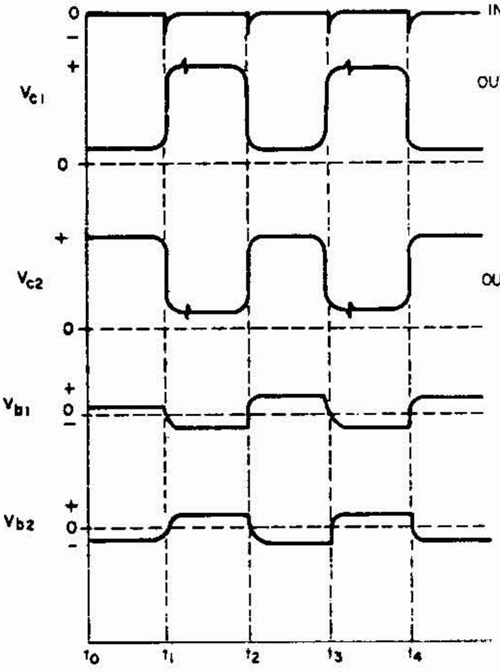


NPN Nonsaturating Multivibrator

Resistors R1 and R2 are the collector resistors of Q1 and Q2, respectively. The collector to base feedback networks are C2 and R5, and C4 and R6, with the common coupling-emitter resistor R8, bypassed by C5 to prevent degeneration. Resistors R7 and R9 are the base return resistors. The clamping diodes are CR1 and CR2 which shunt R3 and R4. Diodes CR3 and CR4 are the respective steering diodes of Q1 and Q2. Breakdown diodes CR5 and CR6 are saturation limiters which prevent the collector voltage of Q1 and Q2 from being forward biased when conducting. Input triggering pulses are injected at input terminal I (connected for parallel triggering), while terminals A and B are the output terminals from which the square wave output is taken. Transistor Q2 is considered to be the normally-on transistor, while Q1 is normally-off. When the negative input trigger is applied to the base of Q2, these conditions are reversed and Q2 is turned off, while Q1 is turned on. When the next negative trigger is applied to the base of Q1, the circuit reverts back to the initial state of operation, with Q1 off, and Q2 on.

In the absence of an input signal, both transistors initially conduct. Although the multivibrator circuit is symmetrical (corresponding resistors have the same value), there is always a slight difference in collector resistivity between transistors of the same type, so that one transistor will conduct more heavily than the other. In turn, the heavier-conducting transistor produces a feedback voltage which cuts off the light-conducting transistor. Assume for the sake of discussion that Q1 is initially in the off-condition while Q2 is in the on-condition.

In the quiescent condition, then, Q1 is effectively at cutoff, or at its lowest limit of conduction held by a negative, reverse-bias feedback voltage from the collector of Q2 via R-C network R5, C2 (NPN transistors require a negative bias voltage for cutoff). With no collector current flowing through R1, the collector of Q1 is at a high positive voltage near the supply value (reverse-biased collector), and both steering diode CR3 and clamping diode CR1 are held in a reverse-biased condition. At the same time, the negative feedback voltage produced by collector current flow through R2, and applies through C2 and R5 holdsbreakdown diode CR5 in a forward-biased condition but cuts off the base of Q1. In a similar manner, the emitter bias developed across R8 and C5 holds the emitter-base junction of Q1 in a reverse-biased condition preventing conduction. Meanwhile, a positive feedback voltage from the collector of Q1 is applied via C4 and R6 to the base of Q2 through breakdown diode CR6. Because of the high reverse voltage (collector of Q1 is near supply level), breakdown diode CR6 conducts in a reverse direction and maintains a constant forward bias on Q2, which causes heavy current flow but not collector saturation. The heavy collector current flow through collector resistor R2 develops a negative-going voltage which is applied to terminal B as an output, simultaneously with the positive output from terminal A. As Q2 collector current increases, the voltage drop across R2 increases also, and the collector voltage of Q2 reduces becoming less positive. Since steering diode CR4 is connected to the collector of Q2 through R4, when the collector voltage drops lower than the positive feedback voltage developed across R1 (which is applied through R6 to the anode of diode CR4) the diode becomes forward-biased and conducts, and as the collector voltage drops further CR2 eventually conducts. The collector of Q2 is now connected through the two diodes to the cathode of breakdown diode CR6 and the junction of R6. As long as the breakdown diode maintains a constant potential between the base and collector of Q2, the collector voltage cannot fall lower than the base voltage. Therefore, the collector cannot be forward biased and saturation cannot occur. Although the collector current may still increase if additional base current drive is supplied, the collector potential remains constant at the fixed minimum value. The operating range of Q2 (and later Q1) then, is from the minimum value of collector voltage to almost the full supply voltage at cutoff. The stage is now in its initial conducting or on-state with Q2 conducting and Q1 off, and rests in this condition until a turn-off trigger is received.



Multivibrator Waveforms

At time t_1 in the accompanying waveform illustration, a negative trigger is applied to steering diode CR4, but since it is already conducting the trigger has no effect and the stage rests in the initially-on condition (interval t_1 to t_2). At time t_2, the next negative trigger is applied through C1 to the cathode of diode CR3 and simultaneously to CR4 via C3. Since Q1 is nonconducting and the base is already negative, no effect is felt on Q1. However, when the negative pulse passes through CR4 and CR6 and appears on the base of Q2 it instantly partially reverse-biases the conducting transistor and causes a reduction in Q2 collector current flow through R2. As the collector current decreases, the drop across R2 is reduced and the collector voltage becomes more positive. This positive-going voltage is applied as feedback through C2 and R5, causing breakdown diode CR5 to conduct in a reverse direction, and driving the base of Q1 in a forward-biased direction. Collector current now flows through R1 and produces a negative-going voltage which is applied through feedback network C4 and R6 to the base of Q2 through breakdown diode CR6. Thus Q2 is driven further in a reverse-biased direction, and a larger turn-on voltage is fed back again to the base of Q1 by the increasing collector current flow through R1. The regenerative feedback continues smoothly and rapidly until Q1 is fully conducting while Q2 is turned-off. The circuit now rests in its second stable state (interval t_2 to t_3) until triggered off again at time t_3. When Q1 conducts, diodes CR3 and CR1 are activated similarly to diodes CR2 and CR4 in the discussion of Q2 operation, so that CR5, CR3, and CR1 continue to conduct, while a negative output pulse is produced at terminal A. With Q2 held at cutoff by feedback from Q1, a positive square-wave output pulse is obtained at terminal B as the collector voltage of Q2 rises toward the full supply value. In this instance, the emitter bias developed across R8 by conduction of Q1 keeps Q2 emitter reverse-biased, while breakdown diode CR5 maintains a constant difference in potential between the base and collector of Q1. Thus, while additional current may be drawn through Q1 if the base current drive increases, the collector voltage remains steady at its minimum clamped potential. If additional current is required, it is supplied through the shunt diode circuit from the cut-off side of the circuit via R2, and R5. Since any additional base current supplied at this time would cause only a small increase of collector current this shunting action will not appreciably reduce the output voltage developed across R2. But, what is more important, is that additional collector current through R1 cannot occur and drop the collector of Q1 to zero and cause saturation. At time t_4, the next negative trigger is applied through C1, and CR3, and CR5, to the base of Q1, reducing the flow of collector current because of the reverse bias it applies. Subsequently, the previously discussed cycle of feedback through C4 and R6 occurs, driving the base of Q2 into conduction, and produces additional feedback through C2 and R5 to drive the base of Q1 in the off-direction. Thus time t_4 corresponds to the initial trigger at t_1 which was previously considered ineffective, since Q2 was already assumed to be turned on.

When a positive trigger pulse is applied through C1 or C3, it reverse-biases the steering diodes and cannot reach a triggering point in the circuit. After the pulse ceases, the positive charge on the capacitor is quickly discharged through either CR1 or CR2. Any similar effect produced by the trailing edge of a negative trigger is also eliminated in this fashion providing a fast recovery time. Diodes CR7 and resistor R10, shown in dotted lines in the schematic, are trigger shaping devices to allow speedy triggering, they are not necessarily a part of the multivibrator. Resistor R10 is used to slow up any positive trigger so that false triggering cannot occur. Diode CR7 acts as a gate for negative triggers and shunts them around R10 to avoid any attenuation, while forcing any positive excursions to travel through R10. Feedback capacitors C2 and C4 function only to pass the high frequency component of the switching transients from collector to base without attenuation. Thus the switching action is speeded up, and the output waveform has steep leading and trailing edges rather than sloping sides produced by slow switching action.

Although clamping and steering diodes provide improved operation, it is possible to design nonsaturating multivibrators using the standard saturated multivibrator circuit with different values of component parts. In this case, parts values are chosen so that saturation does not occur. It is also of interest to note that, while the saturated circuits use heavy currents at very low voltages the dissipation is less than that involved in the nonsaturating circuit, which uses near-saturation currents at higher voltages with a consequent increase in average collector dissipation. Therefore, the nonsaturating circuit usually requires transistors with higher ratings.

FAILURE ANALYSIS.

General. When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low voltage ranges. Be careful also to observe the proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor junction will cause a false low-resistance reading.

Partial or No Output. It is necessary that the proper polarity and amplitude trigger be applied before the circuit will switch from one state to another. However, it will rest in one stable state and produce a single output if unable to respond to a trigger, or if disabled. Use an oscilloscope to determine that the proper trigger is applied, and then check the element voltages to determine if the circuit is otherwise normal. Check the supply voltage first to make certain the fault is not in a blown fuse or defective power supply. With the normal voltages present and a proper trigger at the input, if switching will not occur check steering diodes CR3 and CR4 to see if they pass the pulse. If not, replace the defective diode with a known good one. Should emmitter resistor R8 which is common to both Q1 and Q2 open, neither will function but a dual positive output will be obtained from terminals A and B since they will rise to the full value of the supply voltage. Failure of breakdown diodes CR5 and CR6 will allow saturation to occur, but will not prevent obtaining an output. When the collector voltage is found to be lower than the base voltage the associated breakdown diode is inoperative and should be replaced with one known to be good.

Low Output. Low collector voltage, improper bias, failure of the breakdown diodes, or the transistors themselves can cause a low output. If emitter bypass capacitor C5 is open, degeneration will cause a reduction of output. Use an in-circuit capacitance checker for this test. A change in the associated collector load resistors, R1 or R2, will also effect the output amplitude. Use an oscilloscope to observe the output waveform and determine where the reduced amplitude exists. Then check for the proper bias and collector voltage in that portion of the circuit. If normal voltage is present and the collector resistor is within tolerance, but low output amplitude still exists it must be caused by reduced collector current. Replace the doubtful transistors with known good ones.

Incorrect Frequency or Gate Width. Since the multivibrator has no parts which govern the frequency or width of the output signal, these are both governed by the input triggers applied to the circuit. Hence, any change in these parameters must be the direct result of improper operation of the turn-on or turn-on or turn-off trigger generating circuits.

RELAY CONTROL MULTIVIBRATOR.

APPLICATION.

The relay control multivibrator is used in computers and electronic switching circuits to control a relay or similar electromechanical device where the ratio of the on-off currents is 10 or more.

CHARACTERISTICS.

Usually uses fixed bias.

Requires a turn-on and a turn-off trigger to change state.

Has two stable states (bistable).

Operates at a frequency of one half the trigger pulse frequency.

Is a saturating type of multivibrator.

Uses steering diodes for stability.

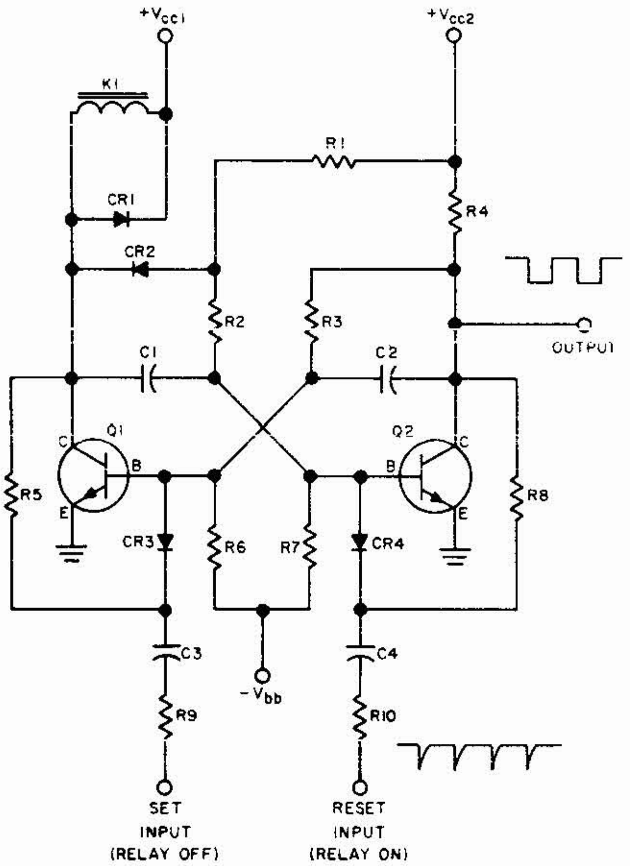
Inductive kickback from the relay coil is prevented by a diode clipper.

Operating speed is limited by the relay operating speed.

CIRCUIT ANALYSIS.

General. In the relay control multivibrator, one transistor is used to operate the relay, with a pull-in to drop-out current ratio of approximately 15 to 1. A rectangular output is simultaneously obtained from the other transistor; a positive output is obtained with the relay closed, and a negative output with the relay open. Steering diodes are provided to prevent false triggering and a protective diode is placed across the relay operating coil to prevent inductive operating transients from affecting the transistor to which the relay is connected.

Circuit Operation. The schematic of a typical relay control multivibrator is shown in the following illustration.



NPN Relay Control Multivibrator

As can be seen from the schematic, relay K1 is operated by transistor Q1, while Q2 provides a rectangular output voltage. The negative input trigger is applied through attenuating resistors R9 or R10 and capacitors C3 or C4 to turn off the conducting transistor. Resistor R4 is the collector resistor for Q2, while the relay coil of K1 functions similarly for Q1. The feedback network for Q1 consists of C2 and R3, while Q2 is held in conduction by a voltage divider arrangement of R1 and R2 together with bias resistor R7. Diode CR2 prevents the collector voltage swing of Q1 across relay coil K1 from supplying the feedback to operate Q2. Resistors R6 and R7 are the base bias resistors. Note that fixed bias is supplied from a separate base bias source, and that two different collector supplies are used, with that of Q1 (Vcc_1) being the lowest.

Normally, transistor Q2 is the conducting transistor while Q1 is cut off. Initially, both transistors will conduct, but with bias voltage divider R1, R2, and R7 connected between the high positive voltage of Vcc_2 and negative base bias supply Vbb, a positive (forward) bias exists on Q2 base. Therefore, Q2 conducts heavily and develops a negative-going voltage across collector resistor R4, which is fed back through C2 and R3 to the base of Q1, driving it into cutoff. As the voltage across K1 coil rises to the supply value of Vcc_1, diode CR2 is reverse biased and prevents any feedback from the collector of Q1 to the base of Q2. The negative feedback voltage on Q1 base holds NPN transistor Q1 in a non-conducting condition with only a small reverse-collector current flow through K1 relay coil. At this time, any voltage drop across K1 places a positive bias on protective diode CR1 to keep it reverse-biased and nonconducting. As long as the cathode of diode CR2 remains at the positive level of Vcc_1, and as long as the voltage drop across R1 keeps the anode lower than the cathode voltage, CR2 also remains in a nonconducting condition.

When a negative trigger is applied to the reset input terminal through R10 and C4, the base of Q2 is momentarily driven negative by the conduction of steering diode CR4, and causes Q2 to stop conducting. Thus, as the forward bias on Q2 is reduced by the input trigger, the collector current voltage drop across R4 reduces (becomes positive-going).

The feedback of the positive-swinging collector voltage through C2 and R3 to the base of Q1 produces a forward bias which causes Q1 collector current to increase. The flow of Q1 collector current through the relay coil of K1 is of a polarity which keeps CR1 reverse-biased. CR2 also remains reverse biased, until the collector potential of Q1 drops below the anode potential applied through R1 and R2. As Q2 collector current decreases and Q1 collector current increases the base of Q1 is further driven towards saturation by the feedback from R4. Eventually, relay K1 pulls in, and transistor Q1 is in saturation, while transistor Q2 is cut off. At this time a positive voltage is developed at the output terminal of Q2 as the collector voltage of Q2 rises to the supply value of Vcc_2. At saturation the collector voltage of Q1 is less than the base voltage (only a few tenths of a volt) and CR2 is forward-biased. Electron current flow from ground through Q1 and CR2 to R1, and voltage supply Vcc_2 produces a negative reverse bias voltage which is fed back through R2 to Q2 base to hold Q2 in a nonconducting state. This is the second stable state, with Q1 on and Q2 off.

When a negative trigger is applied through R9 and C3 from the set-input of Q1, steering diode CR3 temporarily conducts and produces a momentary reverse bias on the base of Q1, causing Q1 collector current to reduce. The reducing collector current allows the voltage on the cathode of CR2 to rise in a positive direction towards supply voltage Vcc_1 and eventually reverse-biases the diode. The positive voltage fed back to the base of Q2 through R1 and R2 now causes Q2 to again conduct. Thus Q2 quickly reaches the initial stable conducting state with Q1 cut off by the negative feedback through C2 and R3. When the collector current flowing through relay coil of K1 is reduced to zero, the inductive field about the coil collapses and causes CR1 to momentarily conduct when a negative trasient appears on the cathode. The negative inductive kick is thereby effectively clipped off, protecting Q1 from the inductive surge voltage.

Steering diodes CR3 and CR4 will not allow a positive trigger pulse to appear on the base of either Q1 or Q2, thus false triggering is prevented. Resistors R9 and R10 are not always required, in fact, they are really not a part of the multivibrator. They are used to provide a high impedance input instead of the approximate 300 ohm impedance offered by the coupling capacitors alone. These resistors also prolong the discharge time of the trigger, ensuring that the switching action occurs before the trigger is removed. With the steering diode cathodes connected back to their associated collector through R5 and R8, the conducting transistor maintains the diode in an almost forward biased condition (in saturation the collector is almost the same value as the base voltage – within tenths of a volt). Thus the large trigger pulse instantly turns the diode on and triggers the conducting transistor off. If a negative trigger pulse was accidentally applied to the nonconducting transistor, the large collector to base reverse bias would prevent the diode from being forward biased, and the trigger would be ineffective.

Since the output voltage is in-phase with the closing of the relay it may be used to signal the position of the relay or to trigger an associated circuit. The prime purpose of this multivibrator circuit, however, is to control the relay. Since the relay is a mechanical device, it operates at slower speeds than the electronic circuit; thus the relay operating speed determines the maximum switching speed.

FAILURE ANALYSIS.

General. When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low voltage ranges. Be careful to observe proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output or Partial Output. Total loss of output could only result from lack of supply voltage, since an output will be produced even if both transistors are inoperative. Although the relay will not operate if Q1 is defective or has a defective circuit part, a positive voltage equal to the V_{cc_2} supply will still be obtained from Q2, if inoperative, or a negative output if operable. Use an oscilloscope to determine that the proper input trigger exists and passes through the correct steering diode (an open diode can prevent triggering). Then measure the supply voltage and check the collector voltage on both transistors. With the correct collector bias supply voltage and base bias voltage present, the collector of the conducting transistor should measure very low (a few tenths of a volt), while the cut off transistor will have a high collector voltage almost the same as that of the supply voltage. If both collector voltages are low, either relay coil K1 or collector resistor R4 is open, or the transistor (s) are shorted. Check the resistance of R4 and K1 coil, if the resistances are satisfactory, replace the transistor (s).

Where an output is obtained but no switching occurs, in addition to defective steering diodes, either R9, R10, C3 or C4 can be open. Hence the necessity to use the oscilloscope to determine if the input trigger appears at the transistor base terminal. The circuit will operate without feedback capacitors C1 and C2 but will be somewhat slowed down, and will most probably cause sloping leading and trailing edges on the output waveform at high switching speeds.

Erratic Operation. Since the circuit is controlled by an external trigger it is important to observe the trigger with an oscilloscope to be certain that the trigger itself is not erratic. If the trigger appears normal in shape and amplitude, check operation of the steering diodes and the resistance of R5 and R8. If the resistance of R5 or R8 increases with age, or they become open, the biasing of the steering diodes and the discharge time of R9, C3 or R10, C4 will be changed. Such condition might also be caused by defective transistors. Check the resistors with an ohmmeter, and the diodes and transistors with an in-circuit checker, if possible. Otherwise, substitute known good diodes or transistors to determine which are defective.

Incorrect Frequency or Gate Width. Since the multivibrator has no parts which govern the frequency or width of the output signal, these are both governed by the input triggers applied to the circuit. Hence, any change in these parameters must be the direct result of improper operation of the turn-on or turn-off trigger generating circuits.

Low Output. Low collector voltage, improper bias, or defective transistors can cause a low output voltage. A change in collector resistor R4 will also affect the output amplitude. Use an oscilloscope to check the output waveform and determine where the reduced amplitude exists. Then check for the proper bias and collector voltages in that portion of the circuit. If normal voltages are present and the collector resistor is within tolerance, but low output amplitude still exists, it can only be because of reduced collector current. Replace the doubtful transistor with one known to be good.

MONOSTABLE MULTIVIBRATORS.

The monostable multivibrator, as contrasted with the bistable type of multivibrator, has only one fixed or stable state. The other state is an operational state determined by an RC time-constant network. Initially, the monostable circuit is triggered into action. Once triggered, the change of state occurs and the formerly conducting transistor is cut off, while the other transistor conducts. This action continues until the RC network is discharged sufficiently to trigger the nonconducting tube on again and restore the initial state of operation which existed before the trigger was applied. The monostable circuit can usually be easily recognized by the base biasing connection of the normally-conducting transistor. It usually consists of a voltage divider connected to the negative supply (for PNP transistors) which holds the transistor forward biased until cut off by the action of the trigger pulse, whereas the other type of multivibrators have symmetrical feedback networks. Because of the single stable state of operation, this circuit is also known in other publications as a **one-shot, single-swing,** or **single-shot** multivibrator. It is sometimes also called a flip-flip circuit, because once the trigger initiates the initial flipping action the circuit itself will flip back at the end of the RC discharge time. Because of the time-constant switching action the circuit needs only one trigger per output waveform, and operates at the same frequency as the input trigger, instead of half the trigger frequency as in other multivibrators.

The basic monostable multivibrator is discussed in following paragraphs. Somewhat more stable circuits can be produced by using steering diodes and clamping diodes to ensure positive triggering. However, these circuits all operate similarly to the basic one-shot multivibrator except that the diodes prevent false triggering by positive noise pulses.

BASIC ONE-SHOT MULTIVIBRATOR.

APPLICATION.

The basic one-shot multivibrator is used to provide a delay function for compatible logic circuits, or is used as a gate in computers, electronic control or communication equipment.

CHARACTERISTICS.

Usually uses fixed bias.

Requires an on-trigger, but will automatically turn itself off.

Operates at the same repetition frequency as that of the trigger.

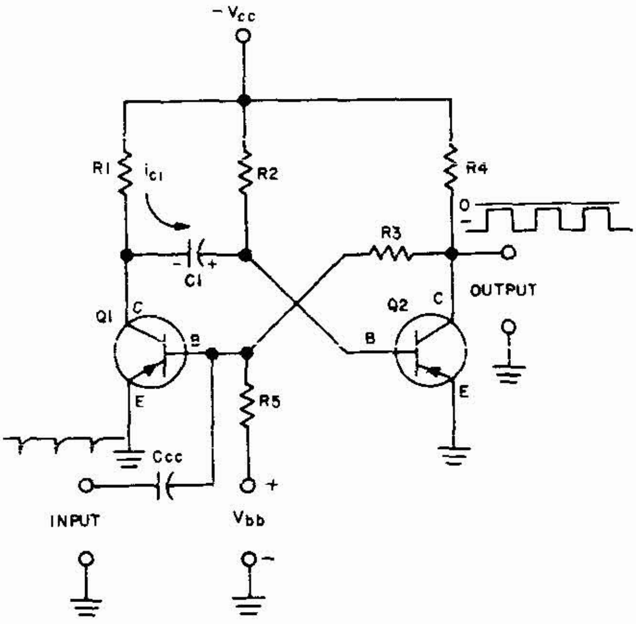
Has one stable state (monostable).

Is a saturating type of multivibrator.

CIRCUIT ANALYSIS.

General. The basic one-shot multivibrator is a triggered circuit, which requires a trigger pulse to initiate action. Once the trigger pulse initiates the action, the circuit uses its own power to complete the operation. Either the stable state of cutoff or saturation is used. Normally, one transistor is operated saturated while the other is at cutoff. When the circuit is triggered by an external pulse, the operating point is moved from the initial stable region to the other stable (operating) region. Meanwhile, the time constant of the circuit elements holds the operating point in the new stable (operating) region for a short period of time. The operating point then moves back to the original stable region.

Circuit Operation. The schematic of a typical basic monostable (one-shot) multivibrator is shown in the accompanying illustration.

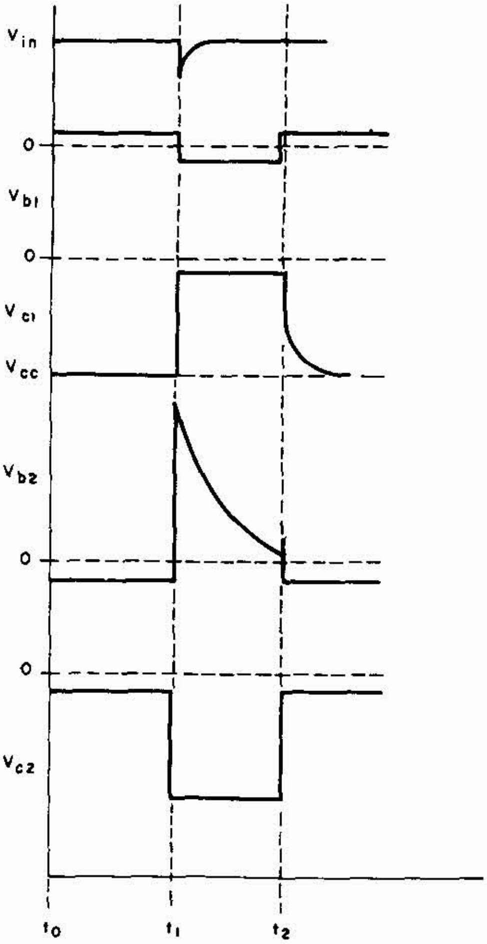


Basic PNP One-Shot Multivibrator

Fixed forward bias is applied to the base of Q2 by resistor R2, while the voltage divider consisting of R4, R3, and R5 form a fixed bias divider between the base bias supply and the collector supply and ground. Thus Q1 is biased slightly positive, and is cut off by this reverse-bias. Resistor R4 also is the collector resistor for Q2, and R1 serves a similar function for Q1. Resistor R3 serves as the collector-to-base feedback resistor for Q1, while C1 is the feedback capacitor for Q2. Both emitters are grounded and a cross-connected, grounded-emitter circuit is used. The input is applied through coupling capacitor Ccc, while the output is taken directly from the collector of Q2. If desired, the output load could also be capacitively coupled.

In the quiescent condition, transistor Q2 conducts heavily while transistor Q1 is cut off. This action occurs initially because of the large negative forward bias placed on the base of Q2 by resistor R2, which is connected back to the negative supply. Thus on application of power Q2 quickly saturates, and develops a positive-swinging output across R4, which is fed back to the base of Q1 through resistor R3, holding the transistor at cut off. During the on-period of Q2, feedback capacitor C1 is charged positively, through R1 and the low base-emitter saturation resistance of Q2. The low saturation resistance of Q2 base-emitter junction acts as a switch, connecting R1 and C1 in series with the negative supply source and ground.

When the negative trigger is applied to Q1 base through coupling capacitor Ccc (time t_1 in the following waveform illustration), transistor Q1 is instantly driven into conduction by this forward bias. The flow of Q1 collector current through R1 reduces the effective collector voltage and produces a positive-swinging voltage across R4, which is applied through feedback capacitor C1 as a positive reverse-bias to cut off Q2. As the collector current of Q2 reduces, the voltage across collector resistor R4 rises toward that of the negative collector supply, and an increasing forward-bias is fed back to the base of Q1 through feedback resistor R3. Thus Q2 is cut off and Q1 is turned on. Operation is now reversed and the output from Q2 is a negative voltage. Since C1 is positively charged, when disconnected from ground by Q2 being driven into cut off, the capacitor holds the base of Q2 highly positive (reverse-biased) while it discharges. The discharge path is through the low collector-to-emitter saturation resistance of Q1, and ground on one side, and through R2 to the negative supply on the other side. The discharge is shown by the typical RC discharge curve on the trailing edge of the V_{b_2} waveform (time t_1 to t_2) in the waveform illustration. Q2 remains nonconducting until the base voltage drops to zero and the base of Q2 goes slightly negative at time t_2. Q2 immediately starts to conduct, and the flow of collector current through R4 produces a positive-swinging voltage, which is applied through feedback resistor R3 to drive Q1 in a reverse-biased direction and stop conduction through Q1. This regenerative feedback action occurs quickly, and the output of Q2 is now a positive square wave voltage. The quiescent state of operation continues until the next trigger (time t_3), whereupon the switching action described above is again repeated.



Monostable Multivibrator Waveforms

FAILURE ANALYSIS.

General. When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low voltage ranges. Be careful to observe proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. Lack of supply voltage, an open collector resistor, R4, or a defective transistor can cause a no-output indication. Measure the supply and collector voltages with a high resistance voltmeter, if the supply voltage is normal but the collector voltage is low or zero, either R4 is open or Q2 is shorted. Checking the resistance of R4 with an ohmmeter will determine if Q2 needs replacement. When replacing transistors use known good ones.

Continuous Output. If bias resistor R2 increases with age or opens, the base of Q2 will tend to float in a zero-biased condition. The collector of Q2 will rise to the supply value, and a continuous output with no switching action will occur. The same indication will also occur if R3 is open, since Q1 will be biased beyond cut off and the trigger will not be large enough to initiate action. At the very best, an attempt to switch may be noticed, with the circuit reverting back to the cut off condition when the trigger ceases. Such action is best observed with an oscilloscope. Should R5 open, a negative (forward-bias) will be placed on Q1, and both Q1 and Q2 will conduct with a continuous positive output from Q2. On the other hand if Q1 is stopped from conducting by a short across R5, Q2 will continue to operate alone, also producing a continuous positive output. Because of the few resistors in the circuit a quick check with an ohmmeter will determine if they are satisfactory. Should C1 be open circuited, no feedback can be applied from the collector of Q1 to the base of Q2 and switching will not occur, again Q2 will rest in a conducting position with a positive output near zero. If C1 becomes short circuited, R1 and R2 will be paralleled and a higher forward bias will be applied Q2 base, holding it in conduction and preventing operation. Use an in-circuit capacitance checker to check the capacity of C1. If the resistors are satisfactory, together with C1, then Q1 must be defective if a continuous output still occurs.

Low Output. Low collector voltage, improper bias, or defective transistors can cause a low output voltage. A change in collector resistor R4 will also affect the output amplitude. Use an oscilloscope to check the output waveform and determine where the reduced amplitude exists. Then check for the proper bias and collector voltages in that portion of the circuit. If normal voltages are present and the collector resistor is within tolerance, but a low output amplitude still exists, it can only be because of reduced collector current. Replace the doubtful transistor with one known to be good.

Incorrect Frequency. Since the multivibrator has no parts which govern the frequency of operation, it is governed by the applied input trigger. Hence any change in frequency must be the result of improper operation of the turn-on trigger generating circuits.

Incorrect Pulse Width. While the frequency is governed by the input trigger, the length of time the circuit operates before flipping back to the initial stable condition is determined by the circuit time-constant governed by the charge and discharge of C1 through R2, and also R1. Thus if the value of C1 changes or that of R1 or R2 changes, or if the saturation resistance of transistor Q2 changes appreciably, a different pulse width may be expected. Observation of the output pulse on an oscilloscope will show any change in width. Measure the value of C1 with an in-circuit capacitance checker, and check the resistance of R1 and R2. If these parts appear satisfactory replace Q2 with a known good transistor. Any delays in switching are the result of minority carrier injection into the base at saturation, which requires a finite discharge time until the circuit can be triggered. Should a noticeable delay in switching occur after the circuit has been operating properly, first check all parts values, if satisfactory, replace the transistor (s) with good ones (usually Q2 will be at fault).

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