RELAXATION OSCILLATORS

RELAXATION OSCILLATORS

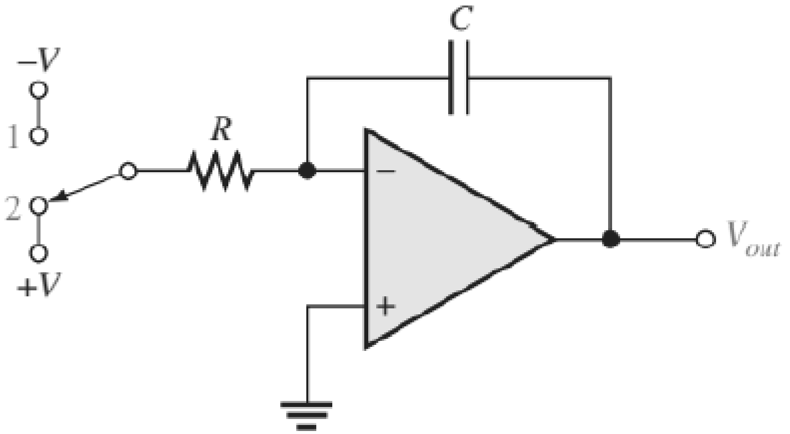
- Relaxation oscillators use an RC timing circuit and a device that changes states to generate a periodic waveform.

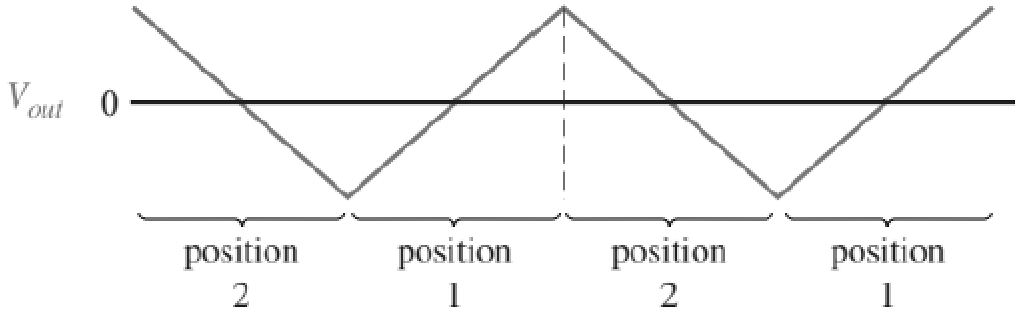
Common Relaxation Oscillators:

- **Triangular-Wave Oscillator**
- **Practical Triangular-Wave Oscillator**
- **Sawtooth Voltage-Controlled Oscillator (VCO)**
- **Square-Wave Oscillator**
- **555 TIMER as an Oscillator**

Triangular-Wave Oscillator

- The op-amp integrator can be used as the basis for a triangular-wave oscillator.

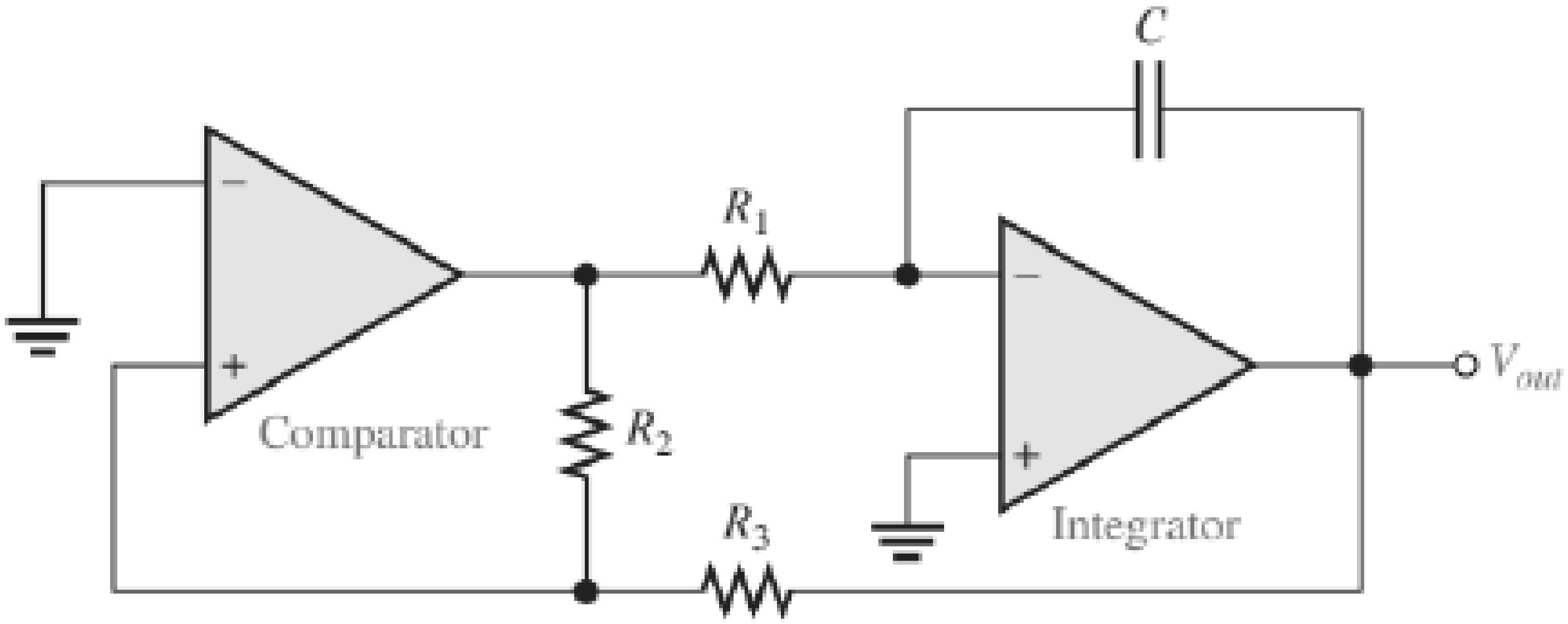




- When the switch is in position 1, the negative voltage is applied, and the output is a positive-going ramp.
- When the switch is thrown into position 2, a negative-going ramp is produced.
- If the switch is thrown back and forth at fixed intervals, the output is a triangular wave consisting of alternating positive-going and negative-going ramps.

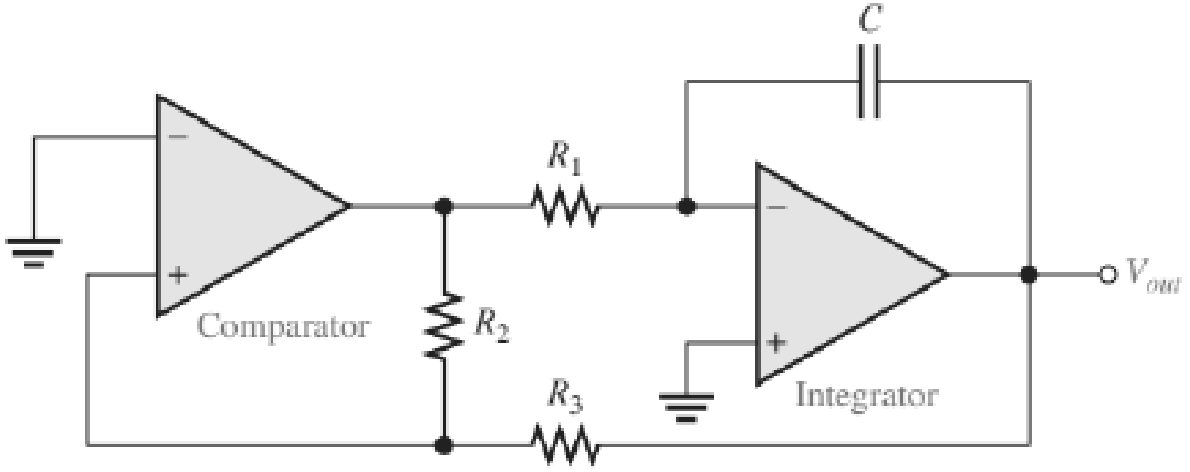
Practical Triangular-Wave Oscillator

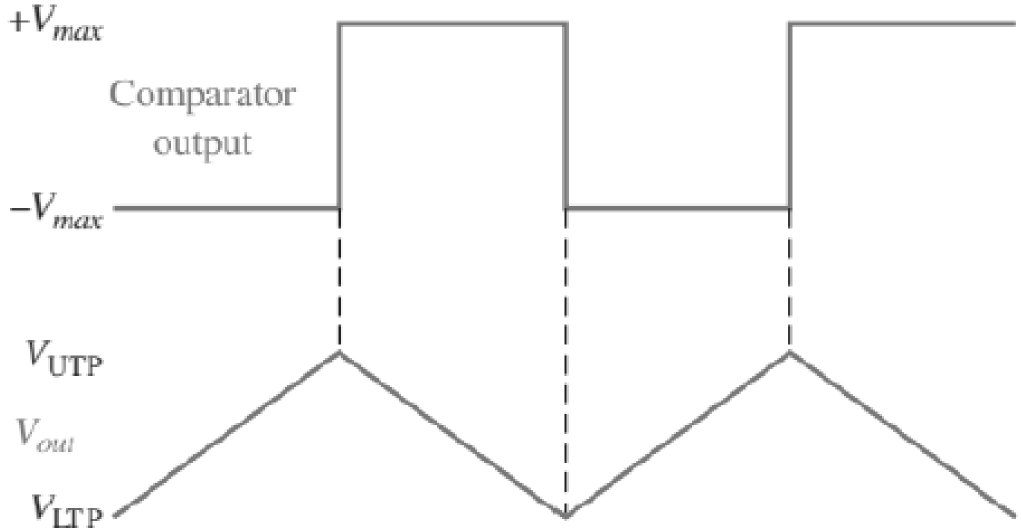
- One practical implementation of a triangular-wave oscillator utilizes an op-amp comparator with hysteresis to perform the switching function, as shown in Figure below.



Practical Triangular-Wave Oscillator

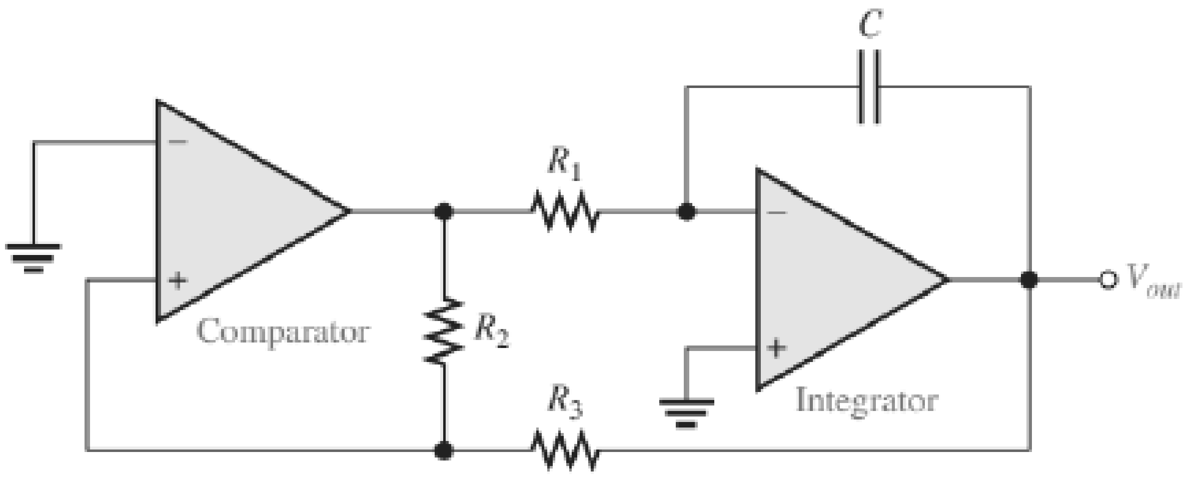
- To begin, assume that the output voltage of the comparator is at its maximum negative level. This output is connected to the inverting input of the integrator through $R1$, producing a positive-going ramp on the output of the integrator.

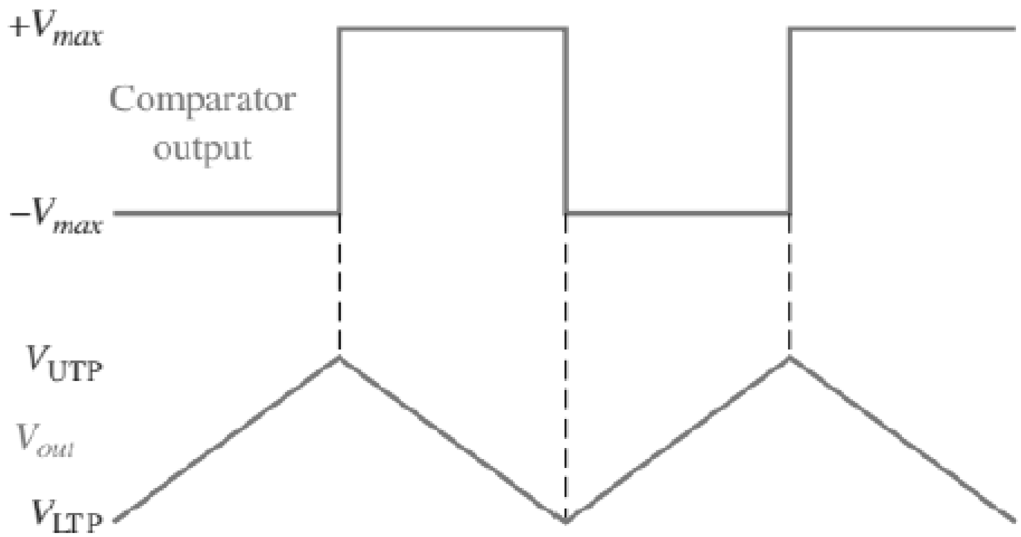




Practical Triangular-Wave Oscillator

- When the ramp voltage reaches the upper trigger point (UTP), the comparator switches to its maximum positive level. This positive level causes the integrator ramp to change to a negative-going direction.
- The ramp continues in this direction until the lower trigger point (LTP) of the comparator is reached.





Practical Triangular-Wave Oscillator

- Since the comparator produces a square-wave output, the circuit can be used as both a triangular-wave oscillator and a square-wave oscillator.
- Devices of this type are commonly known as function
- generators because they produce more than one output function.
- The output amplitude of the square wave is set by the output swing of the comparator, and the resistors $R2$ and $R3$ set the amplitude of the triangular output by establishing the UTP and LTP voltages.

Practical Triangular-Wave Oscillator

- Upper Trigger Point Voltage (V_{UTP}):

$$V_{UTP} = +V_{max}\frac{R_3}{R_2}$$

- Lower Trigger Point Voltage (V_{LTP}):

$$V_{UTP} = -V_{max}\frac{R_3}{R_2}$$

- Frequency of both waveforms:

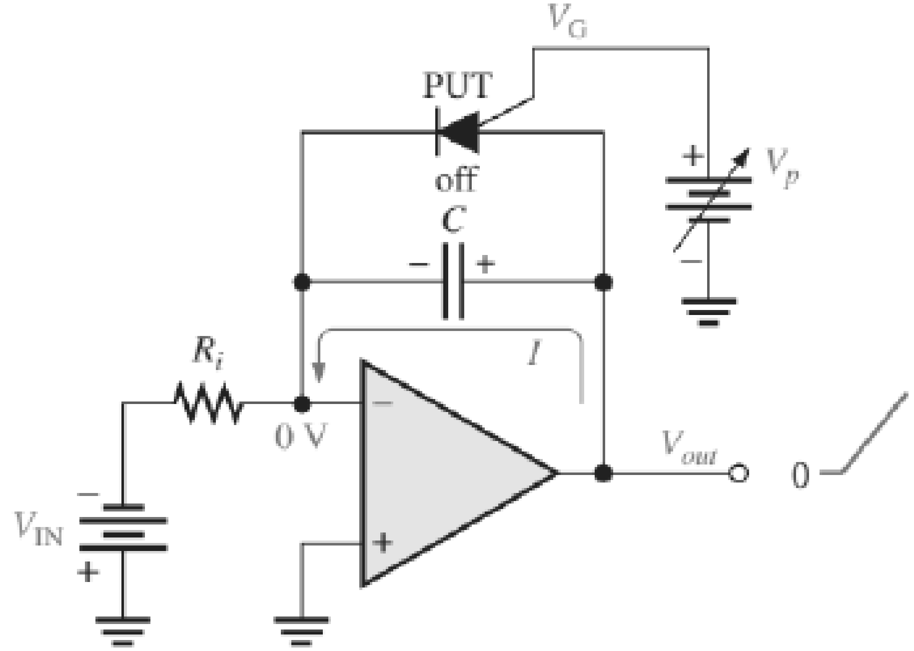
$$f_r = \frac{1}{4R_1C}(\frac{R_2}{R_3})$$

Frequency depends on the R_1C time constant as well as the amplitude-setting resistors, R_2 and R_3.
By varying $R1$, the frequency of oscillation can be adjusted without changing the output amplitude.

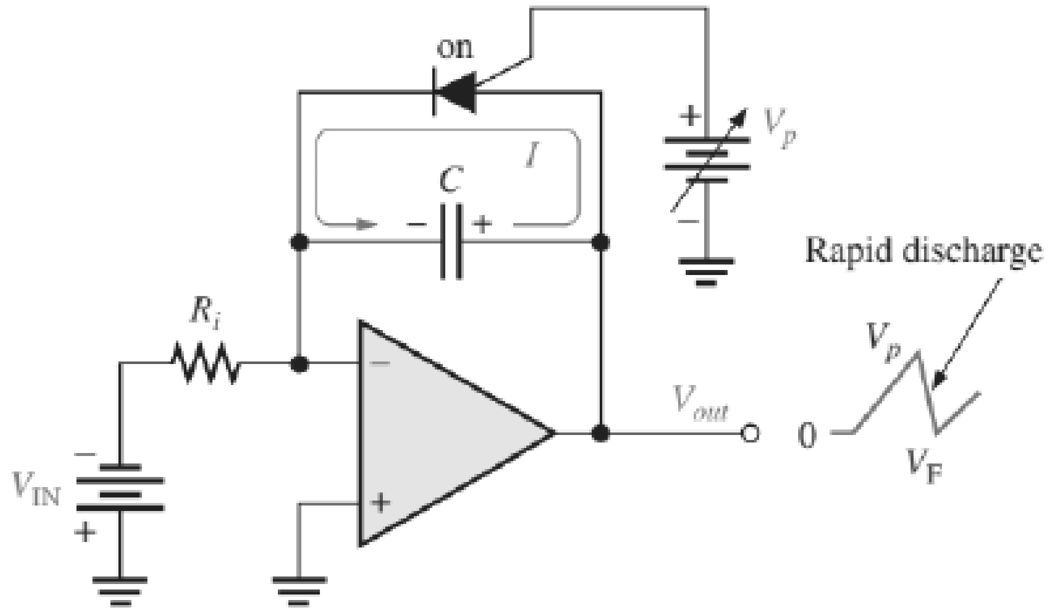
Sawtooth Voltage-Controlled Oscillator (VCO)

- The voltage-controlled oscillator (VCO) is a relaxation oscillator whose frequency can be changed by a variable dc control voltage.
- VCOs can be either sinusoidal or nonsinusoidal.
- One way to build a sawtooth VCO is with an op-amp integrator that uses a switching device (PUT) in parallel with the feedback capacitor to terminate each ramp at a prescribed level and effectively “reset” the circuit.

Sawtooth Voltage-Controlled Oscillator (VCO)



(a) Initially, the capacitor charges, the output ramp begins, and the PUT is off.



(b) The capacitor rapidly discharges when the PUT momentarily turns on.

Sawtooth Voltage-Controlled Oscillator (VCO)

- As you learned in Module number 2, the PUT is a programmable unijunction transistor with an anode, a cathode, and a gate terminal.
- The gate is always biased positively with respect to the cathode.
- When the anode voltage exceeds the gate voltage by approximately 0.7 V, the PUT turns on and acts as a forward-biased diode.
- When the anode voltage falls below this level, the PUT turns off.
- Also, the current must be above the holding value to maintain conduction.
- The operation of the sawtooth VCO begins when the negative dc input voltage, -VIN produces a positive going ramp on the output.

Sawtooth Voltage-Controlled Oscillator (VCO)

- During the time that the ramp is increasing, the circuit acts as a regular integrator.
- The PUT triggers on when the output ramp (at the anode) exceeds the gate voltage by 0.7 V. The gate is set to the approximate desired sawtooth peak voltage.
- When the PUT turns on, the capacitor rapidly discharges, as shown in Figure (b).
- The capacitor does not discharge completely to zero because of the PUT's forward voltage, VF .
- Discharge continues until the PUT current falls below the holding value. At this point, the PUT turns off and the capacitor begins to charge again, thus generating a new output ramp. The cycle continually repeats, and the resulting output is a repetitive sawtooth waveform.
- The sawtooth amplitude and period can be adjusted by varying the PUT gate voltage.

Sawtooth Voltage-Controlled Oscillator (VCO)

Period (T) and Frequency of oscillation ($\mathrm{f_r}$):

- The time it takes a capacitor to charge from V_F to V_P is the period, T, of the sawtooth waveform (neglecting the rapid discharge time).

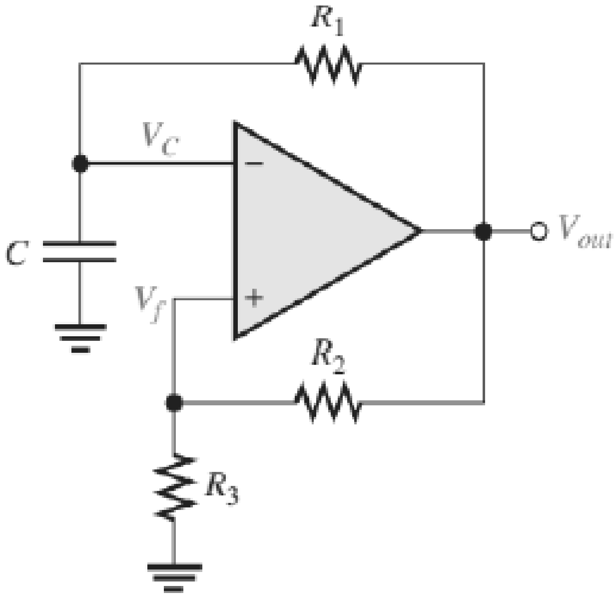
$$\mathrm{T} = \frac{\mathrm{V_P} - \mathrm{V_F}}{|\mathrm{V_{in}}|/\mathrm{R_i C}}$$

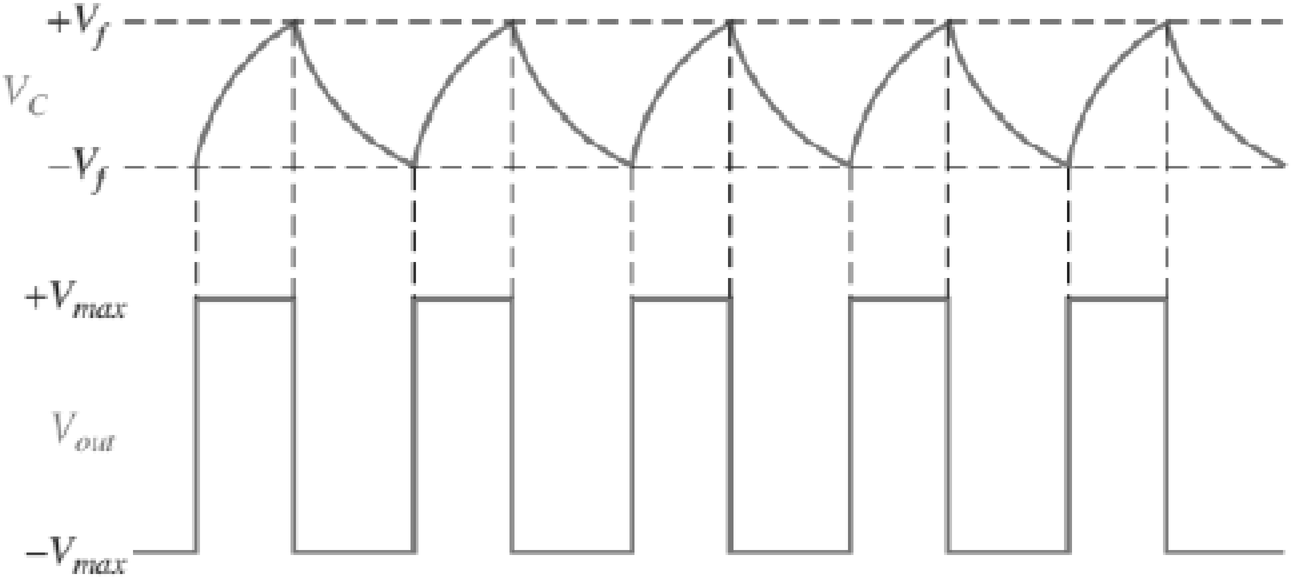
- Frequency of Oscillation:

$$\mathrm{f} = {}^{1}/_{\mathrm{T}} = \frac{|\mathrm{V_{in}}|}{\mathrm{R_i C}}\left(\frac{1}{\mathrm{V_P} - \mathrm{V_F}}\right)$$

Square-Wave Oscillator

- The basic square-wave oscillator shown in Figure is a type of relaxation oscillator because its operation is based on the charging and discharging of a capacitor.
- Notice that the op-amp's inverting input is the capacitor voltage and the noninverting input is a portion of the output fed back through resistors $R2$ and $R3$ to provide hysteresis.



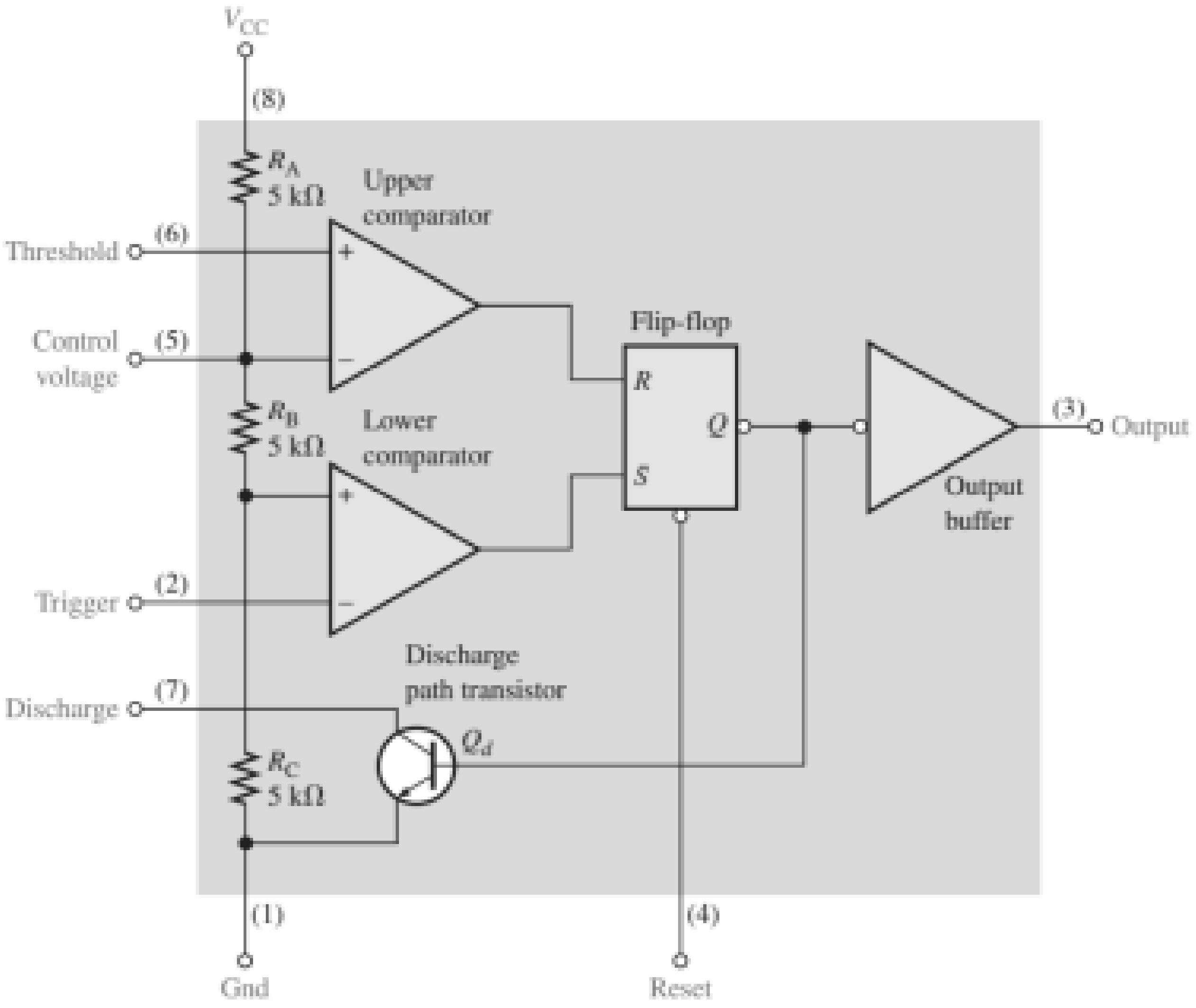


Square-Wave Oscillator

- When the circuit is first turned on, the capacitor is uncharged, and thus the inverting input is at 0 V. This makes the output a positive maximum, and the capacitor begins to charge toward $Vout$ through $R1$.
- When the capacitor voltage (VC) reaches a value equal to the feedback voltage (Vf) on the noninverting input, the op-amp switches to the maximum negative state.
- At this point, the capacitor begins to discharge from $+Vf$ toward $-Vf$.
- When the capacitor voltage reaches $-Vf$, the op-amp switches back to the maximum positive state. This action continues to repeat, as shown in the Figure and a square-wave output voltage is obtained.

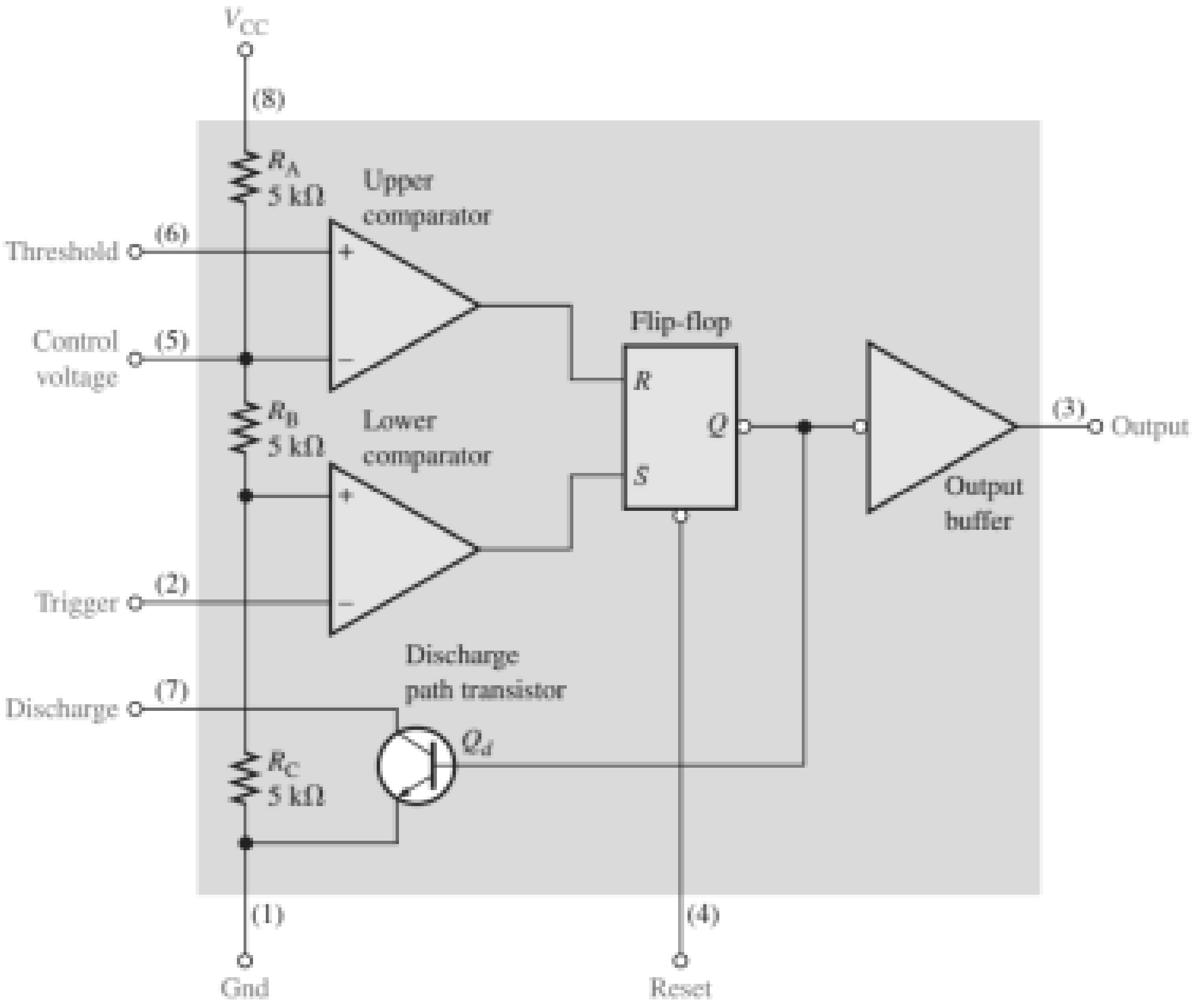
555 TIMER

- The 555 timer consists basically of two comparators, a flip-flop, a discharge transistor, and a resistive voltage divider, as shown in the figure.



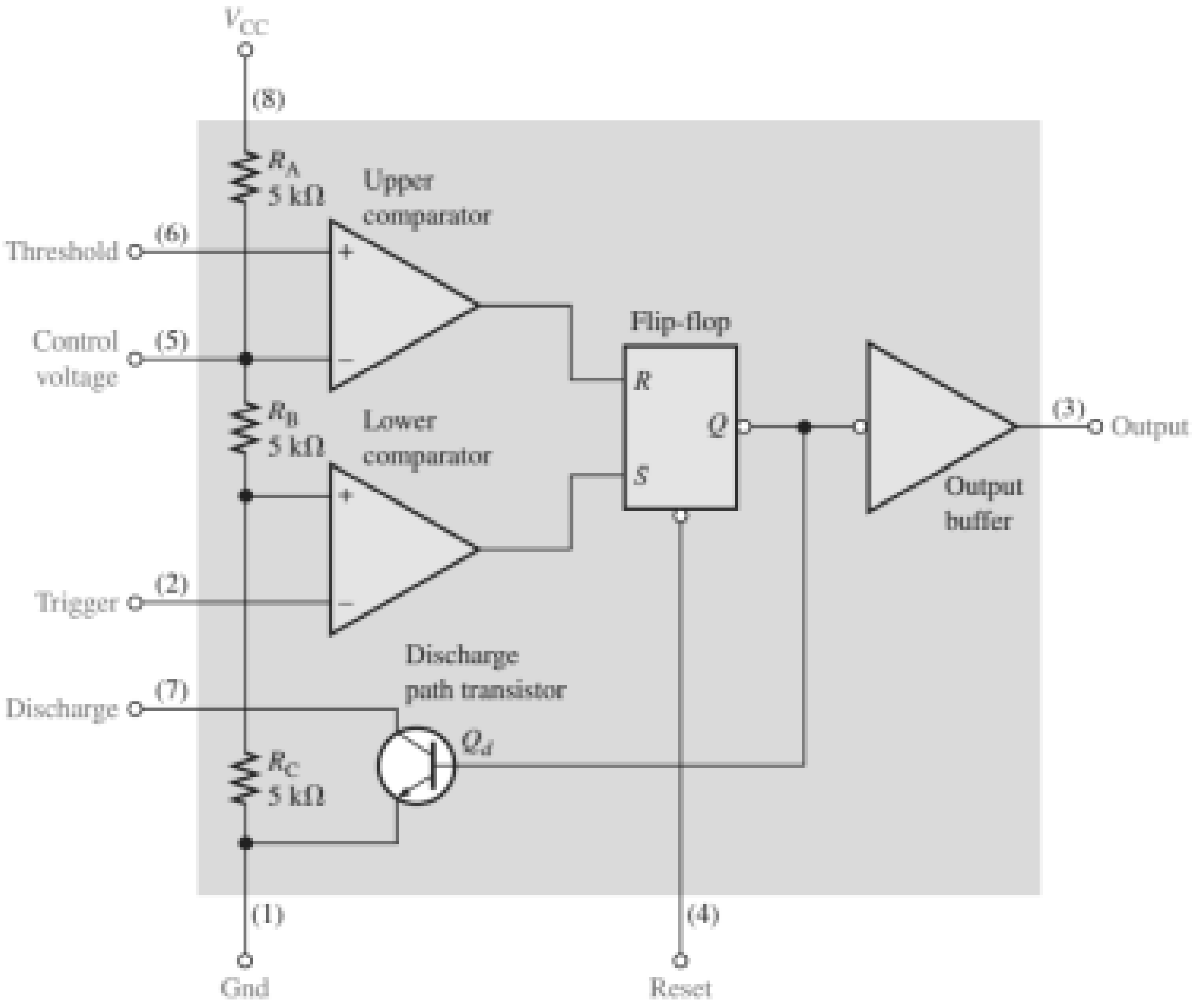
555 TIMER

- Flip-flop
  - It is a two-state device whose output can be at either a high voltage level (set, S) or a low voltage level (reset, R). The state of the output can be changed with proper input signals.



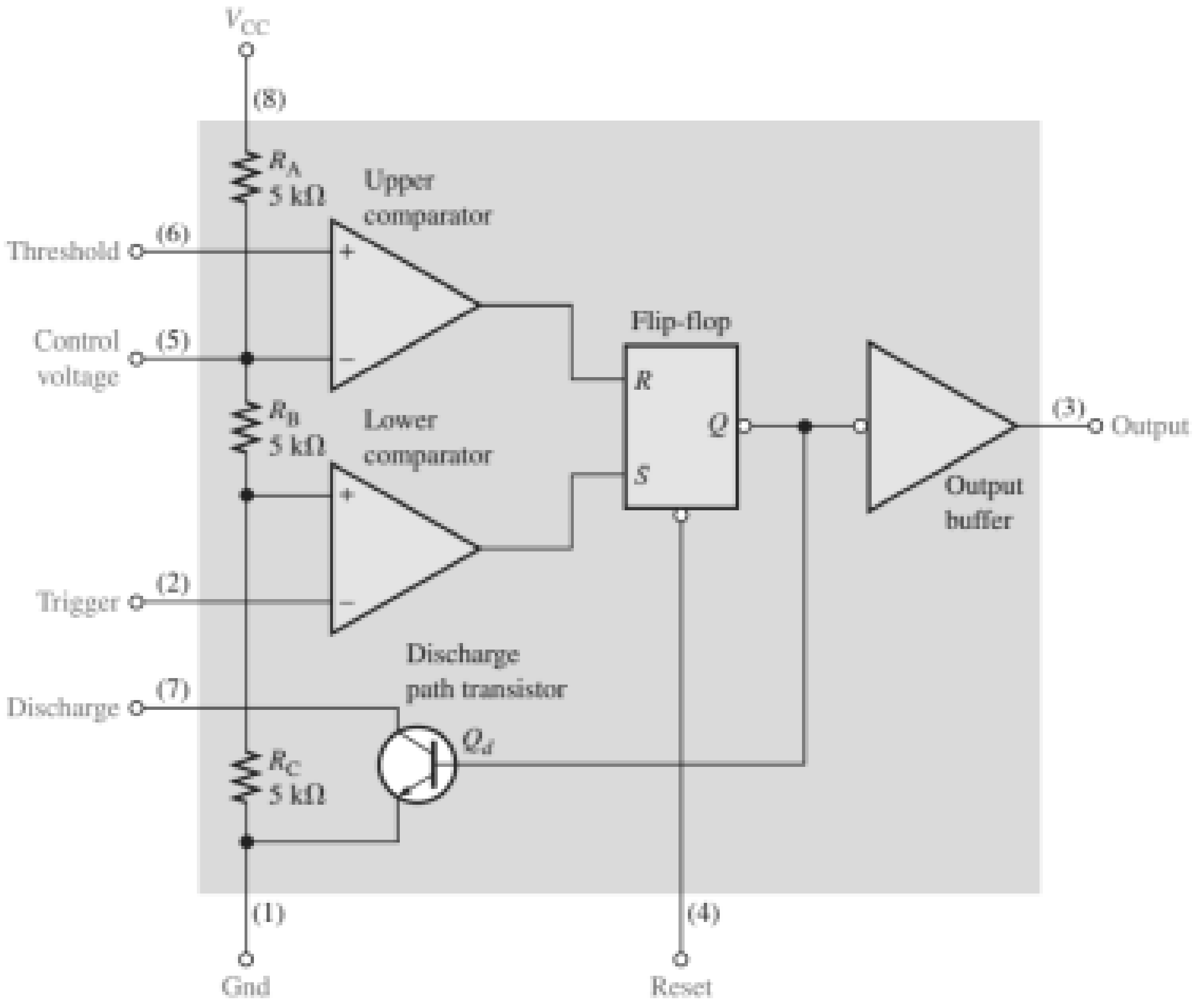
555 TIMER

- The resistive voltage divider is used to set the voltage comparator levels.
- All three resistors are of equal value; therefore, the upper comparator has a reference of $\frac{2}{3}$Vcc, and the lower comparator has a reference of $\frac{1}{3}$Vcc.



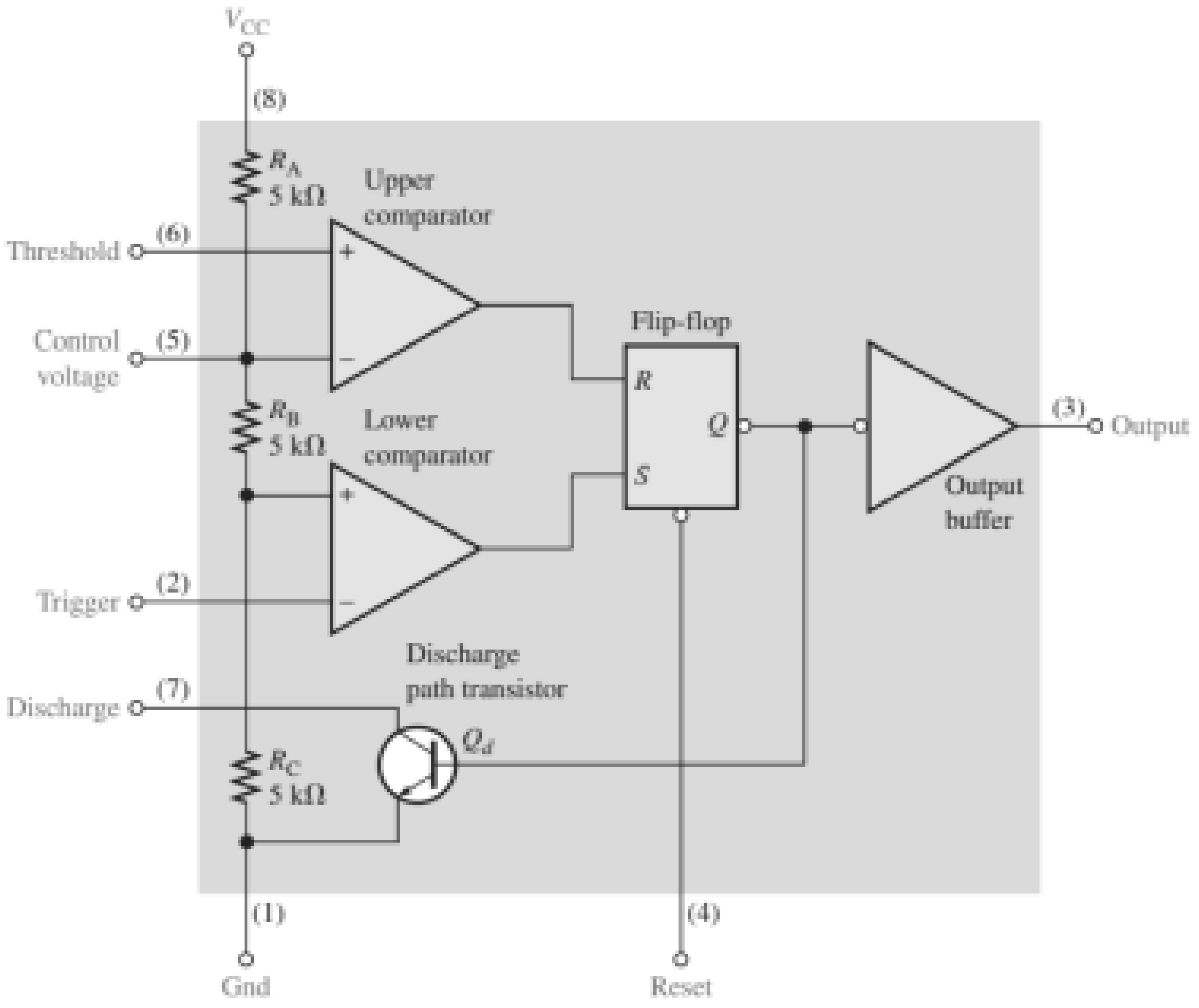
555 TIMER

- The comparators' outputs control the state of the flip-flop.
- When the trigger voltage goes below $\frac{1}{3}$Vcc, the flip-flop sets and the output jumps to its high level.
- The threshold input is normally connected to an external RC timing circuit.
- When the external capacitor voltage exceeds $\frac{2}{3}$Vcc, the upper comparator resets the flip-flop, which in turn switches the output back to its low level.



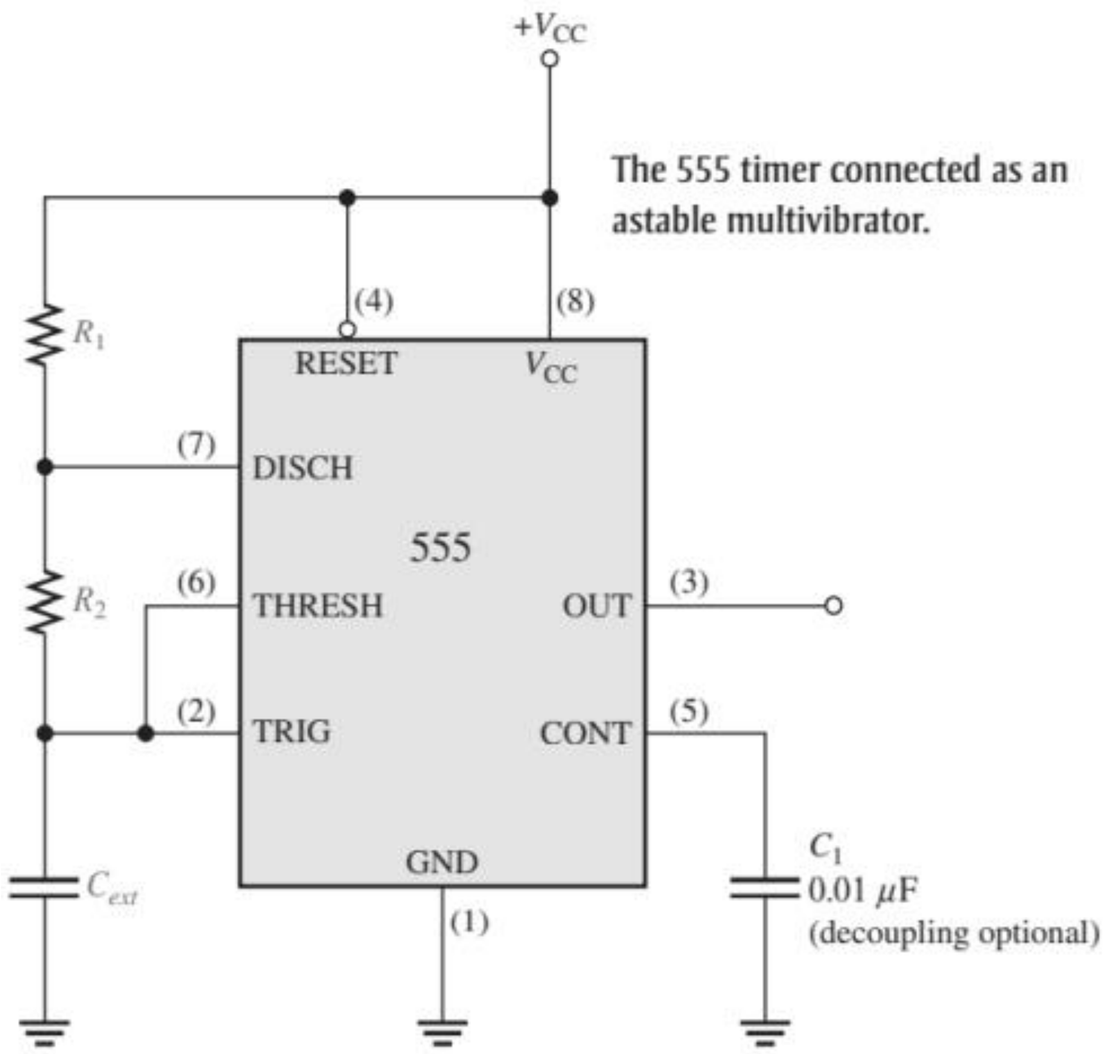
555 TIMER

- When the device output is low, the discharge transistor (Qd) is turned on and provides a path for rapid discharge of the external timing capacitor.
- This basic operation allows the timer to be configured with external components as an oscillator, a one-shot, or a time-delay element.



555 TIMER - Astable Operation

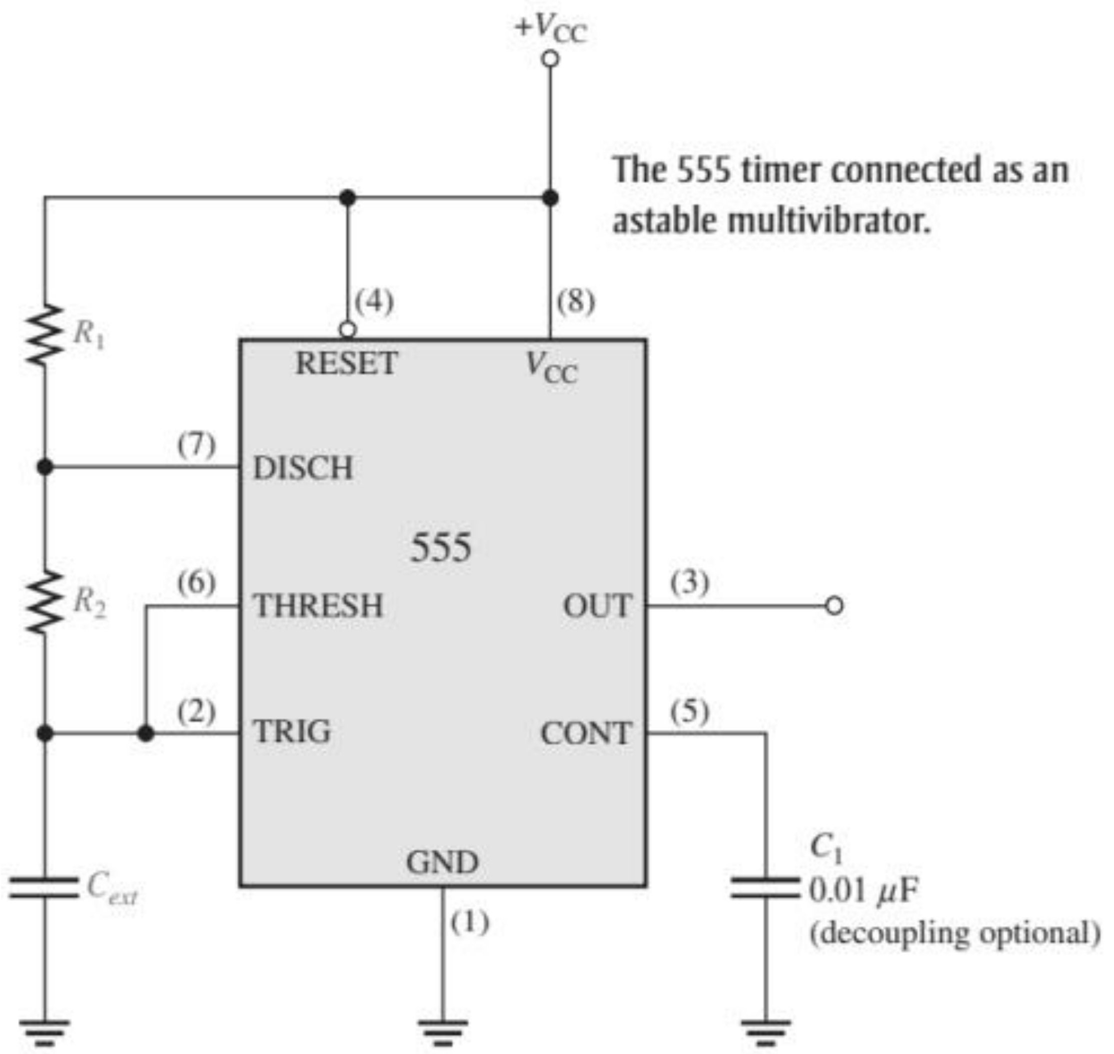
- Astable Operation
  - A 555 timer connected to operate in the astable mode as a free-running relaxation oscillator (astable multivibrator) is shown in the figure.
  - Notice that the threshold input (THRESH) is now connected to the trigger input (TRIG).
  - The external components $R1$, $R2$, and $Cext$ form the timing circuit that sets the frequency of oscillation.
  - The 0.01μF capacitor connected to the control (CONT) input is strictly for decoupling and has no effect on the operation.



The 555 timer connected as an astable multivibrator.

555 TIMER - Astable Operation

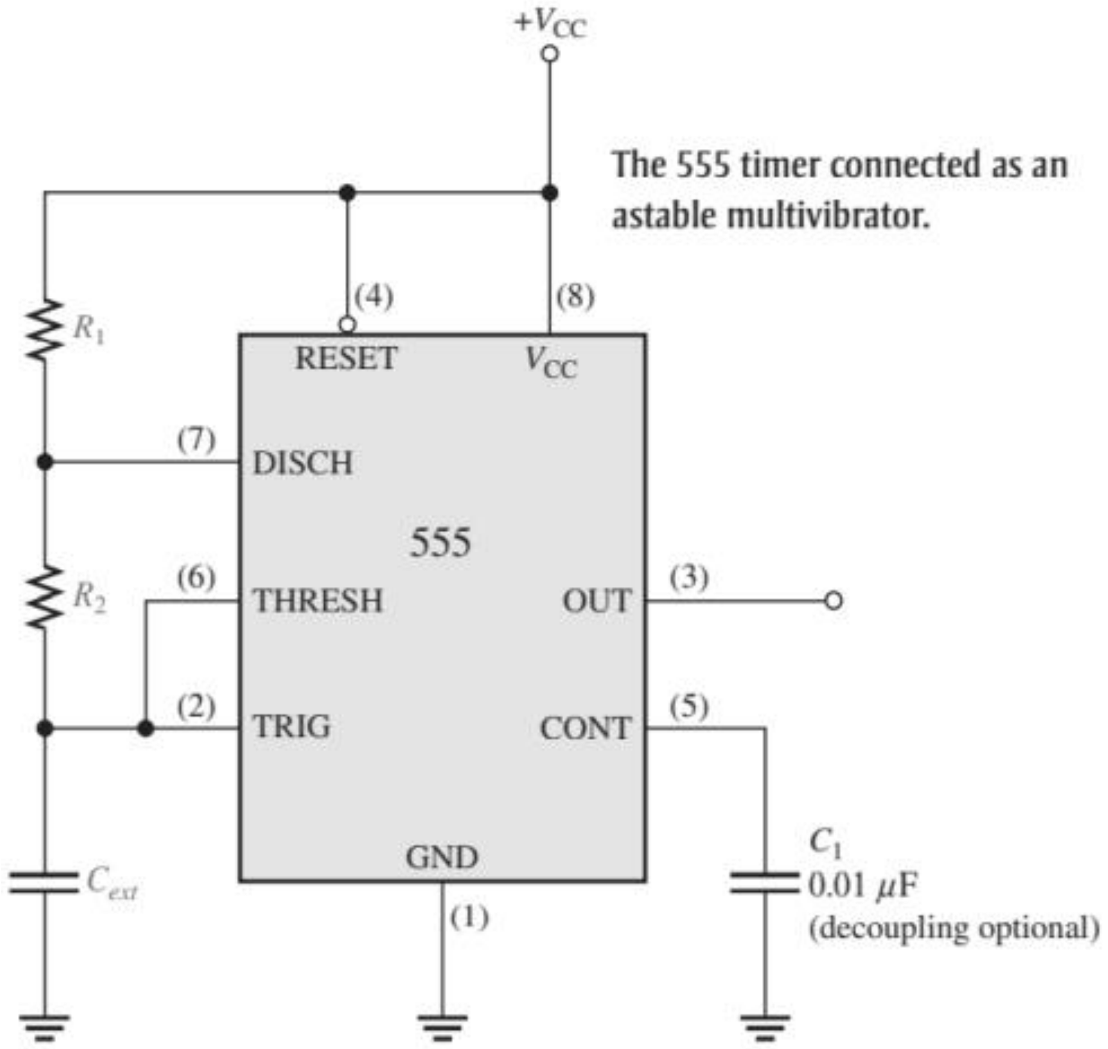
- Astable Operation
  - Decoupling capacitors are used to isolate or decouple two circuits.
  - In other words, they decouple AC signals from DC signals or vice versa.
  - In case of input voltage drop, it provides adequate power to an IC to maintain the voltage level.



The 555 timer connected as an astable multivibrator.

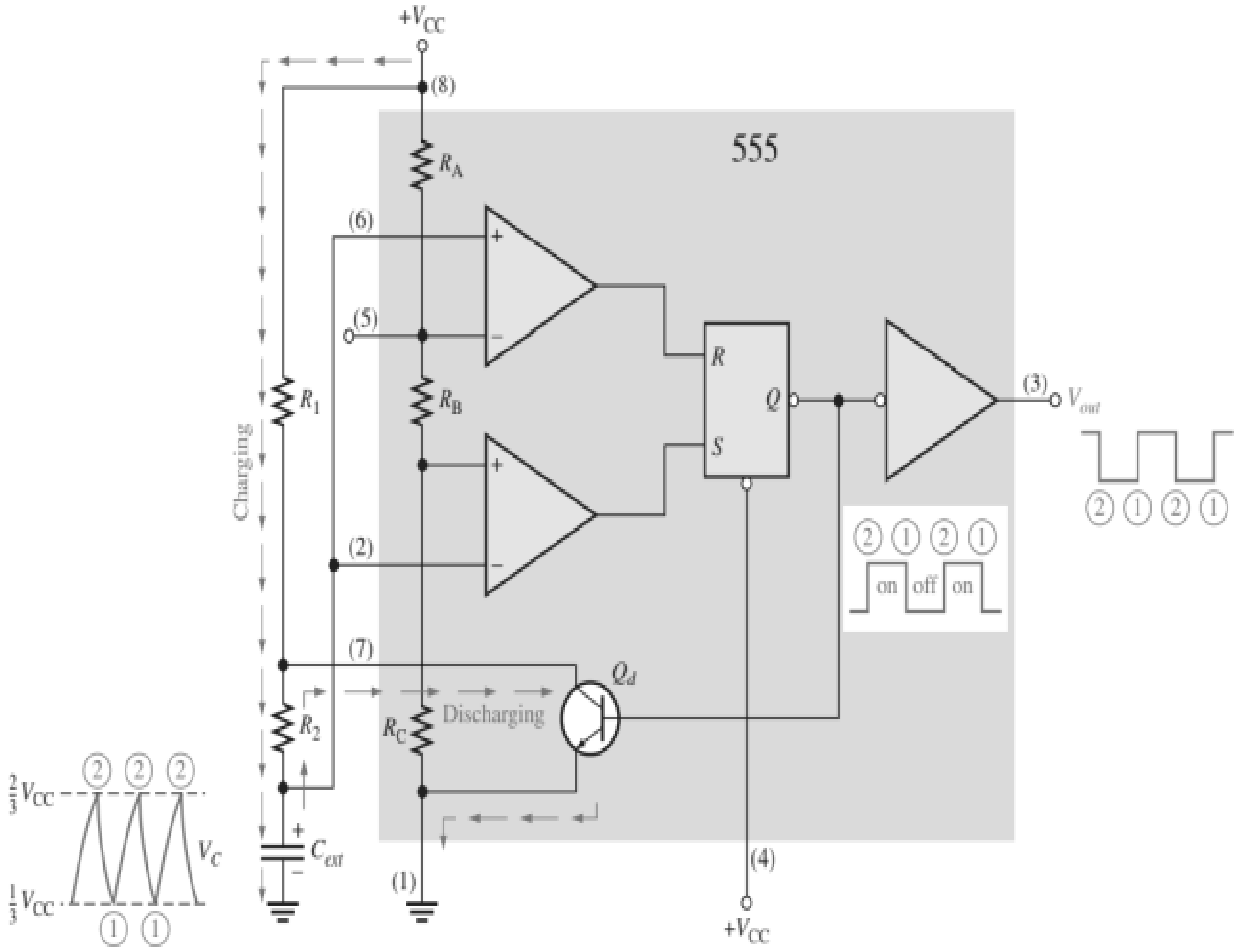
555 TIMER - Astable Operation

- Initially, when the power is turned on, the capacitor $Cext$ is uncharged and thus the trigger voltage (pin 2) is at 0 V.
- This causes the output of the lower comparator to be high and the output of the upper comparator to be low, forcing the output of the flip-flop, and thus the base of Qd low and keeping the transistor off.



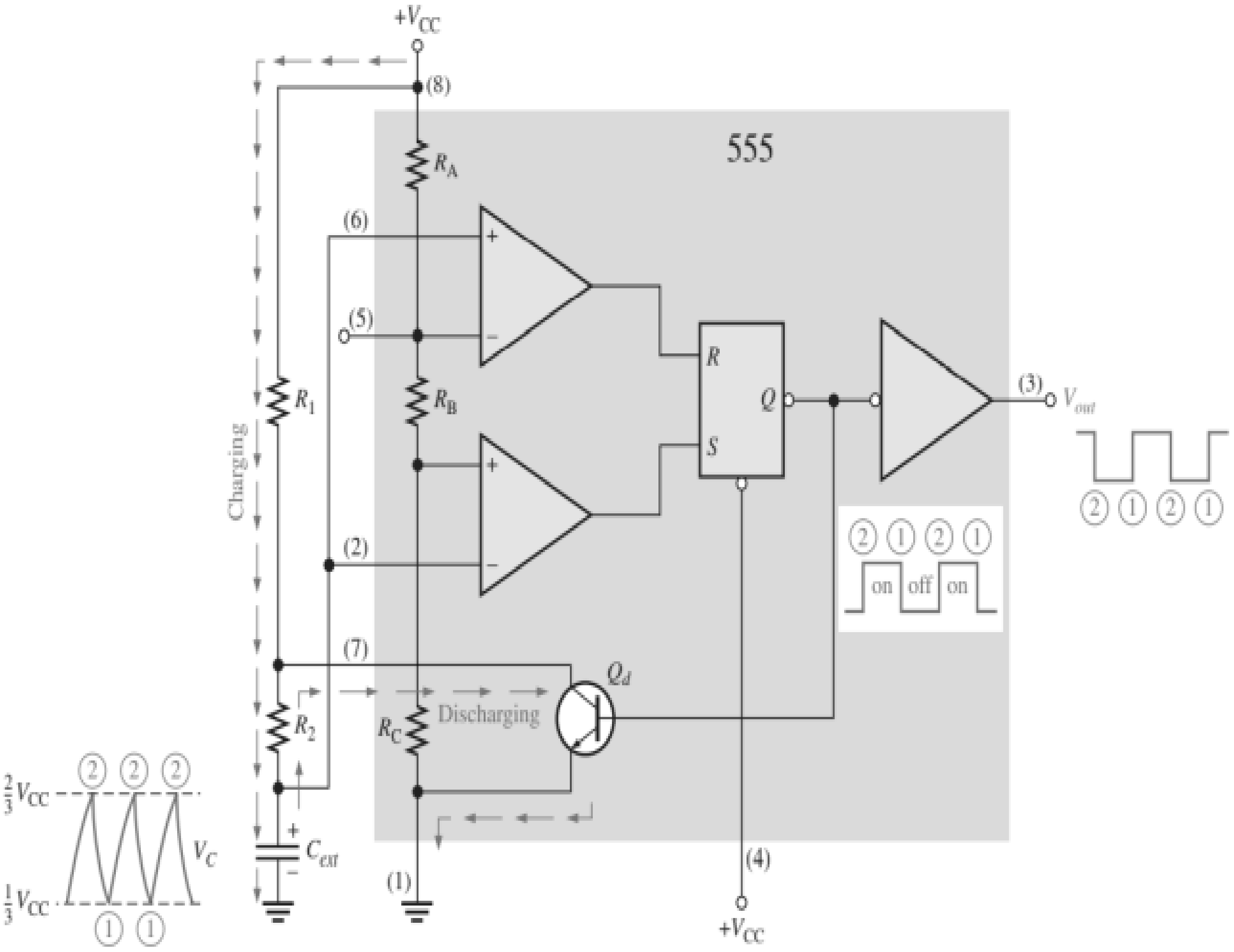
555 TIMER - Astable Operation

- Now, $Cext$ begins charging through $R1$ and $R2$ as indicated in figure.
- When the capacitor voltage reaches $\frac{1}{3}$Vcc, the lower comparator switches to its low output state, and when the capacitor voltage reaches $\frac{2}{3}$Vcc, the upper comparator switches to its high output state.



555 TIMER - Astable Operation

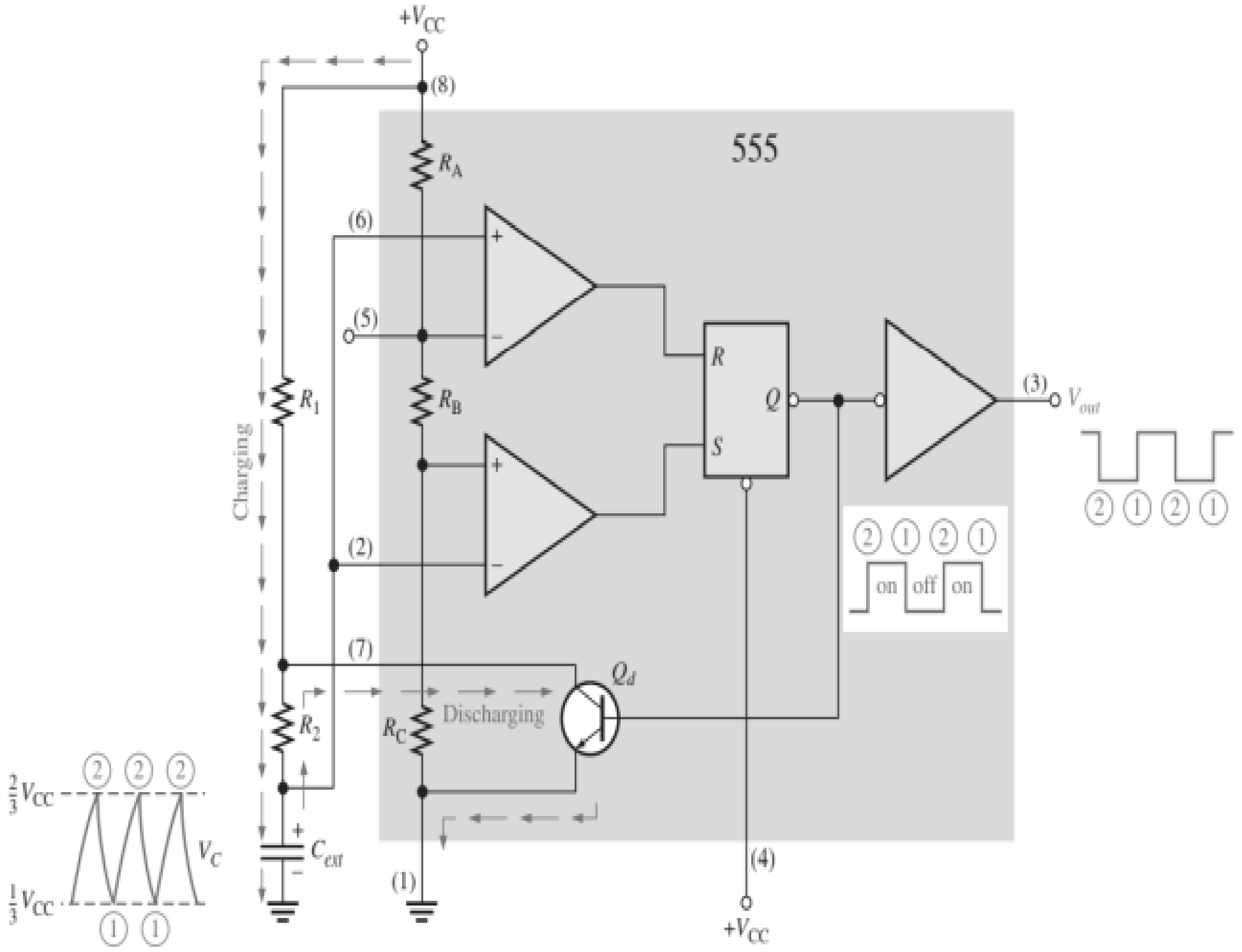
- This resets the flip-flop, causes the base Qd of to go high, and turns on the transistor.
- This sequence creates a discharge path for the capacitor through $R2$ and the transistor, as indicated.
- The capacitor now begins to discharge, causing the upper comparator to go low.
- At the point where the capacitor discharges down to $\frac{1}{3}$ Vcc, the lower comparator switches high, setting the flip-flop, which makes the base of Qd low and turns off the transistor.
- Another charging cycle begins, and the entire process repeats. The result is a rectangular wave output whose duty cycle depends on the values of $R1$ and $R2$.



555 TIMER - Astable Operation

The frequency of oscillation is given by:

$$f_r = \frac{1.44}{(R_1 + 2R_2)C_{ext}}$$



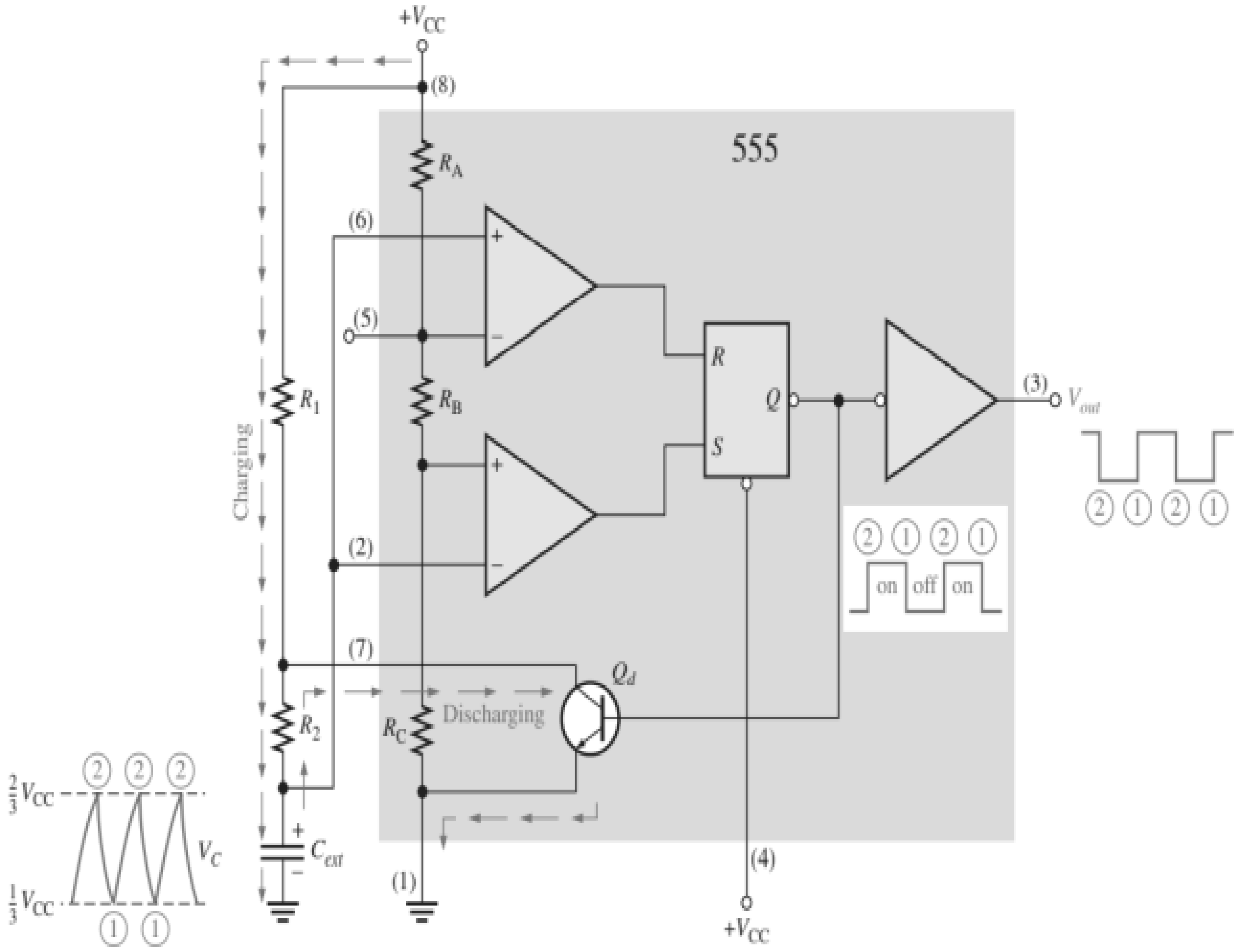
- By selecting $R1$ and $R2$ the duty cycle of the output can be adjusted.
- Since $Cext$ charges through $R1$ + $R2$ and discharges only through $R2$ duty cycles approaching a minimum of 50 percent can be achieved if $R2 \gg R1$ so that the charging and discharging times are approximately equal.

555 TIMER - Astable Operation

- The time that the output is high (t_H) is how long it takes $Cext$ to charge from $\frac{1}{3}$Vcc to $\frac{2}{3}$Vcc:
$$t_H = 0.694(R_1 + R_2)C_{ext}$$

- The time that the output is low (t_L) is how long it takes $Cext$ to discharge from $\frac{2}{3}$Vcc to $\frac{1}{3}$Vcc:
$$t_L = 0.694(R_2)C_{ext}$$

- The period, T, of the output waveform is the sum of t_H and t_L:
$$T = t_H + t_L = 0.694(R_1 + 2R_2)C_{ext}$$

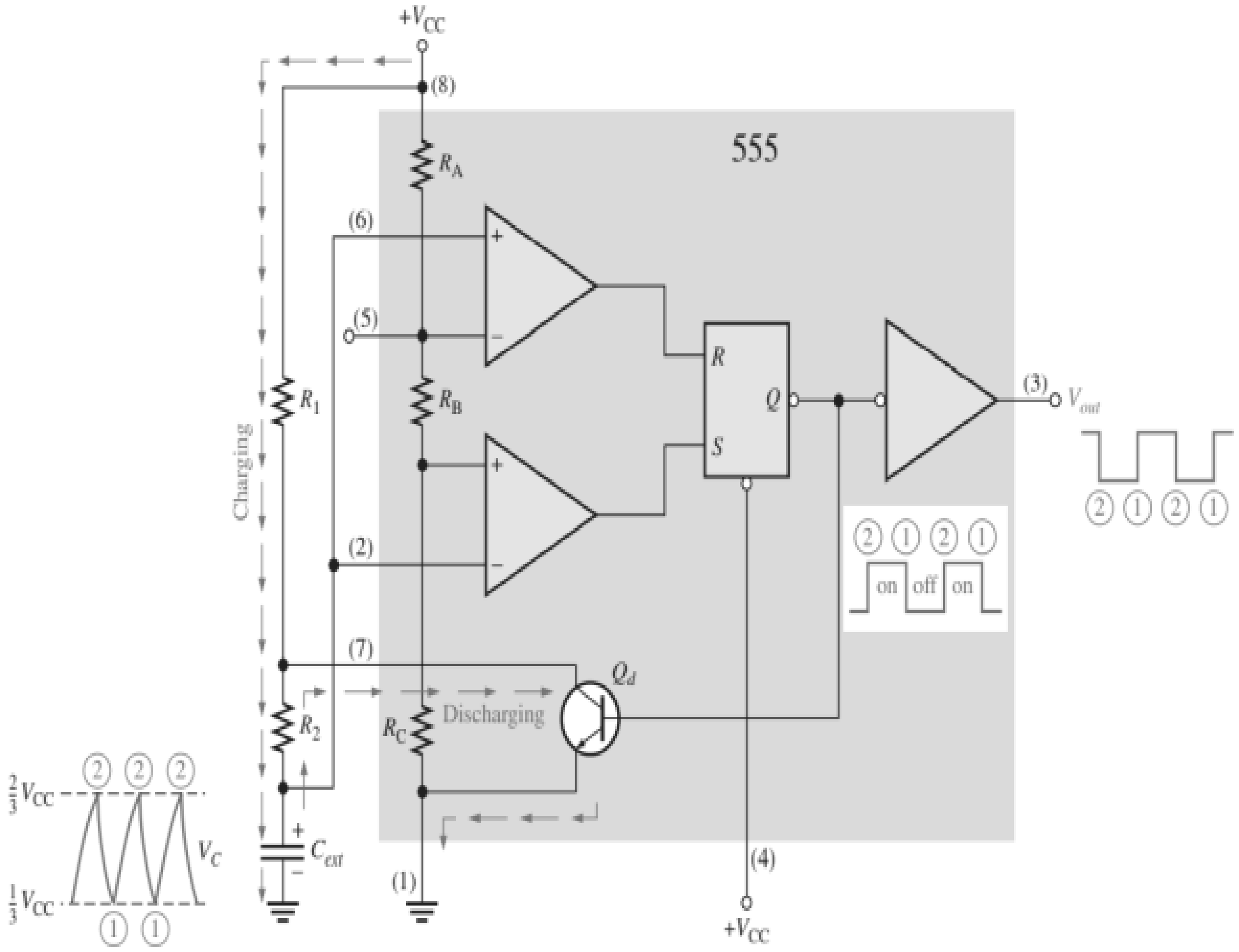


555 TIMER - Astable Operation

- The percent duty cycle (D):

$$Duty\ cycle = \left(\frac{t_H}{T}\right)100\% = \left(\frac{t_H}{t_H + t_L}\right)100\%$$

$$\boldsymbol{Duty\ cycle = \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right)100\%}$$

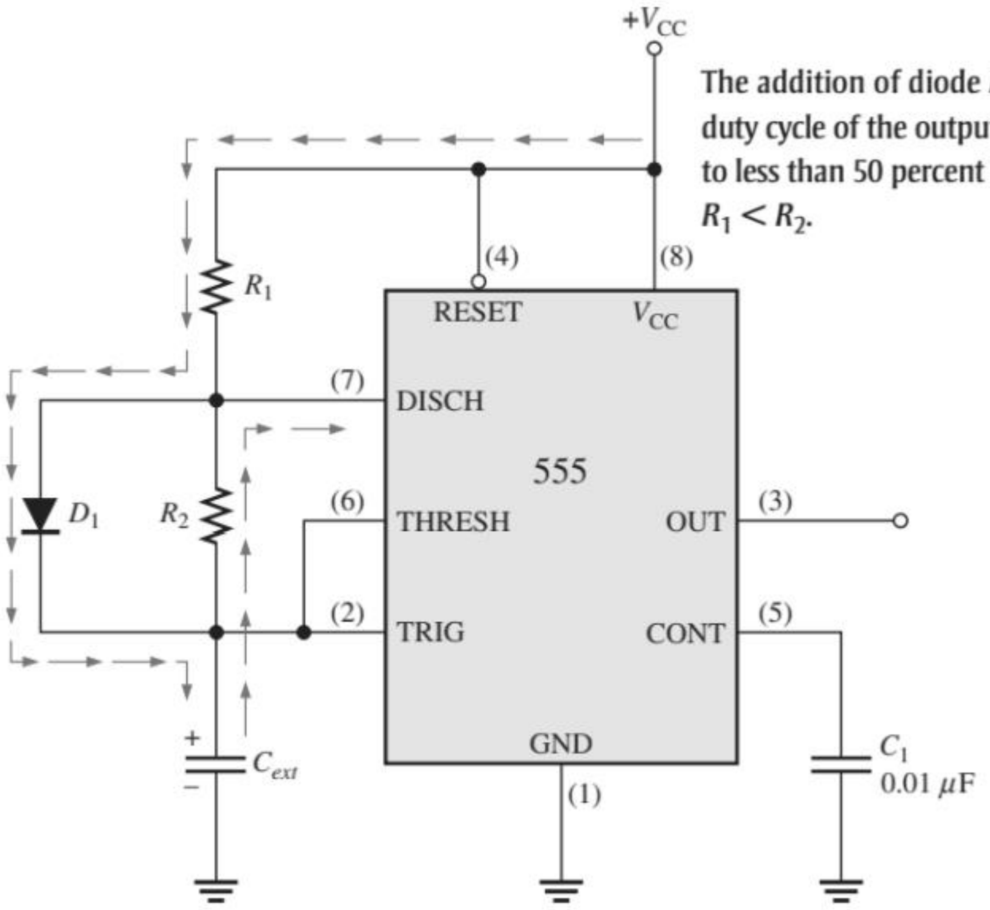


555 TIMER - Astable Operation

- To achieve duty cycles of less than 50 percent, the circuit can be modified so that $Cext$ charges through $R1$ only and discharges through $R2$.
- This is achieved with a diode, $D1$, placed as shown in the figure.
- The duty cycle can be made less than 50 percent by making $R1$ less than $R2$. Under this condition, the formulas for the frequency and percent duty cycle are (assuming an ideal diode)

$$f_r \cong \frac{1.44}{(R_1 + R_2)C_{ext}}$$

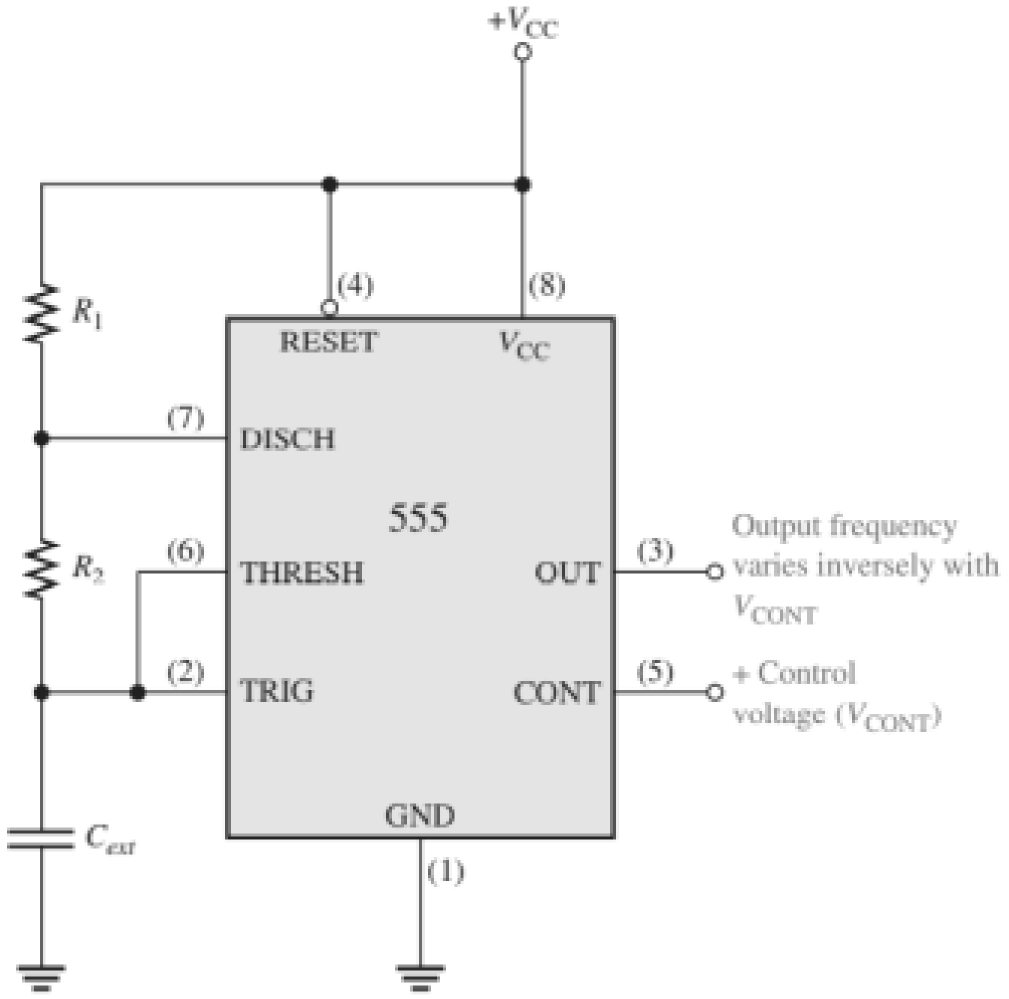
$$Duty\ cycle = \left(\frac{R_1}{R_1 + 2R_2}\right)100\%$$



The addition of diode D_1 allows the duty cycle of the output to be adjusted to less than 50 percent by making $R_1 < R_2$.

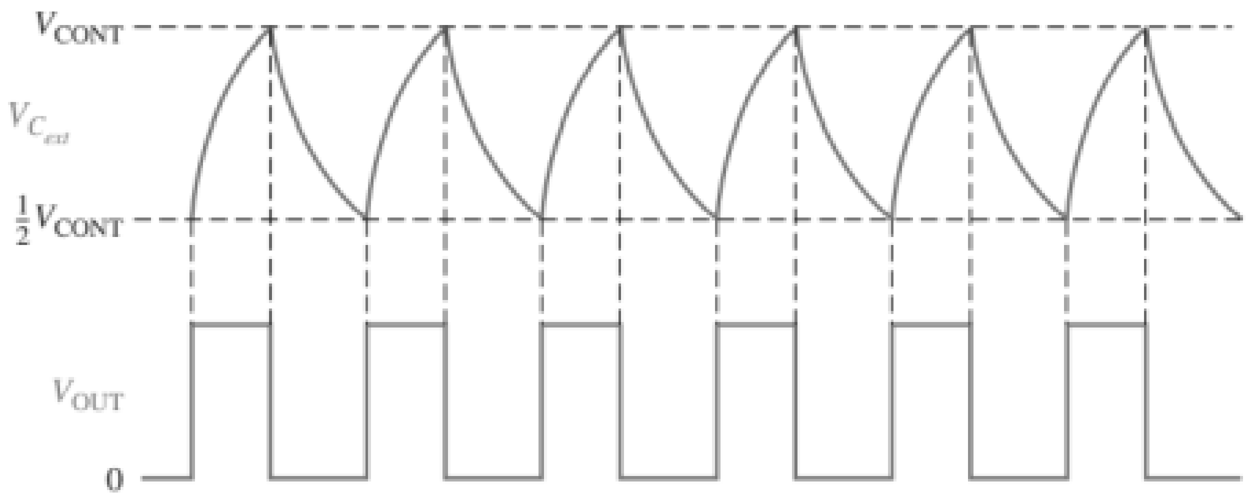
555 TIMER - Voltage-Controlled Oscillator (VCO)

- A 555 timer can be set up to operate as a VCO by using the same external connections as for astable operation, with the exception that a variable control voltage is applied to the CONT input (pin 5), as indicated in the figure.



555 TIMER - Voltage-Controlled Oscillator (VCO)

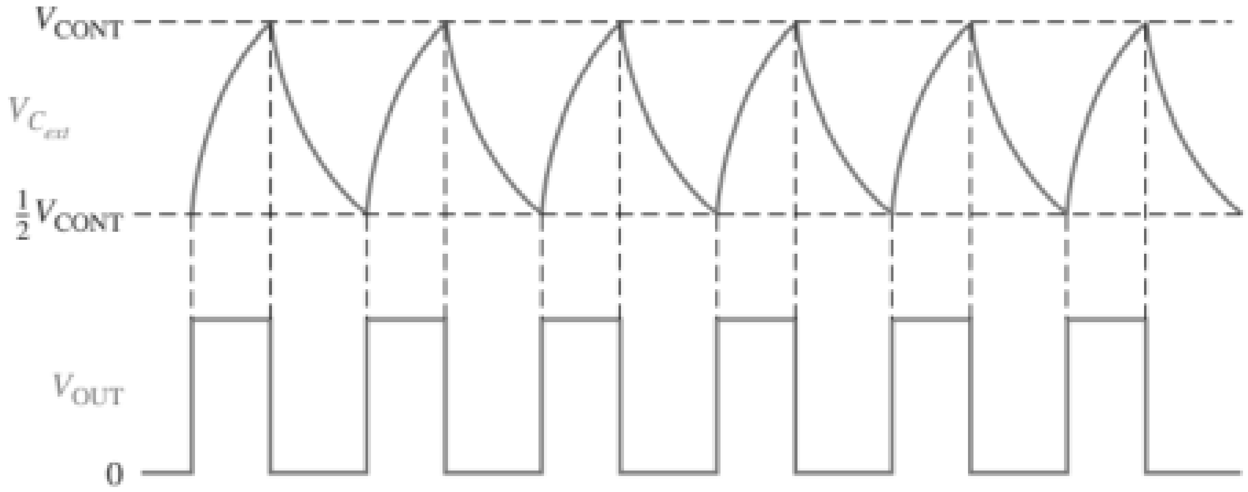
- As shown in the figure, the control voltage (V_{CONT}) changes the threshold values of $\frac{1}{3}$Vcc and $\frac{2}{3}$Vcc for the internal comparators.
- With the control voltage, the upper value is V_{CONT} and the lower value is $\frac{1}{2}V_{CONT}$.



The VCO output frequency varies inversely with V_{CONT} because the charging and discharging time of C_{ext} is directly dependent on the control voltage.

555 TIMER - Voltage-Controlled Oscillator (VCO)

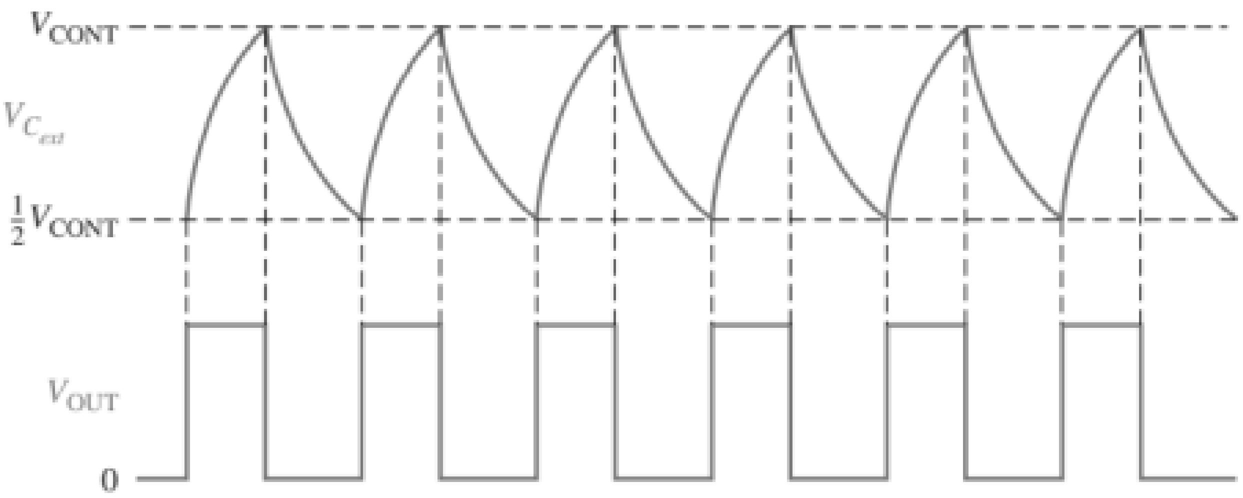
- When the control voltage is varied, the output frequency also varies.
- An increase in V_{CONT} increases the charging and discharging time of the external capacitor and causes the frequency to decrease.
- A decrease in V_{CONT} decreases the charging and discharging time of the capacitor and causes the frequency to increase.



The VCO output frequency varies inversely with V_{CONT} because the charging and discharging time of C_{ext} is directly dependent on the control voltage.

555 TIMER - Voltage-Controlled Oscillator (VCO)

- An interesting application of the VCO is in phase-locked loops, which are used in various types of communication receivers to track variations in the frequency of incoming signals.

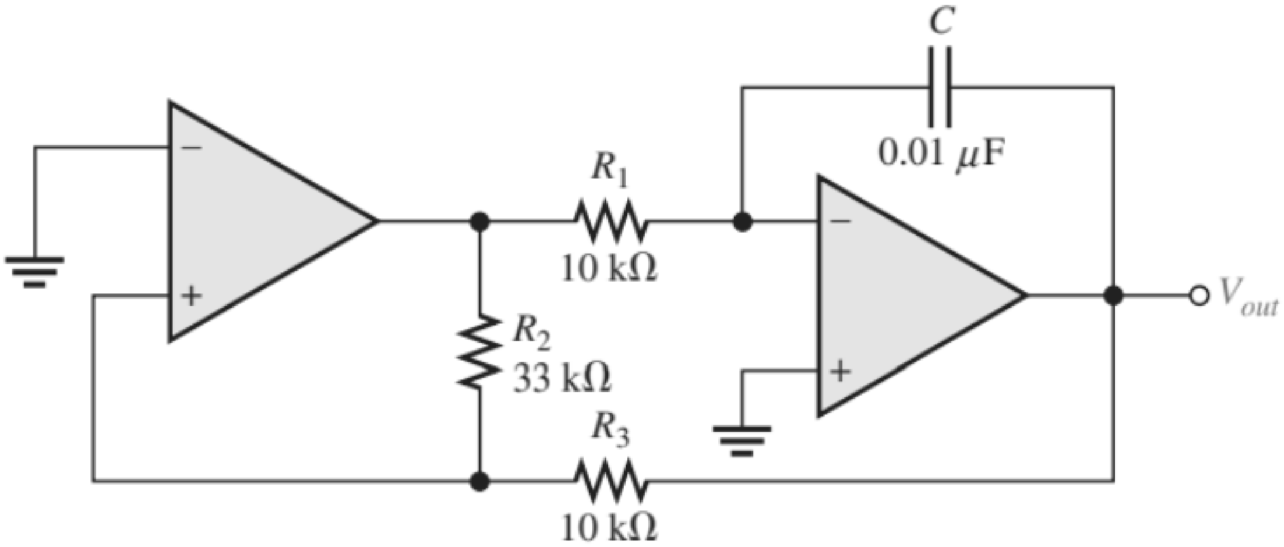


The VCO output frequency varies inversely with V_{CONT} because the charging and discharging time of C_{ext} is directly dependent on the control voltage.

Problem Solving

- Determine the frequency of oscillation of the circuit in the figure; and to what value must $R1$ be changed to make the frequency 20 kHz?

$$f_r = \frac{1}{4R_1C}\left(\frac{R_2}{R_3}\right)$$



Ans.

$$f_r = 8.25\ \text{kHz}$$

$$R_1 = 4.125\ \text{k}\Omega$$

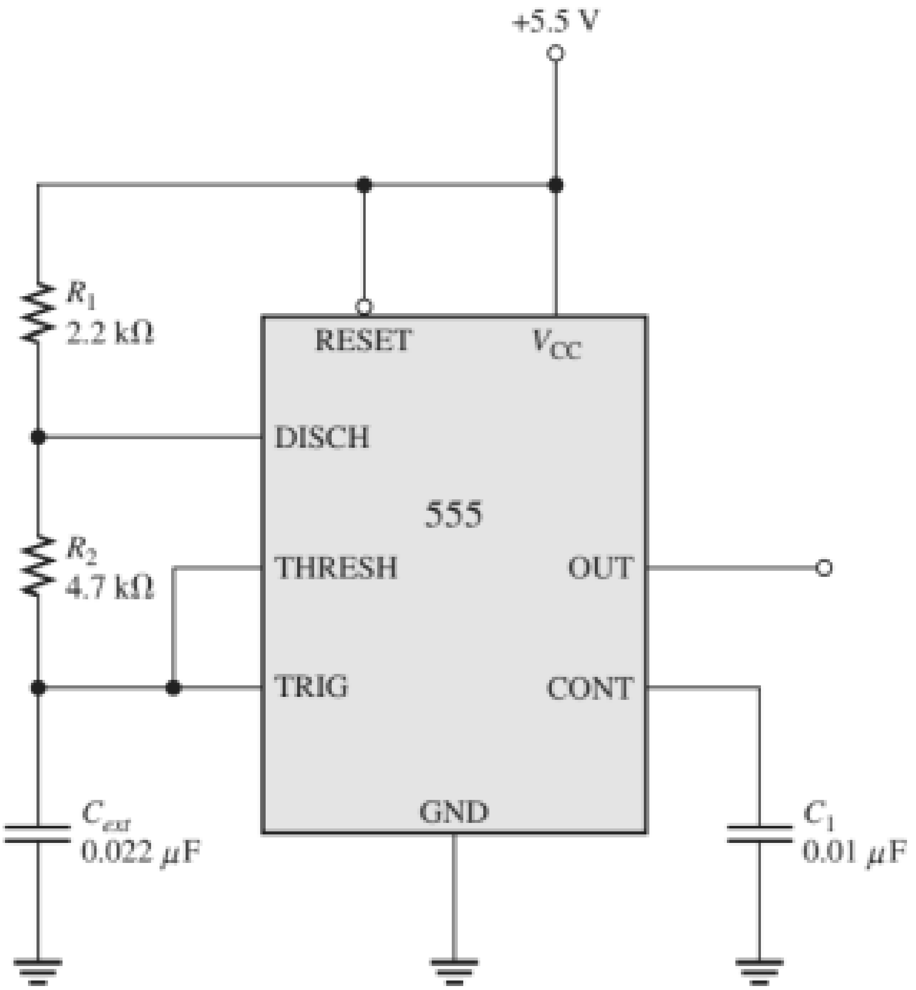
Problem Solving

- A 555 timer configured to run in the astable mode (oscillator) is shown in the figure. Determine the frequency of the output and the duty cycle.

$$f_r = \frac{1.44}{(R_1 + 2R_2)C_{ext}}$$

$$Duty\ cycle = \left(\frac{t_H}{T}\right)100\% = \left(\frac{t_H}{t_H + t_L}\right)100\%$$

$$\textbf{Duty cycle} = \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right)100\%$$



Ans.

$$f = 5.64\ \text{kHz}$$

$$D = 59.48\%$$