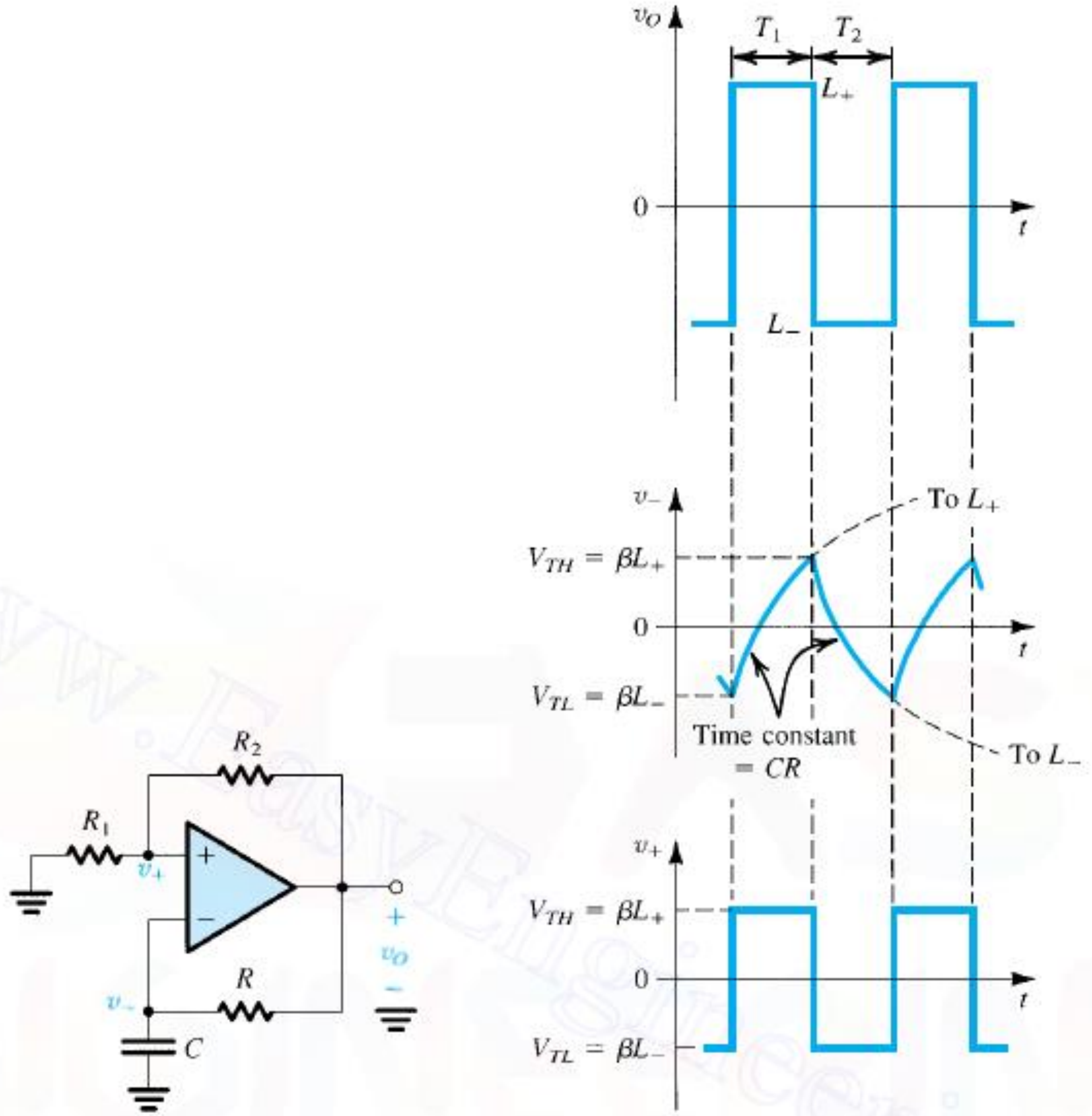
Lecture 33

Astable

Multivibrator



- During the charging interval T_1 the voltage v_1 across the capacitor at any time t, with $t = 0$ at the beginning of T_1, is given by

$$v_- = L_+ - (L_+ - \beta L_-)e^{-t/\tau}$$

where $\tau = CR$. Substituting $v_- = \beta L_+$ at $t = T_1$ gives

$$T_1 = \tau \ln \frac{1 - \beta(L_-/L_+)}{1 - \beta}$$

Similarly, during the discharge interval T_2 the voltage v_- at any time t, with $t = 0$ at the beginning of T_2, is given by

$$v_- = L_- - (L_- - \beta L_+)e^{-t/\tau}$$

Substituting $v_- = \beta L_-$ at $t = T_2$ gives

$$T_2 = \tau \ln \frac{1 - \beta(L_+/L_-)}{1 - \beta}$$

- When both saturation levels are of same magnitude,

- When both saturation levels are of same magnitude,

$L_+ = -L_-$

$\longrightarrow$ 50% duty cycle

Symmetrical square wave of period $T = T_1 + T_2$

$= 2T_1 = 2\tau \ln \frac{1+\beta}{1-\beta}$

How to generate a triangular wave?

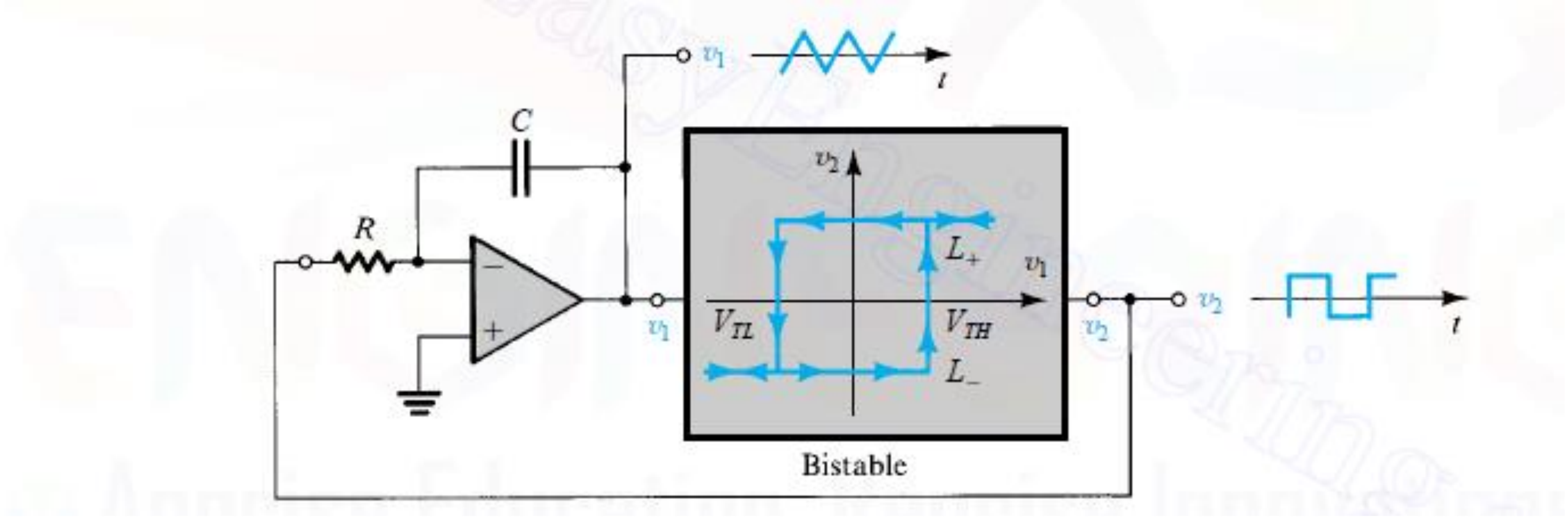
How to generate a triangular wave?

- Cascading an integrator with astable mulitivibrator?

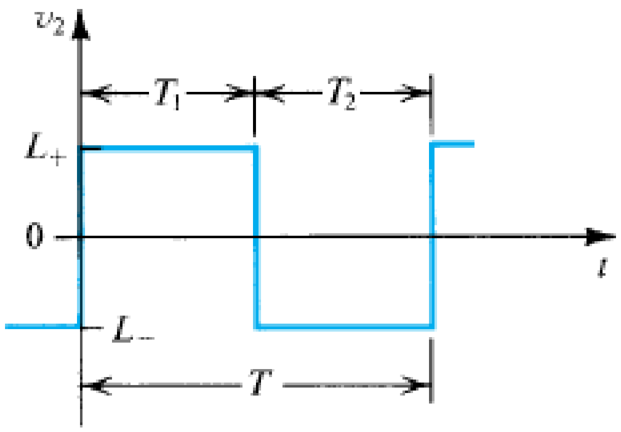
How to generate a triangular wave?

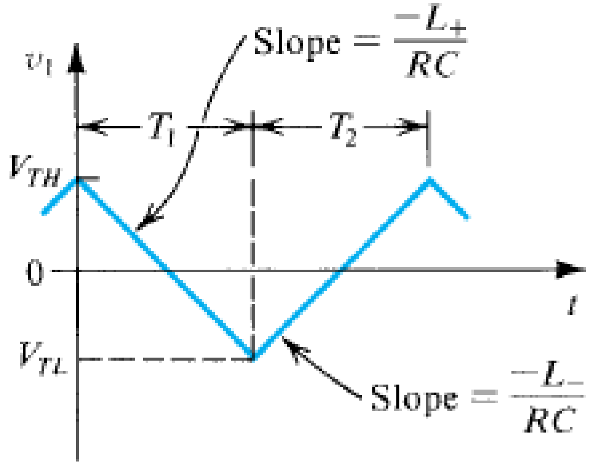
- Tuning the time constant of the RC circuit.

How to generate a triangular wave?



How to generate a triangular wave?





How to generate a triangular wave?

$$\frac{V_{TH} - V_{TL}}{T_1} = \frac{L_+}{CR}$$

from which we obtain

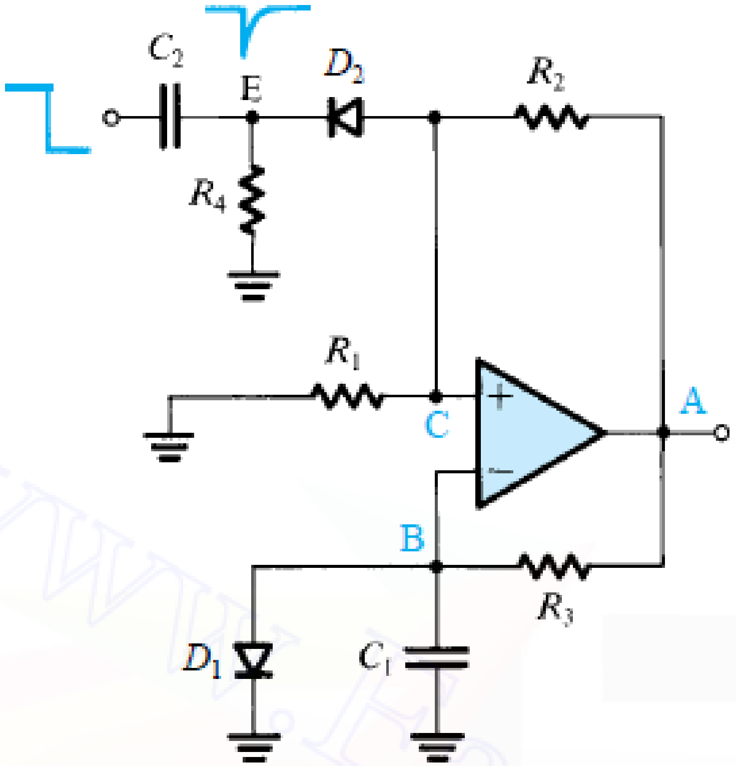
$$T_1 = CR\frac{V_{TH} - V_{TL}}{L_+}$$

Similarly, during T_2 we have

$$\frac{V_{TH} - V_{TL}}{T_2} = \frac{-L_-}{CR}$$

from which we obtain

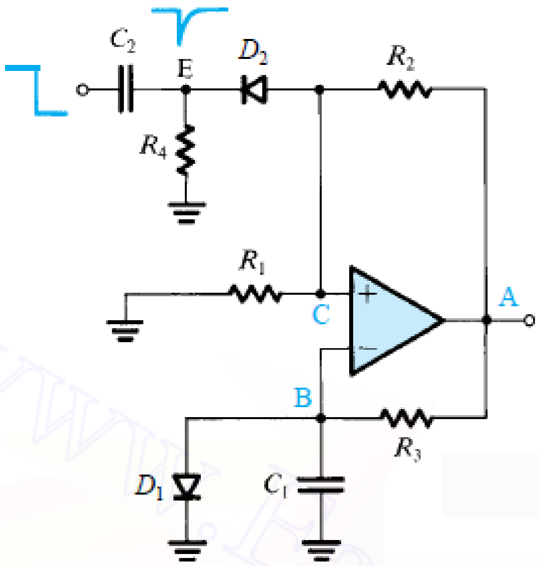
$$T_2 = CR\frac{V_{TH} - V_{TL}}{-L_-}$$

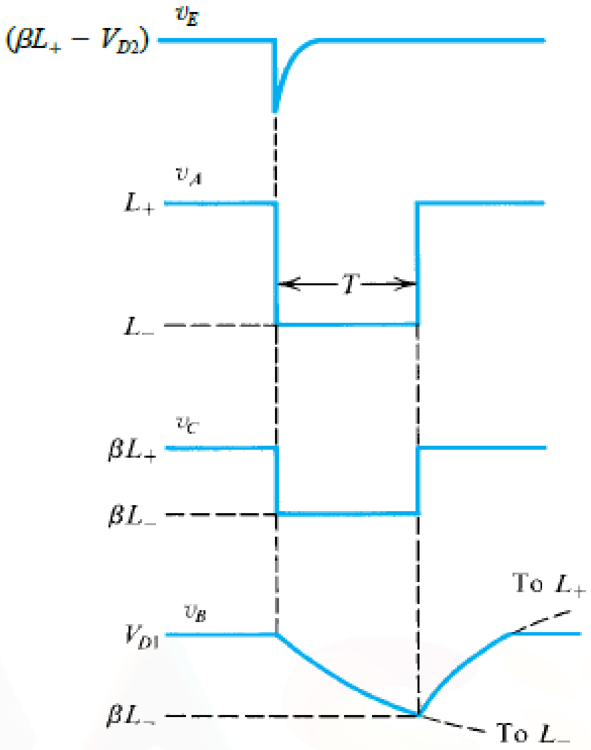


C2
E
D2
R2
R4
R1
C
A
B
R3
D1
C1

Lecture 34

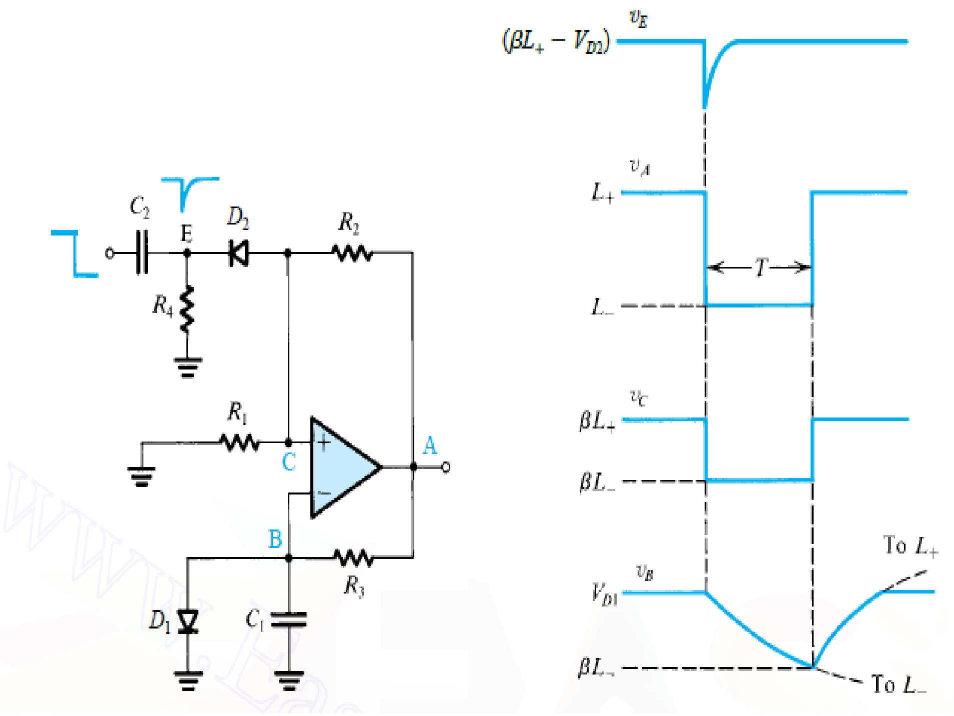
Monostable Multivibrator (An Op-Amp based circuit)





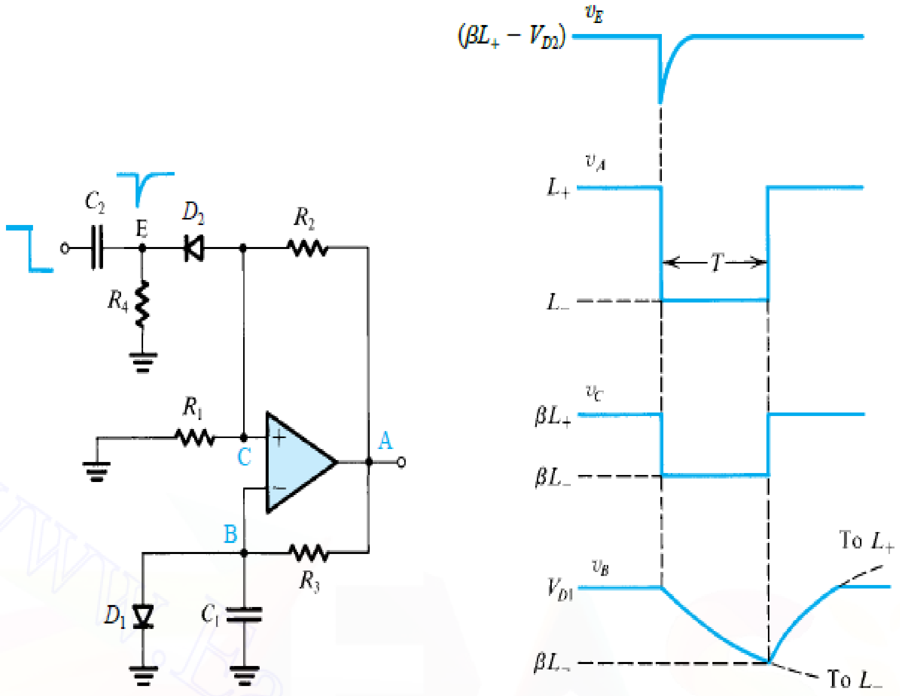
Monostable Multivibrator

- A clamping diode D_1 is added across the Capacitor C_1
- A trigger circuit (C_2, D_2, and R_4) is connected to the noninverting terminal.
- Only one stable state. When the output is L_+ in the absence of any triggering signal.
- *<please check what happens when the output is L_+>*
- D_1 *is conducting, voltage level at the node B is clamped at one diode drop.*



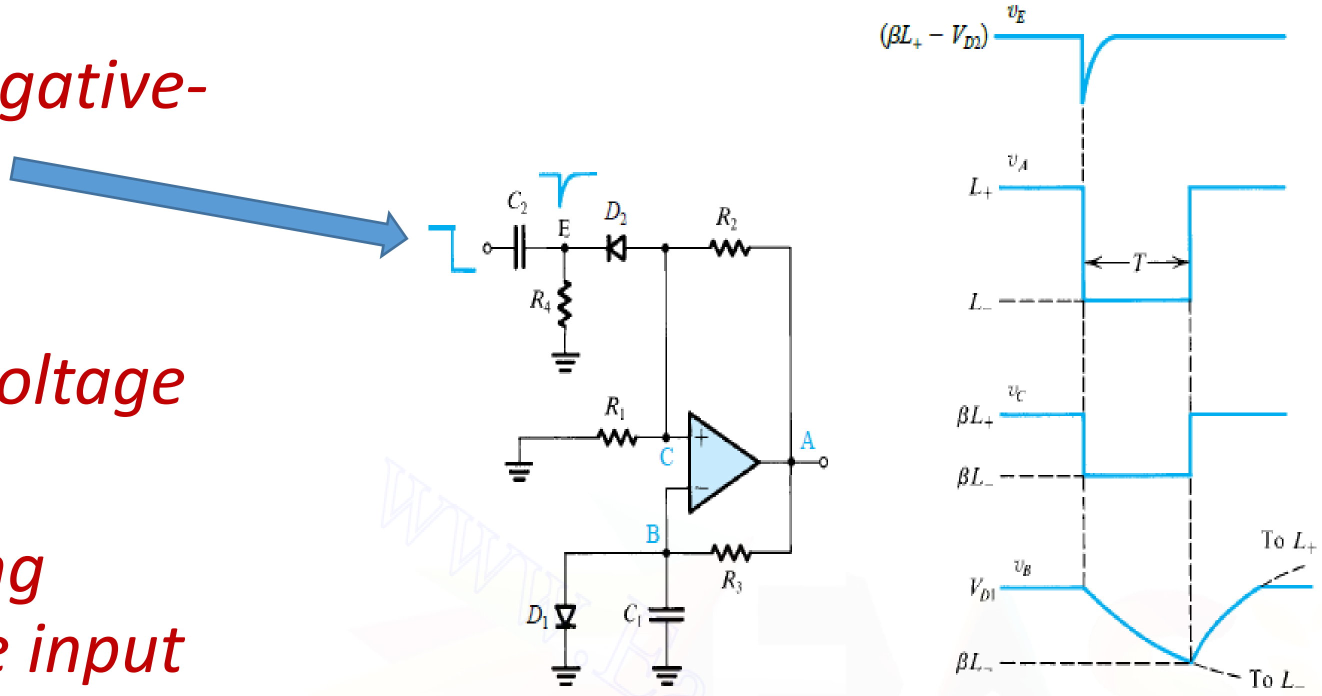
Monostable Multivibrator

- D_1 *is conducting, voltage level at the node B is clamped at one diode drop above the ground.*
- *We select* $R_4 \gg R_1$*. So, the current through* D_2 *is negligible.*
- *Voltage at the noninverting terminal is approximately* βL_+*, where* $\beta = \frac{R_1}{R_1+R_2}$
- *The stable state is maintained, because* $\beta L_+ > one\ diode\ drop\ above\ ground.$

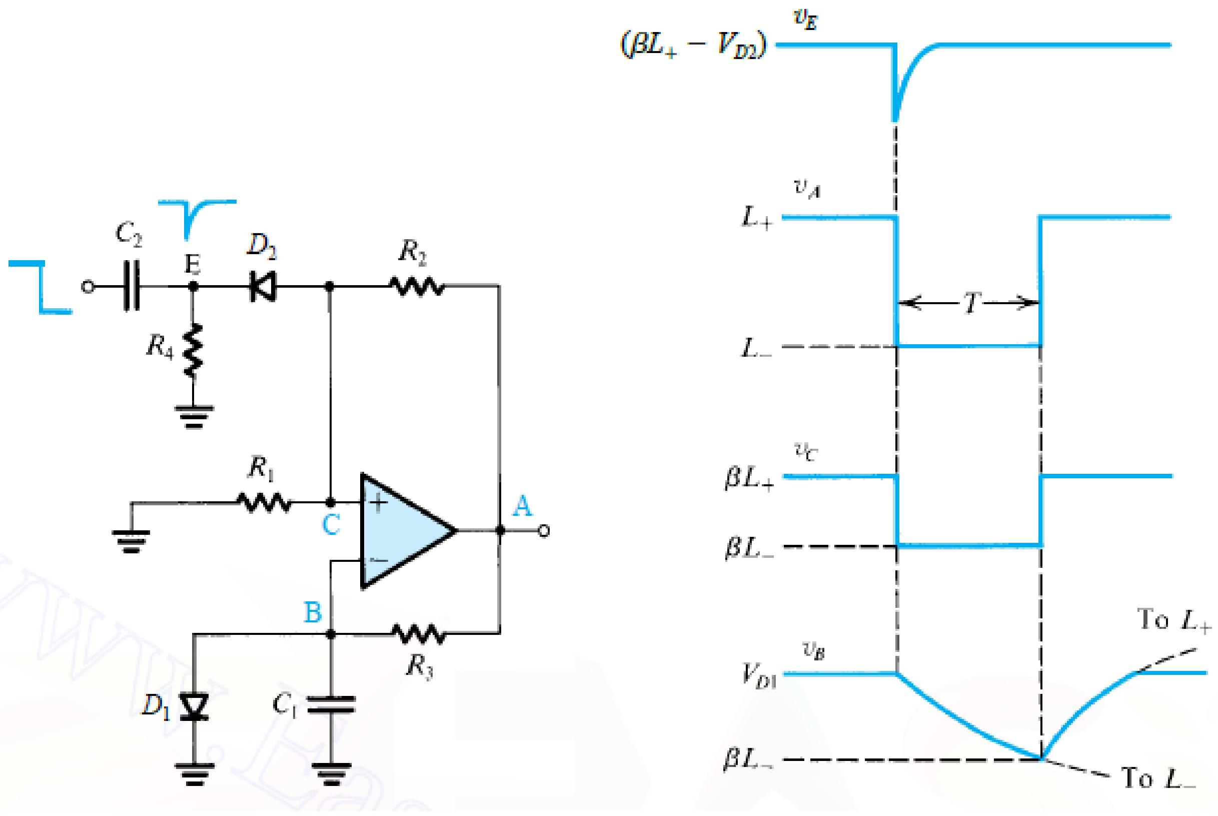


Monostable Multivibrator

- *Now see what happens when a negative-going triggering voltage is applied*



- D_2 *is conducting heavily, pulling voltage level at the node C down.*
- *So, for a sufficiently large triggering voltage the op amp has a negative input (i.e., B is at higher potential than C).*
- *Output changes to* L_-
- D_2 *is cut off. Triggering section is isolated.*



- The negative voltage at A causes D_1 to cut off, and C_1 begins to discharge exponentially toward $L\_$ with a time constant C_1R_3. The monostable multivibrator is now in its *quasi-stable state,* which will prevail until the declining v_B goes below the voltage at node C, which is βL_-. At this instant the op-amp output switches back to L_+ and the voltage at node C goes back to βL_+. Capacitor C_1 then charges toward L_+ until diode D_1 turns on and the circuit returns to its stable state.

From the figure , we observe that a negative pulse is generated at the output during the quasi-stable state. The duration T of the output pulse is determined from the exponential waveform of v_B,

$$v_B(t) = L_- - (L_- - V_{D1})e^{-t/C_1R_3}$$

From the figure , we observe that a negative pulse is generated at the output during the quasi-stable state. The duration T of the output pulse is determined from the exponential waveform of v_B,

$$v_B(t) = L_- - (L_- - V_{D1})e^{-t/C_1 R_3}$$

by substituting $v_B(T) = \beta L_-$,

$$\beta L_- = L_- - (L_- - V_{D1})e^{-T/C_1 R_3}$$

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$$\beta L_- = L_- - (L_- - V_{D1})e^{-T/C_1R_3}$$

which yields

$$T = C_1R_3 \ln\left(\frac{V_{D1} - L_-}{\beta L_- - L_-}\right)$$

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$$v_B(t) = L_- - (L_- - V_{D1})e^{-t/C_1R_3}$$

by substituting $v_B(T) = \beta L_-$,

$$\beta L_- = L_- - (L_- - V_{D1})e^{-T/C_1R_3}$$

which yields

$$T = C_1R_3 \ln\left(\frac{V_{D1} - L_-}{\beta L_- - L_-}\right)$$

For $V_{D1} \ll |L_-|$, this equation can be approximated by

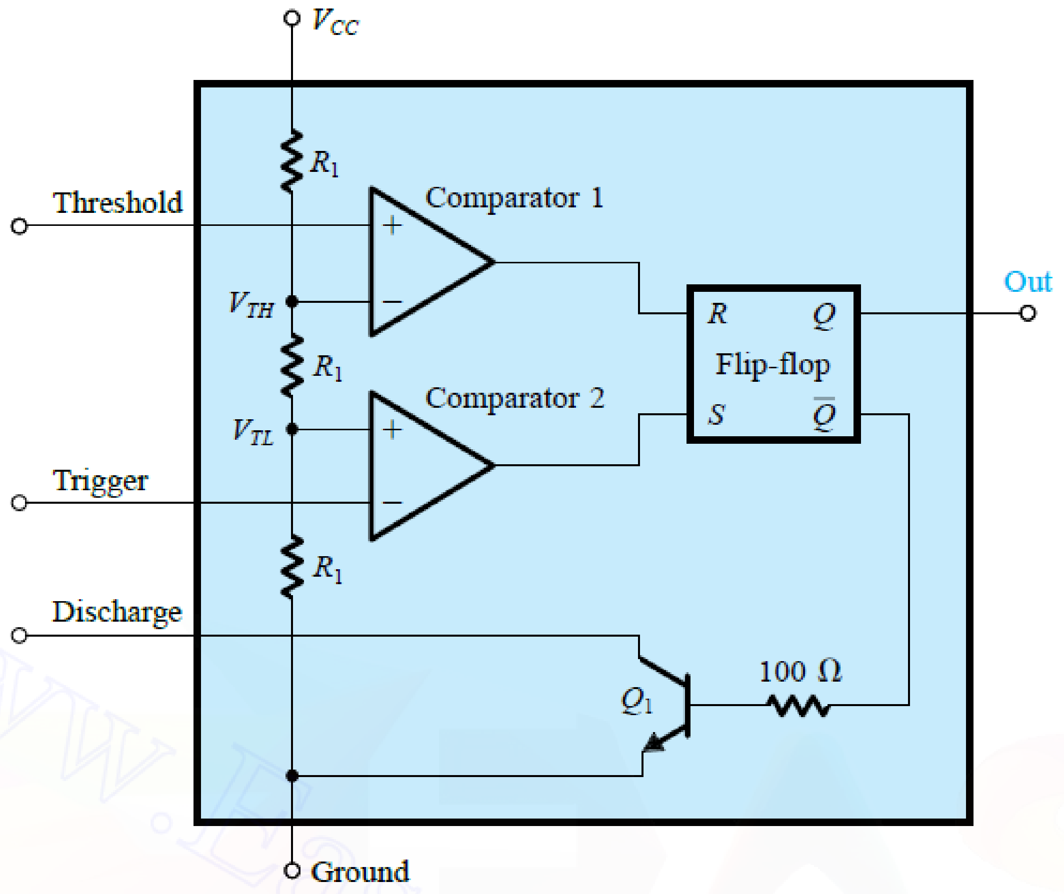
$$T \simeq C_1R_3 \ln\left(\frac{1}{1-\beta}\right)$$

Integrated Circuit Timer

Commercially available integrated-circuit packages exist that contain the bulk of the circuitry needed to implement monostable and astable multivibrators with precise characteristics. In this section we discuss the most popular of such ICs, the **555 timer**. Introduced in 1972 by the Signetics Corporation as a bipolar integrated circuit, the 555 is also available in CMOS technology and from a number of manufacturers.

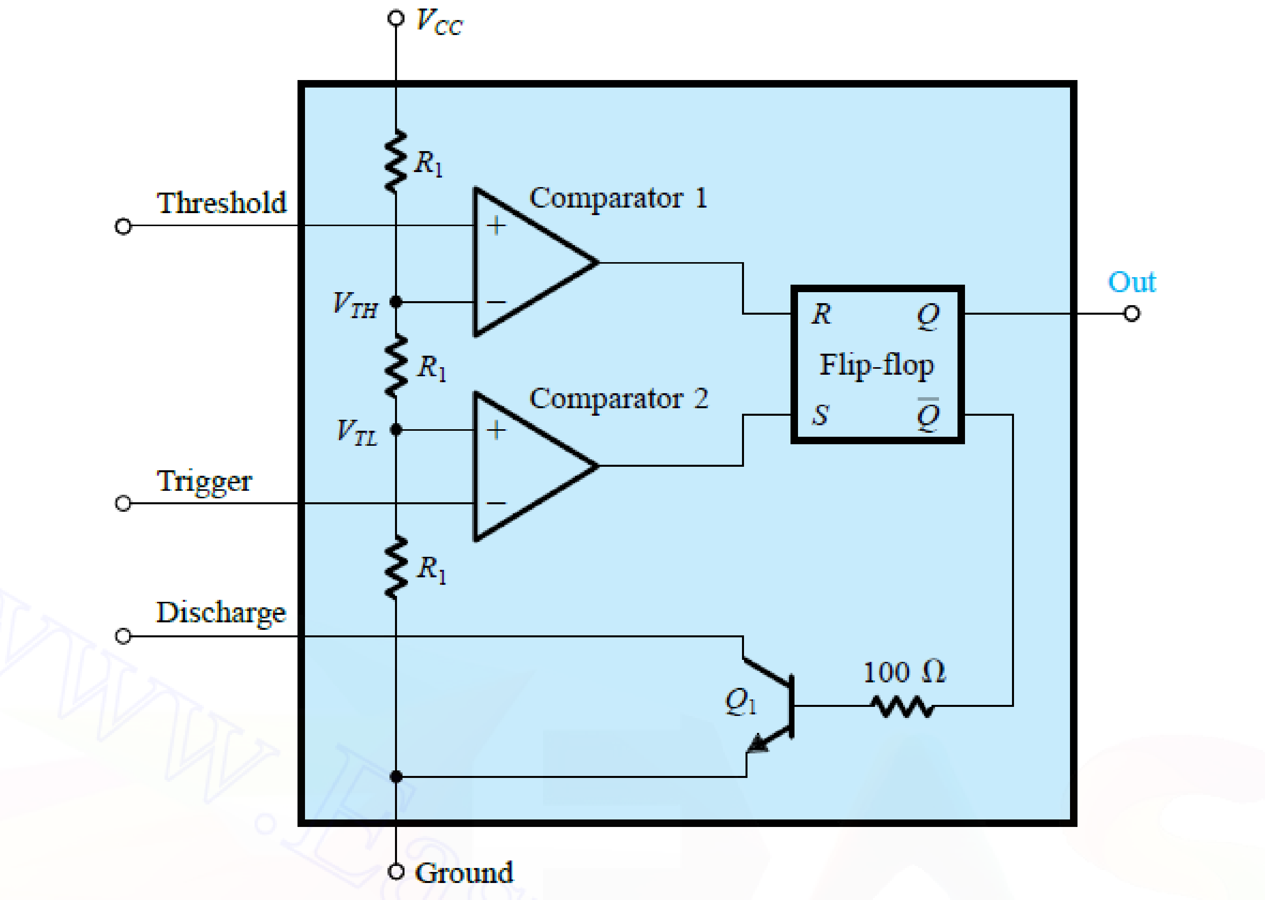
555 Circuit (Block Diagram of Internal circuits)

- 2 comparators
- 1 SR flip-flop
- 1 transistor as electronic switch
- 1 power supply (typically 5 V.)
- 1 resistive voltage divider consisting 3 equally valued resistors.



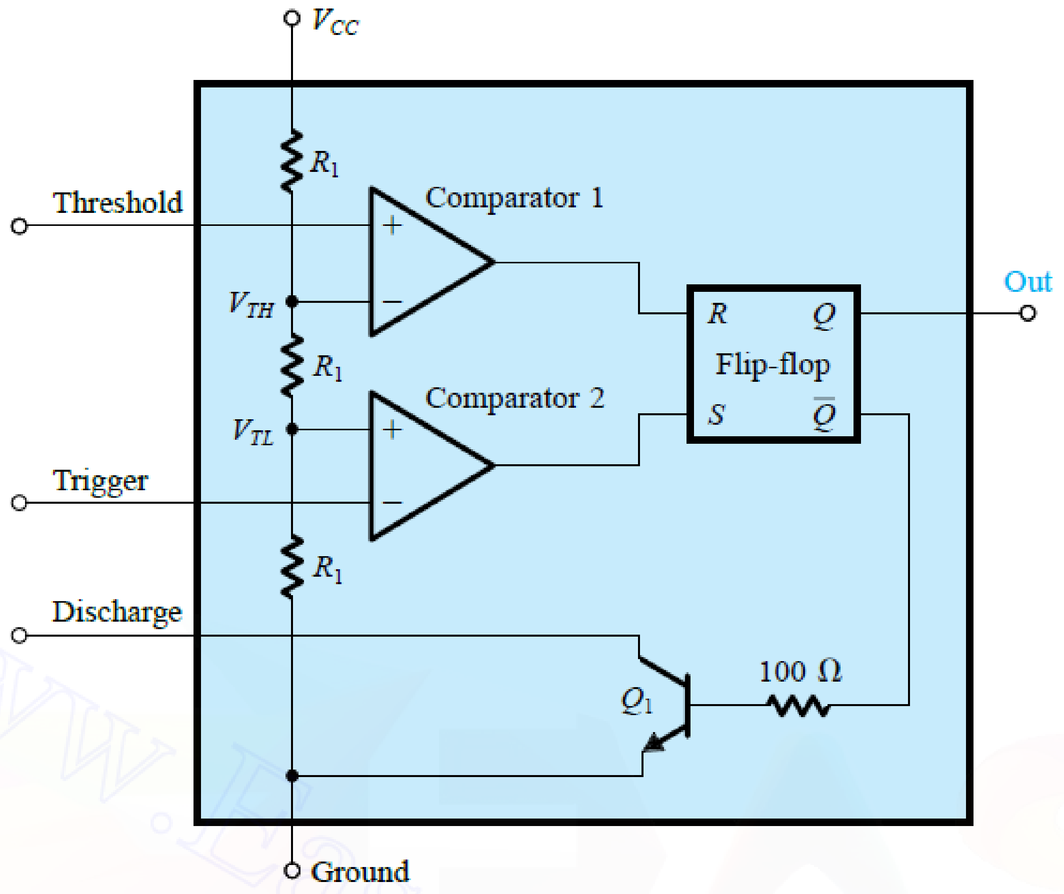
555 Circuit (Block Diagram of Internal circuits)

- Two threshold/reference voltages for two comparators.
- $V_{TH} = \frac{2}{3} V_{CC}$
- $V_{TL} = \frac{1}{3} V_{CC}$



555 Circuit (Block Diagram of Internal circuits)

- Recall that SR flip-flops are bistable multivibrators with two complementary outputs.



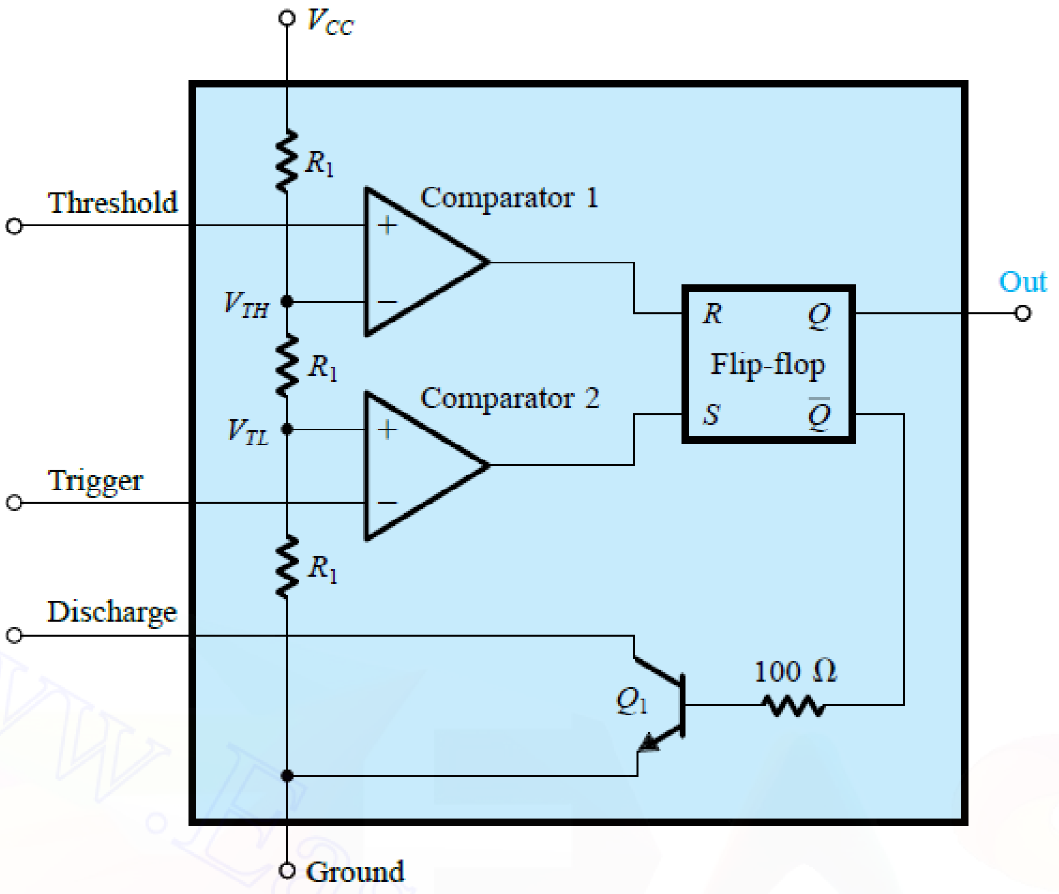
555 Circuit (Block Diagram of Internal circuits)

- The `Threshold’ terminal of the IC package (external pin):

connected to the positive terminal of the comparator 1

- The `Trigger’ terminal of the IC package (external pin):

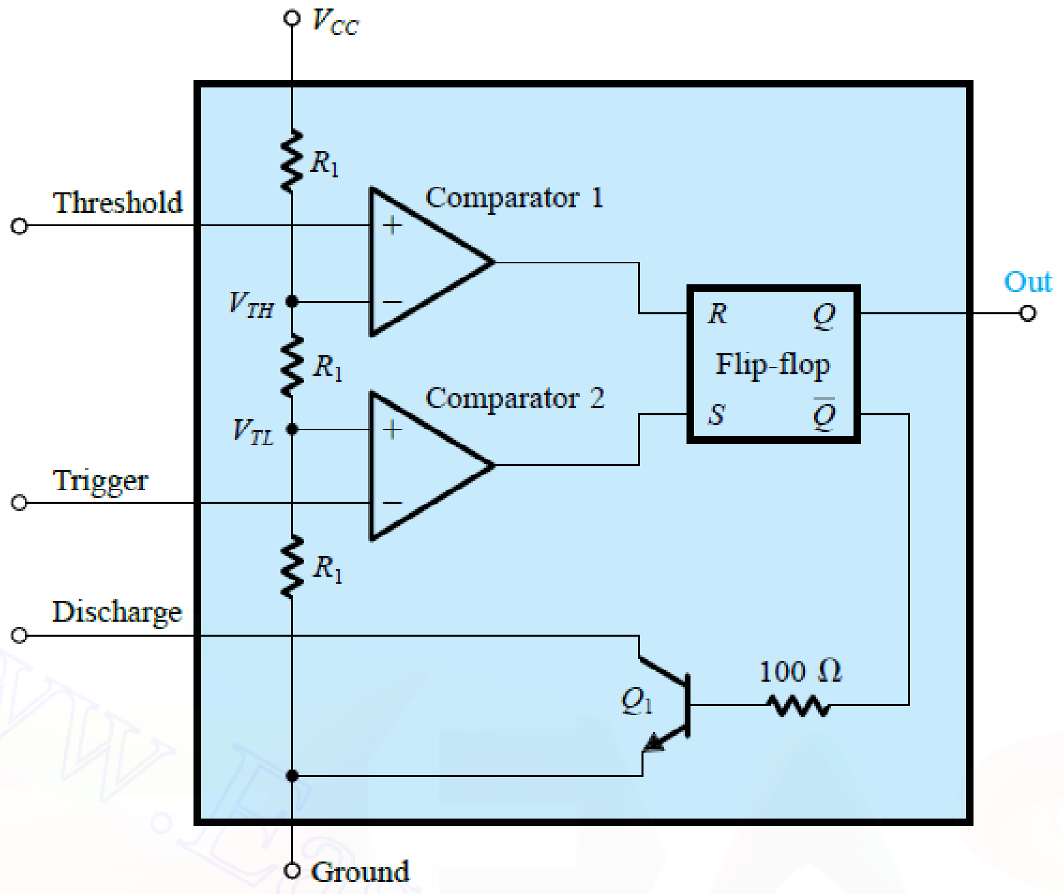
connected to the negative terminal of the comparator 2



555 Circuit (Block Diagram of Internal circuits)

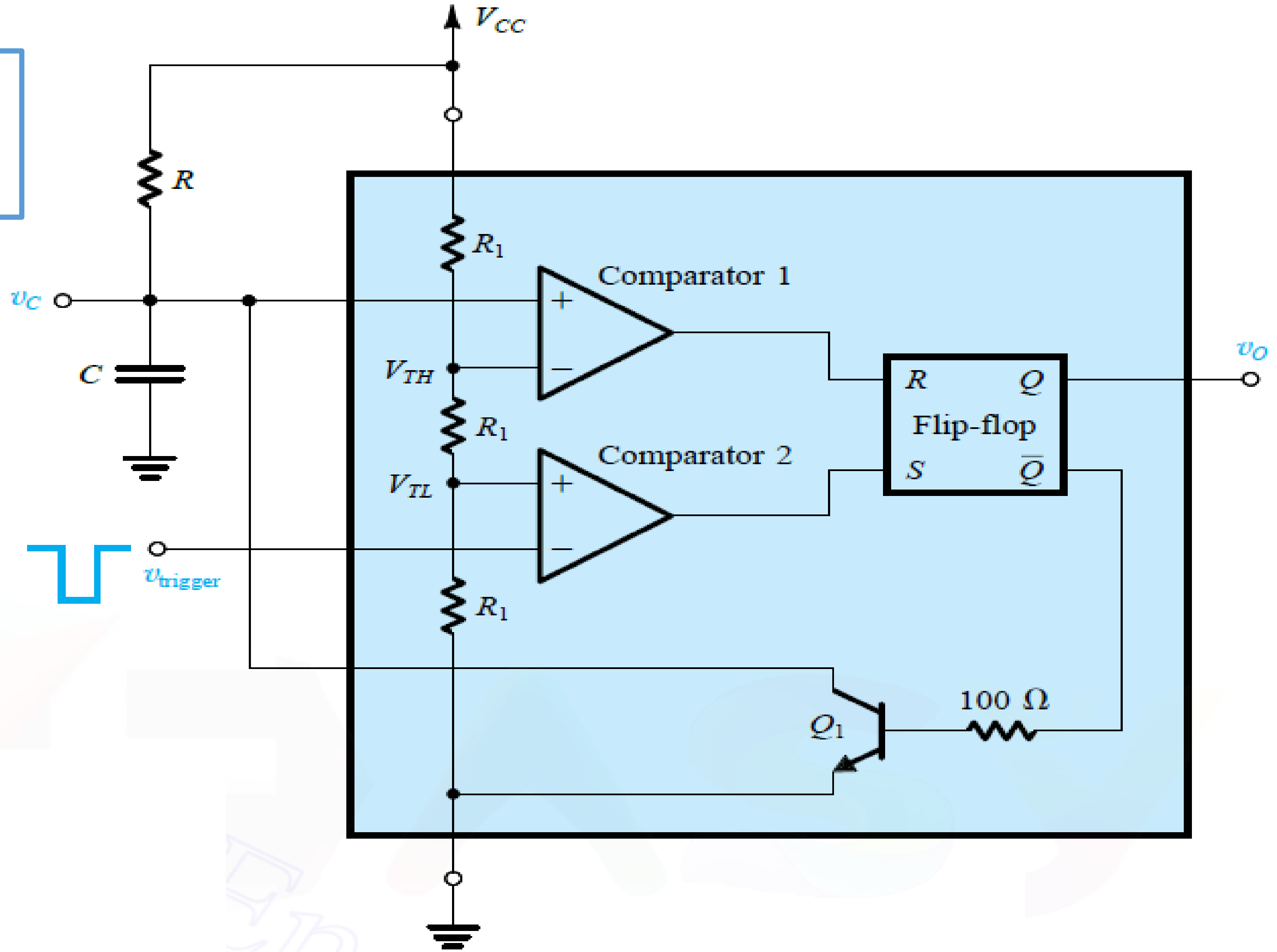
- The `Discharge’ terminal of the IC package (external pin): connected to the `collector’ of the transistor (electronic switch)

- The `Out’ terminal of the IC package (external pin): connected to the `Q’ output terminal of the flip-flop



Implementing a Monostable Multivibrator using the 555 IC

One external R and one external C



Implementing a Monostable Multivibrator using the 555 IC

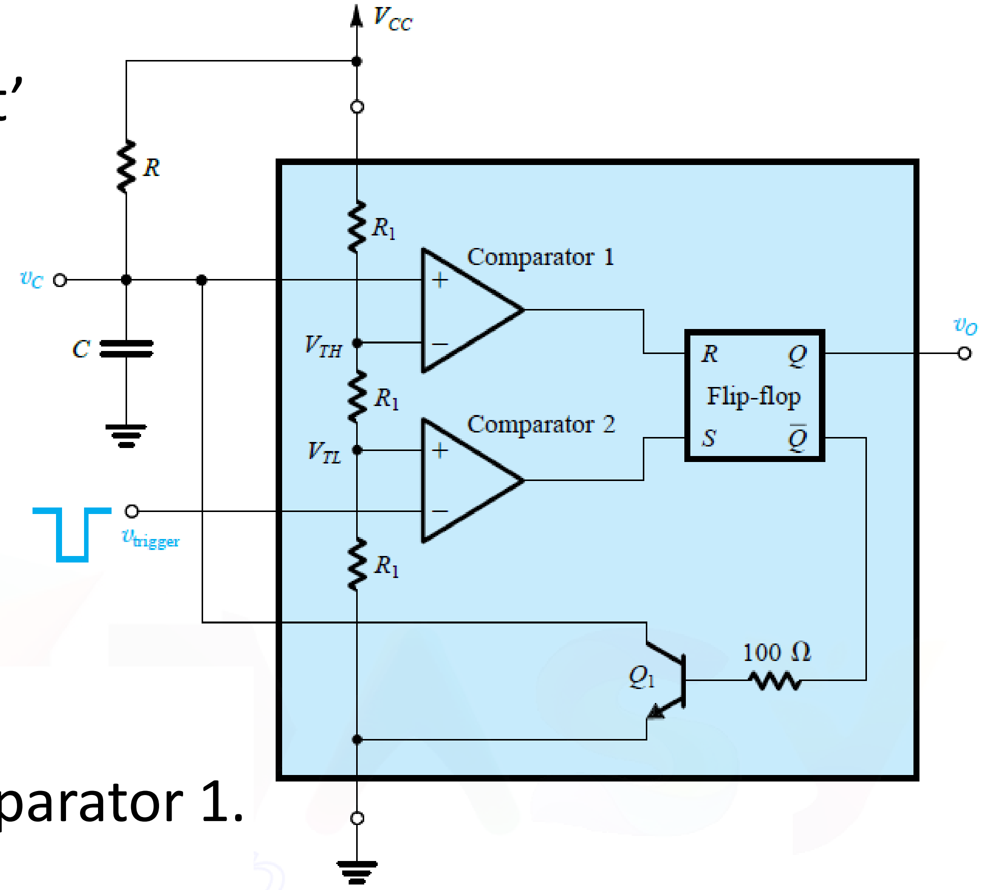
- In the stable state, the flip-flop will be in the `reset' state.

- $\overline{Q}$ output will be high.

- Will turn $'Q_1'$ transistor on.

- v_C will be close to 0 V.

- Will result in a low level at the output of the comparator 1.

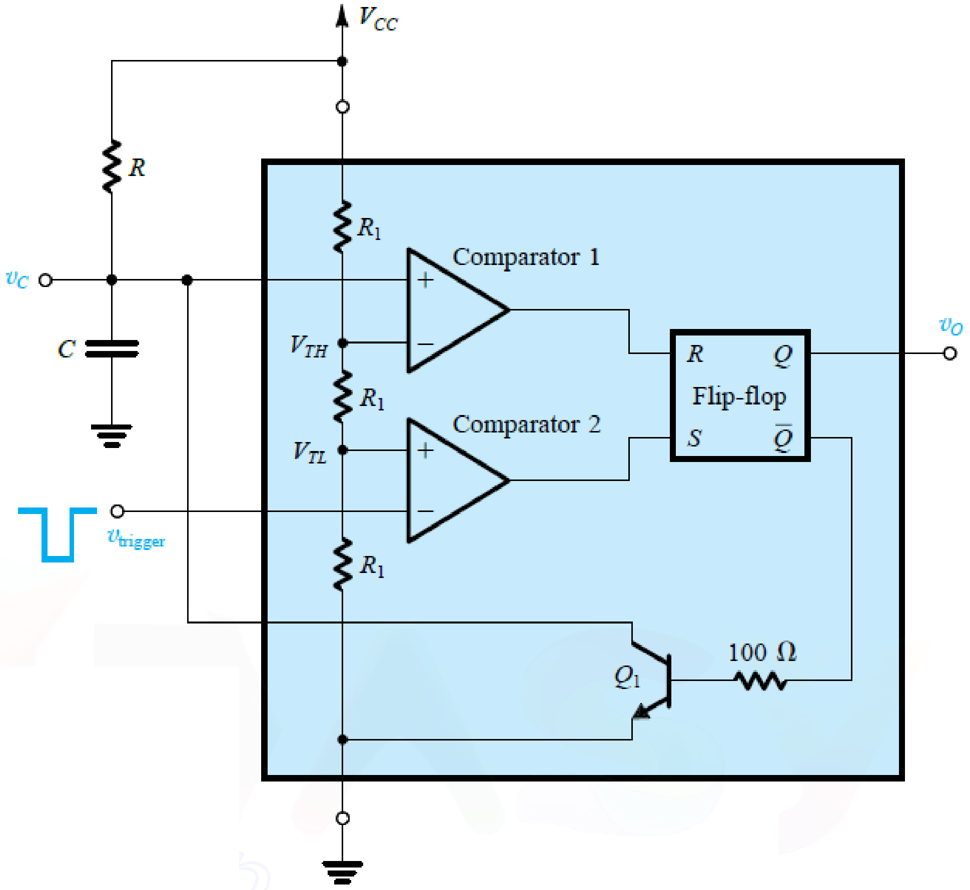


- $v_{trigger}$ is kept high ($> v_{TL}$), and thus a low level at the output of the comparator 2 as well.

Implementing a Monostable Multivibrator using the 555 IC

- In the stable state, the flip-flop is in the `reset' state.

- $\overline{Q}$ will be high and Q will be low. So, the output v_O will be close 0 V.



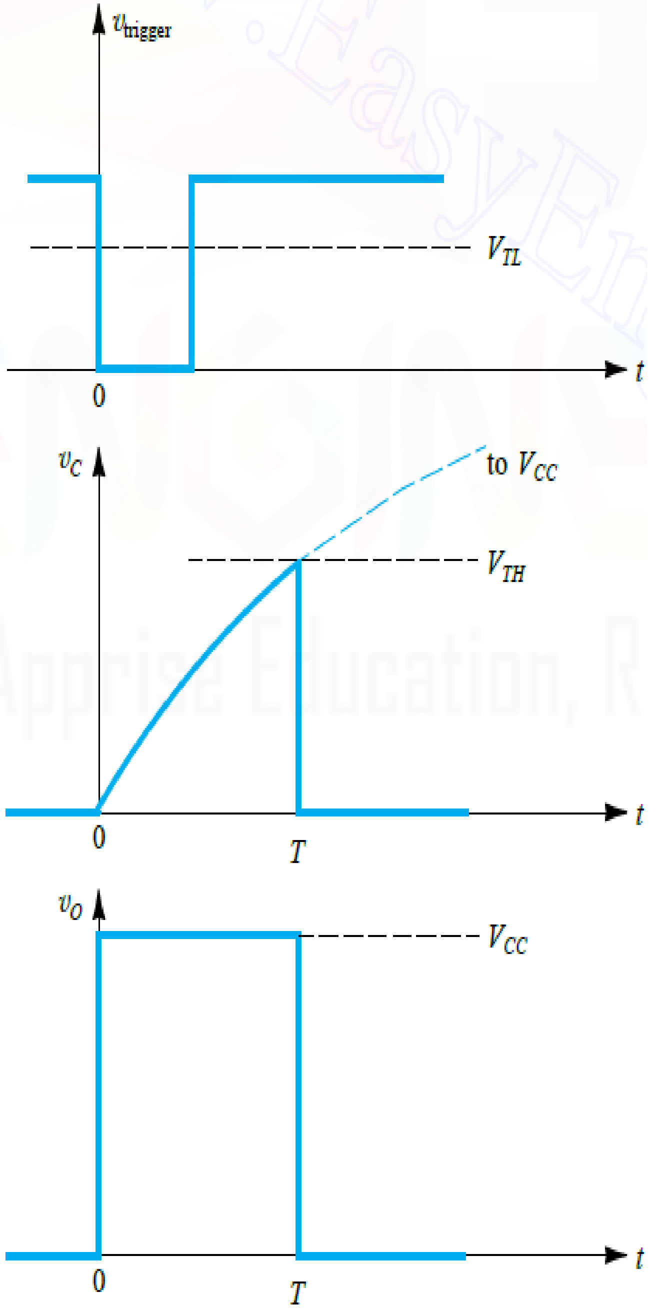
- To trigger the monostable multivibrator, a negative triggering pulse is applied to the \`Trigger' input terminal.

- $v_{trigger} < V_{TL}$

- The output of the comparator 2 goes to the high level.

- The flip-flop is \`set'. Q is high.

- So, the output v_O is high.



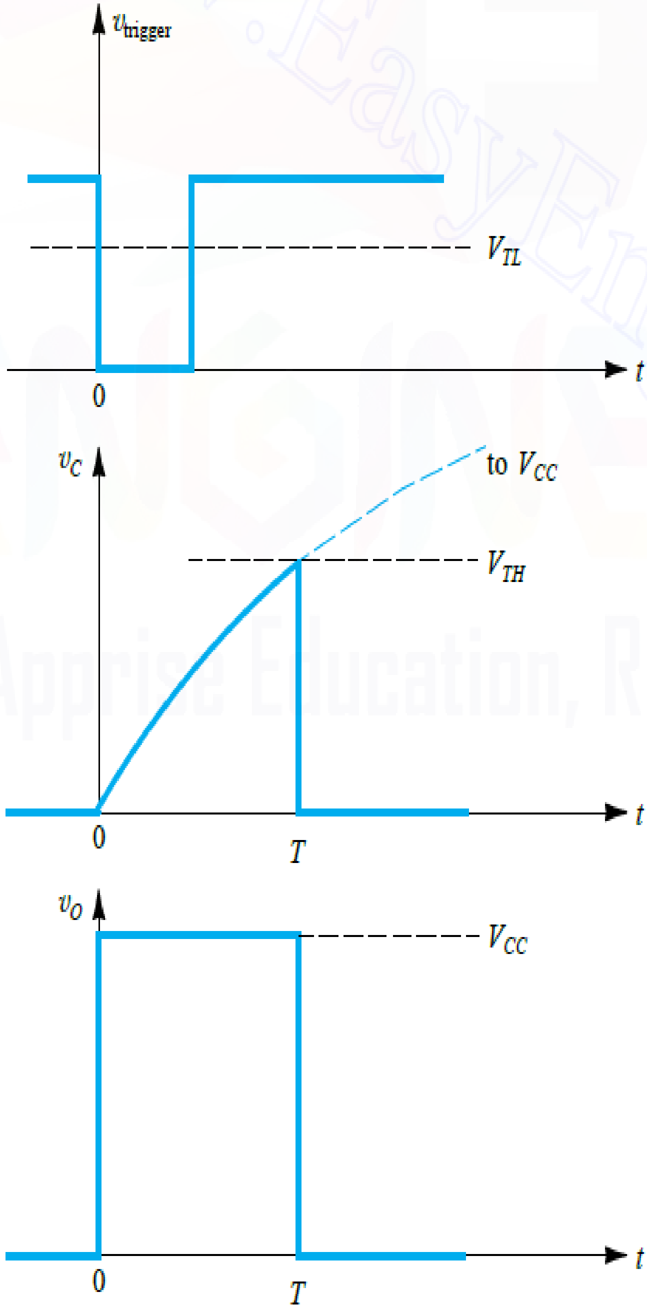
- The flip-flop is `set'. $\overline{Q}$ is low.

- Will turn $'Q_1'$ transistor *off*.

- Capacitor begins to charge up through R.

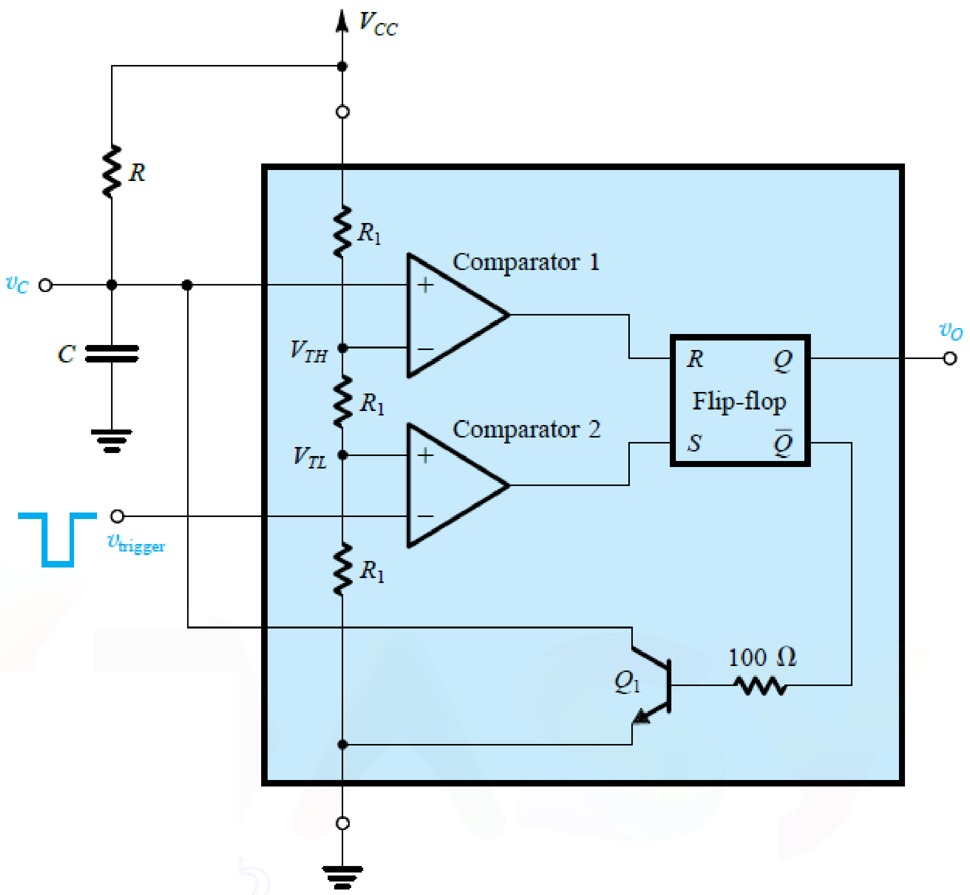
- v_C will rise up exponentially toward V_{CC}.

- The monostable multivibrator reaches the `quasistable' state. The state prevails until v_C reaches V_{TH} and exceeds V_{TH}.



Implementing a Monostable Multivibrator using the 555 IC

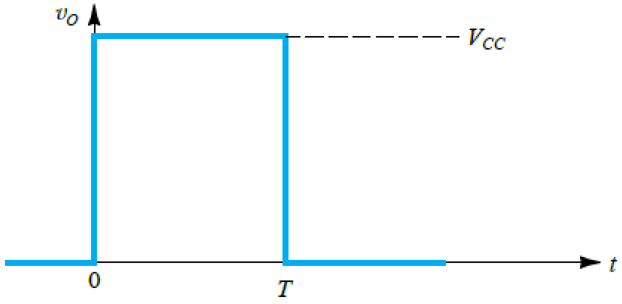
- The output of the comparator 1 will be high.
- The flip-flop will be `reset’ again.
- $\overline{Q}$ will be high and Q will be low. So, the output v_O will be close 0 V.
- The transistor will be switched on again.
- The capacitor will discharge to zero voltage level.
- The monostable multivibrator is back to the `stable’ state.



Lecture 35

Determining the Pulse Width of 555 timer based Monostable Multivibrator

- The width of the pulse, T is the time the Monostable multivibrator spends in a \`quasistable' state.



- The pulse width, T is determined in the following way:
- Referring to the waveforms given here (associated with the

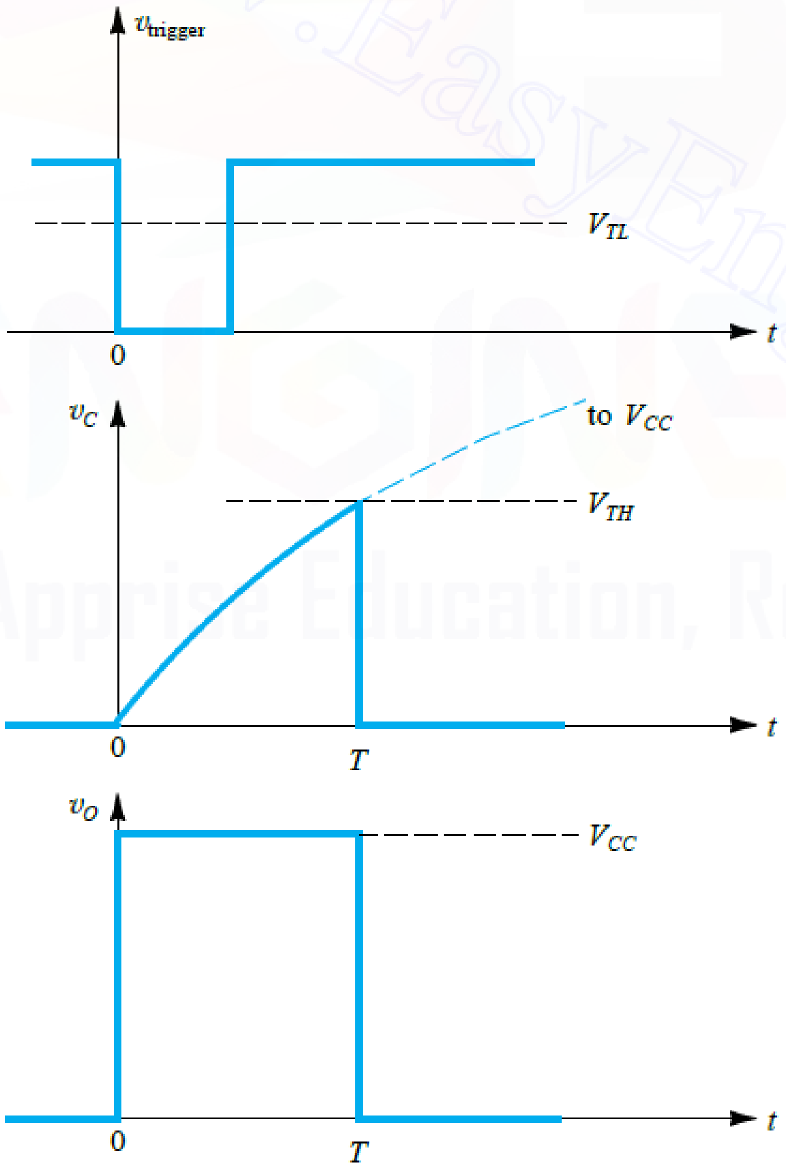
block diagram of 555 based monostable multivibrator),

$$v_C = V_{CC}(1 - e^{-t/CR})$$

Substituting $v_C = V_{TH} = \frac{2}{3}V_{CC}$ at $t = T$ gives

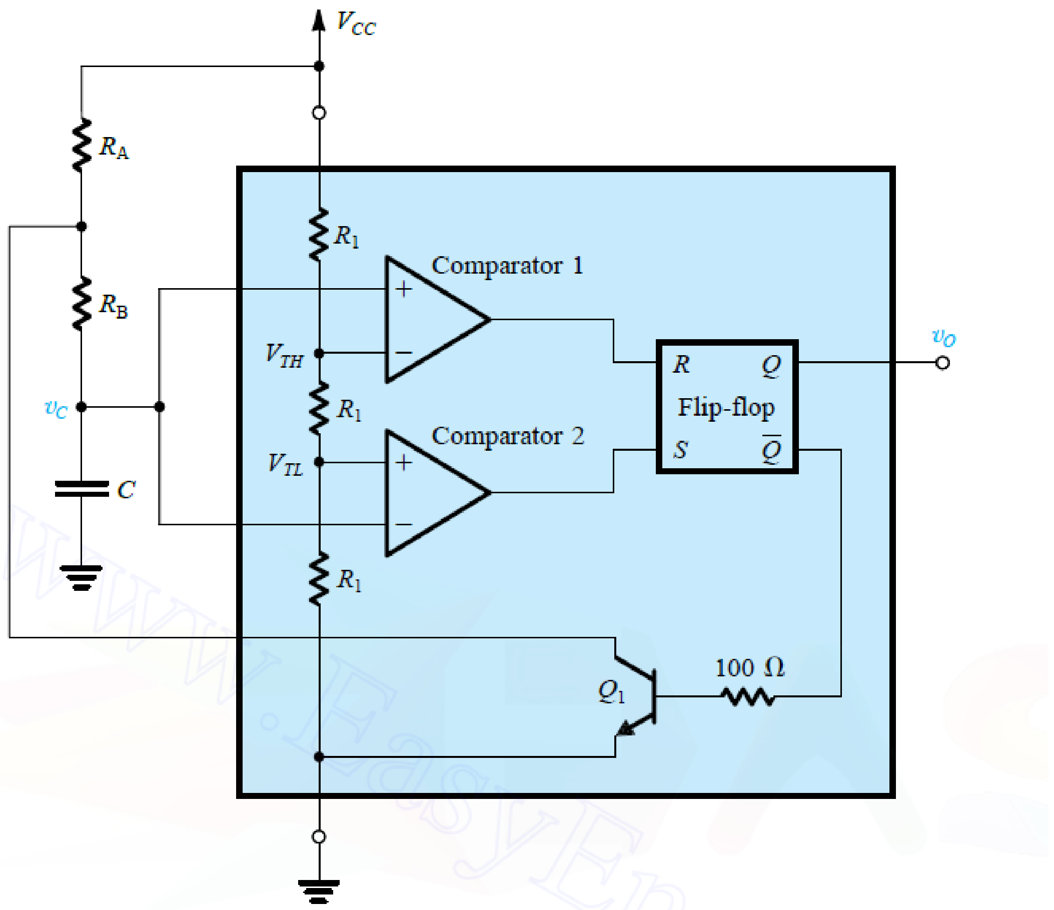
$$T = CR\ln 3 \simeq 1.1\,CR$$

Thus the pulse width is determined by the external components C and R, which can be selected to have values as precise as desired.

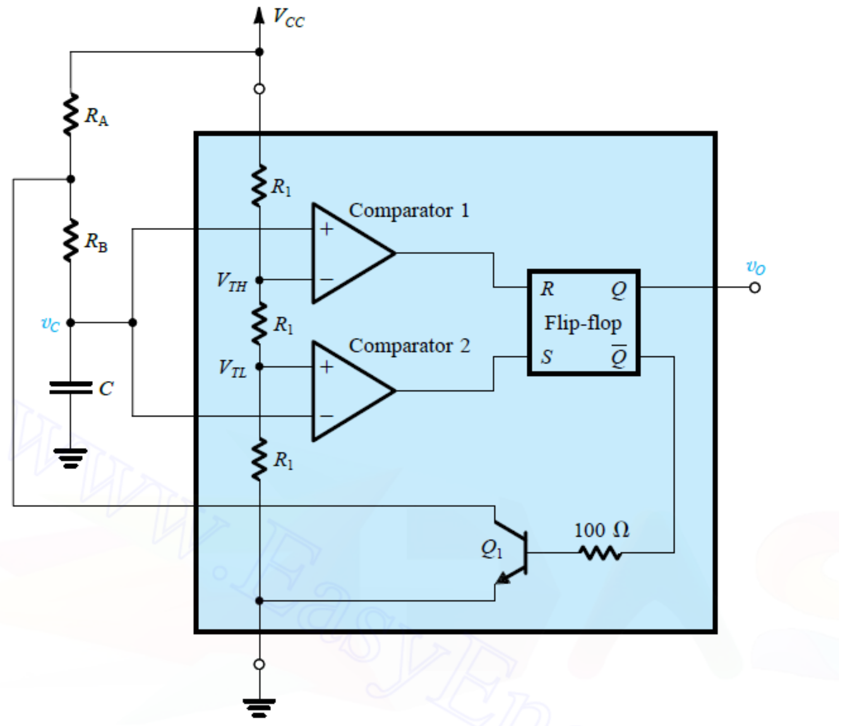


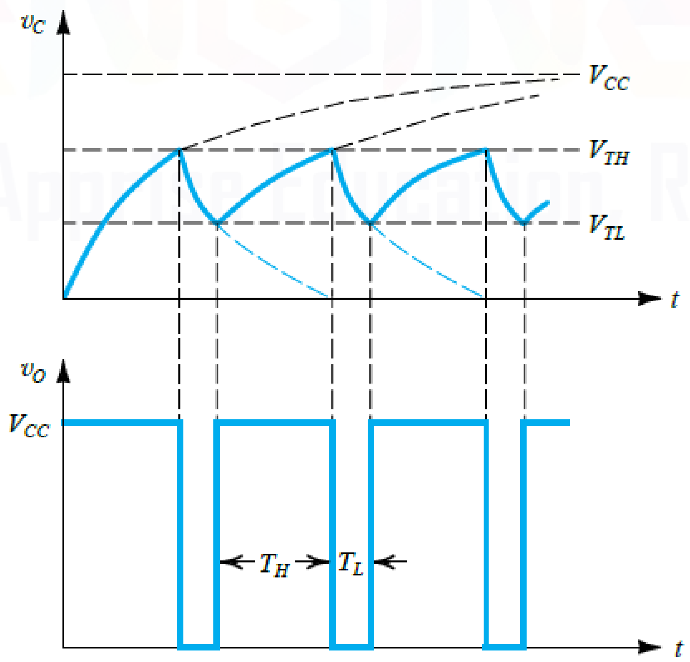
Implementing an Astable Multivibrator using the 555 IC

Two external resistors, and one external capacitor



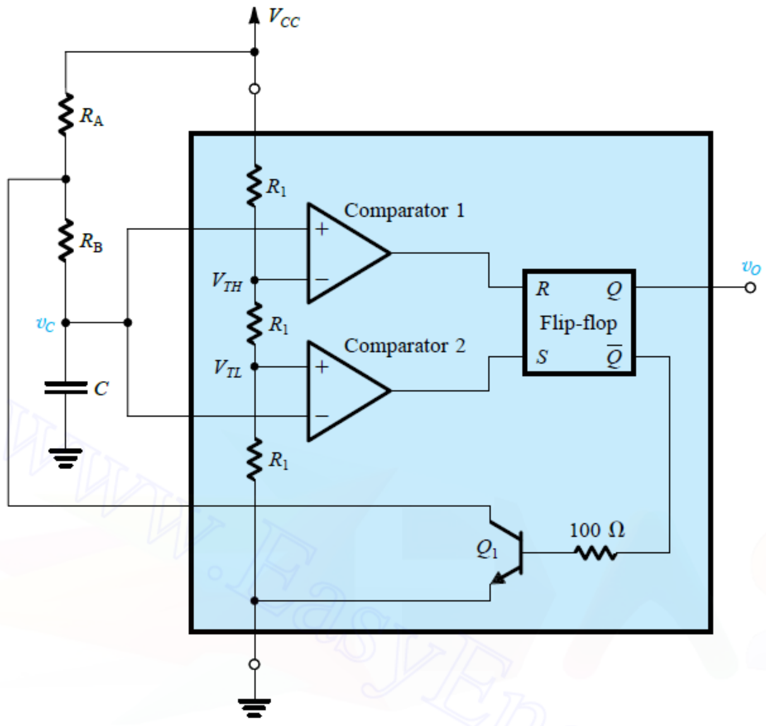
Implementing an Astable Multivibrator using the 555 IC

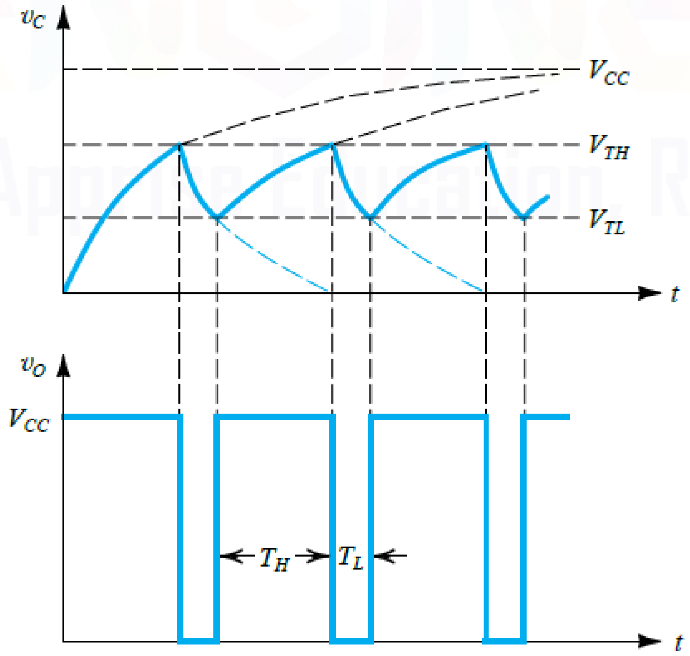




- Assume initially C is discharged.
- The flip-flop is \`set'.
- Thus v_o is high, and Q_1 is off.

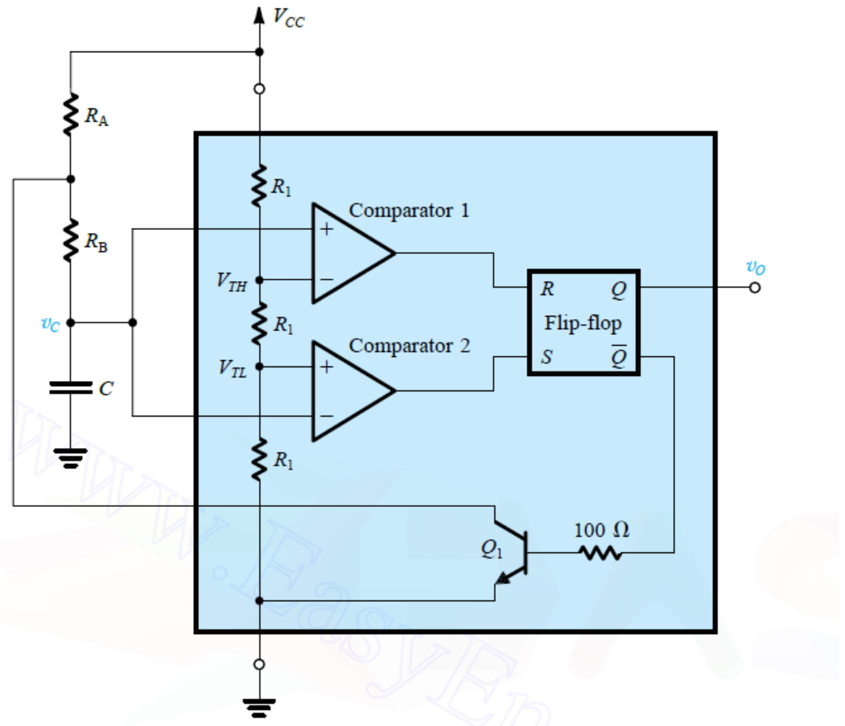
Implementing an Astable Multivibrator using the 555 IC

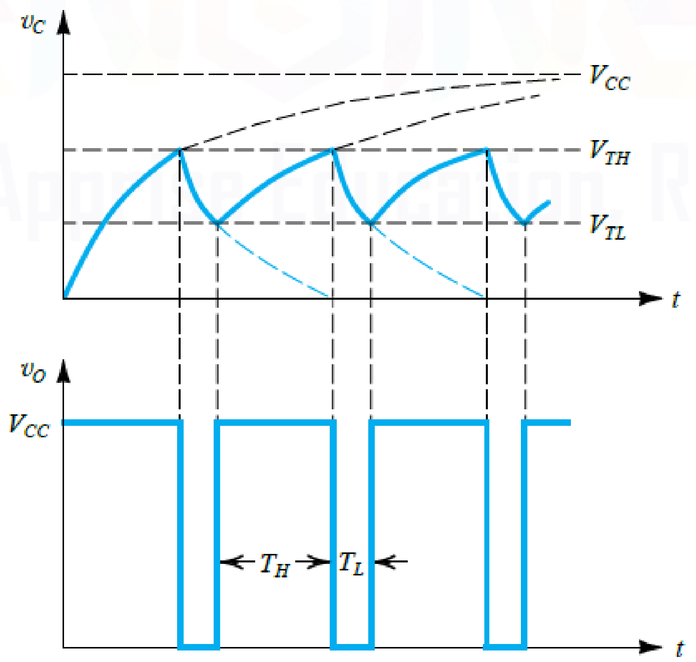




- C will charge up through the series combination of R_A and R_B.
- v_C rises up exponentially toward V_{CC} with a time constant $C(R_A + R_B)$.
- When v_C crosses the level equal to V_{TL}, the output of the comparator 2 goes low.

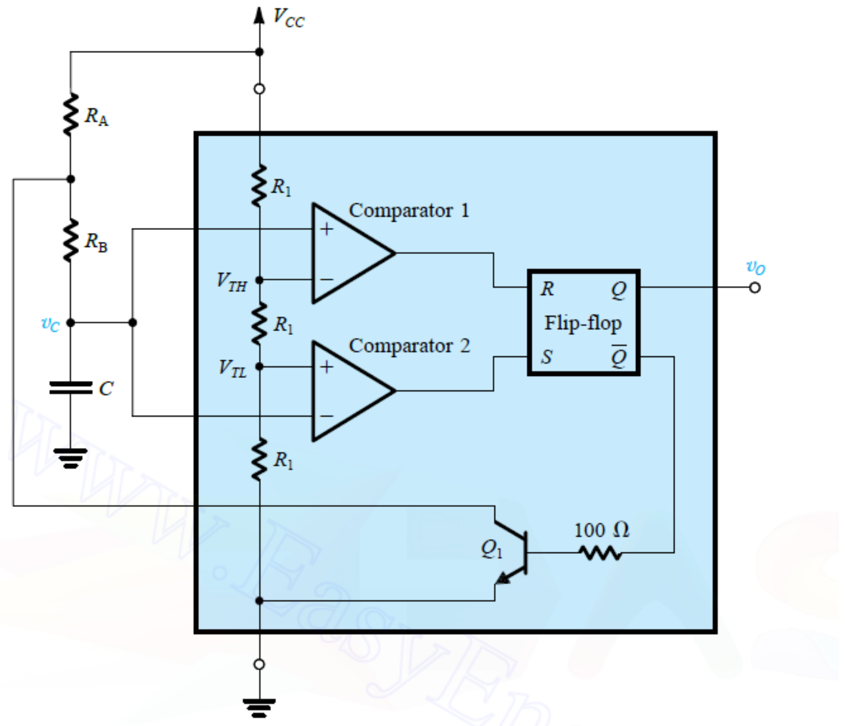
Implementing an Astable Multivibrator using the 555 IC

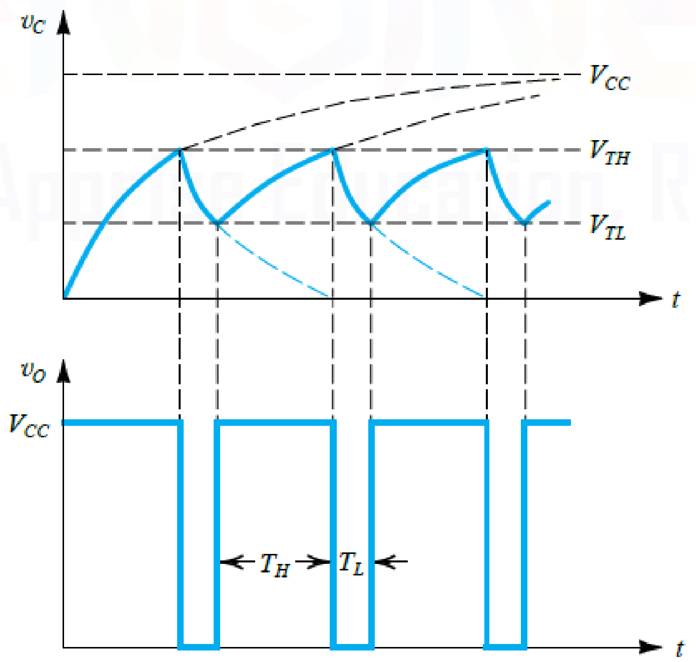




- But, the flip-flop remains `set'.
- This state prevails until v_C crosses the level equal to V_{TH}
- The output of the comparator 1 goes high, the flip-flop is `reset'.

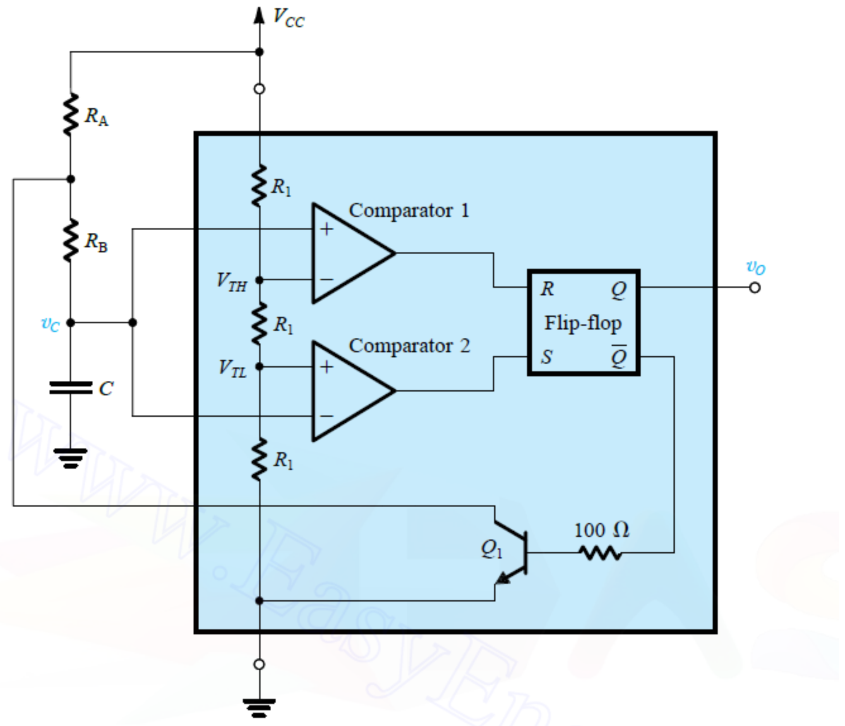
Implementing an Astable Multivibrator using the 555 IC

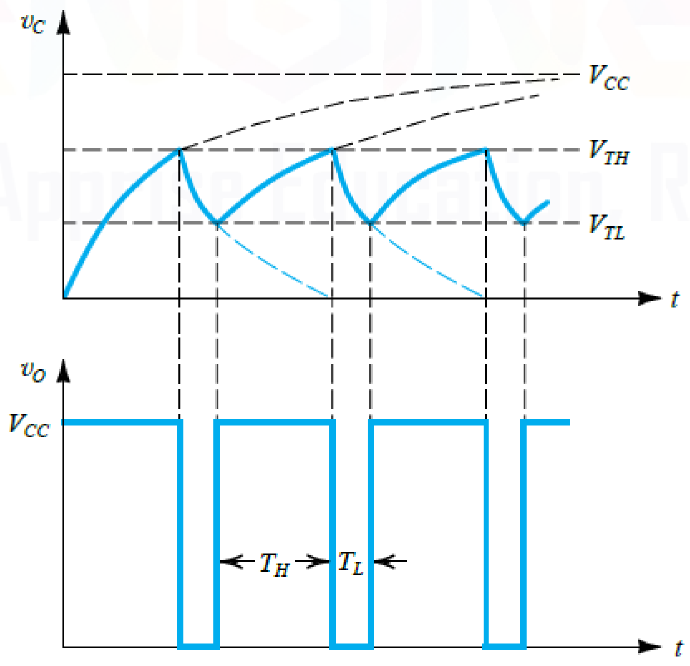




- Thus v_o goes low, and Q_1 is turned on.
- The common node of R_A and R_B is almost at 0 V (approximately).
- Thus, C begins to discharge through R_B and the transistor.

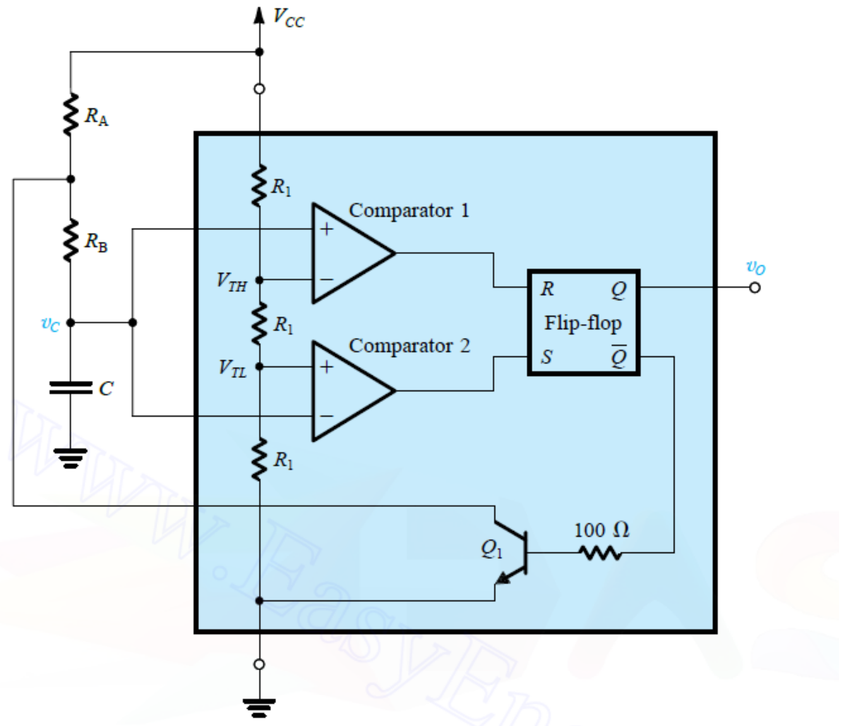
Implementing an Astable Multivibrator using the 555 IC

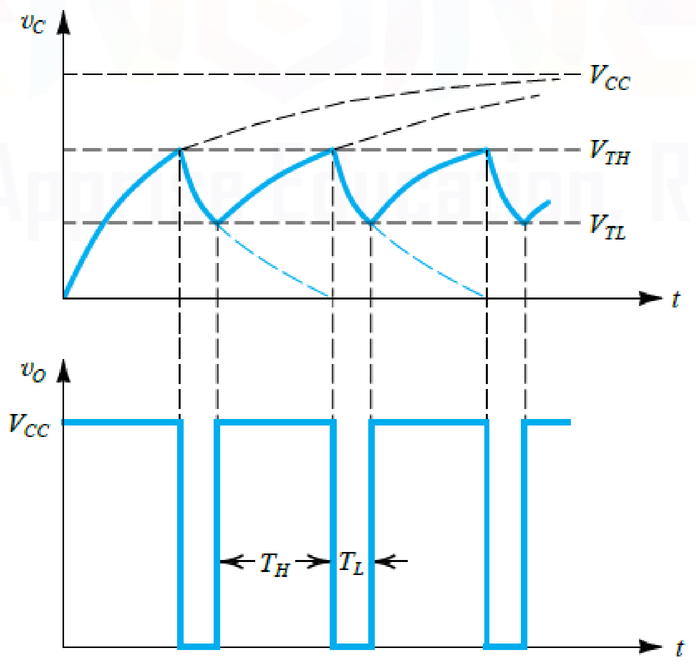




- v_C decreases exponentially with a time constant CR_B toward 0 V.
- When v_C reaches V_{TL} , the output of the comparator 2 goes high.
- The flip-flop is `set'. Thus v_o is high, and Q_1 is off.

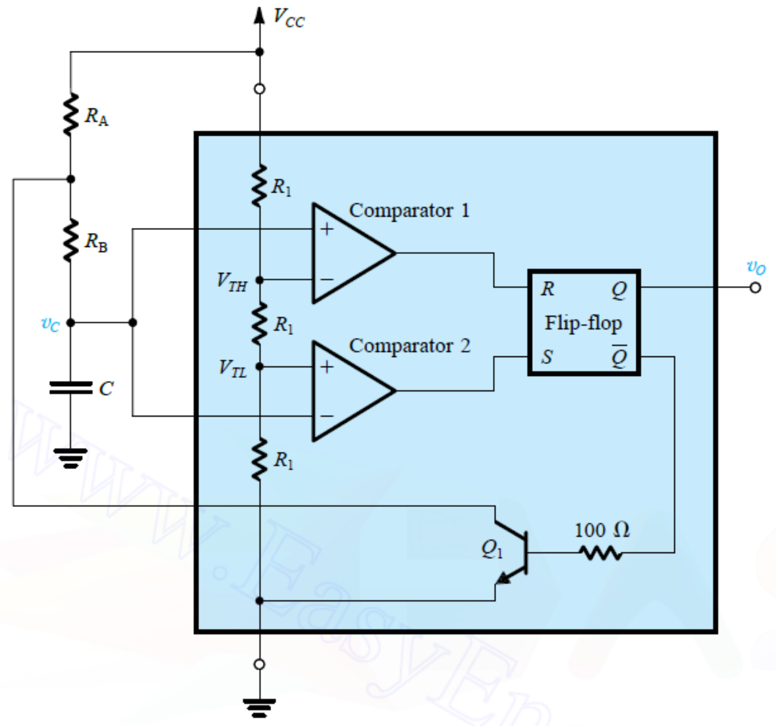
Implementing an Astable Multivibrator using the 555 IC

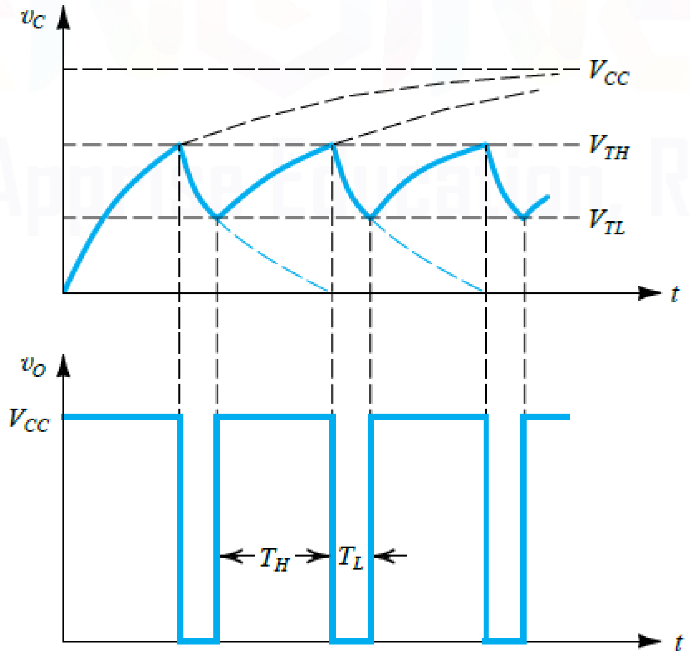




- C will again charge up through the series combination of R_A and R_B.
- v_C rises up exponentially toward V_{CC} with a time constant $C(R_A + R_B)$.
- When v_C crosses the level equal to V_{TH}, the output of the comparator 1 goes high, the flip-flop is `reset'.

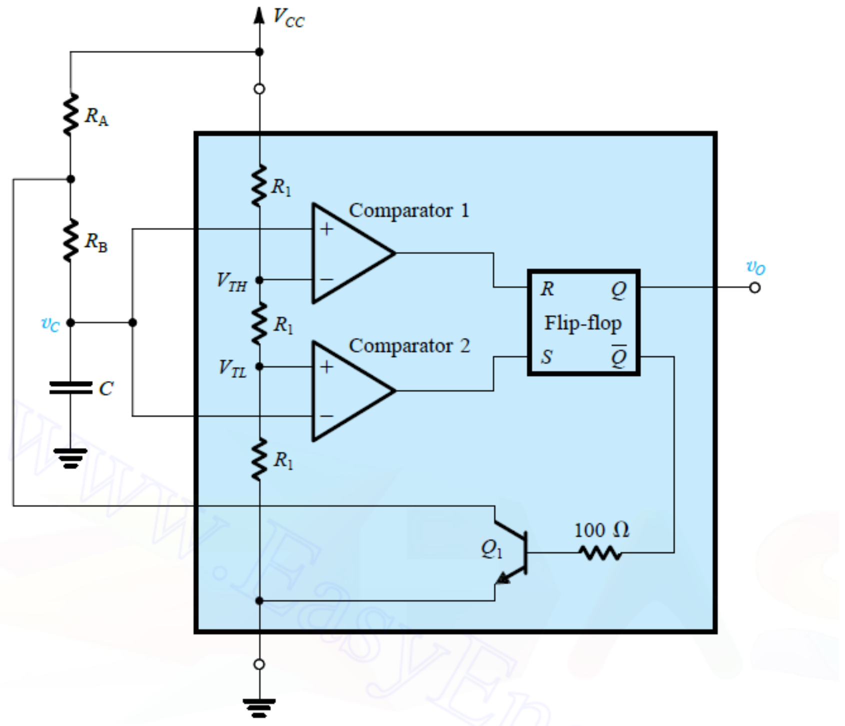
Implementing an Astable Multivibrator using the 555 IC

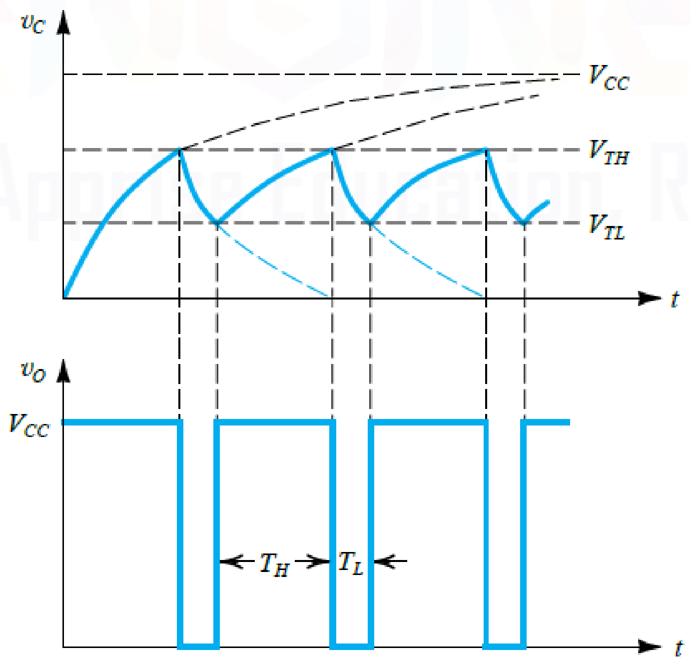




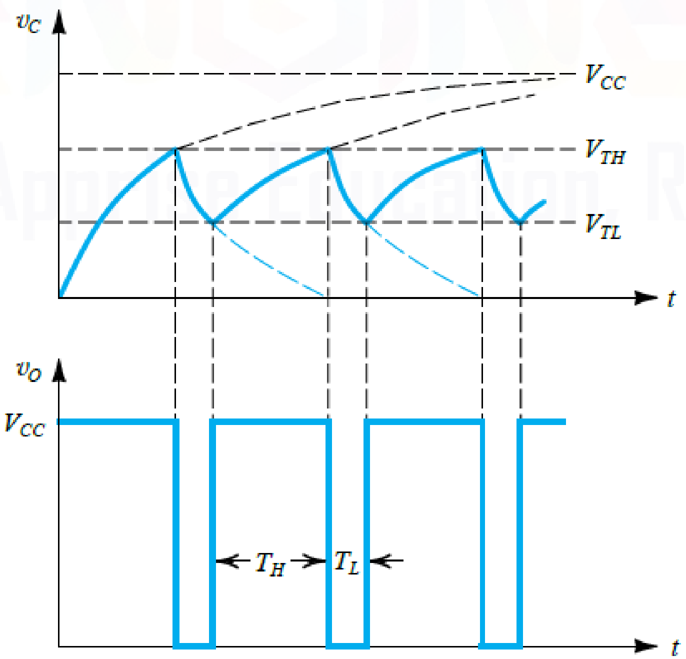
- Thus v_o goes low, and Q_1 is turned on.
- Thus, C begins to discharge through R_B and the transistor.
- And, the cycle continues.

Implementing an Astable Multivibrator using the 555 IC





- The circuit oscillates and a square waveform is produced at the output.

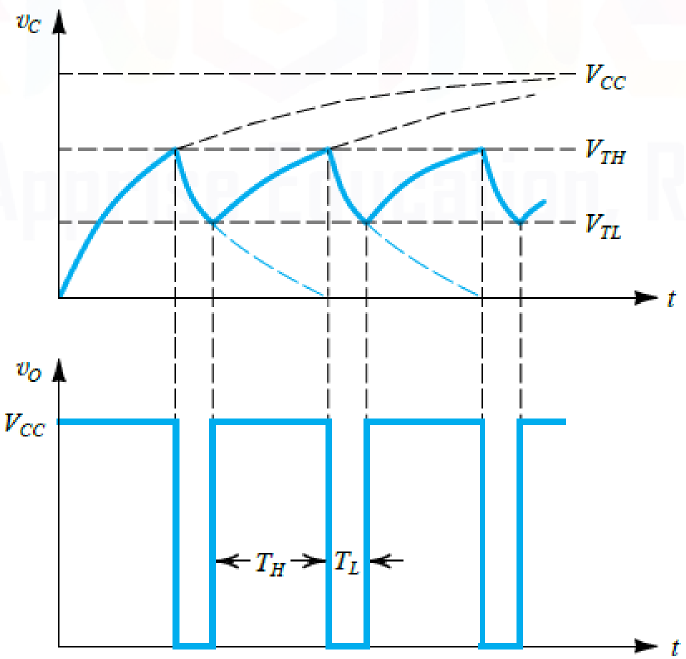


Reference to the fig.-s indicates that the output will be high during the interval T_H, in which v_C rises from V_{TL} to V_{TH}. The exponential rise of v_C can be described by

$$v_C = V_{CC} - (V_{CC} - V_{TL})e^{-t/C(R_A+R_B)}$$

where $t = 0$ is the instant at which the interval T_H begins. Substituting $v_C = V_{TH} = \frac{2}{3}V_{CC}$ at $t = T_H$ and $V_{TL} = \frac{1}{3}V_{CC}$ results in

$$T_H = C(R_A + R_B)\ln 2 \simeq 0.69\, C(R_A + R_B)$$

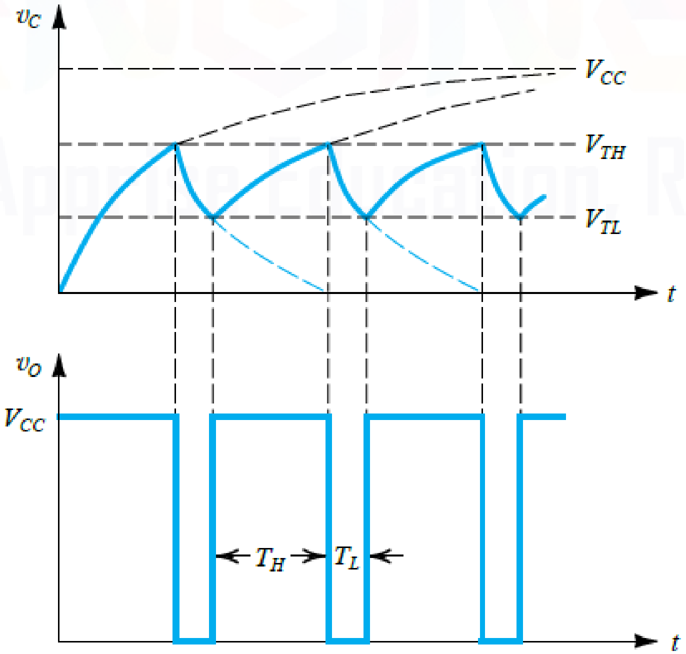


We also note from the fig.-s that v_O will be low during the interval T_L, in which v_C falls from V_{TH} to V_{TL}. The exponential fall of v_C can be described by

$$v_C = V_{TH}e^{-t/CR_B}$$

where we have taken $t = 0$ as the beginning of the interval T_L. Substituting $v_C = V_{TL} = \frac{1}{3}V_{CC}$ at $t = T_L$ and $V_{TH} = \frac{2}{3}V_{CC}$ results in

$$T_L = CR_B \ln 2 \simeq 0.69\ CR_B$$



Equations given before can be combined to obtain the period T of the output square wave as

$$T = T_H + T_L = 0.69\, C(R_A + 2R_B)$$

Also, the **duty cycle** of the output square wave can be found from Eqs given above :

$$\text{Duty cycle} \equiv \frac{T_H}{T_H + T_L} = \frac{R_A + R_B}{R_A + 2R_B}$$

Note that the duty cycle will always be greater than 0.5 (50%); it approaches 0.5 if R_A is selected to be much smaller than R_B (unfortunately, at the expense of supply current).