ASTABLE MULTIVIBRATORS

SUMMARY

1. An astable multivibrator is essentially a square-wave generator.
2. An astable multivibrator is used as a clock in digital circuits.
3. If the time periods T_1 and T_2 are not equal, the astable multivibrator is called an un-symmetric astable multivibrator. If $T_1 = T_2 = T/2$, then it is called a symmetric astable multivibrator.
4. The ratio of T_1 to T is called the duty cycle and is expressed as a percentage.
5. In a symmetric astable multivibrator, the frequency is given by $f = 0.7/RC$ cycles/s.
6. There could be rounding-off of the rising edge of a pulse in an astable multivibrator because of a small recharging current associated with the condenser.
7. An astable multivibrator can be used as a voltage-controlled oscillator (VCO) or a voltage-to-frequency converter (VFC).
8. An astable multivibrator can also be used a frequency modulator.
9. An emitter-coupled astable multivibrator starts oscillating the moment power is switched ON.

MULTIPLE CHOICE QUESTIONS

1. An astable multivibrator is a:
   a) Square-wave generator
   b) Sweep generator
   c) Ramp generator
   d) None of the above
2. For the time period of an astable multivibrator to be stable, in the quasi-stable state, the ON device is required to be driven into:
   a) Saturation
   b) The active region
   c) The cut-off region
   d) The reverse-biased condition
3. The duty cycle of a symmetric multivibrator is:
   a) 50%
   b) 75%
   c) 25%
   d) 100%
4. The frequency of oscillations of a symmetric astable multivibrator is given as:
   a) $\frac{0.7}{\tau}$ c/s
   b) 0.7τ c/s
   c) 2.2τ c/s
   d) None of the above
5. To ensure that the ON device is in saturation, the condition that should be satisfied in a symmetric astable multivibrator is given by:

a) $\boldsymbol{R \leq h_{FE}R_C}$
b) $\boldsymbol{R \geq h_{FE}R_C}$
c) $\boldsymbol{R}$ should be infinity
d) $\boldsymbol{R}$ should be zero

6. The ratio of $\boldsymbol{t_{rec}}/(\boldsymbol{T}/2)$ of a symmetric astable is given by:
   a) $3.2/\boldsymbol{h_{FE}}$
   b) $\boldsymbol{h_{FE}}/3.2$
   c) $3.2\ \boldsymbol{h_{FE}}$
   d) $\boldsymbol{h_{FE}}$
7. An astable multivibrator can be used as a:
   a) Voltage-controlled oscillator
   b) Gating circuit
   c) Ramp generator
   d) Exponential generator
8. An astable multivibrator can also be used as a:
   a) Frequency modulator
   b) Gating circuit
   c) Ramp generator
   d) Exponential generator

SHORT ANSWER QUESTIONS

1. Draw the circuit of a collector-coupled astable multivibrator and explain its operation.
2. Explain how an astable multivibrator can be modified to operate as a voltage-controlled oscillator.
3. Explain why in an astable multivibrator the ON device in the quasi-stable state, is required to be driven into saturation.
4. Explain how an astable multivibrator can be used as a frequency modulator.
5. What are the advantages of an emitter-coupled astable multivibrator over a collector-coupled astable multivibrator?

LONG ANSWER QUESTIONS

1. Draw the circuit of a symmetric collector-coupled astable multivibrator using ***p–n–p*** devices and explain its operation. Derive the expression for its frequency of oscillation and plot the waveforms.
2. Explain how an astable multivibrator can be modified to operate as a voltage-controlled oscillator. Derive the expression for its frequency of oscillations and plot the waveforms.
3. The output of a collector-coupled astable multivibrator does not have sharp rising edges for the voltages at the collectors. Explain why.
4. Draw the circuit of a collector-coupled astable multivibrator with vertical edges and explain its operation.

SOLVED PROBLEMS

Example 7.1: Design an astable multivibrator, assuming that silicon devices with $h_{FE(min)} = 40$ are used. Also assume that $V_{CC} = 10$ V, $I_{C(sat)} = 5$ mA. Let the desired frequency of oscillations be 5 kHz. For transistor used, $V_{CE(sat)} = 0.2$ V, $V_{BE(sat)} = V_\sigma = 0.7$ V.

Solution:

$$R_c = \frac{V_{CC} - V_{CE(sat)}}{I_{C(sat)}} = \frac{10 - 0.2 \text{ V}}{5 \text{ mA}} = \frac{9.8}{5 \text{ mA}} = 1.96 \text{ k}\Omega$$

Select $R_C = 2$ kΩ

$$I_{B\ (min)} = \frac{I_{C(sat)}}{h_{FE\ (min)}} = \frac{5 \text{ mA}}{40} = 0.125 \text{ mA}$$

Select $I_{B(sat)} = 1.5 I_B(\text{min}) = 1.5 \times 0.125 = 0.187$ mA

$$\therefore R = \frac{V_{CC} - V_\sigma}{I_{B(sat)}} = \frac{10 - 0.7}{0.187 \text{ mA}} = \frac{9.3}{0.187 \text{ mA}} = 49.7 \text{ k}\Omega$$

Select $R = 47$ kΩ

For the ON transistor to be in saturation, the condition is $R \leq h_{FE}R_C$. Verify whether $R \leq h_{FE}R_C$ or not.

$h_{FE}R_C = 40 \times 2 \text{ k}\Omega = 80 \text{ k}\Omega$

$R < h_{FE}R_C$, hence, Q_2 is in saturation.

$f = \dfrac{0.7}{RC}$, for a symmetric astable multivibrator.

We have $f = 5$ kHz

$$5 \times 10^3 = \frac{0.7}{47 \times 10^3 \times C}$$

$$C = \frac{0.7}{5 \times 47 \times 10^{-6}} = 0.003\ \mu\text{F}$$

Alternately, if this were to be an un-symmetric astable multivibrator ($T_1 \neq T_2$), then the duty cycle ($= T_1/(T_1 + T_2) = T_1/T$) will have to be specified to fix the component values of $\boldsymbol{R_1}$, $\boldsymbol{R_2}$, $\boldsymbol{C_1}$ and $\boldsymbol{C_2}$. That is, let $\boldsymbol{R_1} = \boldsymbol{R_2} = \boldsymbol{R}$ and duty cycle be specified as 40 per cent. If $\boldsymbol{f} = 5$ kHz, then

$\boldsymbol{T} = \boldsymbol{T_1} + \boldsymbol{T_2} = 0.2$ ms

$\boldsymbol{T_1}/(\boldsymbol{T_1} + \boldsymbol{T_2}) = \boldsymbol{T_1}/\boldsymbol{T} = 0.4$ ms

Hence, $\boldsymbol{T_1} = (0.4)(0.2) = 0.08$ ms, $\boldsymbol{T_2} = 0.2 - 0.08 = 0.12$ ms.

From Eq. (7.6) we know that:

$\boldsymbol{T_2} = 0.69\ \boldsymbol{\tau_1} = 0.69\ \boldsymbol{RC_1}$ $\quad (0.69)(47\text{k}\Omega)\boldsymbol{C_1} = 0.08$ ms

Hence, $C_1 = \dfrac{0.08 \times 10^{-3}}{0.69 \times 47 \times 10^3} = 2.47\ \text{nF}.$

Similarly from Eq. (7.7),

$\boldsymbol{T_1} = 0.69\ \boldsymbol{\tau_2} = 0.69\boldsymbol{RC_2}$ $\quad (0.69)(47\text{k}\Omega)\boldsymbol{C_2} = 0.12$ ms

$$C_2 = \frac{0.12 \times 10^{-3}}{0.69 \times 47 \times 10^3} = 3.7\ \text{nF}$$

Example 7.3: For the astable multivibrator shown in Fig. 7.1:

1. Determine the time period and the frequency of oscillations if $\boldsymbol{R_1} = \boldsymbol{R_2} = \boldsymbol{R} = 10$ kΩ, $\boldsymbol{C_1} = \boldsymbol{C_2} = 0.01\ \mu$F.
2. Determine the time period and the frequency of oscillations if $\boldsymbol{R_1} = 1$ kΩ, $\boldsymbol{R_2} = 10$ kΩ, $\boldsymbol{C_1} = 0.01\ \mu$F, $\boldsymbol{C_2} = 1\ \mu$F.

Solution:

1. Given $\boldsymbol{R_1} = \boldsymbol{R_2} = \boldsymbol{R} = 10$ kΩ, $\boldsymbol{C_1} = \boldsymbol{C_2} = 0.01\ \mu$F.

This is a symmetric astable multivibrator.

$$f = \frac{0.7}{RC} = \frac{0.7}{10 \times 10^3 \times 0.01 \times 10^{-6}} = 7\ \text{kHz}.$$

2. Given $\boldsymbol{R_1} = 1$ kΩ, $\boldsymbol{R_2} = 10$ kΩ, $\boldsymbol{C_1} = 0.01\ \mu$F, $\boldsymbol{C_2} = 0.1\ \mu$F

This is an un-symmetric astable multivibrator:

$T = 0.69(R_1C_1 + R_2C_2) = 0.69(1 \times 10^3 \times 0.01 \times 10^{-6} + 10 \times 10^3 \times 0.1 \times 10^{-6}) = 0.69$ ms

$$f = \frac{1}{T} = \frac{10^3}{0.69} = 1.45 \text{ kHz}$$

Example 7.4: For the astable multivibrator shown in Fig. 7.1:

1. Find the value of C to provide symmetrical oscillations if $R = 10$ kΩ and $f = 10$ kHz.
2. Determine the values of capacitors to provide a train of pulses 0.1 ms wide and at a frequency of 1 kHz, if $R_1 = R_2 = 1$ kΩ
3. Find the minimum value of R_C in a symmetric astable if $R = 10$ kΩ and $h_{FE} = 50$.

Solution:

1. Given $R = 10$ kΩ and $f = 10$ kHz, for a symmetrical astable multivibrator.

$$f = \frac{0.7}{RC} \qquad C = \frac{0.7}{Rf} = \frac{0.7}{10 \times 10^3 \times 10 \times 10^3} = 0.007\ \mu\text{F}$$

2. Given T_1 = duration of the pulse = 0.1 ms, $f = 1$ kHz, for the un-symmetric astable multivibrator:

$$T = \frac{1}{f} = 1 \text{ ms} \qquad T_2 = T - T_1 = 1 - 0.1 = 0.9 \text{ ms} \qquad R_1 = R_2 = R = 1 \text{ k}\Omega \qquad 0.69RC_2 = 0.1\text{ms}$$

$$C_2 = \frac{0.1 \times 10^{-3}}{1 \times 10^3 \times 0.69} = 0.145\ \mu\text{F} \qquad 0.69\ RC_1 = 0.9 \text{ ms} \qquad C_1 = \frac{0.9 \times 10^{-3}}{1 \times 10^3 \times 0.69} = 1.30\ \mu\text{F}$$

3. We have $R = h_{FE}R_C$

$$R_{C(\text{min})} = \frac{R}{h_{FE}} = \frac{10 \times 10^3}{50} = 200\ \Omega$$

Example 7.5: For the multivibrator shown in Fig. 7.13(a), $V_{CC} = 20$ V, $V_{BB} = 10$ V, $R_1 = R_2 = R = 10$ kΩ, $C_1 = C_2 = C = 0.01\ \mu$F. Find the time period and the frequency.

Solution:

$$T = 2RC \ln\left(1 + \frac{V_{CC}}{V_{BB}}\right) = 2 \times 10 \times 10^3 \times 0.01 \times 10^{-6} \ln\left(1 + \frac{20}{10}\right) = 0.22 \text{ ms}$$

$$f = \frac{1}{T} = \frac{10^3}{0.22} = 4.54 \text{ kHz}$$

Example 7.6: In an astable multivibrator if $R_2 = 60$ kΩ, $R_1 = 40$ kΩ, $C_1 = C_2 = 2.9$ nF, find its frequency and duty cycle.

Solution:

$T_2 = 0.69\ R_1C_1 = 0.69 \times 40 \times 10^3 \times 2.9 \times 10^{-9} = 80\ \mu$s $= 0.08$ ms

$T_1 = 0.69R_2C_2 = 0.69 \times 60 \times 10^3 \times 2.9 \times 10^{-9} = 120\ \mu s = 0.12$ ms

$T = T_1 + T_2 = 0.08 + 0.12 = 0.2$ ms $\quad f = \frac{1}{T} = 5\text{ kHz}$

$$\text{Duty cycle} = \frac{T_1}{T} = \frac{0.12\text{ ms}}{0.2\text{ ms}} = 0.6$$

Example 7.7: A symmetrical collector-coupled astable multivibrator has the following parameters:

$V_{CC} = 10$ V, $R_C = 1$ kΩ, $R = 10$ kΩ, and $C = 0.01\ \mu$F. Silicon transistors with $h_{FE} = 50$ and $r_{bb'} = 0.2$ kΩ are used. Plot the waveforms and calculate the overshoot. Also plot the waveforms if the circuit uses ***p-n-p*** transistors.

Solution:

Given $V_{CC} = 10$V, $R_C = 1$ kΩ, $R = 10$ kΩ, $C = 0.01\ \mu$F, $r_{bb'} = 0.2$ kΩ and $h_{FE} = 50$.

Assume $V_\sigma = 0.7$V and $V_{CE(\text{sat})} = 0.2$V.

Let Q_2 be ON and in saturation, then Q_1 is OFF. After a time interval T_1, Q_1 is ON and Q_2 is OFF. Suddenly when a device switches from the OFF state into the ON state, there is an overshoot at its base. Similarly, when the device switches its state from ON to OFF there is an overshoot at its collector. To account for these overshoots the base spreading resistance is taken into account. Let Q_2 switch from OFF to ON and Q_1 from ON to OFF, then the equivalent circuit is shown in Fig. 7.18(a).

When $R \gg R_C$, then $I_R \ll I'_{B2}$. Hence, R is omitted in Fig. 7.18(b).

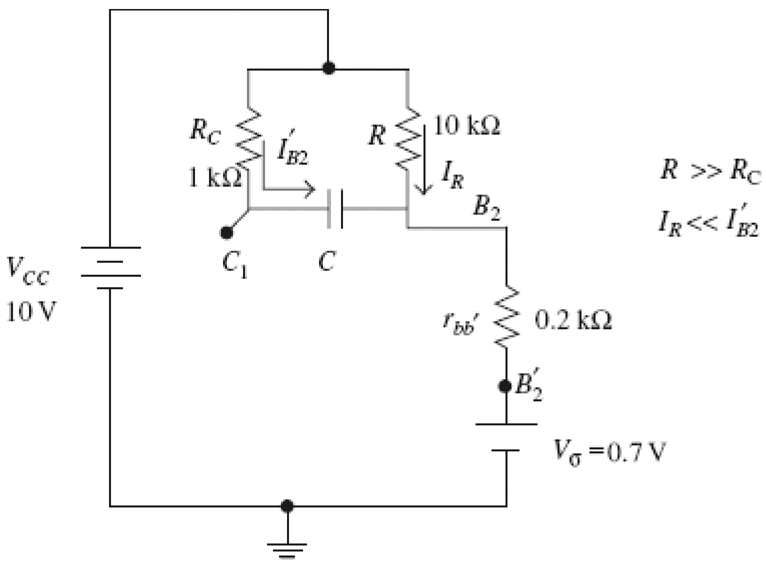

FIGURE 7.18(a) The circuit of the astable multivibrator when Q_2 switches from OFF to ON

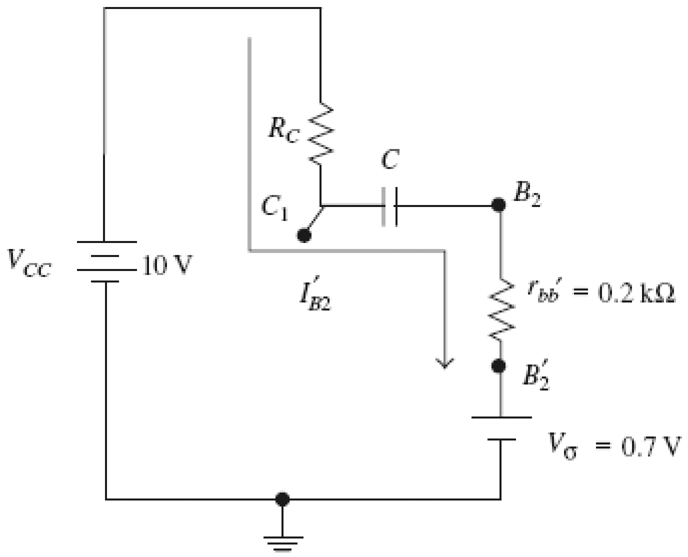

FIGURE 7.18(b) The circuit when ***R*** is much larger than ***R$_C$***

Let $\boldsymbol{\delta'}$ and $\boldsymbol{\delta}$ be the overshoots at the collector of $\boldsymbol{Q}_1$ and the base of $\boldsymbol{Q}_2$.

$V_\sigma = 0.7$ V $V_\gamma = 0.5$ V and $V_{CE(\mathrm{sat})} = 0.2$ V

$$\delta = V_{B2} - V_\gamma = I'_{B2} r_{bb'} + V_\sigma - V_\gamma = I'_{B2} r_{bb'} + 0.7 - 0.5$$

But, $\boldsymbol{\delta} = \boldsymbol{\delta'}$, since the collector $\boldsymbol{Q}_1$ and the base of $\boldsymbol{Q}_2$ are connected through a condenser ***C*** and identical changes are required to take place at these two nodes.

$$\delta' = V_{C1} - V_{CE\,(\mathrm{sat})} = V_{CC} - I'_{B2} R_C - V_{CE\,(\mathrm{sat})} = I'_{B2} r_{bb'} + 0.2 \text{ V}$$

$$9.8 \text{ V} - I'_{B2} R_C = I'_{B2} r_{bb'} + 0.2 \text{ V}$$

$$I'_{B2}(r_{bb'} + R_C) = 9.6 \text{ V} \qquad I'_{B2} = \frac{9.6 \text{ V}}{0.2 + 1} = \frac{9.6 \text{ V}}{1.2 \text{ k}\Omega} = 8 \text{ mA}$$

$$\delta = I'_{B2} r_{bb'} + V_\sigma - V_\gamma = 8 \times 10^{-3} \times 0.2 \times 10^3 + 0.7 \text{ V} - 0.5 \text{ V} = 1.6 + 0.2 = 1.8 \text{ V} \qquad \delta = \delta'$$

The waveforms are shown in Fig. 7.18(c). For the astable multivibrator circuit using ***p–n–p*** transistors, the waveforms are shown in Fig. 7.19.

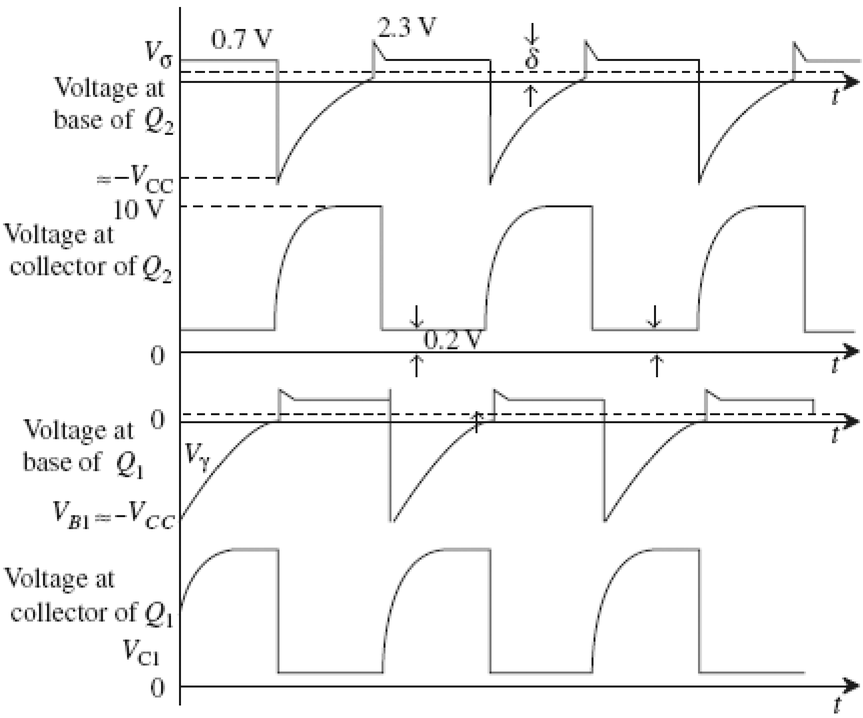

FIGURE 7.18(c) The waveforms of the circuit in Fig. 7.21(a)

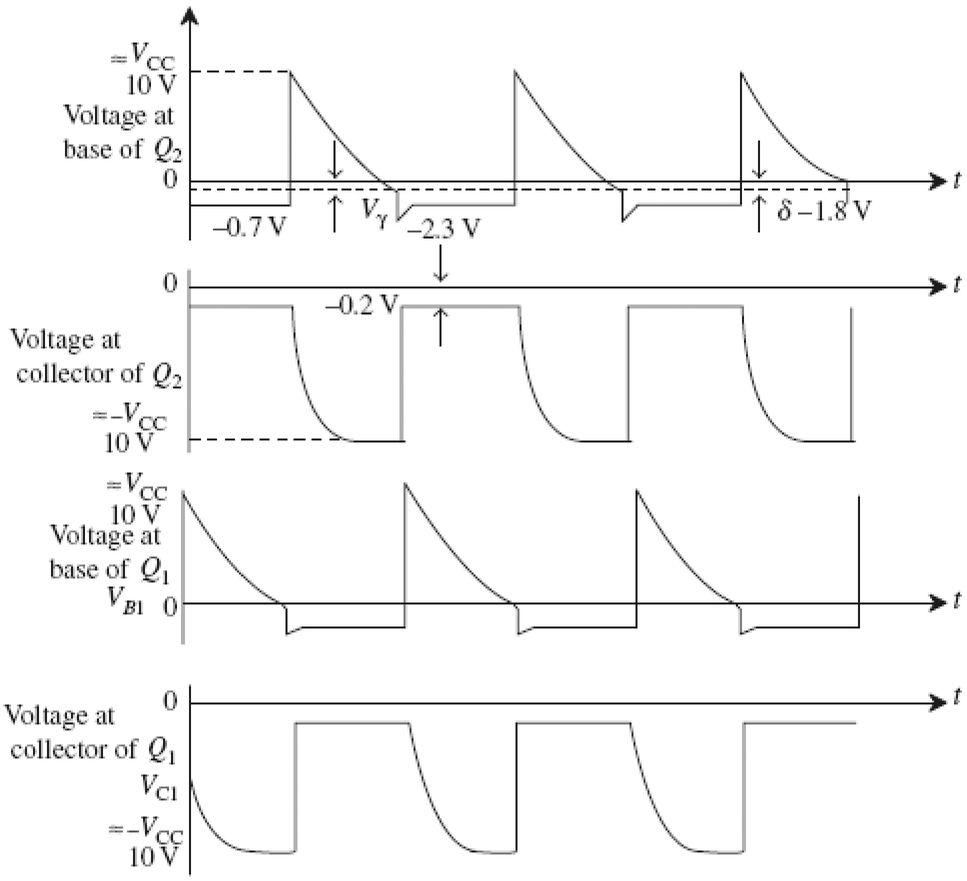

FIGURE 7.19 The Waveforms of the circuit using ***p–n–p*** transistors

Example 7.8: A symmetric astable multivibrator with vertical edges (see in Fig. 7.20) has the following parameters, $\boldsymbol{V_{CC}}$ = 15 V, $\boldsymbol{R_C}$ = 3 kΩ, $\boldsymbol{R_1} = \boldsymbol{R_2} = \boldsymbol{R}$ = 30 kΩ, $\boldsymbol{R_3}$ = 2 kΩ and silicon transistors with $h_{FE} = 50$ are used. $C_1 = C_2 = C = 0.01\ \mu$F. Verify whether the ON device is in saturation or not. Find its frequency.

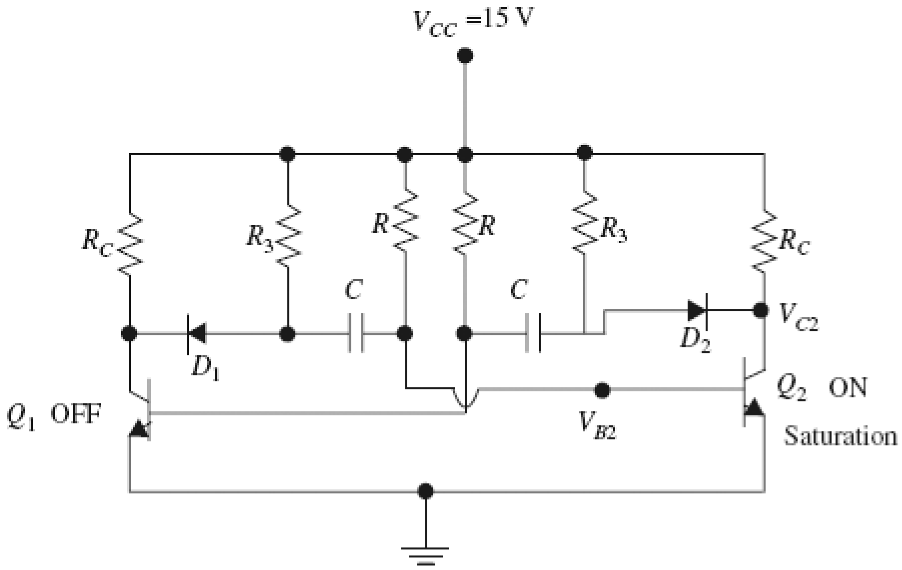

FIGURE 7.20 An astable multivibrator with vertical edges

Assume Q_1 is OFF and Q_2 is ON and in saturation. If Q_2 is ON and in saturation

$V_{C2} = V_{CE(\text{sat})} = 0.2$V, $V_{B2} = V_\sigma = 0.7$ V then D_2 is ON. The collector load is $R_3 || R_C$.

$$R_C' = R_3||RC = \frac{3 \times 2}{5} = 1.2\ \text{k}\Omega \qquad I_{C2} = \frac{V_{CC} - V_{CE(\text{sat})}}{R_C'} = \frac{15 - 0.2}{1.2\ \text{k}\Omega} = \frac{14.8\ \text{V}}{1.2\ \text{k}\Omega} = 12.3\ \text{mA}$$

$$I_{B2} = \frac{V_{CC} - V_\sigma}{R} = \frac{15 - 0.7}{30\ \text{k}\Omega} = \frac{14.3\ \text{V}}{30\ \text{k}\Omega} = 0.477\ \text{mA} \qquad I_{B2}(\text{min}) = \frac{I_{C2}}{h_{FE(\text{min})}} = \frac{12.33\ \text{mA}}{50} = 0.247\ \text{mA}$$

$$I_{B2} \gg I_{B2}(\text{min})$$

Hence, Q_2 is in saturation.

To find, f:

For a symmetric astable multivibrator:

$$f = \frac{0.7}{RC} = \frac{0.7}{30 \times 10^3 \times 0.01 \times 10^{-6}} = 2.33\ \text{kHz}$$

UNSOLVED PROBLEMS

1. For the multivibrator in Fig. 7.1, $R_1 = R_2 = R = 47$ kΩ, $C_1 = C_2 = C = 0.01\mu$ F. Find the time period and frequency.
2. For the astable multivibrator in Fig. 7.1, $R_1 = 20$ kΩ, $R_2 = 30$ kΩ, $C_1 = C_2 = C = 0.01\mu$F. Find the time period, duty cycle and the frequency.

3. For the symmetric astable multivibrator that generates square waves with vertical edges shown in Fig. 7.22, V_{CC} = 10 V, $R_C = R_3$ = 2 kΩ, $R_1 = R_2 = R$ = 20 kΩ, C = 0.1μF, $h_{FE(\text{min})}$ = 30. Show that the ON device is in saturation. Also find f. Assume suitable values for $V_{CE(\text{sat})}$ and $V_{BE(\text{sat})}$. Si transistors are used.

4. Design a symmetric collector-coupled astable multivibrator to generate a square wave of 10 kHz having peak-to-peak amplitude of 10 V where $h_{FE(\text{min})}$ = 30, $I_{C(\text{sat})}$ = 2mA.

5. Design an un-symmetric astable multivibrator having duty cycle of 40 per cent. It is required to oscillate at 5 kHz. Ge transistors with h_{FE} = 40 are used. The amplitude of the square wave is required to be 20 V, I_C = 5 mA, $V_{CE(\text{sat})}$ = 0.1 V and $V_{BE(\text{sat})}$ = 0.3 V.

6. For an un-symmetric astable multivibrator R_1 = 100 kΩ, R_2 = 100 kΩ, C_1 = 0.02 μF, C_2 = 0.01 μF. Find the frequency of oscillation and the duty cycle.

7. Design an unsymmetrical astable multivibrator shown in Fig. 7p.1 using silicon n–p–n transistors having output amplitude of 12 V. Given data, $I_{C(\text{sat})}$ = 5 mA, h_{FE}(min) = 50, f = 5 kHz, duty cycle = 0.6.

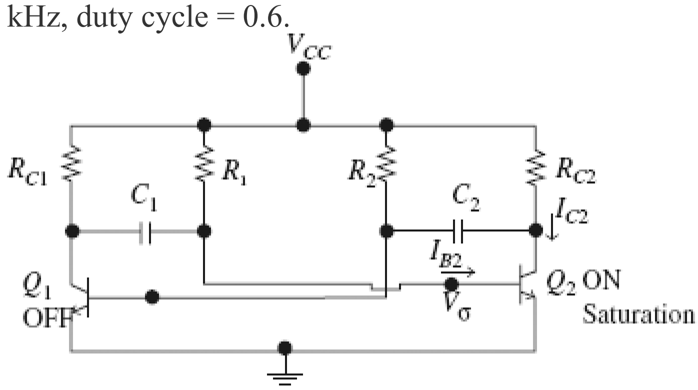

FIGURE 7p.1 Un-symmetric astable multivibrator

8. The voltage-to-frequency converter shown in Fig. 7p.2 generates oscillations at a frequency f_1 when $V_{BB} = V_{CC}$. Find the ratio of V_{CC}/V_{BB} at which the frequency $f_2 = 4f_1$.

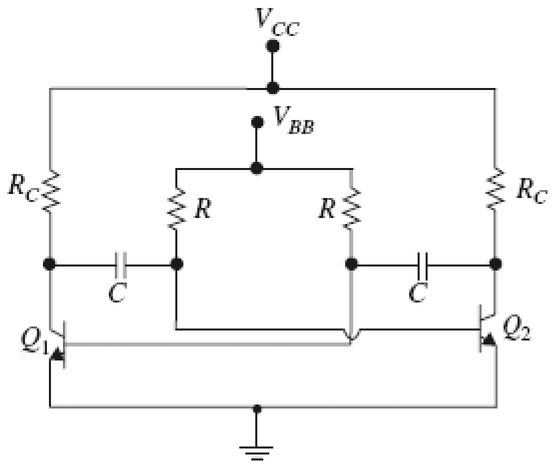

FIGURE 7p.2 The given voltage-to-frequency converter