BISTABLE MULTIVIBRATORS

SUMMARY

- A bistable multivibrator has two stable states. Initially if the multivibrator is in one of the stable states (say Q_1 is ON and Q_2 is OFF), change of state (Q_1 is OFF and Q_2 is ON) occurs only after the application of an external trigger.
- A bistable multivibrator is also known by many names, namely, binary, flip-flop, scale-of-two circuit and Eccles–Jordan circuit.
- A bistable multivibrator can be used for storing and counting of binary information. It can also be used for generating pulsed output.
- The output of a bistable multivibrator, if connected to some other circuit, could cause loading on the bistable multivibrator, which in turn will reduce the output swing.
- To ensure that the output of a bistable multivibrator does not fall below a specified threshold, the collector of the OFF transistor is clamped to a dc voltage using collector catching diodes.
- The time taken for conduction to transfer from one device to the other is called the transition time.
- Once conduction is transferred from one device to the other, an additional time, known as the settling time, is required to elapse before the voltages across the commutating condensers interchange. Only then do we say that the multivibrator has settled down in its new state completely.
- Commutating condensers help in reducing the transition time.
- The resolution time of a bistable multivibrator is the minimum time interval required between successive trigger pulses to be reliably able to drive the multivibrator from one stable state to the other.
- The reciprocal of the resolution time is the maximum switching speed of the bistable multivibrator.
- Unsymmetric triggering is a method of pulse triggering in which one trigger pulse taken from one source is applied at point in the circuit. The next trigger pulse is taken from a different source and is applied at a different point in the circuit to cause a change of state in both the devices. This method of triggering is used to generate a gated output; the duration of gate being dependent on the time interval between these trigger pulses.
- Symmetric triggering is a method of pulse triggering in which successive trigger pulses taken from the same source and applied at the same point in the circuit will cause a change of state in either direction. This method of triggering is used in counters.
- An emitter-coupled bistable multivibrator is called a Schmitt trigger.
- When the loop gain is greater than 1, the Schmitt trigger exhibits hysteresis.
- Hysteresis in a Schmitt trigger can be eliminated by including a suitable resistance in series with either the first emitter (R_{e1}) or the second emitter (R_{e2}).
- A Schmitt trigger can also be used as a comparator and squaring circuit in addition to being used as a bistable multivibrator.
- The input voltage at which the output voltage of a Schmitt trigger goes high is called the upper trip point (UTP).
- The input voltage at which the output voltage of a Schmitt trigger goes low is called the lower trip point (LTP).

MULTIPLE CHOICE QUESTIONS

1. Unless an external trigger is applied, the state of a bistable multivibrator:
   a) Remains unaltered
   b) Changes automatically
   c) Goes into the quasi-stable state
   d) None of the above
2. When a trigger is applied to a bistable multivibrator, conduction is transferred from one device to the other. The time taken for conduction to transfer from one device to the other is called:
   a) Delay time
   b) Rise time
   c) Transition time
   d) Fall time
3. The time taken for the voltages across the commutating condensers to interchange is called:
   a) Transition time
   b) Rise time
   c) Recovery time
   d) Settling time
4. Resolution time of a bistable multivibrator is the sum of the:
   a) Rise time and fall time
   b) Delay time and rise time
   c) Transition time and settling time
   d) Storage time and fall time
5. The reciprocal of the resolution time of the bistable multivibrator is called:
   a) Maximum switching speed of the bistable multi-vibrator
   b) Minimum switching speed of the bistable multi-vibrator
   c) Frequency of oscillations of the bistable multivibrator
   d) Gate width
6. If the commutating condensers are large:
   a) Transition time decreases and the settling time increases
   b) Transition time increases and the settling time decreases
   c) Both, transition time and settling time increase
   d) Both transition time and settling time decrease
7. An emitter-coupled bistable multivibrator is also called as:
   a) Astable multivibrator
   b) Monostable multivibrator
   c) Schmitt trigger
   d) None of the above
8. A Schmitt trigger can be used as a:
   a) Comparator
   b) Astable multivibrator
   c) Monostable multivibrator

d) None of the above

9. If the loop gain is greater than 1, a Schmitt trigger exhibits:
   a) Oscillations
   b) Hysteresis
   c) Instability
   d) None of the above

10. When symmetric pulse triggering is used in a bistable multivibrator, its application is in:
   a) Astable multivibrators
   b) Monostable multivibrators
   c) Counters
   d) Schmitt trigger

11. $\boldsymbol{R_{e2}}$ connected in series with the second emitter in a Schmitt trigger influences:
   a) $\boldsymbol{V}_2$ but not $\boldsymbol{V}_1$
   b) $\boldsymbol{V}_1$ but not $\boldsymbol{V}_2$
   c) Both $\boldsymbol{V}_1$ and $\boldsymbol{V}_2$
   d) None of the above

12. $\boldsymbol{R_{e1}}$ connected in series with the first emitter in a Schmitt trigger influences:
   a) $\boldsymbol{V}_2$ but not $\boldsymbol{V}_1$
   b) $\boldsymbol{V}_1$ but not $\boldsymbol{V}_2$
   c) Both $\boldsymbol{V}_1$ and $\boldsymbol{V}_2$
   d) None of the above

SHORT ANSWER QUESTIONS

1. What is a bistable multivibrator? What are the other names by which it is called? Explain, in short, how a bistable multivibrator can be used as a memory element?
2. What is meant by loading in a bistable multivibrator? How can you make the output swing constant?
3. What is the purpose served by a collector catching diodes?
4. What is the use of commutating condensers in a bistable multivibrator?
5. Define transition time? Suggest how to minimize it.
6. What is meant by the resolution time of a bistable multivibrator? Suggest simple methods to improve it.
7. What do you understand by unsymmetric triggering? What is its application?
8. What do you understand by symmetric triggering? What is its application?
9. What is a Schmitt trigger? Mention some of its applications.
10. Suggest simple methods to eliminate hysteresis in a Schmitt trigger.
11. A Schmitt trigger can be used as a regenerative comparator – justify.

LONG ANSWER QUESTIONS

1. With the help of a neat circuit diagram explain the working of a fixed-bias bistable multivibrator. Derive the expression for the resolution time and maximum switching speed of a bistable multivibrator.
2. With the help of a neat circuit diagram explain the working of a self-bias bistable multivibrator. List the advantages of this circuit over a fixed-bias bistable multivibrator.
3. With the help of a suitable circuit diagram, explain the methods of symmetric and unsymmetric triggering of a bistable multivibrator.
4. Draw the circuit of a Schmitt trigger and explain its operation. Derive the expressions for (i) UTP and (ii) LTP.
5. Explain with the help of waveforms how a Schmitt trigger can be used as a:

   a) Bistable multivibrator;
   b) Squaring circuit; and
   c) Amplitude comparator.

SOLVED PROBLEMS

Example 9.1: The circuit shown in Fig. 9.2(a) uses an ***n-p-n*** silicon transistor having $h_{FE(\text{min})} = 50$, $V_{CE(\text{sat})} = 0.3$ V, $V_{BE(\text{sat})} = 0.7$ V, $V_{CC} = 12$ V, $V_{BB} = 12$ V, $R_C = 1\text{k}\Omega$, $R_1 = 10\ \text{k}\Omega$, $R_2 = 20\ \text{k}\Omega$. Calculate the stable-state currents and voltages.

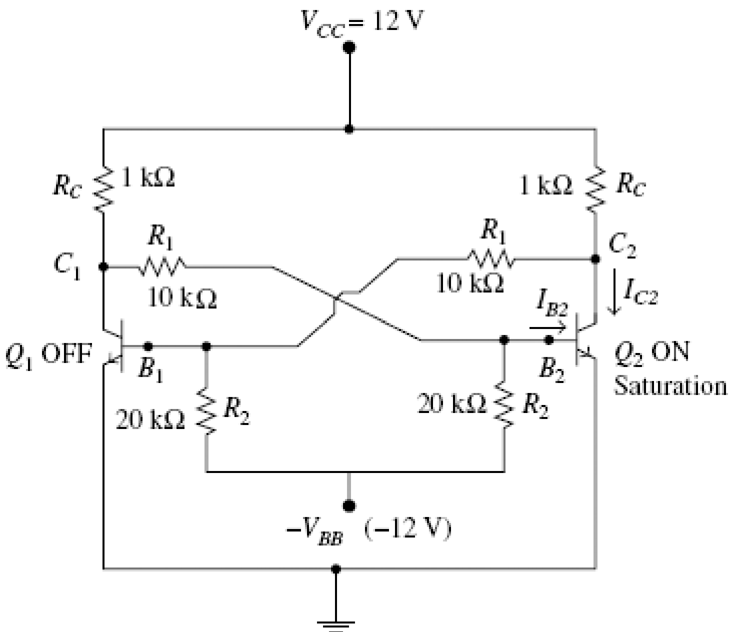

FIGURE 9.2(a) The fixed-bias bistable multivibrator

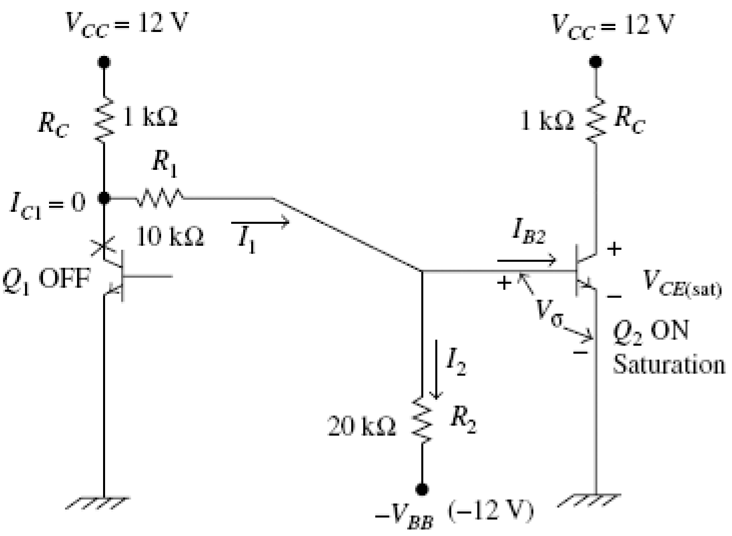

FIGURE 9.2(b) The circuit that enables the calculation of $\boldsymbol{I_{B2}}$

Solution:

(a) To calculate $\boldsymbol{I_{B2}}$ and $\boldsymbol{I_{C2}}$:

Consider the Fig. 9.2(b), in which the cross-coupling network from the first collector to the second base is represented, to calculate $\boldsymbol{I_{B2}}$.

On the assumption that $\boldsymbol{Q_2}$ is in saturation and $\boldsymbol{Q_1}$ is OFF calculations are made and justified. To find $\boldsymbol{I_{B2}}$, we calculate $\boldsymbol{I_1}$ and $\boldsymbol{I_2}$.

Then, $\boldsymbol{I_{B2}} = \boldsymbol{I_1} - \boldsymbol{I_2}$

$$I_1 = \frac{V_{CC} - V_\sigma}{R_C + R_1} = \frac{12 - 0.7}{1 + 10} = \frac{11.3\text{ V}}{11\text{ k}\Omega} = 1\text{ mA} \qquad I_2 = \frac{V_\sigma - (-V_{BB})}{R_2} = \frac{12.7}{20\text{ k}\Omega} = 0.635\text{ mA}$$

$\boldsymbol{I_{B2}} = \boldsymbol{I_1} - \boldsymbol{I_2} = 1\text{mA} - 0.635\text{ mA} = 0.365\text{ mA}$

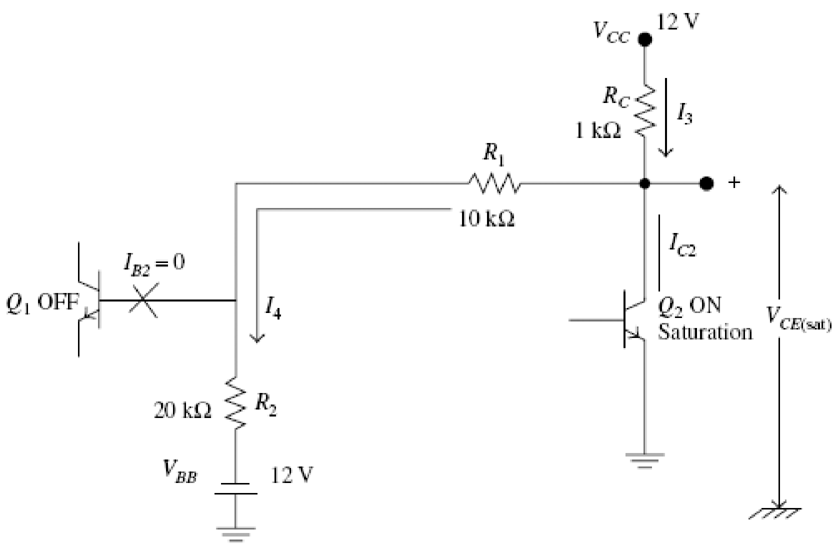

FIGURE 9.2(c) The circuit that enables the calculation of $\boldsymbol{I_{C2}}$

To calculate I_{C2}, consider the cross-coupling network from the second collector to the first base as shown in Fig. 9.2(c).

$$I_3 = \frac{V_{CC} - V_{CE(\text{sat})}}{R_C} = \frac{12 - 0.3}{1\,\text{K}} = 11.7\,\text{mA}$$

$$I_4 = \frac{V_{CE(\text{sat})} - (-V_{BB})}{R_1 + R_2} = \frac{12 + 0.3}{30\,\text{K}} = \frac{12.3}{30\,\text{K}} = 0.41\,\text{mA}$$

$$I_{C2} = I_3 - I_4 = 11.7 - 0.41 = 11.29\text{ mA}$$

(b) To Verify Q_2 is in saturation:

$$I_{B2(\min)} = \frac{I_{C2}}{h_{FE(\min)}} = \frac{11.29\,\text{mA}}{50} = 0.226\,\text{mA}$$

For Q_2 to be saturation:

$I_{B2} \cong 1.5 I_{B2\min}$
$I_{B2} = 1.5 \times 0.226\text{ mA} = 0.339\text{ mA}$

Actually, $I_{B2} = 0.365$ mA, i.e., $I_{B2} >> I_{B2(\min)}$. Hence, Q_2 is in saturation. Therefore, $V_{C2} = 0.3$ V, $V_{B2} = 0.7$ V.

(c) To verify whether Q_1 is OFF or not:

For verifing whether Q_1 is OFF or not, voltage V_{B1} is calculated, using the circuit shown in Fig. 9.2(d).

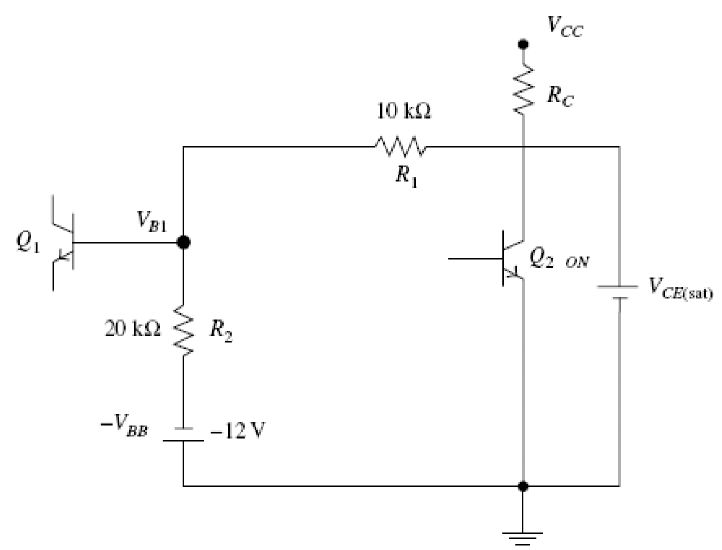

FIGURE 9.2(d) The circuit to calculate V_{B1}

To calculate the voltage V_{B1} at the base of Q_1 due to $-V_{BB}$ and $V_{CE(\text{sat})}$ sources, use Eq. (9.7).

$$V_{B1} = V_{CE(\text{sat})}\frac{R_2}{R_1 + R_2} + (-V_{BB})\frac{R_1}{R_1 + R_2} = 0.3 \times \frac{20}{30} - 12 \times \frac{10}{30} = 0.2 - 4 = -3.8\text{ V.}$$

As voltage V_{B1} reverse-biases the emitter diode, Q_1 is OFF and hence, $V_{C1} = V_{CC} = 12$ V. However, V_{C1} is not exactly 12 V—as it should be when Q_1 is OFF—but, is smaller than this because of the current I_1 in R_1. The actual voltage at the first collector is,

$$V_{C1} = V_{CC} - I_1 R_C = 12 - (1\text{mA})(1\text{K}) = 11 \text{ V}$$

Hence, the voltages in the initial stable state are $V_{C1} = 11$ V, $V_{B1} = -3.8$ V, $V_{C2} = 0.3$ V, $V_{B2} = 0.7$ V.

Example 9.2: Design a fixed-bias bistable multivibrator shown in Fig. 9.1(a) with supply voltages ±12 V, an ***n-p-n*** silicon device having $V_{CE(\text{sat})} = 0.2$ V, $V_{BE(\text{sat})} = V_\sigma = 0.7$ V and $h_{FE(\text{min})} = 50$ are used. Assume $I_C = 5$ mA.

Solution:

From Eq. (9.14),

$$R_C = \frac{V_{CC} - V_{CE(\text{sat})}}{I_{C2}} = \frac{12 - 0.2 \text{ V}}{5 \text{ mA}} = \frac{11.8 \text{ V}}{5 \text{ mA}} = 2.36 \text{ k}\Omega \qquad \approx 2.2 \text{ k}\Omega \text{ (standard resistance).}$$

From Eq. (9.15),

$$R_2 = \frac{V_\sigma - (-V_{BB})}{I_2}$$

$$\text{Choose} \quad I_2 \approx \frac{1}{10} I_{C2} = 0.5 \text{ mA}$$

$$\therefore R_2 = \frac{0.7 + 12}{0.5} = \frac{12.7 \text{ V}}{0.5 \text{ mA}} = 25.4 \text{ k}\Omega \approx 22 \text{ k}\Omega$$

$$I_{B2(\text{min})} = \frac{I_{C2}}{h_{FE(\text{min})}} = \frac{5 \text{ mA}}{50} = 0.1 \text{ mA}$$

If Q_2 is in saturation:

$I_{B2(\text{sat})} = 1.5 I_{B2(\text{min})} = 0.15$ mA

$I_1 = I_2 + I_{B2(\text{sat})} = 0.5 \text{ mA} + 0.15 \text{ mA} = 0.65$ mA

From Eq. (9.18)

$$R_C + R_1 = \frac{V_{CC} - V_\sigma}{I_1} = \frac{12 - 0.7}{0.65 \text{ mA}} = \frac{11.3 \text{ V}}{0.65 \text{ mA}} = 17.38 \text{ k}\Omega$$

from Eq. (9.19)

$R_1 = (R_C + R_1) - R_C = 17.38 - 2.36 = 15.02$ kΩ

Choose R_1 = 15 kΩ

The circuit, so designed, with component values indicated is shown in Fig. 9.3.

After the design is complete and as the components chosen are of standard values, there is a need to verify whether Q_2 is in saturation and Q_1 is OFF or not. For this, we calculate I_{C2} and I_{B2} and verify whether Q_2 is in saturation or not. Afterwards, the voltage V_{B1} is calculated to check whether this voltage reverse-biases the base-emitter diode of Q_1 or not.

$$I_{C2} \approx \frac{V_{CC} - V_{CE(\text{sat})}}{2.2\ \text{K}\Omega} = \frac{12 - 0.2\ \text{V}}{2.2\ \text{k}\Omega} = \frac{11.8\ \text{V}}{2.2\ \text{k}\Omega} = 5.36\ \text{mA}$$

$$I_{B2(\text{min})} = \frac{5.36\ \text{mA}}{50} = 0.107\ \text{mA}$$

$$I_2 = \frac{V_\sigma + V_{BB}}{R_2} = \frac{12.7}{22\ \text{K}} = 0.58\ \text{mA}$$

$$I_1 = \frac{V_{CC} - V_\sigma}{R_C + R_1} = \frac{12 - 0.7}{2 + 10} = \frac{11.3}{12} = 0.94\ \text{mA}$$

$I_{B2} = I_1 - I_2 =$ 0.94 mA − 0.58 mA = 0.36 mA
$I_{B2} \geq I_{B2\min}$

Hence, Q_2 is in saturation.

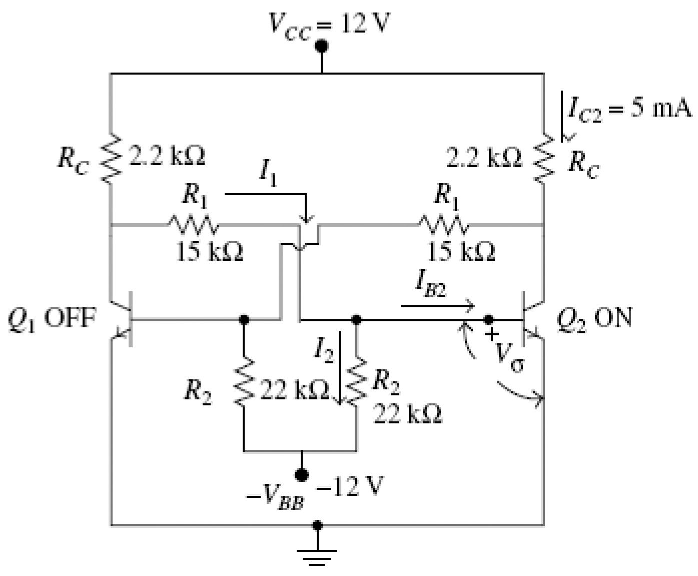

FIGURE 9.3 The designed fixed-bias bistable multivibrator with component values

$$V_{B1} = V_{CE(\text{sat})} \frac{R_2}{R_1 + R_2} - V_{BB} \frac{R_1}{R_1 + R_2} = 0.2 \times \frac{22}{15 + 22} - 12 \times \frac{10}{15 + 22} = 0.118 - 4.86 = -4.742\ \text{V}$$

The voltage, V_{B1} reverse–biases the base–emitter diode of Q_1. Hence, Q_1 is OFF.

Example 9.3: Calculate the stable-state currents and voltages for the circuit of Fig. 9.10(a) in which ***n–p–n*** silicon transistors are used. Given that $V_{BE(\text{sat})} = 0.7$ V, $V_{CE(\text{sat})} = 0.3$ V and $h_{FE(\text{min})} = 50$. Take $V_{CC} = 20$ V, $R_C = 4.7$ kΩ, $R_1 = 30$ kΩ and $R_2 = 15$ kΩ, $R_E = 400$ Ω.

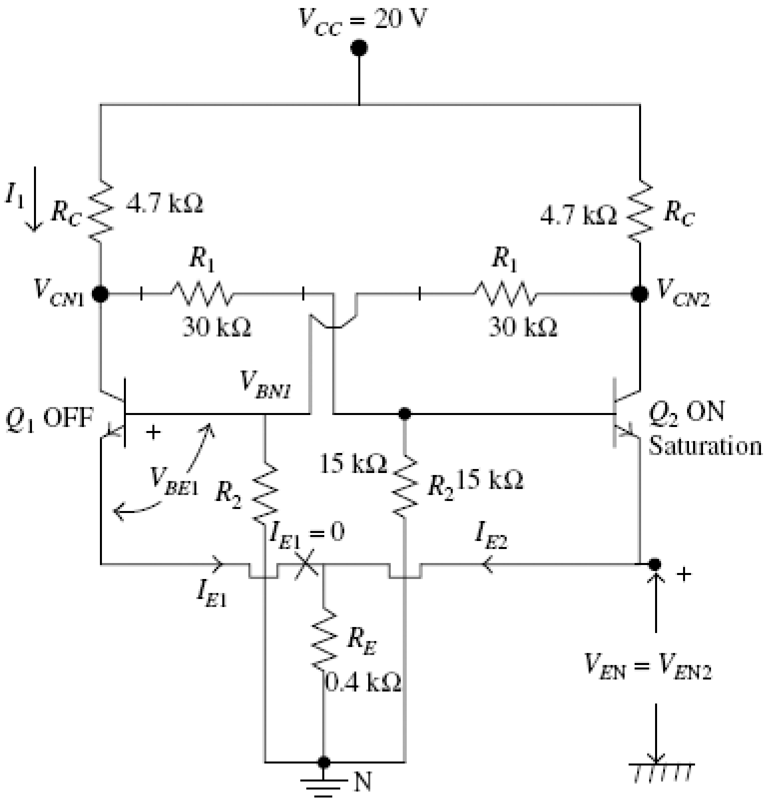

FIGURE 9.10(a) A self-bias bistable multivibrator with component values specified

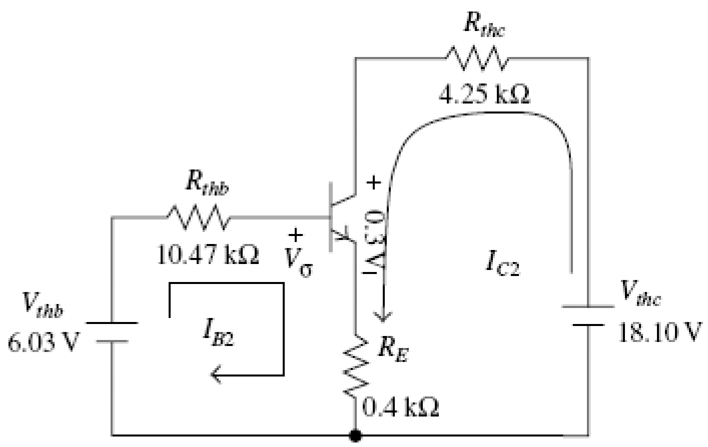

FIGURE 9.10(b) The circuit to calculate the base and collector currents

Solution: Let Q_1 be OFF and Q_2 be ON and in saturation. To verify whether Q_2 is in saturation or not, draw the collector loop and base loop of the circuit by Thévenising at the collector and base terminals of Q_2.

$$V_{thb} = V_{CC} \times \frac{R_2}{R_C + R_1 + R_2} = 20 \times \frac{15}{4.7 + 30 + 15} = 6.03 \text{ V}$$

and

$$R_{thb} = R_2 \; || \; (R_C + R_1) = \frac{R_2(R_C + R_1)}{R_2 + R_C + R_1} = \frac{(15)(30 + 4.7)}{4.7 + 30 + 15} = 10.47\,\text{k}\Omega$$

$$V_{thc} = V_{CC} \times \frac{(R_1 + R_2)}{R_C + R_1 + R_2} = \frac{20 \times (30 + 15)}{4.7 + 30 + 15} = 18.10\,\text{V}$$

$$R_{thc} = (R_1 + R_2) \; || \; R_C = \frac{(30 + 15)(4.7)}{30 + 15 + 4.7} = 4.25\,\text{k}\Omega$$

The base and collector loops of $\boldsymbol{Q}_2$ are drawn as shown in Fig. 9.10(b).

Writing the KVL equations of the input and output loops:

$6.03 - 0.7 = (10.47 + 0.4)\, \boldsymbol{I}_{B2} + 0.4\, \boldsymbol{I}_{C2}$ $\quad 18.10 - 0.3 = 0.4\, \boldsymbol{I}_{B2} + (4.25 + 0.4)\, \boldsymbol{I}_{C2}$

That is,

$$5.33\text{ V} = 10.87\, I_{B2} + 0.4\, I_{C2} \qquad \textbf{(1)}$$

$$17.80\text{ V} = 0.4\, I_{B2} + 4.65\, I_{C2} \qquad \textbf{(2)}$$

Solving Eqs. (1) and (2):

$\boldsymbol{I}_{B2} = 0.35$ mA $\quad \boldsymbol{I}_{C2} = 3.79$ mA

$$I_{B2\text{min}} = \frac{I_{C2}}{h_{FE}} = \frac{3.79\text{ mA}}{50} = 0.075\text{ mA} \qquad I_{B2} \gg I_{B2(\text{min})}$$

Hence, $\boldsymbol{Q}_2$ is saturation.

$\boldsymbol{V}_{EN} = \boldsymbol{V}_{EN2} = (\boldsymbol{I}_{B2} + \boldsymbol{I}_{C2})\, \boldsymbol{R}_E$ $\quad \boldsymbol{V}_{EN2} = (0.35 + 3.79)(0.4) = 1.656$ V

$\boldsymbol{V}_{CN2} = \boldsymbol{V}_{EN2} + \boldsymbol{V}_{CE(\text{sat})} = (1.656\text{ V} + 0.3\text{ V}) = 1.956$ V $\quad \boldsymbol{V}_{BN2} = \boldsymbol{V}_{EN2} + \boldsymbol{V}_{\sigma} = (1.656\text{ V} + 0.7\text{ V}) = 2.356$ V

$$V_{BN1} = V_{CN2} \times \frac{R_2}{R_1 + R_2} = \frac{1.956 \times 15}{15 + 30} = 0.652\,\text{V}$$

$\boldsymbol{V}_{BE1} = \boldsymbol{V}_{BN1} - \boldsymbol{V}_{EN2} = (0.652\text{ V} - 1.656) = -1.004$ V

As this voltage reverse-biases the emitter diode, $\boldsymbol{Q}_1$ is OFF.

$$I_1 = \frac{V_{CC} - V_{BN2}}{R_C + R_1} = \frac{20 - 2.356}{4.7 + 30} = 0.508\,\text{mA}$$

$\boldsymbol{V}_{CN1} = \boldsymbol{V}_{CC} - \boldsymbol{I}_1 \boldsymbol{R}_C = 20 - (0.508)(4.7) = 17.61$ V

The stable-state voltages are:

V_{CN1} = 17.61 V, V_{BN1} = 0.652 V, V_{CN2} = 1.956 V, V_{BN2} = 2.356 V, V_{EN} = 1.656 V

Example 9.4: Design a self-bias bistable multivibrator shown in Fig. 9.9(a) using silicon ***n–p–n*** transistors whose junction voltages are $V_{CE(sat)}$ = 0.3 V, $V_{BE(sat)}$ = 0.7 V, V_{BE}(cut-off) = 0 V and $h_{FE(min)}$ = 50, $V_{CC} = V_{BB}$ = 9 V, I_C = 4mA.

Solution:

Assume $V_{EN} = \frac{1}{3} V_{CC} = \frac{1}{3} \times 9 = 3$ V and I_{C2} = 4mA

$$I_{B2(\min)} = \frac{4\,\mathrm{mA}}{50} = 0.08\,\mathrm{mA}$$

Choose $I_{B2} = 1.5\, I_{B2(min)} = 0.12$ mA

$$(I_{C2} + I_{B2}) = 4 + 0.12 = 4.12\,\mathrm{mA} \qquad R_E = \frac{V_{EN2}}{I_{C2} + I_{B2}} = \frac{3\,\mathrm{V}}{4.12\,\mathrm{mA}} = 0.728\,\mathrm{k\Omega}$$

Select $R_E \approx 500\ \Omega$

$$R_C = \frac{V_{CC} - V_{CE(\mathrm{sat})} - V_{EN2}}{I_C} = \frac{9 - 0.3 - 3}{4\,\mathrm{mA}} = \frac{5.7\,\mathrm{V}}{4\,\mathrm{mA}} = 1.425\,k\Omega$$

Choose R_C = 1kΩ

Let

$$I_2 = \frac{1}{10} I_{C2} = \frac{1}{10} \times 4\,\mathrm{mA} = 0.4\,\mathrm{mA} \qquad V_{BN2} = V_{EN2} + V_\sigma = 3 + 0.7 = 3.7\,\mathrm{V}$$

$$R_2 = \frac{V_{BN2}}{I_2} = \frac{3.7\,\mathrm{V}}{0.4\,\mathrm{mA}} = 9.25\,\mathrm{k\Omega}$$

Choose R_2 = 10 kΩ and then find I_2 for this R_2.

$$I_2 = \frac{V_{BN2}}{R_2} = \frac{3.7\,\mathrm{V}}{10\,\mathrm{K}} = 0.37\,\mathrm{mA}$$

$$R_C + R_1 = \frac{V_{CC} - V_{BN2}}{I_2 + I_{B2}} = \frac{9 - 3.7}{0.37 + 0.12} = \frac{5.3\,\mathrm{V}}{0.49\,\mathrm{mA}} = 10.8\,\mathrm{k\Omega}$$

$(R_C + R_1)$ = 10.8 kΩ $(R_C + R_1) - R_C$ = 10.8 − 1 = 9.8 kΩ

Now, choose R_1 = 10 kΩ. The circuit with the component values is shown in Fig. 9.11.

Verifying whether Q_2 is really in saturation or not and Q_1 is OFF, with the designed component values; when calculated,

I_{B2} = 0.149 mA, I_{C2} = 5.46 mA, $I_{B2(\min)}$ = 0.109 mA, V_{EN2} = 2.8 V,

V_{CN2} = 3.1 V, V_{BN1} = 1.55 V, $V_{BE1} = V_{BN1} - V_{EN2} = -1.25$ V.

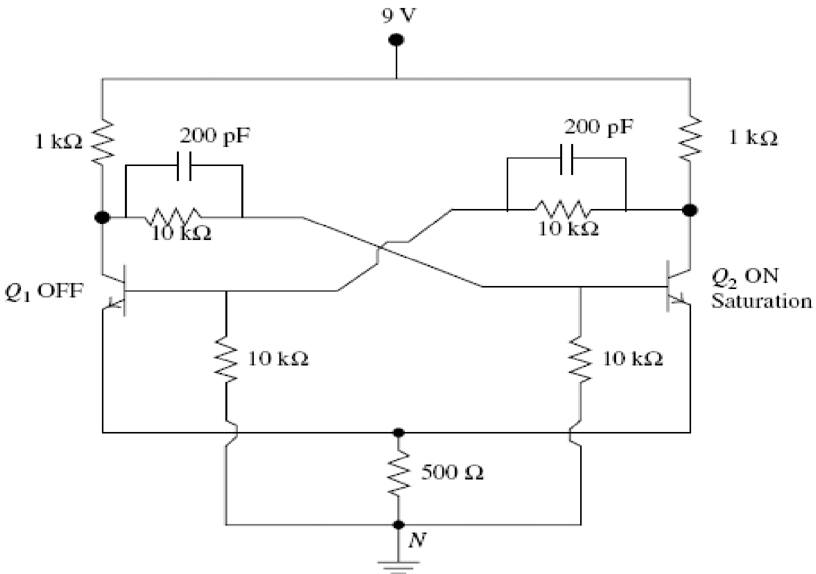

FIGURE 9.11 A self-bias bistable multivibrator with designed component values

These values show that Q_1 is OFF and Q_2 is in saturation.

$R = R_1 \parallel R_2$ $\quad R_1 = R_2 = 10$ kΩ $\quad R = 5$kΩ

$$RC = 1 \times 10^{-6}\text{sec} \qquad C = \frac{1 \times 10^{-6}}{5 \times 10^{3}} = 200\,\text{pF}$$

If t_{res} or $f_{(max)}$ is given, we may use either Eq. (9.28) or Eq. (9.29) to calculate C.

Example 9.5: For the Schmitt trigger circuit shown in Fig. 9.18(a), calculate V_1 and V_2.

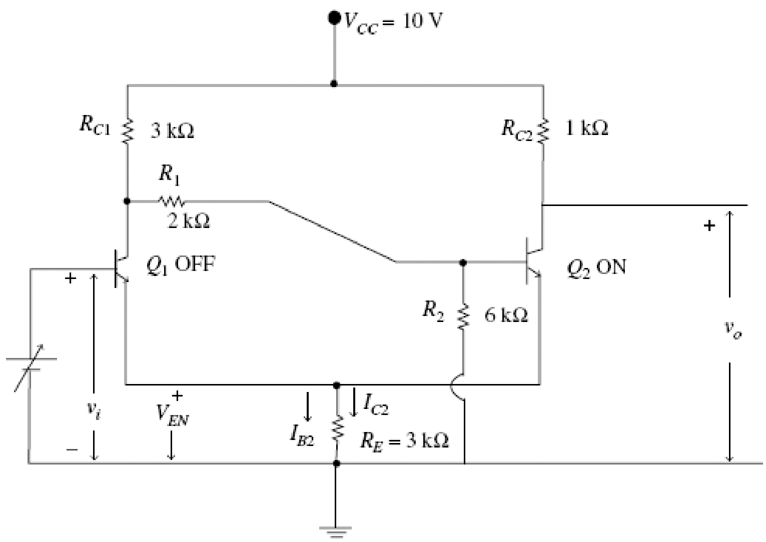

FIGURE 9.18(a) The Schmitt trigger with components mentioned

Solution:

a) Calculation of V_1:

Consider the Schmitt trigger circuit, shown in Fig. 9.18(a). From Eq. (9.55):

$$V' = V_{CC} \times \frac{R_2}{R_{C1} + R_1 + R_2} = 10 \times \frac{6}{3+2+6} = 5.45\ \text{V}$$

R' the internal resistance of this Thévenin source, as given by Eq. (9.56), is:

$$R' = R_2//(R_{C1} + R_1) = 6//(3+2) = \frac{6 \times 5}{6+5} = 2.73\ \text{k}\Omega$$

The resultant circuit is shown in Fig. 9.18(b).

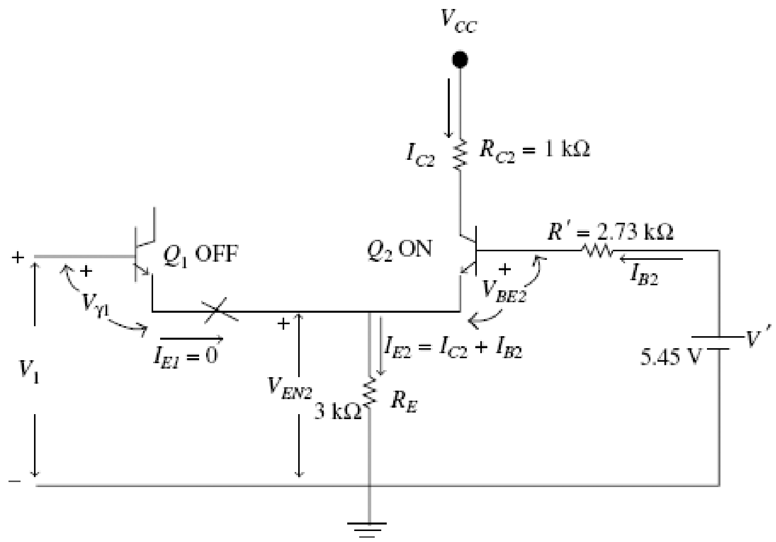

FIGURE 9.18(b) The circuit that enables computation of V_1

From Eq. (9.58):

$$V_{EN2} = (V' - V_{BE2})\frac{R_E(1 + h_{FE})}{R' + R_E(1 + h_{FE})}$$

If Q_2 is in the active region, typically, for silicon V_{BE2} = 0.6 V and let h_{FE} = 50,

$R_E(1 + h_{FE}) = 3(1 + 50) = 153$ kΩ

Therefore,

$$V_{EN2} = (5.45 - 0.6) \times \frac{153}{2.73 + 153} = 4.85 \times \frac{153}{155.73} = 4.76\ \text{V}$$

Therefore,

$V_1 = V_{EN2} + V_{BE2} = 4.76 + 0.6 = 5.36$ V.

The calculation of V_1 is made based on the assumption that Q_2 is in the active region. To find out whether Q_2 is in the active region or not, we calculate V_{CB2}.

$V_{CB2} = V_{CC} - I_{C2}R_{C2} - V_{EN2} - V_{BE2}$.

From Eq. (9.72)

$$R_E'' = (1 + \frac{1}{h_{FE}})R_E = (1 + \frac{1}{50})3 = \frac{51}{50} \times 3 = 3.06\,\text{k}\Omega$$

$$I_{C2} = \frac{V_{EN2}}{R_E''} = \frac{4.76\,\text{V}}{3.06\,\text{k}\Omega} = 1.56\,\text{mA}$$

Hence

$V_{CB2} = 10 - (1.56 \times 1) - 4.76 - 0.6 = 10 - 6.92 = 3.08$ V

As the collector of Q_2 is positive with respect to the base by 3.08 V the collector diode is reverse-biased. Hence, Q_2 is in the active region, as assumed.

(b) Calculation of V_2:

The circuit that enables us to calculate V_2 is shown in Fig. 9.18(c). From the circuit values:

$$\alpha = \frac{R_2}{R_1 + R_2} = \frac{6}{2+6} = 0.75 \qquad R_t = \frac{3(2+6)}{3+2+6} = \frac{24}{11} = 2.18\,\text{k}\Omega$$

$$\alpha R_t = 0.75 \times 2.18\,\text{K} = 1.64\,\text{k}\Omega \qquad R_E'' = 3.06\,\text{k}\Omega \qquad V_2 = V_{BE1} + I_{C1}R_E''$$

$$I_{C1} = \frac{(V' - V_{\gamma 2})}{\alpha R_t + R_E''} = \frac{(5.45 - 0.5)}{1.64 + 3.06} = \frac{4.95}{4.7} = 1.05\,\text{mA}$$

$\therefore$ $V_2 = 0.6$ V + (1.05 mA)(3.06 kΩ)= 0.6 V + 3.22 V = 3.82 V

Hence, for the given Schmitt trigger:

$V_1 = 5.36$ V $\quad V_2 = 3.82$ V $\quad V_H = V_1 - V_2 = 5.36 - 3.82 = 1.54$ V

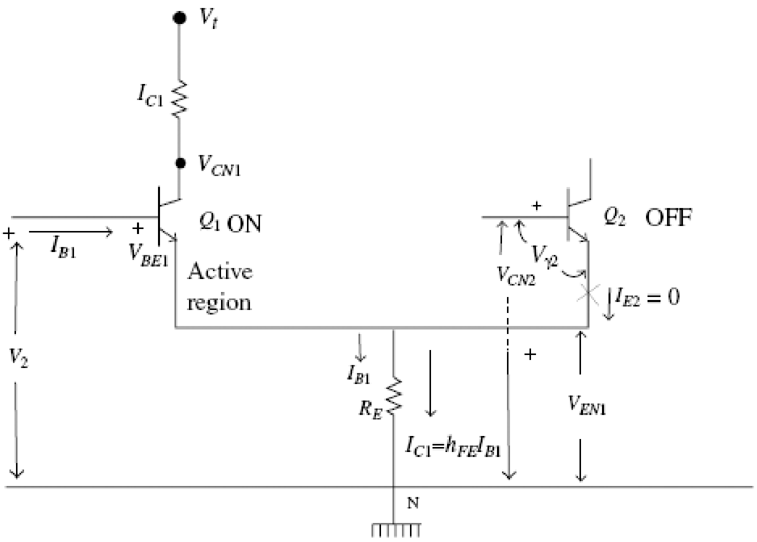

FIGURE 9.18(c) The circuit to calculate V_2

Example 9.8: Design a Schmitt trigger shown in Fig. 9.24(a) with UTP of 6 V and LTP of 3 V. Ge transistors with $h_{FE(\min)} = 50$ and $I_C = 4$ mA are used. The supply voltage is 15 V.

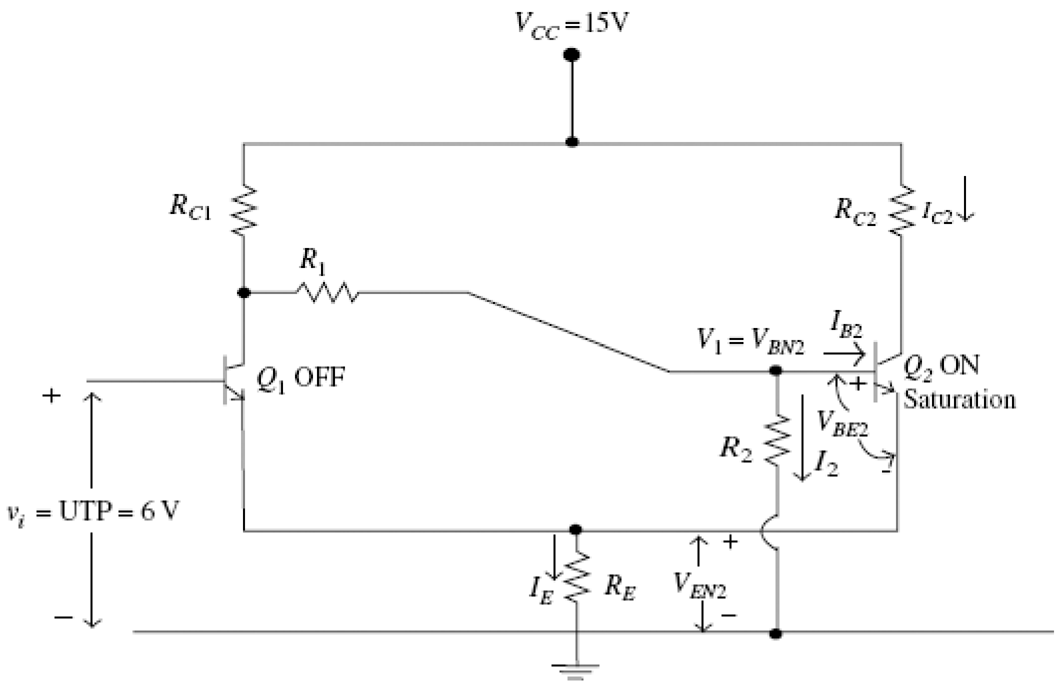

FIGURE 9.24(a) The Schmitt trigger circuit

Solution:

Till UTP is reached, Q_1 is OFF and Q_2 is ON and in saturation. Just at V_1 (UTP) Q_1 goes ON and Q_2 goes OFF.

Therefore, $V_1 = \text{UTP} = V_{BN2} = 6$ V

$I_E = I_C = 4$mA

$$R_E = \frac{V_1 - V_{BE2}}{I_E} = \frac{V_{EN2}}{I_E} = \frac{6 - 0.3}{4\,\text{mA}} = \frac{5.7\,\text{V}}{4\,\text{mA}} = 1.425\,\text{k}\Omega$$

Choose $R_E = 1\text{k}\Omega$

If Q_2 is in saturation $V_{CE(\text{sat})} = 0.1$ V, $V_\sigma = 0.3$ V, so

$I_{C2}R_{C2} = V_{CC} - V_{CE(\text{sat})} - V_{EN2}$

Therefore,

$$R_{C2} = \frac{15 - 0.1 - 5.7}{4\,\text{mA}} = \frac{9.2\,\text{V}}{4\,\text{mA}} = 2.3\,\text{k}\Omega$$

Choose $R_{C2} = 2.2$ kΩ

$$I_2 = \frac{1}{10} I_{C2} = 0.4\,\text{mA} \qquad R_2 = \frac{V_{BN2}}{I_2} = \frac{6\,\text{V}}{0.4\,\text{mA}} = 15\,\text{k}\Omega$$

$$I_{B2(\min)} = \frac{I_{C2}}{h_{FE(\min)}} = \frac{4\,\text{mA}}{50} = 0.08\,\text{mA} \qquad I_{B2} = 1.5 \times I_{B2(\min)} = 1.5 \times 0.08 = 0.12\,\text{mA}$$

$$I_{B2} + I_2 = 0.12\,\text{mA} + 0.4\,\text{mA} = 0.52\,\text{mA} \qquad (R_{C1} + R_1) = \frac{V_{CC} - V_{BN2}}{(I_{B2} + I_2)} = \frac{15 - 6}{0.52} = \frac{9}{0.52} = 17.31\,\text{k}\Omega$$

$\boldsymbol{R}_1 = 17.31\ \text{k}\Omega - \boldsymbol{R}_{C1}$

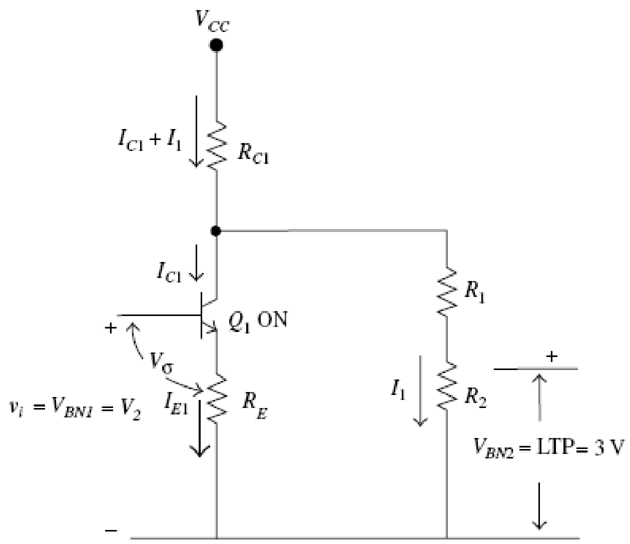

FIGURE 9.24(b) The circuit at LTP

At LTP = 3 V, consider the circuit shown in Fig. 9.24(b).

$\boldsymbol{V}_{BN2} = \boldsymbol{V}_{BN1} = 3\ \text{V} = \text{LTP} = \boldsymbol{V}_2$

Let $\boldsymbol{I}_1$ be the current in $\boldsymbol{R}_2$,

$$I_1 = \frac{V_{BN2}}{R_2} = \frac{3\,\text{V}}{15\,\text{k}\Omega} = 0.2\,\text{mA} \qquad I_{C1} = I_{E1} = \frac{V_2 - V_\sigma}{R_E} = \frac{3 - 0.3}{1\,\text{K}\Omega} = 2.7\,\text{mA}$$

Writing the KVL equation of the outer loop:

$\boldsymbol{V}_{CC} = (\boldsymbol{I}_{C1} + \boldsymbol{I}_1)\boldsymbol{R}_{C1} + \boldsymbol{I}_1(\boldsymbol{R}_1 + \boldsymbol{R}_2) = (\boldsymbol{I}_{C1} + \boldsymbol{I}_1)\boldsymbol{R}_{C1} + \boldsymbol{I}_1(17.31 - \boldsymbol{R}_{C1} + \boldsymbol{R}_2)$

$\boldsymbol{V}_{CC} = \boldsymbol{I}_{C1}\boldsymbol{R}_{C1} + \boldsymbol{I}_1(17.31 + \boldsymbol{R}_2)$

$$R_{C1} = \frac{V_{CC} - I_1(17.31 + R_2)}{I_{C1}} = \frac{15 - 0.2(17.31 + 15)}{2.7} = \frac{8.54}{2.7} = 3.16\,\text{k}\Omega$$

$\boldsymbol{R}_{C1} = 3\text{k}\Omega \quad \boldsymbol{R}_1 = 17.31 - \boldsymbol{R}_{C1} = 17.31 - 3 = 14.31\ \text{k}\Omega$

Choose $\boldsymbol{R}_1 = 15\ \text{k}\Omega$.

The designed Schmitt trigger circuit is shown in Fig. 9.24(c) with all the component values.

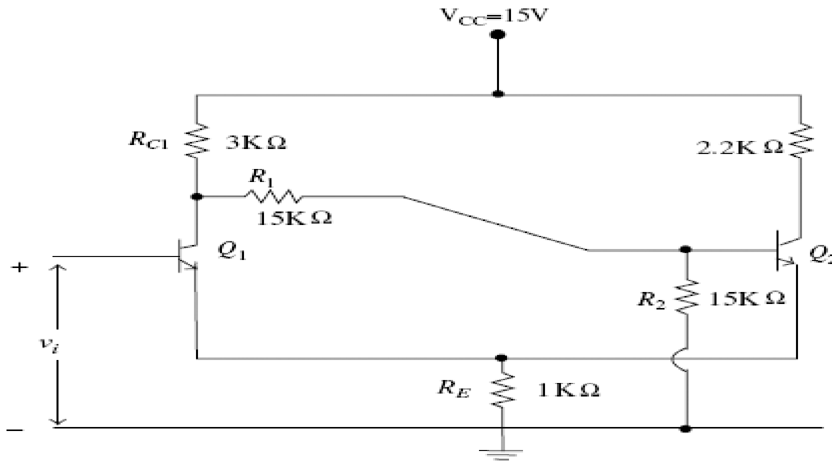

FIGURE 9.24(c) The designed Schmitt trigger

Example 9.9: Design a fixed-bias bistable multivibrator shown in Fig. 9.25 using ***p–n–p*** Ge transistors having $h_{FE(min)} = 50$, $V_{CC} = -10$ V, $V_{BB} = 10$ V, $V_{CE(sat)} = -0.1$, $V_{BE(sat)} = -0.3$ and $I_{C(sat)} = -5$ mA. Assume $I_C = -5$ mA.

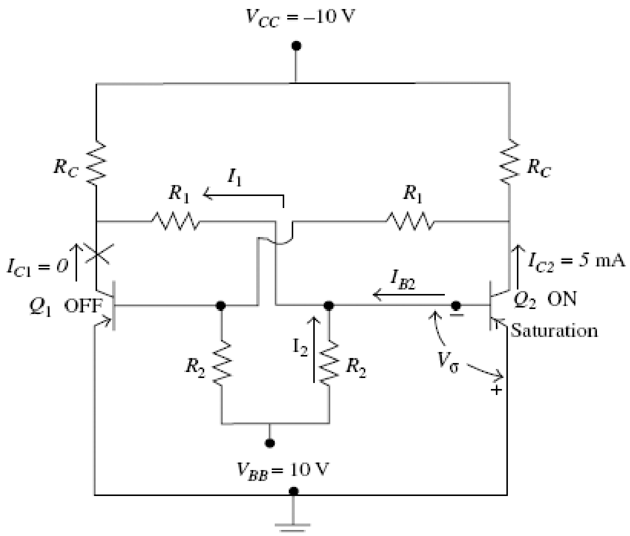

FIGURE 9.25 The fixed-bias bistable multivibrator

Solution:

$$R_C = \frac{V_{CC} - V_{CE(\text{sat})}}{I_{C2}} = \frac{-10 + 0.1V}{-5\,\text{mA}} = \frac{-9.9\,\text{V}}{-5\,\text{mA}}$$

$R_C = 1.98$ kΩ ≈ 2.2 kΩ(standard resistance).

$$R_2 = \frac{-V_\sigma - (V_{BB})}{I_2} \qquad I_2 \approx \frac{1}{10} I_{C2} = -0.5\,\text{mA}$$

$$R_2 = \frac{-0.3 - 10}{-0.5} = \frac{-10.3\text{V}}{-0.5\,\text{mA}} = 20.6\,\text{k}\Omega \approx 20\,\text{k}\Omega$$

$$I_{B2(\text{min})} = \frac{I_{C2}}{h_{FE(\text{min})}} = \frac{-5\,\text{mA}}{50} = -0.1\,\text{mA}$$

If Q_2 is in saturation,

$I_{B2} = 1.5 I_{B2(\min)} = -0.15$ mA $\quad I_1 = I_2 + I_{B2} = -0.5$ mA $- 0.15$ mA $= -0.65$ mA

$$R_C + R_1 = \frac{-V_{CC} + V_\sigma}{I_1} = \frac{-10 + 0.3}{-0.65\,\text{mA}} = \frac{-9.7\,\text{V}}{-0.65\,\text{mA}} = 14.92\,\text{k}\Omega$$

$R_1 = (R_C + R_1) - R_C = 14.92 - 1.98 = 12.94$ kΩ

Choose $R_1 \approx 13$ kΩ

Note: Choose the nearest standard values.

Example 9.10: For a fixed-bias bistable multivibrator using Si transistors, shown in Fig. 9.26(a), $h_{FE} = 20$, $V_{CE(\text{sat})} = 0.3$ V, $V_\sigma = 0.7$ V.

a) Calculate the stable-state currents and voltages.
b) If the commutating condenser is 100 pF, find the maximum switching speed of the bistable multivibrator
c) The maximum switching frequency is 50 kHz. Find the value of the commutating condenser.

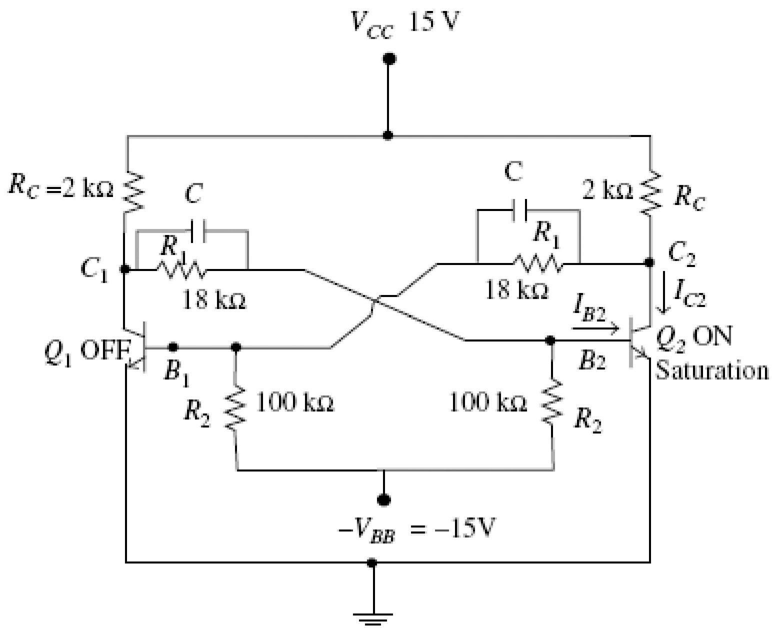

FIGURE 9.26(a) The given fixed-bias bistable multivibrator

Solution: (a) (i) If Q_2 is ON and in saturation, to find its base current I_{B2}, consider the base circuit shown in Fig. 9.26(b).

From Fig. 9.26(b),

$$I_1 = \frac{V_{CC} - V_\sigma}{R_C + R_1}$$

$$= \frac{15 - 0.7}{2 + 18} = 0.715\,\text{mA}$$

$$I_2 = \frac{V_\sigma + V_{BB}}{R_2}$$

$$= \frac{0.7 + 15}{100} = 0.157\,\text{mA}$$

$$I_{B2} = I_1 - I_2$$

$$= 0.715 - 0.157 = 0.558\,\text{mA}$$

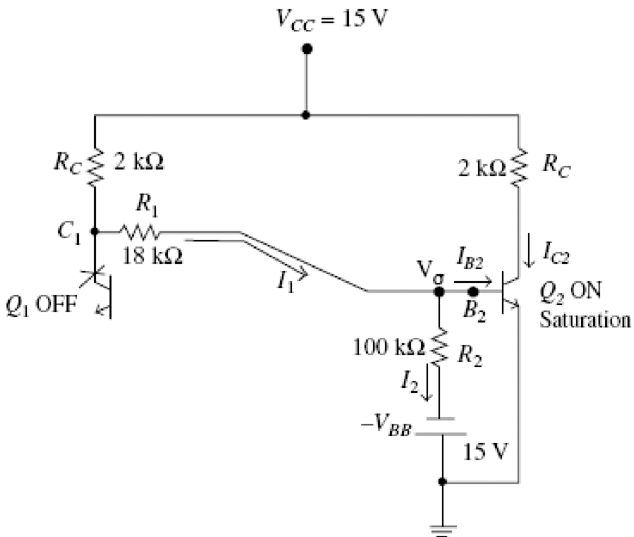

FIGURE 9.26(b) The circuit to calculate $\boldsymbol{I_{B2}}$

(ii) To calculate $\boldsymbol{I_{C2}}$ consider the collector circuit of $\boldsymbol{Q_2}$, shown in Fig. 9.26(c).

From Fig. 9.26(c),

$$I_3 = \frac{V_{CC} - V_{CE(\text{sat})}}{R_C} = \frac{15 - 0.3}{2} = 7.35\,\text{mA}$$

$$I_4 = \frac{V_{CE(\text{sat})} + V_{BB}}{R_1 + R_2} = \frac{0.3 + 15}{100 + 18} = 0.13\,\text{mA}$$

$\boldsymbol{I_{C2}} = \boldsymbol{I_3} - \boldsymbol{I_4} = 7.35 - 0.13 = 7.22$ mA

Given $\boldsymbol{h_{FE}} = 20$.

Therefore,

$$I_{B2(\text{min})} = \frac{I_{C2}}{h_{FE}} = \frac{7.22}{20} = 0.361\,\text{mA}$$

$I_{B2(sat)} = 1.5\, I_{B2(min)} = 1.5 \times 0.361 = 0.54$ mA

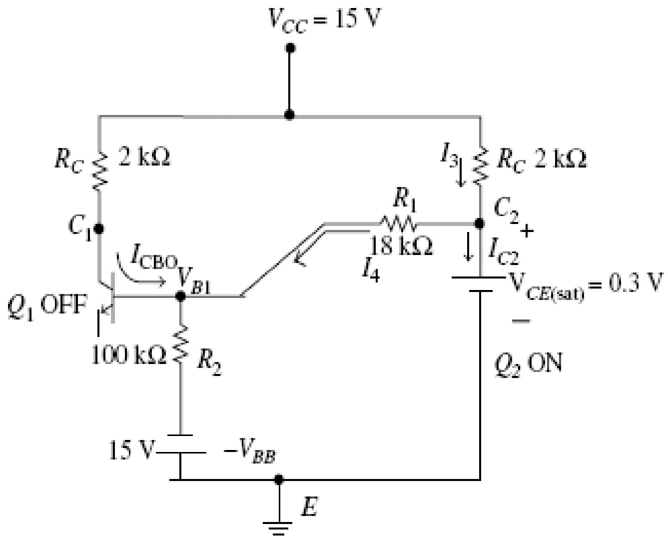

FIGURE 9.26(c) The circuit to calculate I_{C2}

As I_{B2} = 0.558 mA, Q_2 is in saturation.

$$V_{B1} = V_{CE\,(\text{sat})}\frac{R_2}{R_1 + R_2} + (-V_{BB})\frac{R_1}{R_1 + R_2} = (0.3)\frac{100}{118} + (-15)\frac{18}{118} = 0.254 - 2.288 = -2.034\,\text{V}$$

Hence, Q_1 is OFF.

$V_{C1} = V_{CC} - I_1 R_C = 15 - (0.715)2 = 13.57$ V

(b) $$f_{(\max)} = \frac{1}{2\tau} = \frac{(R_1 + R_2)}{2CR_1R_2}.$$

Given C = 100 pF.

Therefore,

$$f_{(\max)} = \frac{(100 + 18) \times 10^3}{2 \times 100 \times 10^{-12}(100 \times 10^3 \times 18 \times 10^3)} = 327\ \text{kHz}$$

(c) Given $f_{(\max)}$ = 50 kHz.

$$C = \frac{(R_1 + R_2)}{2f_{(\max)}R_1R_2} = \frac{(100 + 18) \times 10^3}{2 \times 50 \times 10^3 \times 100 \times 10^3 \times 18 \times 10^3)} = 655\ \text{pF}$$

Example 9.11: The self-bias transistor bistable multivibrator shown in Fig. 9.27(a) uses a ***n–p–n*** Ge transistor. Given that V_{CC} = 15 V, $V_{CE(sat)}$ = 0.1 V, V_σ = 0.3 V, R_C = 2kΩ, R_1 = 30 kΩ, R_2 = 10 kΩ, R_E = 500 Ω.

Find:

a) Stable-state currents and voltages and the h_{FE} needed to keep the ON device in saturation
b) The value of C_1 needed to ensure a resolution time of 0.02 ms.

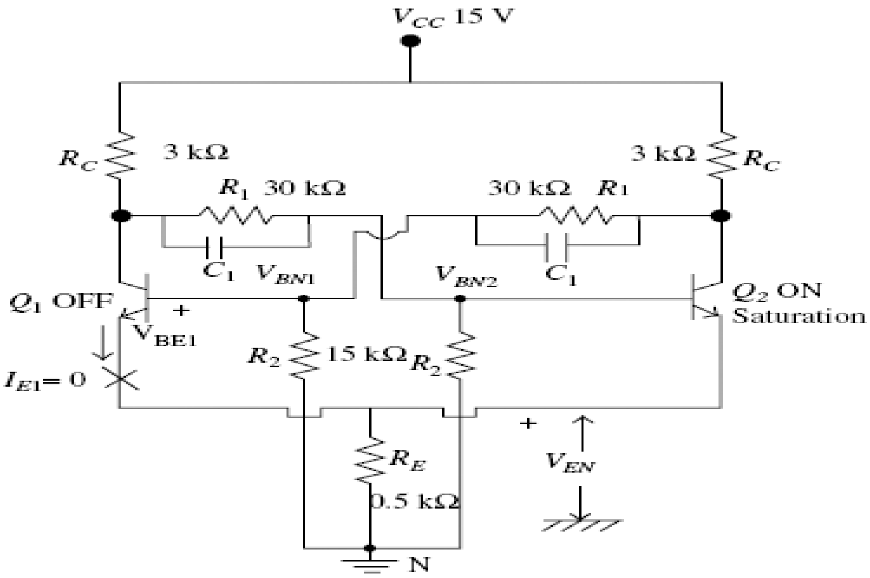

FIGURE 9.27(a) The self-bias bistable multivibrator

Solution: (a)

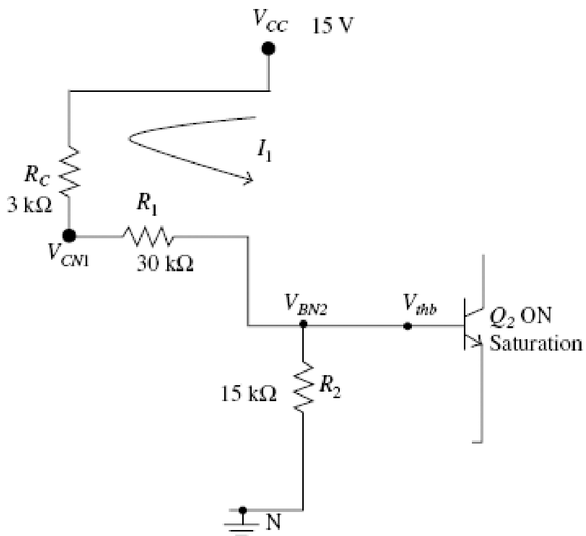

FIGURE 9.27(b) The circuit to calculate $\boldsymbol{V}_{\text{thb}}$ and $\boldsymbol{R}_{\text{thb}}$ of $\boldsymbol{Q}_2$

(i) To calculate $\boldsymbol{I}_{B2}$, consider the base circuit of $\boldsymbol{Q}_2$, shown in Fig. 9.27(b).

From Fig. 9.27(b),

$$V_{thb} = V_{CC}\frac{R_2}{R_C + R_1 + R_2} = \frac{15 \times 15}{3 + 30 + 15} = \frac{225}{48} = 4.69\ \text{V}$$

$$R_{\text{thb}} = R_2 \| (R_C + R_1) = \frac{15 \times (3 + 30)}{3 + 30 + 15} = \frac{495}{48} = 10.31\ \text{k}\Omega$$

(ii) To calculate $\boldsymbol{I}_{C2}$, consider the collector circuit of $\boldsymbol{Q}_2$, Fig. 9.27(c).

$$V_{thc} = V_{CC}\frac{R_1 + R_2}{R_C + R_1 + R_2} = \frac{15 \times (30 + 15)}{3 + 30 + 15} = \frac{675}{48} = 14.06\,\text{V}$$

$$R_{thc} = \mathrm{R_C} \parallel (R_1 + R_2) = \frac{3 \times 45}{48} = \frac{135}{48} = 2.81\,\text{k}\Omega$$

Now let us draw the base and collector circuits of Q_2, shown in Fig. 9.27(d).

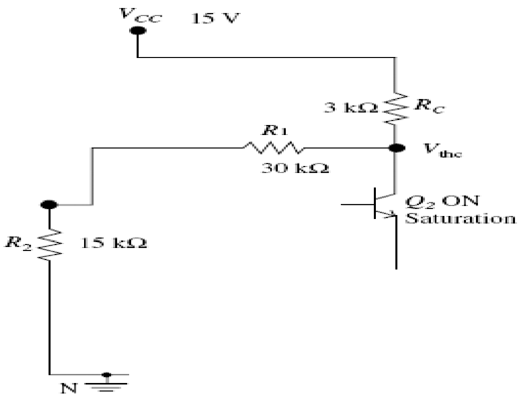

FIGURE 9.27(c) The circuit to calculate V_{thc} and R_{thc} of Q_2

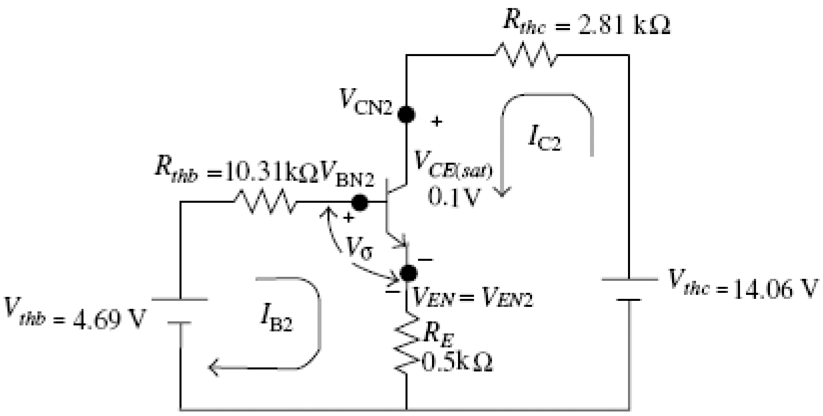

FIGURE 9.27(d) The circuit to calculate I_{B2} and I_{C2}

Writing the KVL equations of the input and output loops:

$$4.69 - 0.3 = (10.31 + 0.5)\,I_{B2} + 0.5\,I_{C2} \quad (1)$$

$$14.06 - 0.1 = 0.5I_{B2} + (2.81 + 0.5)\,I_{C2} \quad (2)$$

Eqs. (1) and (2) are simplified as:

$$4.39 = 10.81\,I_{B2} + 0.5\,I_{C2} \quad (3)$$

$$13.96 = 0.5I_{B2} + 3.31\,I_{C2} \quad (4)$$

Solving Eqs. (3) and (4) for I_{B2} and I_{C2} we get,

$I_{B2} = 0.212$ mA $I_{C2} = 4.18$ mA

Therefore, h_{FE} = 4.18/0.212 = 19.7.

The h_{FE} that keeps the ON device in saturation is 20.

$V_{EN2} = (I_{B2} + I_{C2})\, R_E = (4.18 + 0.212)\, 0.5 = 2.196$ V

$V_{CN2} = V_{EN2} + V_{CE(\text{sat})} = 2.196 + 0.1 = 2.296$ V

$V_{BN2} = V_{EN2} + V_\sigma = 2.196 + 0.3 = 2.496$ V

$$V_{BN1} = V_{CN2}\frac{R_2}{R_1 + R_2} = \frac{2.296 \times 15}{15 + 30} = \frac{2.296}{3} = 0.765\,\text{V}$$

$V_{BE1} = V_{BN1} - V_{EN2} = 0.765 - 2.196 = -1.431$ V

Hence, Q_1 is OFF.

Therefore, V_{CN1} should be V_{CC}, but actually it is less than V_{CC}.

We have from Fig. 9.27(b),

$$I_1 = \frac{V_{CC} - V_{BN2}}{R_C + R_1} = \frac{15 - 2.496}{3 + 30} = 0.379\,\text{mA}$$

$V_{CN1} = V_{CC} - I_1 R_C = 15 - (0.379)(3) = 13.86$ V

(b) $$t_{\text{res}} = \frac{2R_1 R_2 C_1}{(R_1 + R_2)}$$

$$0.02 \times 10^{-3} = \frac{2 \times 30 \times 10^3 \times 15 \times 10^3 C_1}{(15 + 30)10^3} \qquad C_1 = \frac{0.02 \times 10^{-3} \times 45 \times 10^3}{900 \times 10^6} = \frac{0.9}{900} \times 10^{-6} = 1\,\text{nF}$$

Example 9.12: Consider the Schmitt trigger circuit designed, shown in Fig. 9.28(a). R_{e2} is now included to eliminate hysteresis, as shown in Fig. 9.28(a). For this circuit V_1 = 8 V and V_2 = 4 V and h_{FE} = 40. Calculate R_{e2} such that $V_1 = V_2$ = 4 V.

Solution:

$$V' = \frac{V_{CC} R_2}{R_{C1} + R_1 + R_2} = \frac{18 \times 16}{4.5 + 10 + 16} = 9.44\,\text{V}$$

$$R' = R_2 // (R_{C1} + R_1) = \frac{16 \times 14.5}{30.5} = 7.60\,\text{k}\Omega.$$

From Eq. (9.79), we have:

$$(V' - V_{BE2})\frac{(1 + h_{FE})R_E}{R' + (1 + h_{FE})(R_{e2} + R_E)} + V_\gamma = V_2$$

$$(9.44 - 0.6)\frac{41 \times 1.5}{7.60 + (41)(R_{e2} + 1.5)} + 0.5 = 4\,\text{V}$$

$143.5R_{e2} = 301.81 \quad R_{e2} = 2.10\ k\Omega$

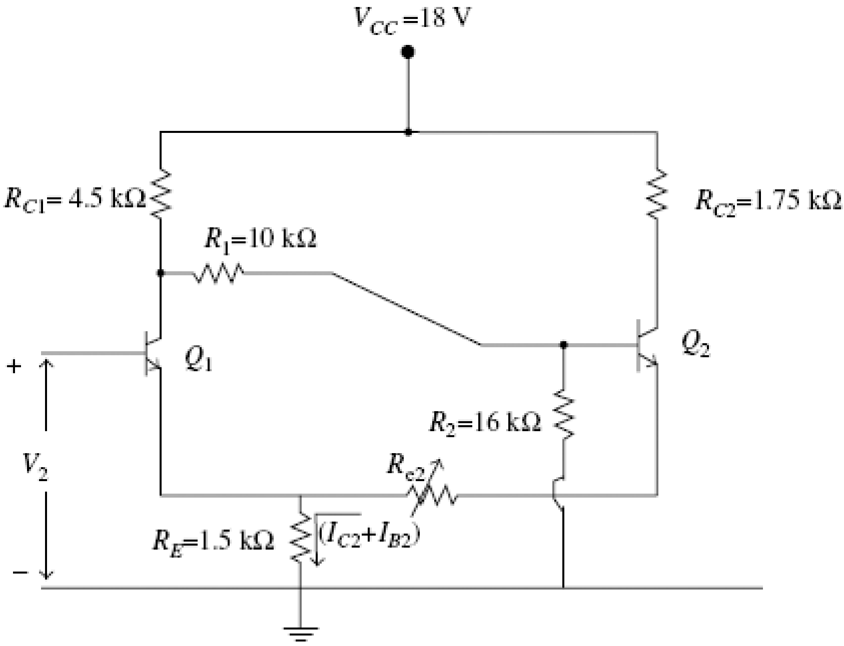

FIGURE 9.28(a) R_{e2} is connected to eliminate hysteresis

UNSOLVED PROBLEMS

1. Design a fixed-bias bistable multivibrator using Ge transistors having $h_{FE(\min)} = 50$, $V_{CC} = 10$ V and $V_{BB} = 10$ V, $V_{CE(\text{sat})} = 0.1$ V, $V_{BE(\text{sat})} = 0.3$ V, $I_{C(\text{sat})} = 5$ mA and assume $I_{B(\text{sat})} = 1.5I_{B(\min)}$.
2. For a fixed-bias bistable multivibrator shown in Fig. 9p.1 using ***n–p–n*** Ge transistor $V_{CC} = 10$ V, $R_C = 1$ kΩ, $R_1 = 10$ kΩ, $R_2 = 20$ kΩ, $h_{FE(min)} = 40$, $V_{BB} = 10$ V. Calculate: Stable-state currents and voltages assuming Q_1 is OFF and Q_2 is ON and in saturation. Verify whether Q_1 is OFF and Q_2 is ON or not.

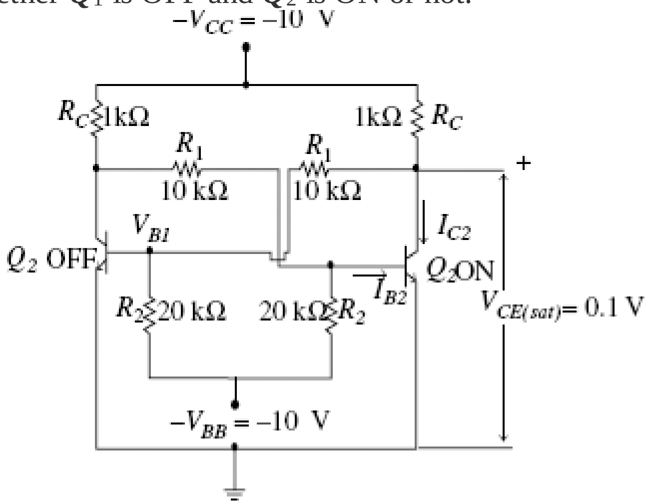

FIGURE 9p.1 The fixed-bias bistable multivibrator

3. Design a self-bias bistable multivibrator shown in Fig. 9p.2 with a supply voltage of −12 V. A ***p–n–p*** silicon transistor with $h_{FE(\min)} = 50$, $V_{CE(\text{sat})} = -0.3$ V, $V_{BE(\text{sat})} = -0.7$ V and $I_{C2} = -4$ mA is used.

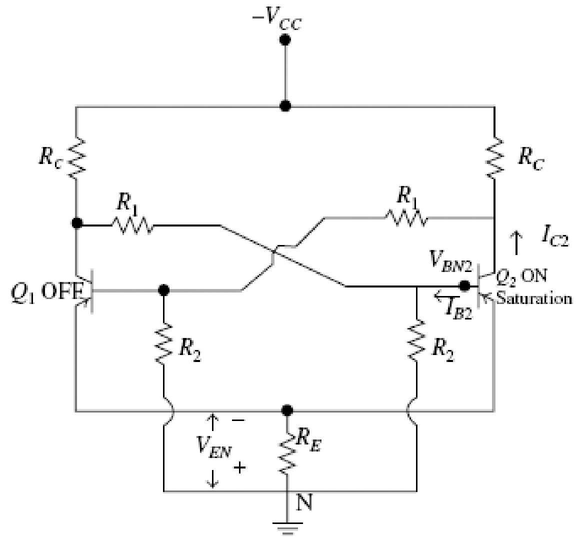

FIGURE 9p.2 The given self-bias bistable multivibrator

4. A self-bias bistable multivibrator uses Si transistors having $h_{FE(\min)} = 50$. $V_{CC} = 18$ V, $R_1 = R_2$, $I_{C(\text{sat})} = 5$ mA. Fix the component values R_E, R_C, R_1 and R_2.

5. For the Schmitt trigger in Fig 9p.4 using ***n–p–n*** silicon transistors having $h_{FE(\min)} = 40$, the following are the circuit parameters: $V_{CC} = 15$ V, $R_S = 0$, $R_{C1} = 4\text{k}\Omega$, $R_{C2} = 1\text{k}\Omega$, $R_1 = 3\text{k}\Omega$, $R_2 = 10$ kΩ and $R_E = 6\text{k}\Omega$. Calculate V_1 and V_2.

6. The self-bias transistor bistable multivibrator shown in Fig. 9p.3 uses ***n–p–n*** Si transistors. Given that $V_{CC} = 15$ V, $V_{CE(\text{sat})} = 0.2$ V, $V_\sigma = 0.7$ V, $R_C = 3\text{k}\Omega$, $R_1 = 20$ kΩ, $R_2 = 10$ kΩ, $R_E = 500\ \Omega$.

Find:

a) Stable-state currents and voltages and the h_{FE} needed to keep the ON device in saturation.

b) $f_{(max)}$, if $C_1 = 100$ pF.

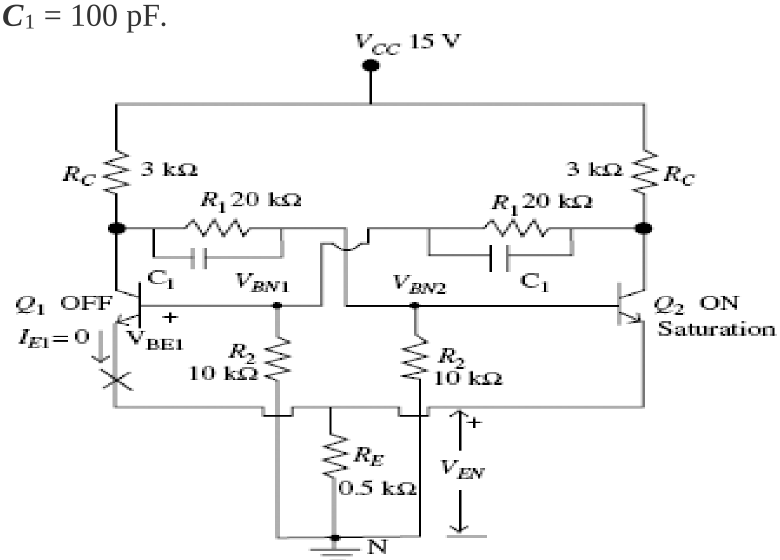

FIGURE 9p.3 The given self-bias bistable multivibrator

7. Design a Schmitt trigger shown in Fig. 9p.4 with UTP of 8 V and LPT of 4 V. Si transistors with $\boldsymbol{h_{FE}}$ = 40 and $\boldsymbol{I_C}$ = 5 mA are used. The supply voltage is 18 V. The ON transistor is in the active region for which $\boldsymbol{V_{BE}}$ = 0.6 V, $\boldsymbol{V_{CE}}$ = 2.0 V. (b) Calculate $\boldsymbol{R_{e1}}$ for eliminating hysteresis.

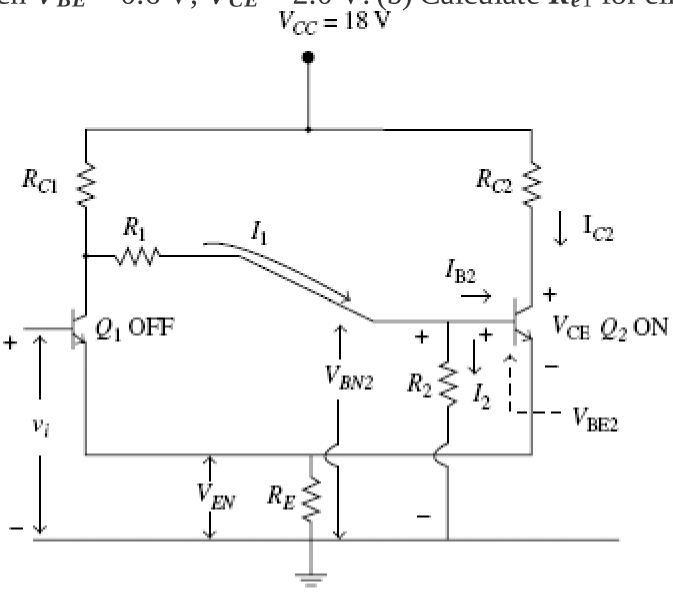

FIGURE 9p.4 The Schmitt trigger circuit

8. Design a Schmitt trigger in Fig. 9p.5 with UTP of 8 V and LTP of 4 V. Si transistors with $\boldsymbol{h_{FE}}$ = 40 and $\boldsymbol{I_C}$ = 4 mA are used. The supply voltage is 12 V. The ON transistor is in saturation for which $\boldsymbol{V_{BE}}$ = 0.7 V, $\boldsymbol{V_{CE(\text{sat})}}$ = 0.2 V.

a) Calculate $\boldsymbol{R_{e1}}$ for eliminating hysteresis.
b) Find $\boldsymbol{R_{e2}}$ to eliminate hysteresis.

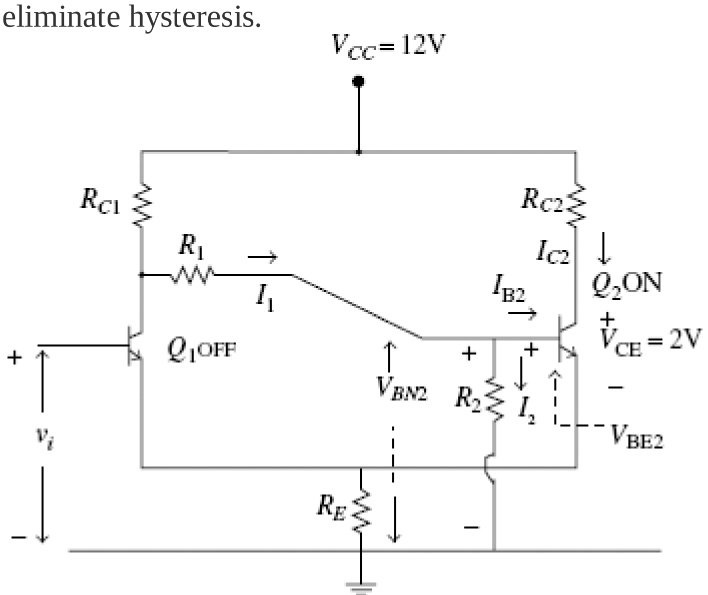

FIGURE 9p.5 The given Schmitt trigger circuit