Chapter 9
Bistable Multivibrators

1. Design a fixed-bias bistable multivibrator using Ge transistors having $h_{FE(\text{min})} = 50$, $V_{CC} = 10$ V and $V_{BB} = 10$ V, $V_{\text{CE(sat)}} = 0.1$ V, $V_{\text{BE(sat)}} = 0.3$ V, $I_{\text{C(sat)}} = 5$ mA and assume $I_{\text{B(sat)}} = 1.5 I_{\text{B(min)}}$.

Solution:

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

$$= 1.98\text{ k}\Omega$$

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

$$\text{Choose } I_2 \approx \frac{1}{10} I_{C2}$$

$$= 0.5\text{ mA}$$

$$\therefore R_2 = \frac{0.3 + 10}{0.5} = \frac{10.3\text{ V}}{0.5\text{ mA}} = 20.6\text{ k}\Omega$$

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

If Q_2 is in saturation

$$I_{B2} = 1.5 I_{B2\min}$$

$$= 0.15\text{ mA}$$

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

$$= 0.5\text{ mA} + 0.15\text{ mA} = 0.65\text{ mA}$$

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

$$R_1 = (R_C + R_1) - R_C$$

$$= 14.92 - 1.98 = 12.94\text{ k}\Omega.$$

---

2. For a fixed-bias bistable multivibrator shown in Fig. 9p.2 using *n–p–n* Ge transistor $V_{CC} = 10$ V, $R_C = 1$ kΩ, $R_1 = 10$ kΩ, $R_2 = 20$ kΩ, $h_{\text{FE(min)}} = 40$, $V_{BB} = 10$ V. Calculate: (a) 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. (b) the maximum load current.

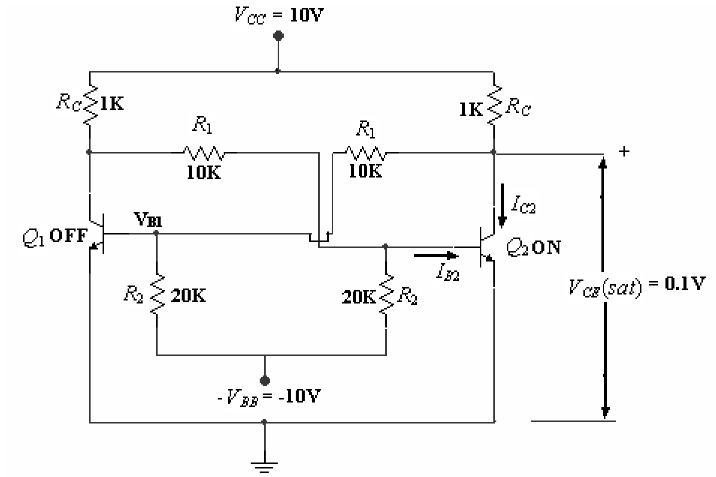

Fig. 9p.2 The fixed-bias bistable multivibrator

Solution:

Assume $V_{CE(\text{sat})} = 0.1$ V, $V_{BE(\text{sat})} = 0.3$ V

Calculate V_{B1} to verify whether Q_1 is OFF or not.

$$V_{B1} = V_{CE(\text{sat})}\frac{R_2}{R_1+R_2} + (-V_{BB})\frac{R_1}{R_1+R_2} = \frac{0.1\times 20}{10+20} + \frac{(-10)10}{10+20}$$

$= 0.066 - 3.333 = -3.267$ V

Hence Q_1 is OFF

$\therefore V_{C1} = V_{CC} = 10$ V

To verify whether Q_2 is in saturation or not:

Calculate I_{B2}, I_{C2}

To calculate I_{B2}.

Consider the cross-coupling circuit shown in Fig.2.1.

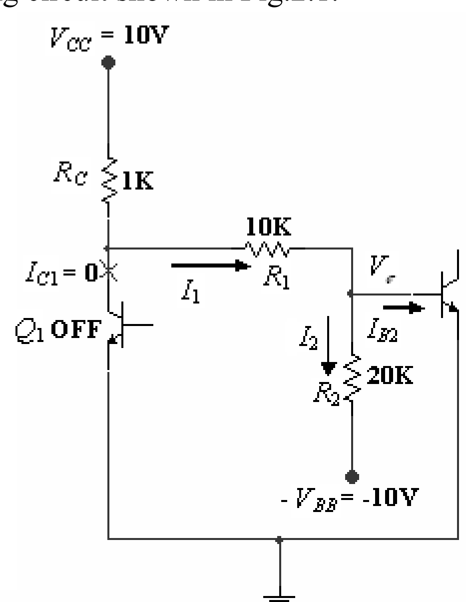

Fig. 2.1 Circuit to calculate the base current of Q_2

$$I_1 = \frac{V_{CC} - V_\sigma}{R_C + R_1} = \frac{10 - 0.3}{1 + 10} = \frac{9.7\text{ V}}{11\text{ k}\Omega} = 0.88\text{ mA}$$

$$I_2 = \frac{V_\sigma + V_{BB}}{R_2} = \frac{0.3 + 10}{20} = \frac{10.3}{20} = 0.515\text{ mA}$$

$$I_{B2} = 0.88 - 0.51$$

$$= 0.37\text{ mA}$$

To calculate I_{C2}

Consider the cross-coupling network shown in Fig. 2.2.

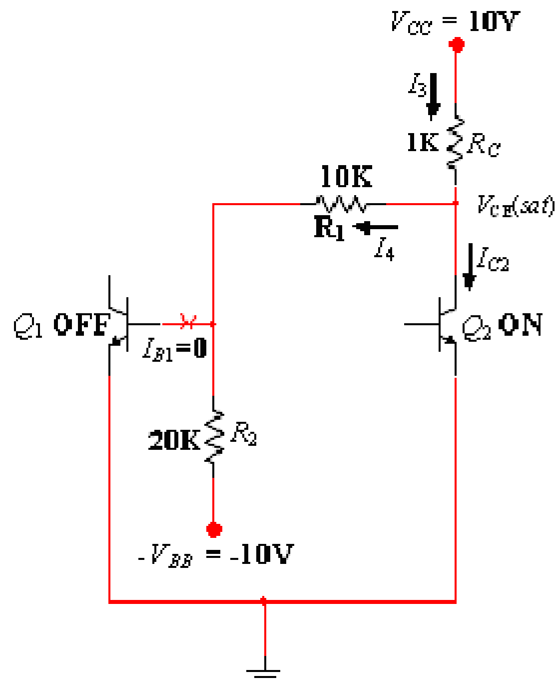

Fig. 2.2 Circuit to calculate the collector current of Q_2

$$I_3 = \frac{V_{CC} - V_{CE(\text{sat})}}{R_C}$$

$$= \frac{10 - 0.1}{1\text{ K}} = 9.9\text{ mA}$$

$$I_4 = \frac{V_{CE(\text{sat})} + V_{BB}}{R_1 + R_2}$$

$$= \frac{10.1}{30\text{ K}} = 0.336\text{ mA}$$

$$I_{C2} = I_3 - I_4$$

$$= 9.9 - 0.34 = 9.56\text{ mA}$$

$$I_{B2\min} = \frac{I_{C2}}{h_{FE\min}} = \frac{9.56\text{ mA}}{40} = 0.24\text{ mA}$$

$$I_{B2} >> I_{B2\min}$$

Hence Q_2 is verified to be in saturation.

$\therefore V_{C2} = 0.1\text{ V},\ V_{B2} = 0.3\text{ V}$.

$V_{C1} = V_{CC} - I_1 R_C$

$= 10 - (0.88)1$

$= 9.12\text{ V}$

Hence the stable-state currents and voltages are as follows:
$V_{C1} = 9.12\text{ V}$, $V_{B1} = -3.267\text{ V}$
$V_{C2} = 0.1\text{ V}$ $I_{B2} = 0.37\text{ mA}$, $I_{C2} = 9.56\text{ mA}$

To find the maximum load current or minimum load resistance, consider Fig.2.3.

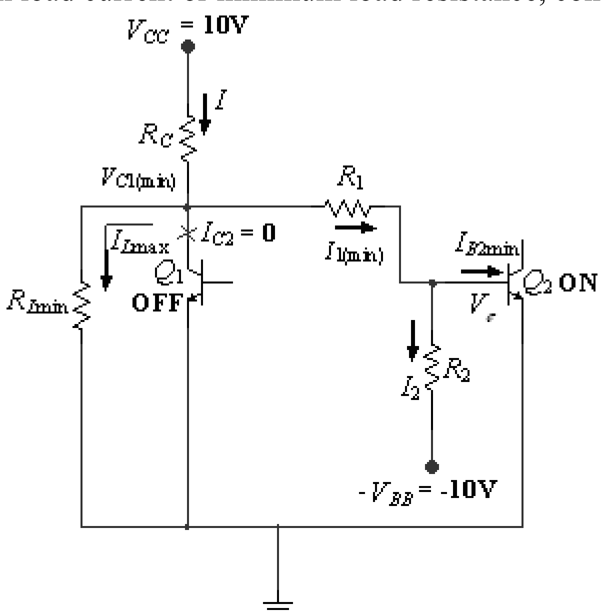

Fig. 2.3 Circuit to calculate maximum load current

I_L is maximum ($I_{L(max)}$) when I_{B2} is $I_{B2(min)}$

$I_{B2(\min)} = 0.2$ mA

$I_2 = 0.51$ mA

$I_{1(\min)} = I_2 + I_{B2(\min)}$

$= 0.51 + 0.24$

$= 0.75$ mA

$V_{C1(\min)} = I_{1(\min)} R_1 + V_\sigma$

$= 0.75 \times 10 + 0.3$

$= 7.8$ V

$$I = \frac{V_{CC} - V_{C1(\min)}}{R_C} = \frac{12 - 7.8}{1} = 4.2 \text{ mA}$$

$I_{L\max} = I - I_{1(\min)} = 4.2 \text{ mA} - 0.75 \text{ mA}$

$= 3.45$ mA

$$R_{L(\min)} = \frac{7.8 \text{ V}}{3.45 \text{ mA}} = 2.26 \text{ k}\Omega.$$

---

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

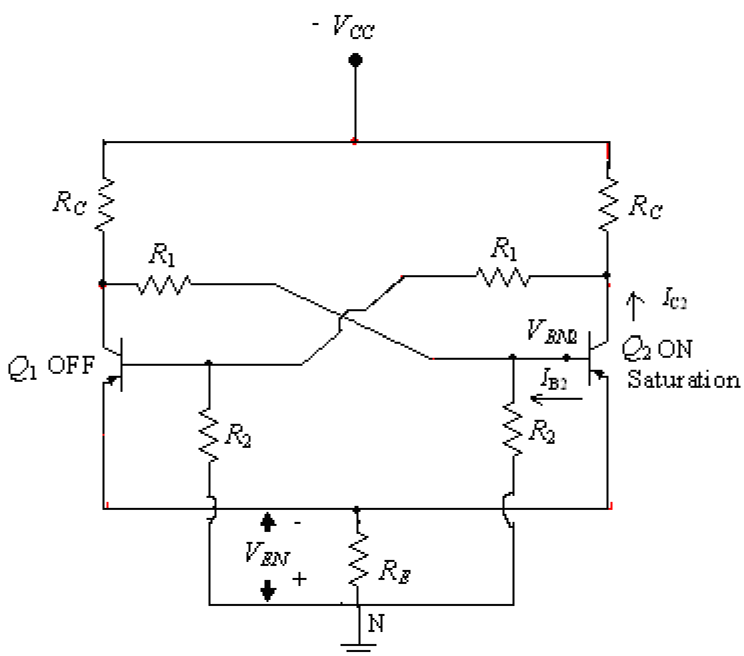

Fig. 9p.2 Self-bias bistable multivibrator

Solution:

Assume $V_{EN} = \frac{1}{3} V_{CC} = \frac{1}{3} \times -12 = -4$ V

$I_{C2} = -4$ mA

$$I_{B2(\min)} = \frac{-4\ \text{mA}}{50} = -0.08\ \text{mA}$$

Choose $I_{B2} = 1.5 I_{B2(\min)} = -0.12$ mA
$(I_{C2}+I_{B2}) = -4 - 0.12 = -6.12$ mA

$$R_E = \frac{V_{EN2}}{I_{C2}+I_{B2}} = \frac{-4\ \text{V}}{-4.12\ \text{mA}} = 0.97\ \text{k}\Omega$$

$$R_C = \frac{V_{CC} - V_{CE}(\text{sat}) - V_{EN2}}{I_C}$$

$$= \frac{-12+0.3+4}{-4\ \text{mA}} = \frac{-7.7\ \text{V}}{-4\ \text{mA}} = 1.925\ \text{k}\Omega$$

Let $I_2 = \frac{1}{10} I_{C2} = \frac{1}{10} \times -4\ \text{mA} = -0.4\ \text{mA}$

$$V_{BN2} = V_{EN2} + V_\sigma = -4 - 0.7 = -4.7\ \text{V}$$

$$R_2 = \frac{V_{BN2}}{I_2} = \frac{-4.7\ \text{V}}{-0.4\ \text{mA}} = 11.75\ \text{k}\Omega$$

Choose $R_2 = 12$ kΩ
Find I_2 for this R_2

$$I_2 = \frac{V_{BN2}}{R_2} = \frac{-4.7\ \text{V}}{12.0\ \text{K}} = -0.392\ \text{mA}$$

$$R_C + R_1 = \frac{V_{CC} - V_{BN2}}{I_2 + I_{B2}}$$

$$= \frac{-12+4.7}{-0.392-0.12} = \frac{-7.3\ \text{V}}{-0.512\ \text{mA}} = 14.26\ \text{k}\Omega$$

$$(R_C + R_1) = 14.26\ \text{k}\Omega$$

$$R_1 = (R_C + R_1) - R_C = 14.26 - 1.925 = 12.33\ \text{k}\Omega$$

Choose R_1=12 kΩ
Note: Choose the nearest standard values.

---

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.

Solution:

Assume $V_{EN} = \frac{1}{3} V_{CC} = \frac{1}{3} \times 18 = 6$ V
and $I_{C(\text{sat})} = 5$ mA

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

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

$(I_{C2}+I_{B2}) = 5 + 0.15 = 5.15$ mA

$$R_E = \frac{V_{EN2}}{I_{C2}+I_{B2}} = \frac{6\text{ V}}{5.15\text{ mA}} = 1.16\text{ k}\Omega$$

$$R_C = \frac{V_{CC} - V_{CE(\text{sat})} - V_{EN2}}{I_C}$$

$$= \frac{18 - 0.3 - 6}{5\text{ mA}} = \frac{11.7\text{ V}}{5\text{ mA}} = 2.34\text{ k}\Omega$$

$$V_{BN2} = V_{EN2} + V_\sigma = 6 + 0.7 = 6.7\text{ V}$$

$$R_C + R_1 = \frac{V_{CC} - V_{BN2}}{I_2 + I_{B2}}$$

$$R_C + R_1 = \frac{V_{CC} - V_{BN2}}{\frac{VBN_2}{R_2} + I_{B2}} = \frac{R_1(V_{CC} - V_{BN2})}{VBN_2 + R_1 I_{B2}}$$

$$2.34 + R_1 = \frac{R_1(18 - 6.7)}{6.7 + 0.15R_1} = \frac{11.3R_1}{6.7 + 0.15R_1}$$

$$0.15R_1^2 - 4.25R_1 + 15.67 = 0$$

$$R_1 = 4.25 \pm \frac{\sqrt{(-4.25)^2 - 4\times 0.15\times 15.67}}{2\times 0.15}$$

$$R_1 = R_2 = 14\text{ k}\Omega\ .$$

---

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

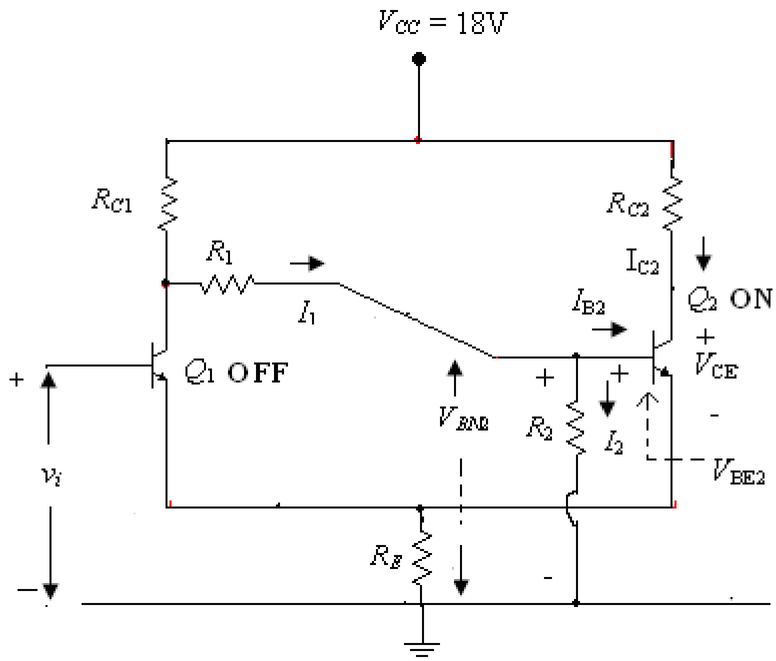

Fig. 9p.4 The Schmitt trigger circuit

Solution:

From the given data, if Q_2 is in the active region, typically, V_{BE2} = 0.6 V and let h_{FE} = 40.

To calculate V_1:

$R_E(1+h_{FE}) = 6(1+40) = 246\ \text{k}\Omega$

$$R' = R_2 // (R_{C1} + R_1) = 10\ \text{k}\Omega // (4\ \text{k}\Omega + 3\ \text{k}\Omega) = 4.11\ \text{k}\Omega$$

$$V' = V_{CC} \times \frac{R_2}{(R_{C1} + R_1 + R_2)} = 15 \times \frac{10}{4+3+10} = 8.82\ \text{V}$$

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

$$\therefore V_{EN2} = (8.82 - 0.6) \times \frac{246}{4.11 + 246} = 8.08\ \text{V}$$

$$\therefore V_1 = V_{EN2} + V_{\gamma_1} = 8.08 + 0.5 = 8.58\ \text{V}$$

To calculate V_2:

$$\alpha = \frac{R_2}{R_1 + R_2} = \frac{10}{3+10} = 0.769$$

$$R_t = \frac{R_{C1}(R_1 + R_2)}{R_{C1} + R_1 + R_2}$$

$$R_t = \frac{4(3+10)}{4+3+10} = 3.05\ \text{k}\Omega$$

$$\alpha R_t = 0.769 \times 3.05 = 2.35\ \text{k}\Omega$$

$$R_E^{"} = (1 + \frac{1}{h_{FE}})R_E = \frac{41 \times 6}{40} = 6.15\ \text{k}\Omega$$

$$\alpha V_t = V^{'} = V_{CC} \times \frac{R_2}{(R_{C1} + R_1 + R_2)} = 15 \times \frac{10}{4 + 3 + 10} = 8.82\ \text{V}$$

$$I_{C1} = \frac{(V^{'} - V_{\gamma 2})}{\alpha R_t + R_E^{"}} = \frac{(8.82 - 0.5)}{2.35 + 6.15} = 0.978\ \text{mA}$$

$$V_2 = V_{BE1} + I_{C1} R_E^{"}$$

$$\therefore V_2 = 0.6\ \text{V} + (0.978\ \text{mA})(6.15\ \text{k}\Omega)$$

$$= 0.6\ \text{V} + 6.01\ \text{V} = 6.61\ \text{V}$$

Hence for the given Schmitt trigger

$V_1 = 8.58$ V

$V_2 = 6.61$ V

---

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

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

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

(iii) The maximum value of I_{CBO} that will still ensure one device is OFF and the other is ON.

(iv) The maximum temperature up to which the multivibrator can work normally if I_{CBO} at 25°C = 20 μA.

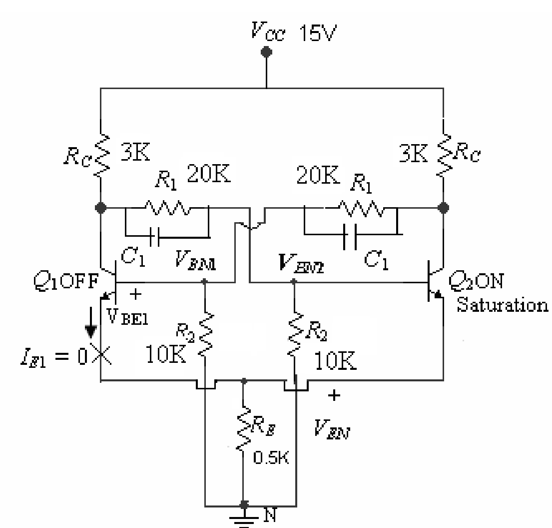

Fig. 9p.3 The given self-bias bistable multivibrator

Solution:

(i) To calculate I_{B2}, consider the base circuit of Q_2, Fig. 6.1.

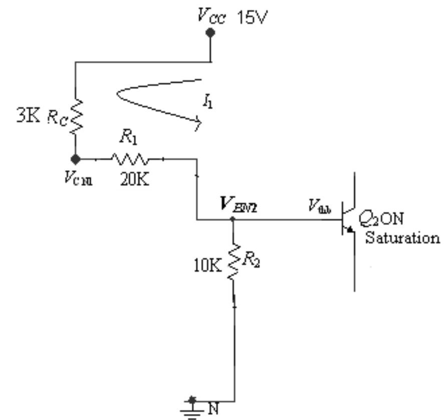

Fig.6.1. Circuit to calculate V_{thb} and R_{thb} of Q_2.

From Fig. 6.1,

$$V_{thb} = V_{CC} \times \frac{R_2}{R_C + R_1 + R_2} = \frac{15 \times 10}{3 + 20 + 10} = \frac{150}{33} = 4.54$$

V

$$R_{thb} = R_2 \| (R_C + R_1) = \frac{10 \times (3 + 20)}{3 + 20 + 10} = \frac{230}{33} = 6.96\,\text{k}\Omega$$

(ii) To calculate I_{C2}, consider the collector circuit of Q_2, Fig. 6.2.

.

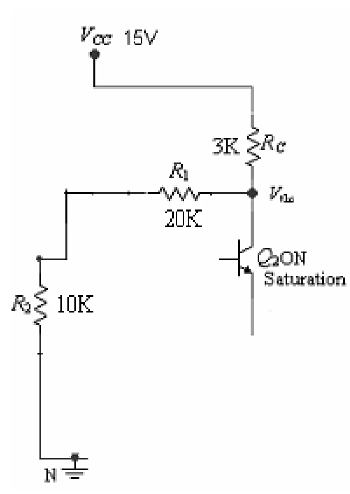

Fig. 6.2. Circuit to calculate V_{thc} and R_{thc} of Q_2

$$V_{thc} = V_{CC} \times \frac{R_1 + R_2}{R_C + R_1 + R_2} = \frac{15 \times (20 + 10)}{3 + 20 + 10} = \frac{450}{33} = 13.6 \text{ V}$$

$$R_{thc} = R_C \| (R_1 + R_2) = \frac{3 \times 30}{33} = \frac{90}{33} = 2.72\,\text{k}\Omega$$

Now let us draw the base and collector circuits of Q_2, Fig. 6.3.

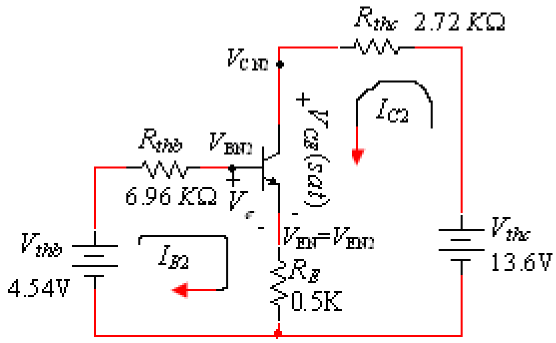

Fig. 6.3. Circuit to calculate I_{B2} and I_{C2}

Writing the KVL equations of the input and output loops

$$4.54 - 0.7 = (6.96+0.5)\, I_{B2} + 0.5 I_{C2} \quad \textbf{(1)}$$

$$13.6 - 0.2 = 0.5 I_{B2} + (2.72+0.5)\, I_{C2} \quad \textbf{(2)}$$

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

$$3.84 = 7.46 I_{B2} + 0.5 I_{C2} \quad \textbf{(3)}$$

$$13.4 = 0.5 I_{B2} + 3.22 I_{C2} \quad \textbf{(4)}$$

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

$$I_{B2} = 0.263 \text{ mA}$$

$$I_{C2} = 3.75 \text{ mA}$$

$$h_{FE} = \frac{3.75}{0.263} = 14.25$$

The h_{FE} that keeps the ON device in saturation is 14.25.

$$V_{EN2} = (I_{B2} + I_{C2}) R_E = (0.263+3.75)0.5 = 2 \text{ V}$$

$$V_{CN2} = V_{EN2} + V_{CE(\text{sat})} = 2 + 0.2 = 2.2 \text{ V}$$

$$V_{BN2} = V_{EN2} + V_{\sigma} = 2 + 0.7 = 2.7 \text{ V.}$$

$$V_{BN1} = V_{CN2} \times \frac{R_2}{R_1 + R_2} = \frac{2.2 \times 10}{20+10} = \frac{22}{30} = 0.733 \text{ V}$$

$$V_{BE1} = V_{BN1} - V_{EN2} = 0.733 - 2 = -1.26 \text{ V}$$

Hence Q_1 is OFF

$\therefore V_{CN1}$ should be V_{CC}. But actually it is less than V_{CC}.

$$I_1 = \frac{V_{CC} - V_{BN2}}{R_C + R_1} = \frac{15 - 2.7}{3 + 20} = 0.534 \text{ mA.}$$

$$V_{CN1} = V_{CC} - I_1 R_C = 15 - (0.534)(3) = 13.4 \text{ V.}$$

$$f_{\max} = \frac{R_1 + R_2}{2 R_1 R_2 C_1} = \frac{(20+10)10^3}{2 \times 20 \times 10^3 \times 10 \times 10^3 \times 100 \times 10^{-12}} = 750 \text{ kHz}$$

(iii) V_{BE1} was calculated as –1.26 V. This voltage exists at the base of Q_1 to keep Q_1 OFF. Till such time the voltage at B_1 of Q_1 is 0 V, let us assume that Q_1 is OFF, Fig. 6.4.To calculate R_B and hence $I_{CBO} R_B$, short V_{EN} (though $I_{E1} = 0$, there exists a voltage V_{EN} at the first emitter) and $V_{CE(sat)}$ sources. From Fig. 6.4, it is seen that R_B is the parallel combination of R_2 and (R_1+R_E).

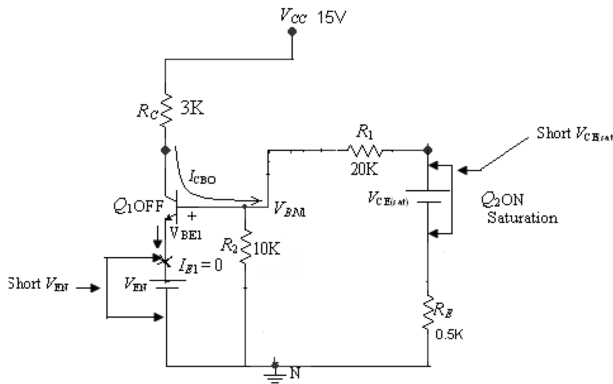

Fig. 6.4. Circuit to calculate $I_{CBO}R_B$

$$R_B = R_2 \| (R_1 + R_E) = \frac{10 \times 20.5}{10 + 20.5} = 6.72 \text{ k}\Omega$$

Until $I_{CBo(max)} R_B = V_{BE1}$, Q_1 will be OFF.

$$\therefore I_{CBo(\max)} = \frac{1.26 \text{ V}}{6.72 \text{ k}\Omega} = 0.187 \text{ mA} = 187 \ \mu\text{A}$$

(iv) I_{CBo} at 25°C = 20 μA

$$\frac{I_{CBo(\max)}}{I_{CB0}} = \frac{187}{20} = 9.35$$

$$9.35 = 2^n$$

$$n = \frac{\log 9.35}{\log 2} = \frac{0.97}{0.3} = 3.23$$

$$\frac{\Delta T}{10} = n$$

$$\frac{T_2 - 25}{10} = 3.23$$

$$T_2 = 25 + 32.3 = 57.3°\text{C}$$

---

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

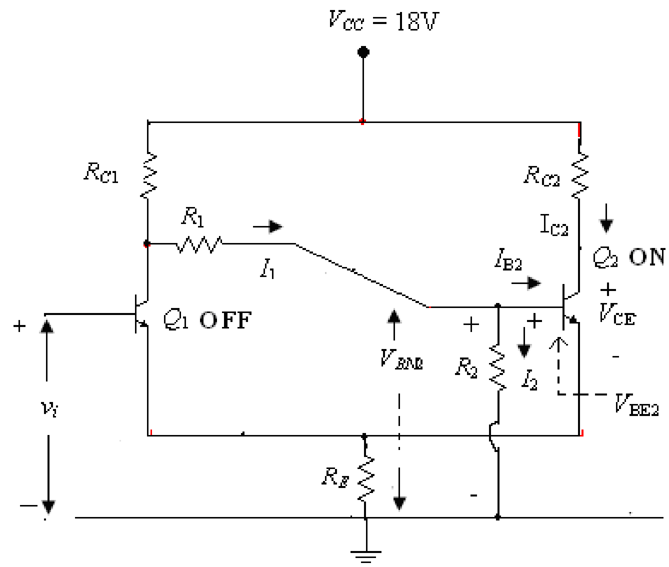

Fig. 9p.4 The Schmitt trigger circuit

Solution:

Till UTP is reached Q_1 is OFF and Q_2 is ON and in active region. Just at V_1(UTP) Q_1 goes ON and Q_2 goes OFF. Just prior to this, Q_2 is ON and Q_1 is OFF, Fig. 7.1.

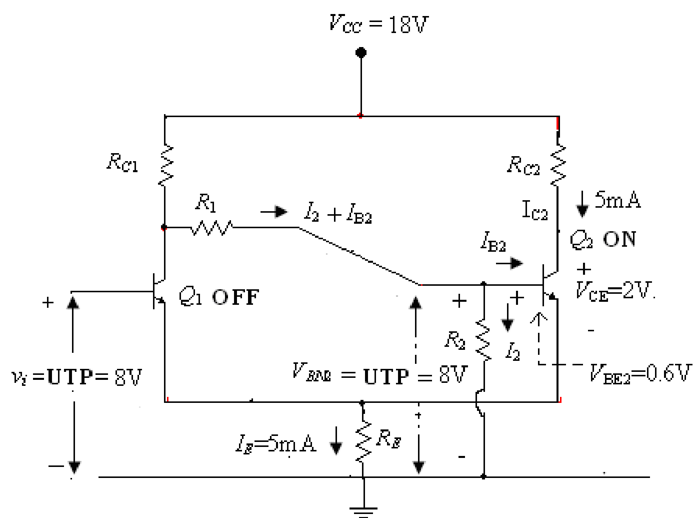

Fig. 7.1 Circuit when Q_1 is OFF and Q_2 is ON

$$V_1 = \text{UTP} = V_{BN2} = 8 \text{ V}$$
$$I_E = I_{C2} = 5 \text{ mA}$$
$$V_{EN} = V_{EN2} = V_{BN2} - V_{BE2}$$
$$V_{EN2} = 8 - 0.6 = 7.4 \text{ V.}$$
$$R_E = \frac{V_{EN2}}{I_E} = \frac{7.4}{5 \text{ mA}}$$

$$= 1.48\ \text{k}\Omega$$

Choose $R_E = 1.5\ \text{k}\Omega$

If Q_2 is in the active region and $V_{CE} = 2$ V

$I_{C2}R_{C2} = V_{CC} - V_{CE} - V_{EN2}$

$$\therefore R_{C2} = \frac{18 - 2.0 - 7.4}{5} = \frac{8.6\ \text{V}}{5\ \text{mA}} = 1.72\ \text{k}\Omega$$

Choose $R_{C2} = 1.75\ \text{k}\Omega$

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

$$R_2 = \frac{V_{BN2}}{I_2} = \frac{8\ \text{V}}{0.5\ \text{mA}} = 16\ \text{k}\Omega$$

$$I_{B2\min} = \frac{I_{C2}}{h_{FE}} = \frac{5\ \text{mA}}{40} = 0.125\ \text{mA}$$

$$I_{B2} = 1.5 \times I_{B2\min} = 1.5 \times 0.125 = 0.1875\ \text{mA}$$

$$I_{B2} + I_2 = 0.1875\ \text{mA} + 0.5\ \text{mA} = 0.6875\ \text{mA}$$

$$(R_{C1} + R_1) = \frac{V_{CC} - V_{BN2}}{(I_{B2} + I_2)} = \frac{18 - 8}{0.6875} = \frac{10}{0.6875} = 14.55\ \text{k}\Omega$$

$$R_1 = 14.55\ \text{k}\Omega - R_{C1}$$

At LTP = 4 V, consider the Fig. 7.2.

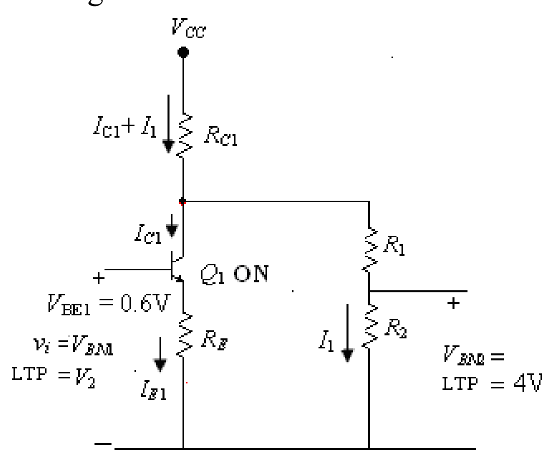

Fig. 7.2 Circuit at LTP

$$V_{BN2} = V_{BN1} = 4\ \text{V} = \text{LTP} = V_2$$

Let I_1 be the current in R_2

$$I_1 = \frac{V_{BN2}}{R_2} = \frac{4\ \text{V}}{16\ \text{k}\Omega} = 0.25\ \text{mA}$$

$$I_{C1} = I_{E1} = \frac{V_2 - V_{BE1}}{R_E} = \frac{4 - 0.6}{1.5\ \text{k}\Omega}$$

$$I_{C1} = 2.27 \text{ mA}$$

Writing the KVL equation of the outer loop consisting of R_{C1}, R_2 and R_1,

$$V_{CC} = (I_{C1}+I_1)R_{C1}+I_1(R_1+R_2) = (I_{C1}+I_1)R_{C1}+I_1(14.55\text{ k}\Omega - R_{C1}+R_2)$$

$$V_{CC} = I_{C1}R_{C1}+I_1(14.55\text{ k}\Omega+R_2)$$

$$R_{C1} = \frac{V_{CC} - I_1(14.55+R_2)}{I_{C1}}$$

$$= \frac{18-0.25(14.55+16)}{2.27} = \frac{10.36}{2.27} = 4.56\text{ k}\Omega$$

$$R_{C1} = 4.56\text{ k}\Omega$$

$$R_1 = (R_{C1} - R_1) - R_{C1} = 14.55 - 4.56 = 9.99\text{ k}\Omega$$

Choose $R_1 = 10\text{ k}\Omega$ and $R_{C1} = 4.5\text{ k}\Omega$.

The designed Schmitt trigger circuit is shown in Fig. 7.3 with component values.

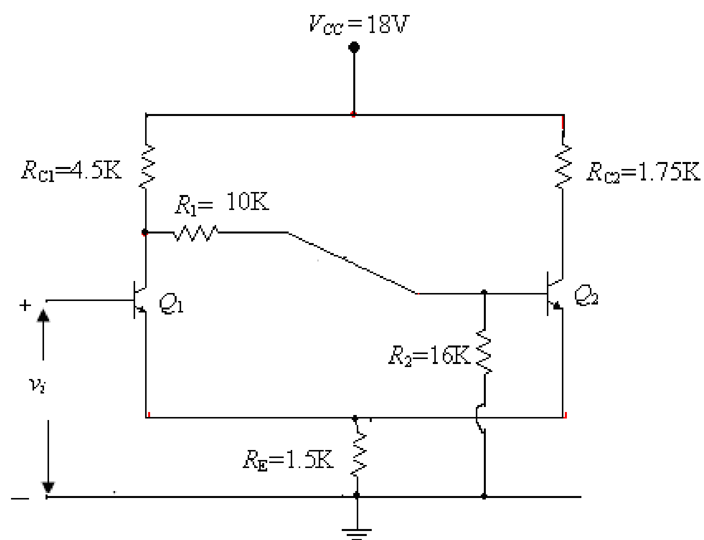

Fig. 7.3 Designed Schmitt trigger

(b) To eliminate hysteresis R_{e1} is added in series with the emitter of Q_1, Fig. 7.4, such that $V_1 - V_2 = V_H = (I_{C1}+I_{B1})R_{e1}$

$$R_{e1} = \frac{4\text{ V}}{2.27\text{ mA}} = 1.76\text{ k}\Omega$$

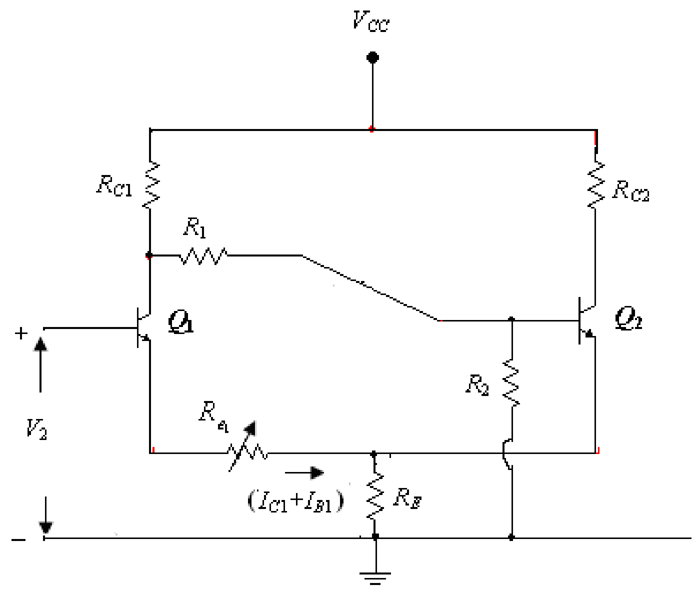

Fig. 7.4 R_{e1} connected to eliminate hysteresis

8. (i) Design a Schmitt trigger in Fig.9p.5 with UTP of 8 V and LTP of 4 V. Si transistors with h_{FE} = 40 and I_C = 4 mA are used. The supply voltage is 12 V. The ON transistor is in saturation for which V_{BE} = 0.7 V, $V_{CE(sat)}$ = 0.2 V. (ii) Calculate R_{e1} for eliminating hysteresis. (iii) Find R_{e2} to eliminate hysteresis.

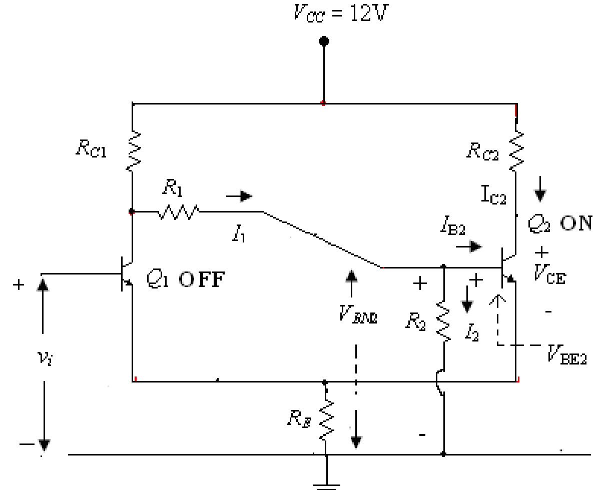

Fig. 9p.5 The given Schmitt trigger circuit

Solution:

(i) Till UTP is reached, Q_1 is OFF and Q_2 is ON and in saturation region. Just at V_1(UTP) Q_1 goes ON and Q_2 goes OFF. Just prior to this, Q_2 is ON and Q_1 is OFF, Fig. 8.1.

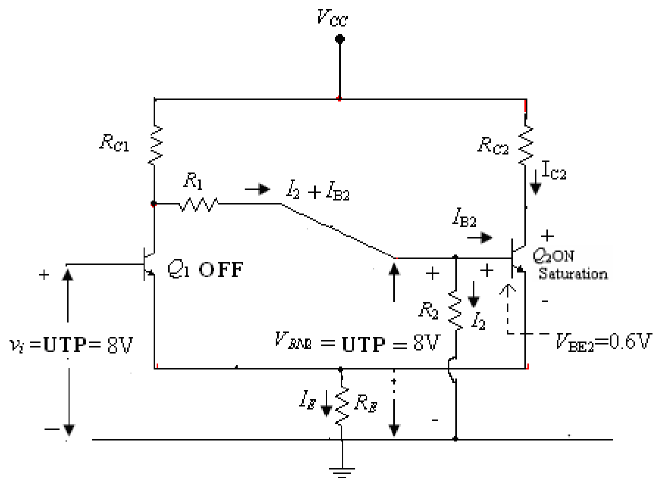

Fig. 8.1 Circuit when Q_1 is OFF and Q_2 is ON

$$V_1 = \text{UTP} = V_{BN2} = 8 \text{ V}$$

$$I_E = I_{C2} = 4 \text{ mA}$$

$$V_{EN} = V_{EN2} = V_{BN2} - V_{BE2}$$

$$V_{EN2} = 8 - 0.7 = 7.3 \text{ V.}$$

$$R_E = \frac{V_{EN2}}{I_E} = \frac{7.3}{4 \text{ mA}} = 1.825 \text{ k}\Omega$$

If Q_2 is in the saturation region and $V_{CE} = 0.2$ V

$$I_{C2}R_{C2} = V_{CC} - V_{CE} - V_{EN2}$$

$$\therefore R_{C2} = \frac{12 - 0.2 - 7.3}{4} = \frac{4.5 \text{ V}}{4 \text{ mA}} = 1.125 \text{ k}\Omega$$

$$I_2 = \frac{1}{10} I_{C2} = 0.4 \text{ mA}$$

$$R_2 = \frac{V_{BN2}}{I_2} = \frac{8 \text{ V}}{0.4 \text{ mA}} = 20 \text{ k}\Omega$$

$$I_{B2\min} = \frac{I_{C2}}{h_{FE}} = \frac{4 \text{ mA}}{40} = 0.1 \text{ mA}$$

$$I_{B2} = 1.5 \times I_{B2\min} = 1.5 \times 0.1 = 0.15 \text{ mA}$$

$$I_{B2} + I_2 = 0.15 \text{ mA} + 0.4 \text{ mA} = 0.55 \text{ mA}$$

$$(R_{C1} + R_1) = \frac{V_{CC} - V_{BN2}}{(I_{B2} + I_2)} = \frac{12 - 8}{0.55} = \frac{4}{0.55} = 7.27 \text{ k}\Omega$$

$$R_1 = 7.27 \text{ k}\Omega - R_{C1}$$

At LTP = 4 V, consider Fig. 8.2.

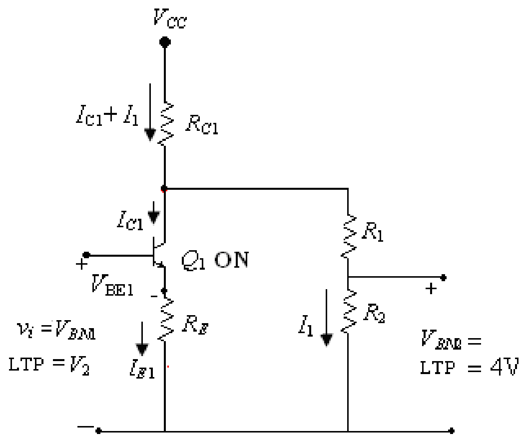

Fig. 8.2 Circuit at LTP

$$V_{BN2} = V_{BN1} = 4\text{V} = \text{LTP} = V_2$$

Let I_1 be the current in R_2

$$I_1 = \frac{V_{BN2}}{R_2} = \frac{4\text{ V}}{20\text{ k}\Omega} = 0.2\text{ mA}$$

$$I_{C1} = I_{E1} = \frac{V_2 - V_{BE1}}{R_E} = \frac{4 - 0.7}{1.825\text{ k}\Omega} = 1.8\text{ mA}$$

Writing the KVL equation of the outer loop consisting of R_{C1}, R_2 and R_1,

$$V_{CC} = (I_{C1}+I_1)R_{C1}+I_1(R_1+R_2)$$

$$V_{CC} = (I_{C1}+I_1)R_{C1}+I_1(7.27 - R_{C1}+R_2)$$

$$V_{CC} = I_{C1}R_{C1}+I_1(7.27+R_2)$$

$$R_{C1} = \frac{V_{CC} - I_1(7.27 + R_2)}{I_{C1}}$$

$$R_{C1} = \frac{12 - 0.2(7.27 + 20)}{1.8} = \frac{10.36}{2.27} = 3.6\text{ k}\Omega$$

$$R_1 = (R_{C1} - R_1) - R_{C1}$$

$$R_1 = 7.27 - 3.6 = 3.67\text{ k}\Omega$$

(ii) To eliminate hysteresis R_{e1} is added in series with the emitter of Q_1, Fig. 8.3, such that

$$V_1 - V_2 = V_H = (I_{C1}+I_{B1})R_{e1}$$

$$R_{e1} = \frac{4\text{ V}}{1.8\text{ mA}} = 2.22\text{ k}\Omega$$

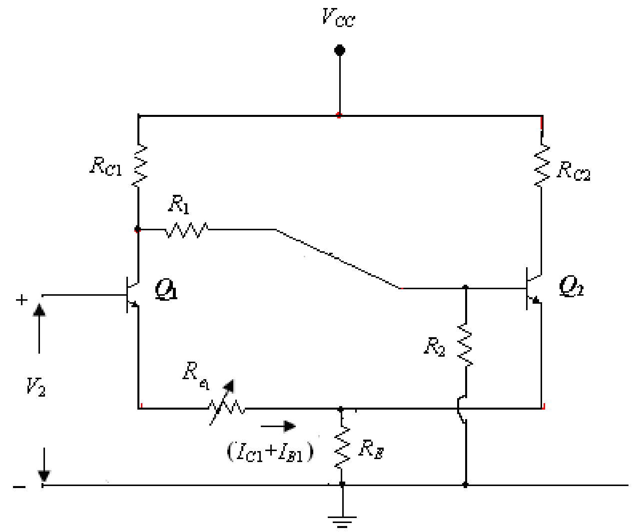

Fig. 8.3 R_{e1} connected to eliminate hysteresis

(iii) To eliminate hysteresis R_{e2} is added in series with the emitter of Q_2, Fig. 8.4, such that

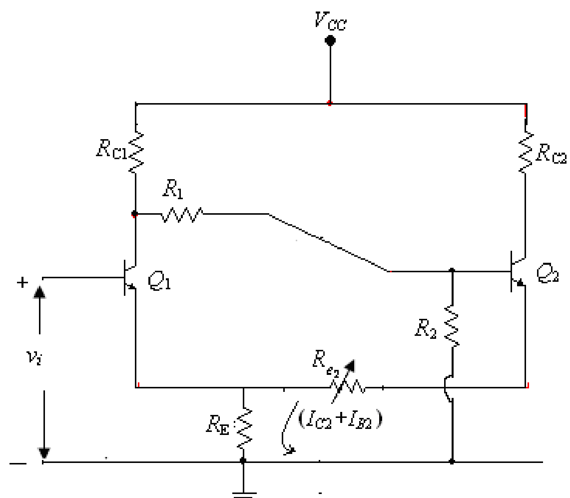

Fig. 8.4 R_{e2} connected to eliminate hysteresis

$$V' = \frac{V_{CC} R_2}{R_{C1} + R_1 + R_2} = \frac{12 \times 20}{3.6 + 3.67 + 20} = 8.8 \text{ V}$$

$$R' = R_2 // (R_{C1} + R_1) = \frac{20 \times 7.27}{27.27} = 5.33 \text{ k}\Omega$$

We know,

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

$$4 = (8.8 - 0.7) \times \frac{41 \times 1.825}{5.33 + (41)(R_{e2} + 1.825)} + 0.5$$

$$3.5 = \frac{606}{80.1 + 41R_{e2}}$$

$$143.5R_{e2}=325.65$$

$$R_{e2}=2.26\ \text{k}\Omega\,.$$
