Chapter 8 : Transistor Biasing and Thermal Stability

Section 8.5:

Ex. 8.5.2: The fixed bias circuit of Fig. P. 8.5.2 uses a silicon transistor. The component values are $R_C = 500 \, \Omega$ and $R_B = 100 \, \text{k}\Omega$. $\beta_{dc}$ of the transistor is 100 at 30°C and increases to 120 at a temperature of 80°C. Determine the percent change in the Q point values over this temperature range. Assume that $V_{BE}$ and $I_{CEO}$ remain constant.

Soln.:

Steps to be followed:

Step 1: Obtain the Q point at 30°C.
Step 2: Obtain the Q point at 80°C.
Step 3: Calculate the percent change in Q point values.

Step 1: To obtain the Q point at 30°C:

- Obtaining Q point values means to calculate $V_{CEQ}$ and $I_{CQ}$. Let us use $\beta_{dc} = 100$.

  Applying KVL to the base circuit of Fig. P. 8.5.2 we get,
  
  $$V_{CC} - I_B R_B - V_{BE} = 0$$
  
  $$\therefore I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.7}{100 \times 10^3} = 113 \, \mu\text{A} \quad \text{(1)}$$

- Now neglecting $I_{CEO}$ we can write,
  
  $$I_{CQ} = \beta_{dc} I_B = 100 \times 113 \times 10^{-6} = 11.3 \, \text{mA} \quad \text{(2)}$$

- Apply KVL to the collector circuit of Fig. P. 8.5.2 to get,
  
  $$V_{CC} - V_{CEQ} - I_{CQ} R_C = 0$$
  
  $$\therefore V_{CEQ} = V_{CC} - I_{CQ} R_C = 12 - (11.3 \times 10^{-3} \times 500) = 6.35 \, \text{V} \quad \text{(3)}$$

- Thus the Q point co-ordinates at 30°C are:

  $$\text{Q point at 30°C} = (V_{CEQ}, I_{CQ}) = (6.35 \, \text{V}, 11.3 \, \text{mA})$$
Step 2: To obtain the Q point at 80°C:

- Let us use $\beta_{dc} = 120$. Now from Equation (1), $I_B = 113 \mu A$.
  Therefore the new value of $I_{CQ}$ is given by,
  $$I_{CQ}(80^\circ°C) = \beta_{dc} \times I_B = 120 \times 113 \times 10^{-6}$$
  $$\therefore I_{CQ}(80^\circ°C) = 13.56 \text{ mA}$$
  \hspace{1cm} \ldots(4)

- Applying KVL to collector circuit we get,
  $$V_{CEQ}(80^\circ°C) = V_{CC} - I_{CQ}R_C = 12 - (13.56 \times 10^{-3} \times 500)$$
  $$\therefore V_{CEQ}(80^\circ°C) = 5.22 \text{ V}$$
  \hspace{1cm} \ldots(5)

- Thus the Q point values at 80°C are:
  $$Q \text{ point at } 80^\circ°C = (V_{CEQ}, I_{CQ}) = (5.22 \text{ V}, 13.56 \text{ mA})$$

Step 3: To calculate percent change in Q point values:

- Percent change in $I_{CQ}$
  $$\frac{I_{CQ}(80^\circ°C) - I_{CQ}(30^\circ°C)}{I_{CQ}(30^\circ°C)} \times 100\% = \frac{13.56 - 11.3}{11.3} \times 100\%$$
  $$\therefore \% \text{ change in } I_{CQ} = 20\% \text{ (increase)}$$
  \hspace{1cm} \ldots \text{Ans.}

- Percent change in $I_C$
  $$\% \text{ change in } I_C = \% \text{ change in } I_{CQ} = 20\%$$
  \hspace{1cm} \ldots \text{Ans.}

- Percent change in $V_{CEQ}$
  $$\frac{V_{CEQ}(80^\circ°C) - V_{CEQ}(30^\circ°C)}{V_{CEQ}(30^\circ°C)} \times 100\% = \frac{5.22 - 6.35}{6.35} \times 100\%$$
  $$\therefore \% \text{ change in } V_{CEQ} = -17.79\% \text{ (decrease)}$$
  \hspace{1cm} \ldots \text{Ans.}

Ex. 8.5.3: Derive the expression for the stability factor “$S$” of a fixed bias circuit. Comment on the result.

Soln.:

- We have defined the stability factor “$S$” as follows:
  $$S = \left. \frac{\Delta I_C}{\Delta I_{CQ}} \right|_{\text{constant } V_{BE} \text{ and } \beta_{dc}}$$

  S gives us the change in $I_C$ due to change in the reverse saturation current $I_{CBO}$. As $I_{CBO}$ changes by $\Delta I_{CBO}$, the base current $I_B$ will change by $\Delta I_B$ and the collector current $I_C$ changes by $\Delta I_C$.

- For a CE configuration we know that,
  $$I_C = \beta_{dc} I_B + I_{CBO} = \beta_{dc} I_B + \left(1 + \beta_{dc}\right) I_{CBO}$$
  $$\therefore \Delta I_C = \left(1 + \beta_{dc}\right) \Delta I_{B} + \beta_{dc} \Delta I_{CBO}$$

- Dividing both the sides by $\Delta I_C$ we get,
  $$1 = \beta_{dc} \left[\frac{\Delta I_B}{\Delta I_C}\right] + \left(1 + \beta_{dc}\right) \left[\frac{\Delta I_{CBO}}{\Delta I_C}\right]$$
\[ 1 - \beta_{dc} \left[ \frac{\Delta I_B}{\Delta I_C} \right] = (1 + \beta_{dc}) \left[ \frac{\Delta I_{CBO}}{\Delta I_C} \right] \]

\[ \frac{\Delta I_{CBO}}{\Delta I_C} = \frac{1 - \beta_{dc} \left[ \frac{\Delta I_B}{\Delta I_C} \right]}{(1 + \beta_{dc})} \]

But, \( S = \frac{\Delta I_C}{\Delta I_{CBO}} \)

\[ S = \frac{(1 + \beta_{dc})}{1 - \beta_{dc} \left[ \frac{\Delta I_B}{\Delta I_C} \right]} \] \quad \ldots \quad (8.5.5)

But for the fixed bias circuit,

\[ I_B = \frac{V_{CC} - V_{BE}}{R_B} \]

In this equation \( V_{CC}, V_{BE}, \) and \( R_B \) all are fixed. Therefore \( I_B \) cannot change. \( \therefore \Delta I_B = 0. \)

Substituting this in Equation (8.5.5) we get,

\[ S = (1 + \beta_{dc}) \] \quad \ldots \quad (8.5.6)

**Comment on the expression for S:**

Substitute \( \beta_{dc} = 49 \) in Equation (8.5.6). The value of \( S = 50 \). i.e. collector current change is 50 times as large as change in the reverse saturation current \( I_{CBO} \). Fixed bias circuit thus gives a very poor stability of the Q point. It is the worst configuration as far as the stability of Q point is concerned.

**Ex. 8.5.4:** Derive the expression for the stability factor \( S' \) of a fixed bias circuit. Also derive the relation between \( S \) and \( S' \) for the same.

**Soln.:**

- We have defined the stability factor \( S' \) as

\[ S' = \frac{\partial I_C}{\partial V_{BE}} \bigg|_{\text{constant } I_{CO} \text{ and } \beta_{dc}} \]

- For a common emitter configuration, we have

\[ I_C = \beta_{dc} I_B + (1 + \beta_{dc}) I_{CO} \] \quad \ldots \quad (1)

- We will substitute \( I_B \) in terms of \( V_{BE} \) into Equation (1).

For this, refer Fig. P. 8.5.4 and apply KVL to get,

\[ V_{CC} = I_B \cdot R_B + V_{BE} \] \quad \ldots \quad (2)

\[ \therefore \ I_B = \frac{V_{CC} - V_{BE}}{R_B} \] \quad \ldots \quad (3)

- Substitute Equation (3) into Equation (1) to get,

\[ I_C = \beta_{dc} \left[ \frac{V_{CC} - V_{BE}}{R_B} \right] + (1 + \beta_{dc}) I_{CBO} \]

- Note that \( I_{CO} \) and \( I_{CBO} \) are one and the same.

\[ \therefore I_C R_B = \beta_{dc} V_{CC} - \beta_{dc} V_{BE} + (1 + \beta_{dc}) I_{CBO} R_B \] \quad \ldots \quad (4)
Differentiate this expression with respect to $V_{BE}$ to get,

$$
R_B \frac{\partial I_C}{\partial V_{BE}} = 0 - \beta_{dc} + 0
$$

\[\therefore R_B S' = -\beta_{dc}\]

$$
S' = \frac{-\beta_{dc}}{R_B} \quad \text{...(8.5.7)}
$$

This is the required expression. The negative sign indicates that $I_C$ decreases as temperature increases due to reduction in $V_{BE}$ at increased temperature.

**Relation between $S$ and $S'$:**

- We have already derived the expression for $S$ as $S = (1 + \beta_{dc})$. In this expression substitute $\beta_{dc} = -S' R_B$ to get,

$$
S = 1 - S' R_B
$$

or

$$
S' = \frac{(1 - S)}{R_B}
$$

This is the required relation.

**Ex. 8.5.5:** Derive the expression for the stability factor $S''$ for a fixed bias circuit.

**Soln. :**

- We have already defined the stability factor $S''$ as

$$
S'' = \frac{\partial I_C}{\partial \beta_{dc}} \bigg|_{I_{CBO}} \text{ and } V_{BE} \text{ constant}
$$

- For a common emitter configuration,

$$
I_C = \beta_{dc} I_B + (1 + \beta_{dc}) I_{CBO}
$$

$$
= \beta_{dc} I_B + \beta_{dc} I_{CBO} + I_{CBO}
$$

Differentiate both sides partially with respect to $\beta_{dc}$, we get,

$$
\frac{\partial I_C}{\partial \beta_{dc}} = I_B + I_{CBO} + 0
$$

- Neglecting $I_{CBO}$ we get,

$$
S'' = \frac{\partial I_C}{\partial \beta_{dc}} \bigg|_{I_{CBO}} = I_B = \frac{I_C}{\beta_{dc}}
$$

\[\therefore S'' = \frac{I_C}{\beta_{dc}} \quad \text{...(8.5.8)}
$$

This is the required expression.

**Note:** Out of $S$, $S'$ and $S''$ the stability factor $S$ is significantly higher than the remaining two.
Ex. 8.5.6: Calculate the stability factor $S$ for the fixed bias circuit shown in Fig. P. 8.5.6.

Fig. P. 8.5.6

Soln.:

- The stability factor $S$ for the fixed bias circuit is given by: $S = 1 + \beta_{dc}$
- Therefore we must find the value of $\beta_{dc}$.
  
  But $\beta_{dc} = \frac{I_C}{I_B}$

So we have to obtain the values of $I_C$ and $I_B$.

- We know that,$$
I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{12 - 6}{1 \text{ k}\Omega} = 6 \text{ mA}
$$
  
  And $I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.7}{100 \text{ k}\Omega} = 113 \mu\text{A}$

Therefore, $\beta_{dc} = \frac{I_C}{I_B} = \frac{6 \times 10^{-3}}{113 \times 10^{-6}} = 53.09$

Hence the stability factor $S = 1 + 53.09 = 54.1$...

Ans.

Ex. 8.5.8: For the device characteristics shown in Fig. P. 8.5.8(a) calculate $V_{CC}$, $R_B$ and $R_C$ for the fixed bias circuit of Fig. P. 8.5.8(b).

Fig. P. 8.5.8
Step 1: Find \( V_{CC} \) and \( I_{C\,(max)} \):

From the dc load line of Fig. P. 8.5.8(a) we get,

\[
V_{CC} = 15 \text{ V} \quad \text{and} \quad I_{C\,(max)} = 10 \text{ mA}
\]

Step 2: Calculate \( R_B \) and \( R_C \):

\[
R_B = \frac{V_{CC} - V_{BE}}{I_{BQ}} = \frac{15 - 0.7}{50 \mu\text{A}} = 286 \text{ k}\Omega \quad \ldots\text{Ans.}
\]

\[
R_C = \frac{V_{CC}}{I_{C\,(max)}} = \frac{15}{10 \text{ mA}} = 1.5 \text{ k}\Omega \quad \ldots\text{Ans.}
\]

Section 8.7:

Ex. 8.7.3: A Si transistor used in self bias has \( V_{CC} = 20 \text{ V}, \ R_C = 2 \text{ k}\Omega \). The nominal operating point is \( V_{CE} = 10 \text{ V} \) and \( I_C = 4 \text{ mA} \). If \( \beta = 50 \), Calculate \( R_1, R_2 \) and \( R_E \) if stability factor \( S = 10 \) is desired. If \( S \leq 3 \) is required, what will be the price paid for achieving this stability? Refer Fig. P. 8.7.3(a).

Fig. P. 8.7.3(a)

**Soln.**:

Steps to be followed:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculate ( I_B ).</td>
</tr>
<tr>
<td>2</td>
<td>Apply KVL to the collector loop and calculate ( R_E ).</td>
</tr>
<tr>
<td>3</td>
<td>Using the expression for “S” calculate ( R_B ) i.e. ( R_1 \parallel R_2 ).</td>
</tr>
<tr>
<td>4</td>
<td>Calculate the values of ( R_1 ) and ( R_2 ).</td>
</tr>
</tbody>
</table>

Step 1: Calculate \( I_B \):

\[
I_B = \frac{I_C}{\beta_{dc}} = \frac{4 \times 10^{-3}}{50} = 80 \mu\text{A} \quad \ldots(1)
\]

Step 2: Apply KVL to the collector loop and calculate \( R_E \):

\[
V_{CC} = I_C R_C + V_{CE} + I_E R_E = I_C R_C + V_{CE} + (I_C + I_B) R_E
\]

\[
\therefore R_E = \frac{V_{CC} - V_{CE} - I_C R_C}{(I_C + I_B)} = \frac{20 - 10 - (4 \times 2)}{(4.08 \times 10^{-3})} = 490.2 \Omega
\]

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Step 3: Calculate $R_B$:

The expression for stability factor of “S” for self bias circuit is given by,

$$S = \frac{1 + \beta_{dc}}{1 + \beta_{dc} + \left(R_B / R_E\right)}$$

$$\therefore S = \frac{(1 + 50)}{(1 + 50) + \left(R_B / 490\right)} = 10$$

$$51 + \frac{51 R_B}{490} = 510 + \frac{10 R_B}{490}$$

$$41 R_B = 459$$

$$
\therefore R_B = 5.485 \text{k}\Omega \quad \ldots \text{Ans.}
$$

But, $R_B = R_1 \parallel R_2 = \frac{R_1 R_2}{(R_1 + R_2)}$

$$\therefore \frac{R_1 R_2}{(R_1 + R_2)} = 5.485 \text{k}\Omega \quad \ldots \text{(3)}$$

$$\frac{R_2}{(R_1 + R_2)} = \frac{5.485 \times 10^3}{R_1} \quad \ldots \text{(4)}$$

Fig. P. 8.7.3(b)

Step 4: To calculate the values of $R_1$ and $R_2$:

The Thevenin’s equivalent circuit is as shown in Fig. P. 8.7.3(b).

Apply KVL to the base loop to write,

$$V_{TH} - I_B R_B - V_{BE} - I_E R_E = 0$$

But $I_B = 80 \mu A$ and $I_E = (1 + \beta) I_B = 51 \times 80 \times 10^{-6} = 4.08 \text{ mA}$

Substituting the values we get,

$$\therefore V_{TH} - 80 \times 10^{-3} \times 5.485 - 0.7 - 4.08 \times 0.4902 = 0$$

$$\therefore V_{TH} = 3.17 \text{ Volts}$$

But $V_{TH} = \frac{R_2}{(R_1 + R_2)} V_{CC}$

$$\therefore \frac{R_2}{R_1 + R_2} = \frac{3.17}{20} = 0.158$$

$$\therefore \frac{R_2 V_{CC}}{R_1 + R_2} = 3.17$$

and $R_B = \frac{R_1 R_2}{R_1 + R_2} = 5.485 \times 10^3$

Substituting the value of $\frac{R_2}{R_1 + R_2} = 0.158$ into expression for $R_B$ we get

$$R_1 \times 0.158 = 5.485 \times 10^3$$

$$\therefore R_1 = 34.7 \text{k}\Omega \quad \ldots \text{Ans.}$$
\[ \frac{R_2}{R_2 + 34.7} = 0.158 \]
\[ \therefore R_2 = 0.158 R_2 + 5.4826 \]
\[ \therefore R_2 = \frac{5.4826 \text{k}\Omega}{0.842} = 6.51 \text{k}\Omega \]

Effect of reducing \( S \) to 3:

If \( S \leq 3 \) then,
\[ \frac{1 + (R_E / R_B)}{1 + \beta + (R_B / R_E)} \leq 3 \]
\[ \frac{51 \times [1 + (R_B / 490)]}{51 + (R_B / 490)} \leq 3 \]

For \( S = 3 \),
\[ 51 + \frac{51 R_B}{490} = 153 + \frac{3 R_B}{490} \]
\[ \therefore R_B = 1.041 \text{k}\Omega \text{ for } S = 3. \]

The effect is reduction in the input impedance. Thus the stabilization is improved at the cost of reduced input impedance.

**Ex. 8.7.4:** The silicon transistor shown in Fig. P. 8.7.4 has \( \beta = 99 \), \( I_{BO} = 30 \mu\text{A} \), \( V_{BEQ} = 0.7\text{V} \). Find \( R_2 \) and \( V_{CEO} \).

**Fig. P. 8.7.4**

\[ R_E = 1 \text{k}\Omega \]
\[ R_1 = 10 \text{k}\Omega \]
\[ R_C = 2 \text{k}\Omega \]
\[ V_{CEQ} = 15 \text{V} \]

**Soln.**:

**Step 1:** Calculate \( I_C \):
\[ I_C = \beta I_B = 99 \times 30 \times 10^{-6} = 2.97 \text{mA} \] \( \ldots (1) \)

**Step 2:** Calculate \( V_{CE} \):

Apply KVL to collector circuit to write:
\[ V_{CC} = I_C R_C + V_{CE} + (I_C + I_B) R_E \]
\[ \therefore V_{CE} = V_{CC} - I_C (R_C + R_E) - I_B R_E \]
\[ = 15 - 2.97 (2 + 1) - 30 \times 10^{-6} \times 1 \times 10^3 = 6.06 \text{V} \] \( \ldots \text{Ans.} \)

**Step 3:** Calculate the value of \( R_2 \):

Apply KVL to the base-emitter loop to write,
\[ V_{R2} = V_{BE} + I_E R_E = V_{BE} + (1 + \beta) I_B R_E \]
\[ \therefore V_{R2} = 0.7 + (100 \times 30 \times 10^{-6} \times 1 \times 10^3) = 3.7 \text{V} \]
\[ V_{R2} = \frac{R_2}{(R_1 + R_2)} \times V_{CC} \quad \text{... Using approximate analysis} \]

\[ \therefore 3.7 = \frac{15R_2}{R_1 + R_2} \quad \therefore 3.7R_1 + 3.7R_2 = 15R_2 \]

\[ R_2 = \frac{3.7R_1}{11.3} = 3.27 \, \Omega \quad \text{...Ans.} \]

**Ex. 8.7.5:** Derive the expression for the stability factor \( S \) of the voltage divider bias circuit. Comment on the result.

**Soln.:**

To derive the expression for \( S \) we are going to use the same equation which we had used to obtain “\( S \)” for the collector to base bias which is,

\[ S = \frac{1 + \beta_{dc}}{1 - \beta_{dc} \left[ \frac{\Delta I_B}{\Delta I_C} \right]} \quad \text{...(1)} \]

and substitute the value of \( \frac{\Delta I_B}{\Delta I_C} \) for the self bias circuit to obtain the required expression for \( S \).

**To obtain the value of \( \frac{\Delta I_B}{\Delta I_C} \):**

Consider the Thevenin’s equivalent circuit which we have discussed in section 8.7.5. The same circuit has been repeated in Fig. P. 8.7.5.

Apply KVL to the base circuit of Fig. P. 8.7.5 we can write,

\[ V_{TH} = I_R R_B + V_{BE} + (I_C + I_B) R_E \quad \text{...(2)} \]

If we consider to be independent of, we can differentiate Equation (2) with respect to \( I_C \) to obtain,

\[ 0 = \frac{\partial I_B}{\partial I_C} + 0 + R_E \frac{\partial I_B}{\partial I_C} \]

\[ \therefore \frac{\partial I_B}{\partial I_C} = \frac{-R_E}{(R_B + R_E)} \quad \text{...(3)} \]

\[ \therefore \frac{\Delta I_B}{\Delta I_C} = \frac{-R_E}{(R_B + R_E)} \]

Substitute this in Equation (1) to obtain,

\[ S = \frac{1 + \beta_{dc}}{1 - \beta_{dc} \left[ \frac{-R_E}{R_B + R_E} \right]} \quad \text{...(4)} \]
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\[ S = \frac{(1 + \beta_{dc}) (R_B + R_E)}{R_B + R_E + \beta_{dc} R_E} = \frac{(1 + \beta_{dc}) (R_B + R_E)}{R_B + (1 + \beta_{dc}) R_E} \]

Divide numerator and denominator by \( R_E \) to get,

\[ S = \frac{1 + \left(\frac{R_B}{R_E}\right)}{(1 + \beta_{dc}) + \left(\frac{R_B}{R_E}\right)} \]  

…(5)

This is the desired result.

Comments on the result :

- The value of \( S \) depends on the ratio \( \frac{R_B}{R_E} \). If \( \frac{R_B}{R_E} \) is small then the value of \( S = 1 \) and if the ratio \( \frac{R_B}{R_E} \to \infty \) then \( S \approx (1 + \beta_{dc}) \). Thus the self bias circuit is more stable for smaller values of the ratio \( \frac{R_B}{R_E} \).
- If the ratio \( \frac{R_B}{R_E} \) is fixed then \( S \) increases with increase in the value of \( \beta_{dc} \). Thus stability decreases with increase in \( \beta_{dc} \).
- \( S \) is independent of \( \beta_{dc} \) for small values of \( \beta_{dc} \).
- Smaller values of \( R_B \) give better stabilization.

Ex. 8.7.7 : The transistor shown in the circuit in the Fig. P. 8.7.7 has \( h_{FE} = 50 \) at 25\(^\circ\) C and \( h_{FE} = 200 \) at 75\(^\circ\) C. Reverse saturation current \( I_{CO} = 0.01 \) \( \mu \)A at with 25\(^\circ\) C a temperature coefficient of 7%/\( \circ\) C and \( V_{BE} = 0.7 \) V at 25\(^\circ\). Temperature coefficient of \( V_{BE} \) is \( –2.5 \) mV/\( \circ\) C. Calculate :

1. Quiescent currents
2. Quiescent collector current drift at 75\(^\circ\) C.

Fig. P. 8.7.7 : Given circuit

Soln. :

Steps to be followed :

Step 1 : Calculate the values of \( I_B \) and \( I_C \) at 25\(^\circ\) C.
Step 2 : Calculate the changes in \( I_{CO} \), \( \beta \) and \( V_{BE} \) with temperature.
Step 3 : Calculate the values of \( S \), \( S' \) and \( S'' \).
Step 4 : Obtain the value of \( \Delta I_C = S \Delta I_{CO} + S' \Delta V_{BE} + S'' \Delta \beta \)

Step 1 : Calculate \( I_B \) and \( I_C \) at 25\(^\circ\) C :

By applying KVL around base loop, we get,

\[ -1 + I_B R_B + V_{BE} + (I_B + I_C) R_E = 0 \]

\[ I_B = \frac{1 - 0.7}{R_B + 1(1 + \beta) R_E} = \frac{1 - 0.7}{1 \times 51 \times 100} = 49 \mu A \]  

…(1)

\[ I_C = \beta I_B = 50 \times 49 \mu A = 2.45 \text{ mA} \]  

…(2)

Step 2 : Changes in \( h_{FE} \), \( I_{CO} \) and \( V_{BE} \) :

From the data, the changes in different parameters are as follows :
**Step 3:** Calculate the values of $S, S', S''$:

\[
S = (1 + \beta) \frac{1 + [R_B / R_E]}{1 + [1 / 0.1]} = 9.2
\]

\[
S' = \frac{-\beta / R_E}{1 + 50 + [1 / 0.1]} = -\frac{50}{100} = -8.196 \times 10^{-3}
\]

\[
S'' = \frac{SI_C}{\beta (1 + \beta)} = \frac{9.2 \times 2.45 \times 10^{-3}}{50 (1 + 50)} = 8.84 \times 10^{-6}
\]

**Step 4:** To calculate change in $I_C$:

\[
\Delta I_C = S \Delta I_{CO} + S' \Delta V_{BE} + S'' \Delta \beta
\]

\[
= (9.2 \times 0.31 \times 10^{-6}) - (8.196 \times 10^{-3} \times -0.125) + (8.84 \times 10^{-6} \times 150)
\]

\[
\therefore \Delta I_C = 2.852 \mu A + 1.0245 mA + 1.326 mA = 2.3533 mA \quad \text{...Ans.}
\]

So new value of $I_C = 2.45 + 2.3533 = 4.8033 mA \quad \text{...Ans.}$

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**Section 8.11:**

**Ex. 8.11.3:** The reverse saturation current of germanium transistor in Fig. P. 8.11.3(a) is 2 $\mu A$ at room temperature and increases by a factor of 2 for each temperature increase of 10°C. The bias $V_{BB} = 5V$. Find the maximum allowable value of $R_B$ if the transistor is to remain cutoff at a temperature of 75°C.
Soln. :

Step 1 : Value of $I_{CBO}$ at 75°C:

Let the room temperature be 25°C.

$\therefore$ at 25°C : $I_{CBO} = 2 \mu A$

$I_{CBO}$ doubles for every 10°C increase in temperature.

$\therefore$ at 75°C : $I_{CBO} = 64 \mu A$.

Step 2 : Calculate value of $R_B$:

In order to keep the transistor off, it is necessary to keep $V_{BE} \leq -0.1$ V.

Refer Fig. P. 8.11.3(b) and apply KVL to the input loop to get,

$$V_{BB} + V_{BE} = I_{CBO} R_B$$

$\therefore$ $V_{BE} = -V_{BB} + R_B I_{CBO} \leq -0.1$

$\therefore$ $R_B \leq \frac{4.9}{128 \times 10^{-6}}$

$\therefore$ $R_B \leq 38.28 \, k\Omega$ or $R_{B_{\text{max}}} = 38.28 \, k\Omega$...Ans.

Ex. 8.11.4 : Fig. P. 8.11.4, a circuit using p-n-p germanium transistor with $\beta_{dc} = 150$ and $I_{CO} = 2.5$ mA.

The quiescent collector current is 500 mA Find :

(a) The value of resistor $R_B$.

(b) The largest value of $\theta$ that can result in a thermally stable circuit.

Soln. :

Given : $\beta_{dc} = 150$, $I_{CO} = 2.5$ mA, $I_{CQ} = 500$ mA.

Step 1 : Calculate $R_B$:

1. Calculate $I_B$

$$I_C = \beta I_B + (1 + \beta) I_{CO}$$

500 = 150 $I_B + (151 \times 2.5)$

$\therefore$ $I_B = 0.816 \, mA$ ...(1)

2. Apply KVL to the base emitter circuit to write,

$$V_{CC} = I_B R_B + V_{EB} + I_E R_E$$

$\therefore$ 20 = $0.816 \times 10^{-3} R_B + 0.3 + (I_C + I_B) R_E$

$\therefore$ $R_B = \frac{20 - 0.3 - (500.816 \times 10^{-3} \times 5)}{0.816 \times 10^{-3}}$

= 21.073 k\Omega

...Ans.

3. Calculate $V_{EC}$

$$V_{CC} = (I_C \times 10) + V_{EC} + I_E \times 5$$

$\therefore$ $V_{EC} = V_{CC} - 10 I_C - 5 I_E = 20 - (10 \times 0.5) - (5 \times 0.500816)$

$V_{EC} = 12.49 \, V$
As \( |V_{CE}| > |V_{CC}/2| \) the circuit of Fig. P. 8.11.4 is not inherently stable.

**Step 2 : Calculate the stability factor \( (S) \) :**

\[
S = \left(1 + \beta\right) \frac{1 + \left(\frac{R_B}{R_E}\right)}{1 + \frac{1}{\beta} + \left(\frac{R_B}{R_E}\right)}
\]

\[
: S = (151) \left(\frac{1 + (21.073 \times 10^3/5)}{151 + (21.073 \times 10^3/5)}\right) = 145.8
\]

**Step 3 : Calculate \( \theta \) :**

Substitute “\( S \)” in the following equation:

\[
[V_{CC} - 2I_C (R_E + R_C)] (S) (0.07I_{CO}) < \frac{1}{\theta}
\]

\[
: [20 - 2 \times 0.5 \times 10] (145.8 \times 0.07 \times 2.5 \times 10^{-3}) < \frac{1}{\theta}
\]

\[
: 0.1275 < \frac{1}{\theta}
\]

\[
: 0 < 7.84^\circ C/W \quad : \theta_{max} = 7.84^\circ C/W.
\]

**Ex. 8.11.5 :** In a circuit shown in Fig. P. 8.11.5(a) determine the coordinates of operating point of the transistor. Draw the DC load line on output characteristics and show the location of \( Q \) point. Comment on the region of operation. Determine \( S_{ICO} \).

**Soln. :**

**Step 1 : Draw the Thevenin’s equivalent circuit :**

To obtain the \( Q \) point of the given circuit, remove all the capacitors and draw the Thevenin’s equivalent circuit as shown in Fig. P. 8.11.5(b).

\[
V_{TH} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{25}{(25 + 68)} \times 16
\]

\[
: V_{TH} = 4.3 \text{ V}
\]

and \( R_H = R_1 || R_2 = \frac{25 \times 68}{25 + 68} = 18.3 \text{ k\Omega} \)
Step 2: Calculate $I_B$:

Apply KVL to the base loop of Fig. P. 8.11.5(b) to write,

$$V_{TH} - I_B R_B - V_{BE} - I_E R_E = 0$$

\[ \therefore I_B = \frac{V_{TH} - V_{BE}}{R_B + (1 + \beta) R_E} = \frac{4.3 - 0.7}{18.3 + (101 \times 1.5)} \times 10^3 \]

\[ \therefore I_B = 2.12 \times 10^{-5} \text{ A} \]

Step 3: Calculate $I_{CQ}$:

$$I_{CQ} = \beta I_B = 100 \times 2.12 \times 10^{-5} = 2.12 \text{ mA}$$

Step 4: Calculate $V_{CEQ}$:

$$V_{CEQ} = V_{CC} - I_C R_C - I_E R_E$$

But

$$I_E = (1 + \beta) I_B = 101 \times 2.12 \times 10^{-5} = 2.1412 \times 10^{-3}$$

$$= 16 - (2.12 \times 2.5) - (2.1412 \times 1.5) = 7.4882 \text{ Volts.}$$

Hence the Q-point is given by: $(7.4882 \text{ V}, 2.12 \text{ mA})$ ...Ans.

Step 5: To draw the load line and locate Q point:

The load line is as shown in Fig. P. 8.11.5(c). The two extreme points A and B are given by,

Point A: $I_{C_{\text{max}}} = \frac{V_{CC}}{R_C + R_E} = \frac{16}{(2.5 + 1.5) \times 10^3} = 4 \text{ mA.}$

Point B: Corresponds to $V_{CE} = V_{CC} = 16 \text{ V.}$

Region of operation: Active Region

Step 6: Calculate $S_{ICO}$:

$S_{ICO}$ is $S$, and the expression for $S$ of a voltage divider bias circuit is given by,

$$S = (1 + \beta) \left( \frac{1 + (R_B / R_E)}{(1 + \beta) + (R_B / R_E)} \right)$$

$$S = \frac{1 + [18.3 / 1.5]}{(1 + 100) + (18.3 / 1.5)} = 11.78$$ ...Ans.
Ex. 8.11.6: A p-n-p germanium transistor is used in the self biasing arrangement with $V_{CC} = 5V$, $R_1 = 27\,\Omega$, $R_2 = 3\,\Omega$, $R_E = 270\,\Omega$, $R_C = 2\,\Omega$ and $\beta = 50$.

Find $V_{CEO}$ and $I_{CO}$.

Soln.:

Given: $V_{CC} = 5V$, $R_1 = 27\,\Omega$, $R_2 = 3\,\Omega$, $R_E = 270\,\Omega$, $R_C = 2\,\Omega$ and $\beta = 50$.

Step 1: Draw the circuit:
The circuit is as shown in Fig. P. 8.11.6(a).

Step 2: Draw Thevenin's equivalent circuit:
Thevenin's equivalent circuit is shown in Fig. P. 8.11.6(b), in which

\[
V_{TH} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{3}{27 + 3} \times 5 = 0.5 \text{ volts}
\]

\[
R_B = R_1 || R_2 = \frac{27 \times 3}{27 + 3} = 2.7 \,\Omega
\]

Step 3: Calculate $I_B$, $I_C$ and $V_{CR}$:
Apply KVL to the base loop of Fig. P. 8.11.6(c) to write,

\[
V_{TH} = I_E R_E + V_{EB} + I_B R_B
\]

But $I_E = (1 + \beta) I_B$

\[
\therefore V_{TH} - V_{EB} = (1 + \beta) I_B R_E + I_B R_B
\]

\[
\therefore I_B = \frac{V_{TH} - V_{EB}}{R_B + (1 + \beta) R_E} = \frac{0.5 - 0.3}{2.7 + (51 \times 0.27)} = 13 \mu A
\]
Collector current, 
\[ I_c = \beta I_b = 50 \times 13 \times 10^{-6} = 0.63 \text{ mA} \] ...Ans.

Apply KVL to the collector loop of Fig. P. 8.11.6(d) to get,
\[ V_{cc} = I_E + R_E + V_{EC} + I_C R_C \]
\[ \therefore V_{EC} = V_{cc} - I_E R_E - I_C R_C = 5 - (1+ \beta) I_B R_E - I_C R_C \]
\[ = 5 - 51 \times 13 \times 10^{-6} \times 270 - 0.63 \times 10^{-3} \times 2 \times 10^3 \]
\[ \therefore V_{EC} = 5 - 0.18 - 1.3 = 3.5 \text{ V} \]
\[ \therefore V_{CE} = -V_{EC} = -3.5 \text{ V} \] ...Ans.

**Ex. 8.11.7:** For the biasing arrangement as shown in Fig. P. 8.11.7, assume that the reverse saturation currents of diode and transistor are equal. Show that :
\[ S = \frac{\partial I_C}{\partial I_{CO}} = 1 \text{ and } S' = -\frac{\beta_{dc}}{R_1} \]

**Soln.:**

**Assumptions:**
1. The diode D is made of same material as that of the transistor.
2. The reverse saturation current of the diode i.e. \( I_o \) is equal to the reverse saturation current of the transistor i.e. \( I_{CO} \).

\[ \therefore I_o = I_{CO} \]

To prove that \( S = 1 \):

Looking at Fig. P. 8.11.7 we can write that,
\[ I_b = I_1 - I_o \] ...(1)

The collector current \( I_c \) is given as :
\[ I_c = \beta_{dc} I_b + (1 + \beta_{dc}) I_{CO} \] ...(2)

Substitute the value of \( I_c \) from Equation (1) to get :
\[ I_c = \beta_{dc} (I_1 - I_o) + (1 + \beta_{dc}) I_{CO} \]
\[ \therefore I_c = \beta_{dc} I_1 - \beta_{dc} I_o + I_{CO} + \beta_{dc} I_{CO} \] ...(3)

But \( I_o = I_{CO} \)

\[ \therefore I_c = I_1 \beta_{dc} + I_{CO} \] ...(4)

\[ \therefore S = \frac{\partial I_c}{\partial I_{CO}} = 0 + 1 \]
\[ \therefore S = 1 \text{ Proved} \] ...Ans.
To prove that $S' = \frac{-\beta_{dc}}{R_1}$:

$S'$ is defined as:

$$S' = \frac{\partial I_C}{\partial V_{BE}} I_{CO} \text{ and } \beta_{dc} \text{ constants}$$

Consider the base circuit of Fig. P. 8.11.7 and apply KVL to write,

$$V_{CC} = I_1 R_1 + V_{BE}$$

$$\therefore I_1 R_1 = V_{CC} - V_{BE}$$

$$\therefore I_1 = \frac{V_{CC} - V_{BE}}{R_1} \tag{5}$$

But from Equation (4),

$$I_C = I_1 \beta_{dc} + I_{CO}$$

Substituting value of $I_1$ we get,

$$I_C = \frac{(V_{CC} - V_{BE}) \beta_{dc}}{R_1} + I_{CO}$$

$$= \frac{V_{CC}}{R_1} \frac{\beta_{dc}}{R_1} V_{BE} + I_{CO}$$

As $\beta_{dc}$ and $I_{CO}$ are assumed to be constants,

$$S' = \frac{\partial I_C}{\partial V_{BE}} = 0 - \frac{\beta_{dc}}{R_1} + 0$$

$$S' = -\frac{\beta_{dc}}{R_1} \quad \text{...Proved.} \quad \text{...Ans.}$$

Ex. 8.11.8 : For the circuit shown in Fig. P. 8.11.8(a).

![Fig. P. 8.11.8(a)](image_url)
Soln. :

Step 1: Draw the dc equivalent circuit:
- For dc analysis all the capacitors offer infinite impedance. Hence they are replaced by open circuit in the dc equivalent circuit of Fig. P. 8.11.8(b).
- The 470 k and 220 k resistances will appear in series with each other in the dc equivalent circuit.

Step 2: To obtain the base current $I_{BQ}$ and $I_{CQ}$:

Applying the KVL to the base circuit of Fig. P. 8.11.8(b) we can write,

$$V_{CC} = (I_C + I_B) R_C + I_B R_B + V_{BE} + I_E R_E \quad \ldots(1)$$

$$I_B (R_B + R_C) = V_{CC} - V_{BE} - I_E R_E - I_C R_C \quad \ldots(2)$$

But, $I_C = \beta_{dc} I_B$ and $I_E = (1 + \beta_{dc}) I_B$

Substituting these values in Equation (2) we get,

$$I_B [R_B + R_C + (1 + \beta_{dc}) R_E + \beta_{dc} R_C] = V_{CC} - V_{BE}$$

$$\therefore \quad I_B = \frac{V_{CC} - V_{BE}}{[R_B + (1 + \beta_{dc}) R_C + (1 + \beta_{dc}) R_E]} \quad \ldots(3)$$

Substituting the values we get,

$$I_B = \frac{30 - 0.7}{[690 + (101 \times 6.2) + (101 \times 1.5)] \times 10^3} \quad \therefore \quad I_{BQ} = 19.96 \mu A \approx 20 \mu A \quad \ldots(4)$$

$$\therefore \quad \text{Collector current} \quad I_{CQ} = \beta_{dc} I_{BQ} = 100 \times 20 \times 10^{-6} \quad \therefore \quad I_{CQ} = 2 \text{ mA} \quad \ldots(5)$$

The emitter current

$$I_E = (1 + \beta_{dc}) \times I_B = 101 \times 20 \times 10^{-6} = 2.02 \text{ mA} \quad \ldots(5)$$

Step 3: To calculate $V_E$, $V_{CE}$ and $V_C$:

To calculate $V_E$:

$$V_E = I_E R_E = 2.02 \times 1.5 \quad \therefore \quad V_E = 3.03 \text{ Volts} \quad \ldots(6)$$

To calculate $V_{CE}$:

Apply KVL to the collector circuit of Fig. P. 8.11.8(b) to write,

$$V_{CC} = (I_C + I_B) R_C + V_{CE} + V_E$$

$$\therefore \quad V_{CE} = V_{CC} - V_E - (I_C + I_B) R_C$$
Substituting values we get,
\[ V_{CE} = 30 - 3.03 - (2.02 \times 6.2) = 14.45 \text{ Volt} \] ...Ans.

To calculate \( V_C \):
\[ V_C = V_{CE} + V_E \]
\[ \therefore V_C = 14.45 + 3.03 = 17.476 \text{ Volts} \] ...Ans.

**Ex. 8.11.9** : A CE amplifier employing NPN transistor has a load resistance \( R_L \) connected between collector and \( V_{CC} \) supply of +16 Volts. To biasing a resistor, \( R_1 \) is connected between \( V_{CC} \) and base. Resistor \( R_2 = 30 \text{ k}\Omega \) is connected between base and ground. \( R_E = 1 \text{ k}\Omega \). Draw the circuit diagram. Calculate the value of \( R_1 \) and \( R_C \) and stability factor “S” if, \( V_{BE} = 0.2 \), \( I_{EQ} = 2 \text{ mA} \), \( V_{CEO} = 6 \text{ Volt} \), \( \alpha = 0.985 \).

**Soln.** :

**Step 1** : Calculate \( \beta_{dc} \) and \( I_{CQ} \):

The circuit diagram is as shown in Fig. P. 8.11.9. Let us first calculate the value of \( \beta_{dc} \).
\[ \beta_{dc} = \frac{\alpha}{1 - \alpha} = \frac{0.985}{1 - 0.985} = 65.67 \] ...(1)

and \[ I_{CQ} = \alpha I_E = 0.985 \times 2 = 1.97 \text{ mA} \] ...(2)

**Step 2** : To obtain the value of \( R_C \):

Apply KVL to the collector circuit of Fig. P. 8.11.9 to write,
\[ V_{CC} = I_{CQ} R_C + V_{CEO} + I_{EQ} R_E \]
\[ \therefore R_C = \frac{V_{CC} - V_{CEO} - I_{EQ} R_E}{I_{CQ}} \]

Substituting the values we get,
\[ R_C = \frac{16 - 6 - (2 \times 1)}{1.97 \times 10^{-3}} = 4.06 \text{ k}\Omega \] ...Ans.

**Step 3** : To obtain the value of \( R_1 \):

Apply KVL to the base circuit of Fig. P. 8.11.9 to write,
\[ V_{CC} = I_{R1} R_1 + V_{BE} + I_{EQ} R_E \]
\[ \therefore R_1 = \frac{V_{CC} - V_{BE} - (I_{EQ} R_E)}{I_{R1}} \] ...(3)

But we do not know \( I_{R1} \).
\[ I_{R1} = I_{R2} + I_B = \frac{V_B}{R_2} + \frac{I_{CQ}}{\beta_{dc}} \]
\[ = \frac{(I_{EQ} R_E + V_{BE})}{R_2} + \frac{I_{CQ}}{\beta_{dc}} \]
\[ I_{R1} = \frac{(2 + 0.2) \times 1.97 \times 10^{-3}}{65.67} = 103.2 \mu A \]

Substituting this value in Equation (3) we get,
\[ R_1 = \frac{16 - 0.2 - (2 \times 1)}{103.2 \times 10^{-6}} = 133.72 \text{ k}\Omega \]
\[ \therefore R_B = R_1 || R_2 = \frac{R_1 R_2}{R_1 + R_2} = \frac{133.72 \times 30}{163.72} = 24.50 \text{ k}\Omega \]

**Step 4:** To obtain the stability factor \( S \):
\[ S = \frac{1 + \beta_{dc}}{1 + \beta_{dc} \left[ \frac{R_E}{R_B + R_E} \right]} = \frac{1 + 65.67}{1 + 65.67 \left[ \frac{1}{24.50 + 1} \right]} = 18.64 \]

**Ex. 8.11.10:** In the self bias circuit shown in Fig. P. 8.11.10(a), \( R_1 = R_C = 500 \Omega, R_2 = 5 \text{ k}\Omega, R_E = 100 \pm 10 \Omega, h_{FE} = 75, I_{CBO} = 0.2 \mu A \text{ and } V_{CC} = 20 \text{ V}.

1. Find an expression for change in \( I_{CO} \text{ due to change in } R_E \) alone.
2. Calculate change in \( I_{CO} \text{ when } R_E \text{ changes from minimum to maximum value.} \)

All other parameters are constant.

**Fig. P. 8.11.10**

(a) Given circuit  
(b) The modified circuit of Fig P. 8.11.10(a)

**Soln.**:

**Step 1:** The simplified DC equivalent circuit is shown in Fig. P. 8.11.10(b).

**Step 2:** Apply KVL around the base loop to obtain expression for \( V_B \):
\[ V_B = I_B R_B + V_{BE} + (I_B + I_C) R_E \]
\[ \therefore V_B = I_B (R_B + R_E) + V_{BE} + I_C R_E \]
\[ \therefore V_B = I_B (R_B + R_E) + V_{BE} + \beta I_B R_E \]

\[ \therefore V_B = I_B [R_B + (1 + \beta) R_E] + V_{BE} \]
Step 3 : Get the expression for $I_C$:

We know that,

$$I_C = \beta I_B + (1 + \beta) I_{CBO} \quad ...(3)$$

From Equation (2) we get

$$I_B = \frac{V_B - V_{BE}}{R_B + (1 + \beta) R_E}$$

Now substitute this expression into Equation (3) to get,

$$I_C = \frac{\beta (V_B - V_{BE})}{R_B + (1 + \beta) R_E} + (1 + \beta) I_{CBO}$$

For $\beta >> 1$,

$$I_C = \frac{\beta (V_B - V_{BE})}{R_B + \beta R_E} + \beta I_{CBO}$$

$$= \frac{\beta (V_B - V_{BE}) + \beta I_{CBO} (R_B + \beta R_E)}{R_B + \beta R_E}$$

Step 4 : Obtain the stability factor $S_{RE}$:

Differentiating both sides of the above equation with respect to $R_E$ with $I_{CBO}$, $V_B$ and $\beta$ constants we get stability factor $S_{RE}$:

$$\frac{\partial I_C}{\partial R_E} = S_{RE} = \frac{\beta}{(R_B + R_E \beta)} \left[ I_{CBO} R_B - \beta \{ V_B + R_B I_{CBO} - V_{BE} \} \right] \quad ...(4)$$

Substitute $R_E = 100 - 10 = 90 \ \Omega$,

$R_B = R_1 \parallel R_2 = 500 \ \Omega \parallel 5 \ k\Omega = 454.5 \ \Omega$

$V_B = \frac{R_1}{R_1 + R_2} V_{CC} = \frac{500 \ \Omega}{500 \ \Omega + 5 \ k\Omega} \times 20V$

$V_B = 1.82 \ V$, $I_{CBO} = 0.2 \ \mu A$

Step 5 : Calculate the value of $S_{RE}$:

Substituting the values into Equation (4) we get,

$$S_{RE} = \frac{75}{[454.5 + (90 \times 75)]} \left[ 0.2 \times 10^{-6} \times 454.5 - 75 (1.82 + 454.2 \times 0.2 \times 10^{-6} - 0.7 \right]$$

$$\therefore S_{RE} = -1.1659 \times 10^{-4} \ A/\Omega$$

This is the value of stability factor.

Step 6 : Obtain $\Delta I_C$:

Change in collector current is given by,

$$\Delta I_C = S_{RE} \Delta R_E = -1.1659 \times 10^{-4} \times (110 - 90)$$

$$\therefore \Delta I_C = -2.3318 \ mA \quad \text{...Ans.}$$
**Ex. 8.11.11** : The silicon transistor shown in Fig. P. 8.11.11 has $I_{CBO} = 0.5 \, \mu A$, $V_{BE} = 0.7 \, V$ and $\beta = 75$ at room temperature. Calculate the value of $I_{CQ}$.

If $I_{CBO}$ doubles for every $10^\circ C$ rise in temperature and $V_{BE}$ has a temperature coefficient of $2 \, \text{mV/}^\circ C$. Calculate value of $I_{CQ}$ if the temperature rises by $20^\circ C$. Assume $\beta$ to be constant.

**Soln. :**

**Step 1 :** To calculate $I_B$ and $I_C$ at room temperature :

By applying KVL around the base loop we get,

$- 6 + I_B R_B + V_{BE} + (I_B + I_C) R_E = 0$

But $I_C = \beta I_B + (1 + \beta) I_{CO} \approx \beta I_B$

$\therefore - 6 + I_B R_B + V_{BE} + I_B R_E + \beta I_B R_E = 0$

$\therefore I_B [R_B + R_E + \beta R_E] = 6 - V_{BE}$

$I_B = \frac{6 - V_{BE}}{R_B + (1 + \beta) R_E}$

$= \frac{6 - 0.7}{50 \, k + 76 \, k} = 42 \, \mu A$ ... (2)

Our assumption is justified.

$I_C = I_{CO} = \beta I_B = 75 \times 42 \times 10^{-6}$

$I_C = 3.15 \, mA$. ... (3)

**Step 2 :** New values of $V_{BE}$ and $I_{CBO}$ at increased temperature :

$\frac{T_2 - T_1}{10}$

$I_{CBO2} = I_{CBO1} \times 2^{10} = I_{CBO1} \times 2^{202}$

$= 0.5 \, \mu A \times 2^2 = 2 \, \mu A$ ... (4)

$V_{BE2} = V_{BE1} - 2 \, \text{mV/}^\circ C \times 20^\circ C$

$= 0.7 \, V - 40 \, \text{mV} = 0.66 \, V$ ... (5)

**Step 3 :** New value of $I_B$ :

From Equation (1), we can get the new value of $I_B$ as,

$I_B = \frac{6 - 0.66}{50 \, k + 76 \, k}$

$I_B = 42.4 \, \mu A$ ... (6)

**Step 4 :** New value of $I_C$ :

$I_C = \beta I_B + (1 + \beta) I_{CBO}$

$= (75 \times 42.4 \, \mu A) + (76 \times 2 \, \mu A) = 3.332 \, mA$ ... Ans.
Ex. 8.11.12: An amplifier circuit is shown in Fig. P. 8.11.12(a). Determine the co-ordinates of the operating point Q and the thermal stability factor $S_{ICO}$.

---

**Soln. :**

**Step 1: Draw the DC equivalent circuit:**

The DC equivalent circuit is as shown in Fig. P. 8.11.12(b). This is obtained by replacing all the capacitors in the given circuit by open circuit.

**Step 2: Draw the Thevenin's equivalent circuit:**

The Thevenin's equivalent circuit is as shown in Fig. P. 8.11.12(c).

**Step 3: Obtain $I_B$:**

Apply KVL to the base loop to write

$$V_{TH} - I_B R_B - V_{BE} - I_E R_E + 6 = 0$$

$$\therefore -2.92 - I_B R_B - 0.7 - (1 + \beta) I_B R_E + 6 = 0$$

$$\therefore 2.38 - I_B [R_B + (1 + \beta) R_E] = 0$$

$$\therefore I_B = \frac{2.38}{R_B + (1 + \beta) R_E}$$

From the data sheet $\beta_{(typical)} = 180$, and $R_E = 940 \, \Omega$ or 0.94 k

$$\therefore I_B = \frac{2.38}{17.5 \, k + (181) \times 0.94 \, k} = 12.68 \, \mu A$$

---

**Fig. P. 8.11.12**

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**Fig. P. 8.11.12(c) : Thevenin's equivalent circuit**
Step 4: Calculate \( I_C \) and \( V_{CE} \):

\[
\therefore \quad I_C = \beta I_B = 180 \times 12.68 \times 10^{-6} = 2.283 \text{ mA} \quad \ldots \text{Ans.}
\]

\[
I_E = (1 + \beta) I_B = 181 \times 12.68 \times 10^{-6} = 2.2951 \text{ mA}
\]

Apply KVL to the collector loop to write

\[
6 - I_C R_C - V_{CE} - I_E R_E + 6 = 0
\]

\[
\therefore \quad V_{CE} = 12 - I_C R_C - I_E R_E = 12 - (2.283 \times 2.5) - (2.2951 \times 0.94)
\]

\[
\therefore \quad V_{CE} = 4.135 \text{ Volts} \quad \ldots \text{Ans.}
\]

Step 5: Calculate \( S_{ICO} \):

For a voltage divider bias circuit \( S_{ICO} \) is given by,

\[
S_{ICO} = \frac{\partial I_C}{\partial I_{CO}} = (1 + \beta) \frac{1 + (R_E / R_b)}{(1 + \beta) + (R_E / R_b)}
\]

\[
= (1 + 180) \frac{1 + (17.5/0.94)}{1 + 180 + (17.5/0.94)}
\]

\[
\therefore \quad S_{ICO} = 17.79 \quad \ldots \text{Ans.}
\]

**Ex. 8.11.13:** In the circuit of Fig. P. 8.11.13, transistor has \( \beta = 100 \) and \( V_{BE \text{ (active)}} = 0.6 \) V. Calculate the values of \( R_1 \) and \( R_3 \) such that collector current is of 1 mA and \( V_{CE} = 2.5 \) V.

**Fig. P. 8.11.13 : Given circuit**

**Solv. :**

1. To calculate value of \( R_3 \):

   It is given that \( I_C = 1 \) mA and \( V_{CE} = 2.5 \) V.

   Apply KVL to the collector circuit of Fig. P. 8.11.13 to get,

   \[
   V_{CC} = I_C R_3 + V_{CE} + I_E R_4
   \]

   Substitute \( I_E = (I_C + I_B) \) and \( I_B = I_C / \beta \)

   \[
   V_{CC} = I_C R_3 + 2.5 + \left( \frac{I_C + I_B}{\beta} \right) R_4
   \]

   Substituting the other values,

   \[
   5 = (1 \times 10^{-3} R_3) + 2.5 + \left( \frac{1 \text{ mA} + \frac{I_{mA}}{100}}{100} \right) 300
   \]

   \[
   5 = (1 \times 10^{-3} R_3) + 2.803
   \]

   \[
   \therefore \quad R_3 = 2.197 \text{ k}\Omega \quad \ldots \text{Ans.}
   \]
To calculate the value of $R_1$ :

\[ R_1 = \frac{V_{R1}}{I_1} = \frac{5 - V_B}{I_2 + I_B} \]

But \[ V_B = I_E R_A + V_{BE} \]

But \[ I_E = 1.01 \text{ mA} \]

\[ \therefore \quad V_B = (1.01 \times 0.3) + 0.6 = 0.903 \text{ volt} \]

and \[ I_B = \frac{I_C}{\beta} = 1 \text{ mA} = 10 \mu\text{A} \]

As \[ R_2 = 10 \text{ k}\Omega \quad \text{...given} \]

\[ I_2 = \frac{V_B}{R_2} = \frac{0.903}{10 \times 10^3} = 0.0903 \times 10^{-3} \]

\[ \therefore \quad I_2 = 90.3 \mu\text{A} \]

Substituting all these values we get,

\[ R_1 = \frac{5 - 0.903}{(90.3 + 10) \times 10^{-3}} = 40.8 \text{ k}\Omega \quad \text{...Ans.} \]

**Ex. 8.11.14 :** The circuit shown in Fig. P. 8.11.14(a) uses a Si transistor with $\beta = 200$ and it is designed to make $V_o = 0$ and $V_{CEQ} = 3$ V. (a) Determine $R_C$ and $R_E$ (b) Using the values obtained in (a) find the change in $V_o$ if $\beta$ is halved.

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**Soln. :**

(a) **Redraw the output circuit of the Fig. P. 8.11.14(a) :**

Redraw only the output circuit of Fig. P. 8.11.14(a) as shown in Fig P. 8.11.14(b). Now apply KVL to write,

\[ 6 - I_C R_C - V_{CEQ} - I_E R_E + 6 = 0 \quad \text{...(1)} \]

But \[ V_{CEQ} = 3 \text{ V} \]

\[ \therefore \quad 12 - I_C R_C - 3 - I_E R_E = 0 \quad \text{...(2)} \]
Looking at Fig. P. 8.11.14(b) we can write that,

\[ V_o = V_{CEQ} + I_E R_E - 6 \]  

…(3)

But \( V_o = 0 \) and \( V_{CEQ} = 3 \) V

\[ \therefore 0 = 3 + I_E R_E - 6 \]

\[ \therefore I_E R_E = 3 \text{ V} \]  

…(4)

Substitute Equation (4) into Equation (2) to get,

\[ 9 - I_C R_C - 3 = 0 \]

\[ \therefore I_C R_C = 6 \text{ V} \]  

…(5)

We know that \( \beta = 200 \) but we do not know the value of \( I_B \) to calculate \( I_C \) and \( I_E \).

1. **To obtain the value of \( I_B \):**

Redraw only the input side of the given circuit as shown in Fig. P. 8.11.14(c).

Applying KVL, we get,

\[ 0 - [(90 \text{ k} \parallel 90 \text{ k}) \times I_B] - 0.7 - I_E R_E + 6 = 0 \]

Substitute \( I_E R_E = 3 \text{ V} \)

And \( 90 \parallel 90 = 45 \text{ k} \) to get

\[ 0 - (45 \text{ k} \times I_B) - 0.7 - 3 + 6 = 0 \]

\[ \therefore I_B = 58.11 \mu\text{A} \]  

…(6)

2. **To obtain the value of \( R_E \):**

\[ I_E R_E = 3 \text{ V} \]

\[ \therefore R_E = \frac{3}{I_E} = \frac{3}{(1 + \beta) I_B} \]

\[ \therefore R_E = \frac{3}{201 \times 51.11 \times 10^{-6}} = 292 \Omega \]  

…Ans.

3. **To obtain the value of \( R_C \):**

\[ I_C R_C = 6 \text{ V} \]

\[ \therefore R_C = \frac{6}{I_C} = \frac{6}{\beta I_B} = \frac{6}{200 \times 51.11 \times 10^{-6}} = 586.96 \Omega \]  

…Ans.

(b) **To obtain the change in \( V_o \) if \( \beta = 100 \):**

The new values of \( I_C \) and \( I_E \) are as follows:

\[ I_C = 100 \times 51.11 \mu\text{A} = 5.11 \text{ mA} \]

and \[ I_E = 101 \times 51.11 \mu\text{A} = 5.16 \text{ mA} \]

From Equation (3) we have,

\[ V_o = V_{CEQ} + I_E R_E - 6 = 3 + (5.16 \times 10^{-3} \times 292) - 6 \]

\[ \therefore V_o = -1.4932 \text{ Volts} \]

Hence change in \( V_o = -1.4932 - 0 = -1.4932 \text{ Volts} \)  

...Ans.