Chapter Seven (2nd Semester)
Transistor Biasing

7.1: Introduction

A **transistor is operated (used) by selecting an appropriate** $\boldsymbol{Q-point}$ in **the active region** of its output characteristics. This is achieved by establishing suitable dc voltages and currents at different terminals of the transistor by using external batteries and circuits. The choice of an appropriate $\boldsymbol{Q-point}$ depends on:

- **The amplitude of the** $\boldsymbol{ac}$ **input signal**
- **Supply voltages**
- **Load resistance**
- **Permissible distortion in the output**

In spite of the given values of these parameters, the **operating point** may not be **stable** and may shift as a result of a **change in temperature** or **transistor characteristics**.

This is mainly because of the **temperature** dependence of the transistor parameters like $\boldsymbol{I_{CO}}$, $\boldsymbol{\beta}$, **and** $\boldsymbol{V_{BE}}$. The **parameter** $\boldsymbol{\beta}$ **changes** considerably with temperature it **doubles** for **every 10** °C rises in temperature for Ge transistors while for silicon transistors, the **change is much less**. Therefore, the differential coefficient $\frac{\partial I_C}{\partial I_{CO}}$ can be used as a **measure of the temperature stability** of a transistor provided the change in β and V_{BE} is insignificant. Thus, the **stability** $\boldsymbol{S}$ of a transistor can be approximately expressed as:

$$S = \frac{\partial I_C}{\partial I_{CO}} \quad \dots (1)$$

The **lower the value of** $\boldsymbol{S}$ **more stable the** $\boldsymbol{Q-point}$. The **lowest value of** $\boldsymbol{S}$ is unity since $\boldsymbol{I_C}$ **must contain** $\boldsymbol{I_{CO}}$. In **actual transistor** circuits, $\boldsymbol{S}$ **is greater than unity**.

The **increase in** $\boldsymbol{I_{CO}}$ with **temperature** may eventually cause the **burning out of the transistor**, a condition known as ***thermal runaway***.

As $\boldsymbol{I_{CO}}$ **increases** due to a **rise in temperature**, there is a corresponding **increase** in $\boldsymbol{I_C}$.

An excessive amount of **heat** is, therefore, evolved at the collector junction, the **temperature** of which **rises** further.

This, in turn, **increases** $\boldsymbol{I_{CO}}$ and the cycle repeats itself. As the process is cumulative, the temperature of the collector junction may increase so much that it exceeds the rated value of the transistor, thereby **burning out the transistor**.

We describe below some biasing circuits for the common-emitter npn transistor as it is preferred in most applications.

7.2: Base Bias (Fixed Bias)

In this type of bias, the same power supply is used to forward-bias the emitter-base junction and reverse-bias the collector-base junction as shown in figure (1b).

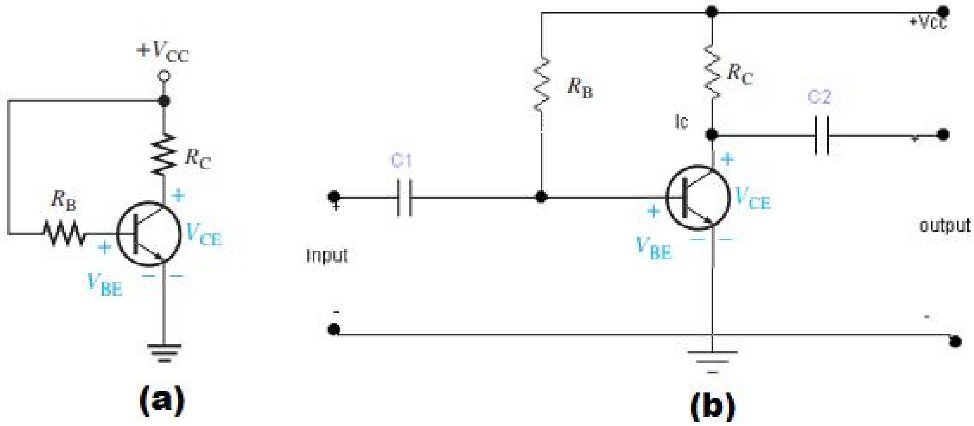


Figure (1): (a): Base bias. (b): Common emitter *npn* transistor with fixed bias.

This method of biasing is common in switching circuits. Figure (1a) shows a base-biased transistor. The analysis of this circuit for the linear region shows that it is directly dependent on β_{DC}.

Starting with **Kirchhoff's voltage law** around the base circuit: $\boldsymbol{V_{CC} - V_{R_B} - V_{BE} = 0}$

Substituting $\boldsymbol{V_{R_B} = I_B R_B}$, you get: $V_{CC} - I_B R_B - V_{BE} = 0 \rightarrow I_B R_B = V_{CC} - V_{BE}$

The resistances $\boldsymbol{R_B}$ **and** $\boldsymbol{R_c}$ **(or** $\boldsymbol{R_L}$**)** are <u>*used to establish*</u> the quiescent (no signal) **base** $\boldsymbol{I_B}$ **and collector** $\boldsymbol{I_C}$ **currents** respectively.

The quiescent **base current** $\boldsymbol{I_B}$ is:

$$\boldsymbol{I_B} = \frac{V_{CC} - V_{BE}}{R_B} \quad \dots (2)$$

The voltage $\boldsymbol{V_{BE}}$ **is about 0.7 V for silicon transistors** and **may be neglected** in comparison with V_{CC} therefore, we have: $\boldsymbol{I_B \cong \frac{V_{CC}}{R_B}}$

Kirchhoff's voltage law applied around the collector circuit in Figure (1a) gives the following equation: $\boldsymbol{V_{CC} - I_C R_C - V_{CE} = 0}$

Solving for $\boldsymbol{V_{CE}}$: $\boldsymbol{V_{CE}} = V_{CC} - I_C R_C \quad \dots (3)$

Substituting the expression for I_B into the formula $\boldsymbol{I_C = \beta_{DC} I_B}$ yields:

$$\boldsymbol{I_C} = \beta_{DC}\left(\frac{V_{CC} - V_{BE}}{R_B}\right) \quad \dots (4)$$

Thus, the base current is independent of the quiescent collector current and is constant for the given values of V_{CC} and R_B, hence this circuit is called the fixed bias circuit. If the $Q-point$ is chosen in the region of the output characteristics, then α is a constant independent of the collector voltage. The current $\boldsymbol{I_C}$ ($\boldsymbol{I_C} = \boldsymbol{\beta I_B} + \boldsymbol{\gamma} I_{CO}$) as given by equation (5) is:

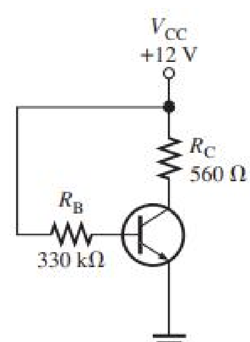
$$\boldsymbol{I_C} = \frac{\boldsymbol{\alpha}}{\mathbf{1-\alpha}} I_B + \frac{\mathbf{1}}{\mathbf{1-\alpha}} I_{CO} \quad \ldots (5)$$

where $\boldsymbol{\beta} = \frac{\Delta I_C}{\Delta I_B} = \frac{\boldsymbol{\alpha}}{\mathbf{1-\alpha}}$ **(have in Page 155)** and $\boldsymbol{\gamma} = \frac{\Delta I_E}{\Delta I_B} = \frac{\mathbf{1}}{\mathbf{1-\alpha}}$ **(have in Page 157)**

Therefore, the stability factor $\boldsymbol{S}$ is: $\boldsymbol{S} = \frac{\partial I_C}{\partial I_{CO}} = \frac{\mathbf{1}}{\mathbf{1-\alpha}} \quad \ldots (6)$

Taking $\boldsymbol{\alpha = 0.98}$**, we obtain** $\boldsymbol{S = 50}$. This indicates that Ic increases fifty times as fast as I_{CO}, i.e., the circuit cannot provide a stable operating point and there exists a good probability of thermal runaway occurs. Another disadvantage of this circuit is that if the transistor is replaced by another similar transistor, the quiescent current and voltage may change markedly resulting in a shift of the $Q-point$.

In the circuit of figure (1b) the capacitors $C1$ and $C2$ are the coupling capacitors which are used to connect the transistor with some input and output devices. They allow the passage of ac signal but block the dc currents and voltages which might be present along with the ac signal.



Example 1: Determine how much the $Q-point$ (I_C, V_{CE}) for the circuit in this figure will change over a temperature range where β_{DC} increases from 100 to 200.

Solution:

For $\beta_{DC} = 100$, and $V_{BE} = 0.7\ V$.

$$\boldsymbol{I_C} = \beta_{DC}\left(\frac{V_{CC}-V_{BE}}{R_B}\right) \rightarrow \boldsymbol{I_{C(1)}} = 100\left(\frac{12-0.7}{330\times 10^3}\right) = 3.42\ mA$$

$$\boldsymbol{V_{CE}} = V_{CC} - I_C R_C \rightarrow \boldsymbol{V_{CE(1)}} = 12 - (3.42 \times 10^{-3} \times 560) = 10.1\ V$$

For $\beta_{DC} = 200$, and $V_{BE} = 0.7\ V$.

$$\boldsymbol{I_C} = \beta_{DC}\left(\frac{V_{CC}-V_{BE}}{R_B}\right) \rightarrow \boldsymbol{I_{C(2)}} = 200\left(\frac{12-0.7}{330\times 10^3}\right) = 6.84\ mA$$

$$\boldsymbol{V_{CE}} = V_{CC} - I_C R_C \rightarrow \boldsymbol{V_{CE(2)}} = 12 - (6.84 \times 10^{-3} \times 560) = 8.17\ V$$

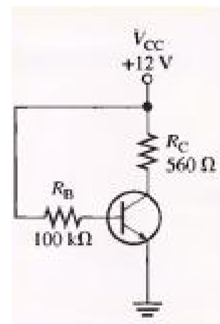
The percent change in $\boldsymbol{I_C}$ as β_{DC} changes from 100 to 200 is:

$$\%\,\Delta \boldsymbol{I_C} = \left(\frac{\boldsymbol{I_{C(2)}} - \boldsymbol{I_{C(1)}}}{\boldsymbol{I_{C(1)}}}\right) \times 100\% = \left(\frac{\mathbf{6.84 - 3.42}}{\mathbf{3.42}}\right) \times 100\% = \mathbf{100}\%\ (an\ increase)$$

The percent change in $\boldsymbol{V_{CE}}$ is:

$$\%\,\Delta \boldsymbol{V_{CE}} = \left(\frac{\boldsymbol{V_{CE(2)}} - \boldsymbol{V_{CE(1)}}}{\boldsymbol{V_{CE(1)}}}\right) \times 100\% = \left(\frac{\mathbf{8.17 - 10.1}}{\mathbf{10.1}}\right) \times 100\% = \mathbf{-19.1}\%\ (a\ decrease)$$

As you can see, the $Q-point$ is very dependent on β_{DC} in this circuit and therefor makes the base bias arrangement very unreliable. Consequently, base bias is not normally used if linear operation is required. However, it can be used in switching applications



H.W: Q1: Determine how much the $Q-point$ (I_C, V_{CE}) for the circuit in this figure will change over a temperature range where β_{DC} increases from 85 to 100 and V_{BE} decreases from 0.7 V to 0.6 V.

Solution:

H.W: Q2: If β_{DC} = 50 at 0°C and 125 at 100°C for the circuit in figure above, determine the percent change in the $Q-point$ values over the temperature range. Assume no change in V_{BE}.

7.3: Collector-Feedback Bias

Collector feedback bias is created by connecting a single resistance R_B between the collector and the base as shown in figure (2b). the forward base bias is provided by collector voltage V_{CE} rather than the collector supply voltage V_{CC}. It is, therefore, also known as collector-to-base bias. This circuit has better stability than the previous one.

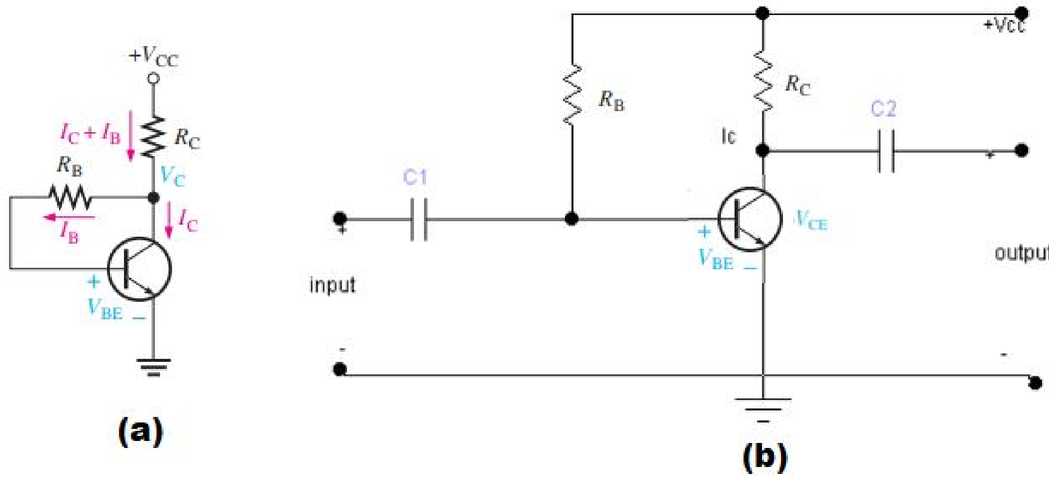


Figure (2): (a): Collector-feedback bias. (b): Common emitter npn transistor with collector-feedback bias.

If I_C increases because of a change in temperature or replacement of the transistor by another one of the same types, the drop across R_C increases. Since V_{CC} is fixed, there is a corresponding decrease in V_{CE}.

This causes I_B to decrease which, in turn, decreases I_C. Thus, the initial increases in I_C are automatically compensated for in this circuit. From figure (3), it follows that:

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

By **Ohm's law**, the base current can be expressed as: $\boldsymbol{I_B} = \frac{\boldsymbol{V_{CE} - V_{BE}}}{\boldsymbol{R_B}} \rightarrow V_{CE} = I_B R_B + V_{BE}$

$$V_{CC} = I_C R_C + I_B R_C + I_B R_B + V_{BE}$$

Neglecting $I_B R_C$ and $\boldsymbol{I_C} = \beta_{DC} I_B \rightarrow I_B = \frac{I_C}{\beta_{DC}}$ we get: $\boldsymbol{I_C} R_C + \frac{I_C}{\beta_{DC}} R_B = V_{CC} - V_{BE} \rightarrow$

$$\boldsymbol{I_C} = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_B}{\beta_{DC}}} \dots (7)$$

Neglecting V_{BE} we get:

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

$$\boldsymbol{I_B} = \frac{V_{CC} - I_C R_C}{R_C + R_B} \quad \dots (8)$$

In indicates the decrease in I_B with an increase in I_C as explained above. From equation (5), we have:

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CO}$$

Using equation (8) we obtain:

$$I_C = \frac{\alpha}{1-\alpha}\left(\frac{V_{CC} - I_C R_C}{R_C + R_B}\right) + \frac{1}{1-\alpha} I_{CO}$$

Or

$$I_C(1-\alpha) = \frac{\alpha V_{CC}}{R_C + R_B} - \frac{\alpha I_C R_C}{R_C + R_B} + I_{CO} \rightarrow I_C\left(1 - \alpha + \frac{\alpha R_C}{R_C + R_B}\right) = \frac{\alpha V_{CC}}{R_C + R_B} + I_{CO} \rightarrow$$

$$I_C = \frac{1}{1 - \alpha + \frac{\alpha R_C}{R_C + R_B}} \frac{\alpha V_{CC}}{R_C + R_B} + \frac{1}{1 - \alpha + \frac{\alpha R_C}{R_C + R_B}} I_{CO}$$

Therefore, the stability factor S is:

$$S = \frac{\partial I_C}{\partial I_{CO}} = \frac{1}{1 - \alpha + \frac{\alpha R_C}{R_C + R_B}} \rightarrow S = \frac{1}{1 - \frac{\alpha R_C + \alpha R_B}{R_C + R_B} + \frac{\alpha R_C}{R_C + R_B}} \rightarrow S = \frac{1}{1 - \frac{\alpha R_B}{R_C + R_B}} \quad \text{... (9)}$$

Using equation ($\beta = \frac{\alpha}{1-\alpha} \rightarrow \alpha = \frac{\beta}{1+\beta}$), it becomes:

$$S = \frac{1}{1 - \alpha + \frac{\alpha R_C}{R_C + R_B}} = \frac{1}{\frac{\alpha}{\beta} + \frac{\alpha R_C}{R_C + R_B}} = \frac{1 \times \frac{\beta}{\alpha}}{\left(\frac{\alpha}{\beta} + \frac{\alpha R_C}{R_C + R_B}\right) \times \frac{\beta}{\alpha}} = \frac{1 + \beta}{\left(1 + \frac{\beta R_C}{R_C + R_B}\right)} \quad \text{... (10)}$$

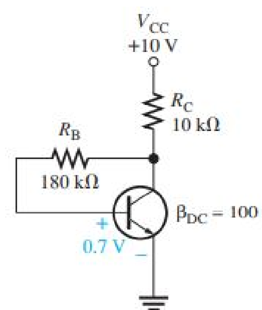
Comparing equation (9) with (6), we find that the stability is better in this case than in the previous case. However, for the improvement is only marginal.

Example 2: Calculate the $Q - point$ value (I_C and V_{CE}) for the circuit in this figure.

Solution:

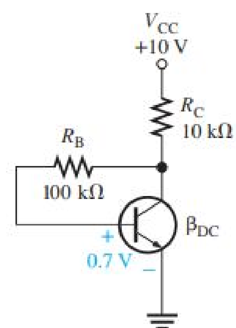
$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{DC}} = \frac{10\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega + 180\text{ k}\Omega/100} = \mathbf{788\ \mu A}$$

$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (788\ \mu\text{A})(10\text{ k}\Omega) = \mathbf{2.12\ V}$$



H.W: Q3: Calculate the $Q - point$ values in figure above for β_{DC} = 200 and determine the percent change in the $Q - point$ in this figure from β_{DC} = 100 to β_{DC} = 200.

H.W: Q4: Determine the percent change in the $Q - point$ in this figure from β_{DC} = 100 to β_{DC} = 85.



7.4: Emitter–Feedback Bias

To calculate I_E, you can write Kirchhoff's voltage law (KVL) around the base circuit.

$$-V_{CC} + I_B R_B + V_{BE} + I_E R_E = 0 \rightarrow I_E R_E + I_B R_B = V_{CC} - V_{BE}$$

Substituting I_E / β_{DC} for I_B, you can see that I_E is still dependent on β_{DC}:

$$I_E R_E + \frac{I_E}{\beta_{DC}} R_B = V_{CC} - V_{BE} \rightarrow I_E = \frac{V_{CC} - V_{BE}}{R_E + \frac{R_B}{\beta_{DC}}} \quad \ldots (11)$$

Kirchhoff's voltage law applied around the collector circuit in Figure (3a) gives the following equation: $V_{CC} - I_C R_C - I_C R_E - V_{CE} = 0$

Solving for V_{CE}: $V_{CE} = V_{CC} - I_C (R_C + R_E) \quad \ldots (12)$

As described above, the collector feedback circuit results in poor stabilization if the collector or load resistance R_C is small compared with the base resistance R_B.

The emitter feedback bias shown in figure (3) proves promising in such a case and leads to good stabilization even for R_C equal to zero.

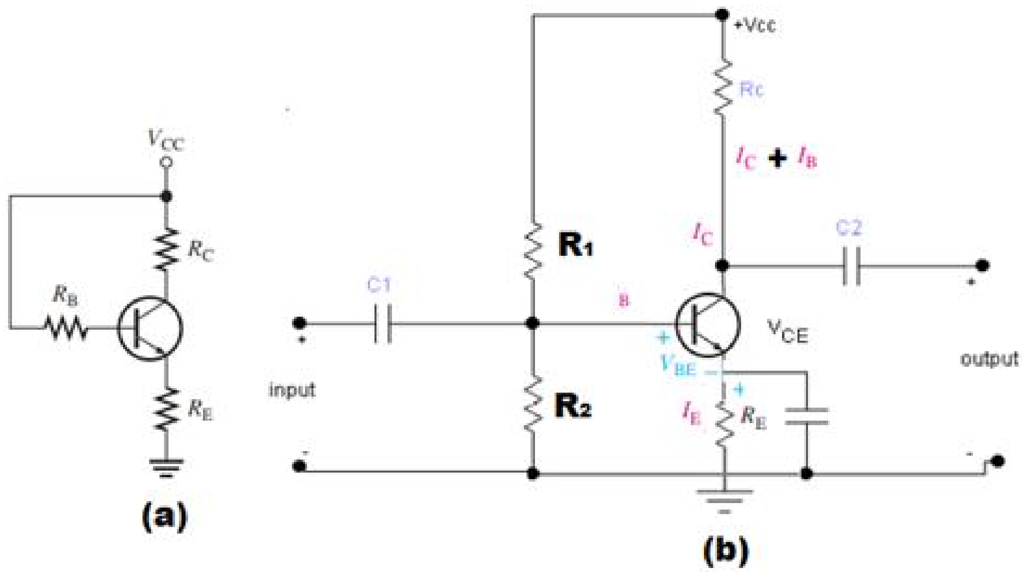


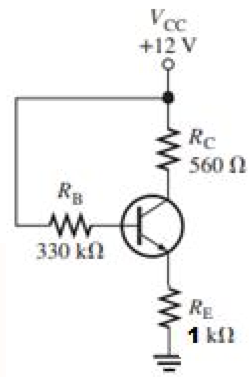
Figure (3): (a): Emitter-feedback bias. (b): Common emitter npn transistor with emitter-feedback bias.

The circuit consists of a network of four resistance R_1, R_2, R_E and R_C.

The dc voltage drops across R_E reverse biases the emitter base junction. However, a suitable parallel combination of resistance R_1 and R_2 produces a voltage drop V_B across R_2 which is greater than the drop across R_E and has opposite polarity this makes the emitter base junction forward biased. The resistance R_C reverse biases the collector base junction.

As I_C tends to increase owing to increase in I_{CO} which is caused by rise in temperature the current I_E increases. This increases the voltage drop across R_E which makes the base terminal less positive with respect to the emitter terminal. Hence the base current decreases which, in turn, decreases the collector current thus, we find that the emitter resistor R_E provides negative current feedback to the base that tends to maintain I_E at a constant value. Hence this bias is called the emitter feedback bias.

Example 3: Determine how much the $Q-point$ (I_C, V_{CE}) for the circuit in this figure will change over a temperature range where β_{DC} increases from 100 to 200.



Solution:

For $\beta_{DC} = 100$,

$$I_{C(1)} = I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{DC}} = \frac{12\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega + 330\text{ k}\Omega/100} = 2.63\text{ mA}$$

$$V_{CE(1)} = V_{CC} - I_{C(1)}(R_C + R_E) = 12\text{ V} - (2.63\text{ mA})(560\ \Omega + 1\text{ k}\Omega) = 7.90\text{ V}$$

For $\beta_{DC} = 200$,

$$I_{C(2)} = I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{DC}} = \frac{12\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega + 330\text{ k}\Omega/200} = 4.26\text{ mA}$$

$$V_{CE(2)} = V_{CC} - I_{C(2)}(R_C + R_E) = 12\text{ V} - (4.26\text{ mA})(560\ \Omega + 1\text{ k}\Omega) = 5.35\text{ V}$$

The percent change in I_C is

$$\%\Delta I_C = \left(\frac{I_{C(2)} - I_{C(1)}}{I_{C(1)}}\right)100\% = \left(\frac{4.26\text{ mA} - 2.63\text{ mA}}{2.63\text{ mA}}\right)100\% = \mathbf{62.0\%}$$

$$\%\Delta V_{CE} = \left(\frac{V_{CE(2)} - V_{CE(1)}}{V_{CE(1)}}\right)100\% = \left(\frac{7.90\text{ V} - 5.35\text{ V}}{7.90\text{ V}}\right)100\% = \mathbf{-32.3\%}$$

7.5: Voltage-Divider Bias

You will now study a method of biasing a transistor for linear operation using a single source resistive voltage divider. This is the most widely used biasing method.

Generally, **voltage-divider bias circuits** are designed so that the **base current (I_B) is much smaller than the current (I_2)** through R_2 in Figure (4).

In this case, the **voltage-divider circuit** *is very straightforward* to analyse because the loading effect of the base current ($I_{B(BASE)}$) **can be ignored**.

A voltage divider in which the base current **(I_B)** is small compared to the current **(I_2)** in R_2 is *said to be* a **stiff voltage divider** because the **base voltage** *is relatively **independent*** of *different transistors* and *temperature effects*.

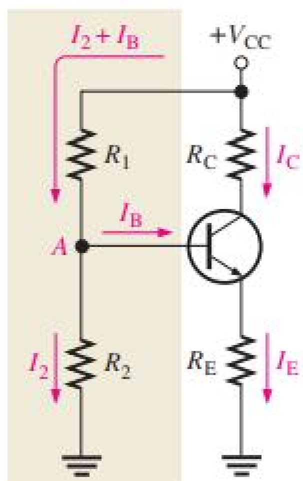


Figure (4): Voltage-divider bias.

To analyse a voltage-divider circuit in which I_B is small compared to I_2, first calculate the **voltage on the base** using the unloaded voltage-divider rule:

$$\boldsymbol{V_B} = \frac{R_2}{R_1 + R_2} V_{CC} \quad \dots (13)$$

Once you know the base voltage, you can find the voltages and currents in the circuit, as follows: $\boldsymbol{V_E} = V_B - V_{BE} \quad \dots (14)$

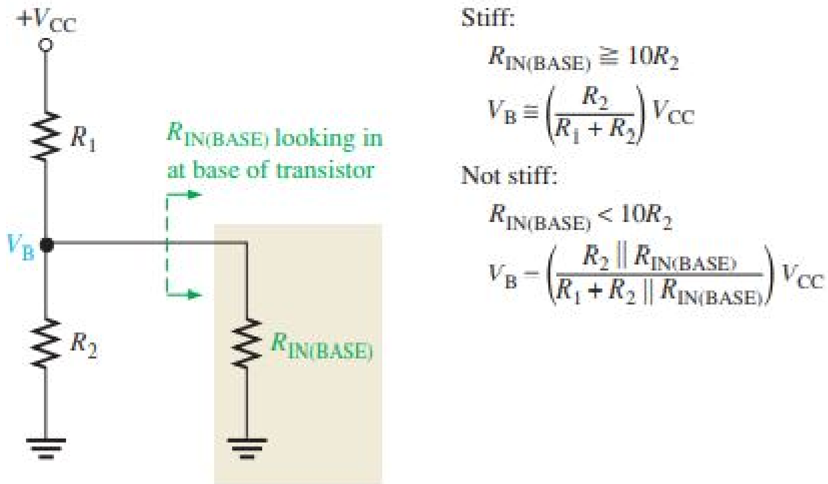
and $\boldsymbol{I_C} \cong \boldsymbol{I_E} = \frac{V_E}{R_E} \quad \dots (15)$

Then: $\boldsymbol{V_C} = V_{CC} - I_C R_C \quad \dots (16)$

Once you know $\boldsymbol{V_C}$ and $\boldsymbol{V_E}$, you can determine VCE.

$$\boldsymbol{V_{CE}} = V_C - V_E \quad \dots (17)$$

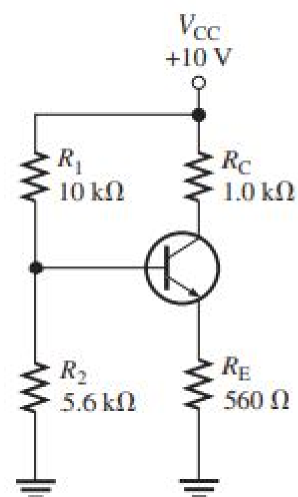
Voltage Divider with Load:



Loading Effects of Voltage-Divider Bias:

$$R_{IN\ (BASE)} = \frac{\beta_{DC}V_B}{I_E} \quad \dots (18)$$

Example 4: Determine V_{CE} and I_C in the stiff voltage-divider biased transistor circuit of this figure if $\beta_{DC} = 100$.



Solution:

The base voltage is:

$$V_B = \frac{R_2}{R_1 + R_2}V_{CC} = \frac{5.6 \times 10^3}{10 \times 10^3 + 5.6 \times 10^3}10 = 3.59\ V$$

So, $V_E = V_B - V_{BE} = 3.59 - 0.7 = 2.89\ V$

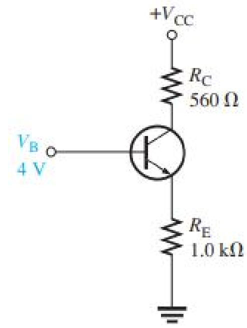
and $I_C \cong I_E = \frac{V_E}{R_E} = \frac{2.89}{560} = 5.16\ mA$

and $V_C = V_{CC} - I_C R_C = 10 - (5.16 \times 10^{-3} \times 1 \times 10^3) = 4.84\ V$

Therefore; $V_{CE} = V_C - V_E = 4.84 - 2.89 = 1.95\ V$

H.W: Q5: If the voltage divider in figure above was not stiff, how would V_B be affected?

Example 5: Determine the dc input resistance looking in at the base of the transistor in this figure. β_{DC} = 125 and V_B = 4 V.



Solution:

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E} = \frac{4 - 0.7}{1 \times 10^3} = 3.3\,mA$$

$$R_{IN\,(BASE)} = \frac{\beta_{DC} V_B}{I_E} = \frac{125 \times 4}{3.3 \times 10^{-3}} = 152\,K\Omega$$

H.W: Q6: What is $R_{IN\,(BASE)}$ in figure above if β_{DC} = 60 and V_B = 2 V?

Solution:

7.6: Thevenin's Theorem Applied to Voltage-Divider Bias

The equivalent circuit of figurer (3) obtained by applying the Thevenin's theorem to the left of the terminals BG is shown in figurer (5) the input and output voltage and the capacitor C_E are not shown.

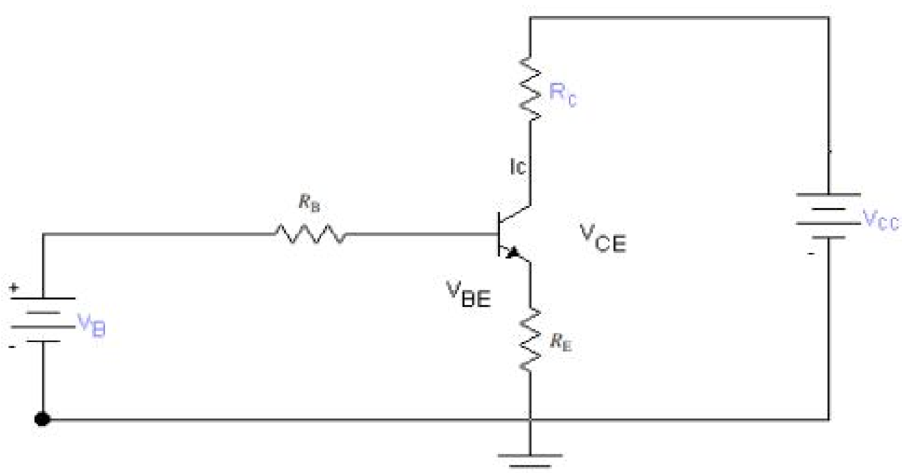


Figure (5): Equivalent circuit of figure (3).

The **Thevenin of equivalent base voltage V_B** is given by:

$$V_{TH} = V_B = \frac{R_2}{R_1 + R_2} V_{CC} \quad \dots (19)$$

The **Thevenin or equivalent base resistance R_B** is given by:

$$R_{TH} = R_B = \frac{R_1 R_2}{R_1 + R_2} \quad \dots (20)$$

Appling the Kirchhoff's voltage law to input circuit of figure (5), we get:

$$V_{TH} - V_{R_{TH}} - V_{BE} + V_{R_E} = 0$$

Substituting, using Ohm's law, and solving for V_{TH},

$$V_B = I_B R_B + V_{BE} - I_E R_E$$

The voltage V_{BE} **can be neglected** in comparison to V_B since in an npn transistor amplifier. Substituting $-(I_B + I_C)$ for I_E i.e.; $(I_E = -(I_B + I_C))$

$$V_B = I_B R_B + (I_B + I_C) R_E = I_B R_B + I_B R_E + I_C R_E = I_B (R_B + R_E) + I_C R_E$$

Then solving for I_B:

$$I_B = \frac{V_B - I_C R_E}{R_B + R_E} \quad \dots (21)$$

Substituting it in equation (5) ($I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CO}$), we obtain:

$$(1-\alpha) I_C = \alpha \frac{V_B - I_C R_E}{R_B + R_E} + I_{CO} \rightarrow (1-\alpha) I_C = \frac{\alpha V_B}{R_B + R_E} - \frac{\alpha R_E I_C}{R_B + R_E} + I_{CO}$$

$$\left(1 - \alpha + \frac{\alpha R_E}{R_B + R_E}\right) I_C = \frac{\alpha V_B}{R_B + R_E} + I_{CO} \rightarrow I_C = \frac{\frac{\alpha V_B}{R_B + R_E}}{1 - \alpha + \frac{\alpha R_E}{R_B + R_E}} + \frac{I_{CO}}{1 - \alpha + \frac{\alpha R_E}{R_B + R_E}}$$

The stability factor S is calculated as:

$$S = \frac{\partial I_C}{\partial I_{CO}} = \frac{1}{1 - \alpha + \frac{\alpha R_E}{R_B + R_E}} \rightarrow S = \frac{1}{1 - \frac{\alpha R_E + \alpha R_B}{R_B + R_E} + \frac{\alpha R_E}{R_B + R_E}} \rightarrow S = \frac{1}{1 - \frac{\alpha R_B}{R_B + R_E}} \dots (22)$$

Using equation ($\beta = \frac{\alpha}{1-\alpha} \rightarrow \alpha = \frac{\beta}{1+\beta}$), it becomes:

$$S = \frac{1}{1 - \alpha + \frac{\alpha R_E}{R_B + R_E}} = \frac{1}{\frac{\alpha}{\beta} + \frac{\alpha R_E}{R_B + R_E}} = \frac{1 \times \frac{\beta}{\alpha}}{\left(\frac{\alpha}{\beta} + \frac{\alpha R_E}{R_B + R_E}\right) \times \frac{\beta}{\alpha}} = \frac{1 + \beta}{\left(1 + \frac{\beta R_E}{R_B + R_E}\right)} \dots (23)$$

Equation (23) indicates that as $\frac{R_B}{R_E} \rightarrow 0$, $S \rightarrow 1$ and $\frac{R_B}{R_E} \rightarrow \infty$, $S \rightarrow 1 + \beta$.

Hence smaller the R_B or larger the R_E, better is the stabilization. For finite values of R_B, is always exceeds 1 which means I_C always increases faster than I_{CO}. keeping the $Q-point$ fixed, the stability can be improved by either decreasing R_B or increasing R_E. If R_B is reduced the R_1R_2 network draws more current from the supply which causes greater power loss. The increase in R_E (with fixed R_B), on the other hand, requires higher V_{CC} to maintain the same quiescent currents which again increases the power loss or decreases in efficiency of the device.

When this circuit is used for amplification of ac signals, the ac voltage drops across R_E produces unwanted negative feedback which reduces the gain of the amplifier. This is avoided by connecting a large bypass capacitor C_E across R_E which has very small reactance at the lowest frequency of the input signal.

7.6.1: Voltage-Divider Biased NPN Transistor

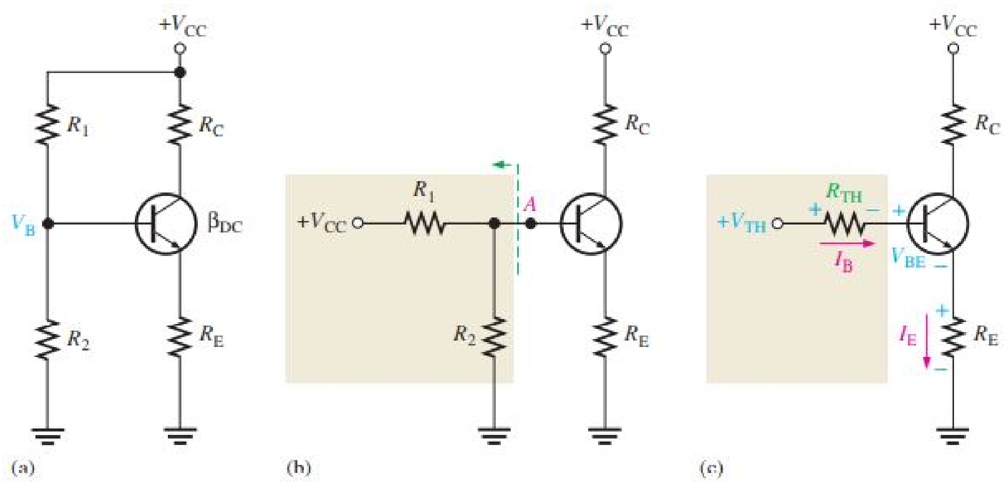


Figure (6): Thevenizing the bias circuit.

The Thevenin equivalent of the bias circuit, connected to the transistor base, is shown in the beige box in Figure (6c). Applying Kirchhoff's voltage law around the equivalent base-emitter loop gives:

$$V_{TH} - V_{R_{TH}} - V_{BE} - V_{R_E} = 0$$

Substituting, using Ohm's law, and solving for V_{TH},

$$V_B = I_B R_B + V_{BE} + I_E R_E$$

Substituting I_E/β_{DC} for I_B:

$$V_B = \frac{I_E}{\beta_{DC}} R_B + V_{BE} + I_E R_E$$

Then solving for I_E:

$$\boldsymbol{I_E} = \frac{V_B - V_{BE}}{R_E + \frac{R_B}{\beta_{DC}}} \quad \ldots (24)$$

If $\frac{R_B}{\beta_{DC}}$ ***is small*** compared to $\boldsymbol{R_E}$, the result is the same as for an unloaded voltage divider. Voltage-divider bias *is widely used* because reasonably **good bias stability** is achieved with a **single supply voltage**.

7.6.2: Voltage-Divider Biased PNP Transistor

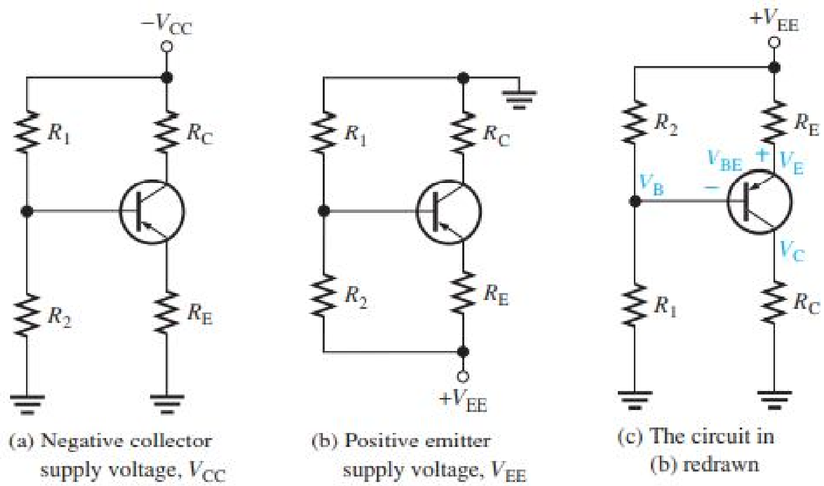


Figure (7): Voltage-divider biased *pnp* transistor.

The analysis procedure is the same as for an *npn* transistor circuit using Thevenin's theorem and Kirchhoff's voltage law, as demonstrated in the following steps with reference to Figure (7).
For Figure (7a), applying Kirchhoff's voltage law around the base-emitter circuit gives

$$V_{TH} + V_{R_{TH}} - V_{BE} + V_{R_E} = 0$$

Substituting, using Ohm's law, and solving for $\boldsymbol{V_{TH}}$,

$$\boldsymbol{V_B} = V_{BE} - I_B R_B - I_E R_E$$

The base current is: $I_B = I_E / \beta_{DC}$

$$\boldsymbol{V_B} = V_{BE} - \frac{I_E}{\beta_{DC}} R_B - I_E R_E \rightarrow \frac{I_E}{\beta_{DC}} R_B + I_E R_E = -V_B + V_{BE}$$

The equation for I_E is:

$$\boldsymbol{I_E} = \frac{-V_B + V_{BE}}{R_E + \frac{R_B}{\beta_{DC}}} \quad \ldots (25)$$

By Thevenin's theorem: $\boldsymbol{V_{TH}} = \boldsymbol{V_B} = \frac{R_2}{R_1+R_2} V_{CC}$ and $\boldsymbol{R_{TH}} = \boldsymbol{R_B} = \frac{R_1 R_2}{R_1+R_2}$

For Figure (7b), the analysis is as follows:

$$-V_{TH} + V_{R_{TH}} - V_{BE} + V_{R_E} + V_{EE} = 0$$

Substituting, using Ohm's law, and solving for V_{TH},

$$V_B = I_B R_B + I_E R_E - V_{BE} + V_{EE}$$

The base current is: $I_B = I_E / \beta_{DC}$

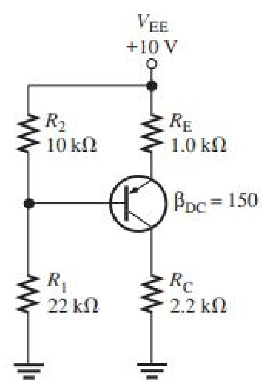
$$V_B = \frac{I_E}{\beta_{DC}} R_B + I_E R_E - V_{BE} + V_{EE} \rightarrow \frac{I_E}{\beta_{DC}} R_B + I_E R_E = V_B + V_{BE} - V_{EE}$$

The equation for I_E is:

$$I_E = \frac{V_B + V_{BE} - V_{EE}}{R_E + \frac{R_B}{\beta_{DC}}} \quad \dots (26)$$

By Thevenin's theorem: $V_{TH} = V_B = \frac{R_1}{R_1+R_2} V_{EE}$ and $R_{TH} = R_B = \frac{R_1 R_2}{R_1+R_2}$

Example 6: Find I_C and V_{EC} for the *pnp* transistor circuit in this figure.



Solution:

Apply Thevenin's theorem.

$$V_{TH} = \left(\frac{R_1}{R_1 + R_2}\right) V_{EE} = \left(\frac{22\,k\Omega}{22\,k\Omega + 10\,k\Omega}\right) 10\,V = (0.688)10\,V = 6.88\,V$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(22\,k\Omega)(10\,k\Omega)}{22\,k\Omega + 10\,k\Omega} = 6.88\,k\Omega$$

$$I_E = \frac{V_{TH} + V_{BE} - V_{EE}}{R_E + R_{TH}/\beta_{DC}} = \frac{6.88\,V + 0.7\,V - 10\,V}{1.0\,k\Omega + 45.9\,\Omega} = \frac{-2.42\,V}{1.0459\,k\Omega} = -2.31\,mA$$

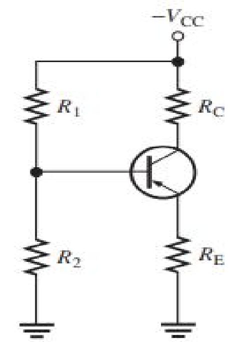
$$I_C = I_E = \mathbf{2.31\,mA}$$

$$V_C = I_C R_C = (2.31\,mA)(2.2\,k\Omega) = 5.08\,V$$

$$V_E = V_{EE} - I_E R_E = 10\,V - (2.31\,mA)(1.0\,k\Omega) = 7.68\,V$$

$$V_{EC} = V_E - V_C = 7.68\,V - 5.08\,V = \mathbf{2.6\,V}$$

Example 7: Find I_C and V_{CE} for a *pnp* transistor circuit with these values: R_1 = 68KΩ, R_2 = 47KΩ, R_C = 1.8KΩ, R_E = 2.2KΩ, V_{CC} = -6V, and β_{DC} = 75. Refer to this figure, which shows the schematic with a negative supply voltage.



Solution:

Apply Thevenin's theorem.

$$V_{TH} = V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{47 \times 10^3}{68 \times 10^3 + 47 \times 10^3}(-6) = -2.45\,V$$

$$R_{TH} = R_B = \frac{R_1 R_2}{R_1 + R_2} = \frac{68 \times 10^3 \times 47 \times 10^3}{68 \times 10^3 + 47 \times 10^3} = 27.8\,K\Omega$$

$$I_C \approx I_E = \frac{-V_B + V_{BE}}{R_E + \frac{R_B}{\beta_{DC}}} = -\frac{-(-2.45) + 0.7}{2.2 \times 10^3 + \frac{27.8 \times 10^3}{75}} = \frac{3.15}{2571} = 1.23\,mA$$

$I_C \approx -I_E = -1.23\,mA$

So, $V_E = -I_E R_E = -1.23 \times 10^{-3} \times 2.2 \times 10^3 = -2.71\,V$

and $V_C = V_{CC} - I_C R_C = -6 - (-1.23 \times 10^{-3} \times 1.8 \times 10^3) = -3.79\,V$

Therefore; $V_{CE} = V_C - V_E = -3.79 - (-2.71) = -1.08\,V$

SUMMARY:

- Loading effects are neglected for a stiff voltage divider.
- The dc input resistance at the base of a BJT is approximately $\beta_{DC}R_E$.
- Voltage-divider bias provides good $Q - point$ stability with a single-polarity supply voltage. It is the most common bias circuit.

- Emitter bias generally provides good $Q - point$ stability but requires both positive and negative supply voltages.
- The base bias circuit arrangement has poor stability because its $Q - point$ varies widely with β_{DC}.
- Emitter-feedback bias combines base bias with the addition of an emitter resistor.
- Collector-feedback bias provides good stability using negative feedback from collector to base.

KEY TERMS:

Feedback: The process of returning a portion of a circuit's output back to the input in such a way as to oppose or aid a change in the output.

Q-point: The dc operating (bias) point of an amplifier specified by voltage and current values.

Stiff Voltage Divider: A voltage divider for which loading effects can be neglected.

SELF-TEST: https://quizlet.com/520347124/chapter-5-transistor-bias-circuits-flash-cards/

1. The input resistance at the base of a biased transistor depends mainly on
   (a) β_{DC} (b) R_B (c) R_E (d) β_{DC} and R_E
2. In a voltage-divider biased transistor circuit such as in Figure (6), $R_{IN\ (BASE)}$ can generally be neglected in calculations when
   (a) $R_{IN\ (BASE)} > R_2$ (b) $R_2 > 10R_{IN\ (BASE)}$ (c) $R_{IN\ (BASE)} > 10R_2$ (d) $R_1 \ll R_2$
3. In a certain voltage-divider biased npn transistor, V_B is 2.95 V. The dc emitter voltage is approximately
   (a) 2.25 V (b) 2.95 V (c) 3.65 V (d) 0.7 V
4. Voltage-divider bias
   (a) cannot be independent of β_{DC} (b) can be essentially independent of β_{DC}
   (c) is not widely used (d) requires fewer components than all the other methods
5. Emitter bias is
   (a) essentially independent of β_{DC} (b) very dependent on β_{DC}
   (c) provides a stable bias point (d) answer (a) and (c)
6. In an emitter bias circuit, $R_E = 2.7\ K\Omega$ and $V_{EE} = 15\ V$. The emitter current
   (a) is 5.3 mA (b) is 2.7 mA (c) is 180 mA (d) cannot be determined
7. The disadvantage of base bias is that
   (a) it is very complex (b) it produces low gain
   (c) it is too beta dependent (d) it produces high leakage current
8. Collector-feedback bias is
   (a) based on the principle of positive feedback (b) based on beta multiplication
   (c) based on the principle of negative feedback (d) not very stable