Various biasing methods of BJT

Types of Transistor Biasing

The types of transistor biasing include:

- Fixed Bias Circuit
- Collector to Base bias Circuit
- Voltage Divider Bias
- Emitter Feedback

Fixed Bias (Base Resistor Bias)

The biasing circuit shown in Figure 1.4.1 has a base resistor R_B connected between the base and the V_{CC}. Here the base-emitter junction of the transistor is forward biased by the voltage drop across $R_{B,}$ which is the result of I_B flowing through it.

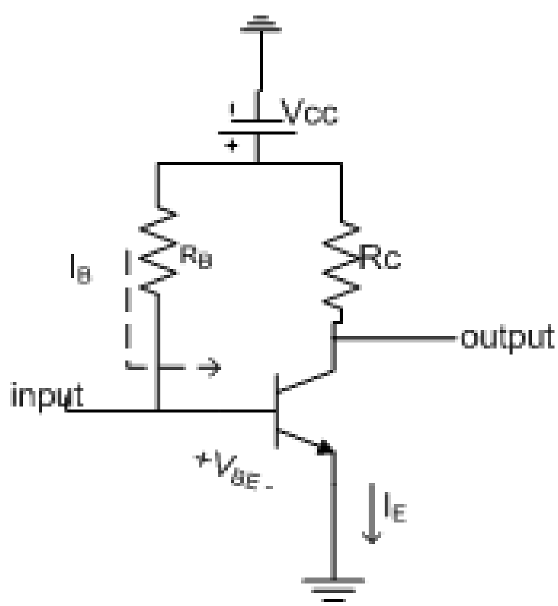

Figure 1.4.1 Fixed bias circuit

Diagram Source Brain Kart

The Figure 1.4.1 shows the fixed bias circuit. It is the simplest d.c. bias configuration. For the d.c. analysis we can replace capacitor with an open circuit because the reactance of a capacitor for d.c. is

$$X_C = 1/2\pi fC = 1/2\pi(0)C = \infty.$$

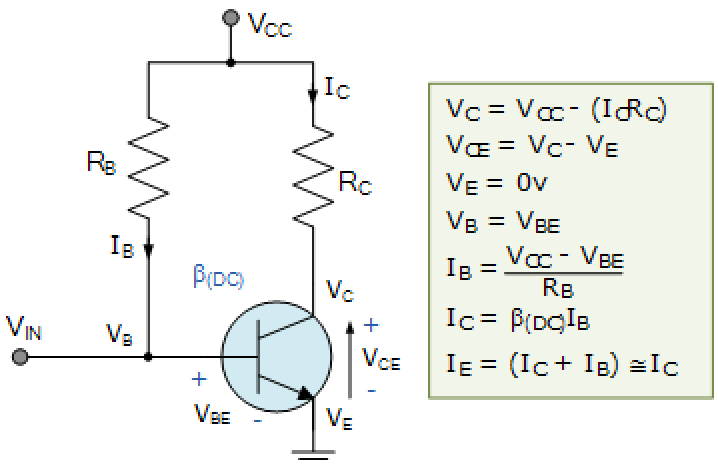

Figure 1.4.2 DC Analysis Fixed bias circuit

Diagram Source Brain Kart

In the base circuit figure 1.4.2,

Apply KVL, we get

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

Therefore,

$I_B = (V_{CC} - V_{BE})/R_B$

For a given transistor, V_{BE} does not vary significantly during use. As V_{CC} is of fixed value, on selection of R_B, the base current I_B is fixed. Therefore this type is called *fixed bias* type of circuit.

In the Collector circuit

Apply KVL, we get

$V_{CC} = I_C R_C + V_{CE}$

Therefore,

$V_{CE} = V_{CC} - I_C R_C$

The common-emitter current gain of a transistor is an important parameter in circuit design, and is specified on the data sheet for a particular transistor. It is denoted as β.

$I_C = \beta I_B$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$

$$V_{CE} = V_C - V_E$$

$$V_{BE} = V_B - V_E$$

In this circuit $V_E = 0$

$$V_{BE} = V_B$$

$$V_{CE} = V_C$$

Stability factor S for Fixed bias circuit

Stability factor S

$$I_B \cong \frac{V_{CC}}{R_B}$$

When I_B changes by ∂I_B, V_{CC} and V_{BE} are unaffected.

$\therefore \frac{\partial I_B}{\partial I_C} = 0 \quad \because I_C$ is not present in the equation.

Substituting this value in equation , we get,

$$S = \frac{1+\beta}{1-\beta(\partial I_B / \partial I_C)} = \frac{1+\beta}{1-0}$$

$$\therefore \quad S = 1 + \beta$$

Merits:

- It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).
- A very small number of components are required.

Demerits:

- The collector current does not remain constant with variation in temperature or power supply voltage. Therefore the operating point is unstable.
- Changes in V_{be} will change I_B and thus cause R_E to change. This in turn will alter the gain of the stage.
- When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.
- For small-signal transistors (e.g., not power transistors) with relatively high values of β (i.e., between 100 and 200), this configuration will be prone to thermal runaway. In particular, the stability factor, which is a measure of the change in collector current with changes in reverse saturation current, is approximately β+1. To ensure absolute stability of the amplifier, a stability factor of less than 25 is preferred, and so small-signal transistors have large stability factors.

Usage:

Due to the above inherent drawbacks, fixed bias is rarely used in linear circuits (i.e., those circuits which use the transistor as a current source). Instead, it is often used in circuits where transistor is used as a switch. However, one application of fixed bias is to achieve crude automatic gain control in the transistor by feeding the base resistor from a DC signal derived from the AC output of a later stage.

Collector to Base Bias

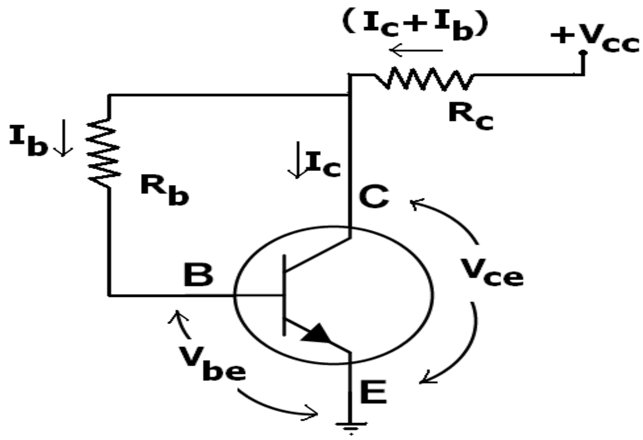

Figure 1.4.3 Collector to Base Bias circuit

Diagram Source Brain Kart

Figure 1.4.3 shows the dc bias with voltage feedback. It is also called as collector to base bias circuit. It is an improvement over fixed bias method. In this, biasing resistor is connected between collector and base of the transistor to provide feedback path.

Circuit analysis:

Base circuit:

Consider the base circuit in figure 1.4.4 and applying voltage law then we get,

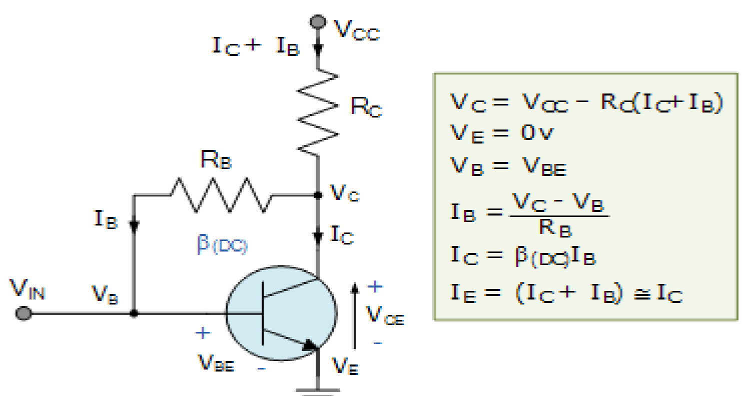

Figure 1.4.4 DC Analysis Collector to Base Bias circuit

Diagram Source Brain Kart

$$V_{CC} - (I_B + I_C) R_C - I_B R_B - V_{BE} = 0$$

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

$$= (R_B + R_C) I_B + \beta I_B R_C + V_{BE}$$

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

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_C}} \qquad \because \beta >> 1$$

Only the difference between the equation for I_B and that obtained for fixed bias configuration is βR_C, so the feedback path results in a reflection of the resistance R_C to the input circuit.

Collector circuit:

Applying KVL to the collector circuit,

$$V_{CC} - (I_C + I_B) R_C - V_{CE} = 0$$

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

If there is a change in β due to piece to piece variation between transistors or if there is a change in β and I_{CO} due to the change in temperature. So collector current tends to increase. As a result, voltage drop across R_C increases. Due to reduction in V_{CE}, I_B reduces. The result is that the circuit tends to maintain a stable value of collector current, keeping the Q point fixed.

In this circuit, R_B appears directly across input and output. A part of output is feedback to the input. And increase in collector current decreases the base current. So negative feedback exists in the circuit. It is also called as voltage feedback bias circuit.

Modified collector to base bias circuit:

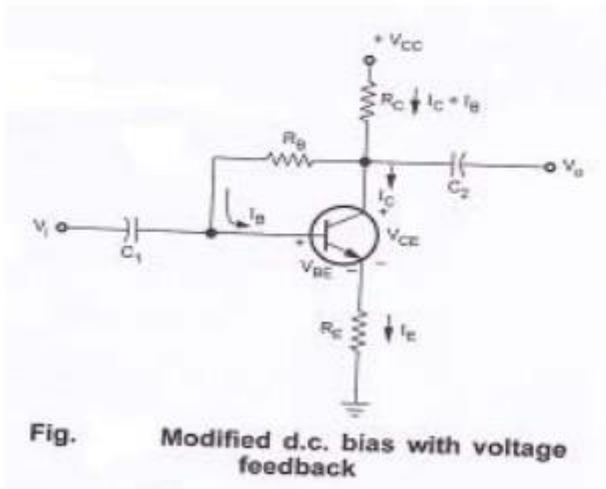

Figure 1.4.5 Modified collector to base bias circuit

Diagram Source Brain Kart

To improve the level of stability, emitter resistance is connected in this circuit.

Base circuit:

Applying KVL to base circuit in figure 1.4.5,

$$V_{CC} – (I_C + I_B\,) RC – I_BR_B – V_{BE} – I_ER_E = 0$$

$$I_B = [V_{CC} – V_{BE}\,] / [R_B + (1+\beta)\,(R_C + R_E)]$$

$$I_B = \quad [V_{CC} – V_{BE}]/ [R_B + \beta\,(R_C + R_E)]$$

Only difference between the equation for I_B and that obtained for the fixed bias configuration is the term β (R_C + R_E).So feedback path results in a reflection of the resistance R_C back to the input circuit.

In general,

$I_B = V' / R_B + \beta R'$

Where $V' = V_{CC} - V_{BE}$

$R' = 0$ for fixed bias

$R' = R_E$ for emitter bias

$R' = R_C$ for collector to base bias

$R' = R_C + R_E$ for collector to base bias with R_E

Collector circuit:

Applying KVL to collector circuit,

$V_{CC} – (I_C+I_B) RC – V_{CE} – I_ER_E = 0$

$V_{CE} = V_{CC} – I_E (R_C+R_E)$

Stability factor S for collector to base bias circuit:

$V_{CC} = I_C RC – I_{B(}R_B+R_C) + V_{BE}$

When I_{CBO}, I_B and I_C changes with no effect on VCC and V_{BE}, the equation becomes,

$S = [1+\beta] / 1+\beta (R_C/ (R_C+R_B))$

$$S = \frac{1+\beta}{1+\beta (R_C/ (R_C+R_B))}$$

Collector to base bias circuit is having lesser stability factor than for fixed bias circuit. So this circuit provides better stability than fixed bias circuit.

Voltage divider bias circuit:

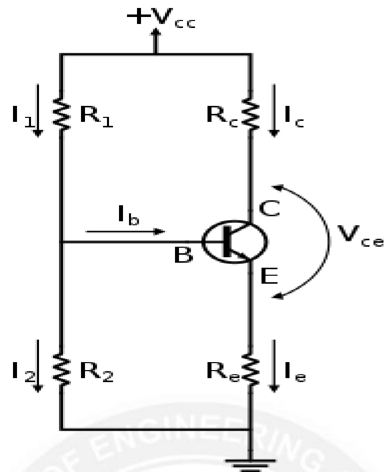

Figure 1.4.6 Voltage divider bias circuit

Diagram Source Brain Kart

Figure 1.4.6 shows the voltage divider bias circuit. In this, biasing is provided by three resistors R_1, R_2 and R_E. The resistors R_1& R_2 act as a potential divider giving a fixed voltage to base. If collector current increases due to change in temperature or change in β, emitter current I_E also increases and voltage drop across R_E increases thus reducing the voltage difference between base and emitter. Due to reduction in base emitter voltage, base current and collector current reduces. So we can say that negative feedback exists in emitter bias circuit. This reduction in collector current compensates for the original change in I_C.

Circuit analysis:

Base circuit:

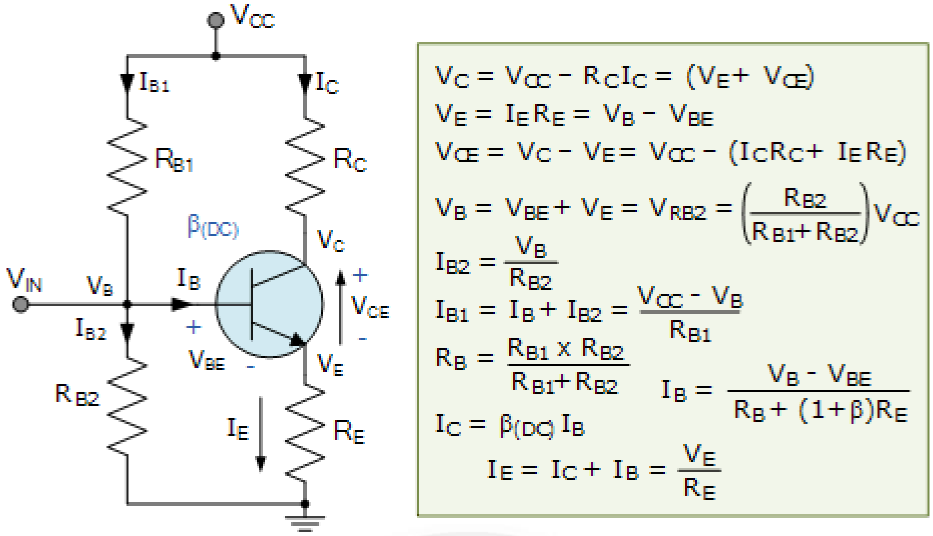

Figure 1.4.7 Voltage divider bias circuit Base circuit

Diagram Source Brain Kart

Let us consider figure 1.4.7 the base circuit as shown in above figure. Voltage across R_2 is base voltage V_B. Applying voltage divider rule to find V_B

$$V_B = \frac{R_2 (I)}{R_1 (I+I_B) + R_2 (I)} * V_{CC}$$

$$= \frac{R2}{R_1+R_2} * V_{CC} \qquad \text{with } I >> I_B$$

Collector circuit:

Let us consider the collector circuit as shown in above figure 1.4.7 . Voltage across R_E can be obtained as,

$$V_E = I_E R_E = V_B - V_{BE}$$

$$I_E = \frac{V_B - V_{BE}}{R_E}$$

Apply KVL to collector circuit,

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

Simplified circuit of voltage divider bias

Thevenin's equivalent circuit for voltage divider bias From above figure 1.4.7 , R_1 and R_2 are replaced by R_B and V_T. Where R_B is the parallel combination of R=1 and R_2 V_T is the thevenin's voltage

$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$

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

$$V_T = V_{BE} + (R_B + R_E) I_B + I_C R_E$$

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

Stability factor for voltage divider bias:

Stability factor S:

For determining stability factor S for voltage divider bias, consider the equivalent circuit. Thevenin's voltage is given by,

$$V_T = \frac{R_2 \times V_{CC}}{R_1 + R_2}$$

R_1, R_2 are replaced by R_B which is the parallel combination of R_1 and R_2.

$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$

Apply KVL to base circuit,

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E$$

Differentiating with respect to I_C and considering V_{BE} to be independent of I_C,

$$0 = \frac{\partial I_B}{\partial I_C} \times R_B + \frac{\partial I_B}{\partial I_C} \times R_E + R_E$$

$$\frac{\partial I_B}{\partial I_C}(R_E + R_B) = -R_E$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_E + R_B}$$

Stability factor S is given by,

$$S = \frac{1+\beta}{1-\beta(\partial I_B/\partial I_C)}$$

From above equation, the following points are observed.

1. The ratio R_B /R_E controls value of stability factor S. If $R_B/R_E << 1$ then it is reduced to S = (1+β). 1/ (1+β) = 1

Practically R_B/R_E not equal to zero. But to have better stability factor S , we have to keep ratio R_B/R_E as small as possible.

2. To keep R_B/R_E small, it is necessary to keep R_B small. Due to small value of R_1 and R_2, potential divider circuit will draw more current from V_{CC} reducing the life of the battery. Another important aspect is that reducing R_B will reduce input impedance of the circuit, since R_B comes in parallel with the input. This reduction of input impedance in amplifier circuit is not desirable and hence R_B cannot be made very small.

3. Emitter resistance R_E is another parameter, it is used to decrease the ratio R_B/R_E. Drop across R_C will reduce. This shifts the operating point Q which is not desirable and hence there is limit for increasing R_E.

While designing voltage divider bias circuit, the following conditions are to be satisfied,

S – Small

RB - Reasonably small

RE - Not very large

4. If ratio R_B/R_E is fixed, S increases with β. So stability decreases with increasing β.
5. Stability factor S is essentially independent of β for small value of S.

Substituting the differentiation value of I_B/I_C,

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

Dividing each term by R_E,

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

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

Transistor Biasing with Emitter Feedback

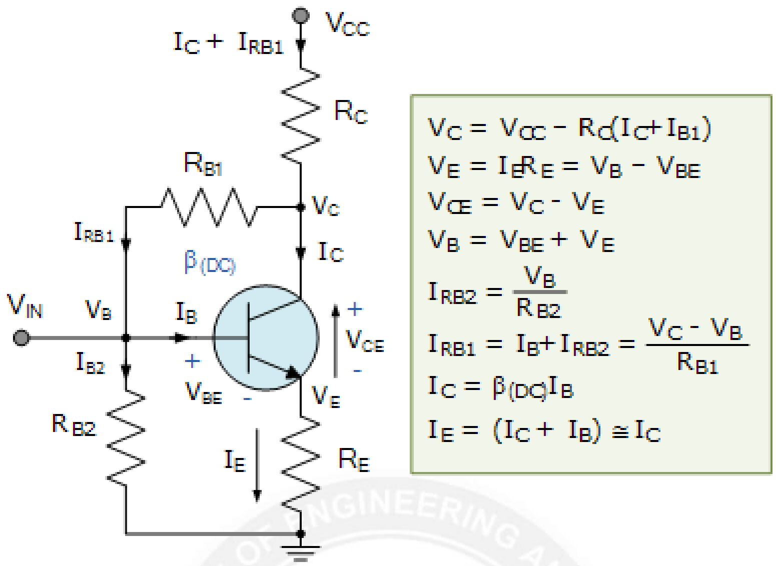

Figure 1.4.8 Transistor Biasing with Emitter Feedback circuit

Diagram Source Brain Kart

This type of transistor biasing configuration, often called self-emitter biasing, uses both emitter and base-collector feedback to stabilize the collector current even further. This is because resistors R_{B1} and R_E as well as the base-emitter junction of the transistor are all effectively connected in series as shown in the figure 1.4.8 with the supply voltage, V_{CC} .

The downside of this emitter feedback configuration is that it reduces the output gain due to the base resistor connection. The collector voltage determines the current flowing through the feedback resistor, R_{B1} producing what is called “degenerative feedback”.

The current flowing from the emitter, I_E (which is a combination of $I_C + I_B$) causes a voltage drop to appear across R_E in such a direction, that it reverse biases the base-emitter junction.

So if the emitter current increases, due to an increase in collector current, voltage drop I*R_E also increases. Since the polarity of this voltage reverse biases the base-emitter junction, I_B automatically decrease. Therefore the emitter current increase less than it would have done had there been no self biasing resistor.

Generally, resistor values are set so that the voltage dropped across the emitter resistor R_E is approximately 10% of V_{CC} and the current flowing through resistor R_{B1} is 10% of the collector current I_C.

Thus this type of transistor biasing configuration works best at relatively low power supply voltages.