EE 204 - Analog Circuits
Lecture 5

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Contents

1 Bipolar Junction Transistors

A form of transistor that employs both electrons and electron holes as charge carriers is known as a bipolar junction transistor (BJT).

1.1 Transistor Configurations

A transistor may be connected in any one of three basic configurations:

1. Common Emitter (CE)
2. Common Base (CB)
3. Common Collector (CC)

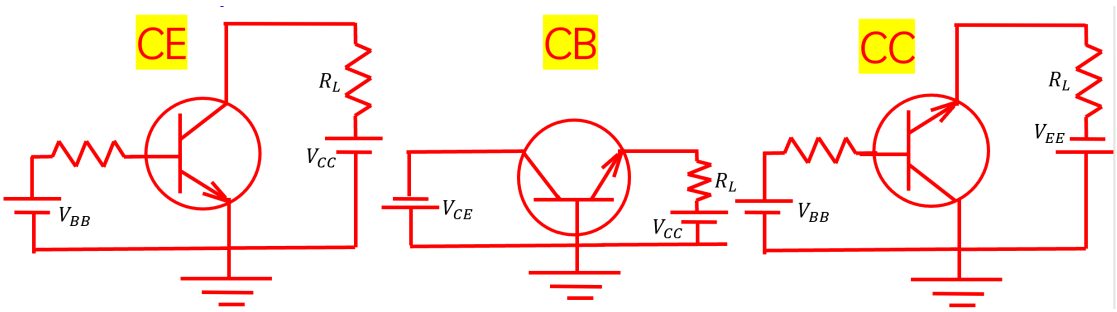


Figure 1: Transistor Configurations (for NPN transistor)

The term common is used to denote the element that is common to both input and output circuits.

1.2 Normal Operation of Transistor

- Emitter-Base Junction (J_{EB}) should be forward bias.
- Collector-Base Junction (J_{CB}) should be reverse bias.

1.3 Transistor Characteristics

Transistor Characteristics

Input — I_{input} vs V_{input} — *Output voltage is parameter*

Output — I_{output} vs V_{output} — *Input current is parameter*

In CE configuration,

- Input: $I_B(mA)$ vs $V_{BE}(V)$. $V_{CE}(V)$ is the parameter.
- Output: $I_C(mA)$ vs $V_{CE}(V)$. $I_B(mA)$ is the parameter.

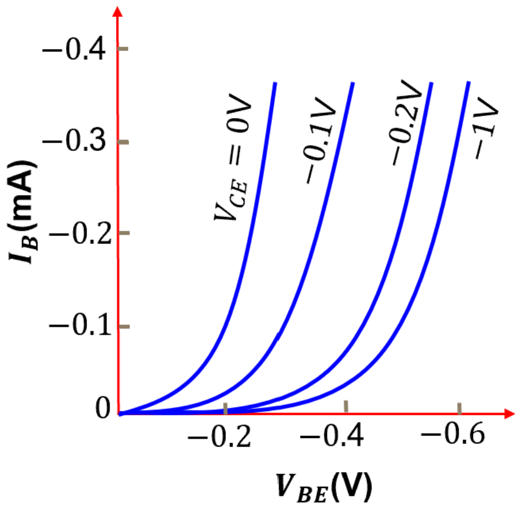


Figure 2: Input Characteristics (in CE configuration)

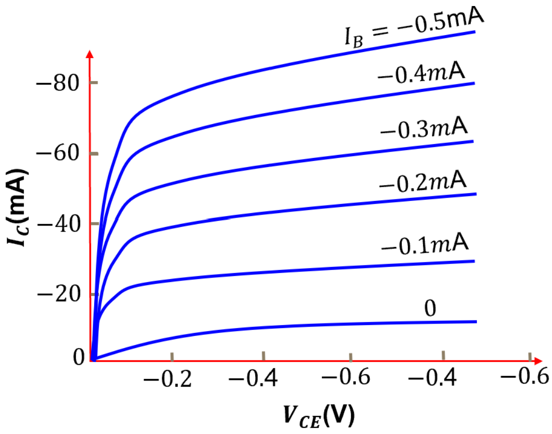


Figure 3: Output Characteristics (in CE configuration)

2 Transistors and Biasing

The operation of a BJT involves controlling the flow of current between the emitter and collector terminals by varying the current at the base terminal.

To make a BJT work properly, it needs to be biased. Biasing involves applying appropriate voltages to the emitter-base and collector-base junctions to ensure the transistor operates in the desired region. There are three common biasing modes(4):

1. **Active Mode:** In this mode, the base-emitter junction is forward-biased, allowing a small current to flow from emitter to base. This current controls the much larger collector current, resulting in amplification.
2. **Cut-off Mode:** The base-emitter junction is reverse-biased, preventing any significant current from flowing between emitter and base. This turns the transistor off.
3. **Saturation Mode:** Both the base-emitter and base-collector junctions are forward-biased, allowing maximum current to flow from collector to emitter. The transistor is effectively "ON" in this mode.

3 Q-point

The Q-point is the operating point of a transistor (Refer 4). It's the point on the output characteristic curve that represents the DC voltage or current at a specified terminal of an active device with no input signal applied. The goal of Transistor Biasing is to establish a known quiescent operating point, or Q-point for the bipolar transistor to work efficiently and produce an undistorted output signal.

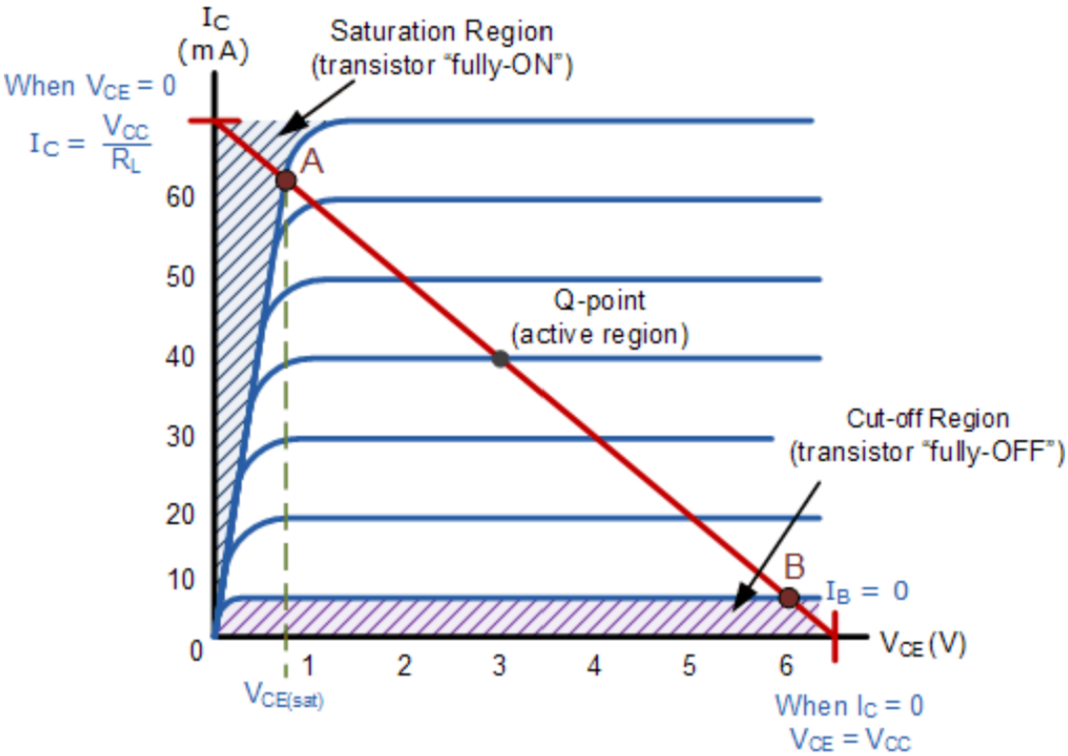


Figure 4: Operating Regions of a BJT

In other words, the Q-point is the point on the load line that represents the collector current and collector-emitter voltage when no signal is present. The Q-point is also called the operating point or bias point. The Q-point is important because it determines the class of operation for the amplifier circuit. If the Q-point is set too low, then the amplifier will not be able to amplify signals to their full extent. If it is set too high, then the amplifier will be in saturation and will not be able to amplify signals at all.

3.1 Considerations for Q-point

The choice of Q-point is determined by -

- The availability of supply voltage
- The load resistance of amplifiers
- The amplitude of the signal to be amplified
- The allowable distortion of the output signal

The operating point can change due to the instability of the collector current I_C. There are three sources for the instability of I_C -

- The reverse saturation current I_{CO}: This is the current that flows through the collector-emitter junction when the base is biased at zero volts. I_{CO} doubles for every 10° Celsius rise in temperature.
- The base-emitter voltage V_{BE}: This is the voltage drop across the base-emitter junction. V_{BE} falls at the rate of 2.5 mV per ° Celsius for both Ge and Si transistors.
- The current gain β: This is the ratio of the collector current to the base current. β increases with temperature.
- The effect of the change in V_{BE} is ignored here because the transistor is assumed to be in the active region, where I_C is practically independent of V_{BE}.

4 Biasing

In general, there are three biasing methods, namely:

1. Fixed Bias (FB)
2. Collector to Base Bias (CB)
3. Self/Emitter Bias

4.1 Fixed Bias

A fixed bias transistor circuit is a type of transistor biasing configuration that uses a fixed resistor to set the collector current.

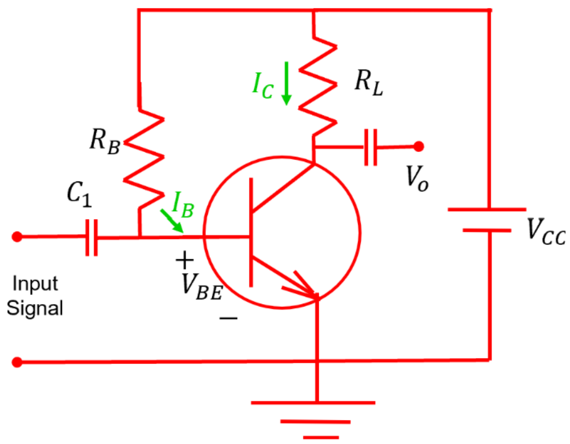


Figure 5: Fixed Bias

According to the circuit:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

The collector current is,

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

$$\therefore I_C = \beta \frac{V_{CC} - V_{BE}}{R_B} + (\beta + 1)I_{CO}$$

4.1.1 Stability Factors

Smaller the stability factor, better the stability of Q-point

$$\boxed{S = \frac{\delta I_c}{\delta I_{CO}} = \beta + 1}$$

$$\boxed{S' = \frac{\delta I_c}{\delta V_{BE}} = -\frac{\beta}{R_B}}$$

$$\boxed{S'' = \frac{\delta I_c}{\delta \beta} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO} = \frac{V_{CC}}{R_B}\ I_{CO}}$$

Figure 6: Fixed Bias

4.2 Collector to Base Bias

In this type of biasing base resistor is connected between the collector and base terminals

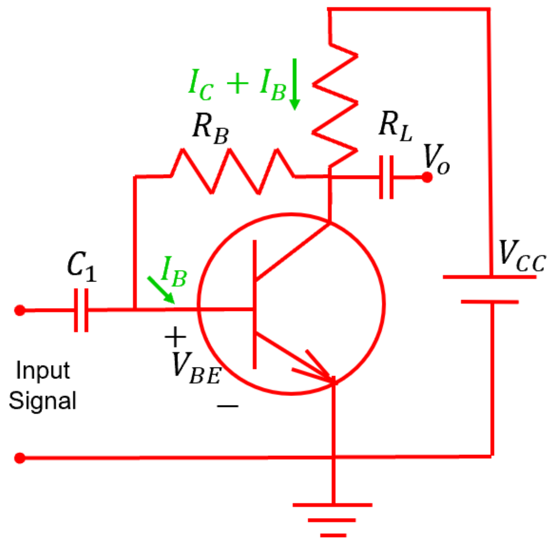


Figure 7: Collector to Base Bias

The equation for collector current using Kirchoff's law is:

$$I_C\left(1+\frac{\beta R_L}{R_B+R_L}\right)=\beta\frac{(V_{CC}-V_{BE})}{R_B+R_L}+(\beta+1)\,I_{CO}$$

4.2.1 Stability Factors

$$\boxed{\boldsymbol{S}=\frac{\delta I_c}{\delta I_{CO}}=\frac{\boldsymbol{\beta}+1}{1+\boldsymbol{\beta}R_L/(R_L+R_B)}}$$

$$\boxed{\boldsymbol{S'}=\frac{\delta I_c}{\delta V_{BE}}=-\frac{\boldsymbol{\beta}}{R_B+R_L(\boldsymbol{\beta}+1)}}$$

$$\boxed{\boldsymbol{S''}=\frac{\delta I_c}{\delta \boldsymbol{\beta}}=\frac{V_{CC}-V_{BE}-I_C R_L+(R_B+R_L)\,I_{CO}}{R_B+R_L(\boldsymbol{\beta}+1)}}$$

$$\boldsymbol{V_{BE} \ll V_{CC}} \qquad \boxed{\boldsymbol{S''}=\frac{\delta I_c}{\delta \boldsymbol{\beta}}=\frac{V_{CC}-I_C R_L+(R_B+R_L)\,I_{CO}}{R_B+R_L(\boldsymbol{\beta}+1)}}$$

Figure 8: CB Bias

4.3 Emitter Bias

A self-bias transistor circuit is a type of transistor biasing configuration that uses negative feedback to stabilize the collector current

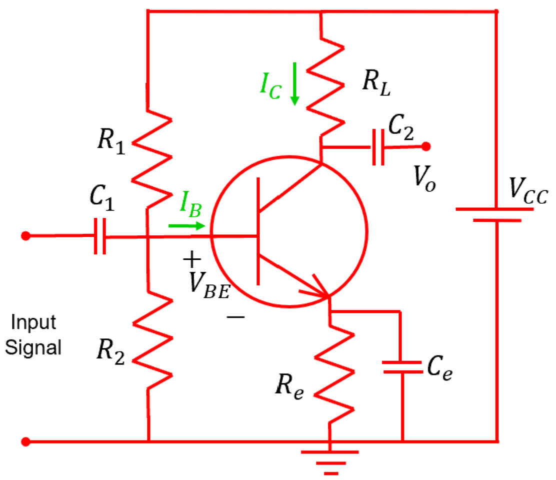
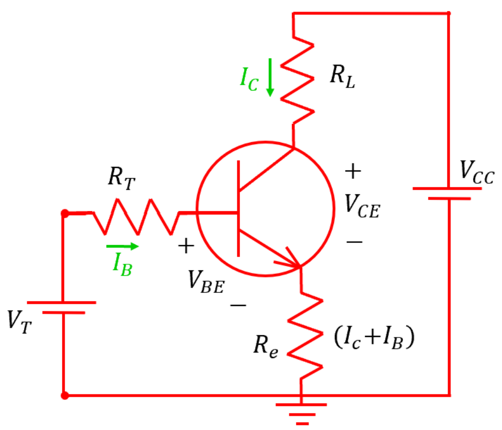


Figure 9: Emitter Bias

The base emitter terminal portion can be simplified using thevenin theorem



Thevenin source

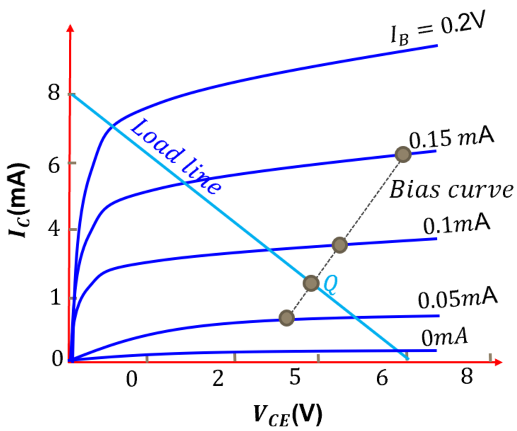
$$V_T = \frac{R_2 V_{CC}}{R_1 + R_2}$$

Thevenin resistance

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

Figure 10: Emitter Bias

Load Line and Bias Curve Representation for Emitter Bias Circuit.



LOADLINE

$$V_{CE} = -I_C(R_L + R_e) + V_{CC}$$

Load line slope: $-(R_L + R_e)$

BIAS CURVE

$$I_B R_T + V_{BE} + (I_B + I_C)R_e = V_T$$

A relation between V_{CE} and I_B to be achieved. For each vale of I_B marked on the collector curves, V_{CE} calculated from the relationship. The interaction of the dc loadline and the bias curve gives the quiescent point Q.

Figure 11: Emitter Bias Curve

4.3.1 Stability Factors

The collector current can be represented as $I_C = \beta\, I_B + (\beta + 1)\, I_{CO}$

The base current can be represented as $I_B = \dfrac{V_T - V_{BE} - I_C R_e}{R_T + R_e}$

Using above 2 eqn: $\boxed{I_C\left(1 + \dfrac{\beta R_e}{R_T + R_e}\right) = \dfrac{\beta V_T}{R_T + R_e} - \dfrac{\beta V_{BE}}{R_T + R_e} + (\beta + 1)\, I_{CO}}$

$$\boxed{\boldsymbol{S} = \frac{\delta I_c}{\delta I_{CO}} = \frac{\boldsymbol{\beta} + 1}{1 + \boldsymbol{\beta} R_e/(R_T + R_e)} = (\boldsymbol{\beta} + 1)\frac{\mathbf{1} + R_T/R_e}{1 + \boldsymbol{\beta} + R_T/R_e)}}$$

$$\boxed{\boldsymbol{S'} = \frac{\delta I_c}{\delta V_{BE}} = -\frac{\boldsymbol{\beta}}{R_T + R_e(\boldsymbol{\beta} + 1)}}$$

$$\boxed{\boldsymbol{S''} = \frac{\delta I_c}{\delta \boldsymbol{\beta}} = \frac{1}{\boldsymbol{\beta}(\boldsymbol{\beta} + 1)}\left[I_C \frac{(R_T + R_e)(\boldsymbol{\beta} + 1) - \boldsymbol{\beta S} I_{CO}}{R_T + R_e} - \boldsymbol{S} I_{CO}\right]}$$

Figure 12: Emitter Bias

4.4 Introduction to Bias Compensation Circuits

Now, after learning the basic transistor circuits, we can modify our circuits for better control and advantages.

Some of the (bias compensation) circuits which we would analyse in the upcoming lectures are :

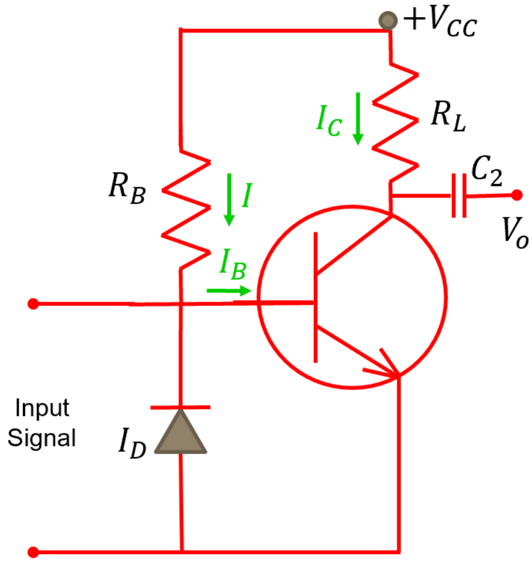


Figure 13: Bias Compensation with Diode

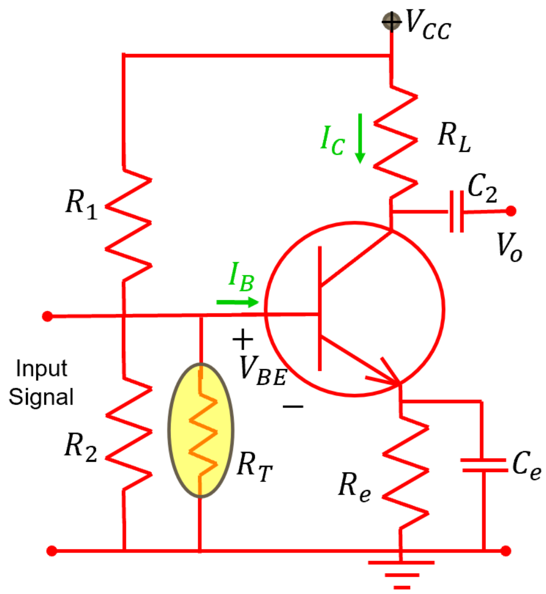


Figure 14: Bias Compensation using a Thermistor