

Bipolar Junction Transistor (BJT)

Introduction

BJT consists of 2 PN junctions shown in the figure 1.1.1. It has three terminals: emitter, base and collector. Transistor can be operated in three regions, namely cut-off, active and saturation by applying proper biasing conditions.

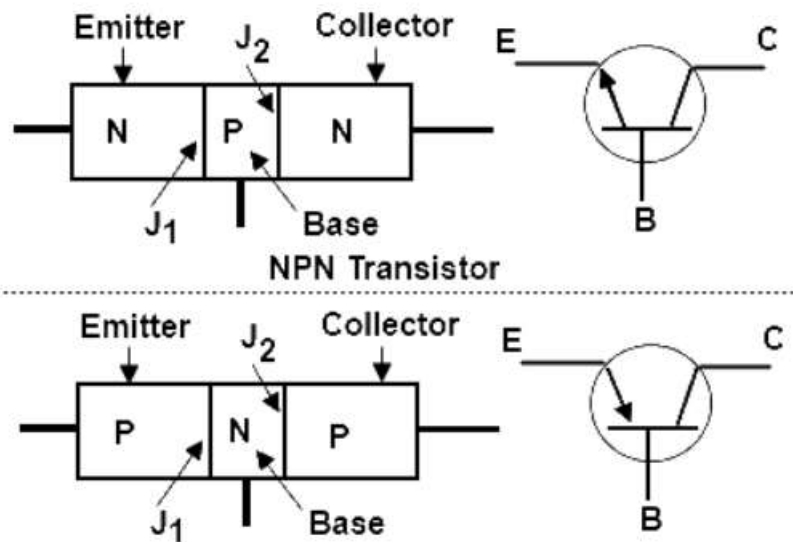


Figure 1.1.1 PN Junctions of BJT

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Active Region:

- Most important mode, e.g. for amplifier operation and switching application
- The region where current curves are practically flat.

Saturation:

- Barrier potential of the junctions cancels each other out causing a virtual short.
- Ideal transistor behaves like a closed switch.

Cutoff:

- Current reduced to zero
- Ideal transistor behaves like an open switch.

In order to operate transistor in the desired region we have to apply external d.c. voltages of correct polarity and magnitude to the two junctions of the transistor. This is nothing but the biasing of the transistor.

When we bias a transistor we establish a certain current and voltage conditions for the transistor. These conditions are known as operating conditions or d.c. operating point or quiescent point. The operating point must be stable for proper operation of the transistor. However, the operating point shifts with changes in transistor parameters such as β , I_{CO} and V_{BE} . As transistor parameters are temperature dependent, the operating point also varies with changes in temperature.

Bipolar Transistor Configurations

As the **Bipolar Transistor** is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor vary with each circuit arrangement.

- Common Base Configuration – has Voltage Gain but no Current Gain.
- Common Emitter Configuration – has both Current and Voltage Gain.
- Common Collector Configuration – has Current Gain but no Voltage Gain.

The Common Base (CB) Configuration

As its name suggests, in the **Common Base** or grounded base configuration, the BASE connection is common to both the input signal AND the output signal. The input signal is applied between the transistors base and the emitter terminals, while the corresponding output signal is taken from between the base and the

collector terminals as shown. The base terminal is grounded or can be connected to some fixed reference voltage point.

The input current flowing into the emitter is quite large as its the sum of both the base current and collector current respectively therefore, the collector current output is less than the emitter current input resulting in a current gain for this type of circuit of “1” (unity) or less, in other words the common base configuration “attenuates” the input signal.

The Common Base Transistor Circuit shown in the figure 1.1.2

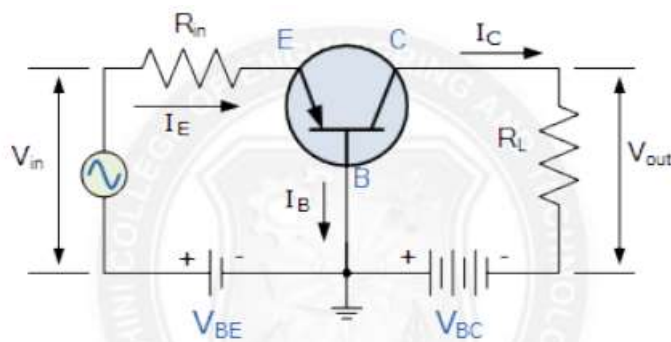


Figure 1.1.2 Common Base Transistor Circuit

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This type of amplifier configuration is a non-inverting voltage amplifier circuit, in that the signal voltages V_{in} and V_{out} are “in-phase”. This type of transistor arrangement is not very common due to its unusually high voltage gain characteristics. Its input characteristics represent that of a forward biased diode while the output characteristics represent that of an illuminated photo-diode.

Also this type of bipolar transistor configuration has a high ratio of output to input resistance or more importantly “load” resistance (R_L) to “input” resistance (R_{in}) giving it a value of “Resistance Gain”. Then the voltage gain (A_v) for a common base configuration is therefore given as:

Common Base Voltage Gain

$$A_V = \frac{V_{out}}{V_{in}} = \frac{I_C \times R_L}{I_E \times R_{IN}}$$

Where: I_C/I_E is the current gain, alpha (α) and R_L/R_{in} is the resistance gain.

The common base circuit is generally only used in single stage amplifier circuits such as microphone pre-amplifier or radio frequency (R_f) amplifiers due to its very good high frequency response.

The Common Emitter (CE) Configuration

In the **Common Emitter** or grounded emitter configuration, the input signal is applied between the base and the emitter, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers and which represents the “normal” method of bipolar transistor connection.

The common emitter amplifier configuration produces the highest current and power gain of all the three bipolar transistor configurations. This is mainly because the

input impedance is LOW as it is connected to a forward biased PN-junction, while the output impedance is HIGH as it is taken from a reverse biased PN-junction.

The Common Emitter Amplifier Circuit shown in the figure 1.1.3

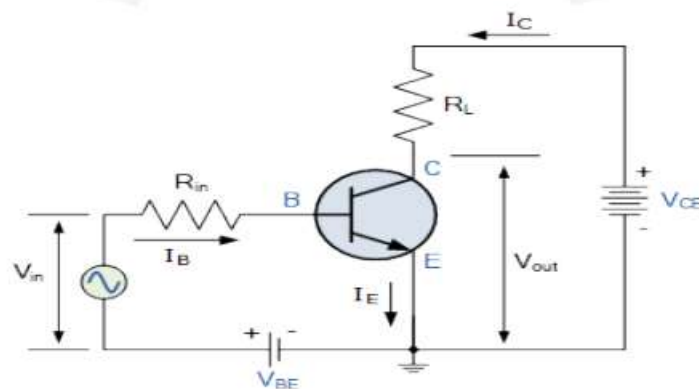


Figure 1.1.3 Common Emitter Transistor Circuit

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In this type of configuration, the current flowing out of the transistor must be equal to the currents flowing into the transistor as the emitter current is given as $I_e = I_c + I_b$.

As the load resistance (R_L) is connected in series with the collector, the current gain of the common emitter transistor configuration is quite large as it is the ratio of I_c/I_b . A transistor's current gain is given the Greek symbol of Beta, (β).

As the emitter current for a common emitter configuration is defined as $I_e = I_c + I_b$, the ratio of I_c/I_e is called Alpha, given the Greek symbol of α . Note: that the value of Alpha will always be less than unity.

Since the electrical relationship between these three currents, I_b , I_c and I_e is determined by the physical construction of the transistor itself, any small change in the base current (I_b), will result in a much larger change in the collector current (I_c).

Then, small changes in current flowing in the base will thus control the current in the emitter-collector circuit. Typically, Beta has a value between 20 and 200 for

most general purpose transistors. So if a transistor has a Beta value of say 100, then one electron will flow from the base terminal for every 100 electrons flowing between the emitter-collector terminal.

By combining the expressions for both Alpha, α and Beta, β the mathematical relationship between these parameters and therefore the current gain of the transistor can be given as:

$$\text{Alpha, } (\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta, } (\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha \cdot I_E = \beta \cdot I_B$$

$$\text{as: } \alpha = \frac{\beta}{\beta + 1} \quad \beta = \frac{\alpha}{1 - \alpha} \quad I_E = I_C + I_B$$

Where: “Ic” is the current flowing into the collector terminal, “Ib” is the current flowing into the base terminal and “Ie” is the current flowing out of the emitter terminal.

Then to summarise a little. This type of bipolar transistor configuration has a greater input impedance, current and power gain than that of the common base configuration but its voltage gain is much lower. The common emitter configuration is an inverting amplifier circuit. This means that the resulting output signal has a 180° phase-shift with regards to the input voltage signal.

The Common Collector (CC) Configuration

In the **Common Collector** or grounded collector configuration, the collector is connected to ground through the supply, thus the collector terminal is common to both the input and the output. The input signal is connected directly to the base terminal, while the output signal is taken from across the emitter load resistor as shown. This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

The common collector, or emitter follower configuration is very useful for impedance matching applications because of its very high input impedance, in the region of hundreds of thousands of Ohms while having a relatively low output impedance.

The Common Collector Transistor Circuit shown in the figure 1.1.4

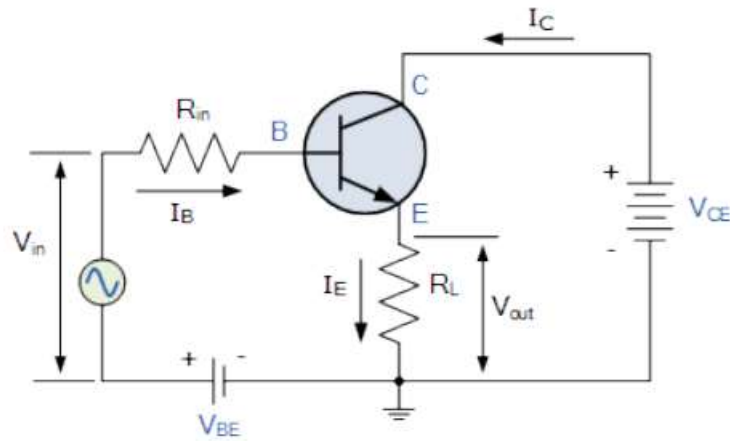


Figure 1.1.4 Common Collector Transistor Circuit

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The common emitter configuration has a current gain approximately equal to the β value of the transistor itself. However in the common collector configuration, the load resistance is connected in series with the emitter terminal so its current is equal to that of the emitter current. As the emitter current is the combination of the collector AND the base current combined, the load resistance in this type of transistor configuration also has both the collector current and the input current of the base flowing through it. Then the current gain of the circuit is given as:

The Common Collector Current Gain

$$I_E = I_C + I_B$$

$$A_i = \frac{I_E}{I_B} = \frac{I_C + I_B}{I_B}$$

$$A_i = \frac{I_C}{I_B} + 1 \quad A_i = \beta + 1$$

This type of bipolar transistor configuration is a non-inverting circuit in that the signal voltages of V_{in} and V_{out} are “in-phase”. The common collector

configuration has a voltage gain of about “1” (unity gain). Thus it can be considered as a voltage-buffer since the voltage gain is unity.

The load resistance of the common collector transistor receives both the base and collector currents giving a large current gain (as with the common emitter configuration) therefore, providing good current amplification with very little voltage gain.

Having looked at the three different types of bipolar transistor configurations, we can now summarise the various relationships between the transistors individual DC currents flowing through each leg and its DC current gains given above in the following table.

Relationship between DC Currents and Gains

$I_E = I_B + I_C$ $I_C = I_E - I_B$ $I_B = I_E - I_C$	$\alpha = \frac{I_C}{I_E} = \frac{\beta}{1 + \beta}$ $\beta = \frac{I_C}{I_B} = \frac{\alpha}{1 - \alpha}$
$I_B = \frac{I_C}{\beta} = \frac{I_E}{1 + \beta} = I_E (1 - \alpha)$	
$I_C = \beta \cdot I_B = \alpha \cdot I_E$	$I_E = \frac{I_C}{\alpha} = I_B (1 + \beta)$

Note that although we have looked at *NPN Bipolar Transistor* configurations here, PNP transistors are just as valid to use in each configuration as the calculations will all be the same, as for the non-inverting of the amplified signal. The only difference will be in the voltage polarities and current directions.