TRANSISTORS

Transistor's introduction

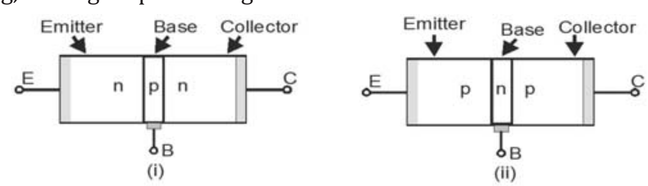
Transistors revolutionized the field of electronics upon their introduction. These semiconductor devices serve as fundamental building blocks in countless electronic circuits, enabling amplification, switching, and signal processing. Unlike earlier vacuum tube technology, transistors are smaller, more reliable, and consume less power. Developed in the mid-20th century, transistors swiftly replaced vacuum tubes in applications ranging from radios and televisions to computers and telecommunications equipment. Their compact size, efficiency, and versatility have propelled technological advancements across various industries, shaping the modern world in ways unimaginable before their advent.

A transistor consists of three doped regions, forming two p–n junctions between them. These regions are typically made of semiconductor materials such as silicon or germanium. The arrangement of these doped regions determines the type of transistor.

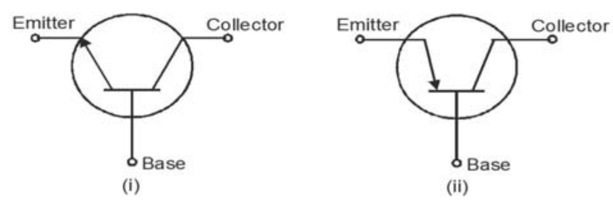
The figure depicts two main types of transistors: bipolar junction transistors (BJTs) and field-effect transistors (FETs). BJTs have a structure consisting of three doped semiconductor regions: the emitter, the base, and the collector. These regions are either p-type or n-type, forming two p–n junctions.

On the other hand, FETs are characterized by their distinct arrangement of doped regions. They typically consist of a source, a gate, and a drain. The gate region controls the flow of current between the source and the drain by modulating the conductivity of a channel between them.

Overall, the composition and arrangement of doped regions in transistors play a crucial role in their operation and functionality, allowing them to serve as key components in electronic circuits for amplification, switching, and signal processing.



(a) Schematic representations of a n–p–n transistor and p–n–p transistor



(b) Symbols for n–p–n and p–n–p transistors.

(i) n–p–n transistor:

In this arrangement, there are two sections of n–type semiconductor material, specifically the emitter and collector, situated on opposite sides of a segment of p–type semiconductor, which is referred to as the base. This setup forms the structure of an n–p–n transistor. The diagram illustrates the schematic representation of this transistor configuration.

(ii) p–n–p transistor:

On the contrary, the p–n–p transistor comprises two sections of p–type semiconductor material, designated as the emitter and collector, which are separated by a segment of n–type semiconductor functioning as the base. The figure visually presents the schematic layout of a p–n–p transistor.

Both types of transistors exhibit variations in thickness and doping levels across their three segments. The schematic symbols utilized to represent these p–n–p and n–p–n transistors, as illustrated in Figure (b), feature an arrowhead indicating the direction of conventional current flow within the transistor.

The unique characteristics of the three segments of a transistor—the emitter, base, and collector—are briefly described below.

These components play crucial roles in controlling and amplifying electrical signals within electronic circuits, influencing the transistor's functionality.

Emitter:

This region, depicted on one side of the transistor in Figure (a), possesses a moderate size and is heavily doped. Its primary role is to supply a substantial number of majority carriers, thus facilitating current flow throughout the transistor. The high level of doping ensures that this area significantly contributes to the availability of charge carriers, thereby influencing the overall conductivity and performance of the transistor.

Base:

Situated at the center of the transistor, the base is characterized by a slender profile and low doping level. Its thinness and light doping are distinctive features. Despite its modest size, this central region plays a crucial role in controlling and modulating current flow within the transistor. Its unique characteristics contribute to the precision and sensitivity of the transistor's performance within electronic circuits.

Collector:

The collector segment is essential for the transistor's operation as it gathers a significant portion of the majority carriers supplied by the emitter. It is moderately doped and larger in size compared to the emitter. This size difference ensures efficient dissipation of heat generated during the collection of charge carriers into the surrounding environment.

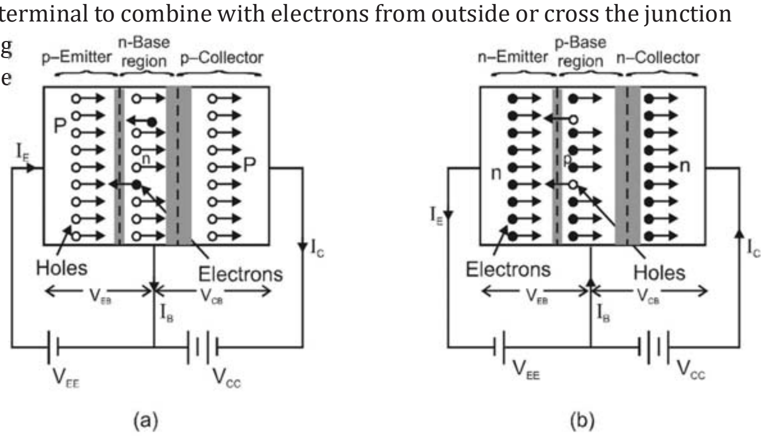
In the context of a p–n junction, the transistor forms two depletion regions: one at the emitter-base junction and the other at the base-collector junction.

The transistor functions as an amplifier with the emitter-base junction forward-biased and the base-collector junction reverse-biased. This biasing configuration is depicted in the figure, with VCC and VEE utilized for creating the respective biases. When biased in this manner, the transistor is in the active state.

The voltage between the emitter and base is denoted as VEB, while that between the collector and base is VCB. The base serves as a common terminal for two power supplies, represented as VEE' and VCC' respectively, where VEE' corresponds to the power supply between the base and emitter in circuits where the emitter is the common terminal.

The heavily doped emitter contains a high concentration of majority carriers, which are either holes in a p–n–p transistor or electrons in an n–p–n transistor. These carriers enter the thin and lightly doped base region in large numbers. In a p–n–p transistor, where the base is of n–type semiconductor, the majority carriers in the base are electrons. The significant number of holes entering the base from the emitter surpasses the limited number of electrons present.

With the base-collector junction reverse-biased, the holes, considered minority carriers at the junction, can easily traverse the junction and enter the collector. These holes in the base region can either move toward the base terminal to combine with electrons from outside or cross the junction to enter the collector, reaching the collector terminal. The thinness of the base ensures that a significant proportion of holes are near the reverse-biased base-collector junction, facilitating their crossing of the junction rather than moving toward the base terminal. This intentional design enhances the efficiency of the transistor's operation.



Bias Voltage applied on : (a) p–n–p transistor and (b) n–p–n transistor

Note:

Due to forward bias, a significant current flow into the emitter–base junction, a substantial portion of which is redirected towards the adjacent reverse-biased base–collector junction. Consequently, the current exiting the base becomes a minute fraction of the total current that initially entered the junction. If we denote the hole current and electron current crossing the forward-biased junction as the sum $I_h + I_e$, we observe that the emitter currents $I_E = I_h + I_e$, while the base current IB is considerably smaller than $I_h + I_e$. This is because a significant portion of I_E is directed toward the collector rather than exiting through the base terminal. Therefore, the base current is a small fraction of the emitter current. It is evident from this explanation, and by applying Kirchhoff's law to Figure (a), that the emitter current is the sum of the collector current and base current: $I_E = I_C + I_B$. Additionally, we note that $I_C \approx I_E'$.

The description of hole motion aligns with the direction of conventional current. However, the motion of electrons is opposite to the current direction. In a p–n–p transistor, current enters from the emitter into the base, while in an n–p–n transistor, it enters from the base into the emitter. The arrowhead in the emitter indicates the direction of conventional current.

During the transistor's active state, the emitter–base junction acts as a low-resistance path, while the base–collector junction serves as a high-resistance path.

A transistor has only three terminals: emitter (E), base (B), and collector (C). Consequently, in a circuit, the input/output connections must be such that one of these terminals (E, B, or C) is common to both the input and output. Accordingly, transistors can be connected in one of three configurations: Common Emitter (CE), Common Base (CB), and Common Collector (CC).

Working of Transistor

(1) Four distinct methods are utilized for biasing the two P-N junctions, namely the emitter junction and the collector junction, of a transistor:
   (i) Active Mode: Also known as linear mode operation, this mode involves the transistor functioning as an amplifier, allowing for proportional amplification of the input signal.
   (ii) Saturation Mode: In this mode, the transistor reaches maximum collector current flow, effectively operating as a closed switch between the collector and emitter terminals. The transistor is fully turned on during this mode.
   (iii) Cut-off Mode: This mode resembles the operation of an open switch, with minimal leakage current flowing through the transistor. In this state, the transistor is effectively turned off.
   (iv) Inverse Mode: In this mode, the positions of the emitter and collector are swapped or interchanged, resulting in a distinct operational configuration for the transistor. The roles of the emitter and collector are reversed from their typical orientations in this mode.

Different Modes of Operation of A Transistor		
Operating mode	**Collector base bias**	**Emitter base bias**
Active	Reverse	Forward
Saturation	Forward	Forward
Cut off	Reverse	Reverse
Inverse	Forward	Reverse

(2) Typically, a transistor operates in the active region, where the emitter-base junction is forward biased, and the collector-base junction is reverse biased. This configuration is crucial for the transistor to act as an amplifier, enabling it to modulate the current flow in response to changes in the input signal.

(3) Examining the behavior of a junction transistor reveals a direct correlation between variations in the current within the emitter circuit and corresponding changes in the collector current. This relationship highlights the transistor's function in amplifying signals, as adjustments in one part of the device result in proportional modifications in another.

(4) In each state of operation, a transistor has both an input port and an output port. Typically, the electrical parameters, such as voltage (V) or current (I), obtained at the output, are governed by the input. This characteristic is fundamental to the transistor's role as an active device that processes and amplifies signals based on fluctuations in its input.

alpha, beta parameters

The alpha (α) and beta (β) parameters of transistors are key performance metrics used to characterize their behavior, particularly in amplifier circuits.

Alpha (α) Parameter:

Alpha (α) is defined as the ratio of the collector current (I_c) to the emitter current (I_e) in a bipolar junction transistor (BJT).

Mathematically, $\alpha = \frac{I_C}{I_e}$.

Alpha (α) is a measure of the transistor's current gain and represents the fraction of emitter current that flows into the collector terminal.

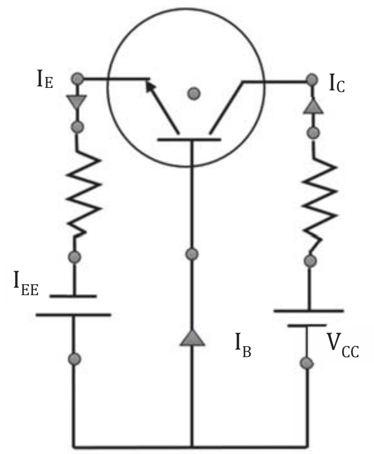
Beta (β) Parameter:

Beta (β), also known as the current gain, is defined as the ratio of the collector current (Ic) to the base current (Ib) in a BJT.

Mathematically, $\beta = \frac{I_C}{I_b}$.

Beta (β) indicates the amplification capability of the transistor. It represents how much the collector current increases relative to the base current.

Beta (β) is also commonly referred to as the hFE parameter in datasheets, where "h" stands for hybrid, "F" denotes forward current gain, and "E" represents the emitter.



Relationship between Alpha (α) and Beta (β)

The relationship between alpha (α) and beta (β) is given by $\beta = \frac{\alpha}{(1-\alpha)}$.

In some cases, the beta (β) parameter is approximately equal to alpha (α), especially when the transistor is operating in the active region with high currents.

Overall, alpha (α) and beta (β) parameters provide valuable insights into the amplification capabilities and current-handling characteristics of transistors, aiding in circuit design and analysis.

Assuming the currents IB and IC serve as the input and output currents for the transistor, respectively, adhering to the relationship IC = βIB, we observe that IC is typically 50 to 200 times greater than IB. Consequently, a transistor can function as an amplifier.

Transistor Configurations

A transistor can be incorporated into a circuit through one of three unique setups: Common Base (CB), Common Emitter (CE), and Common Collector (CC).

Now, let's explore the specifics of the Common Base configuration (CB):

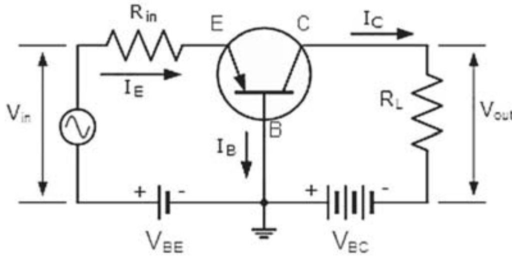
Common Base (CB) Configuration:

In the Common Base (CB) configuration, the base serves as the common terminal shared by both the emitter and collector.

Key electrical parameters in this configuration comprise:

(i) Input current (I_e)
(ii) Input voltage (V_{EB})
(iii) Output voltage (V_{CB})
(iv) Output current (I_C)

A significant attribute of the CB configuration is that a slight rise in the emitter-base voltage (V_{EB}) leads to a swift escalation in the emitter current (I_e), primarily due to the low input resistance inherent in this setup.

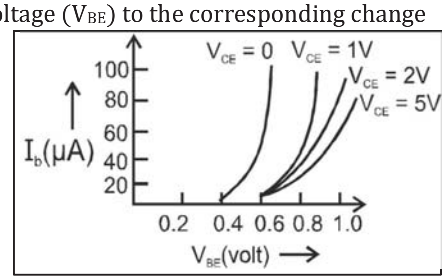


Input and output characteristics

Input Characteristics:

When V_{CB} is maintained constant, the relationship between I_e and V_{EB} is known as the input characteristics. This graph is also commonly referred to as emitter characteristics. In the case of an NPN transistor, the input characteristics resemble the diagram depicted, but both I_e and V_{EB} are negative, while V_{CB} remains positive. The dynamic input resistance (R_i) of a transistor is determined by the equation $R_i = \frac{V_{EB}}{I_e}$ with V_{CB} held constant. It's worth noting that R_i typically falls within the range of 100 ohms.

The input characteristics curve is established by plotting the correlation between the base current (I_B) and the emitter-base voltage (V_{EB}) while maintaining a steady collector-emitter voltage (V_{CE}). This graphical representation holds significant importance in comprehending the transistor's behavior in the Common Emitter (CE) configuration. The dynamic input resistance (R_i) is determined as the ratio of the variation in emitter-base voltage (V_{BE}) to the corresponding change in base current (I_B), with the collector-emitter voltage (V_{CE}) kept constant. Mathematically, $R_i = \frac{V_{BE}}{I_B}$ where V_{CE} remains consistent throughout the analysis. This dynamic input resistance offers valuable insights into the transistor's reaction to alterations in the input conditions and serves as a crucial parameter in characterizing transistor behavior in electronic circuits.



output characteristics

The fluctuation in collector current (I_C) in relation to the collector-emitter voltage (V_{CE}) is observable within the range of V_{CE} from 0 to 1 volt. The specific value of V_{CE} at which I_C starts to vary is termed as the knee voltage. The transistor is effectively operated in the region above this knee voltage. The dynamic output resistance (R_0) is computed as the ratio of the change in collector-emitter voltage (V_{CE}) to the corresponding change in collector current (I_C), while maintaining the base current (I_B) constant. Mathematically, $R_0 = \frac{V_{CE}}{I_C}$ where I_B remains unchanged. This dynamic output resistance serves as a critical parameter for comprehending how the transistor reacts to modifications in the output conditions, particularly in the Common Emitter (CE) configuration.