ELECTRICAL SCIENCE-2
(15B11EC211)
Lecture-35

Topics to be Discussed

- Introduction
- Salient Features of a Transistor
- Bipolar Junction Transistor (BJT)
- Device Structure
- Naming of Transistor Terminals/Regions
- Important features
- Operation of the npn Transistor in the Active Mode
- Operation of the pnp Transistor in the Active Mode
- Diode Equivalent of a Transistor
- Layout and Circuit Symbol: npn Transistor
- Layout and Circuit Symbol: pnp Transistor
- References

Introduction

- The transistor was developed by Dr. William Shockley along with Bell Laboratories team in 1948.
- The transistor is a main building block of all modern electronic systems .
- It is a three terminal device. In the common case, third terminal controls the flow of current between other two terminals or the voltage between two terminals to control the current flowing in the third terminal. This can be used for amplification.
- An amplifier is a circuit that is used to increase the strength of an ac/dc signal.
- Also, the control signal can be used to cause the current in the third terminal to change from zero to a large value, thus allowing the device to act as a switch.
- The switch is the basis for the realization of the logic inverter, the basic element of digital circuits.

- Therefore, three-terminal devices are far more useful than two-terminal ones, such as the diodes.
- The important property of the transistor is that it can raise the strength of a weak signal. This property is called amplification.
- Due to this quality, the transistor is one of the most widely used semiconductor devices.
- Transistors are used in digital computers, satellites, mobile phones and other communication systems, control systems etc.
- In communication systems, transistor is the primary component in the amplifier.
- Basically there are two types of transistors:
- Bipolar: Bipolar Junction Transistor (BJT)
- Unipolar: Field Effect Transistor (FET)

Salient Features of a Transistor [1, 2]

- The transistors are more desirable than the vaccum tubes because of their following salient features:
  (i) Small Size and ruggedness
  (ii) Do not require any filament power
  (iii) Operate at a low voltage
  (iv) Higher efficiency

- The term transistor was derived from the words “***Transfer*** and ***Resistors***”.

- This term was adopted because it best describes the operation of a transistor which is the transfer of an input signal current from a low resistance circuit to a high resistance circuit.

Bipolar Junction Transistor (BJT) [1, 2]

- The invention of the BJT also eventually led to the dominance of information technology and the emergence of the knowledge-based economy.
- The bipolar transistor enjoyed nearly three decades as the device of choice in the design of both discrete and integrated circuits.
- The BJT consists of two pn junctions, three terminals, three regions.
- The middle region is kept thinner than other two.
- Charge carriers of both polarities i.e. electrons and holes, participate in the current-conduction process in a bipolar transistor, which is the reason for the name ***bipolar***.
- Both minority and majority carrier movements are considered.

Device Structure [1]

- As shown in Fig. 1, the BJT consists of three semiconductor regions:
  - The emitter region (n type)
  - The base region (p type)
  - The collector region (n type)

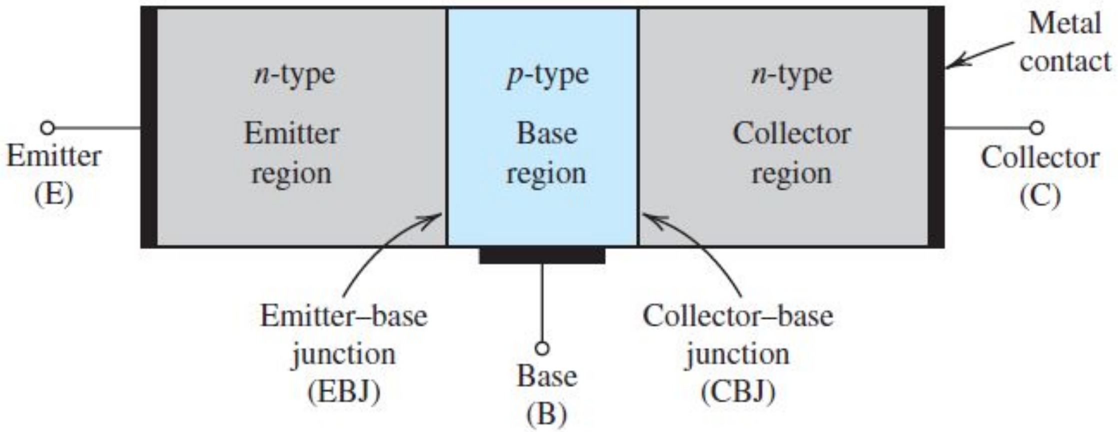


Fig. 1 A simplified structure of the npn transistor

- Such a transistor is called an ***npn transistor***.

- Another transistor, a dual of the npn as shown in Fig. 2, has a p-type emitter, an n-type base, and a p-type collector, and is appropriately called a ***pnp transistor***.

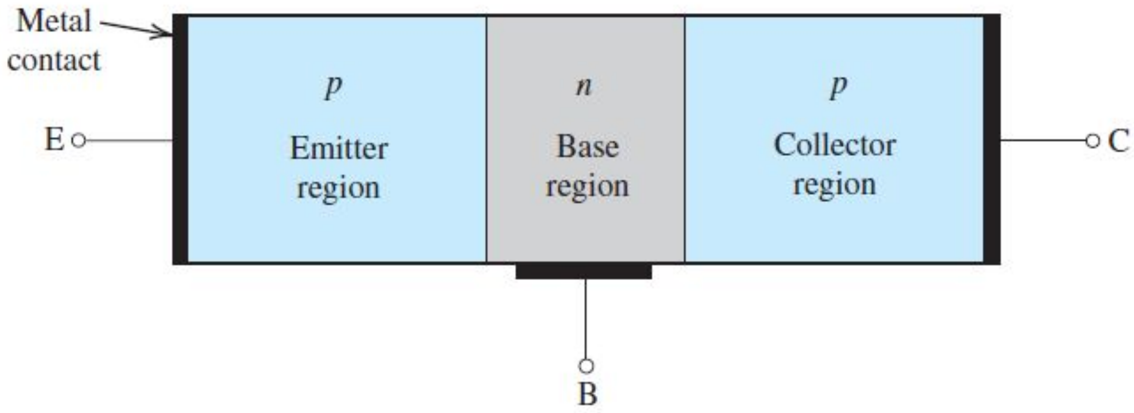


Fig. 2 A simplified structure of the pnp transistor

Naming of Transistor Terminals/Regions [1, 2]

Emitter (E):

- The section of one side that supplies carriers is called emitter.
- Emitter is always forward biased with respect to base so it can supply carriers.
- For npn transistor emitter supply electrons to its junction.
- For pnp transistor emitter supply holes to its junction.

Collector (C):

- The section on the other side that collects carrier is called collector.
- The collector is always reversed biased with respect to base.
- For npn transistor collector receives electrons to its junction.
- For pnp transistor collector receives holes to its junction.

Base (B):

- Middle section which forms two junctions with emitter and collector is called base.

Important Features [1, 2]

- The transistor has three regions named E, B and C.
- The base is much thinner than other regions.
- Emitter is heavily doped so it can inject large amount of carriers into the base.
- Base is lightly doped so it can pass most of the carriers to the collector.
- Collector is moderately doped.
- The junction between emitter and base is called **EB junction** (emitter diode) and junction between collector base junction is called as **CB junction** (collector diode).
- The emitter diode is always forward biased and collector diode is revered biased.
- The resistance of emitter diode is very small and resistance of collector diode is very high.

- The transistor consists of two pn junctions, the **emitter–base junction (EBJ)** and **the collector–base junction (CBJ)**. Depending on the bias condition (forward or reverse) of each of these junctions, different modes of operation of the BJT are obtained, as shown in Table 1.

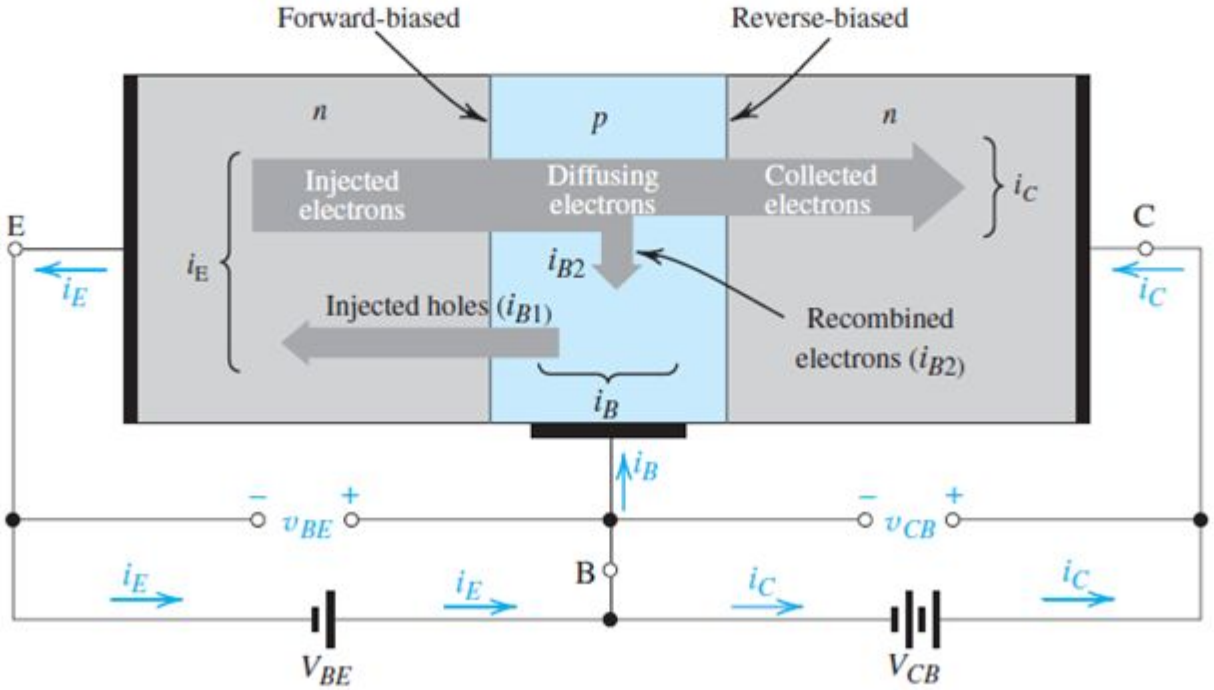
Table 1 BJT Modes of Operation

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

- The active mode is the one used if the transistor is to operate as an amplifier.
- Switching applications (e.g., logic circuits) utilize both the cutoff mode and the saturation mode.
- As the name implies, in the cutoff mode, no current flows because both junctions are reverse biased.

Operation of the npn Transistor in the Active Mode [1]

- Two external voltage sources (shown as batteries) are used to establish the required bias conditions for active-mode operation.
- The voltage V_{BE} causes the p-type base to be higher in potential than the n-type emitter, thus forward-biasing the emitter–base junction. The collector–base voltage V_{CB} causes the n-type collector to be at a higher potential than the p-type base, thus reverse-biasing the collector–base junction.



Current Flow:

- The forward bias on the emitter–base junction will cause current to flow across this junction. Current will consist of two components:
    - Electrons injected from the emitter into the base, and
    - Holes injected from the base into the emitter.
- The current that flows across the emitter–base junction will constitute the emitter current i_E, as indicated in previous Figure.
- The direction of i_E is "out of" the emitter lead, which, following the usual conventions, is in the direction of the positive-charge flow (hole current) and opposite to the direction of the negative-charge flow (electron current), with the emitter current i_E being equal to the sum of these two components.
- However, since the electron component is much larger than the hole component, the emitter current will be dominated by the electron component.

The Collector Current:

- From the above description we see that most of the diffusing electrons will reach the boundary of the collector–base depletion region.

- Because the collector is more positive than the base (by v_{CB} volts), these successful electrons will be swept across the CBJ depletion region into the collector.

- They will thus get "collected" to constitute the collector current i_C. Thus $i_C = I_n$, which will yield a negative value for i_C, indicating that i_C flows in the negative direction of the x axis (i.e., from right to left). We can express collector current as

$$i_C = I_S e^{\frac{v_{BE}}{V_T}}$$

where, I_S is saturation current.

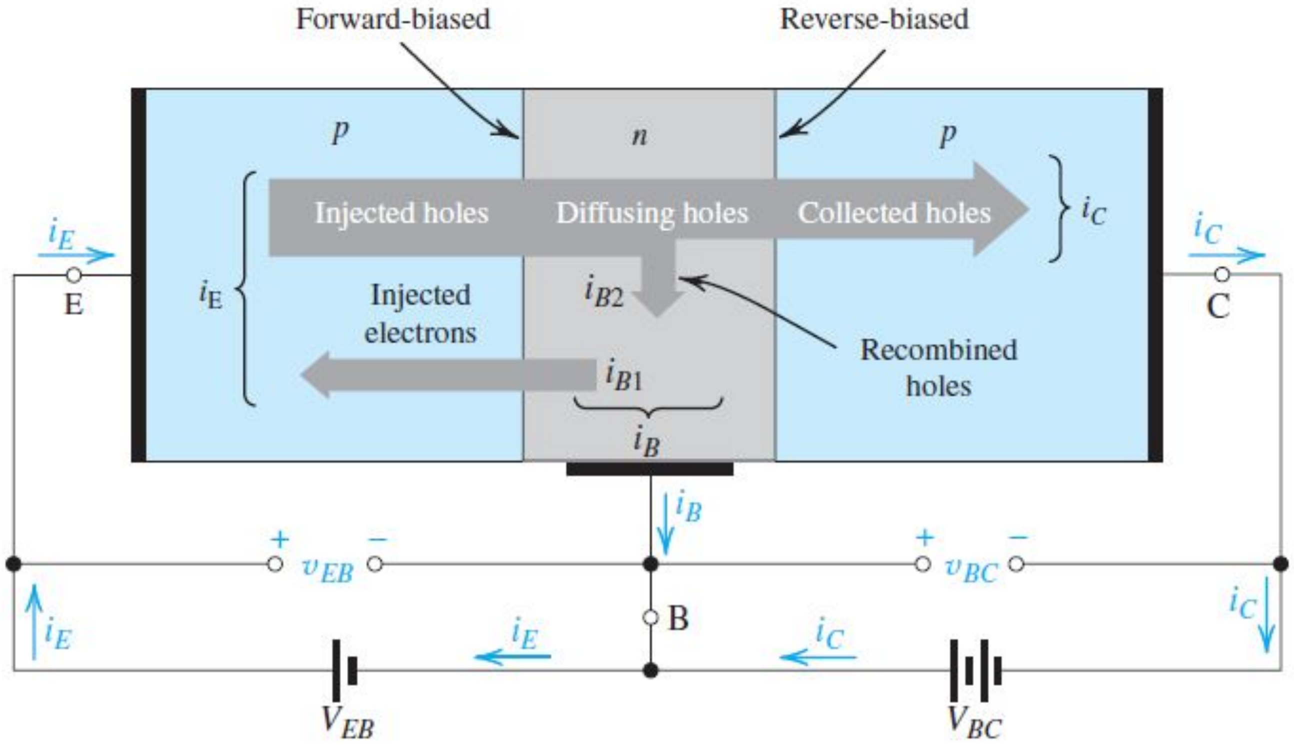
The Base Current:

- The base current i_B is composed of two components. The first component i_{B1} is due to the holes injected from the base region into the emitter region. This current component is proportional to exp[v_{BE}/V_T].
- The second component of base current, i_{B2}, is due to holes that have to be supplied by the external circuit in order to replace the holes lost from the base through the recombination process. Because i_{B2} is proportional to the number of electrons injected into the base, it also will be proportional to exp[v_{BE}/V_T].
- Thus the total base current, $i_B = i_{B1} + i_{B2}$, will be proportional to and can be expressed as a fraction of the collector current i_C.

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$$

Operation of the pnp Transistor in the Active Mode [1]

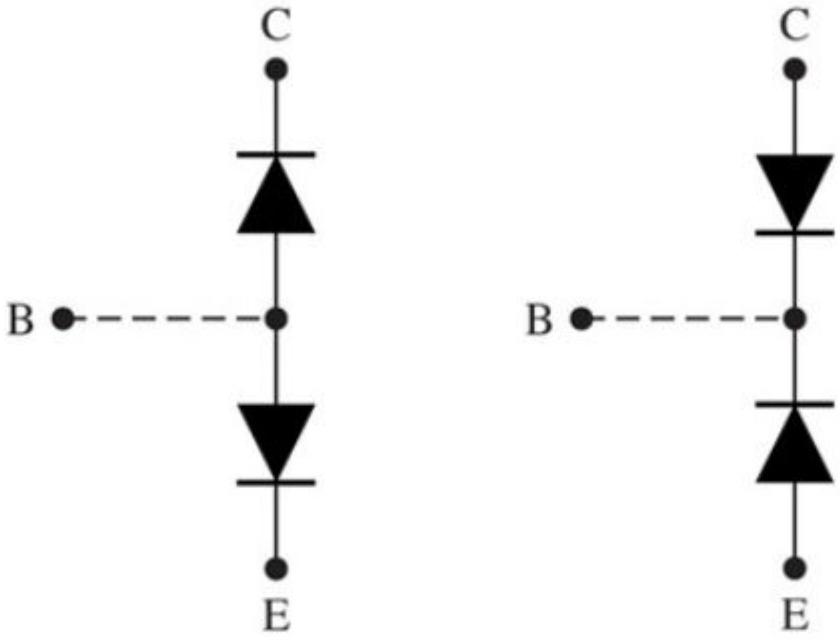
- Here the voltage V_{EB} causes the p-type emitter to be higher in potential than the n-type base, thus forward-biasing the emitter–base junction. The collector–base junction is reverse biased by the voltage V_{BC}, which keeps the p-type collector lower in potential than the n-type base.



- Unlike the npn transistor, current in the pnp device is mainly conducted by holes injected from the emitter into the base as a result of the forward-bias voltage V_{EB}.
- Since the component of emitter current contributed by electrons injected from base to emitter is kept small by using a lightly doped base, most of the emitter current will be due to holes.
- The electrons injected from base to emitter give rise to the first component of base current, i_{B1}.
- Also, a number of the holes injected into the base will recombine with the majority carriers in the base (electrons) and will thus be lost. The disappearing base electrons will have to be replaced from the external circuit, giving rise to the second component of base current, i_{B2}.
- The holes that succeed in reaching the boundary of the depletion region of the collector–base junction will be attracted by the negative voltage on the collector.
- Thus these holes will be swept across the depletion region into the collector and appear as collector current.

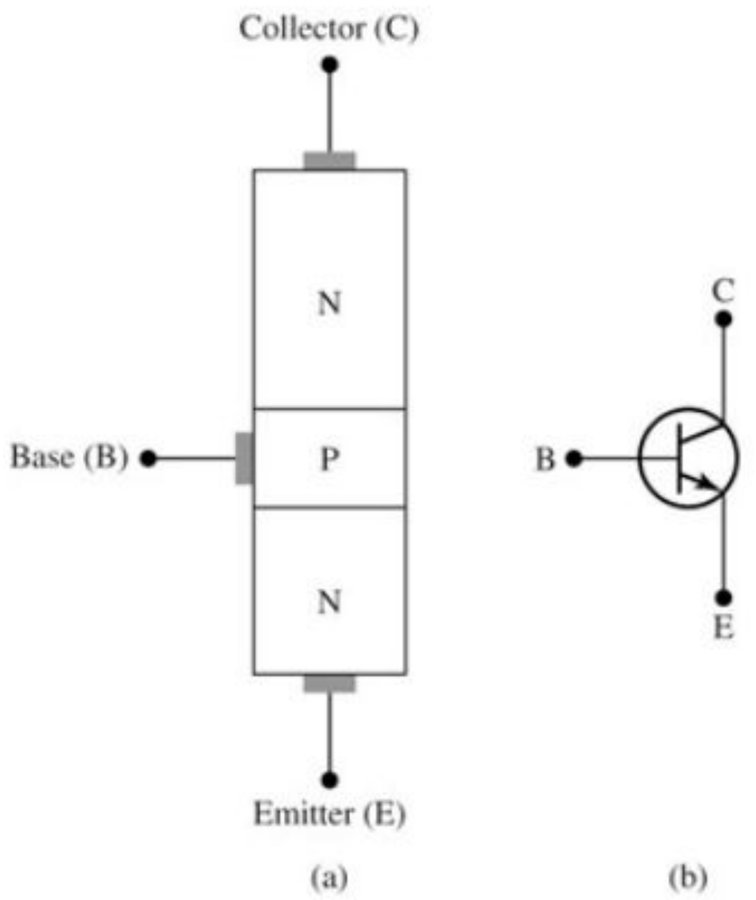
Diode Equivalent of a Transistor [2]

- Transistors can be constructed as two diodes that are connected together.



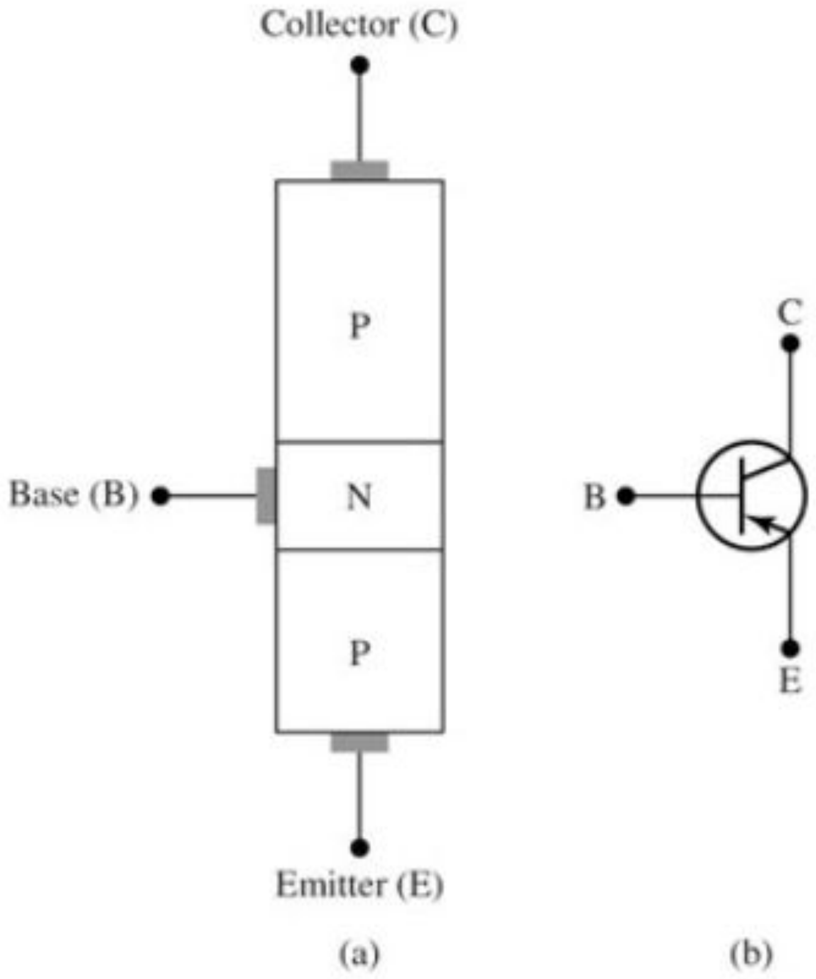
(a) NPN (b) PNP

Layout and Circuit Symbol: npn Transistor



- The arrow indicates the direction of current flow.
- The current flows from collector to emitter in an npn transistor.
- The arrow is drawn on the emitter.
- The arrow always points towards the n-type.
- So the emitter is n-type and the transistor is npn type.

Layout and Circuit Symbol: pnp Transistor



- The arrow indicates the direction of current flow.
- The current flows from emitter to collector in an pnp transistor.
- The arrow points towards the n-type.
- So the base is n-type and transistor is pnp type.

References

1. A. S. Sedra, and K. C. Smith, "Microelectronic Circuits", 7th Edition, Oxford University Press, 2012.

2. R. L. Boylestad, L. Nashelsky, "Electronic Devices and Circuit Theory", 11th Edition, Prentice Hall of India, 2014.