UNIT – 4 TRANSISTORS

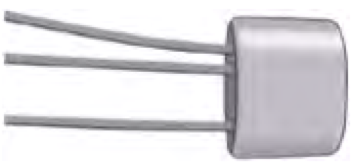
TRANSISTORS

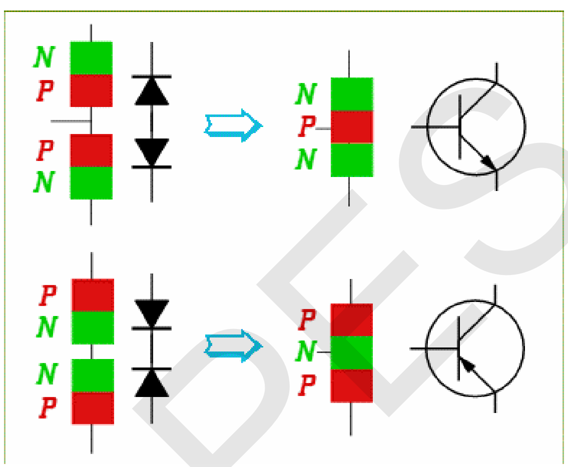
At the end of this unit, student will be able to -

- Describe the Construction of three terminal semiconductor device.
- Interpret the Transistors current relations & current gains expression.
- Classify the Transistor configurations.
- Examine the V-I characteristics of transistors in different modes.
- Summarize the Construction & working of MOS devices.

Invention of the Transistor

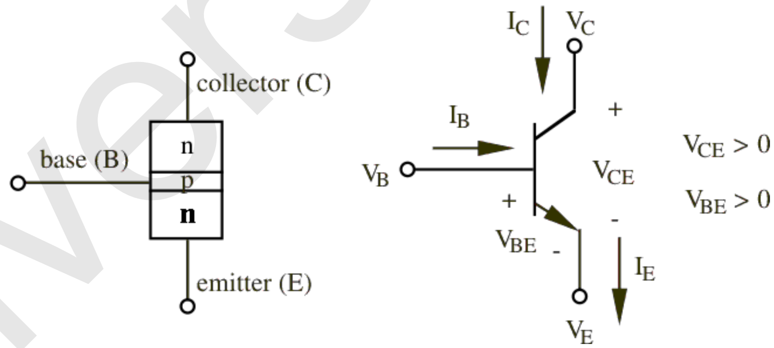
- Bell Labs (1947): Bardeen, Brattain, and Shockley
- Originally made of germanium
- Current transistors made of doped silicon



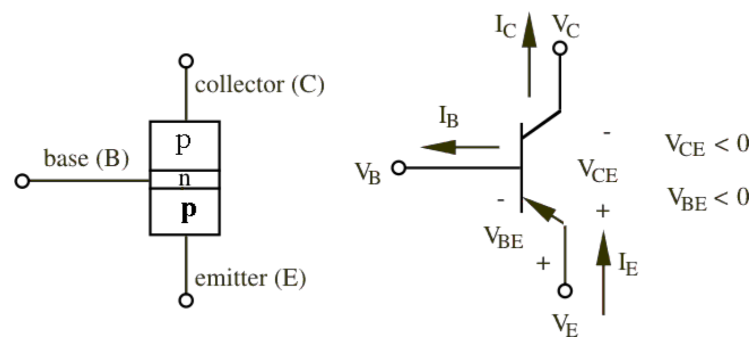


Bipolar Junction Transistor (BJT)

- 3 adjacent regions of doped Si (each connected to a lead):
  - Base (thin layer, less doped).
  - Collector (largest, moderate)
  - Emitter (moderate, heavily)
- 2 types of BJT:
  - npn
  - Pnp
- Most common: npn (focus on it)



npn bipolar junction transistor



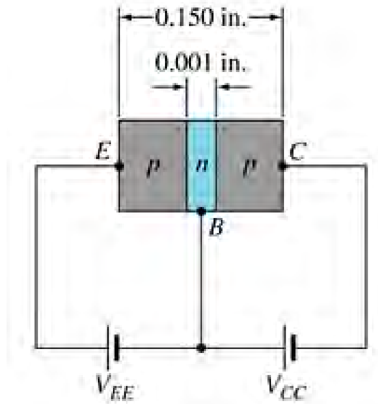
pnp bipolar junction transistor

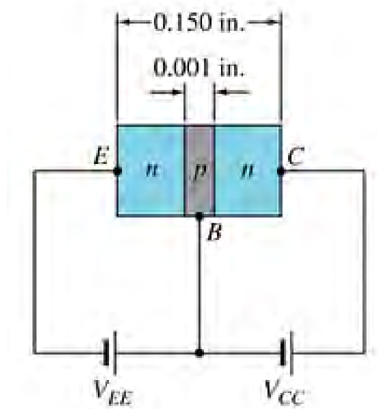
Transistor Biasing

Transistor is made of two junctions. Namely, EB-junction & CB-junction

Hence a transistor can be biased in 4 ways as:
1. EB & CB junctions both are forward Biased
2. EB & CB junctions both are reverse biased
3. EB junction is forward biased & CB is reverse biased
4. EB junction is reverse biased & CB is forward biased

Best biasing techniques is, EB-Forward biased & CB-Reverse biased

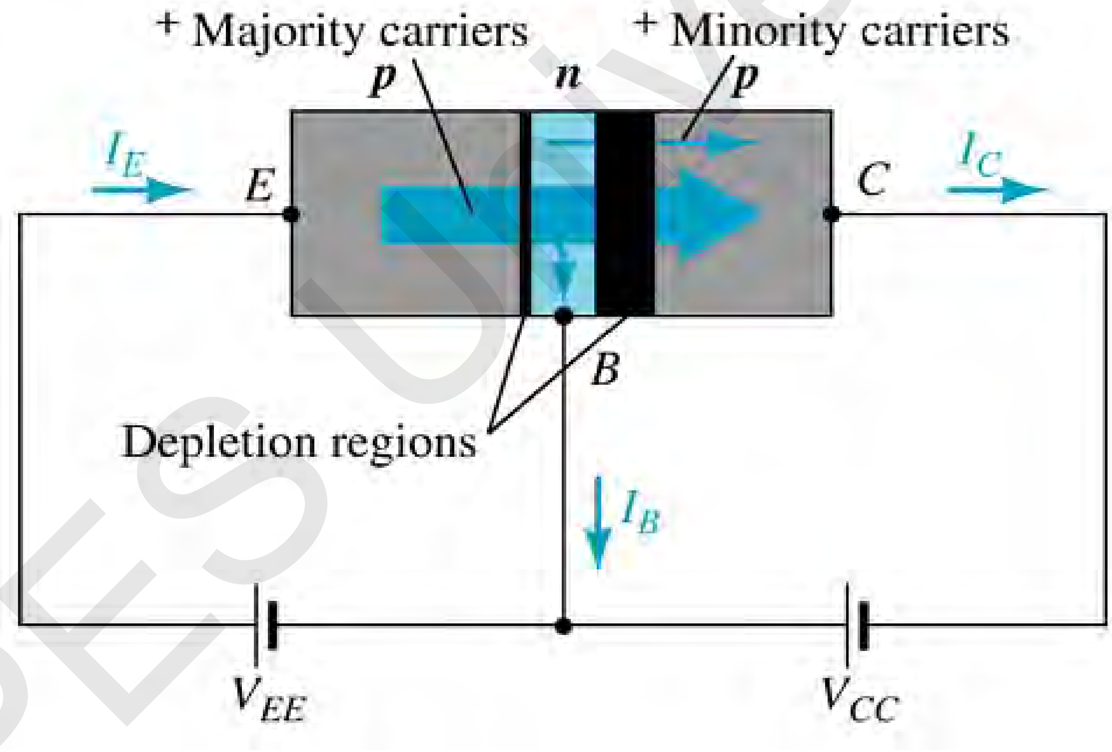




Transistor Operation

With the external sources, V_{EE} and V_{CC}, connected as shown:

- **The emitter-base junction is forward biased**
- **The base-collector junction is reverse biased**



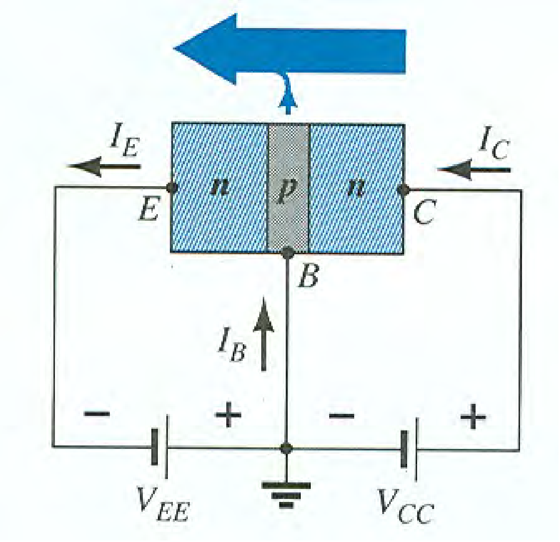
Currents in a Transistor

Emitter current is the sum of the collector and base currents:

$$I_E = I_C + I_B$$

The collector current is comprised of two currents:

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$



Transistors Configurations

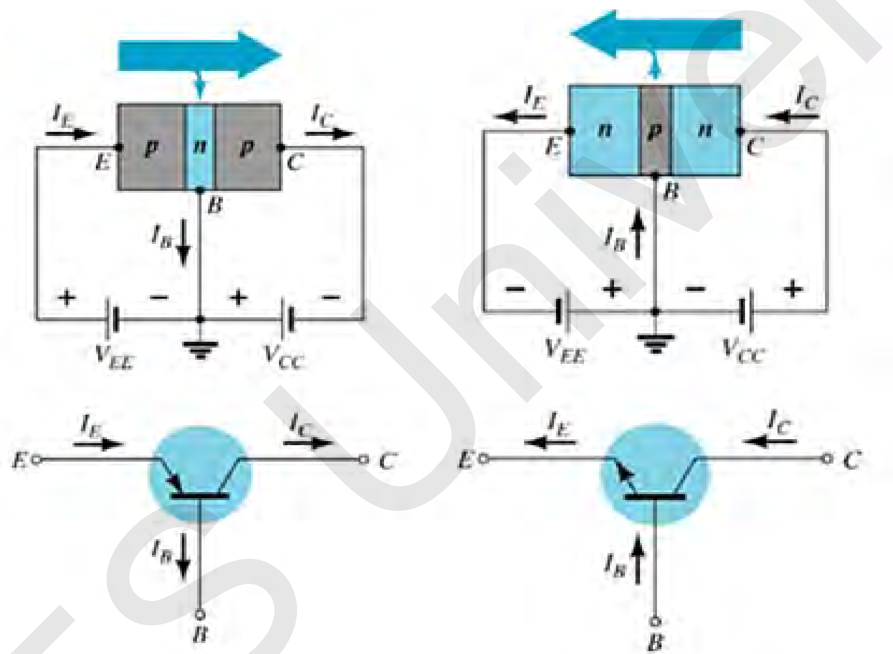
Transistors configurations are categorised as,
1. CB mode configuration
2. CE mode configuration
3. CC mode configuration

In each mode of transistors configuration, the study of its input characteristics & output characteristics is conducted.

- Input characteristics is, the graph between Input voltage variations and the respective changes in the input current for the constant control by input current

- Output characteristics is, the graph between Output voltage variations and the respective changes in the Output current for the constant control by input current

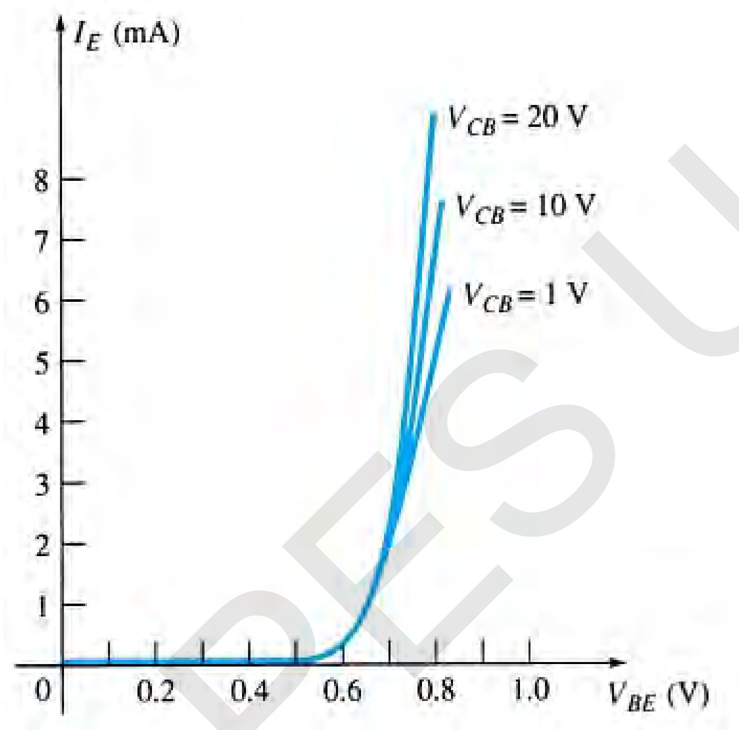
Transistor characteristics in CB mode



The base is common to both input (emitter–base) and output (collector–base) of the transistor.

CB mode - Input Characteristics

This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.



Input Resistance (Rin) is the ratio of input voltage to the input current of the transistor for a constant value of output voltage.

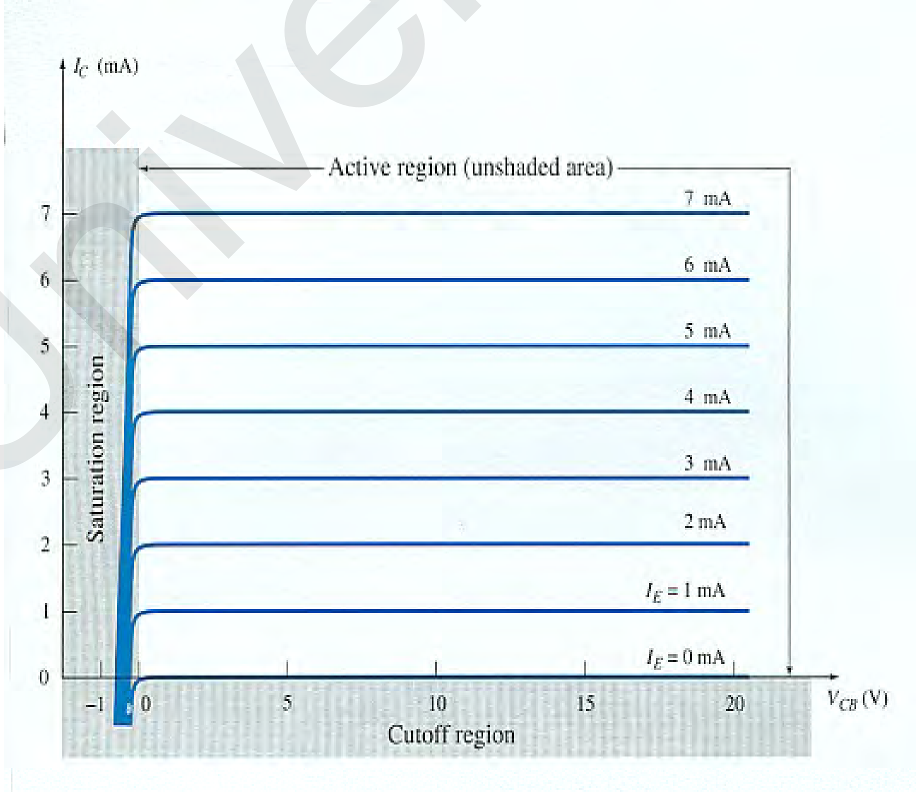
i.e Rin = VEB/IE for a constant value of VCB

CB mode - Output Characteristics

- **This graph demonstrates the output current (I_C) to an output voltage (V_{CB}) for various levels of input current (I_E).**

Output Resistance (Rout) is the ratio of output voltage to the output current of the transistor for a constant value of input current.

i.e Rout = V_{CB}/I_C for a constant value of I_E



Operating Regions

- **Active – Operating range of the amplifier.**
- **Cutoff – The amplifier is basically off.**
- **Saturation – The amplifier is ON.**

Alpha (α) is the ratio of I_C to I_E :

$$\alpha_{dc} = \frac{I_C}{I_E}$$

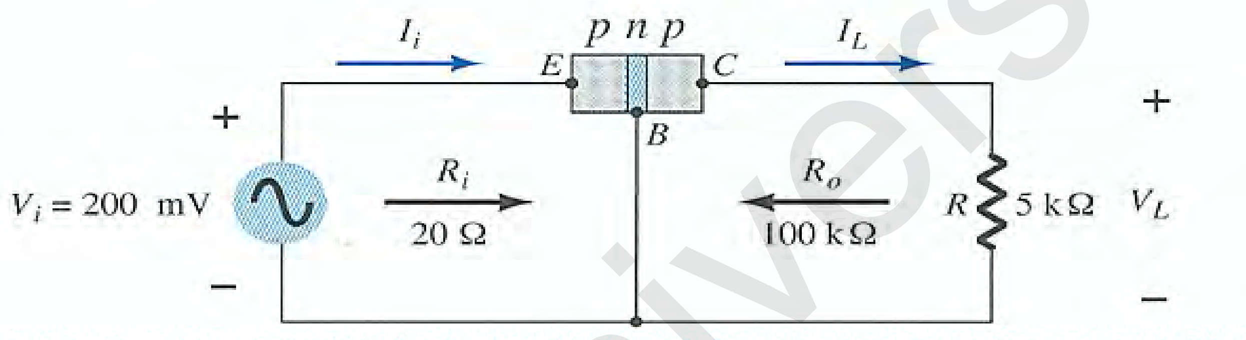
Ideally: $\alpha = 1$

In reality: α is between 0.9 and 0.998

Alpha (α) in the AC mode:

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$$

Transistor Amplification



Currents and Voltages:

$$I_E = I_i = \frac{V_i}{R_i} = \frac{200mV}{20\,\Omega} = 10mA$$

$$I_C \simeq I_E$$

$$I_L \simeq I_i = 10\text{ mA}$$

$$V_L = I_L R = (10\text{ ma})(5\text{ k}\Omega) = 50\text{ V}$$

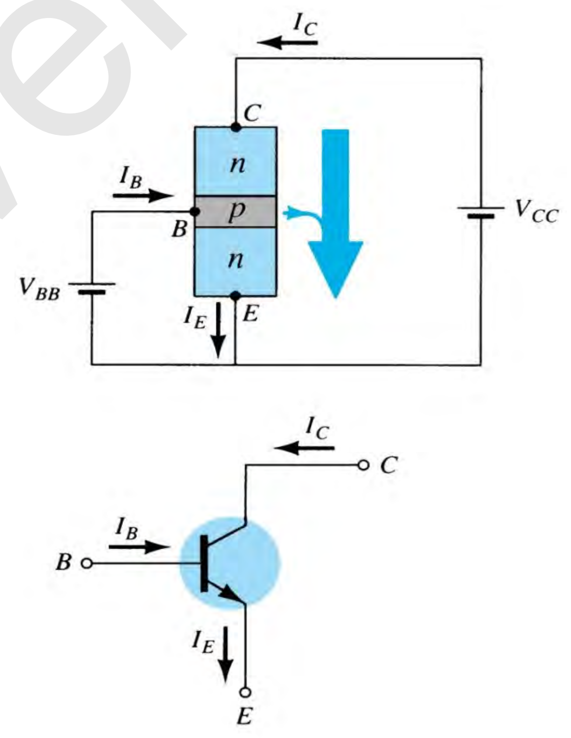
Voltage Gain:

$$A_v = \frac{V_L}{V_i} = \frac{50V}{200mV} = 250$$

Transistor characteristics in CE mode

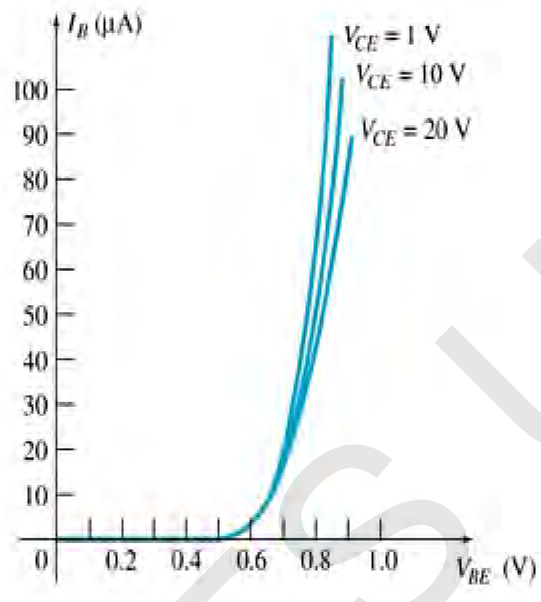
The emitter is common to both input (base-emitter) and output (collector-emitter).

The input is on the base and the output is on the collector.

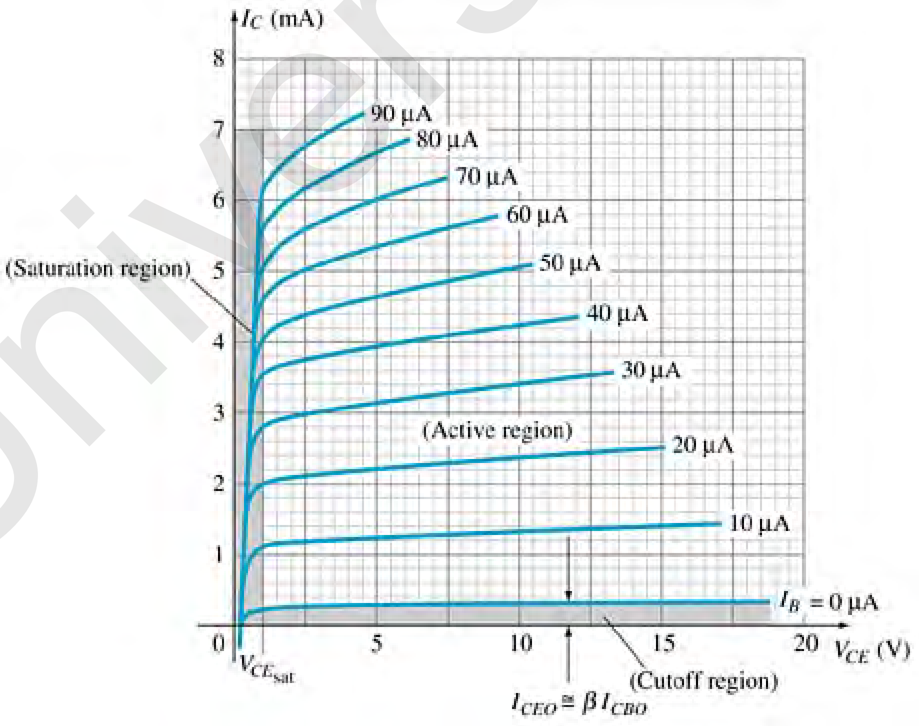


(a)

CE mode - Input & Output Characteristics



Input Characteristics



Output Characteristics

Common-Emitter Amplifier Currents

Ideal Currents

$$I_E = I_C + I_B \qquad\qquad I_C = \alpha I_E$$

Actual Currents

$$I_C = \alpha I_E + I_{CBO}$$

where I_{CBO} = minority collector current

I_{CBO} is usually so small that it can be ignored, except in high power transistors and in high temperature environments.

When I_B = 0 A the transistor is in cutoff, but there is some minority current flowing called I_{CEO}.

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha}\Big|_{I_B = 0\ \mu A}$$

Beta (β) – Current Gain of CE mode

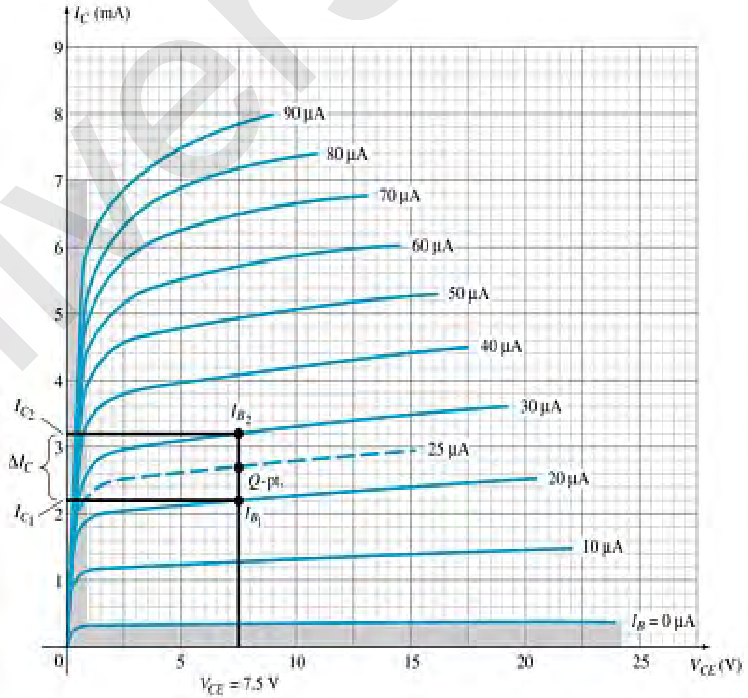
β represents the amplification factor of a transistor. (β is sometimes referred to as h_{fe}, a term used in transistor modeling calculations)

In DC mode:

$$\beta_{dc} = \frac{I_C}{I_B}$$

In AC mode:

$$\beta_{ac} = \frac{\Delta IC}{\Delta IB}\Big|_{V_{CE}=\text{constant}}$$



Determining β from a Graph

$$\beta_{AC} = \frac{(3.2\ mA - 2.2\ mA)}{(30\ \mu A - 20\ \mu A)}$$

$$\frac{1\ mA}{10\ \mu A}\Big|_{V_{CE}=7.5}$$

$$100$$

$$\beta_{DC} = \frac{2.7\ \text{mA}}{25\ \mu A}\Big|_{V_{CE}=7.5}$$

$$108$$

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Relation between α and β

From Kirchhoff's Current Law

$$I_E = I_C + I_B$$

$$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$$

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

MOSFET

- **M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor is abbreviated as **MOSFET**

MOSFETs vs. BJTs

Similarities:

- **Amplifiers**
- **Switching devices**
- **Impedance matching circuits**

Differences:

- **MOSFETs are voltage controlled devices.**
  BJTs are current controlled devices.

- **MOSFETs have a higher input impedance.**
  BJTs have higher gains.

- **MOSFETs are less sensitive to temperature variations and are more easily integrated on ICs.**

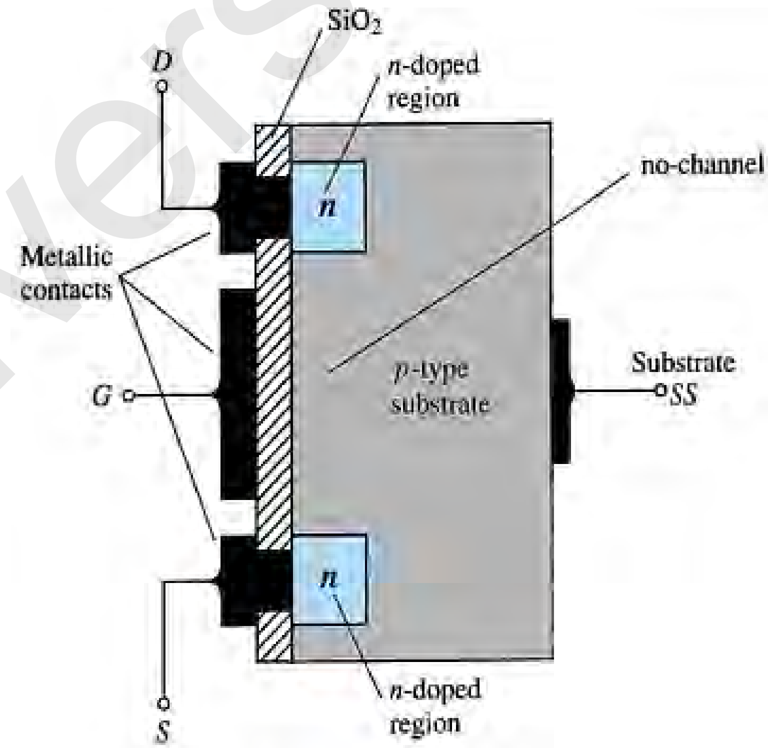
E-Type MOSFET Construction

- **The Drain (D) and Source (S) connect to the to *n*-doped regions. These *n*-doped regions are connected via an *n*-channel**

- **The Gate (G) connects to the *p*-doped substrate via a thin insulating layer of SiO_2**

- **There is no channel**

- **The *n*-doped material lies on a *p*-doped substrate that may have an additional terminal connection called the Substrate (SS)**



Types Of MOSFET

MOSFET: Metal–Oxide–Semiconductor FET

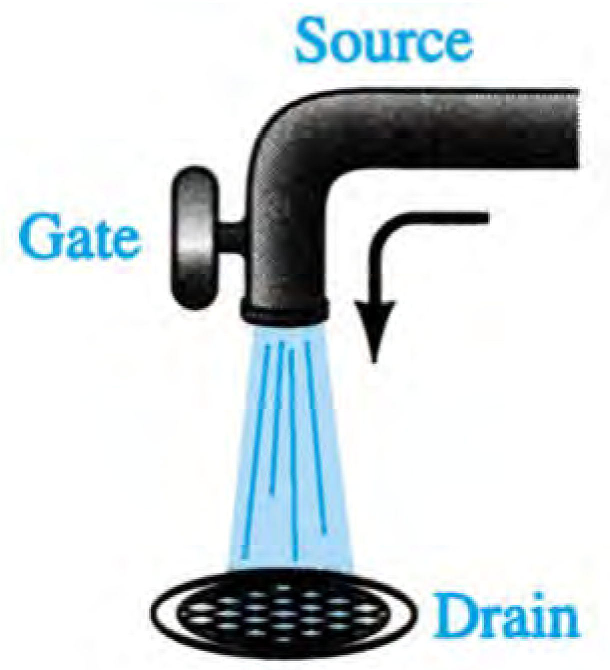
- **D-MOSFET: Depletion MOSFET**
- **E-MOSFET: Enhancement MOSFET**

JFET operation can be compared to a water spigot

The source of water pressure is the accumulation of electrons at the negative pole of the drain-source voltage.

The drain of water is the electron deficiency (or holes) at the positive pole of the applied voltage.

The Gate of flow of water is the gate voltage that controls the width of the n-channel and, therefore, the flow of charges from source to drain.



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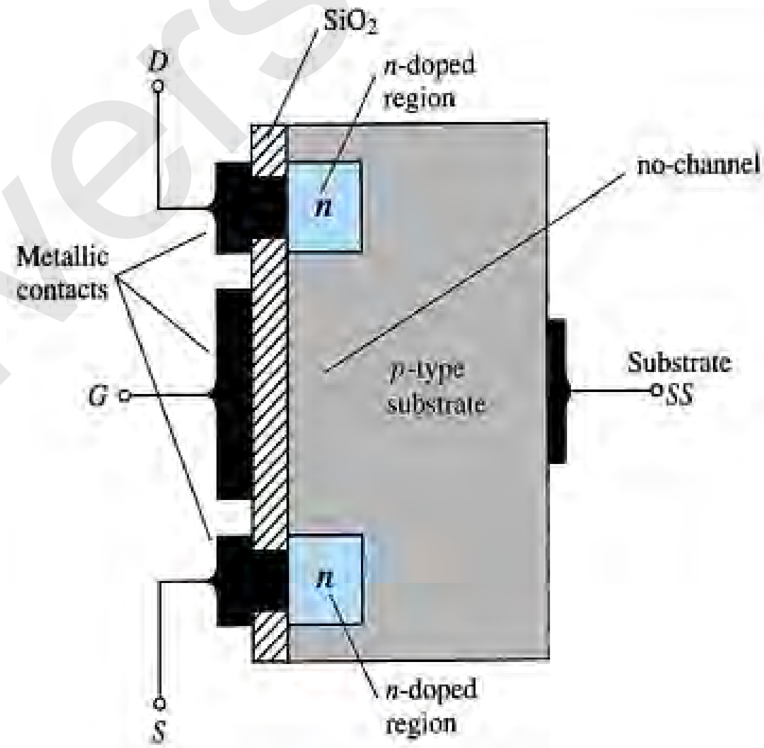
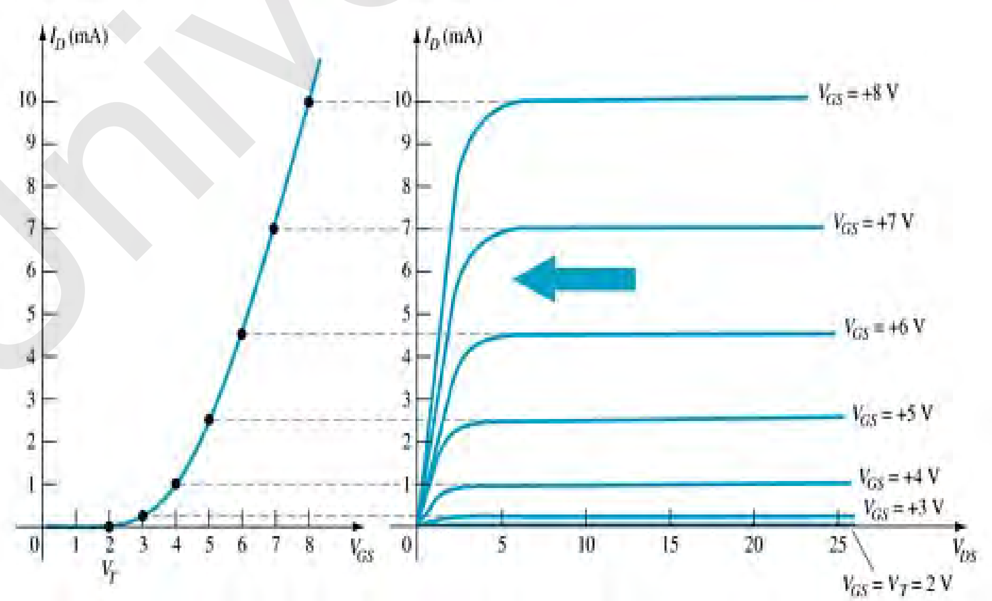


Basic Operation of the E-Type MOSFET

The enhancement-type MOSFET operates only in the enhancement mode.

- **V_{GS} is always positive**
- **As V_{GS} increases, I_D increases**
- **As V_{GS} is kept constant and V_{DS} is increased, then I_D saturates (I_{DSS}) and the saturation level, V_{DSsat} is reached**



Transfer Characteristics

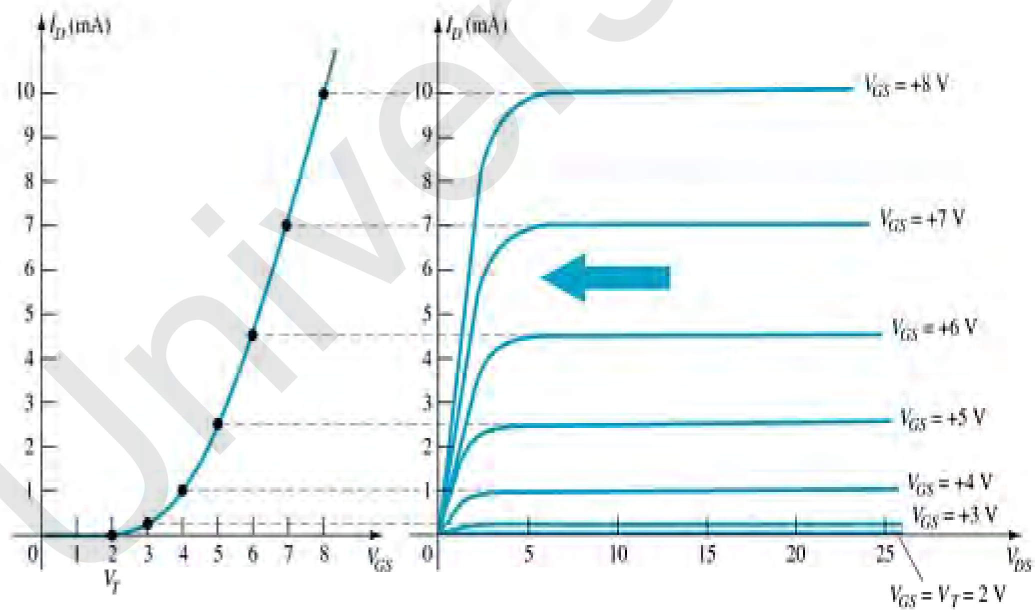
Drain Characteristics

E-Type MOSFET Transfer Curve

To determine I_D given V_{GS}:

$$I_D = k(V_{GS} - V_T)^2$$

Where:
V_T = threshold voltage or voltage at which the MOSFET turns on



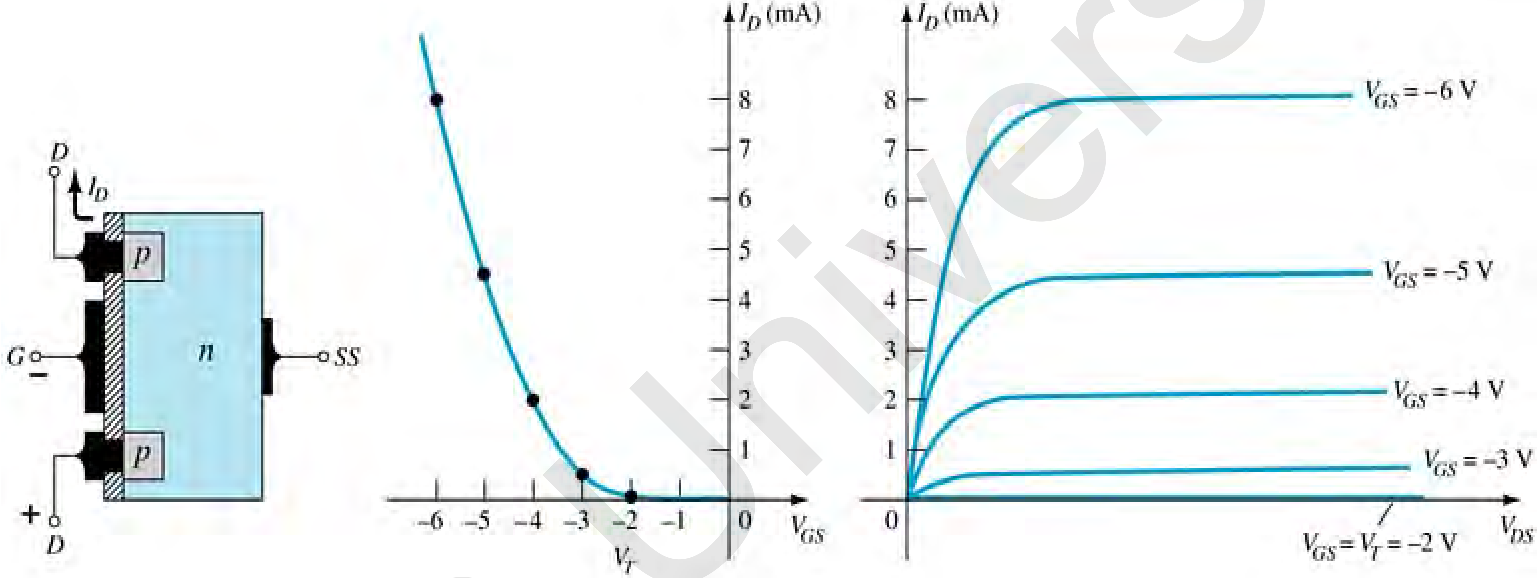
V_{DSsat} can be calculated by:

$$V_{Dsat} = V_{GS} - V_T$$

***k*, a constant, can be determined by using values at a specific point and the formula:**

$$k = \frac{I_{D(\text{ON})}}{(V_{\text{GS(ON)}} - VT)^2}$$

p-Channel E-Type MOSFETs



The *p*-channel enhancement-type MOSFET is similar to the *n*-channel, except that the voltage polarities and current directions are reversed.

MOSFET Symbols