Department of Computer Science and Engineering
Daffodil International University

Transistor & Mosfet

Course Title: Embedded Systems and IoT

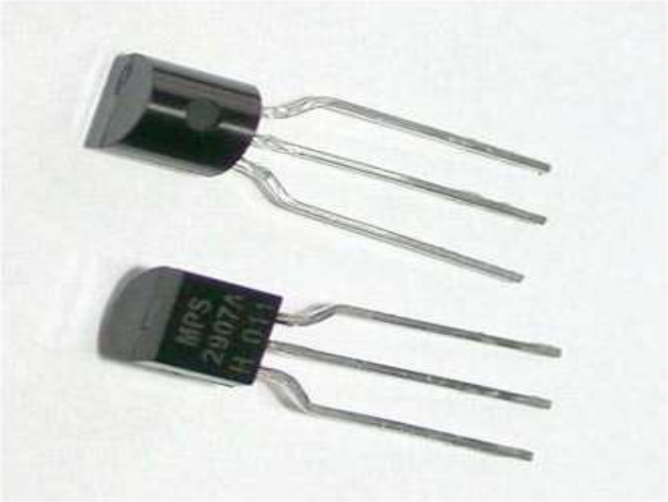
Course Code: CSE233

Prepared By:
Bakhtiar Muiz
Lecturer, Dept. of CSE, DIU

Transistor

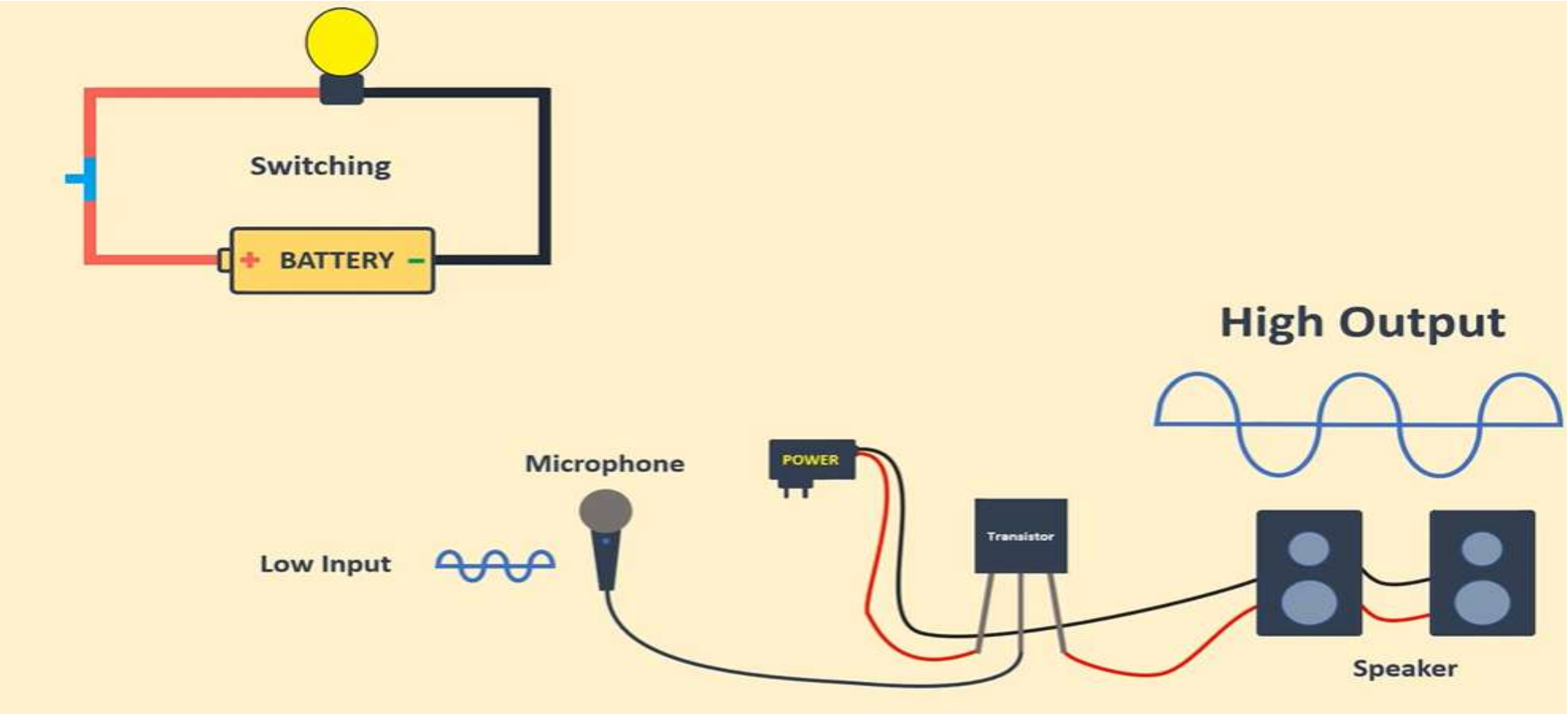
- A transistor is a type of semiconductor device that can be **used to conduct and insulate electric current or voltage.** A transistor basically **acts as a switch and an amplifier.** In simple words, a transistor is a miniature device that is used to control or regulate the flow of electronic signals.

  - Semiconductors: ability to change from conductor to insulator
  - Can either allow current or prohibit current to flow
  - Useful as a switch, but also as an amplifier
  - Essential part of many technological advances



A transistor is a semiconductor device used to amplify and switch electronic signals and electrical power.

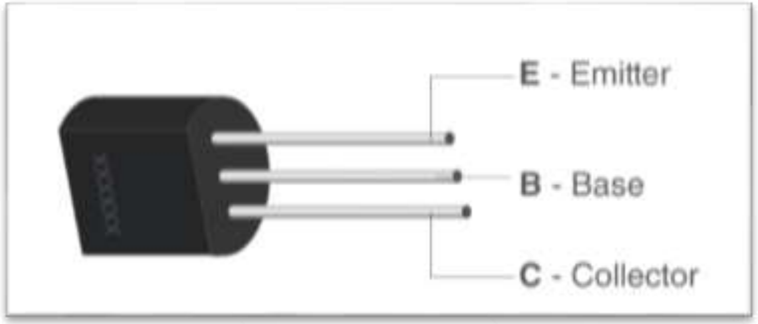
Use of transistor



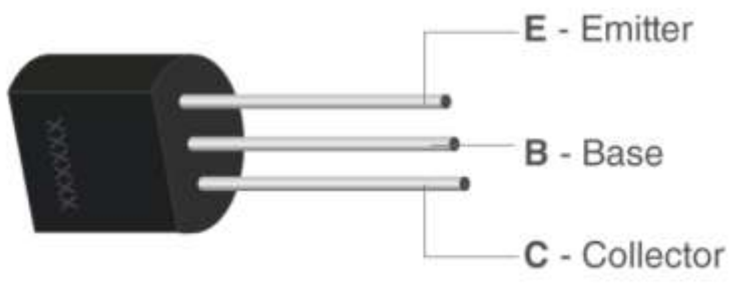
Parts of a Transistor

- A typical transistor is composed of three layers of semiconductor materials or, more specifically, terminals which help to make a connection to an external circuit and carry the current. A voltage or current that is applied to any one pair of the terminals of a transistor controls the current through the other pair of terminals. There are three terminals for a transistor. They are listed below:

- **Base:** This is used to activate the transistor.
- **Collector:** It is the positive lead of the transistor.
- **Emitter:** It is the negative lead of the transistor.



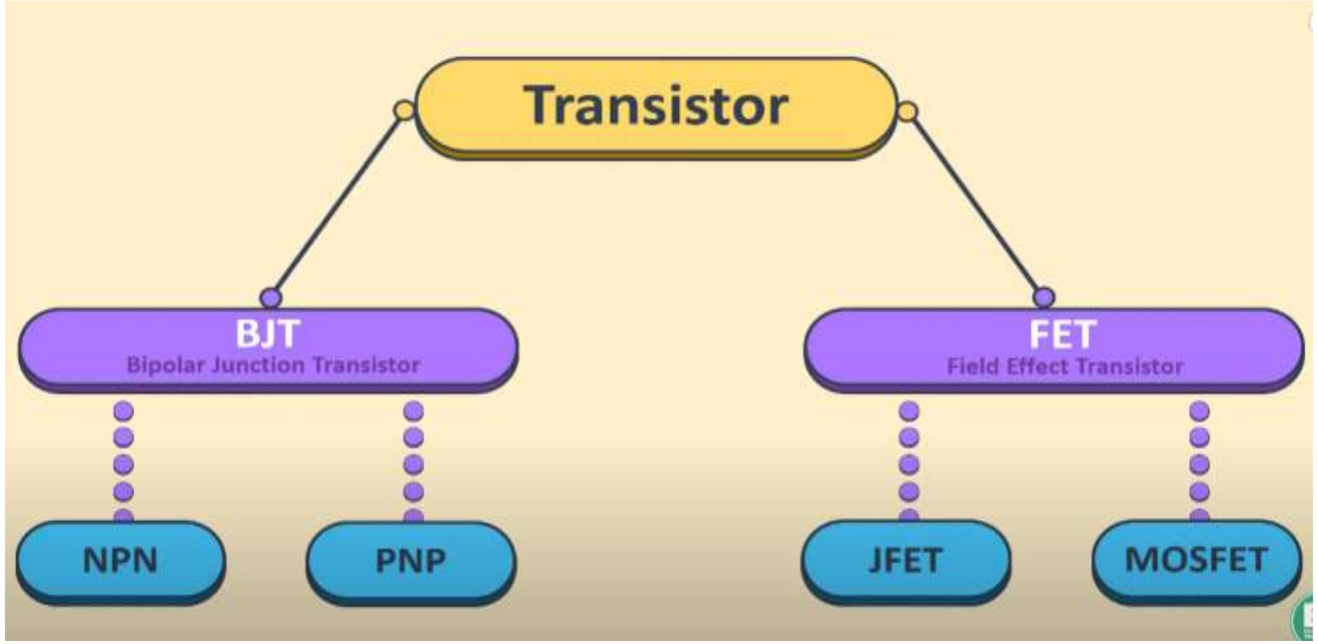
Parts of a Transistor



- ❑ **Basic working principle of a transistor is based on controlling the flow of current through one channel by varying the intensity of a smaller current that is flowing through a second channel.**

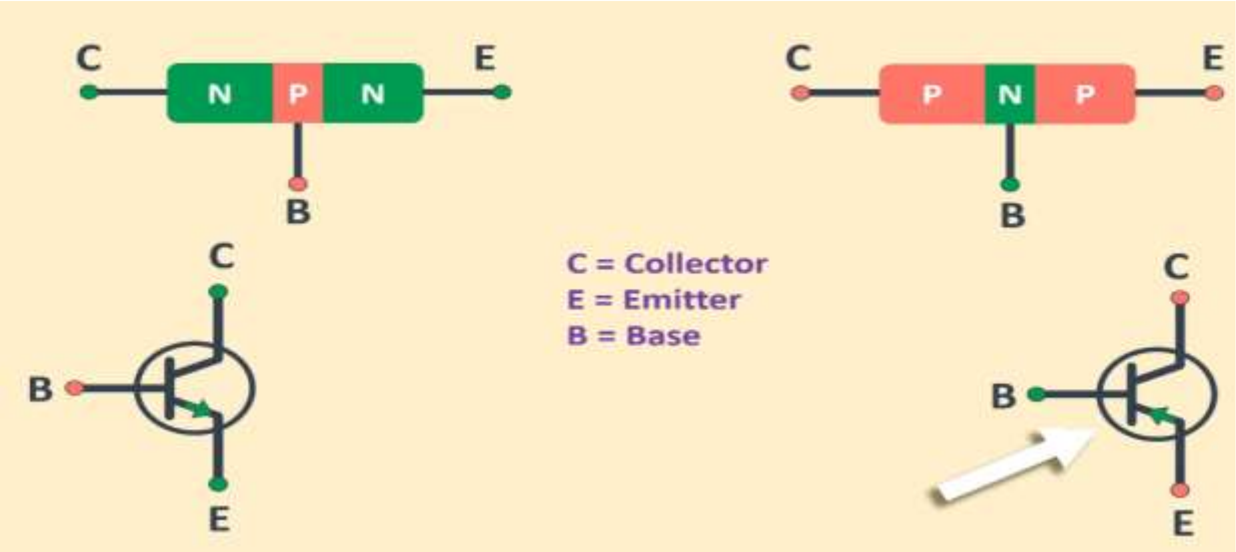
Types of Transistor

- There are mainly two types of transistors, based on how they are used in a circuit.



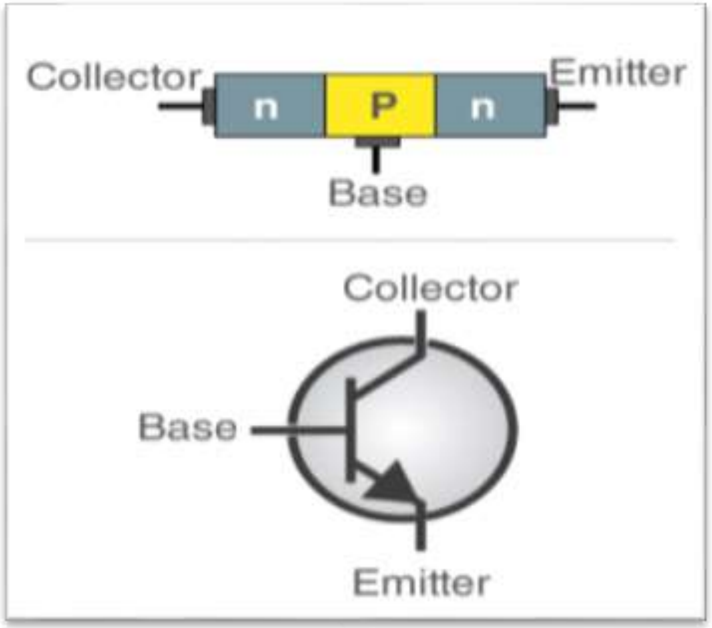
Bipolar Junction Transistor (BJT)

- The three terminals of BJT are the base, emitter and collector. A very small current flowing between the base and emitter can control a larger flow of current between the collector and emitter terminal.



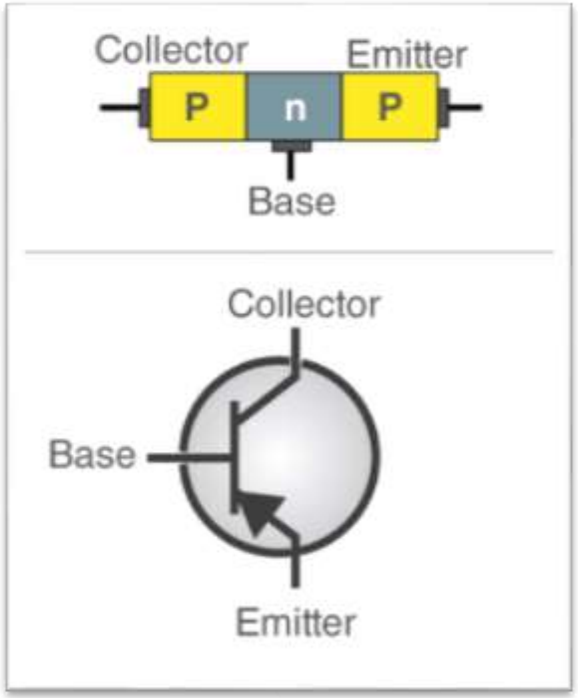
NPN

- N-P-N Transistor: In this transistor, we will find one p-type material that is present between two n-type materials.
  1. N-P-N transistor is basically used to amplify weak signals to strong signals.
  2. In an NPN transistor, the electrons move from the emitter to the collector region, resulting in the formation of current in the transistor. This transistor is widely used in the circuit.



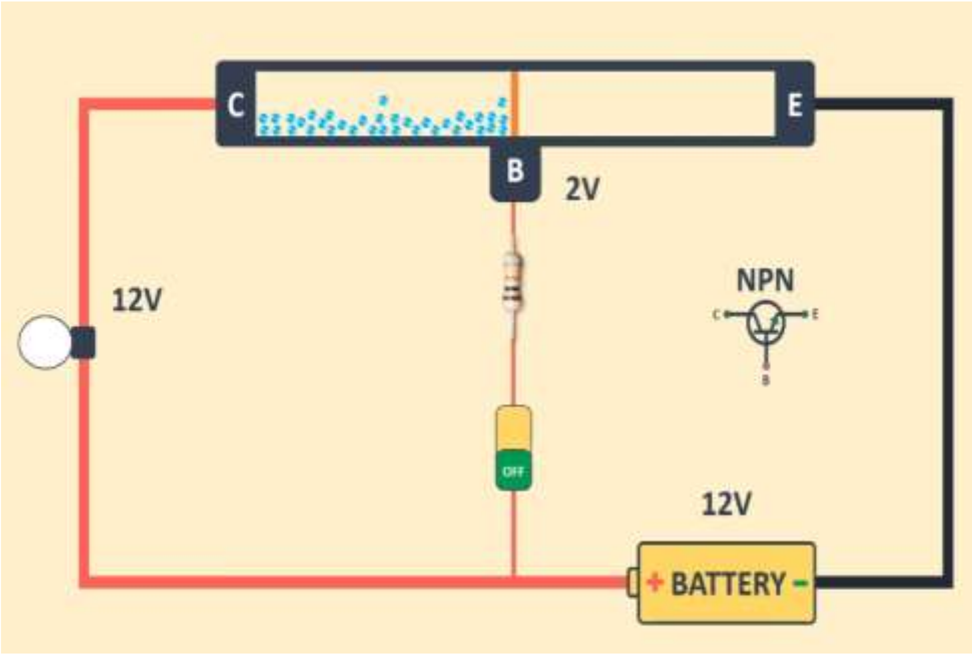
PNP

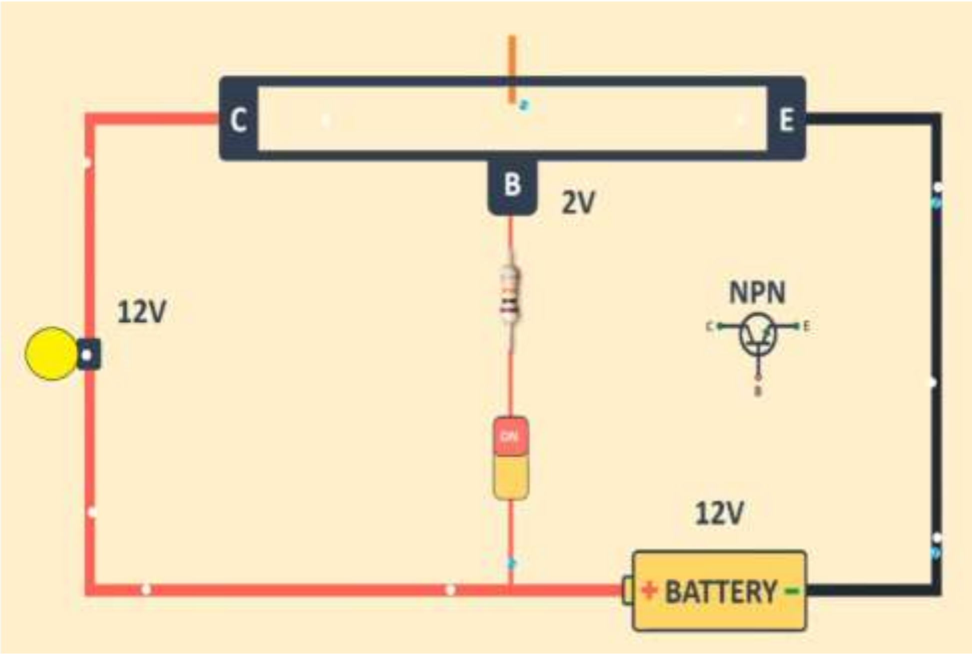
- **P-N-P Transistor: It is a type of BJT where one n-type material is introduced or placed between two p-type materials. In such a configuration, the device will control the flow of current.**



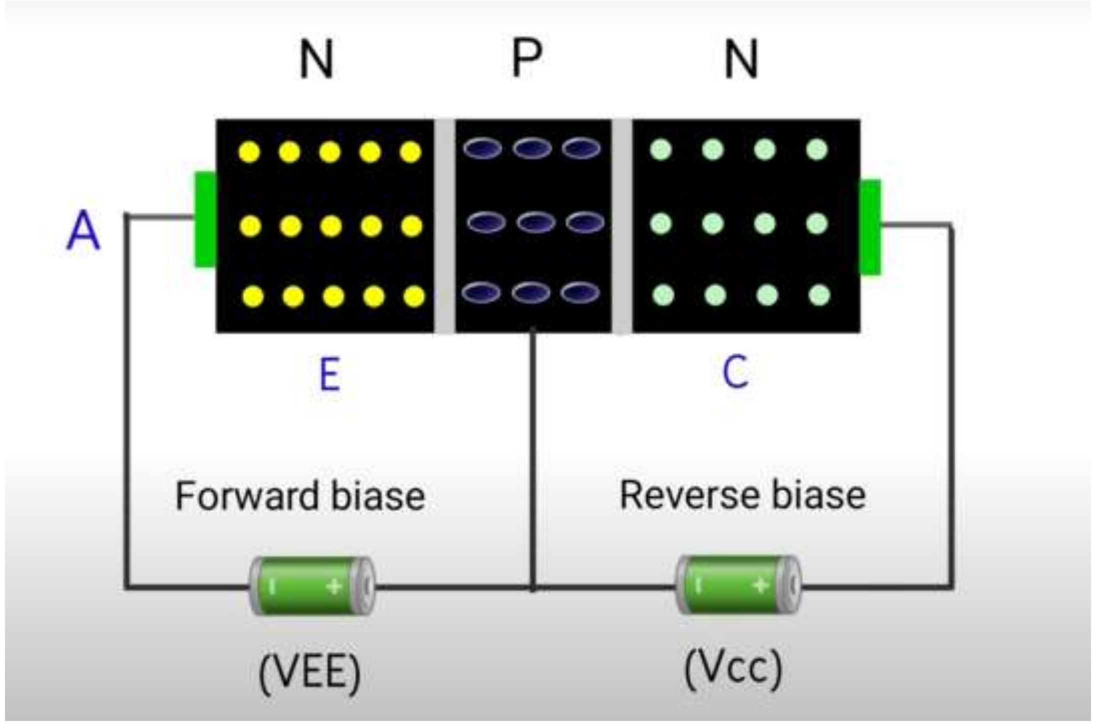
1. **PNP transistor consists of 2 crystal diodes which are connected in series. The right side and left side of the diodes are known as the collector-base diode and emitter-base diode, respectively.**

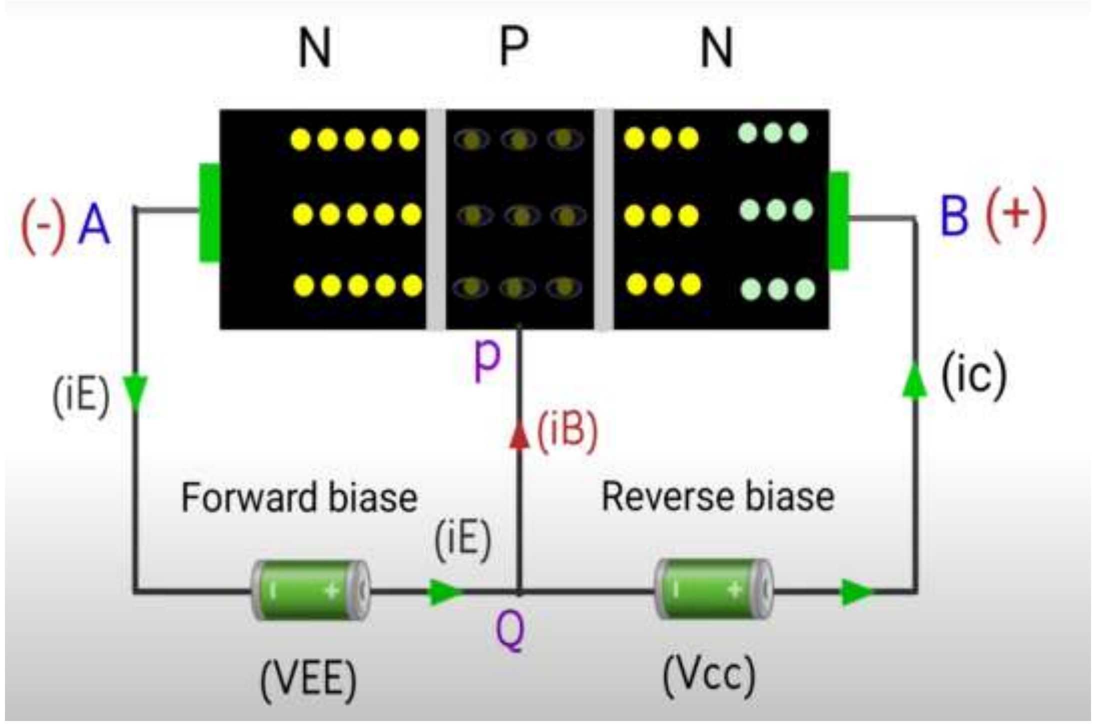
How Do Transistors Work?



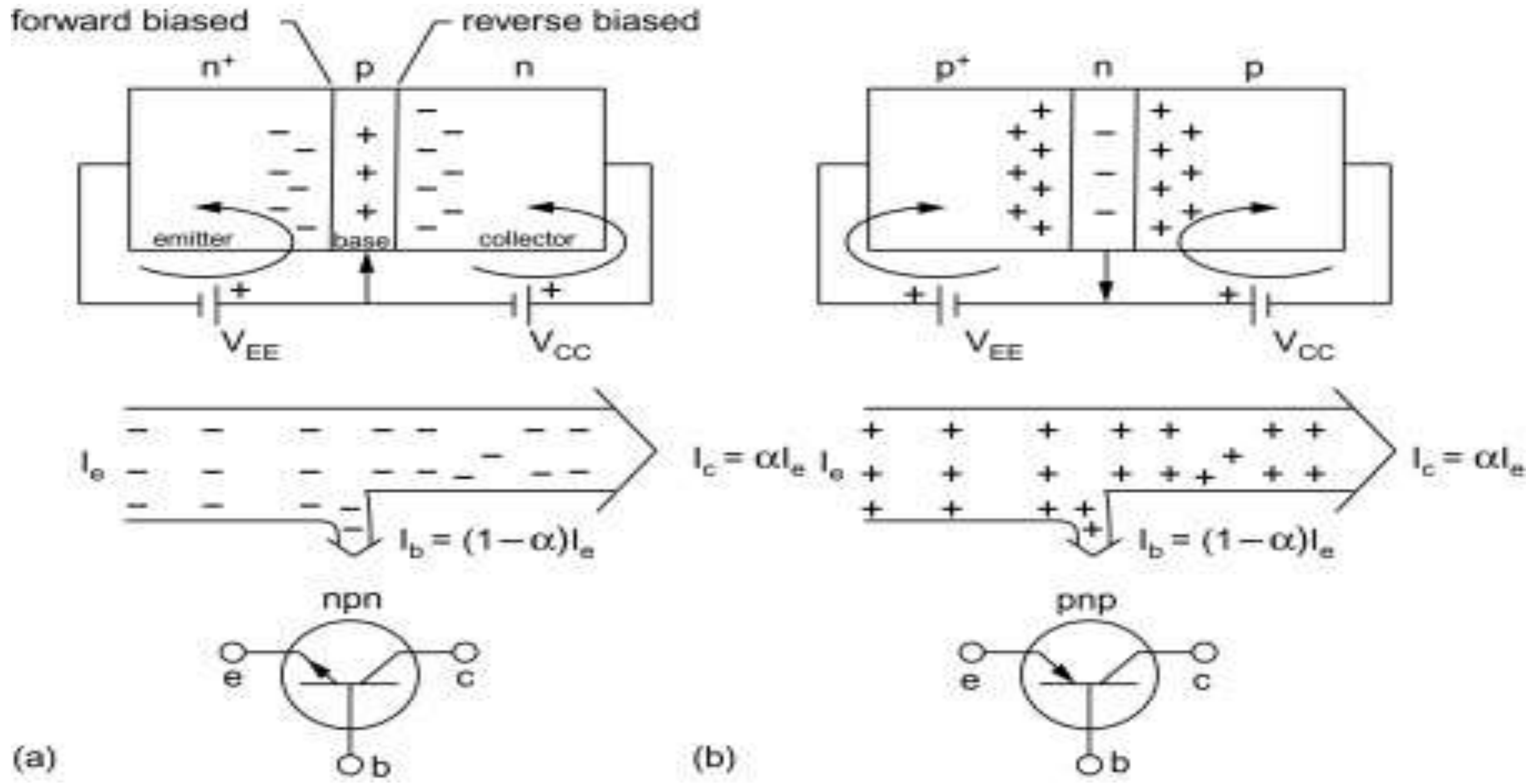


Operation of NPN Transistor



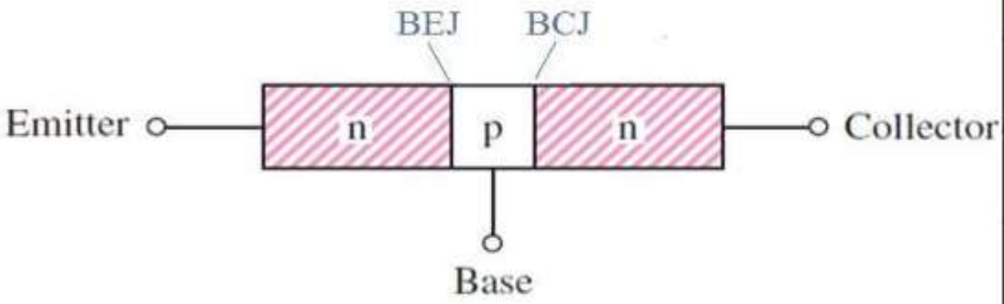


Operation of PNP Transistor



Operation of PNP Transistor

- A single p-n junction has two different types of bias:
  - Forward Bias
  - Reverse Bias
- Thus, a two pn-jnuction device has four types of bias.



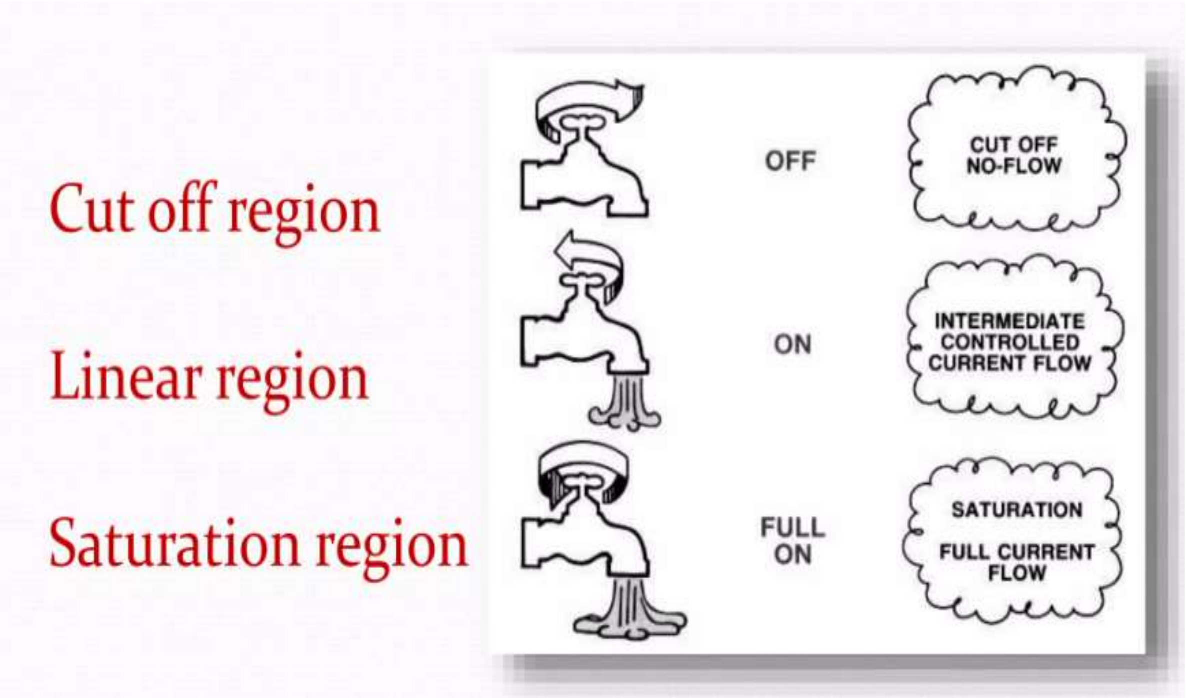
BC junction (BCJ)	BE junction (BEJ)	Mode of operation
Reverse	Reverse	Cut-off
Forward	Reverse	Cut-off
Reverse	Forward	Active
Forward	Forward	Saturation

Limitations of Transistors

- Transistors have a few limitations, and they are as follows:

  i. Transistors lack higher electron mobility.
  ii. Transistors can be easily damaged when electrical and thermal events arise.
  iii. For example, electrostatic discharge in handling.
  iv. Transistors are affected by cosmic rays and radiation.

Operation Regions of BJT



Operation Regions of BJT

OFF Mode (Cutoff Region)

•No base current (Ib = 0).

•No current flows between collector and emitter (Ic = 0).

•Transistor acts as an open switch.

ON Mode (Saturation Region)

•Base current is high.

•Maximum current flows from collector to emitter.

•Transistor acts as a closed switch.

Amplification Mode (Active Region)

•A small base current controls a large collector-emitter current.

•Transistor acts as an amplifier.

Common configuration

1. Common Emitter Configuration –

has both Current and Voltage Gain.

2. Common Base Configuration –

has Voltage Gain but no Current Gain.

3. Common Collector Configuration –

has Current Gain but no Voltage Gain.

Common configuration

Emitter and collector currents:

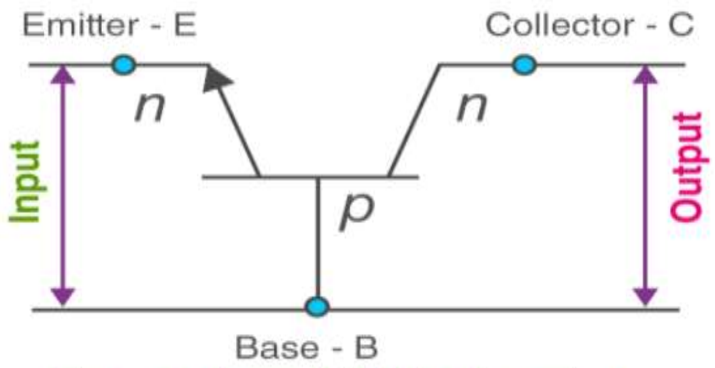
$$I_C \cong I_E$$

Base-emitter voltage:

$$V_{BE} = 0.7\text{ V} \quad \text{(for Silicon)}$$

Common Base (CB)

- In common base (CB) configuration, the base terminal of the transistor is common between input and output terminals.



Common base (CB) Configuration

Current Amplification Factor α

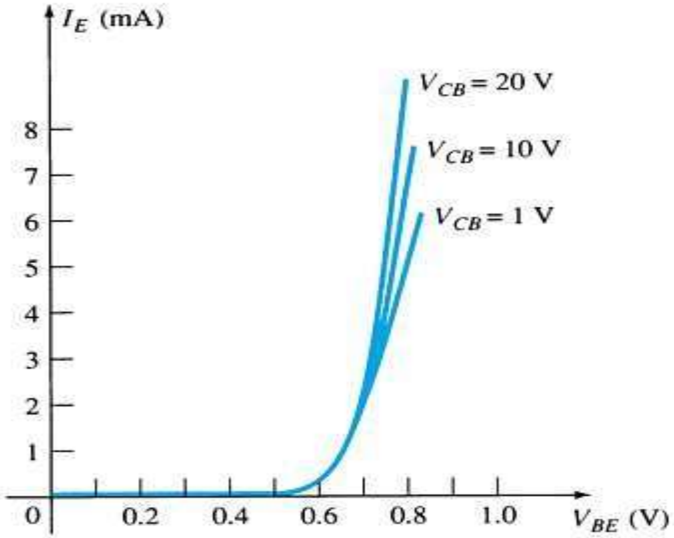
The ratio of change in collector current $\$\Delta I_C\$$ to the change in emitter current $\$\Delta I_E\$$ when collector voltage $\mathbf{V_{CB}}$ is kept constant, is called as **Current amplification factor**. It is denoted by α.

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \ \text{at constant } V_{CB}$$

Common Base (CB)

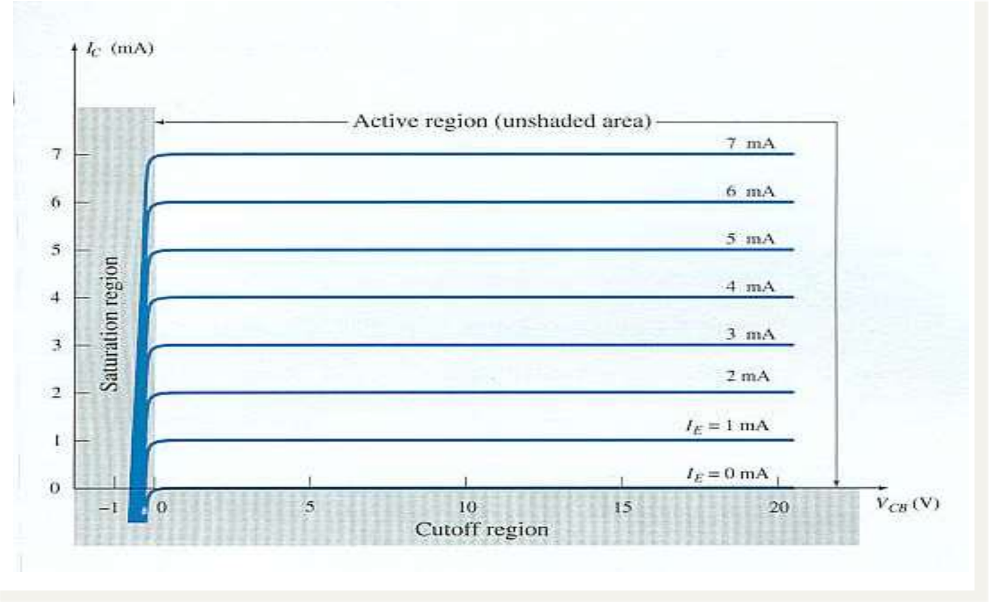
Input Characteristics

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



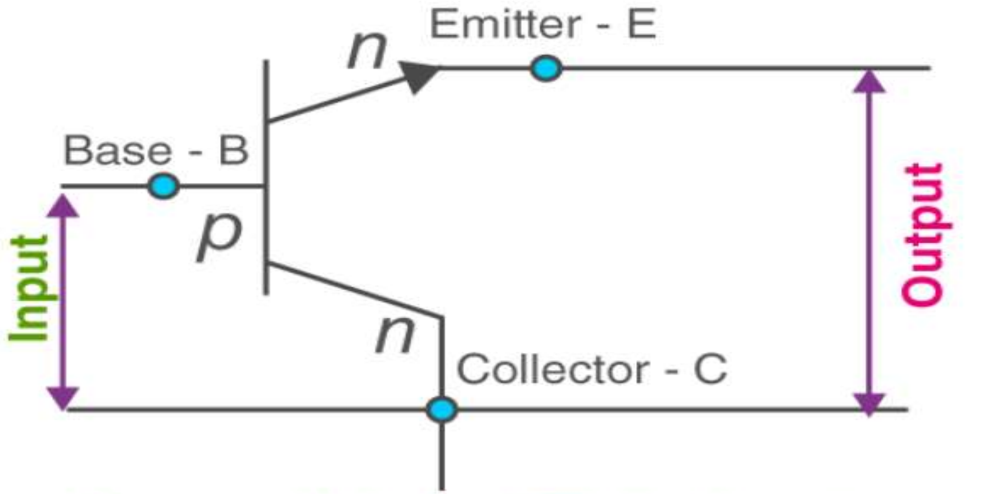
Output Characteristics

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



Common Collector (CC)

- In common collector (CC) configuration, the collector terminals are common between the input and output terminals.



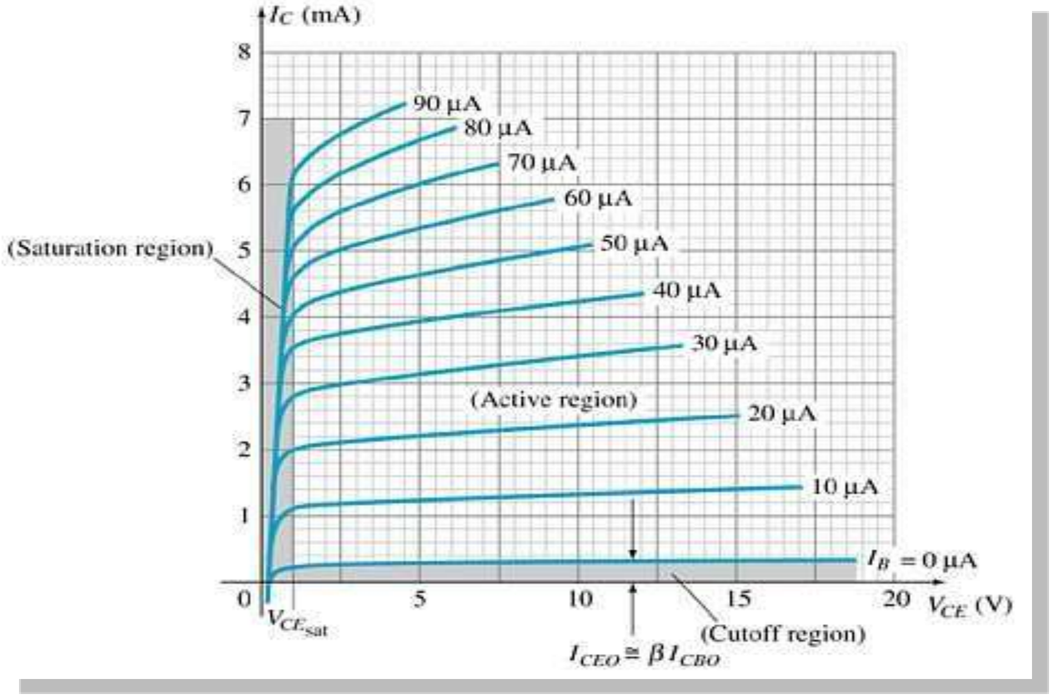
Common Collector (CC) Configuration

The ratio of change in emitter current ΔI_E to the change in base current ΔI_B is known as **Current Amplification factor** in common collector CC configuration. It is denoted by **γ**.

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

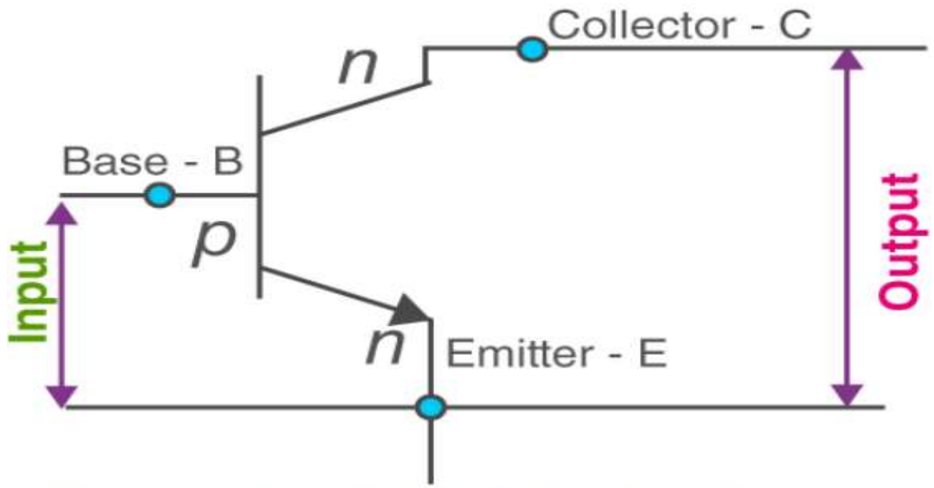
Common Collector (CC)

The characteristics are similar to those of the common-emitter configuration, except the vertical axis is I_E.



Common Emitter (CE)

- In common emitter (CE) configuration, the emitter terminal is common between the input and the output terminals.



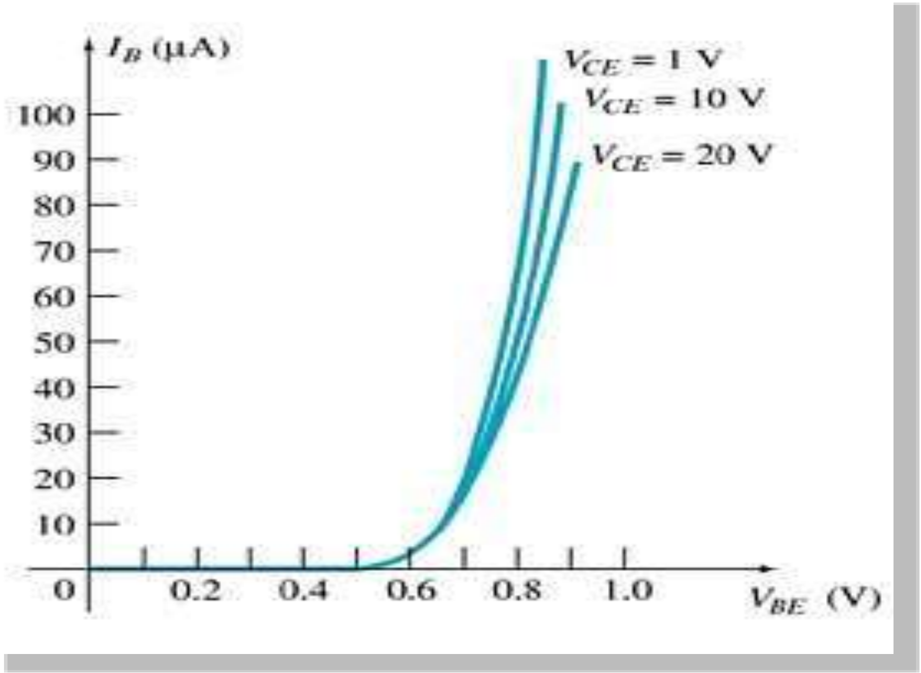
Common Emitter (CE) Configuration

Base Current Amplification factor β

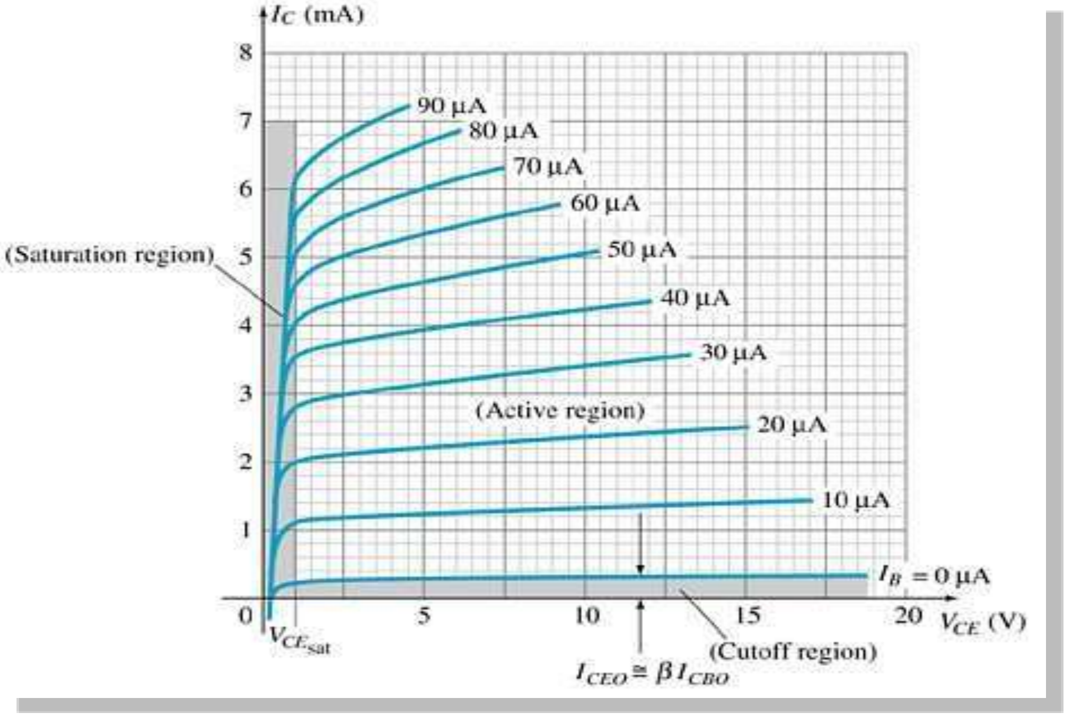
The ratio of change in collector current ΔI_C to the change in base current ΔI_B is known as **Base Current Amplification Factor**. It is denoted by β

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

Common Emitter (CE)



Base Characteristics



Collector Characteristics

Amplification Factor

Relation between β and α

Let us try to derive the relation between base current amplification factor and emitter current amplification factor.

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

We can write

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

Dividing by $$

$$\beta = \frac{\frac{\Delta I_C}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

We have

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

Therefore,

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

Amplification Factor

Relation between γ and α

Let us try to draw some relation between γ and α

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of I_B, we get

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

Dividing by ΔI_E

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}}$$

$$\frac{1}{1 - \alpha}$$

$$\gamma = \frac{1}{1 - \alpha}$$

Transistor Simple Mathematical Problem

- In a common base connection, IE = 1mA, IC = 0.95mA. Calculate the value of IB .
- In a common base connection, current amplification factor is 0.9. If the emitter current is 1mA, determine the value of base current.
- In a common base connection, IC = 0.95 mA and IB = 0.05 mA. Find the value of α.

- In a common base connection, the emitter current is 1mA. If the emitter circuit is open, the collector current is 50 µA. Find the total collector current. Given that α = 0.92.

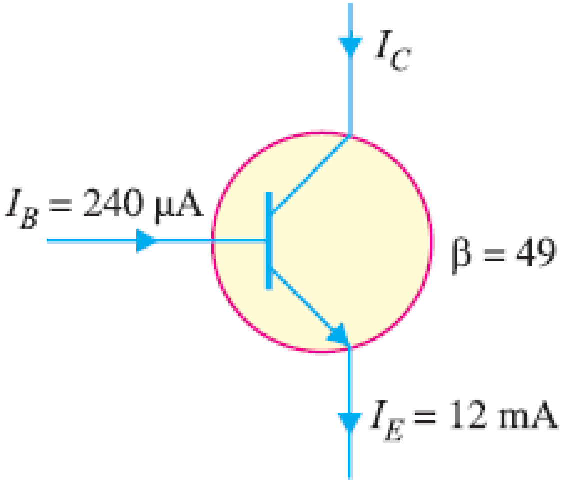
$$\text{Here, } I_E = 1\text{ mA}, \alpha = 0.92, \quad I_{CBO} = 50\ \mu\text{A}$$

$$\text{Total collector current, } I_C = \alpha I_E + I_{CBO} = 0.92 \times 1 + 50 \times 10^{-3}$$

$$= 0.92 + 0.05 = \mathbf{0.97\ mA}$$

Transistor Simple Mathematical Problem

- Find the α rating of the transistor shown in Fig. Hence determine the value of IC using both α and β rating of the transistor.



- **Solve**

$$\alpha = \frac{\beta}{1+\beta} = \frac{49}{1+49} = 0.98$$

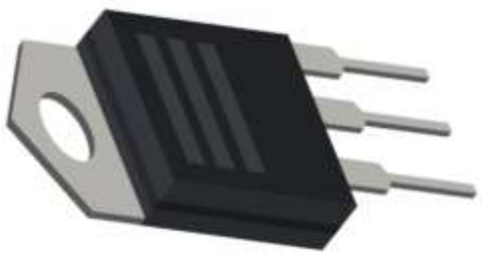
The value of I_C can be found by using either α or β rating as under :

$$I_C = \alpha I_E = 0.98\ (12\ mA) = 11.76\ mA$$

Also $$I_C = \beta I_B = 49\ (240\ \mu A) = 11.76\ mA$$

What Is a MOSFET?

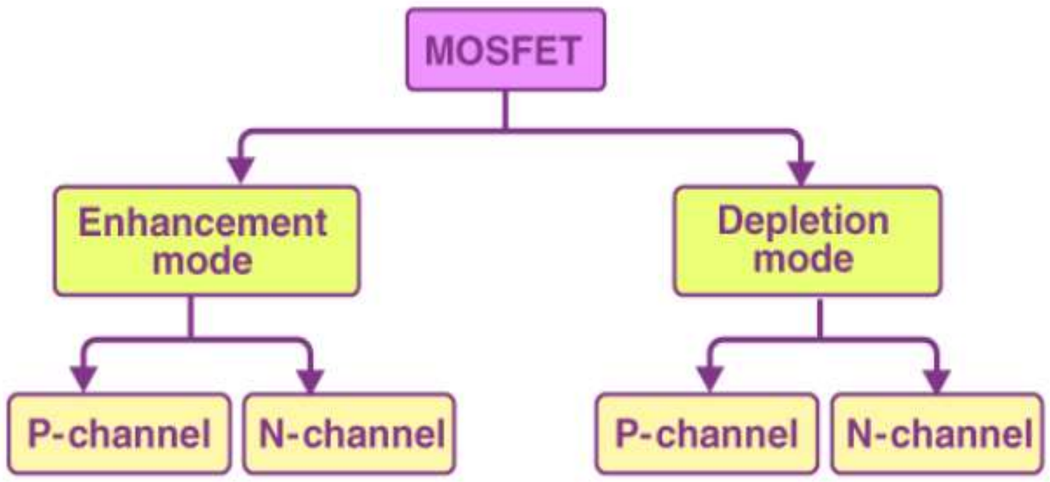
- Metal Oxide Silicon Field Effect Transistors commonly known as MOSFETs are electronic devices used to switch or amplify voltages in circuits. It is a voltage controlled device and is constructed by three terminals. The terminals of MOSFET are named as follows:

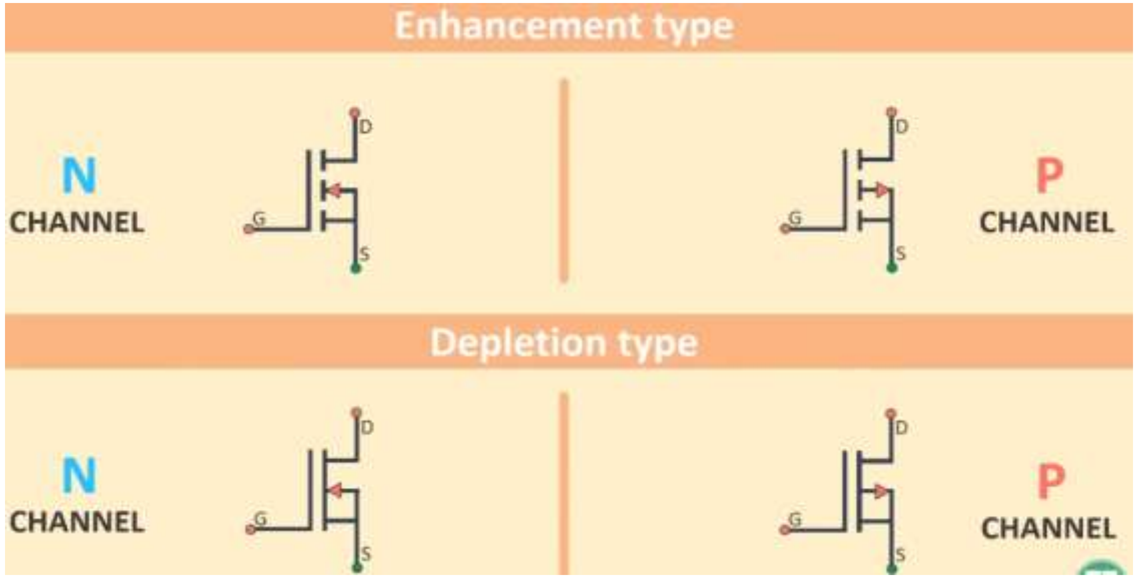


- Source
- Gate
- Drain

MOSFET Types

- The classification of MOSFET based on the construction and the material used is given below in the flowchart.





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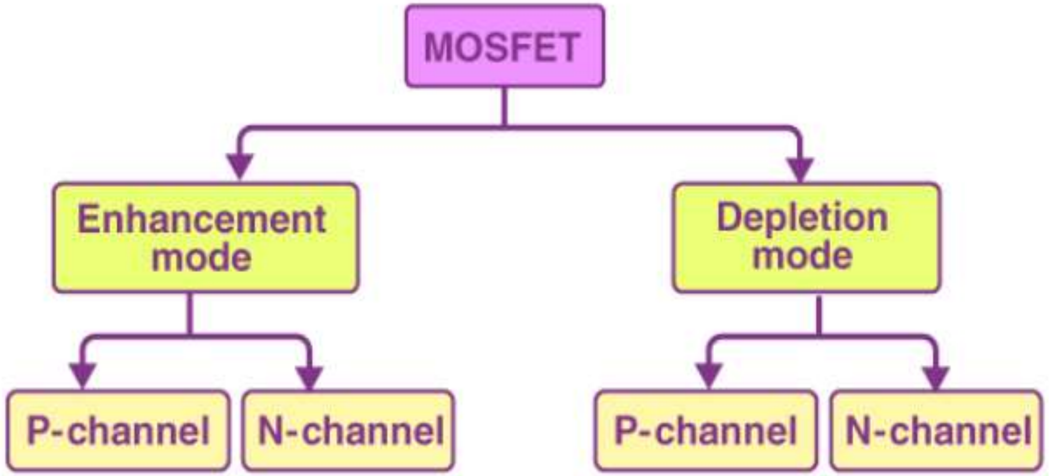
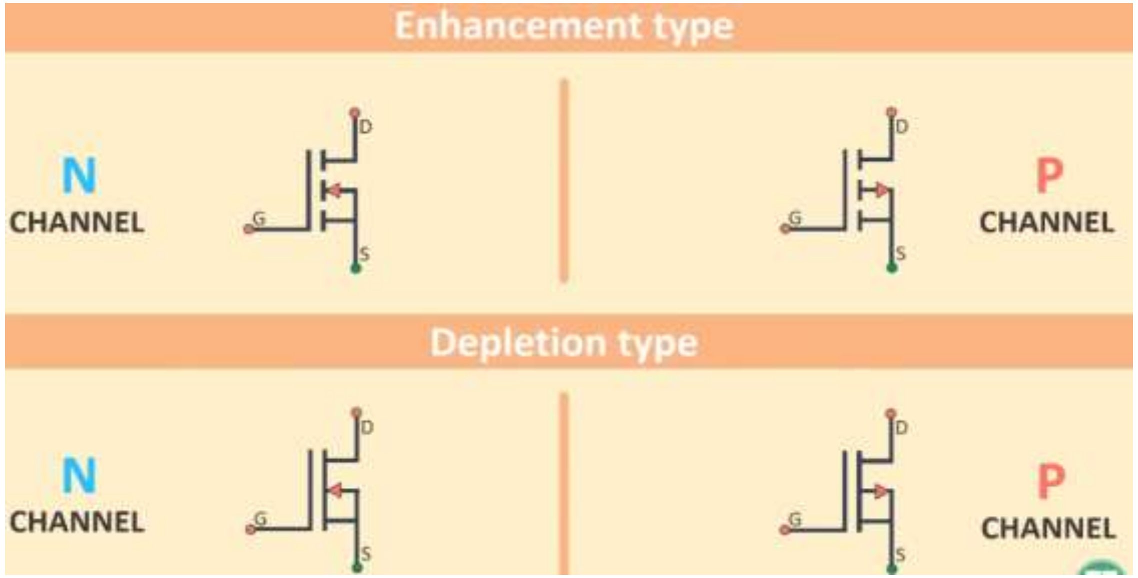
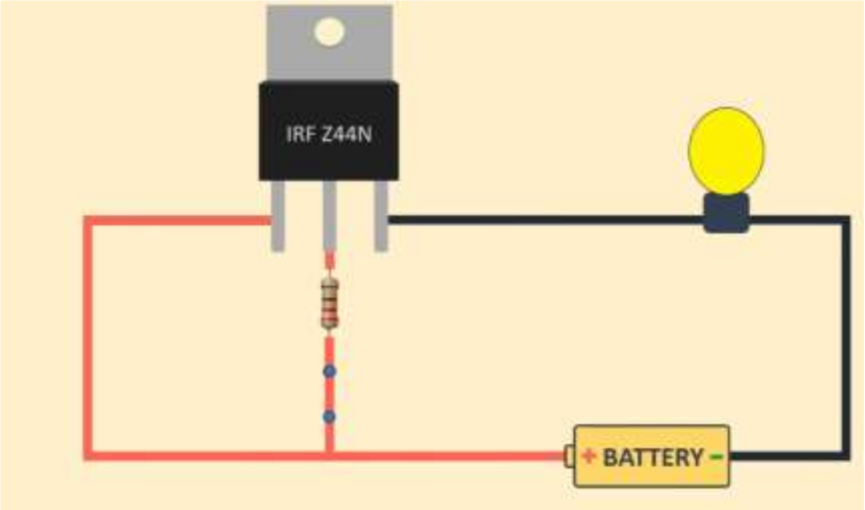
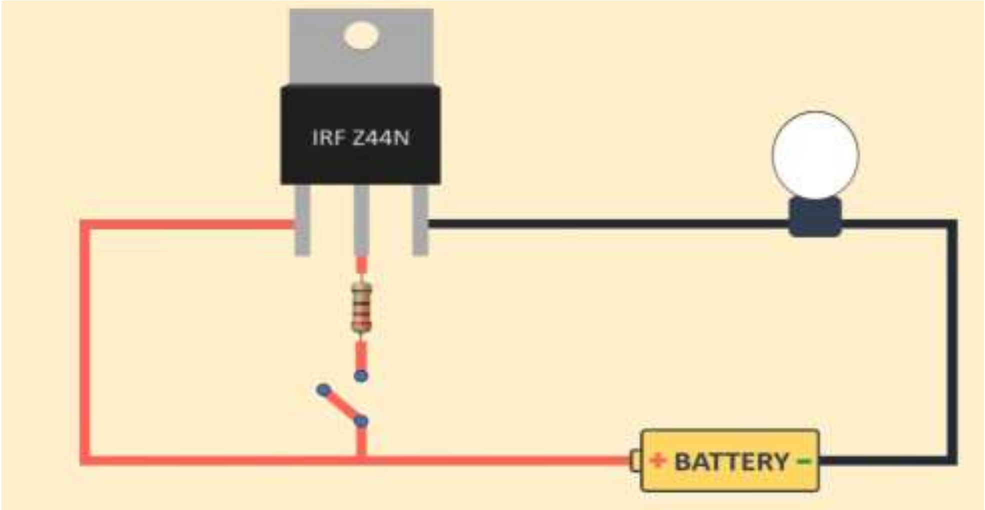




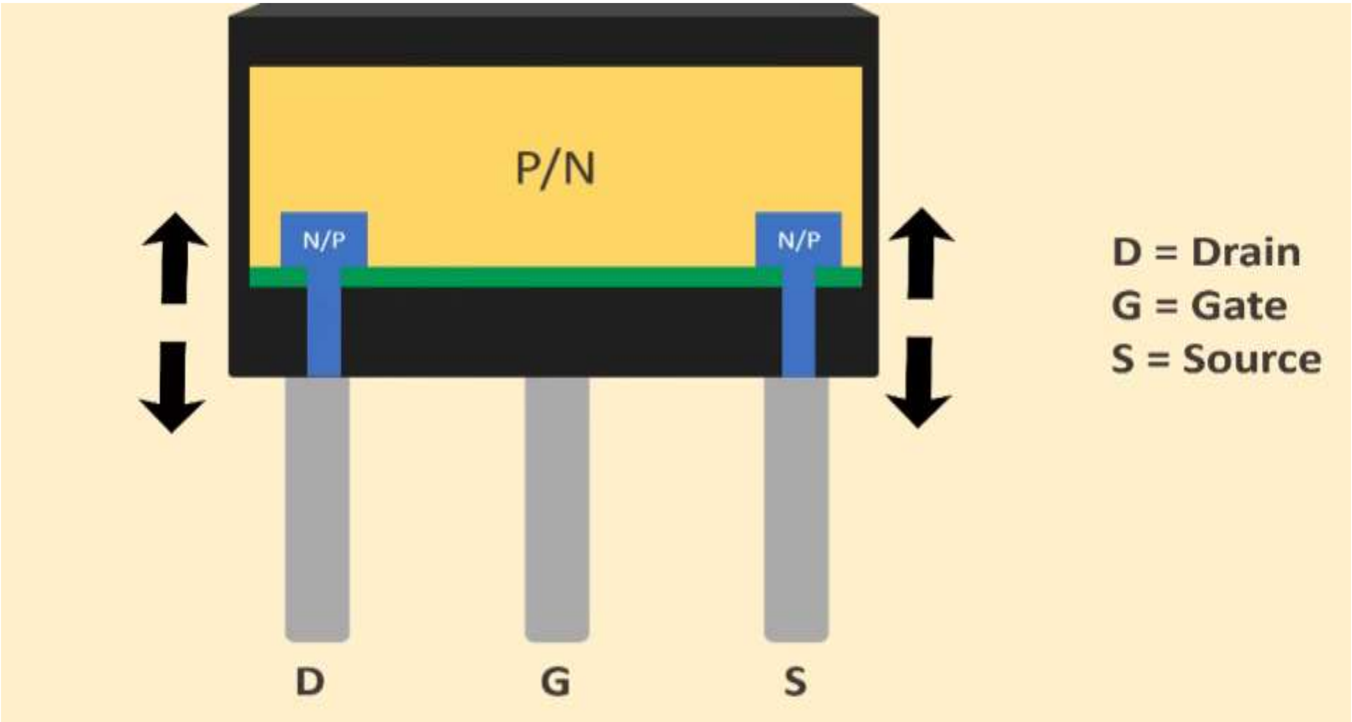
Working Principle of MOSFET

- When voltage is applied to the gate, an electrical field is generated that changes the width of the channel region, where the electrons flow. The wider the channel region, the better conductivity of a device will be.

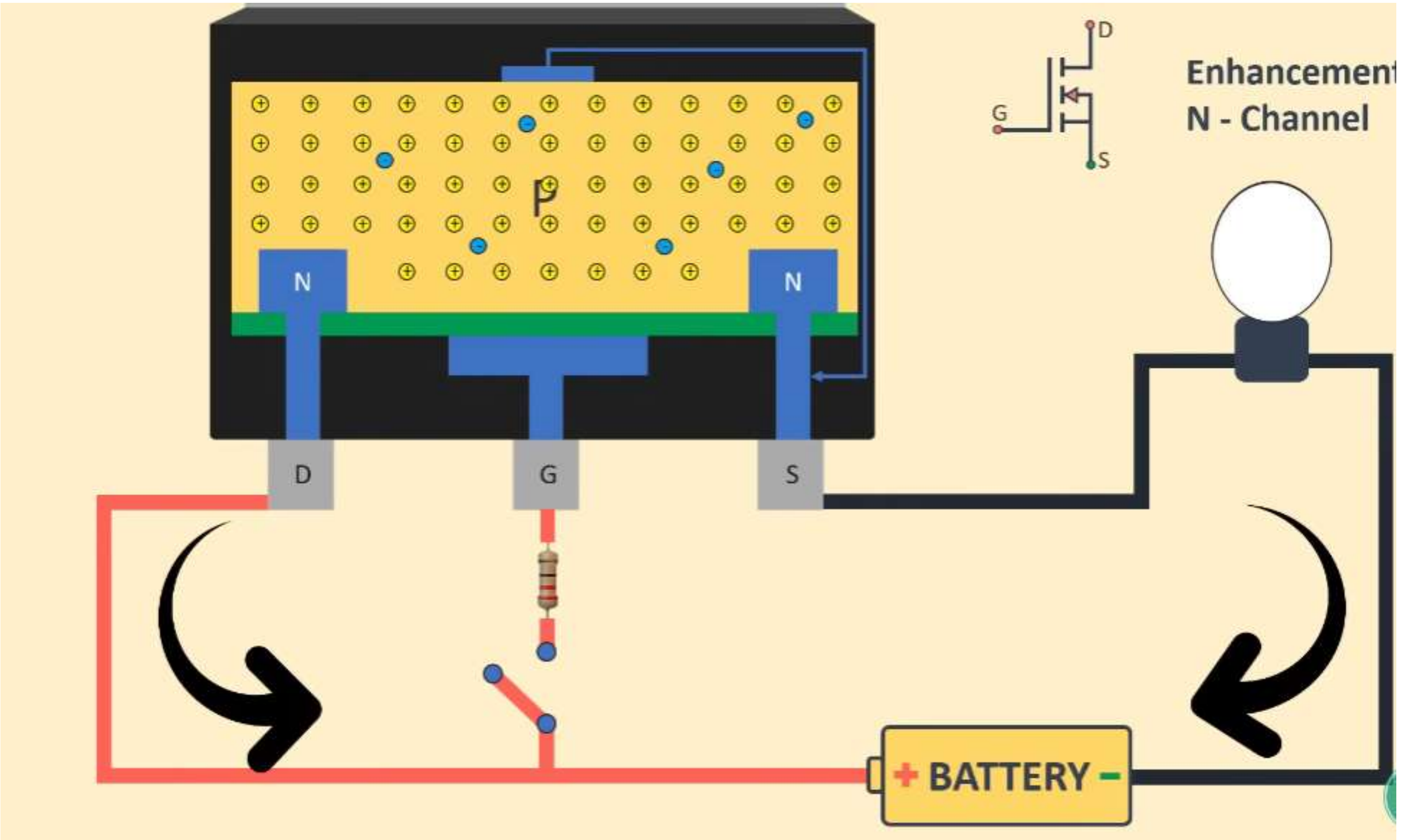




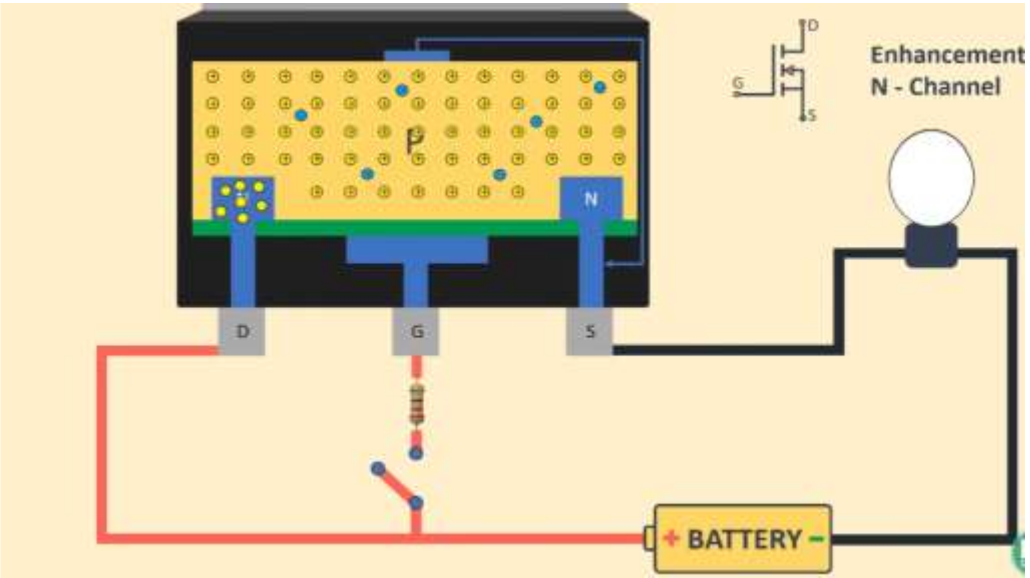
Working Principle of MOSFET

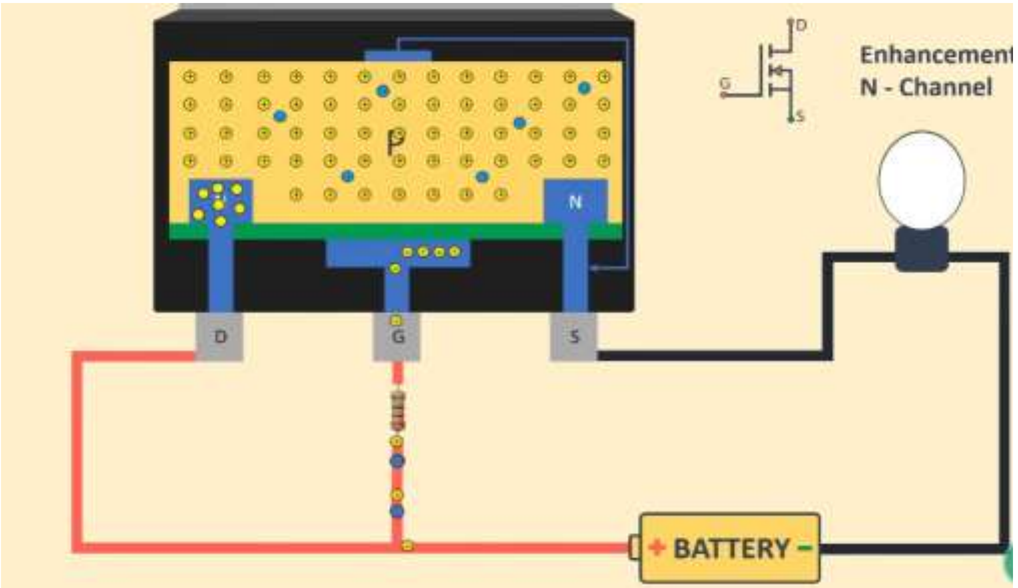


Enhancement N - Channel MOSFET

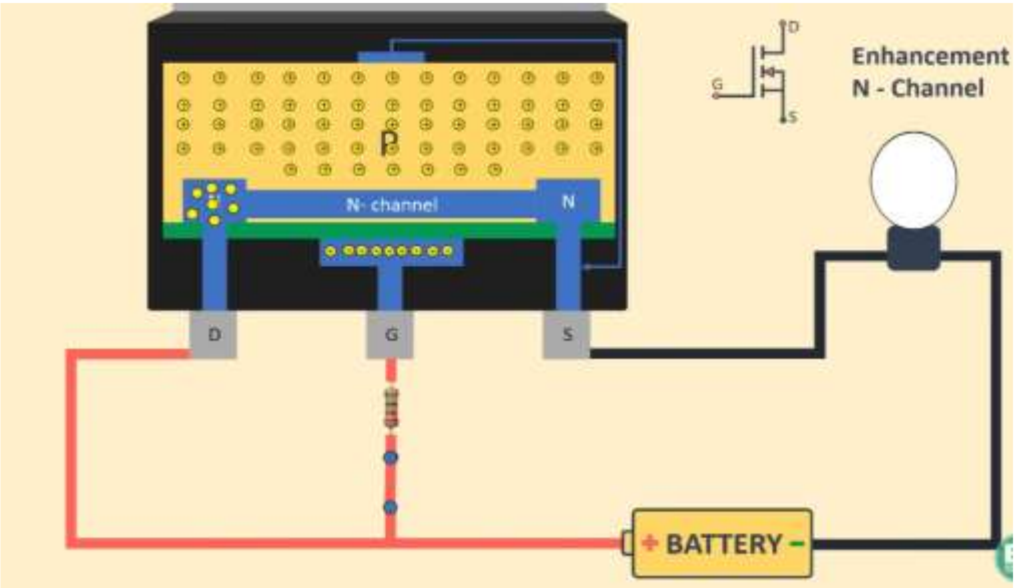


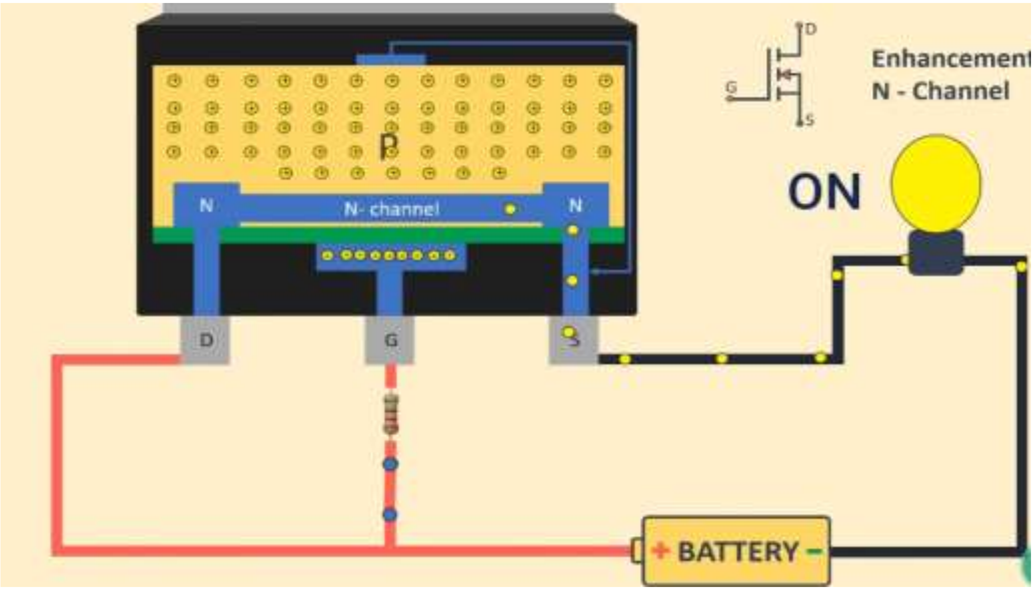
Enhancement N - Channel MOSFET



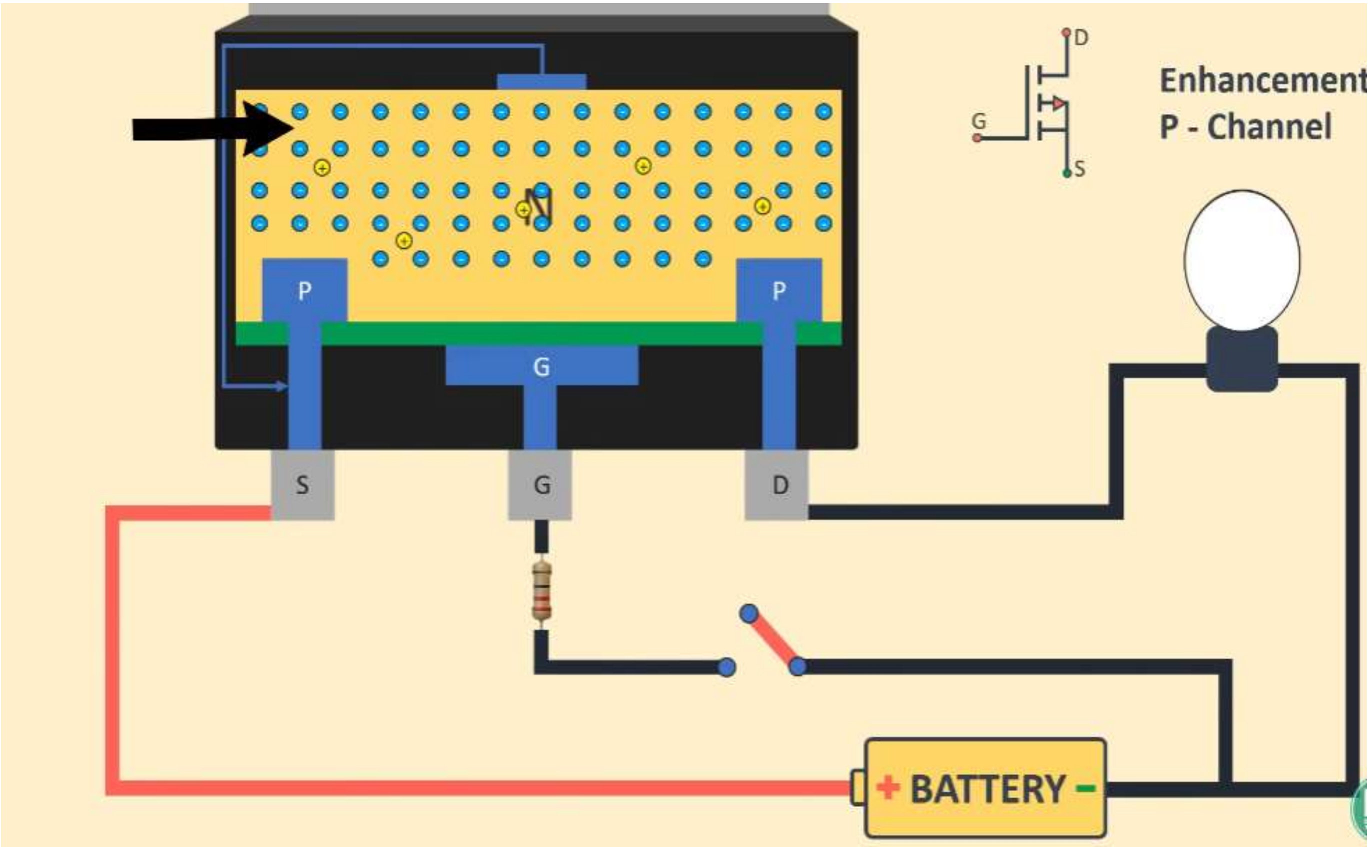


Enhancement N - Channel MOSFET

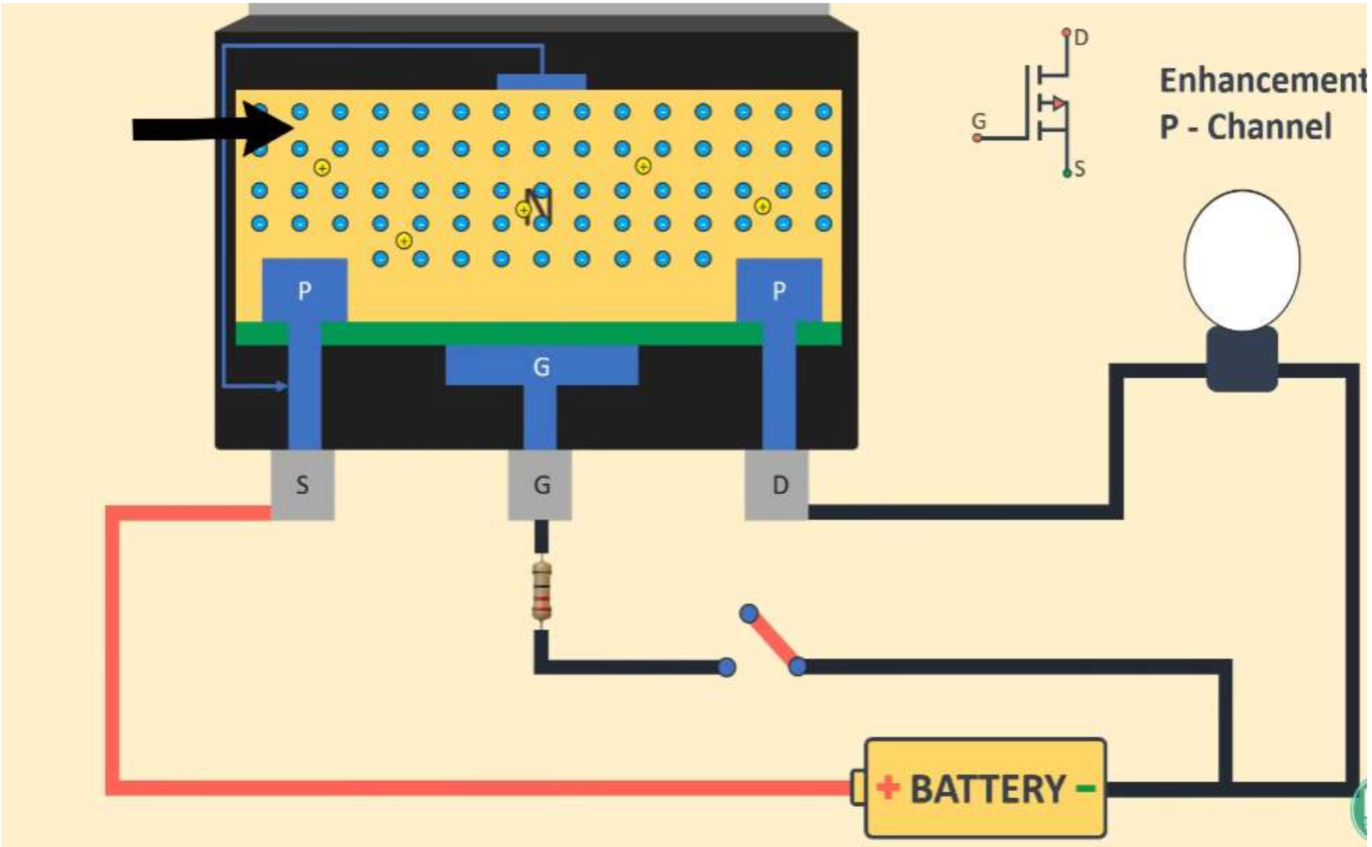




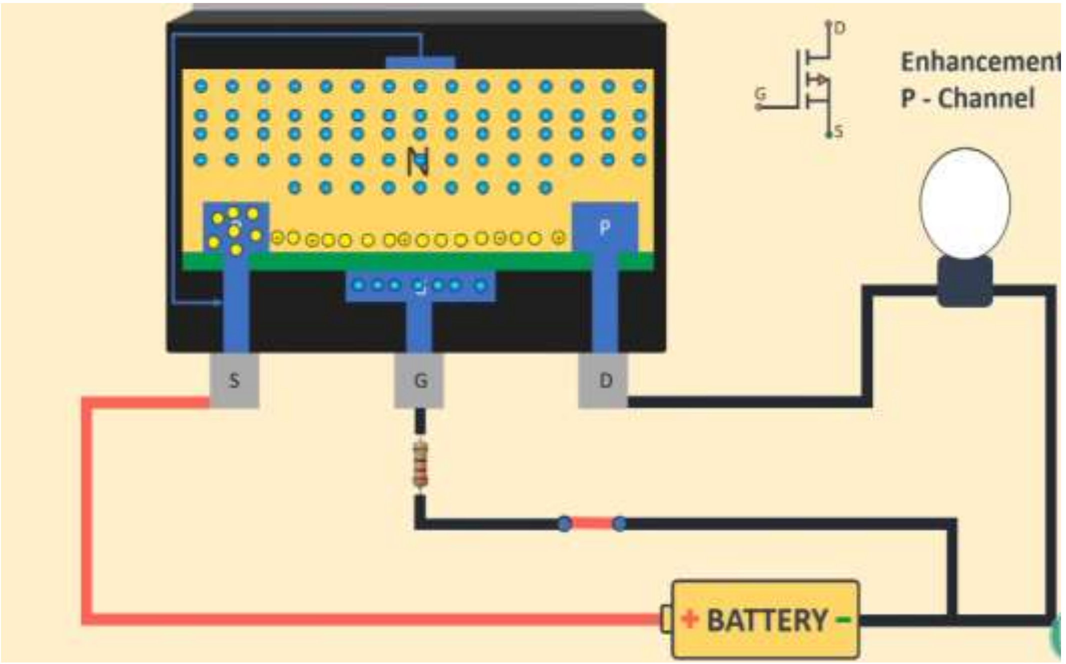
Enhancement P - Channel MOSFET

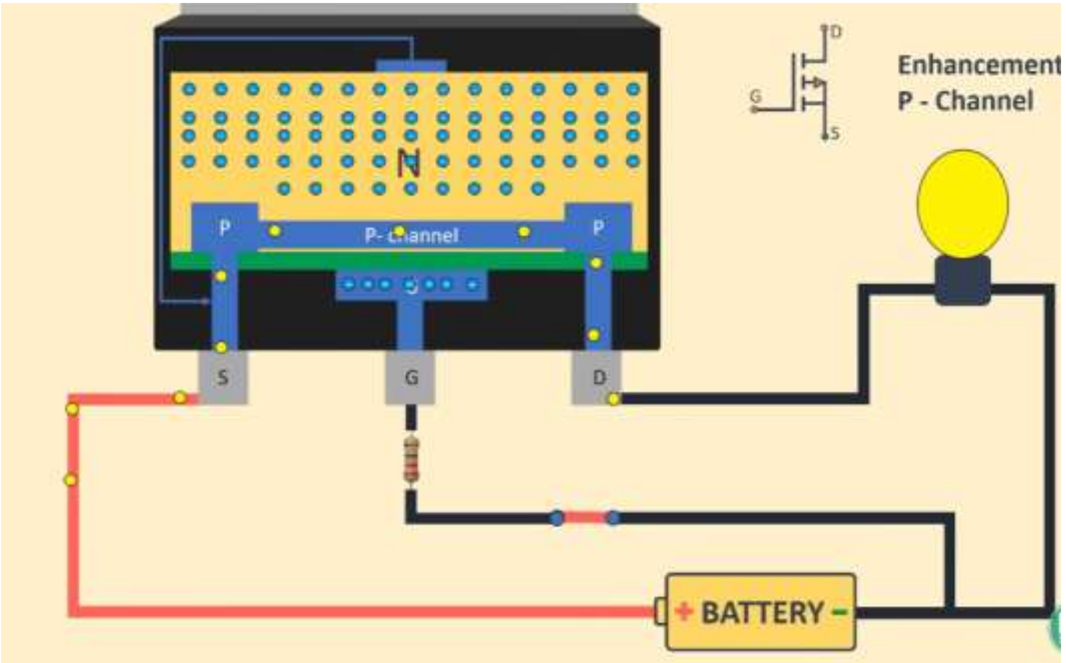


Enhancement P - Channel MOSFET

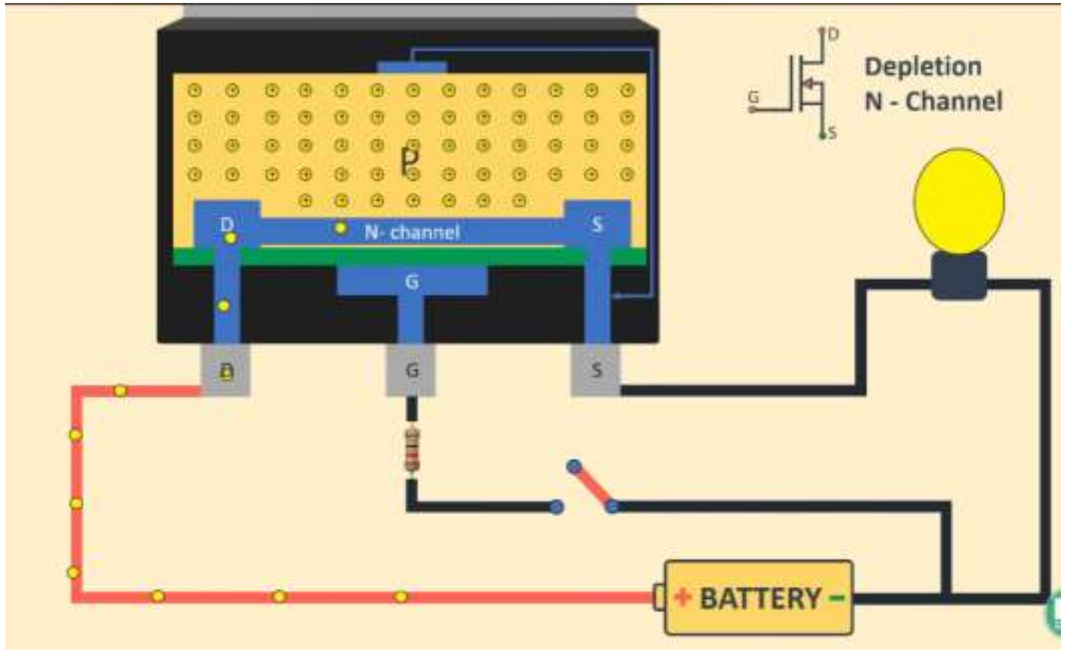


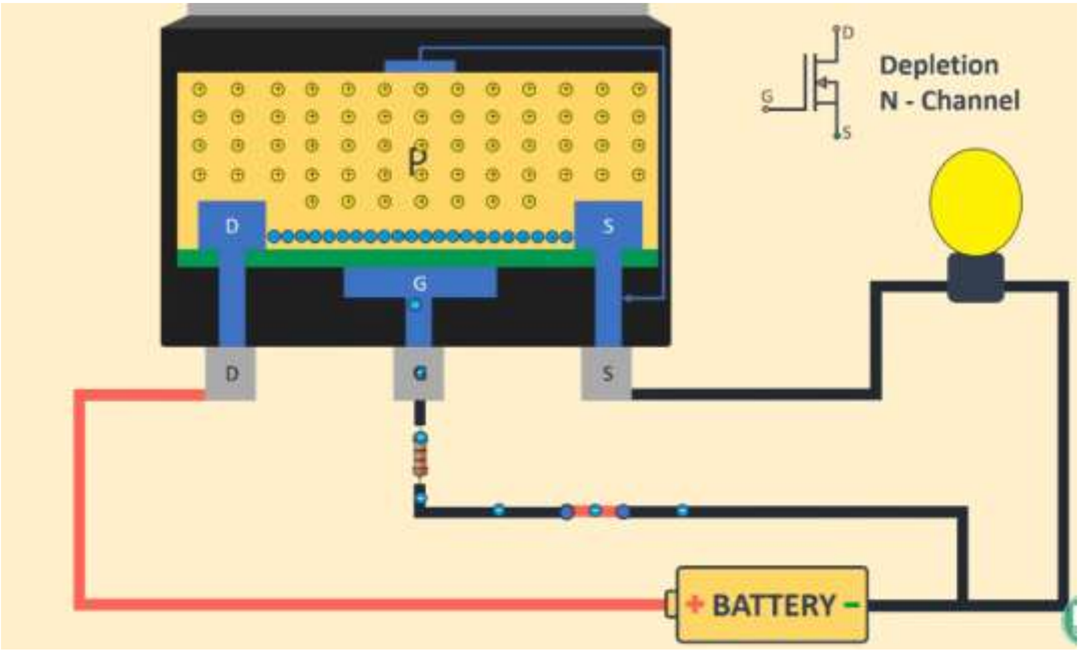
Enhancement P - Channel MOSFET



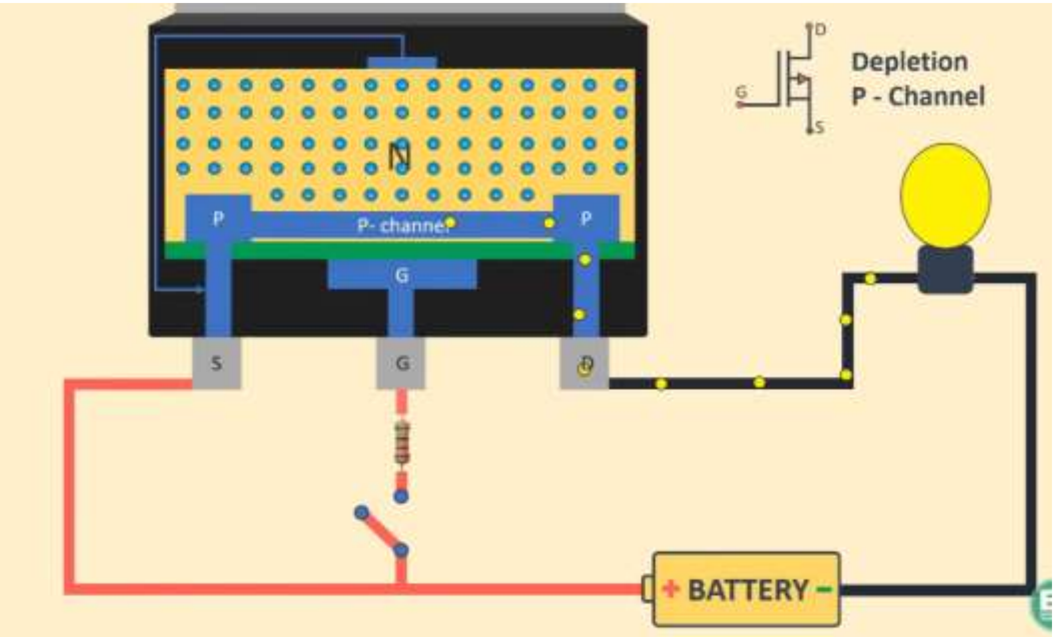


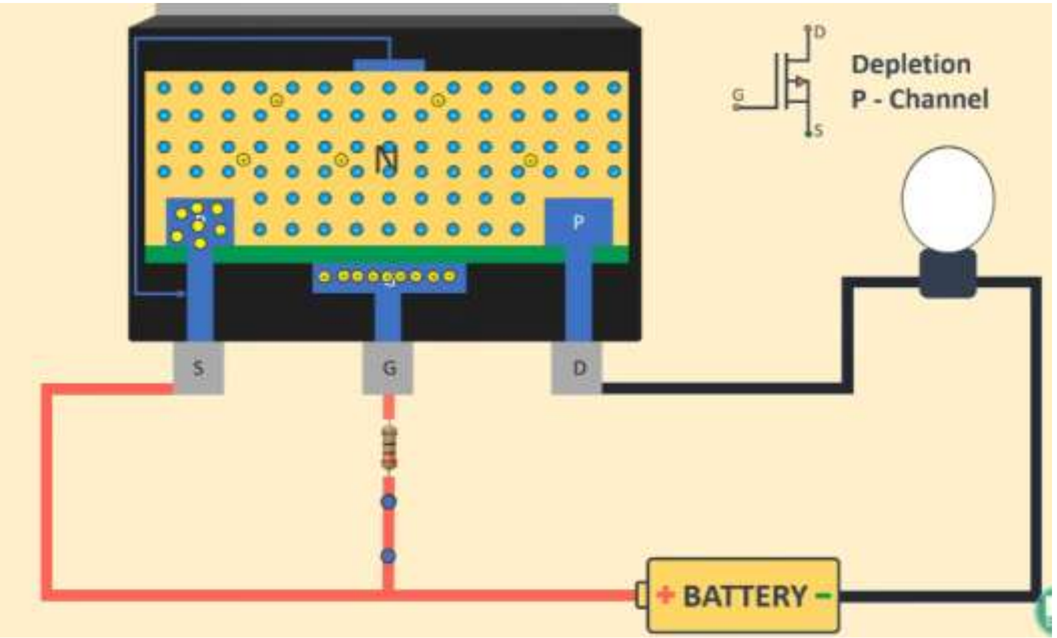
Depletion N - Channel MOSFET



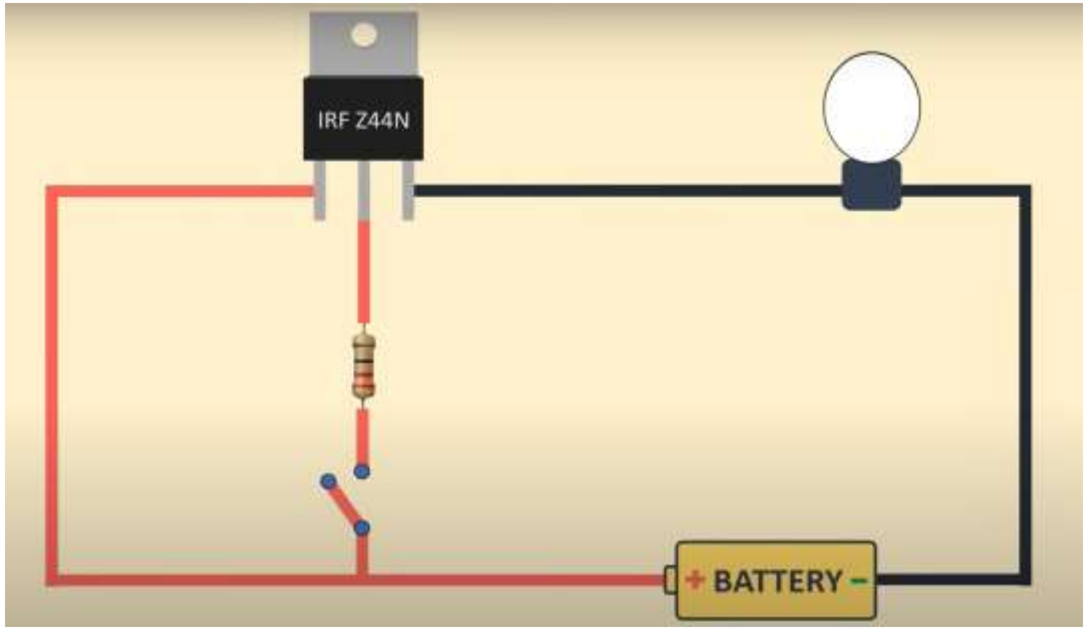


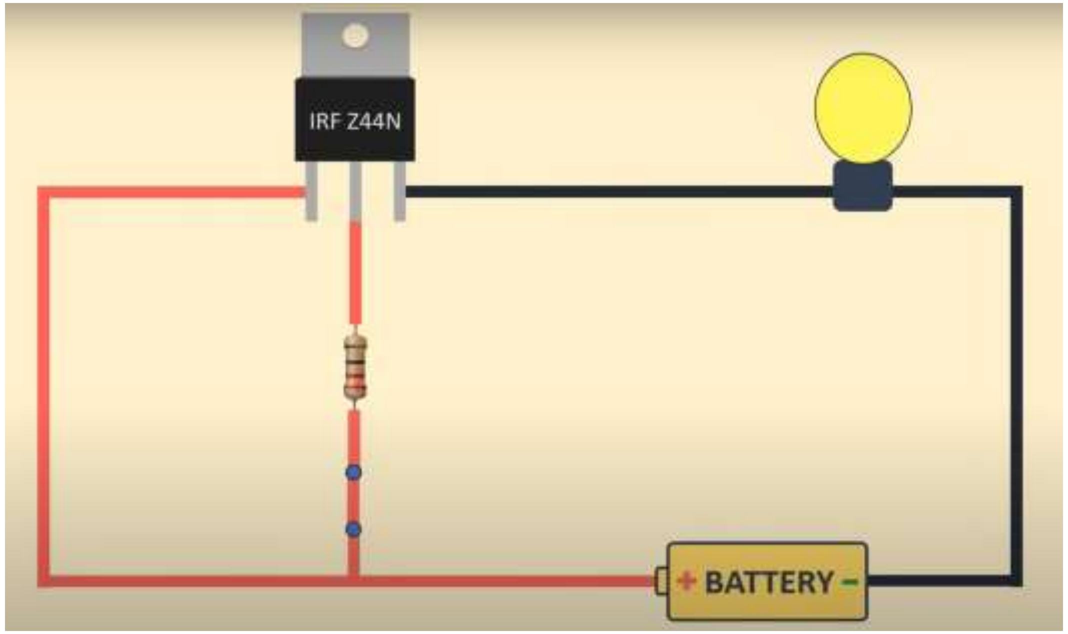
Depletion N - Channel MOSFET



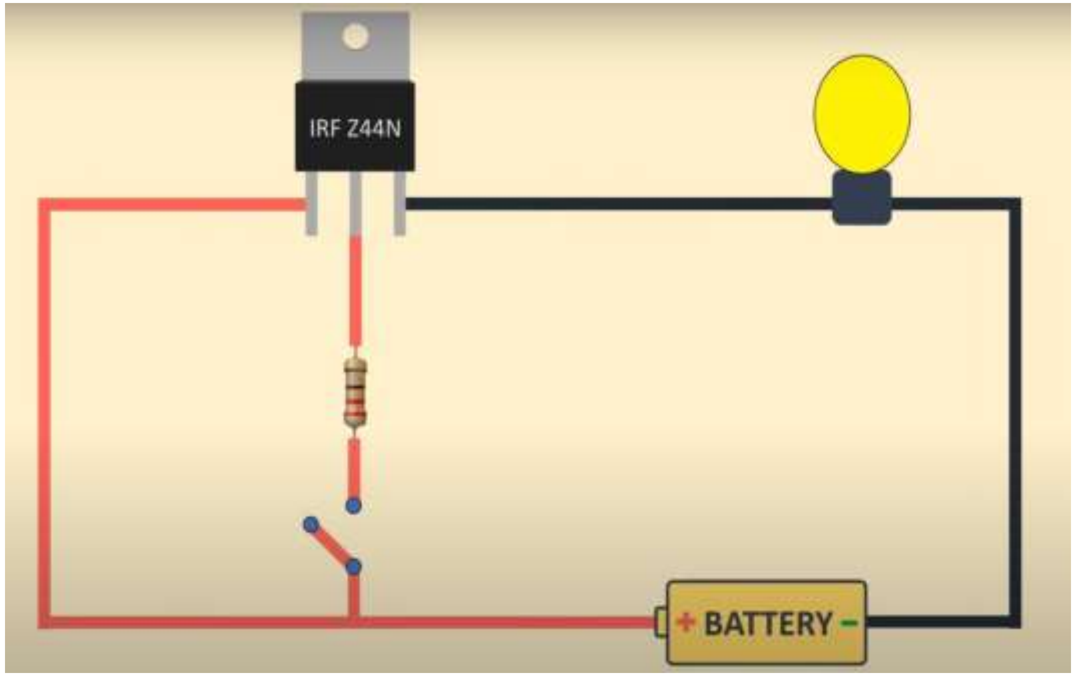


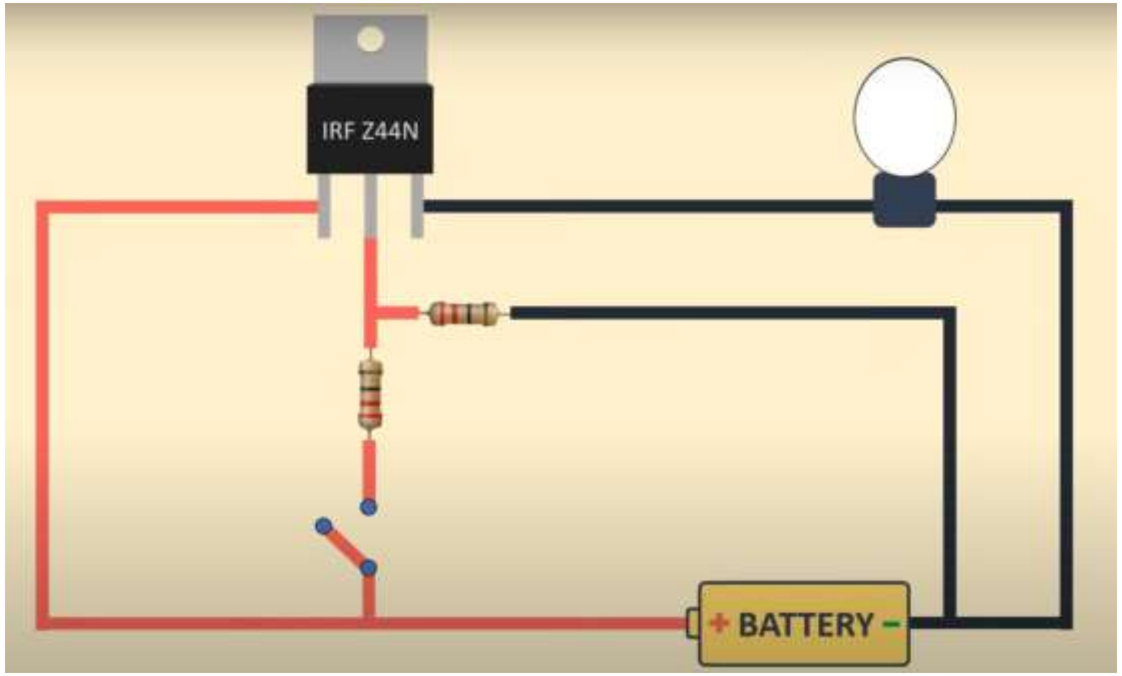
MOSFET Setup





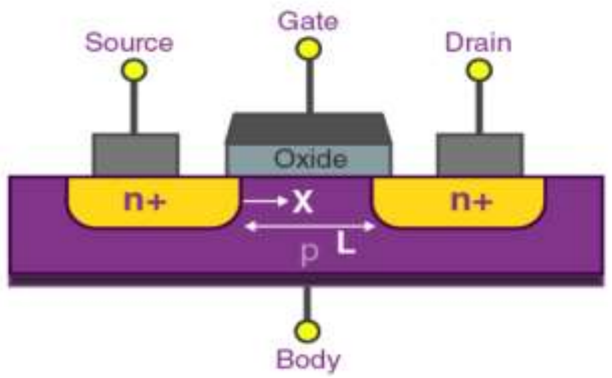
MOSFET Setup





MOSFET Construction

- The **p-type semiconductor** forms the base of the MOSFET.
- The two types of the base are highly doped with an n-type impurity which is marked as n+ in the diagram.
- From the heavily doped regions of the base, the terminals source and drain originate.
- The layer of the substrate is coated with a layer of silicon dioxide for insulation.
- A thin insulated metallic plate is kept on top of the silicon dioxide and it acts as a capacitor.
- The gate terminal is brought out from the thin metallic plate.
- A DC circuit is then formed by connecting a voltage source between these two n-type regions.



Operating Regions of MOSFET

A MOSFET is seen to exhibit three operating regions. Here, we will discuss those regions.

❑Cut-Off Region

The cut-off region is a region in which there will be no conduction and as a result, the MOSFET will be OFF. In this condition, MOSFET behaves like an open switch.

❑Ohmic Region

The ohmic region is a region where the current (I_{DS})increases with an increase in the value of V_{DS}. When MOSFETs are made to operate in this region, they are used as amplifiers.

❑ Saturation Region

In the saturation region, the MOSFETs have their I_{DS} constant in spite of an increase in V_{DS} and occurs once V_{DS} exceeds the value of pinch-off voltage V_P. Under this condition, the device will act like a closed switch through which a saturated value of I_{DS} flows. As a result, this operating region is chosen whenever MOSFETs are required to perform switching operations.

Symbols details

I_D **(Drain Current)** – The current flowing from drain to source in a MOSFET.

I_D(on) **(Drain Current when ON)** – The drain current when the MOSFET is fully turned ON.

V_GS **(Gate-Source Voltage)** – The voltage applied between the gate and source terminals.

V_GS(off) **(Gate-Source Cutoff Voltage)** – The gate-source voltage at which the MOSFET turns OFF (for JFETs and depletion-mode MOSFETs).

V_GS(th) **(Threshold Voltage)** – The minimum gate-source voltage required to turn ON an enhancement-mode MOSFET.

Example

Example 19.32. *Determine the drain-to-source voltage (V_{DS}) in the circuit shown in Fig. 19.51 above if V_{DD} = +18V and R_D = 620Ω. The MOSFET data sheet gives $V_{GS(off)}$ = – 8V and I_{DSS} = 12 mA.*

Solution. Since $I_D = I_{DSS}$ = 12 mA, the V_{DS} is given by;

$$V_{DS} = V_{DD} - I_{DSS} R_D$$
$$= 18\text{V} - (12\text{ mA})(0.62\text{ k}\Omega) = \mathbf{10.6V}$$

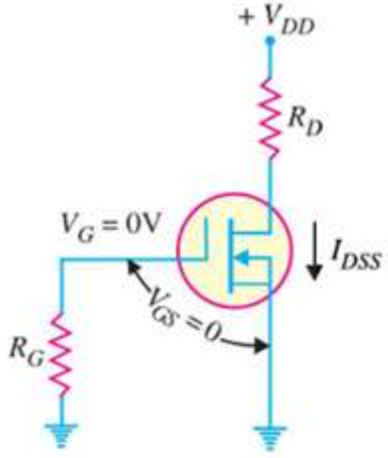


Fig. 19.51

Example

Example 19.33. *The D-MOSFET used in the amplifier of Fig. 19.54 has an I_{DSS} = 12 mA and g_m = 3.2 mS. Determine (i) d.c. drain-to-source voltage V_{DS} and (ii) a.c. output voltage. Given v_{in} = 500 mV.*

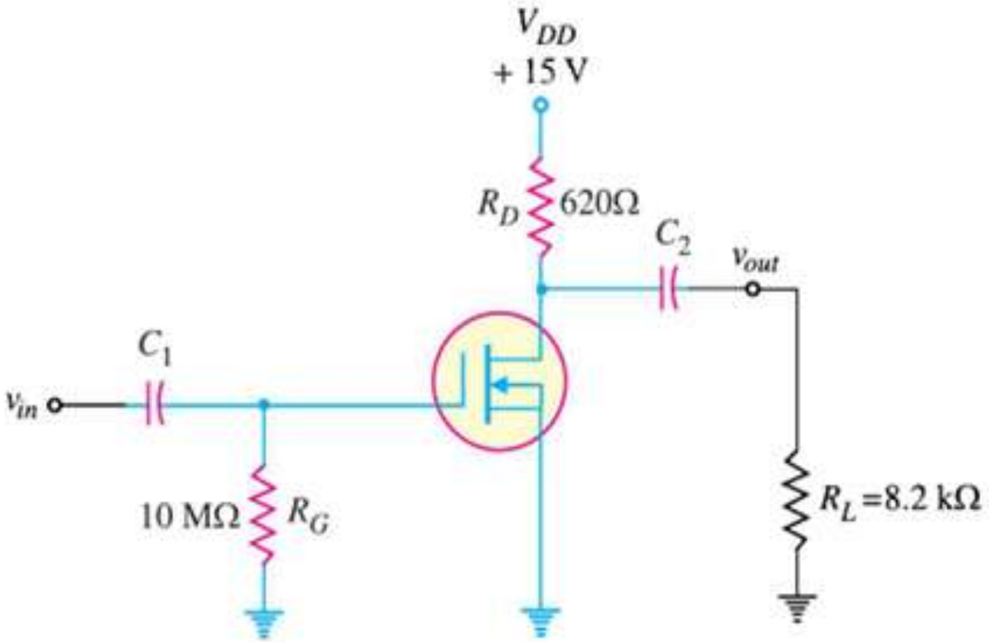


Fig. 19.54

Example

Example 19.33. *The D-MOSFET used in the amplifier of Fig. 19.54 has an I_{DSS} = 12 mA and g_m = 3.2 mS. Determine (i) d.c. drain-to-source voltage V_{DS} and (ii) a.c. output voltage. Given v_{in} = 500 mV.*

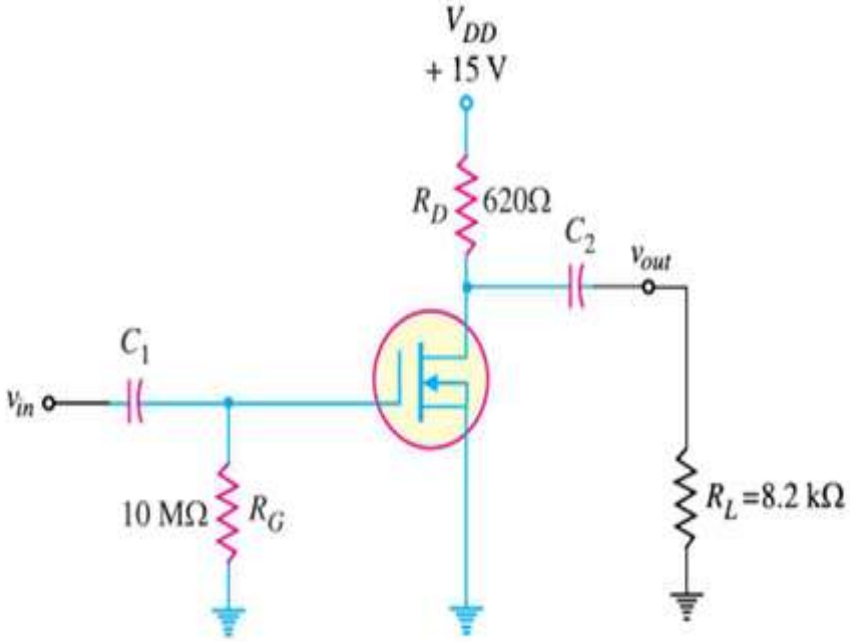


Fig. 19.54

Solution.

(*i*) Since the amplifier is zero biased, $I_D = I_{DSS}$ = 12 mA.

$$\therefore \quad V_{DS} = V_{DD} - I_{DSS} R_D$$
$$= 15\text{V} - (12 \text{ mA})(0.62 \text{ k}\Omega) = \mathbf{7.56V}$$

(*ii*) Total a.c. drain resistance R_{AC} of the circuit is

$$R_{AC} = R_D \,||\, R_L = 620\Omega \,||\, 8.2 \text{ k}\Omega = 576\Omega$$

$$\therefore \quad v_{out} = A_v \times v_{in} = (g_m R_{AC})(v_{in})$$
$$= (3.2 \times 10^{-3}\, S \times 576\ \Omega)(500 \text{ mV}) = \mathbf{922 \text{ mV}}$$

Example

Example 19.37. *Determine the values of I_D and V_{DS} for the circuit shown in Fig. 19.62. The data sheet for this particular MOSFET gives $I_{D(on)} = 10$ mA when $V_{GS} = V_{DS}$*

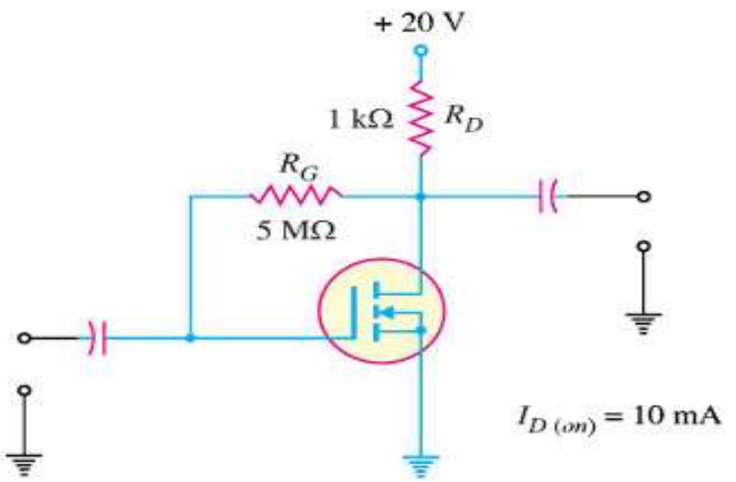


Fig. 19.62

Solution. Since in the drain-feedback circuit $V_{GS} = V_{DS}$,

$$\therefore \quad I_D = I_{D(on)} = \mathbf{10\ mA}$$

The value of V_{DS} (and thus V_{GS}) is given by ;

$$V_{DS} = V_{DD} - I_D R_D$$
$$= 20\text{V} - (10\text{ mA})(1\text{ k}\Omega) = 20\text{V} - 10\text{V} = \mathbf{10V}$$

MOSFET vs BJT

MOSFET	BJT
There are two types of MOSFET and they are named: N-type or P-type	BJT is of two types and they are named as: PNP and NPN
MOSFET is a voltage-controlled device	BJT is a current-controlled device
The input resistance of MOSFET is high.	The input resistance of BJT is low.
Used in high current applications	Used in low current applications

MOSFET Applications

- Radiofrequency applications use MOSFET amplifiers extensively.
- MOSFET behaves as a passive circuit element.
- Power MOSFETs can be used to regulate DC motors.
- MOSFETs are used in the design of the chopper circuit.

Advantages & Disadvantages

❑ Advantages of MOSFET

- MOSFETs operate at greater efficiency at lower voltages.
- Absence of gate current results in high input impedance producing high switching speed.

❑ Disadvantages of MOSFET

- MOSFETs are vulnerable to damage by electrostatic charges due to the thin oxide layer.
- Overload voltages make MOSFETs unstable.

Thank you for hearing with patience