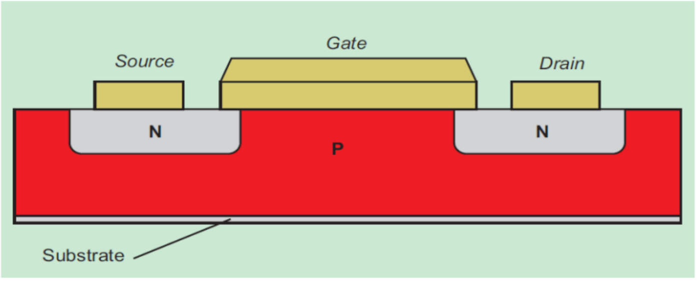
Jimma University
College of Natural Sciences
Department of Physics

Lecture Notes : Electronics I (Phys 2062)

Chapter Four: Field Effect Transistor (FET)

By: Mrs. Hiwot Tegegn (lecturer)



Outline of the Chapter

- The junction field effect transistor (JFET), JFET Common Source Amplifier, JFET
- Common Drain amplifier
- Insulated-Gate Field Effect Transistor. Power,
- Multiple Transistor Circuit

Chapter Four: Field Effect transistor (FET)

Chapter Objective

- In this chapter the junction field-effect transistor (JFET) is introduced and its practical uses,
- construction, biasing and characteristics are emphasized in an elaborate manner.
- In addition to this construction of the metal-oxide semiconductor (MOS), the structural characteristics and
- biasing of MOS field-effect transistor (MOSFET) are also discussed in detail. The last portion of
- the chapter deals with the various complimentary metal-oxide semiconductor (CMOS) circuits.

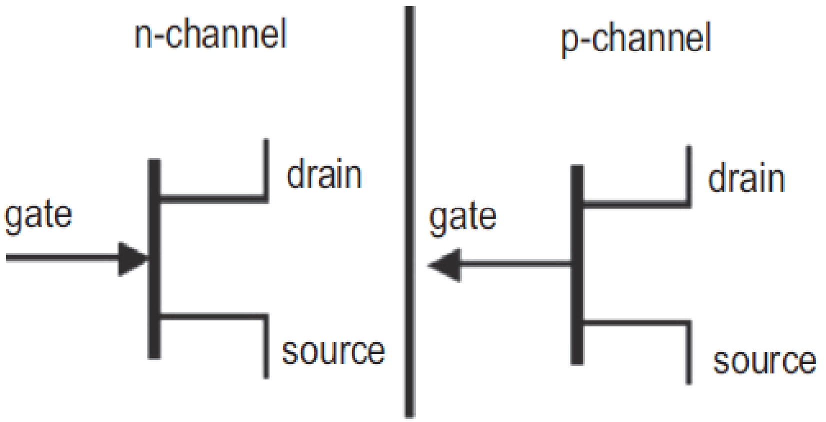
Introduction: Field Effect Transistor

- The invention of the BJT has brought a great twist in the modern era of semiconductor technology.
- This device, along with its field-effect counterpart, known as the field-effect transistor (FET), has had a huge impact on virtually every area of modern life.

- Practical field-effect transistors were first made in the form of JFET in 1953 and MOSFET in 1963.
- The field-effect transistor has taken various forms like that of the junction field-effect transistor (JFET), in which the gate voltage controls the depletion width of a reverse-biased *p*–*n* junction;
- The metal-semiconductor field-effect transistor (MESFET), in which the junction is replaced by a Schottky barrier;
- The metal-insulator-semiconductor field-effect transistor (MISFET), where the metal gate electrode is separated from the semiconductor by an insulator; and
- the metal-oxidesemi conductor field-effect transistor (MOSFET), which is the most common field-effect transistor in both digital and analog circuits.

Introduction: Field Effect Transistor

- A field effect transistor is a three terminal semiconductor device in which current conduction is by one type of carriers (i.e either electrons or holes) and is controlled by the effect of electric field.
- Unlike the usual transistor, its operation depends upon the flow of majority carriers only i.e. the current conduction in this case is either by electrons or holes.
- The flow of current is controlled by means of an electric field developed between the gate electrode and the conducting channel of the device.



FET
Field-Effect Transistor

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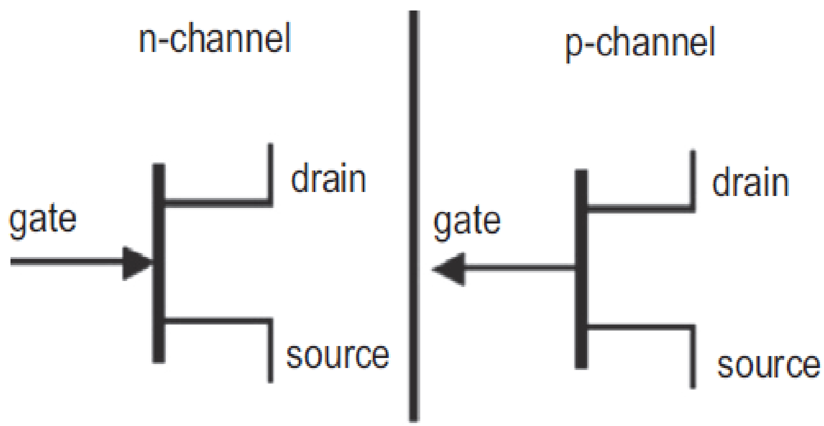
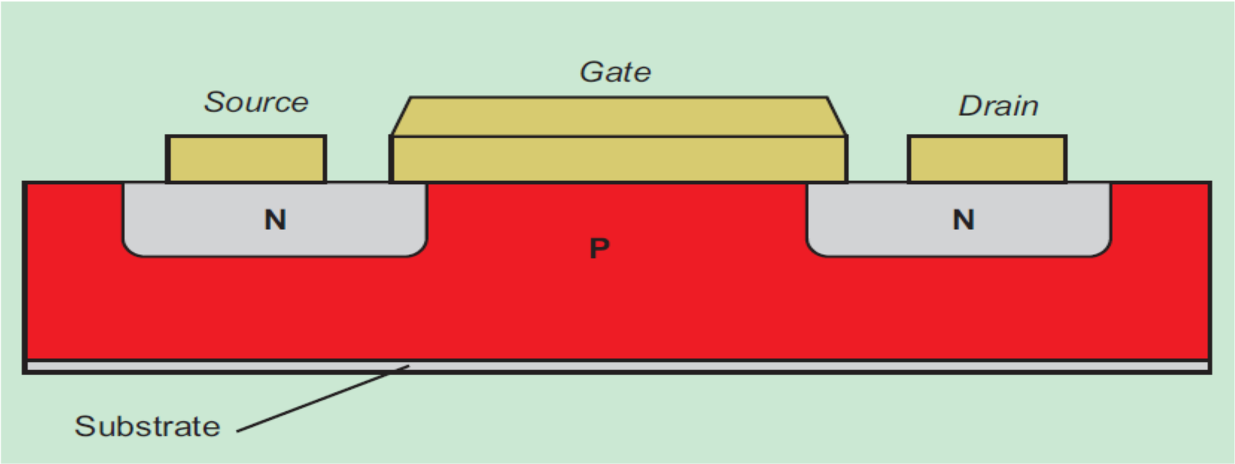


FET
Field-Effect Transistor

Introduction: Semiconductors

❖Construction

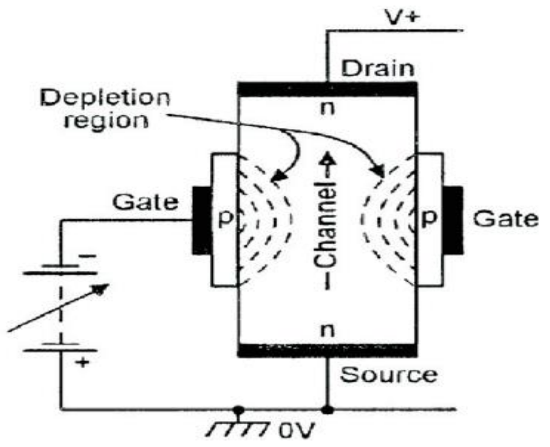
- An n-channel field effect transistor is shown in fig. below.
- It consists of an n-type silicon bar with two islands of p- type semiconductor material embedded in the sides, thus forming two pn junctions.
- The two p region are connected with each other (externally or internally) and are called gate (G).
- Ohmic contacts are made at the two ends of the n- type semiconductor bar.
- One terminal is known as the source (S) through which the majority carriers (electrons in this case) enter the bar.
- The other terminal is known as the drain (D) through which these majority carriers leave the bar.
- Thus a FET has essentially three terminals called gate(G), source(S) and drain(D).



Introduction: Field Effect Transistor

❖ Working of FET

- The circuit diagram of an n- channel FET with normal polarities is shown.
- When a voltage Vds is applied across the drain and source terminals and voltage applied across the gate and source Vgs is zero (i.e gate circuit is open) as shown in fig., the two pn junction establish a very thin depletion layer.
- Thus a large amount of electrons will flow from source to drain through a wide channel formed between the two depletion layers.
- When a reverse Vgs is applied across the gate and source as shown in fig. the width of the depletion layer is increased. This reduces the width of the conducting channel thereby decreasing the conduction (flow of electrons) through it.
- Thus the current flowing from source to drain depends upon the width of the conducting channel which depends upon the thickness of depletion layer establish by the two pn junctions depends upon the voltage applied across the gate source terminals.
- Hence it is clear that the current from source to drain can be controlled by the application of potential (I.e electric field) on the gate.
- That is why the device is called field effect transistor.
- It may be noted that a p- channel FET also operates in the same manner as an n-channel FET except that the channel current carriers will be holes instead of electrons and all the polarities will be reversed.



Field Effect Transistor

❖ Advantages

❖ A FET is a voltage controlled device. In which the output current (drain current) is controlled by the input (gate) voltage, therefore it has the following important advantages.

- ✓ FET has a very high input impedance which shows a high degree of isolation between the input and output circuit.
- ✓ The operation of FET depends upon the majority carriers (i.e. electron in n-channel and holes in P-channel FET) which do not cross junctions. Therefore, the inherent noise of tubes (because of high temperature operation) and those of ordinary transistor are not present in a FET.
- ✓ In FET the risk of thermal runway is avoided since it has a negative temperature coefficient of resistance.
- ✓ A FET has smaller size, longer life and higher efficiency.

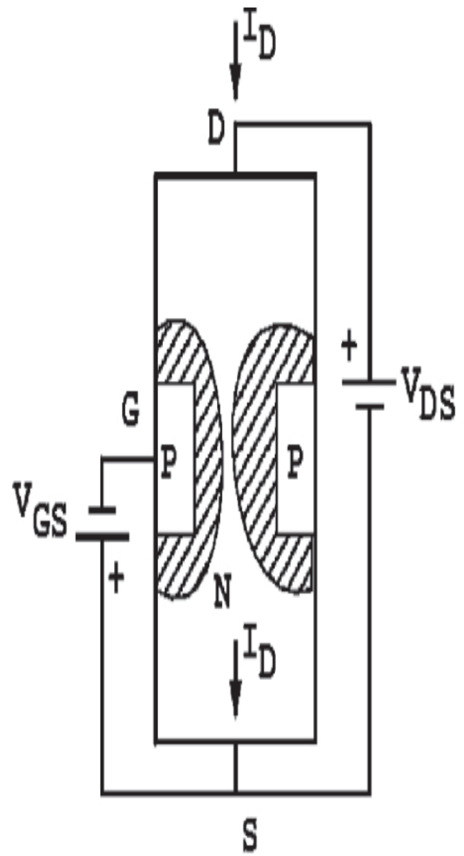
❖ Disadvantages

❖ Since FET has high input impedance the gate voltage has less voltage and has less control over the drain current. Therefore FET amplifier has much less voltage gain than a bipolar amplifier.

Junction Field Effect Transistor

- There are two major categories of field effect transistors namely:
  - ✓ (i) Junction field effect transistors (JFET)
  - ✓ (ii) Metal oxide field effect transistor (MOSFET)
- JFET are of two types viz. N-channel JFET and P-channel JFETs. Generally N-channel JFET are preferred.

Construction and Characteristics of JFETs



- In an N- channel JFET an N-type silicon bar, referred to as the channel, has two smaller pieces of P-type silicon material diffused on the opposite sides of its middle part, forming P-N junctions as shown in figure
- The two P-n junctions forming diodes or gates are connected internally and a common terminal called the gate terminal is brought out.
- Ohmic contacts are made at the two ends of the channel-one lead is called the source terminal S and the other drain terminal D.
- The silicon bar behaves like a resistor between its two terminals D and S.
- The gate terminal is analogous to the base of an ordinary transistor It is used to control the flow of current from source to drain. Thus source and drain terminal are analogous to emitter and collector terminals respectively of a BJT.

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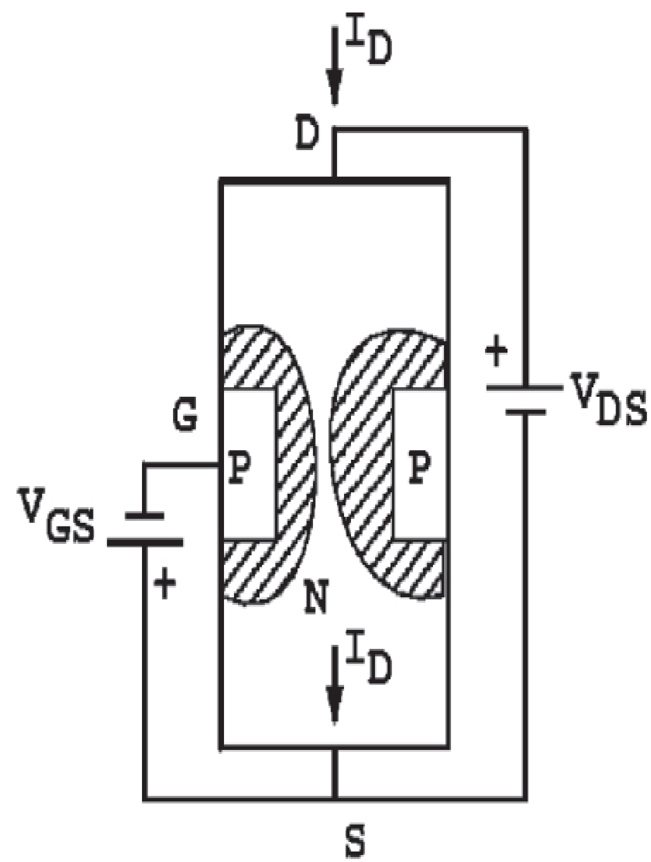
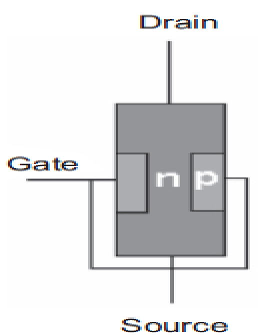
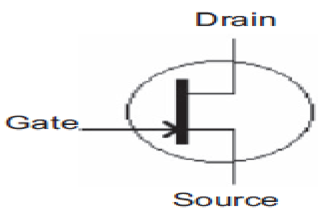


Junction Field Effect Transistor: Operation

- When neither any bias is applied to the gate (i.e when Vgs=0) nor any voltage to the drain w.r.t, sources (i.e. when Vds=0), the depletion regions around the P-N junctions are of equal thickness and symmetrical.
- When positive voltage is applied to the drain terminals D w.r.t sources terminals S without connecting gate terminals G to supply as shown.
- The electrons flow from terminals S to terminal D whereas conventional drain current Id flows through the channel from D to S.
- Due to flow of this current there is a uniform voltage drop across the channel resistance as we move from terminal D to terminal S. Due to flow of this current there is a uniform voltage drop across the channel resistance as we move from terminal D to terminal S.
- This voltage drop reverse biases the diode. The gate is more negative with respect to those points in the channel which are nearer to D than to S. Hence depletion layer penetrate more rapidly into the channel at points lying closer to D than to S. thus wedge shape depletion layer is formed as shown in figure below . When Vds is applied the size of the depletion layer formed determines the width of the channel and hence the magnitude of current Id flowing through the channel.

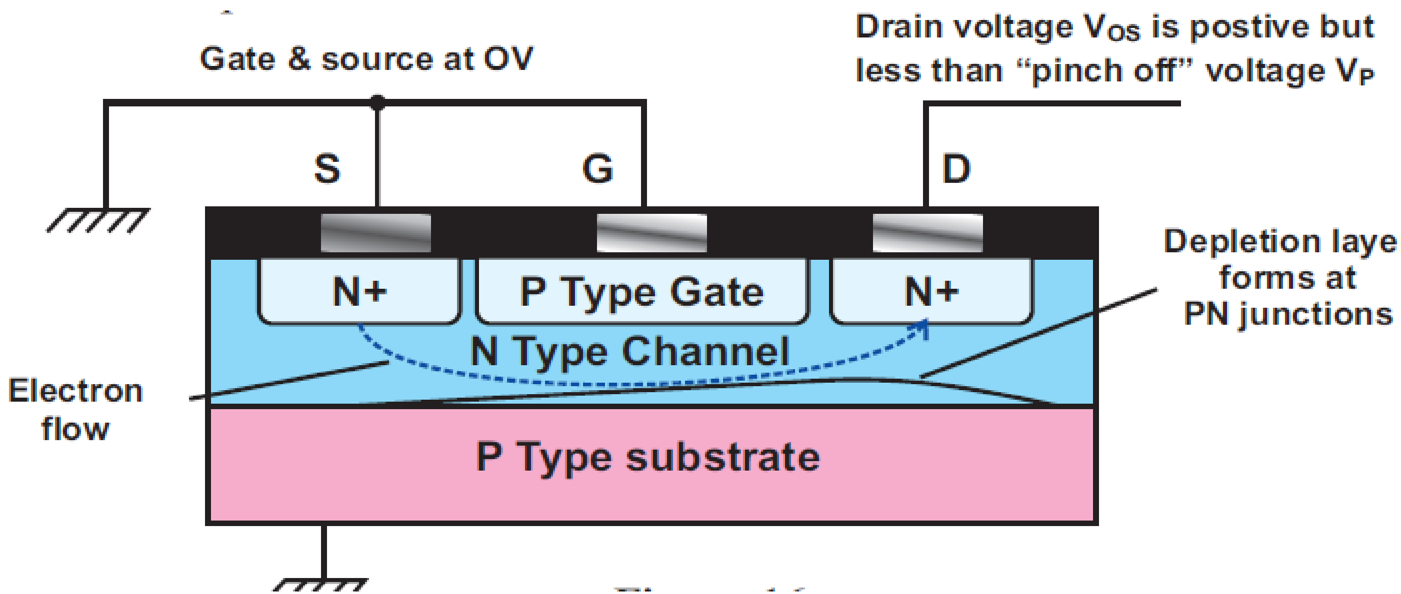




N-channel FET

Metal Oxide Semiconductor Field Effect (MOSFET)

- A metal oxide semiconductor field effect transistor is a three terminal semiconductor device.
- The three terminal are source, gate and drain.
- Unlike a FET in this device the gate is insulate from the channel and therefore sometimes it is also known as insulated gate FET (IGFET).
- Because of this reason the gate current is very small whether the gate is positive or negative.
- The MOSFET can be used in any of the circuits covered for the FET.
- Therefore all the equations apply equally well to MOSFET and FET in amplifier connections

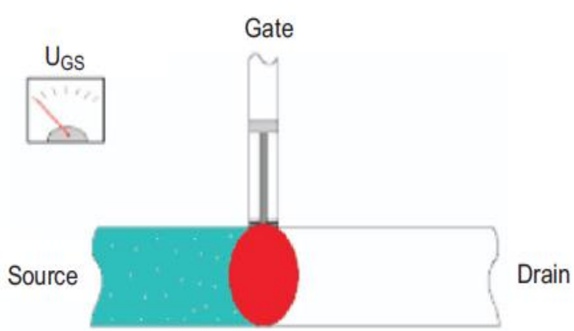


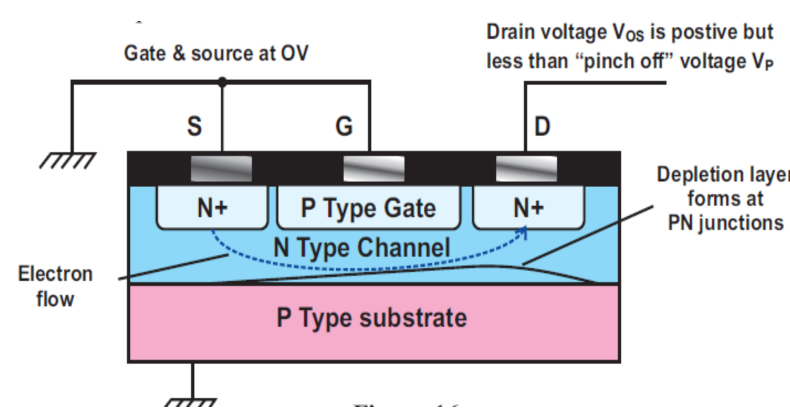
Metal Oxide Semiconductor Field Effect (MOSFET)

❖ Construction

➢ The simple side view of an n-channel MOSFET is shown in fig. left the figure shows its constructional details it is similar to FET except with following modifications:

- ✓ (i) There is only one p-region instead of two this region is known as substrate.
- ✓ (ii) Over the left side of the channel, a thin layer of metal oxide (usually silicon dioxide SiO) is deposited. A metallic gate is deposited over the layer of silicon dioxide as shown below right . The gate is insulated from the channel since silicon dioxide is an insulator. That is why it is also known as insulated gate FET.
- ✓ (iii) Since the gate is insulated from the channel by a thin layer of silicon dioxide, the input impedance of MOSFET is very high (of the order of 10^10 to 10^15 ohms).
- ✓ (iv) Unlike the FET, a MOSFET has no gate diode rather it forms a capacitor. The capacitor has gate and channel as electrodes and the oxide layer as dielectric. Because of this property, the device can be operated with negative as well as positive gate voltage.

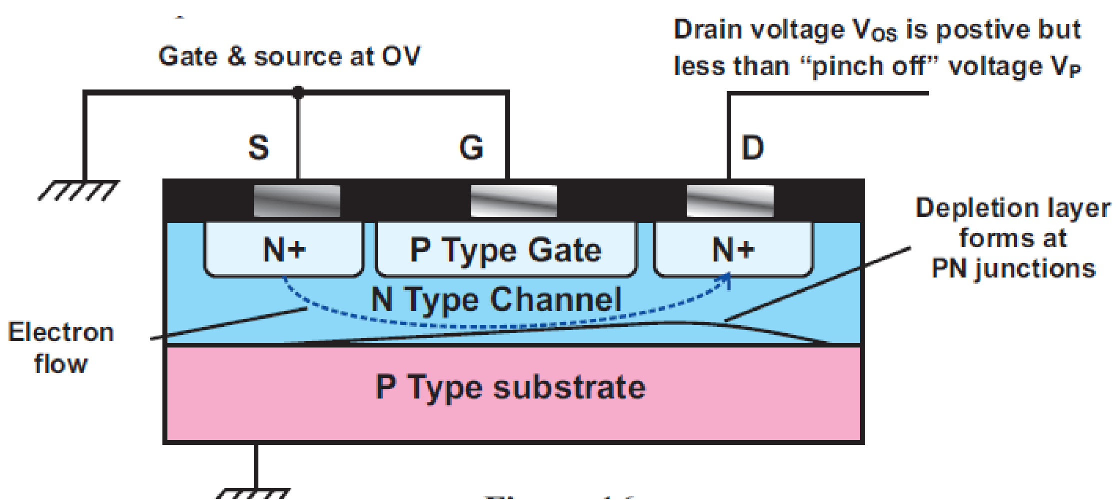




Metal Oxide Semiconductor Field Effect (MOSFET)

❖ Working

- The circuit diagram of an n-channel MOSFET with normal polarities is shown fig. below
- Unlike the FET a MOSFET has no gate rather it forms a capacitor which has two electrodes i.e. gate and channel. The oxide layer acts as dielectric.
- When negative voltage is applied to the gate, electrons accumulate on it. These electrons repel the conduction hand electrons in the n- channel.
- Therefore the number of conduction electrons available for current conduction through the channel will reduce. The greater the negative potential on the gate, the lesser is the current conduction from source to drain. However in this case if the gate is given positive voltage, more electrons are made available in the n- channel. Consequently, current from source to drain increases



BJT	*FET*
1. Two types of carriers (electrons and holes) are required.	1. Only one type of carrier (electron or hole) is required.
2. Carriers move through the base by diffusion process.	2. Carriers move through the channel by drift process.
3. The BJT has a comparatively lower switching speed due to the diffusion process.	3. The FET has a higher switching speed due to the drift process; the drift of the carrier is faster than diffusion.
4. The BJT is not a thermally stable device.	4. The FET has a negative temperature coefficient at high-current operations, i.e., the current decreases as temperature increases Due to this particular feature, a uniform temperature distribution and protection against breakdown can be achieved.
5. In case of IC fabrication, the BJT requires more space than the FET.	5. In case of IC fabrication the FET requires lesser space than the BJT.
6. At audio frequencies the BJT offers less power gain.	6. At audio frequencies the FET offers greater power gain.
7. The BJT is a current-controlled device.	7. The FET is a voltage-controlled device.
8. The BJT offers low input impedance.	8. The FET offers high input impedance, therefore, it can be used as a buffer.

Thank you