

TRANSISTOR TECHNOLOGY

- The objective of this tutorial is:
 - To understand “What is a transistor ?”
 - To recognize the types of transistors;
 - to discuss and understand the operation of each of them.
 - Applications of various transistors.

TRANSISTOR CLASSIFICATION

Transistors can broadly be classified into
Bipolar Junction Transistor i.e BJT and Field Effect Transistor i.e FET.
FETs can further be classified into
Junction Field Effect Transistor i.e. JFET, Metal Oxide Semiconductor Field Effect
Transistor i.e. MOSFET and High Electron Mobility Transistor i.e. HEMT

- The transistor is considered by many to be the greatest invention of the twentieth century. It is the key active component in practically all modern devices.
- The transistor is the fundamental building block of modern electronics devices, and is used in radio, telephone, computer and other electronic systems. Some transistors are packaged individually but most are found in integrated circuits.
- Transistor is a semiconductor device commonly used to amplify or switch electronic signals. The transistor's amplifying action is basically due to its capability of transferring its signal current from a low resistance circuit to a high resistance circuit.

Contracting the two terms: transfer and resistor results in the name transistor, i.e.

Transfer + Resistor → Transistor

- The BJT was invented in 1948 by John Bardeen, Walter Brattain and William Shockley at Bell Laboratory in America. This invention completely revolutionized the electronics industry.
- A transistor is basically a silicon or germanium crystal containing three separate regions, the three regions are known as emitter, base and collector.
- These regions essentially form two 'back to back' pn junctions in the same block of semiconductor material i.e. silicon.

- A BJT can either be NPN type or PNP type. Figure shows a npn and a pnp transistor. It has three regions The middle region is called the base and the two outer regions are called the emitter and the collector.
- Although the two outer regions are of the same type, their functions cannot be interchanged. the two regions have different physical and electrical properties.

- the function of the emitter is to emit or inject electrons (in case of npn type) or holes (in case of pnp type) into the base. the base passes most of these electrons onto the collector. the collector has the job of collecting or gathering these electrons from the base.
 - A transistor has two junctions- Emitter-Base junction (E-B) and a Collector-Base junction (C-B).
 - A transistor can be operated in four possible modes – Saturation, Active, Inverted, and Cutoff .
-
- Three BJT configurations are possible – Common Base (CB), Common Emitter (CE), and Common collector (CC). The transistor is a three-terminal device and any of the three electrodes can be made common to input and output. This common terminal is usually grounded.
 - In the CB configuration; the base terminal is made common to both input and output and the input signal is fed between the emitter and the base and the output signal is developed between the collector and the base.
 - Similarly by making the emitter or the collector terminal common, we can have what are known as common emitter (CE) or common collector (CC) configurations.
 - In all these configurations, the emitter base junction is always forward biased and the collector base junction is always reverse biased.
 - Comparison of the three configurations allows us to determine their suitable applications. The important parameters that govern the suitability of the configuration are input impedance, output impedance, current gain and leakage current. CC can be used for cascading the amplifier stages because it has very high input impedance and low output impedance. The common emitter configuration has very high current gain and hence is suitable for amplifying action

Comparison Between BJT and FET

BJT	FET
Bipolar Device	Unipolar device
Higher current gain	Higher power gain
Current controlled device	Voltage controlled device
Lower input impedance	Higher input impedance

More sensitive to temperature variation	Less sensitive to temperature variation
Lower integration density	Higher integration density
Lower static sensitivity	Higher static sensitivity

FIELD EFFECT TRANSISTORS

- All field effect transistors are majority carrier devices, i.e. current is conducted by the majority carrier species present in the channel of the FET.
- In its simplest form, FET is essentially a voltage controlled resistor. The resistive element is usually a bar of silicon.
- There are two types of JFET's: n-channel and p-channel, the n-channel is more widely used.
- There are three terminals: Drain (D) and Source (S) are connected to n-channel while Gate (G) is connected to the p-type material
- It is the Gate voltage that controls the width of the n-channel, which in turn controls the flow of electrons in the n-channel from source to drain hence the name junction field effect transistor.
- Application of a reverse bias voltage on the drain/gate terminals results in the formation of depletion regions at the PN junction.
- Increasing the voltage causes the depletion regions to reach further into the channel and effectively reduces its cross-sectional area. This increases the channel resistance.
- Continuing to increase the voltage will result in the depletion regions touching in the middle of the channel. The channel is then said to be pinched off and the voltage required to cause this is called the pinch-off voltage.

MOSFET

- MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor.
- The basic principle of the device was first proposed by [Julius Edgar Lilienfeld](#) in 1925.
- MOSFETs have characteristics similar to JFETs and additional characteristics that make them very useful.
- If the MOSFET is an n- channel (nMOS) FET, then the source and drain are 'n+' regions and the body is a 'p' region.
- If the MOSFET is a p-channel or pMOS FET, then the source and drain are 'p+' regions and the body is a 'n' region.

- There are 2 types:
 - Depletion-Type MOSFET (Normally On)
 - Enhancement-Type MOSFET (Normally Off)

- The physical construction of a depletion MOSFET is identical to the enhancement MOSFET, with one exception:
- The conduction channel is physically implanted (rather than induced)!

Thus, a depletion mode transistor behaves like an enhancement mode transistor for $V_{gs} > 0$.

The n^+ source and drain regions are diffused or implanted into a relatively lightly doped p-type substrate. No current flows from drain to source without a conducting n-channel between them.

When a positive voltage is applied to the gate relative to the substrate, positive charges are in effect deposited on the gate metal. In response, negative charges are induced in the underlying silicon, by the formation of a depletion region and a thin surface region containing mobile electrons.

These induced electrons form the channel of the FET, and allow current to flow from drain to source. The effect of the gate voltage is to vary the conductance of the induced channel.

- In the absence of any gate bias, there is a uniform depletion region under the gate region.
- As the gate bias is increased, the total charge available for conduction increases till the n-type channel is formed between the source and the drain.
- If the gate bias is held fixed and the drain `bias is increased the depletion width towards the drain end starts to increase. The channel then starts to pinchoff at the drain end. As this happens, the drain current starts to saturate.
- As the drain voltage is increased beyond the saturation voltage, the pinchoff point starts to move towards the source without any further increase in the saturation current

Why High Electron Mobility Transistor (HEMT) ?

- Major limitation of silicon MOSFETs is that silicon itself is an inherently low –mobility material.

- **Most compound materials have significantly higher mobilities than silicon, hence devices made using compound semiconductors can exhibit higher frequencies of operation.**
- **One of the most important developments that greatly increased the importance of compound semiconductors is modulation doping.**
- **Modulation doping provides an important advantage in that the free carrier concentration within the semiconductor layer can be increased significantly without the introduction of dopant impurities.**
- **HEMT (High Electron Mobility Transistor) is a field effect transistor which incorporates a junction between two materials with different band gaps as the channel instead of a doped region, as is generally the case for MOSFETs.**
- **Heterojunction and Modulation Doping are used to increase mobility.**
- **Doping is confined in higher band gap layer and channel is of small band gap material.**
- **Electrons accumulate in triangular potential well near heterointerface and form Two Dimensional Electron Gas(2DEG).**
- **Mobility of the electrons increases because of their separation from parent ionized donor.**
- **Mobility is increased further by using a spacer layer which separates the 2DEG from ionized donors near heterointerface.**

HEMT (High Electron Mobility Transistor) is a field effect transistor which incorporates a junction between two materials with different band gaps as the channel instead of a doped region, as is generally the case for MOSFETs.

Heterojunction and Modulation Doping are used to increase mobility. Doping is confined in higher band gap layer and channel is of small band gap material. Electrons accumulate in triangular potential well near heterointerface and form Two Dimensional Electron Gas (2DEG). Mobility of the electrons increases because of their separation from parent ionized donor. Mobility is increased further by using a spacer layer which separates the 2DEG from ionized donors near heterointerface .

Since the Fermi levels must align throughout the structure, when the two materials are brought into contact, the electrons are transferred from wider bandgap material to narrower band gap material to align the Fermi level. This results in sizeable increase in the electron concentration within the narrow bandgap layer without the introduction of donor impurities. The ionized donor atoms within the wide bandgap layer result in a net positive charge which balances the net negative charge due to electrons transferred in the narrow bandgap layer.

The conduction band edge is strongly bent near the heterointerface such that this sharp bending and the conduction band discontinuity leads to the formation of a potential well in the narrow bandgap layer. The high carrier concentration along with a concomitant higher mobility can thus be achieved simultaneously.

APPLICATIONS OF TRANSISTORS

- **The BJT remains a device that excels in some applications, such as discrete circuit design, due to the very wide selection of BJT types available and because of knowledge about the bipolar transistor characteristics**
- **The BJT is also the choice for demanding analog circuits, both integrated and discrete. This is especially true in very-high frequency applications, such as radio-frequency circuits for wireless systems**
- **The bipolar transistors can be combined with MOSFET's in an integrated circuit by using a BiCMOS process to create innovative circuits that take advantage of the best characteristics of both types of transistor.**
- **Temperature sensors**
- **Logarithmic converters**
- **Microwave and Millimeter wave communications,**
- **Imaging, Radar, and Radio astronomy**
- **HEMT-based devices can be discrete transistors but are more usually in the form of an integrated circuit called a MMIC standing for 'monolithic microwave integrated circuit'.**
- **HEMT devices are found in many types of equipment ranging from cellphones and DBS receivers to electronic warfare systems such as radar and for radio astronomy.**
- **Any application where high gain and low noise at high frequencies are required, HEMTs are available .**