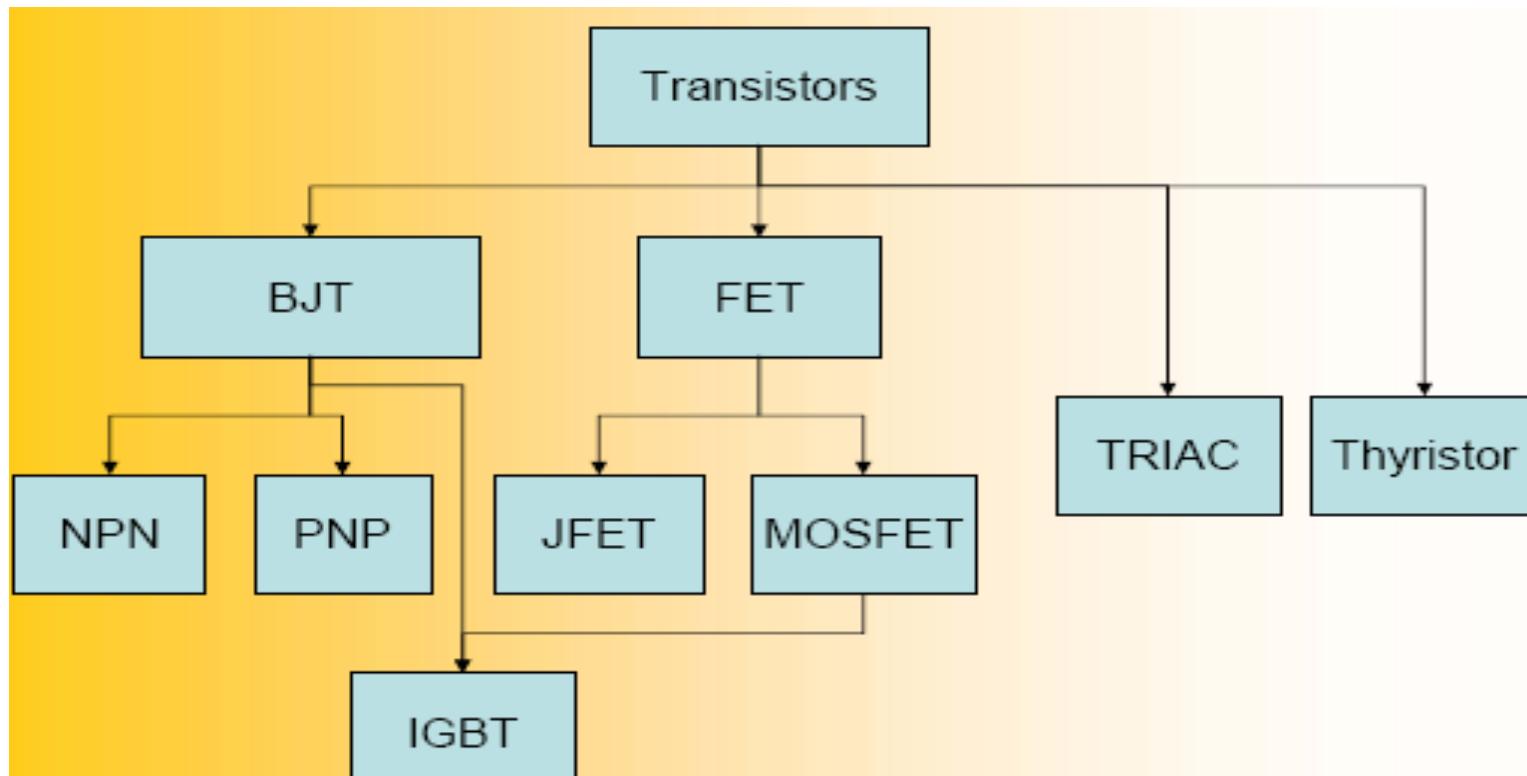


TRANSISTORS

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Types of Transistors



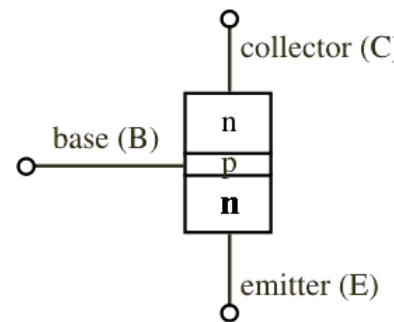
TRANSISTORS

- 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

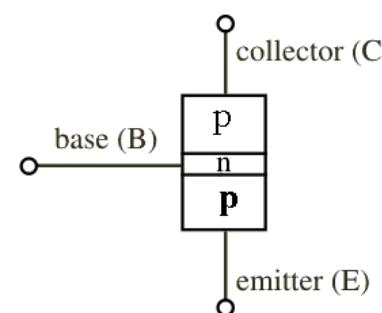
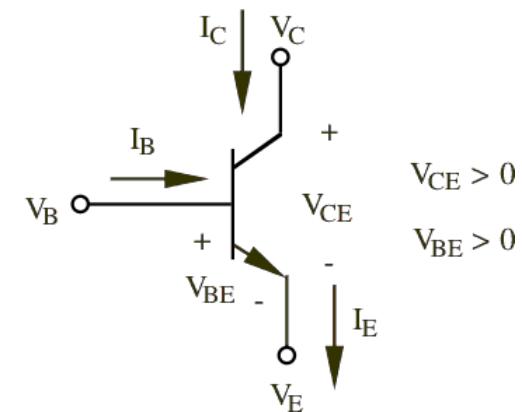


Bipolar Junction Transistor (BJT)

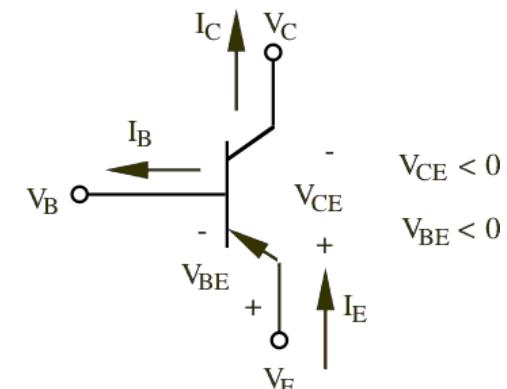
- 3 adjacent regions of doped Si (each connected to a lead):
 - Base. (thin layer, less doped).
 - Collector.
 - Emitter.
- 2 types of BJT:
 - npn.
 - pnp.
- Most common: npn (focus on it).



npn bipolar junction transistor



pnp bipolar junction transistor



BJT NPN Transistor

- 1 thin layer of p-type, sandwiched between 2 layers of n-type.
- N-type of emitter: more heavily doped than collector.
- With $V_C > V_B > V_E$:
 - Base-Emitter junction forward biased, Base-Collector reverse biased.
 - Electrons diffuse from Emitter to Base (from n to p).
 - There's a depletion layer on the Base-Collector junction □ no flow of e^- allowed.
 - BUT the Base is thin and Emitter region is n^\pm (heavily doped) □ electrons have enough momentum to cross the Base into the Collector.
 - The small base current I_B cor

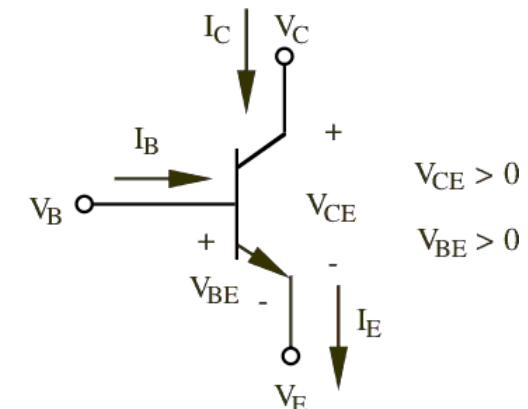
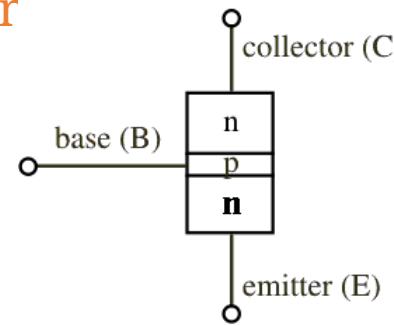
$$V_C > V_B > V_E$$

$$I_E = I_C + I_B$$

$$V_{BE} = V_B - V_E$$

$$V_{CE} = V_C - V_E$$

$$I_C = \beta I_B$$



BJT characteristics

- Current Gain:
 - α is the fraction of electrons that diffuse across the narrow Base region
 - $1 - \alpha$ is the fraction of electrons that recombine with holes in the Base region to create base current
- The current Gain is expressed in terms of the β (beta) of the transistor (often called h_{fe} by manufacturers).
- β (beta) is Temperature and Voltage dependent.
- It can vary a lot among transistors (common values for signal BJT: 20 - 200).



NPN Common Emitter circuit

- Emitter is grounded.
- Base-Emitter starts to conduct with $V_{BE}=0.6V$, I_C flows and it's $I_C=\beta*I_B$.
- Increasing I_B , V_{BE} slowly increases to 0.7V but I_C rises exponentially.
- As I_C rises , voltage drop across R_C increases and V_{CE} drops toward ground. (transistor in saturation, no more linear relation between I_C and I_B)

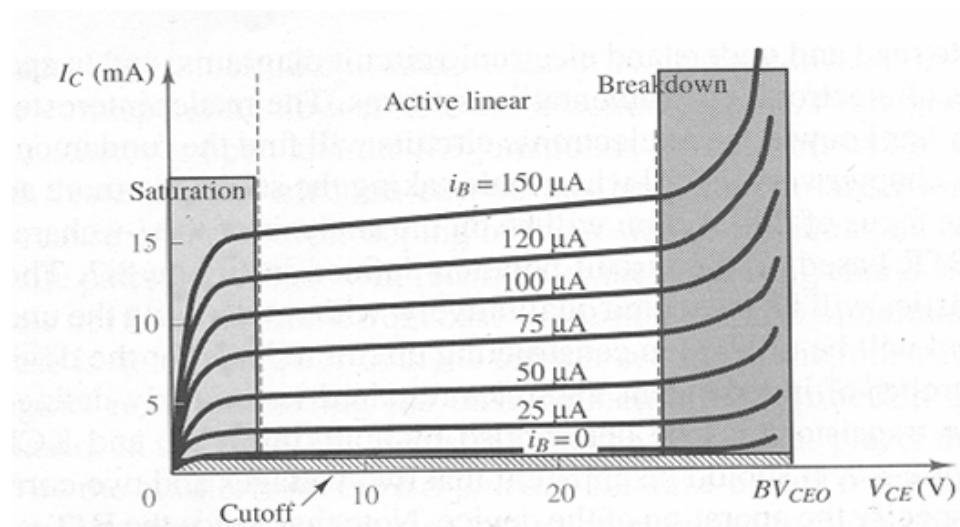
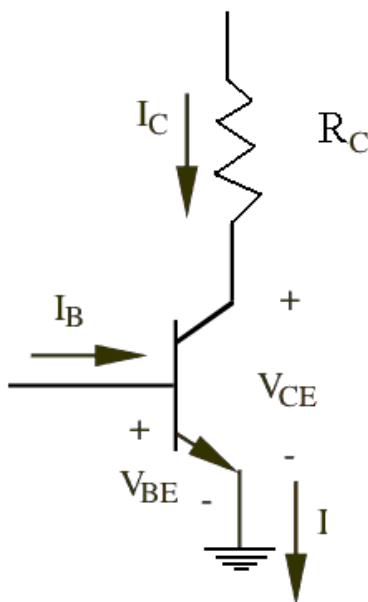


Figure 8.9(b) The collector-emitter output characteristics of a BJT

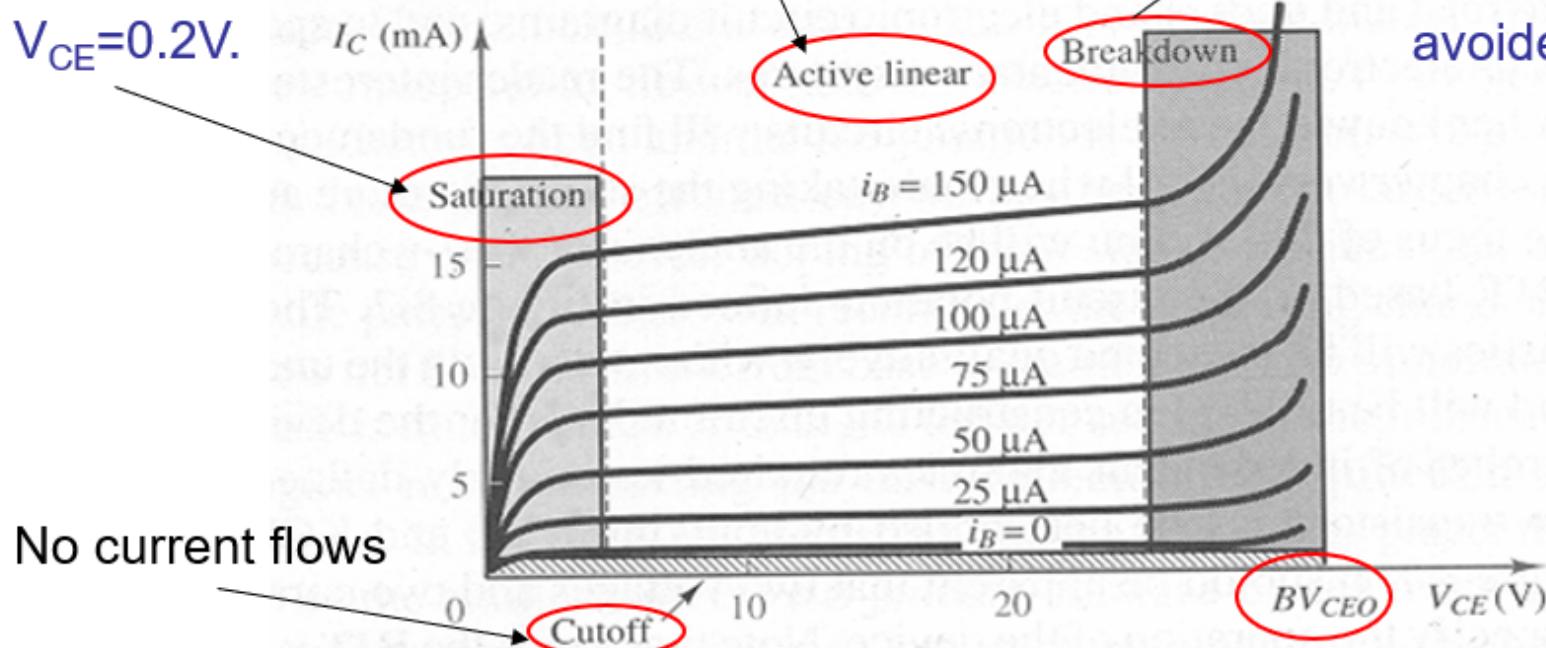
Common Emitter characteristics

Collector current controlled by the collector circuit.
(Switch behavior)

In full saturation
 $V_{CE} = 0.2V$.

Collector current proportional to Base current

The avalanche multiplication of current through collector junction occurs: to be avoided



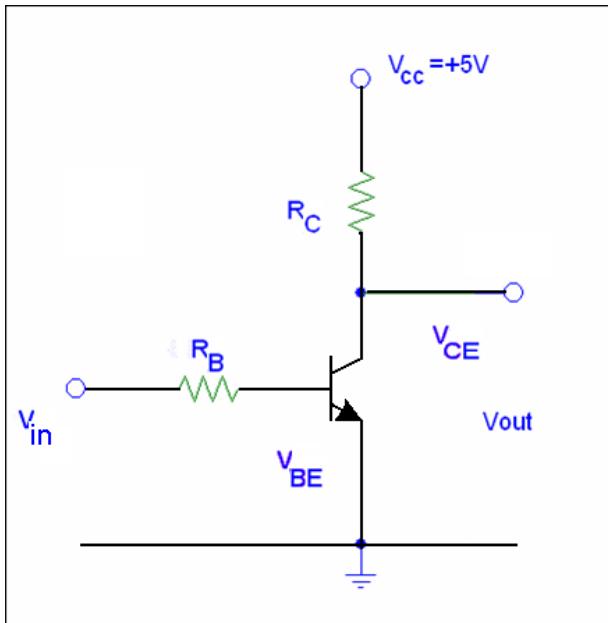
No current flows

Figure 8.9(b) The collector-emitter output characteristics of a BJT

Operation region summary

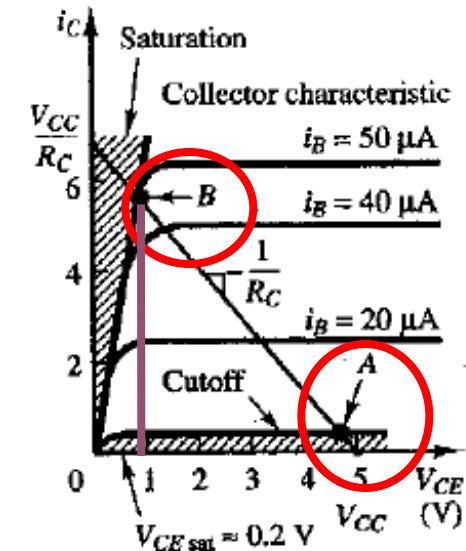
<i>Operation Region</i>	I_B or V_{CE} Char.	BC and BE Junctions	Mode
Cutoff	I_B = Very small	Reverse & Reverse	Open Switch
Saturation	V_{CE} = Small	Forward & Forward	Closed Switch
Active Linear	V_{CE} = Moderate	Reverse & Forward	Linear Amplifier
Break-down	V_{CE} = Large	Beyond Limits	Overload

BJT as Switch



- V_{in} (Low) < 0.7 V
 - BE junction not forward biased
 - Cutoff region
 - No current flows
 - $V_{out} = V_{CE} = V_{cc}$
 - V_{out} = High

- V_{in} (High)
 - BE junction forward biased ($V_{BE}=0.7V$)
 - Saturation region
 - V_{CE} small (~0.2 V for saturated BJT)
 - V_{out} = small
 - $I_B = (V_{in}-V_B)/R_B$
- V_{out} = Low



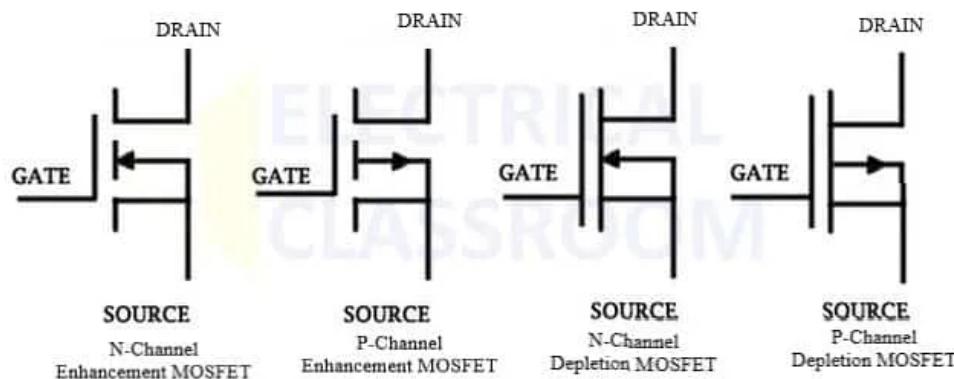
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BJT OPERATION

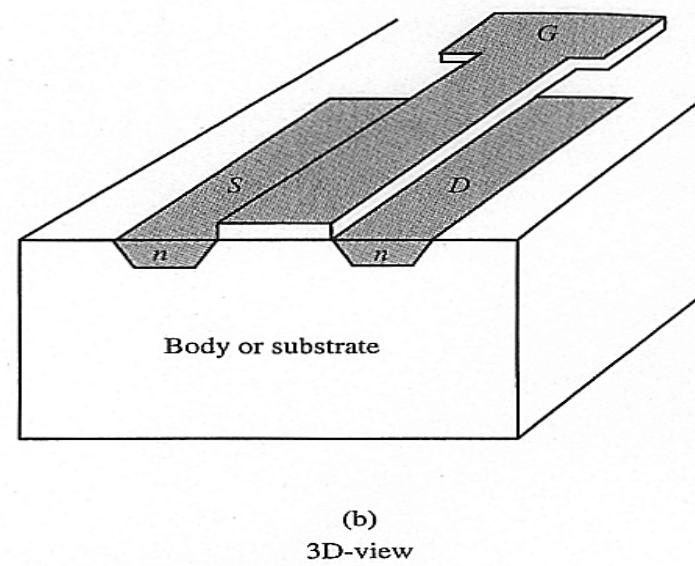
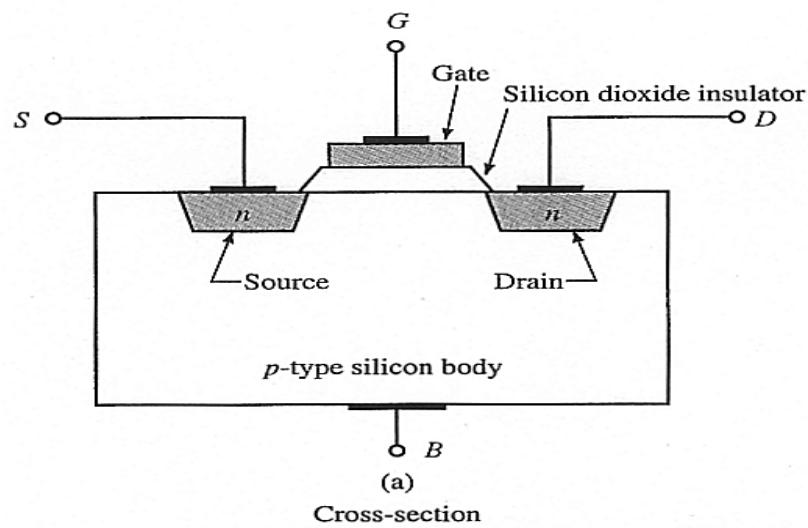
MOSFET (Types)

- Four types:
 - n-channel enhancement mode
 - Most common since it is cheapest to manufacture
 - p-channel enhancement mode
 - n-channel depletion mode
 - p-channel depletion mode

MOSFET SYMBOLS



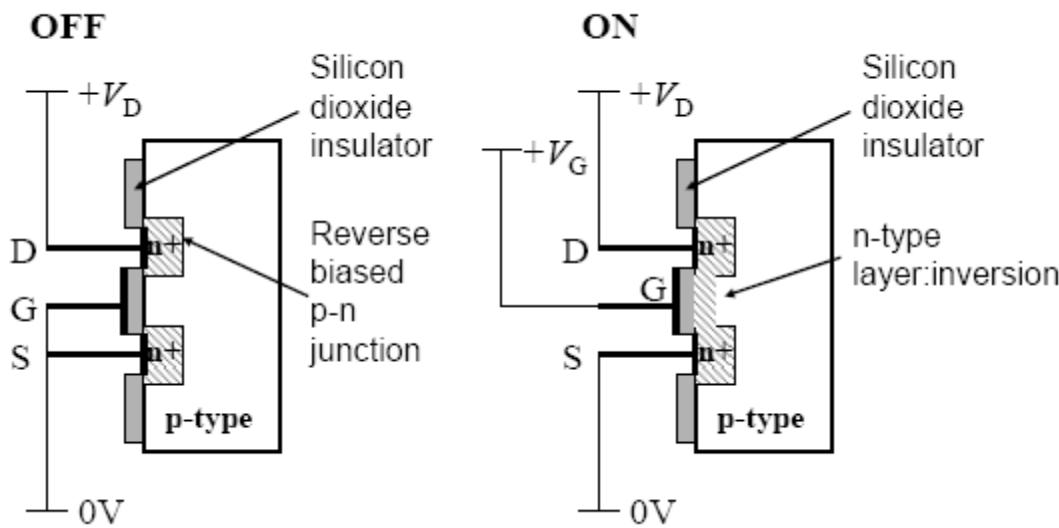
MOSFET



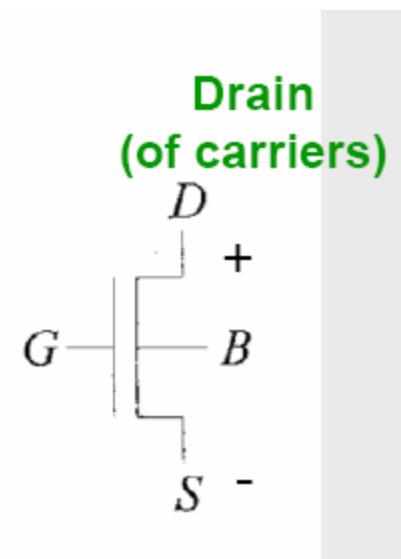
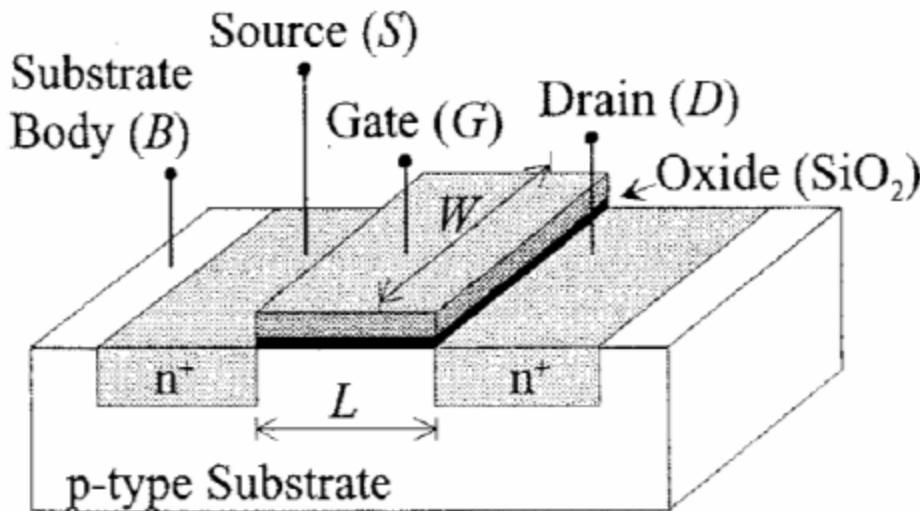
MOSFET

- The transistor consists of three regions, labeled the ``source'', the ``gate'' and the ``drain''.
- The area labeled as the gate region is actually a ``sandwich'' consisting of the underlying substrate material, which is a single crystal of semiconductor material (usually silicon); a thin insulating layer (usually silicon dioxide); and an upper metal layer.
- Electrical charge, or current, can flow from the source to the drain depending on the charge applied to the gate region.
- The semiconductor material in the source and drain region are ``doped'' with a different type of material than in the region under the gate, so an NPN or PNP type structure exists between the source and drain region of a MOSFET.

n-Channel MOSFET



NMOS Structure

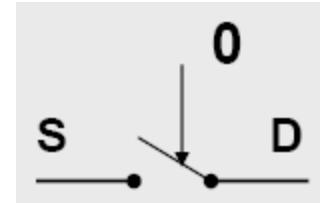


- MOS (Metal-Oxide-Semiconductor) Nowadays gate is made of poly-silicon
 - ❑ Channel length L and width W
 - ❑ In most digital design, L is set at the minimum feature size
 - ❑ W is selectable by the designer
 - ❑ Bulk is connected to the Gnd in NMOS to prevent forward-biased PN junction

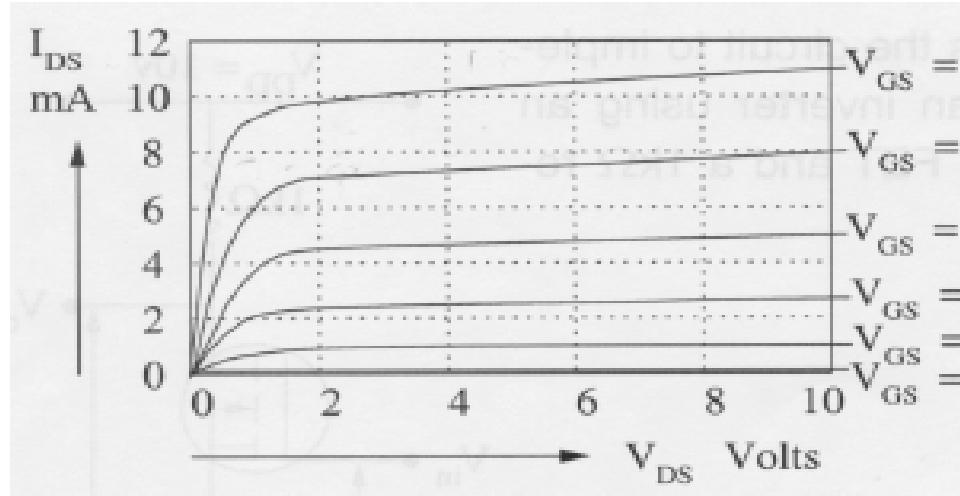
On state



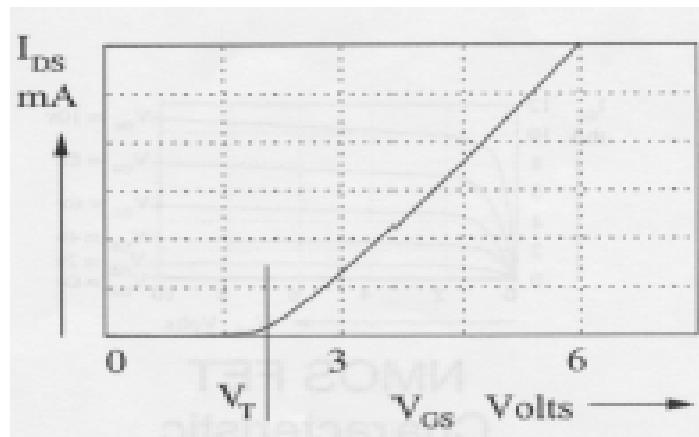
Off state



n-MOSFET Characteristics

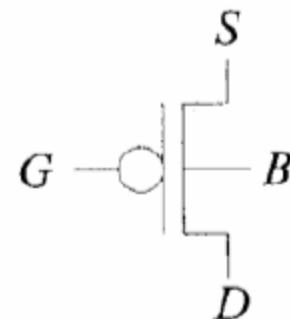
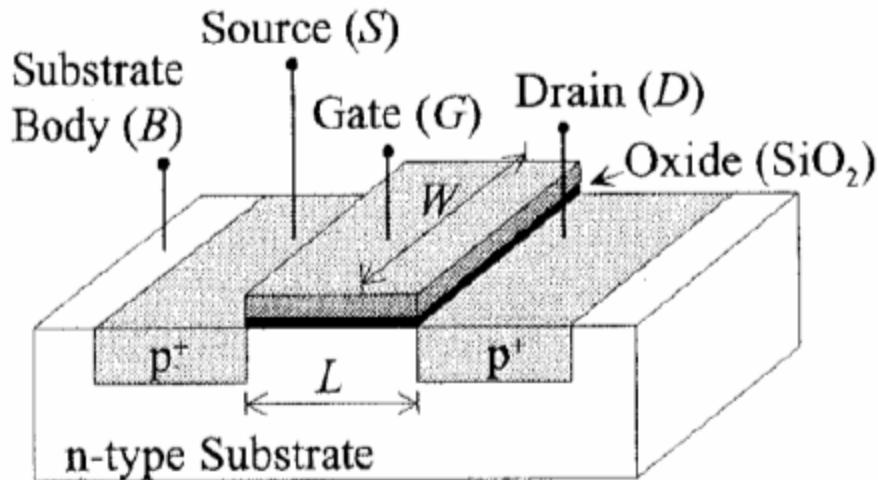


Plots V-I characteristics
of the device for various
Gate voltages (V_{GS})

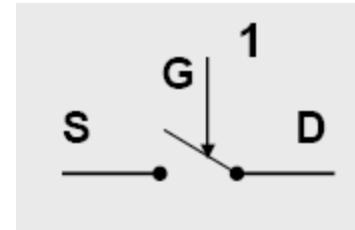
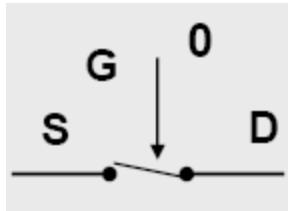


At a constant value of V_{DS} , we can also see that I_{DS} is a function of the Gate voltage, V_{GS}
The transistor begins to conduct when the Gate voltage, V_{GS} , reaches the Threshold voltage: V_T

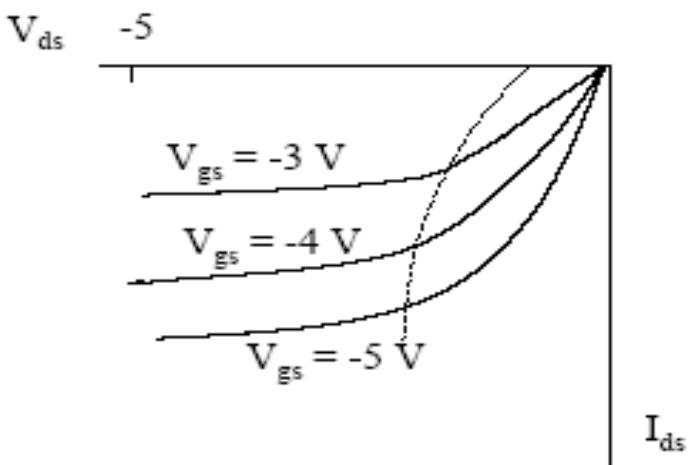
PMOS Structure



- PMOS transistor has a negative threshold voltage (V_{tp}) $-0.3v \sim -1.2v$
- A pMOS turns on when $V_{gs} < V_{tp}$

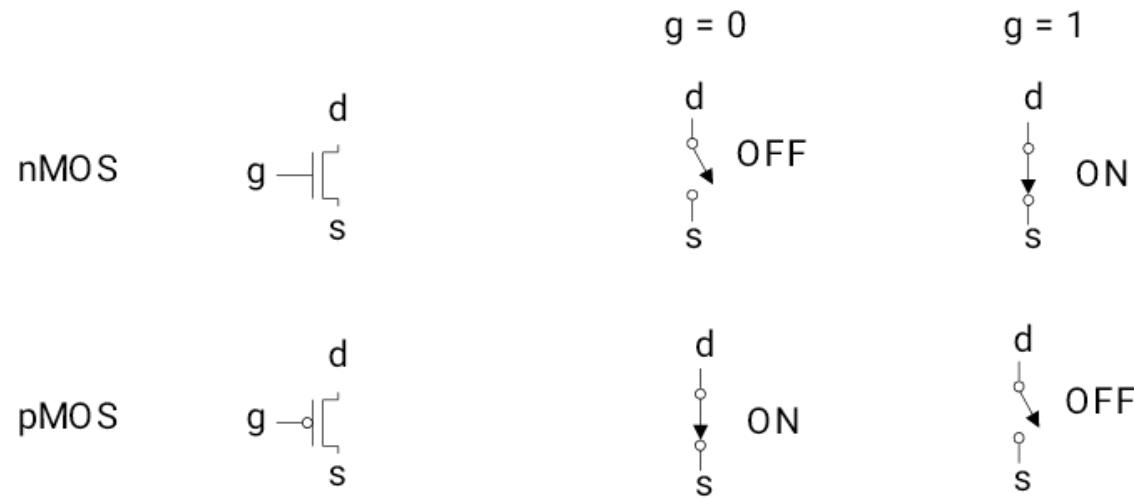


The terminal characteristics of the device are given by drain-to-source current I_{ds} against drain-to-source voltage V_{ds} for different values of *gate-to-source* voltage V_{gs} . All voltages are referenced with respect to the source voltage, which is assumed to be at ground potential.



Switch models of MOSFETs

$V_i (V_{gs})$	Logic Level	nMOS	pMOS
V_{dd}	1	ON	OFF
$V_{ss}(GND)$	0	OFF	ON



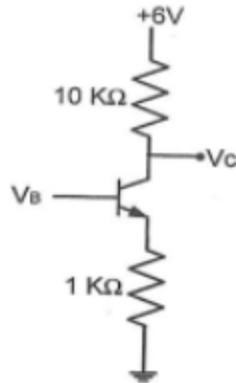
<https://youtu.be/rkbjHNEKcRw?feature=shared>

Mosfet operation

Parameter	BJT	MOSFET
Full form	BJT stands for Bipolar Junction Transistor.	MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor.
Definition	BJT is a three-terminal semiconductor device used for switching and amplification of signals.	MOSFET is a four-terminal semiconductor device which is used for switching applications.
Types	Based on the construction, BJTs are classified into two types: NPN and PNP.	Based on the construction and operation, the MOSFETs are classified into four types: P-channel enhancement MOSFET, N-channel enhancement MOSFET, P-channel depletion MOSFET and N-channel depletion MOSFET.
Terminals	BJT has three terminals viz. emitter, base and collector.	MOSFET has four terminals, i.e., source, drain, gate and body (or substrate).
Charge carriers	In BJT, both electrons and holes act as charge carriers.	In MOSFET, either electrons or holes act as charge carriers depending on the type of channel between source and drain.
Polarity	BJT is a bipolar device.	MOSFET is a unipolar device.
Controlling quantity	BJT is a current controlled device.	MOSFET is a voltage controlled device.
Input impedance	BJT has low input impedance.	MOSFET has relatively high input impedance.
Temperature coefficient	BJT has negative temperature coefficient.	MOSFET has positive temperature coefficient.
Switching frequency	The switching frequency BJT is low.	For MOSFET, the switching frequency is relatively high.
Power consumption	BJT consumes more power than MOSFET.	The power consumed by a MOSFET is less than BJT

Questions

For the circuit shown below the value of V_B is ____ Given $V_B = V_C$ and $\beta = 50$



1. 0.9 V

2. 1.19 V

3. 2.14 V

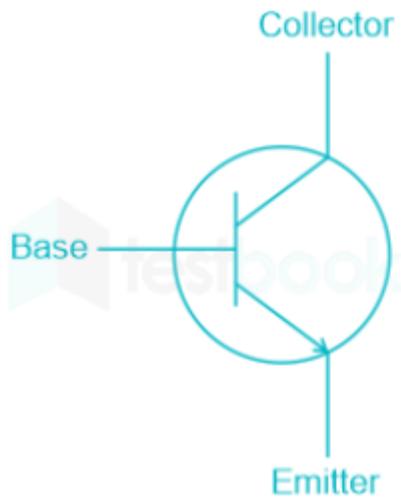
4. 1.84 V

In an unbiased PNP transistor, the barrier voltages are _____ on the base and _____ on the emitter and collector.

1. positive; negative
2. positive; positive
3. negative; positive
4. negative; negative

Which part of a transistor is heavily doped and emits majority carriers, either electrons or holes?

1. Collector
2. Emitter
3. Base and emitter
4. Base



The circuit symbol represents _____

1. NPN transistor
2. Zener diode
3. PNP transistor
4. PN diode

An enhancement type NMOS transistor with $V_t = 0.7$ V and source terminal grounded and 1.5 V applied to the gate. In what region does the device operate for $V_D = 0.5$ V?

1. Cut off region
2. Saturation region
3. Triode region
4. None of the above

The threshold voltage of an n-channel enhancement mode MOSFET is 0.5 V. When the device is biased at a gate voltage of 3 V, pinch-off would occur at a drain voltage of:

1. 2 V
2. 2.5 V
3. 3 V
4. 1.5 V

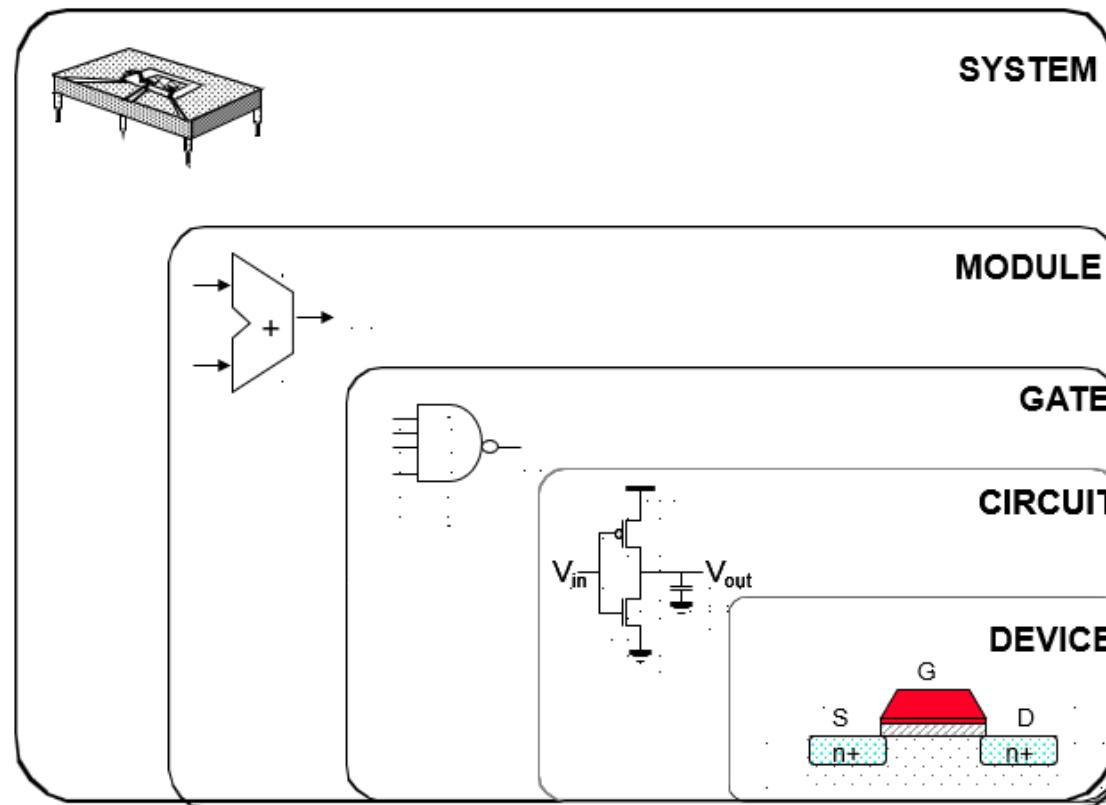
Which of the following is the fastest switching device?

1. JFET
2. BJT
3. MOSFET
4. Triode

For an n-channel E-MOSFET $V_{th} = 5V$, what is the condition to turn ON the device?

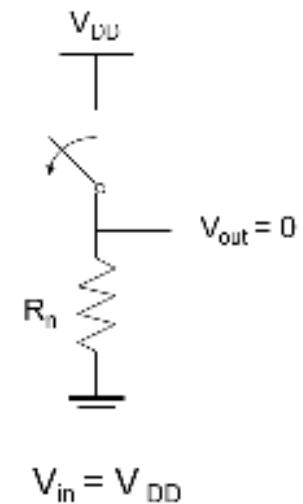
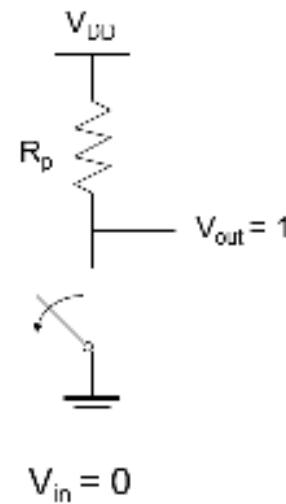
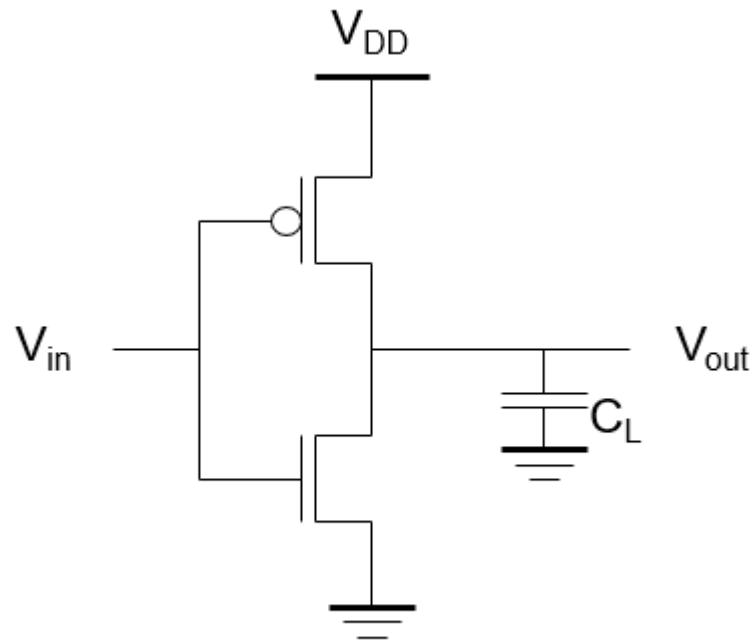
1. $V_{DS} > 5V$
2. $V_{GS} < 5V$
3. $V_{GS} > 5V$
4. $V_{DS} = 5V$

CMOS –Complementary Metal Oxide Semiconductor

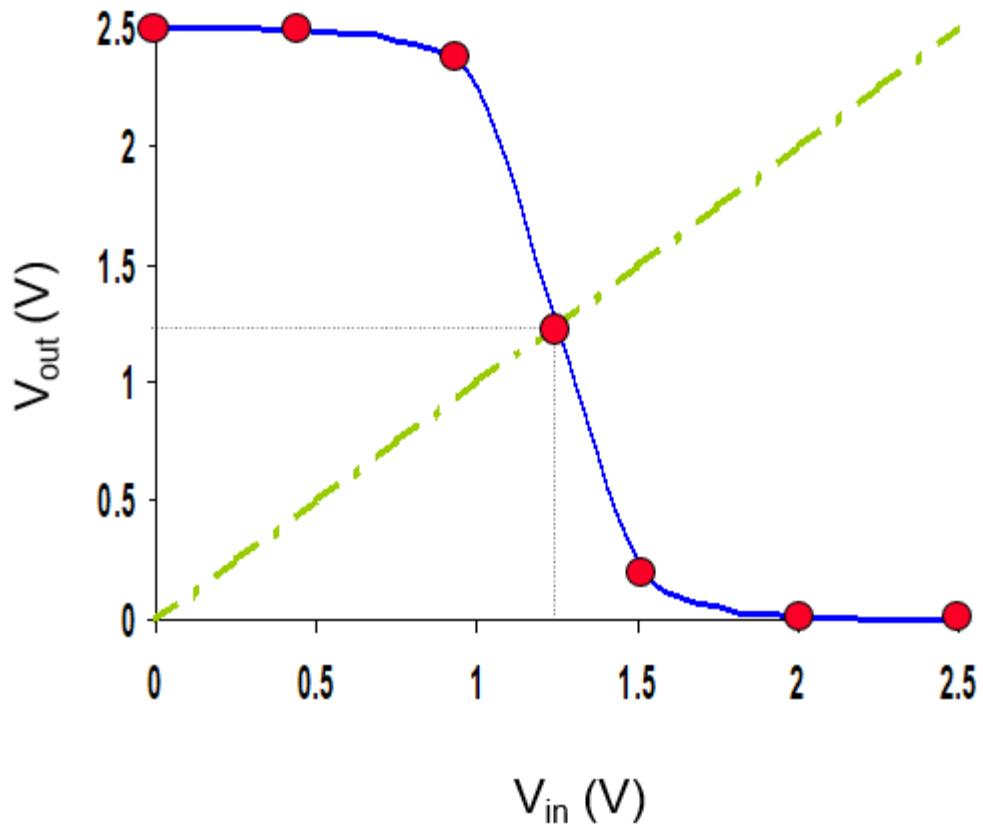


Design Abstraction Levels

CMOS AS AN INVERTER



Inverter Characteristics



WHY CMOS

- Much smaller power dissipation (because one transistor is always OFF)
- High noise immunity
- Strong temperature stability

Comparison of n-channel & p-channel MOSFETs

- While an n-channel MOSFET requires a positive gate-source voltage to activate, a p-channel MOSFET needs a negative gate-source voltage.
- The key distinction lies in their reverse doping profiles: p-channel MOSFETs rely on holes as the majority charge carriers, generating hole current, while n-channel devices utilize electrons, creating electron current.
- Due to electrons' superior mobility, which is roughly 2 to 3 times that of holes, moving holes in a p-channel device is more challenging than electrons in an n-channel device.
- This leads to higher area-specific on-state resistance in p-channel MOSFETs compared to n-channel MOSFETs.

N-channel & p-channel MOSFETS

- N channel MOSFETS have better packaging density due to their smaller size
- P channel MOSFETS are more efficient in terms of power dissipations
- N-channel MOSFETS are used in high power and high speed applications such as motor, control, switching power supplies and amplifier circuits.
- P-channel MOSFETS are used in low power applications such as battery powered devices, logic circuits, voltage regulators etc.