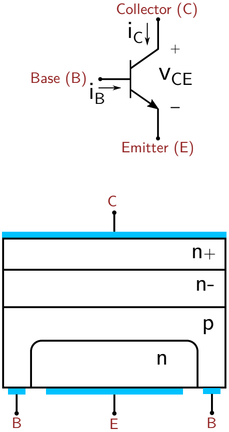
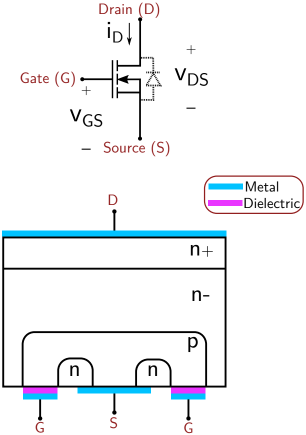
Fully-controlled power semiconductor switches

n-p-n Bipolar Junction Transistor (BJT)



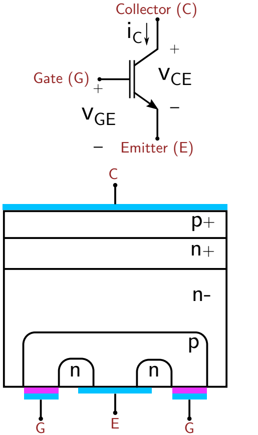
Minority carrier device
Conduction is due to
flow of electrons and holes

n-channel enhancement-mode
Metal Oxide Semiconductor
Field Effect Transistor (MOSFET)



Majority carrier device
Conduction is primarily due to
flow of electrons

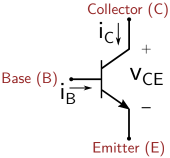
Insulated Gate Bipolar Transistor (IGBT)

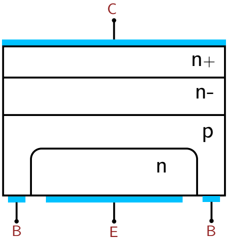


Minority carrier device
Conduction is due to
flow of electrons and holes

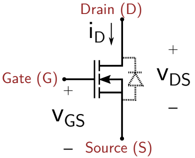
Fully-controlled power semiconductor switches

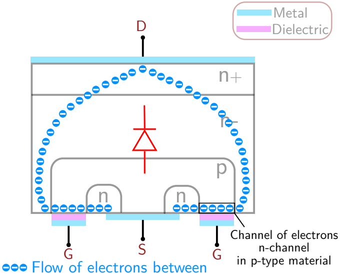
n-p-n Bipolar Junction Transistor (BJT)





n-channel enhancement-mode Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

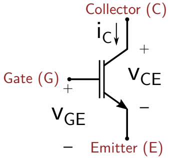


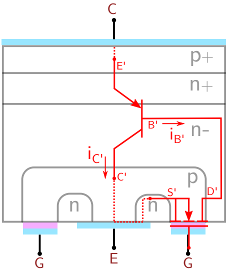


Flow of electrons between source and drain when v_{GS} is +ve

Body-diode of a MOSFET

Insulated Gate Bipolar Transistor (IGBT)

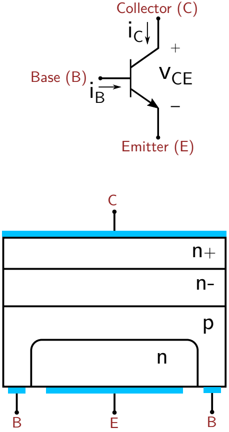




IGBT can be viewed as a MOSFET driving a p-n-p BJT

Fully-controlled power semiconductor switches

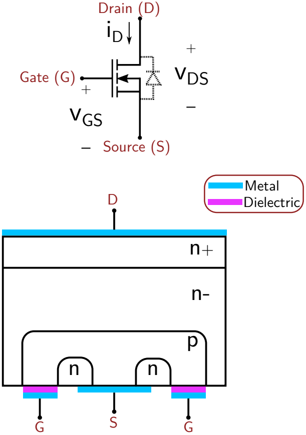
BJT



Can conduct only in one direction (C to E)

B-E junction should be forward-biased for conduction

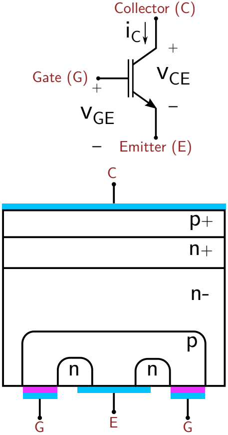
MOSFET



Can conduct in both directions

With positive v_{GS}, electrons can flow from D to S or S to D

IGBT

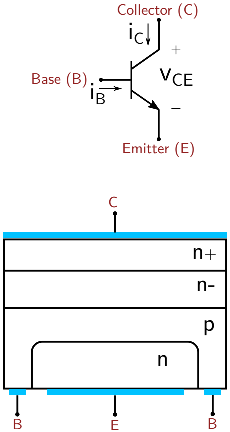


Can conduct only in one direction (C to E)

The p-n-p transistor can conduct only in one direction

Fully-controlled power semiconductor switches

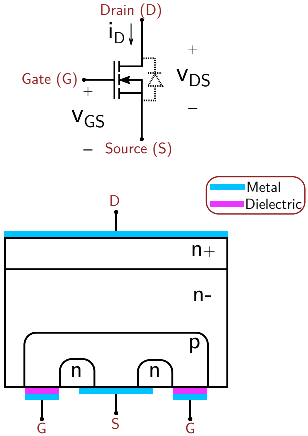
BJT



Can only block positive v_{CE}

Base is thin and lightly doped
Emitter is heavily doped
B-E juction breaks down
at very low negative voltages

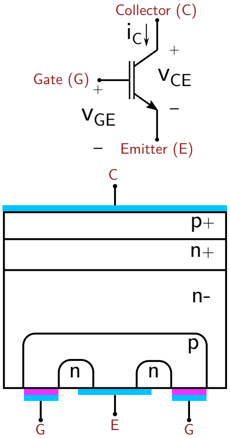
MOSFET



Can only block positive v_{DS}

Body diode conducts
for negative v_{DS}

IGBT

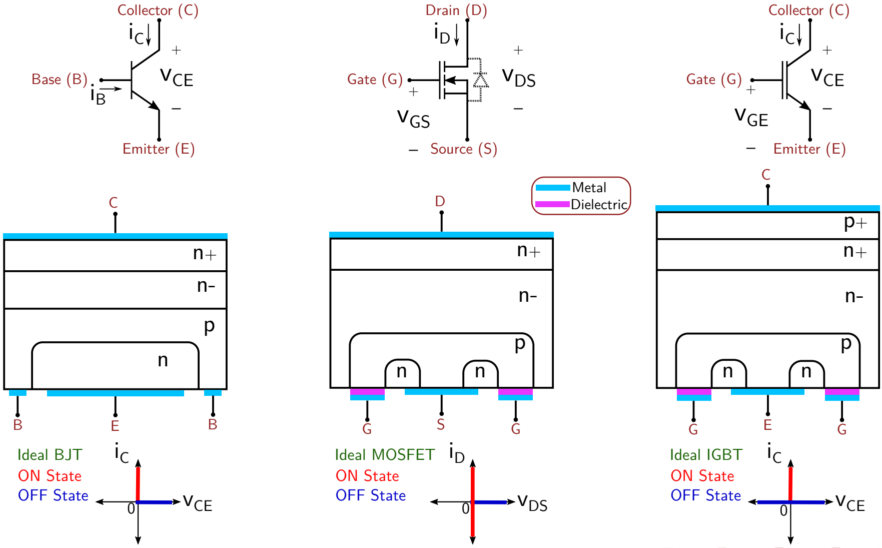


Can block v_{CE} in either direction

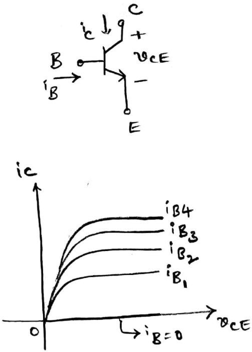
Reverse-blocking capability depends on
the breakdown voltage of
the p+ / n+ junction

Fully-controlled power semiconductor switches

BJT | MOSFET | IGBT

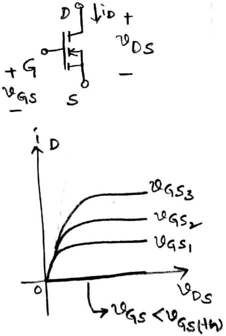


Fully-controlled power semiconductor switches



$i_{B_4} > i_{B_3} > i_{B_2} > i_{B_1}$

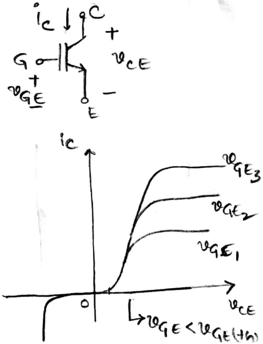
current-controlled device



$v_{GS_3} > v_{GS_2} > v_{GS_1} > v_{GS\,th}$

voltage-controlled device

MOSFET can be modeled as a resistor in the ON state ⇒ $R_{DS(on)}$

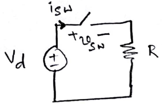


$v_{GE_3} > v_{GE_2} > v_{GE_1} > v_{GE(th)}$

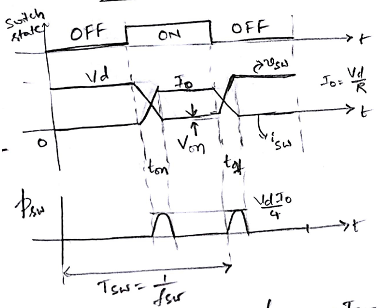
voltage-controlled device

Estimation of switching loss

Switching resistive load



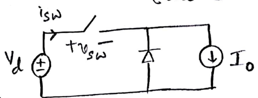
current-rise & voltage-fall occur simultaneously during turn-ON



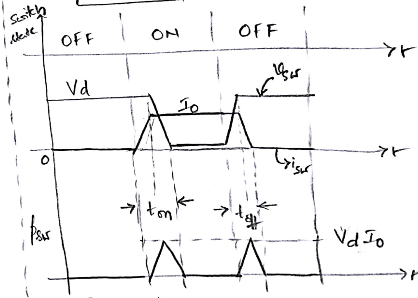
P_{SW} = Average of p_{SW} over T_{SW}

$= \frac{1}{6} V_d I_o (t_{on} + t_{off}) f_{SW}$

Switching inductive load (diode-clamped)



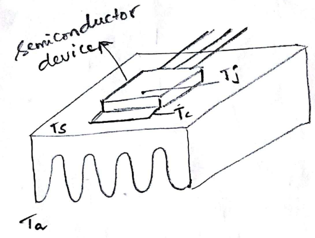
More Losses

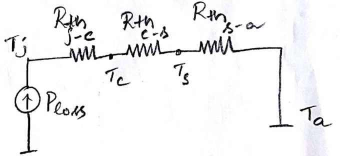


$P_{SW} = \frac{1}{2} V_d I_o (t_{on} + t_{off}) f_{SW}$

current-rise is followed by voltage-fall during turn-ON

Thermal model: Design of heat sink





$$T_j - T_a = P_{loss}\left[R_{th\,j-c} + R_{th\,c-s} + R_{th\,s-a}\right]$$

$R_{th\,j-c}$: Thermal resistance of semiconductor

$R_{th\,c-s}$: Thermal resistance of the interface material between device & heat sink

$R_{th\,s-a}$: Thermal resistance of heat sink

$R_{th\,s-a}$ is lowered by using fan [forced-air cooling].

Module 3: Summary

- Fully-controlled switches: BJT, MOSFET and IGBT
- Estimation of switching loss in case of resistive load and diode-clamped inductive load
- Thermal model of a power semiconductor switch