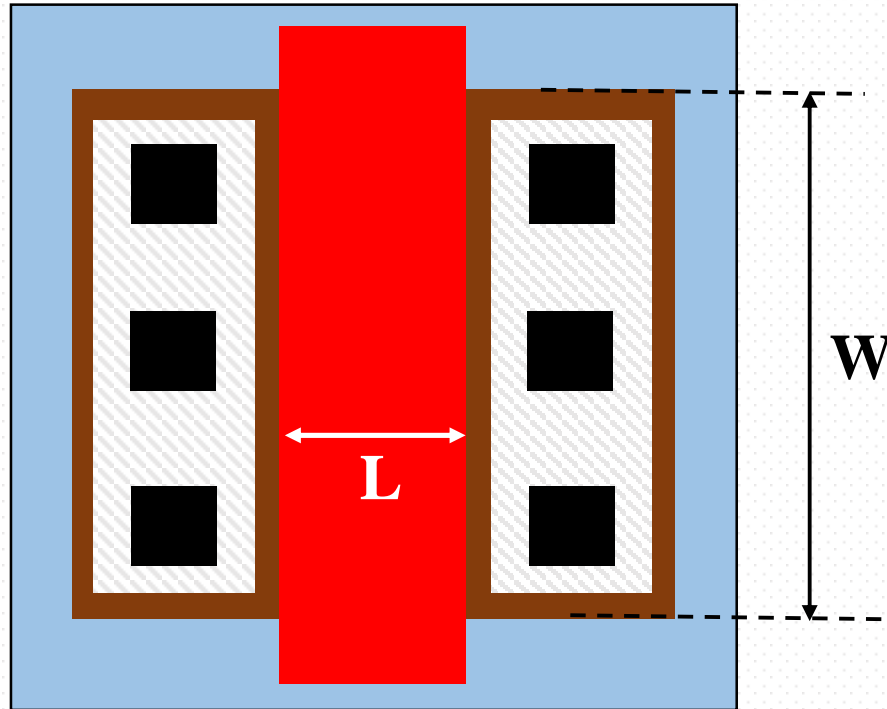


Metal-Oxide-Semiconductor FIELD EFFECT TRANSISTOR

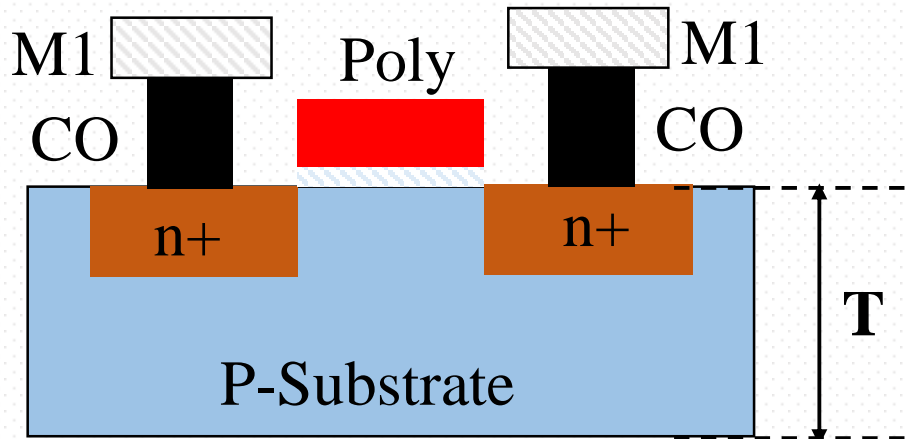
Santunu Sarangi

Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET)

Top View
(Layout View)
of MOSFET



Front View
(Cross-section)
of MOSFET

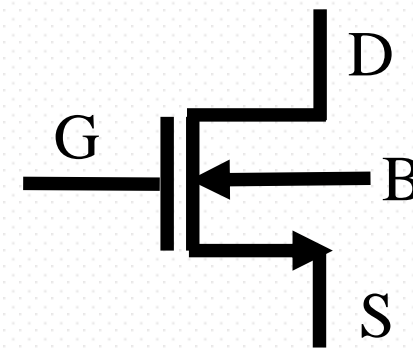


Layout Layers:

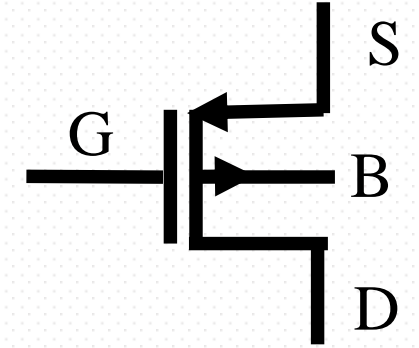
- P-substrate
- Thin oxide
- Polysilicon
- n+ diffusion
- Contact
- Metal

Layout Rules:

- Min. width
- Max Width
- Spacing
- Area
- Enclosure
- Extension

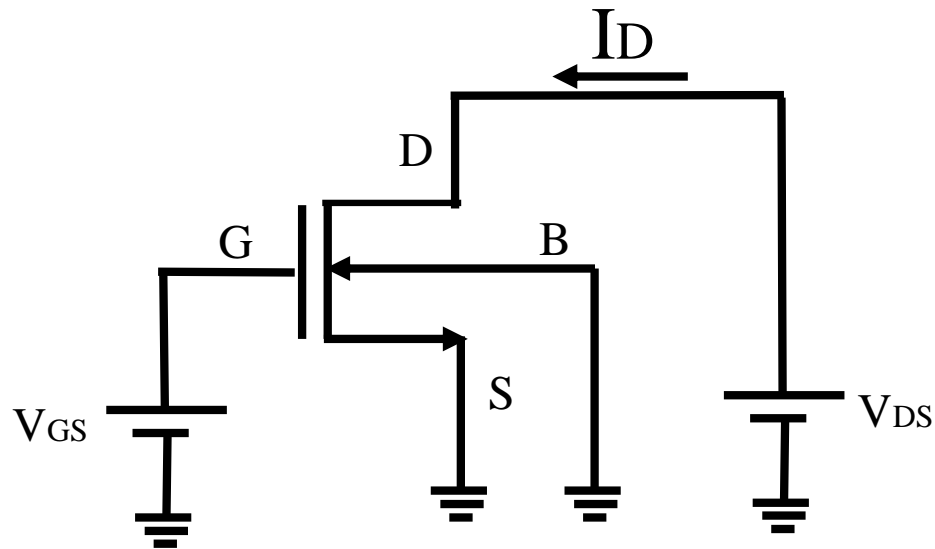
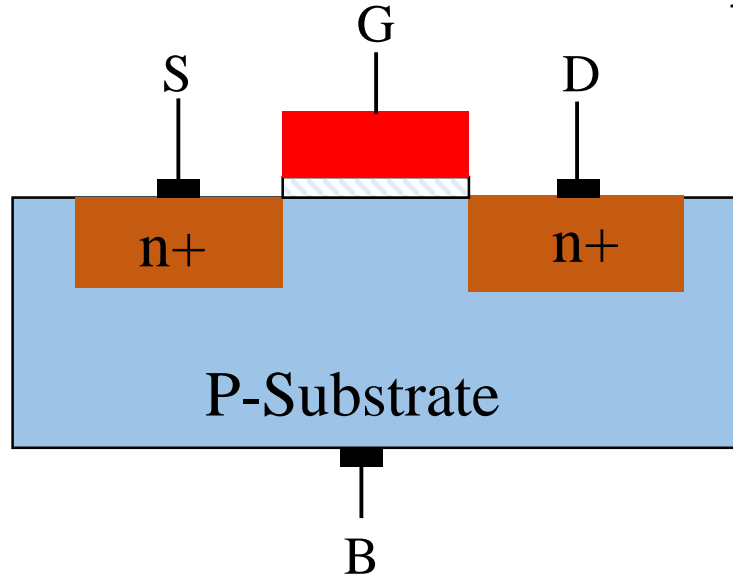


N-MOSFET



P-MOSFET

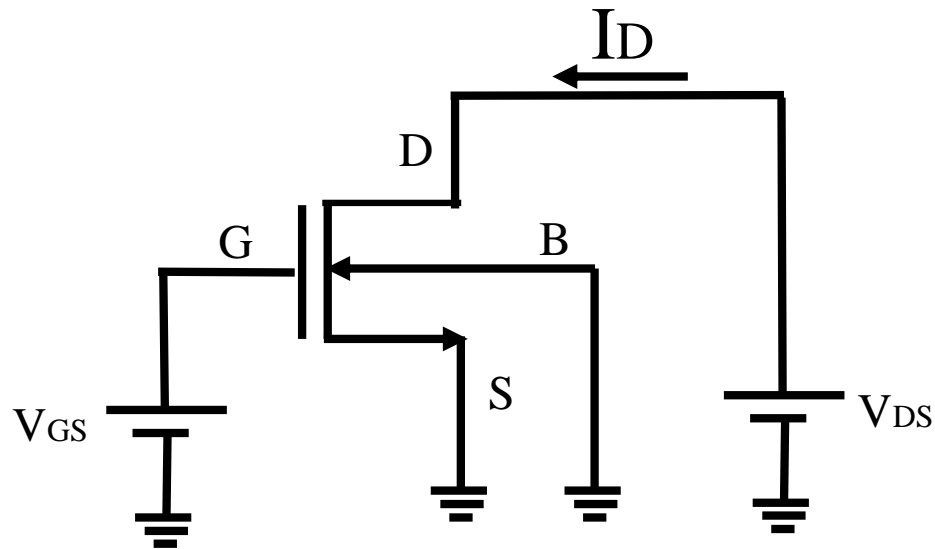
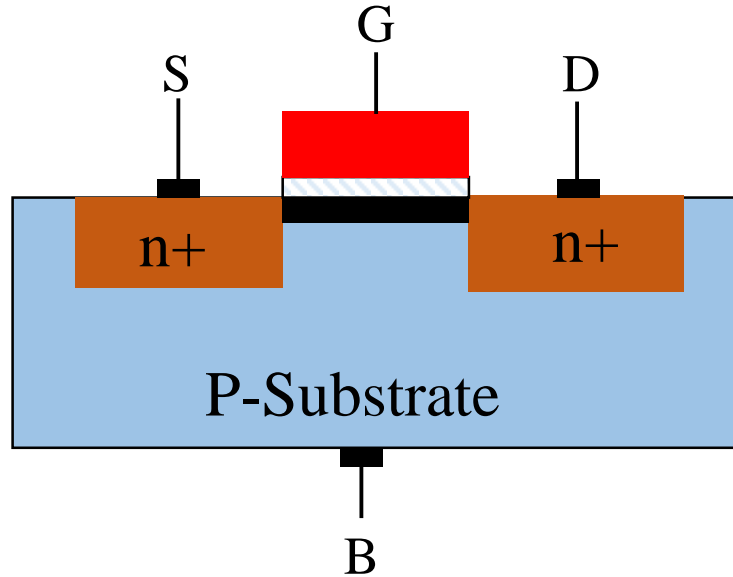
MOSFET Operation (N-Channel Enhancement)



MOSFET Operation:

- Case-1: $V_{GS} < V_T$
 - Cutoff
- Case-2: $V_{GS} > V_T$
 - Linear or Saturation
 - Linear: $V_{GS} - V_T > V_{DS}$
 - Saturation: $V_{GS} - V_T \leq V_{DS}$
- $I_{D-Cutoff} = 0$
- $I_{D-Lin.} = \mu_n C_{ox} \frac{W}{L} \left\{ (V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right\}$
- $I_{D-Sat.} = \mu_n C_{ox} \frac{W}{2L} \{ (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \}$

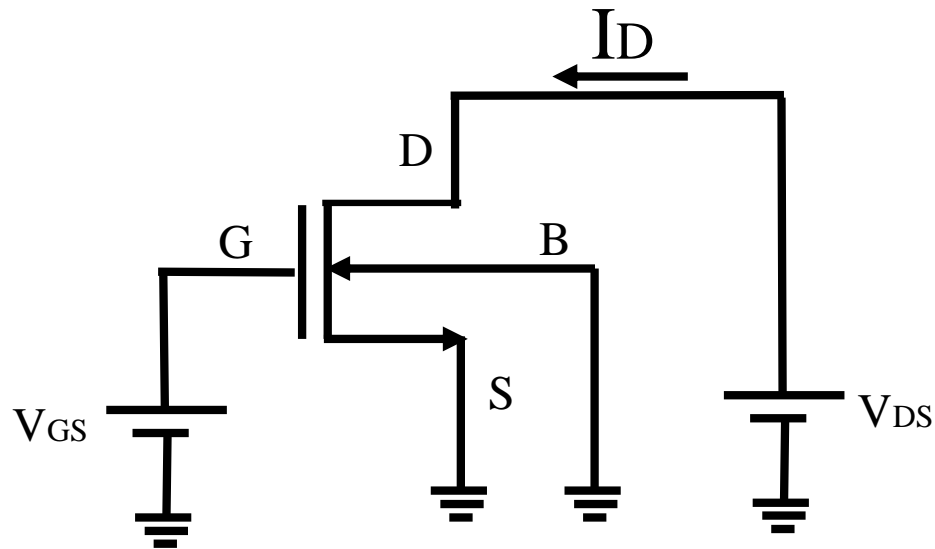
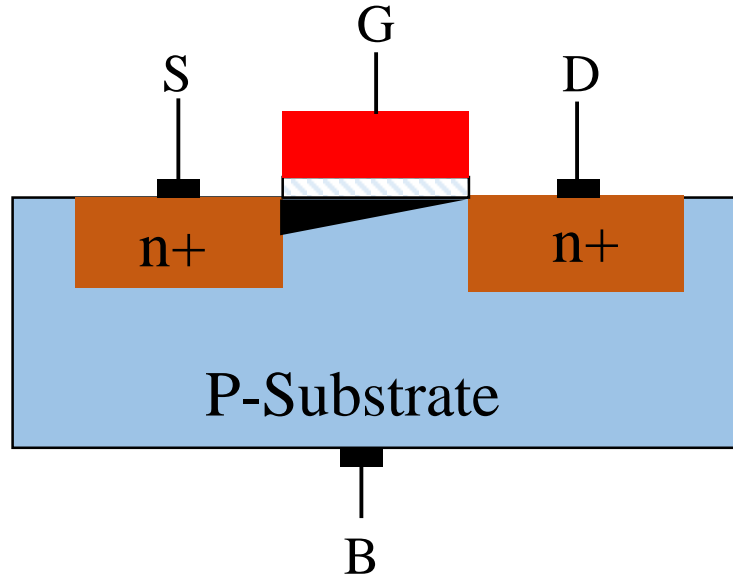
MOSFET Operation: Linear



MOSFET Operation:

- Case-1: $V_{GS} < V_T$
 - Cutoff
- Case-2: $V_{GS} > V_T$
 - Linear or Saturation
 - Linear: $V_{GS} - V_T > V_{DS}$
 - Saturation: $V_{GS} - V_T \leq V_{DS}$
- $I_{D-Cutoff} = 0$
- $I_{D-Lin.} = \mu_n C_{ox} \frac{W}{L} \left\{ (V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right\}$
- $I_{D-Sat.} = \mu_n C_{ox} \frac{W}{2L} \{ (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \}$

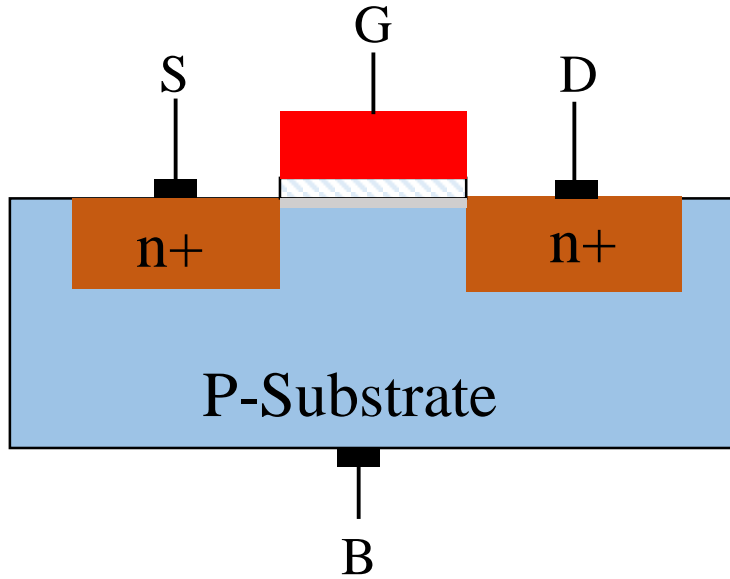
MOSFET Operation: Saturation



MOSFET Operation:

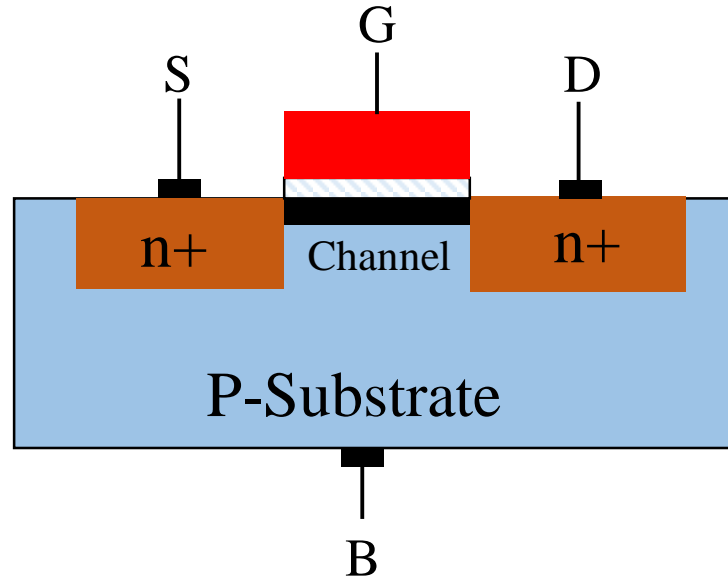
- Case-1: $V_{GS} < V_T$
 - Cutoff
- Case-2: $V_{GS} > V_T$
 - Linear or Saturation
 - Linear: $V_{GS} - V_T > V_{DS}$
 - Saturation: $V_{GS} - V_T \leq V_{DS}$
- $I_{D-Cutoff} = 0$
- $I_{D-Lin.} = \mu_n C_{ox} \frac{W}{L} \left\{ (V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right\}$
- $I_{D-Sat.} = \mu_n C_{ox} \frac{W}{2L} \{ (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \}$

MOSFET Channel Profile



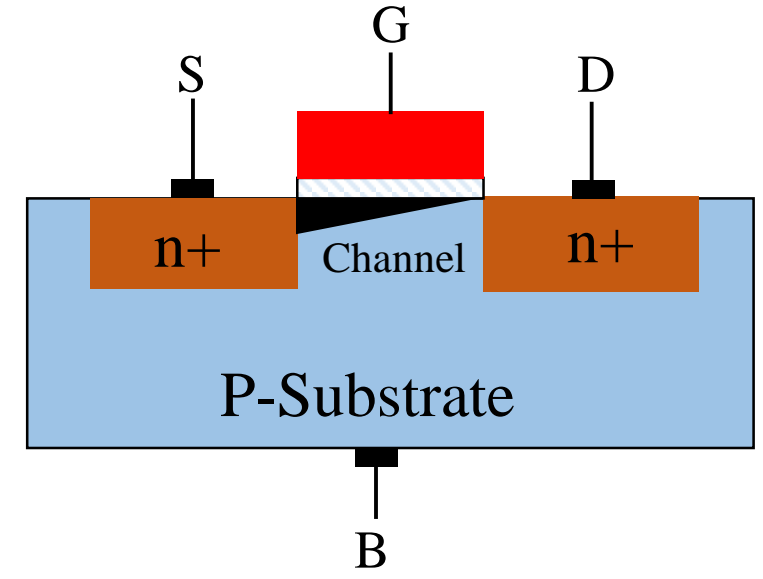
MOSFET in cutoff mode of operation

- Application: Switch



MOSFET in linear or triode mode of operation

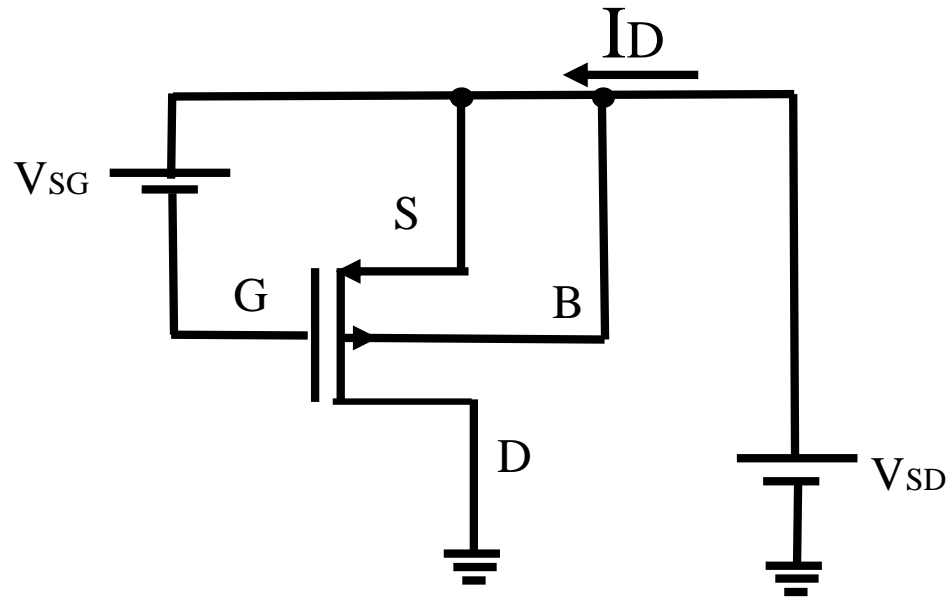
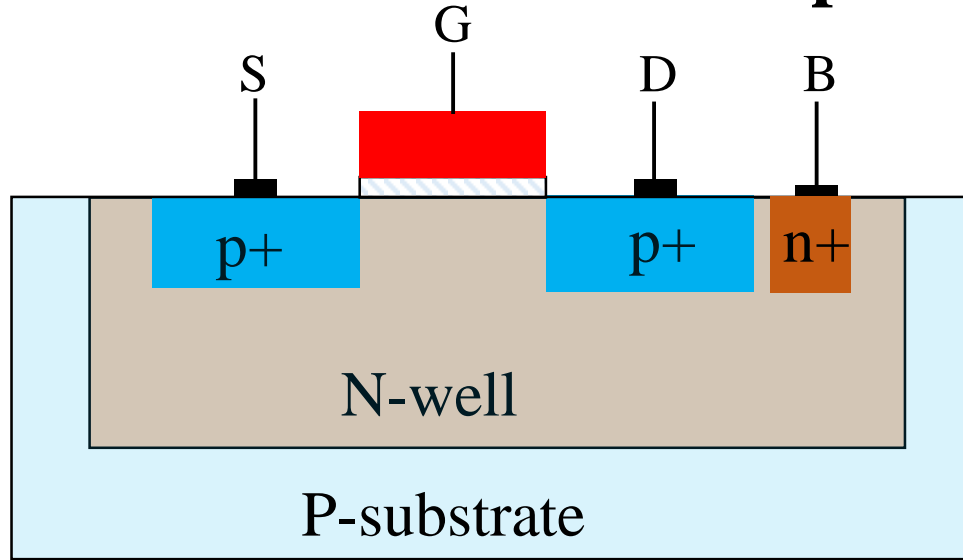
- Application: switch and linear resistor



MOSFET in saturation mode of operation

- Application: Amplifier and constant current source

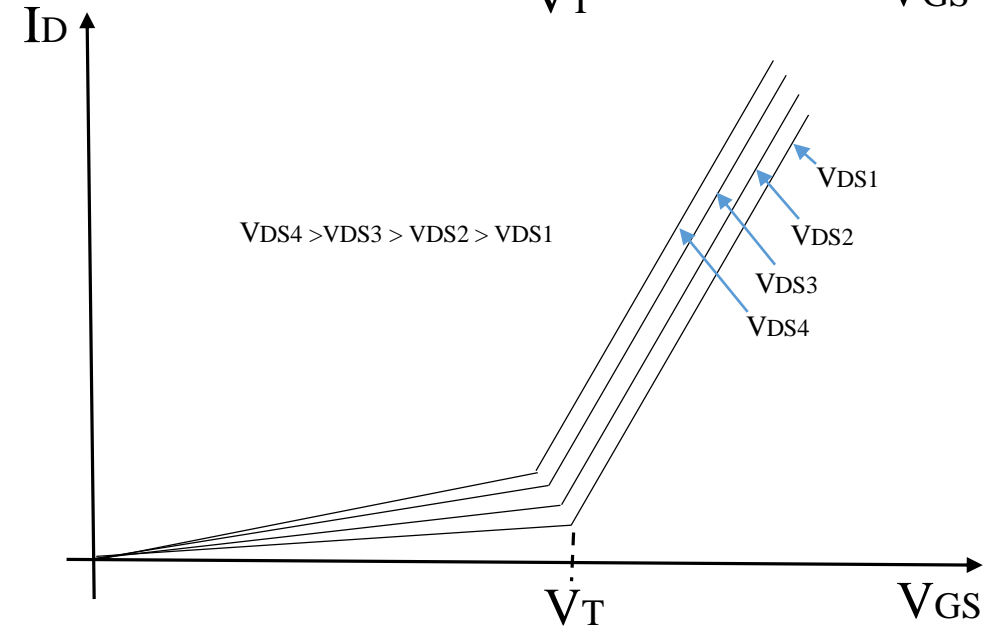
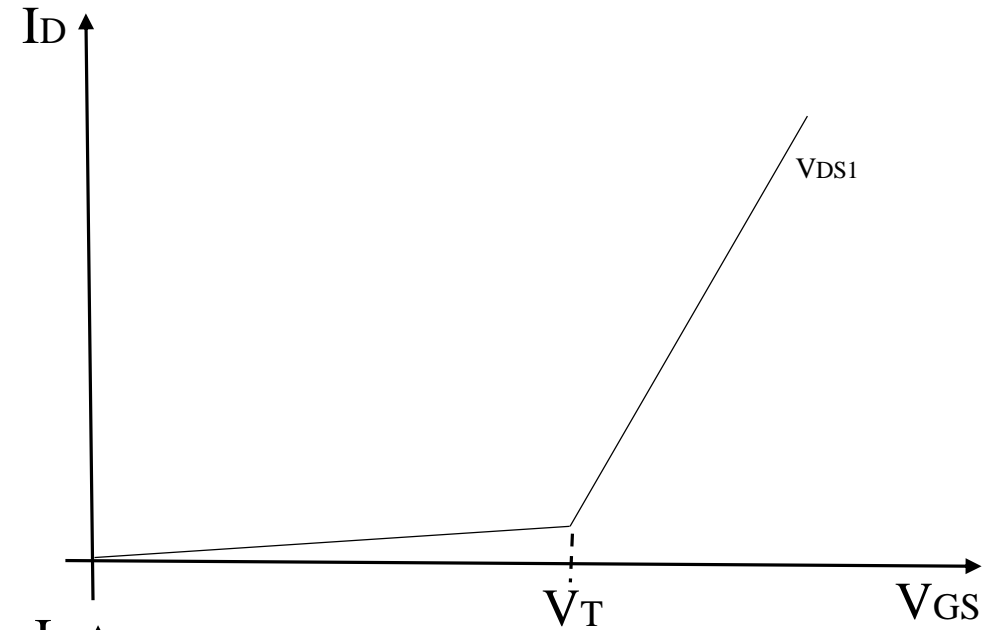
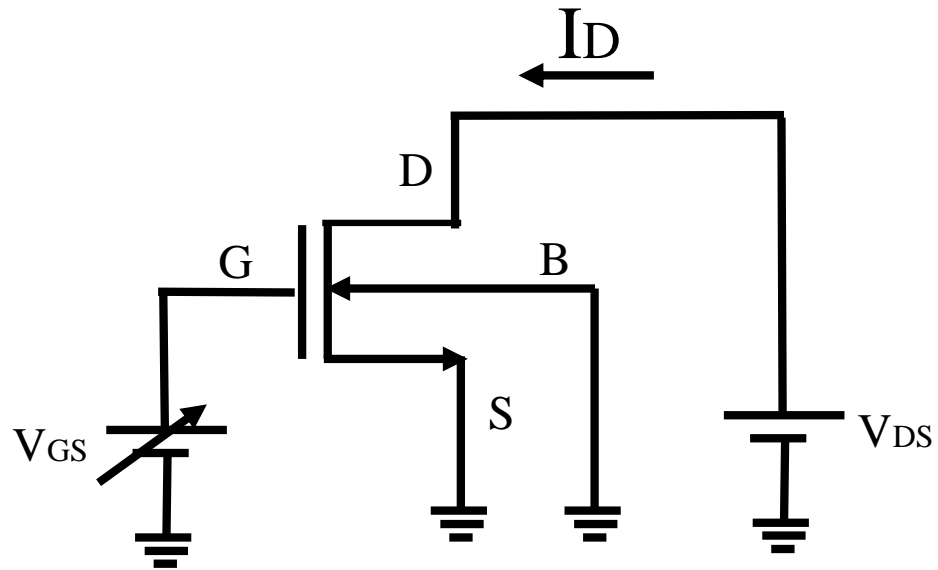
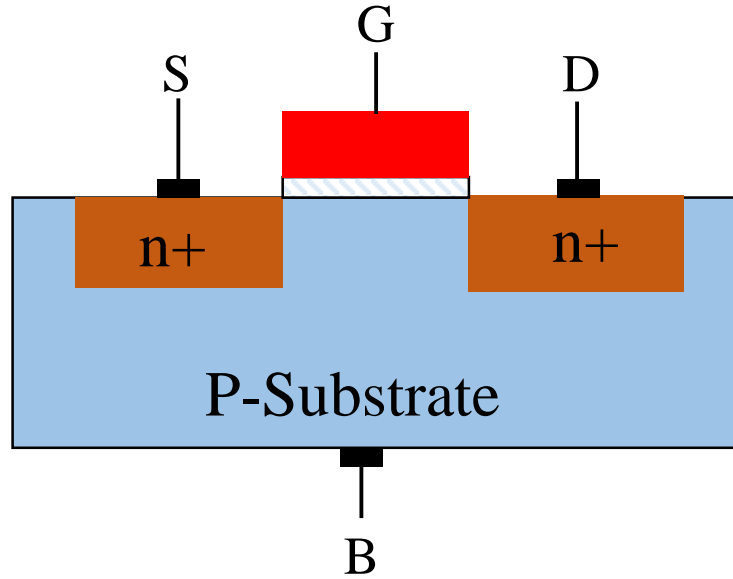
MOSFET Operation (P-Channel Enhancement)



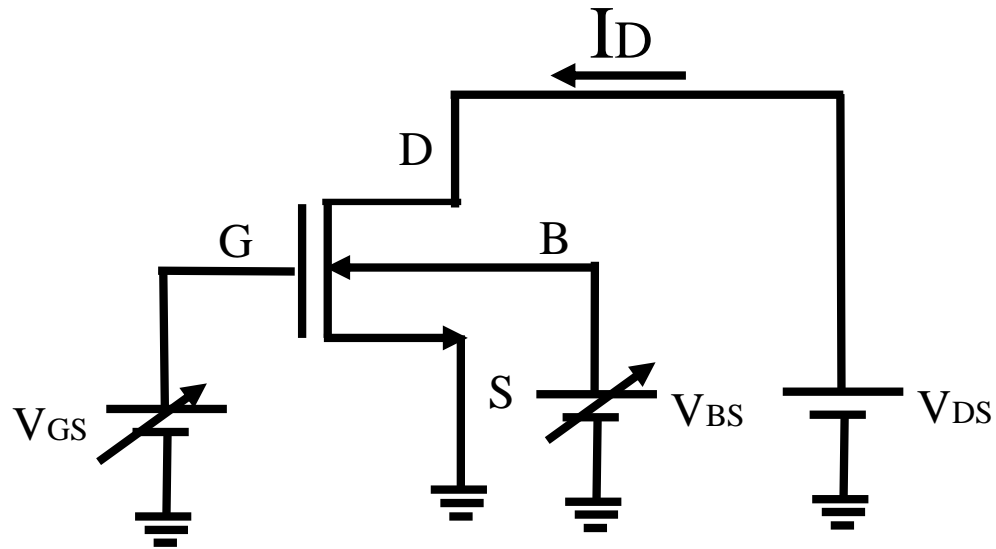
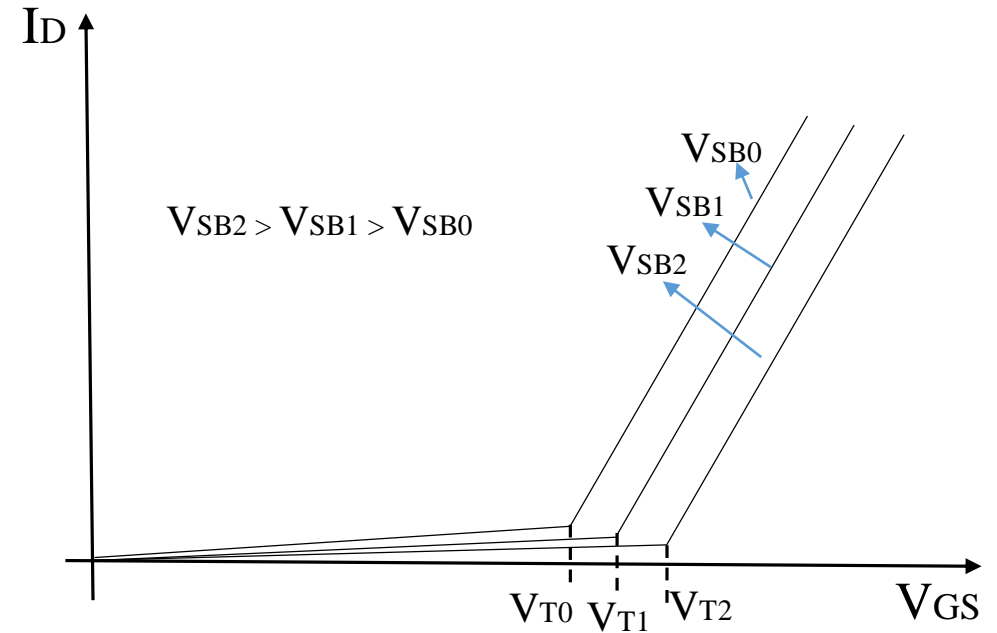
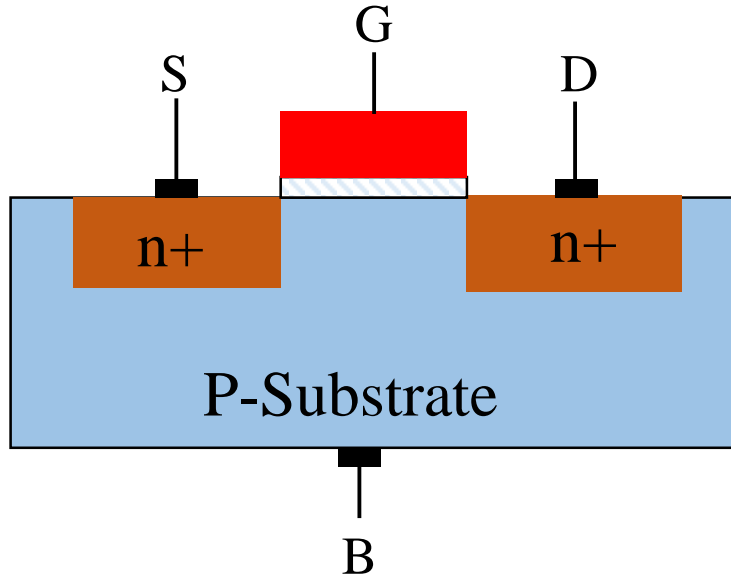
MOSFET Operation:

- Case-1: $V_{SG} < |V_T|$
 - Cutoff
- Case-2: $V_{SG} > |V_T|$
 - Linear or Saturation
 - Linear: $V_{SG} - |V_T| > V_{SD}$
 - Saturation: $V_{SG} - |V_T| \leq V_{SD}$
- $I_{D-Cutoff} = 0$
- $I_{D-Lin.} = \mu_p C_{ox} \frac{W}{L} \left\{ (V_{SG} - |V_T|) V_{DS} - \frac{V_{DS}^2}{2} \right\}$
- $I_{D-Sat.} = \mu_p C_{ox} \frac{W}{2L} \{ (V_{SG} - |V_T|)^2 (1 + \lambda V_{SD}) \}$

ID-VGS Characteristics



ID-VGS Characteristics with Body Bias



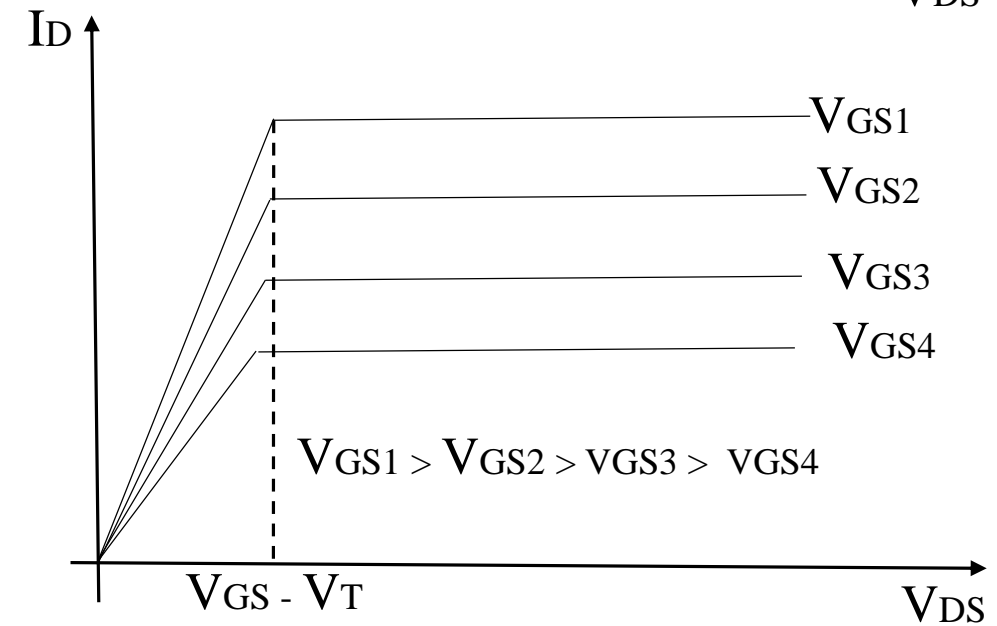
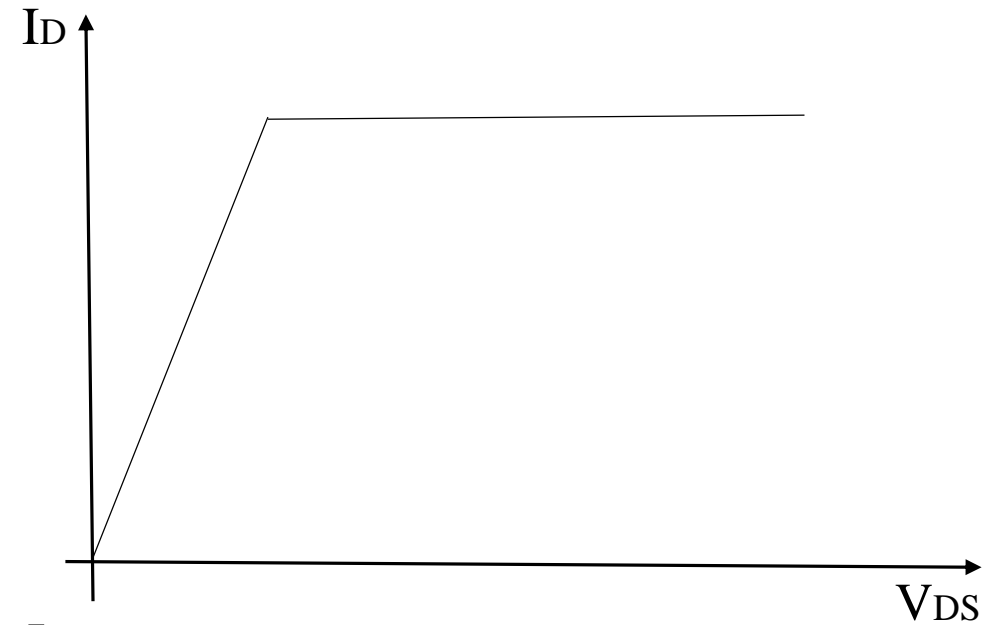
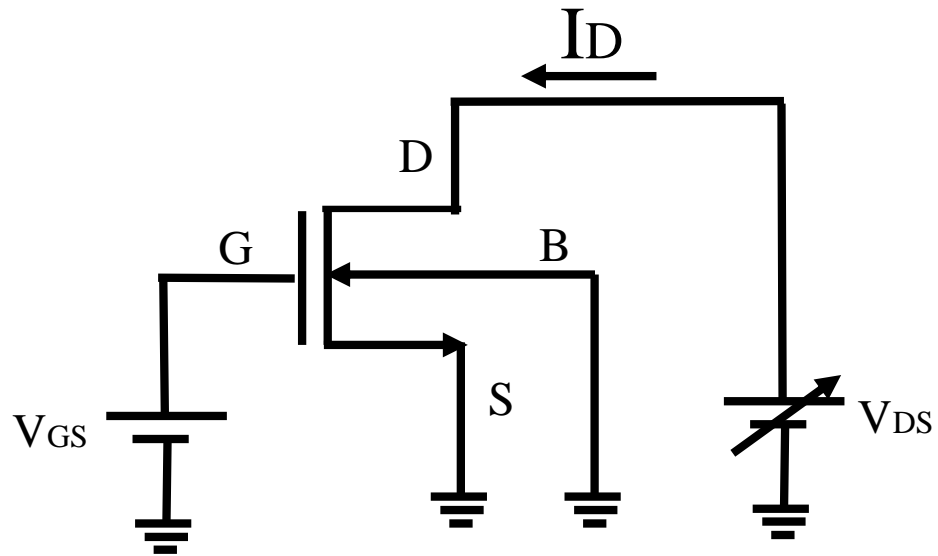
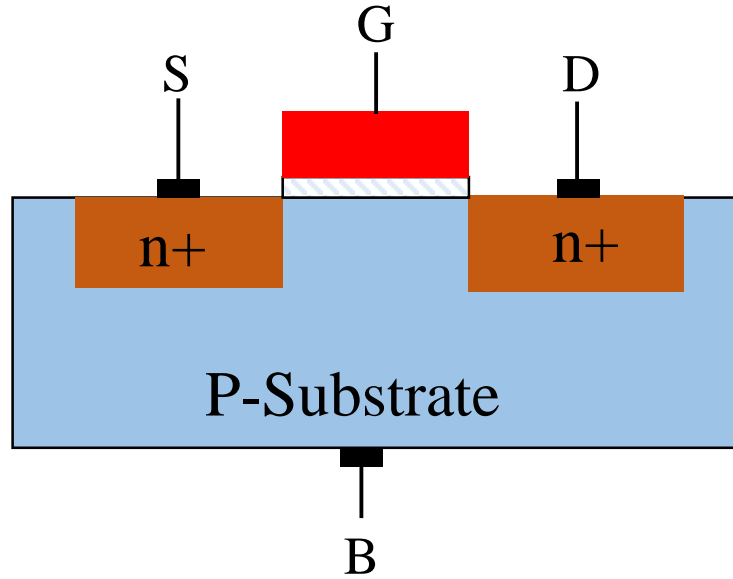
$$V_T = V_{T0} + \left\{ \sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f} \right\}$$

$$V_{T0} = \left\{ \frac{\sqrt{q\epsilon_{si}N_A\phi_t}}{C_{ox}} + \phi_t \right\}$$

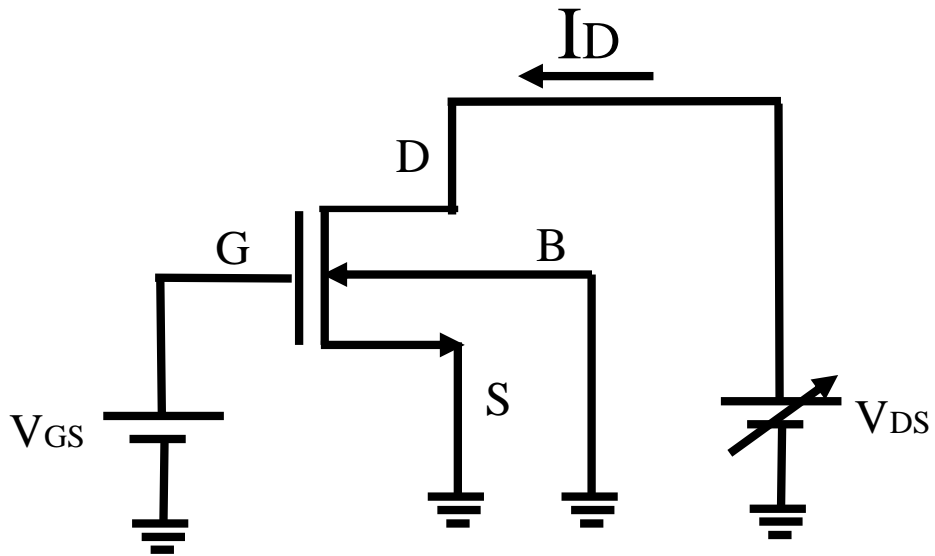
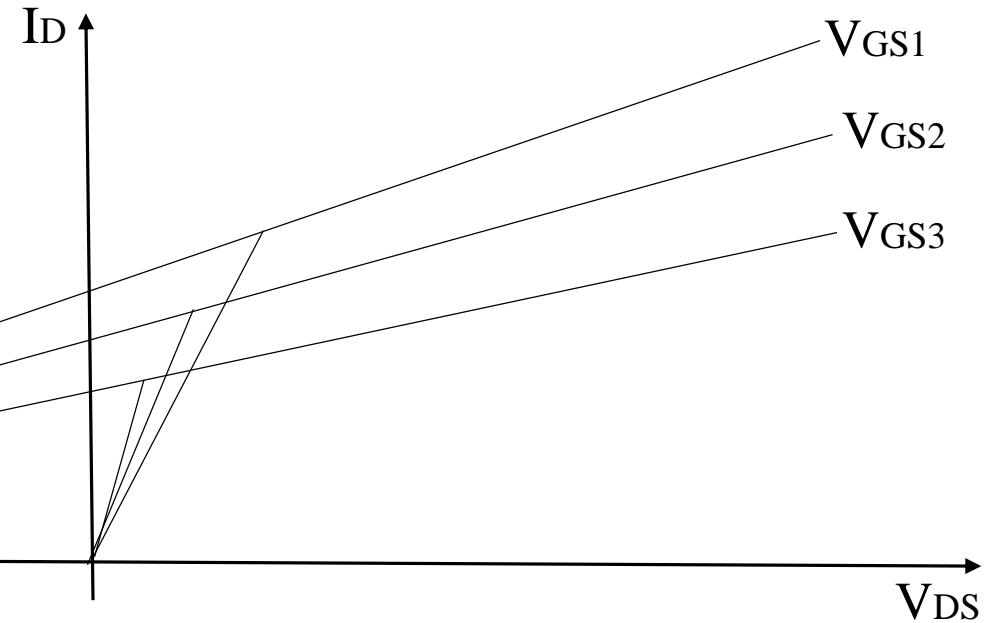
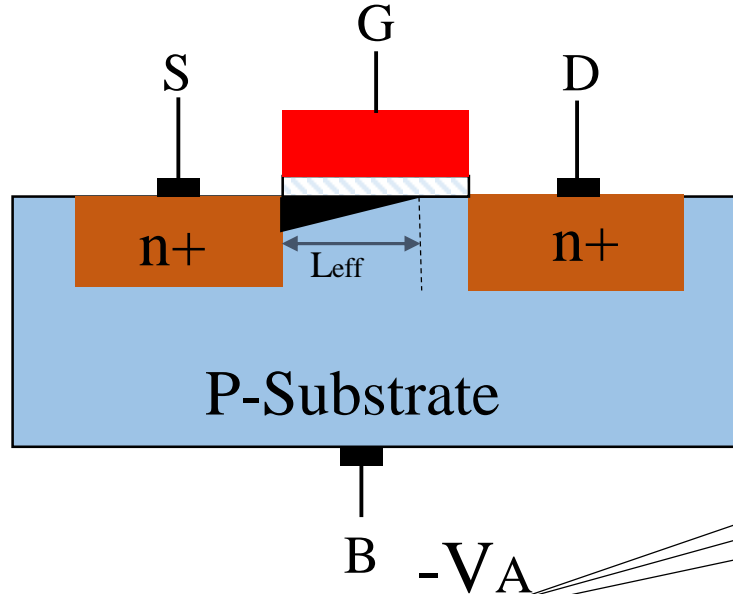
$$\phi_t = 2\phi_f$$

$$\phi_f = \frac{kT}{q} \ln \frac{N_A}{n_i}$$

ID-VDS Characteristics



ID-VDS Characteristics: Channel Length Modulation



$$I_{D-Sat.} = \mu_p C_{ox} \frac{W}{2L} \{ (V_{SG} - |V_T|)^2 (1 + \lambda V_{SD}) \}$$

V_A = Early voltage

λ = Channel length modulation parameter

$$\lambda = \frac{1}{V_A}$$

Thank You