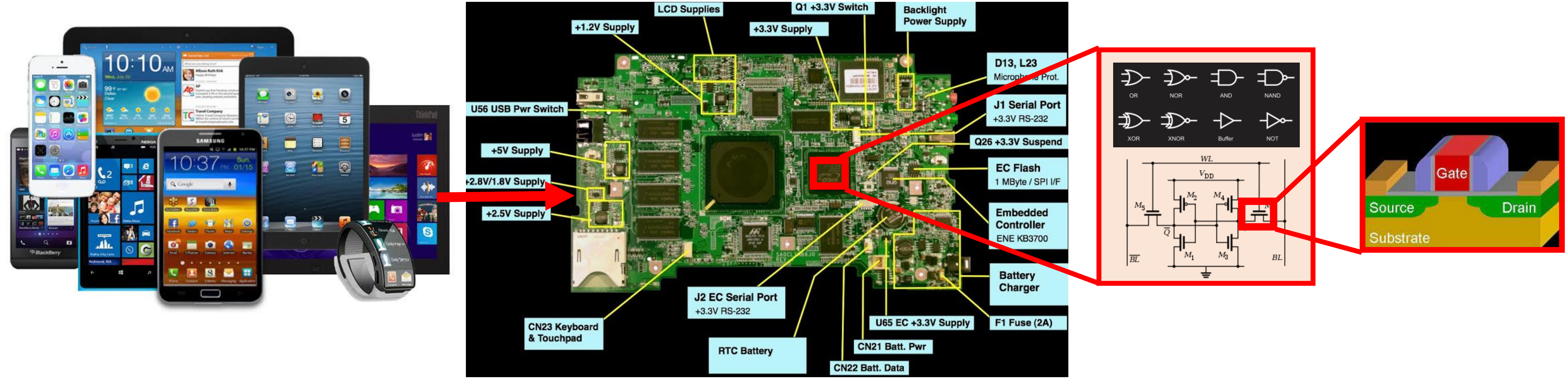


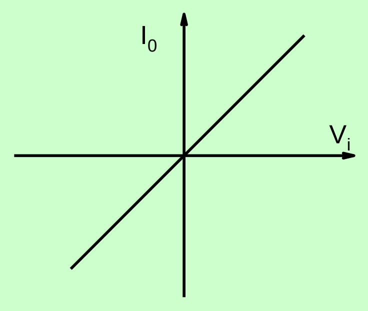
ESC201: Introduction to Electronics

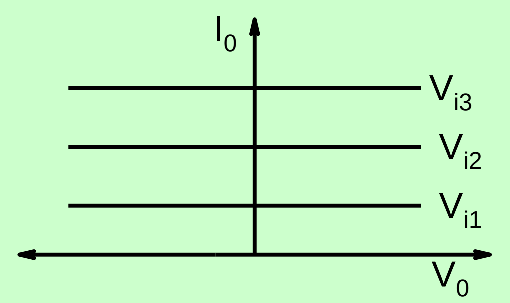
Module 5: Amplifiers

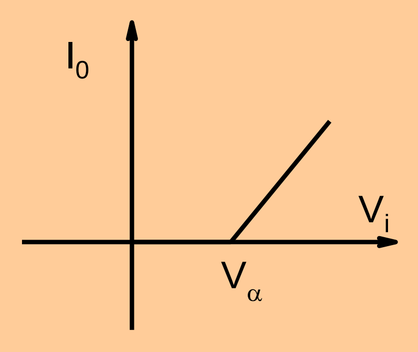
Dr. Shubham Sahay,
Assistant Professor,
Department of Electrical Engineering,
IIT Kanpur

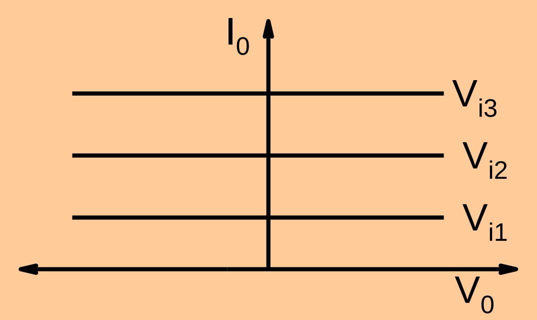
Why do Transistors Amplify Signals if Biased Properly

Ideal transistor

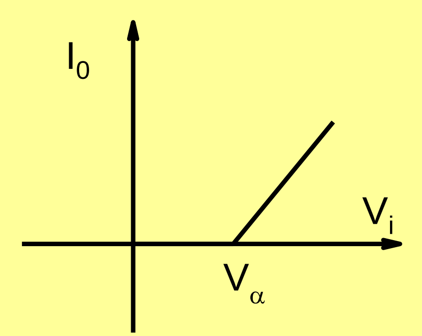


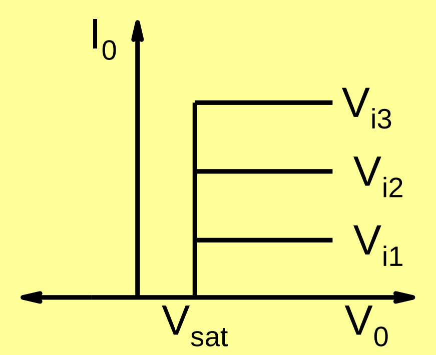




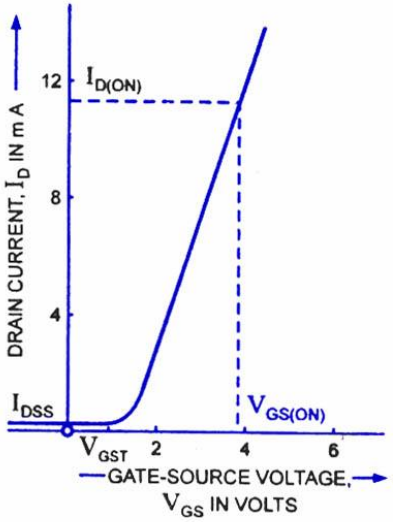


Device X

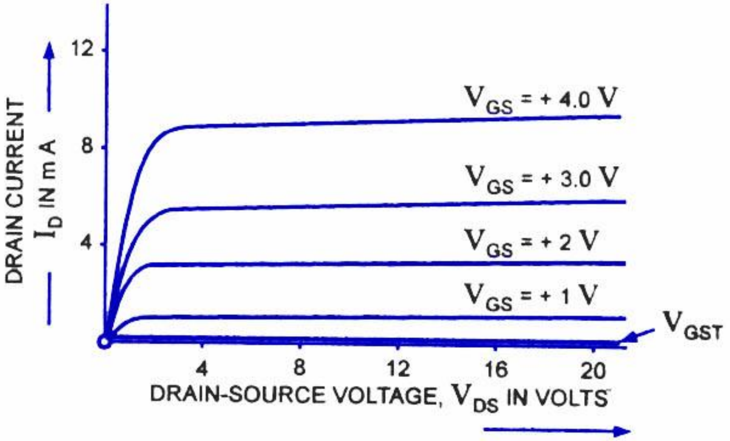




Device Y

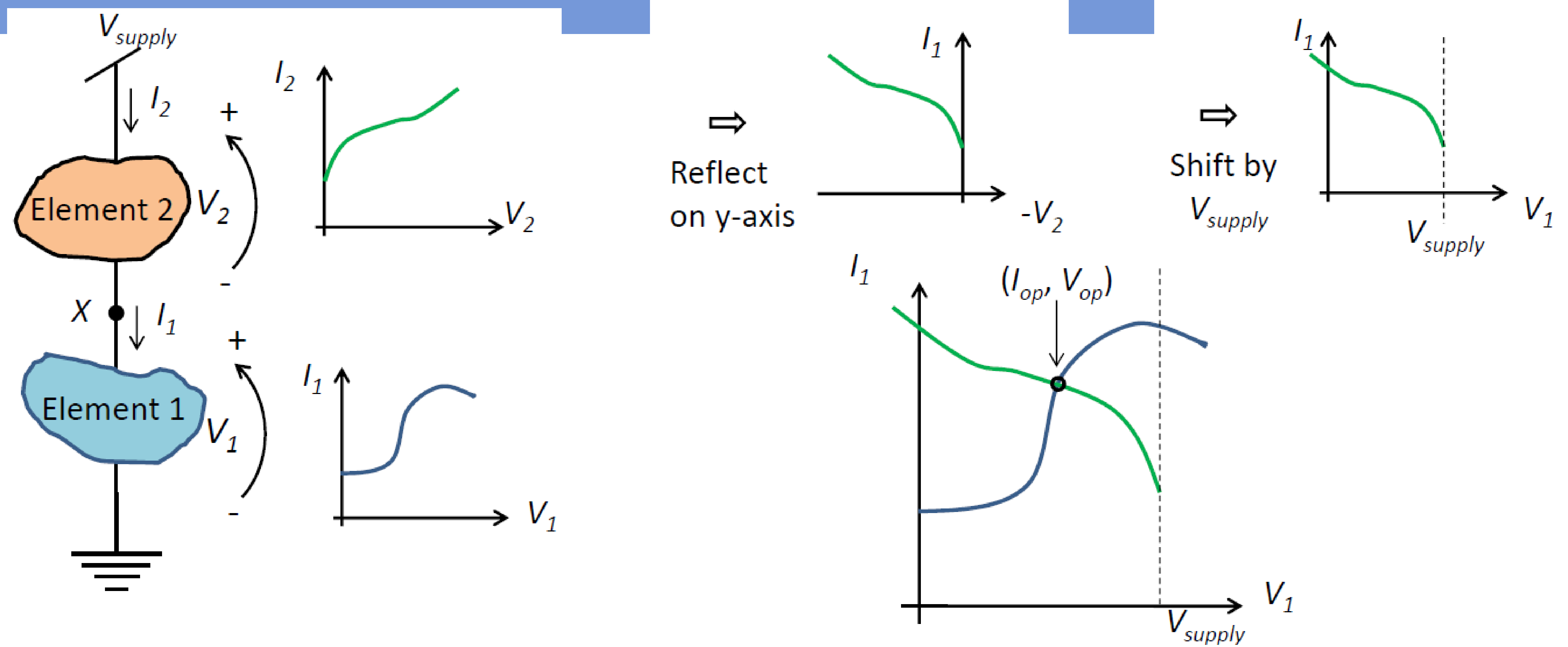


Transfer Characteristic



Drain Characteristics

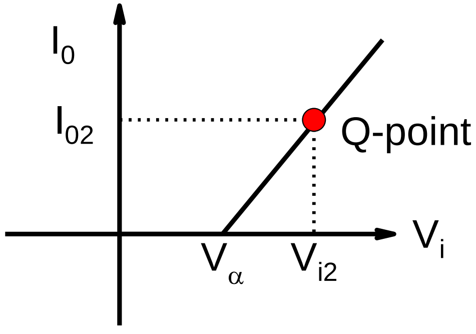
REVISITING LOAD LINE ANALYSIS



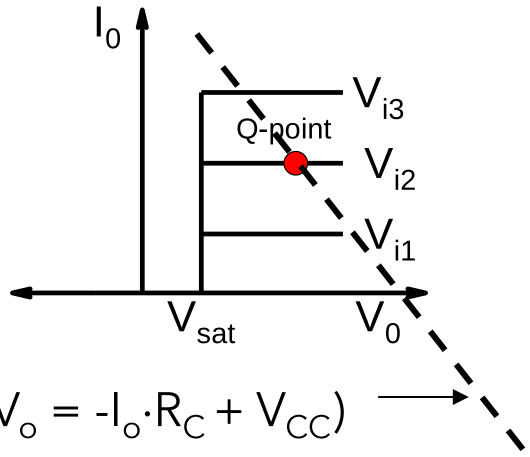
- $I_2 = I_1$ (no change in the direction); $V_2 = V_{supply} - V_1$ i.e. $V_1 = V_{supply} - V_2$
- Current in both Elements 1 & 2 is I_{op}.
- Voltage in node X is V_{op}.
- Voltage drop is V_{op} and (V_{supply} - V_{op}) in Elements 1 & 2, respectively.

Revised Amplifier Schematic for Device Y

Transfer Characteristics

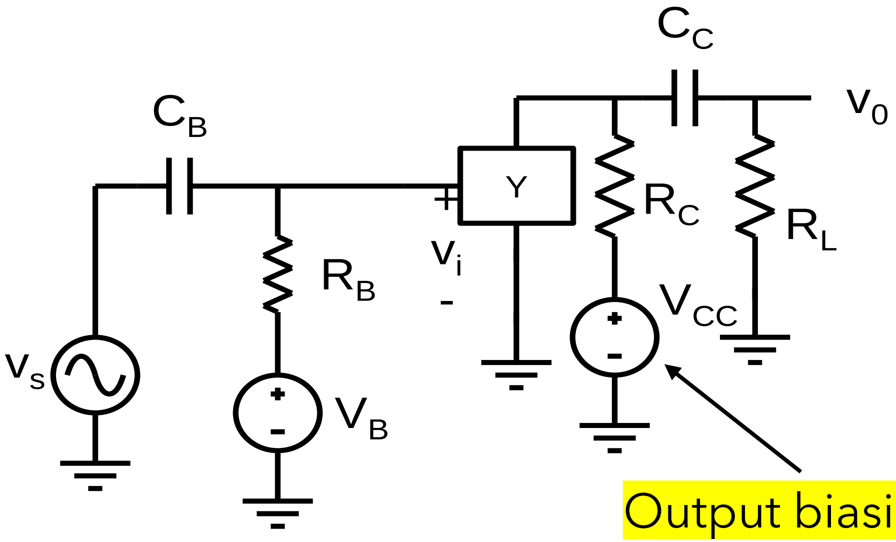


Output Characteristics



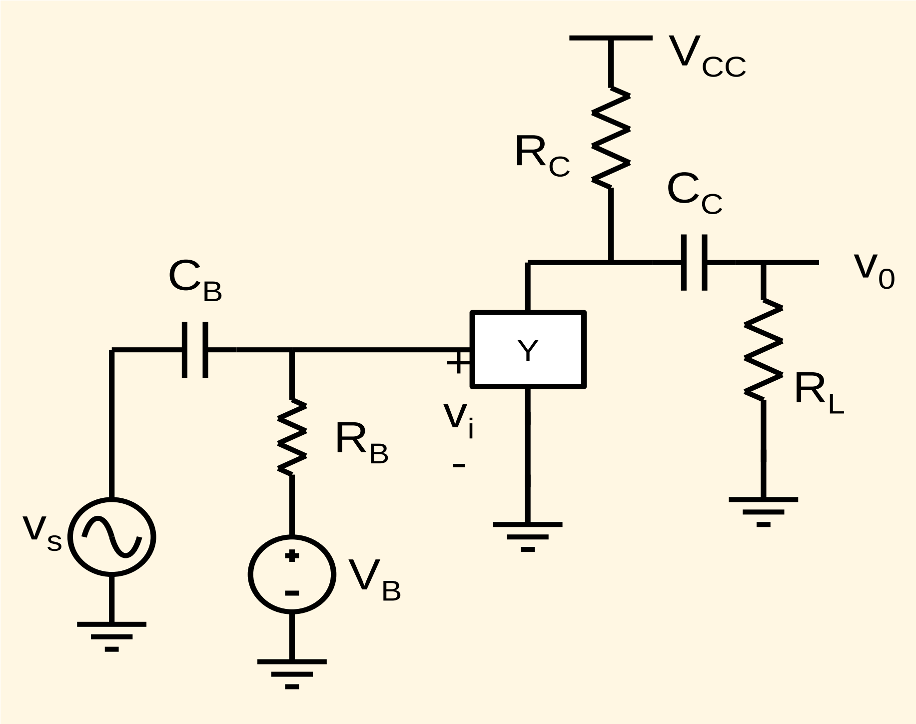
Load line ($V_o = -I_o \cdot R_C + V_{CC}$)

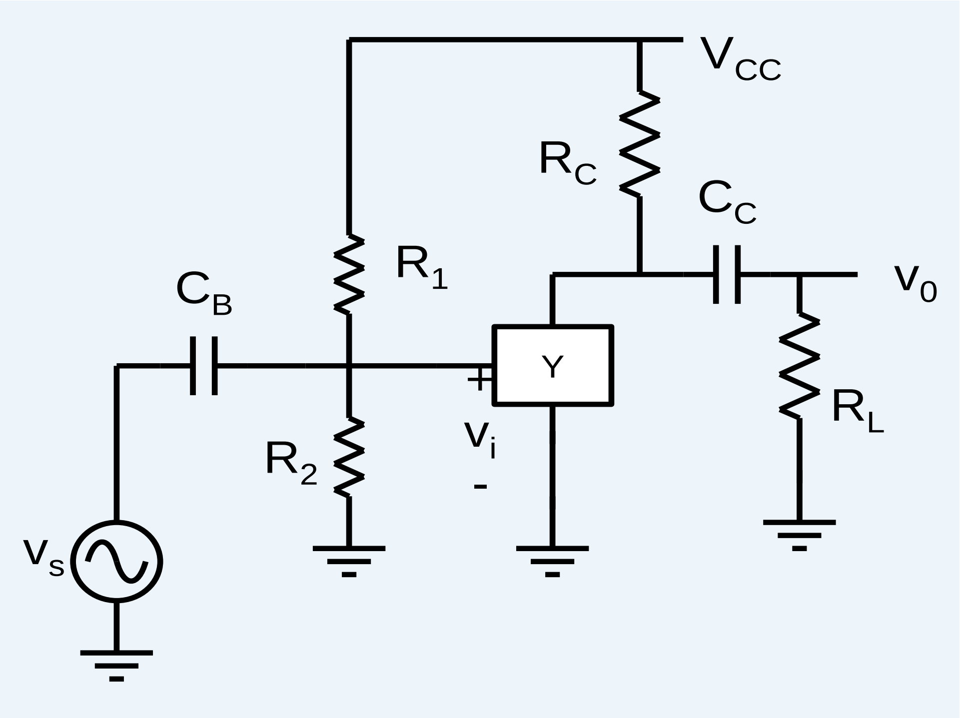
Usually V_{CC} is fixed
I_0 and R_C are varied



Output biasing is included

Do we really need two DC power supplies?



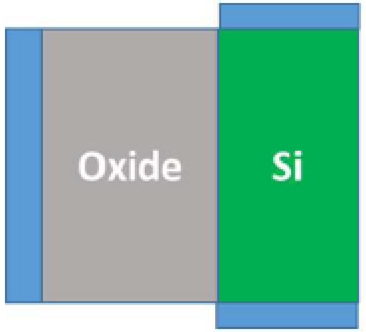


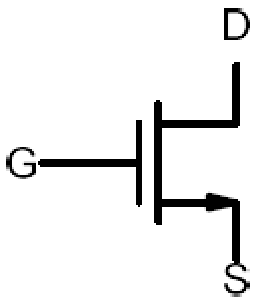
$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2}$$

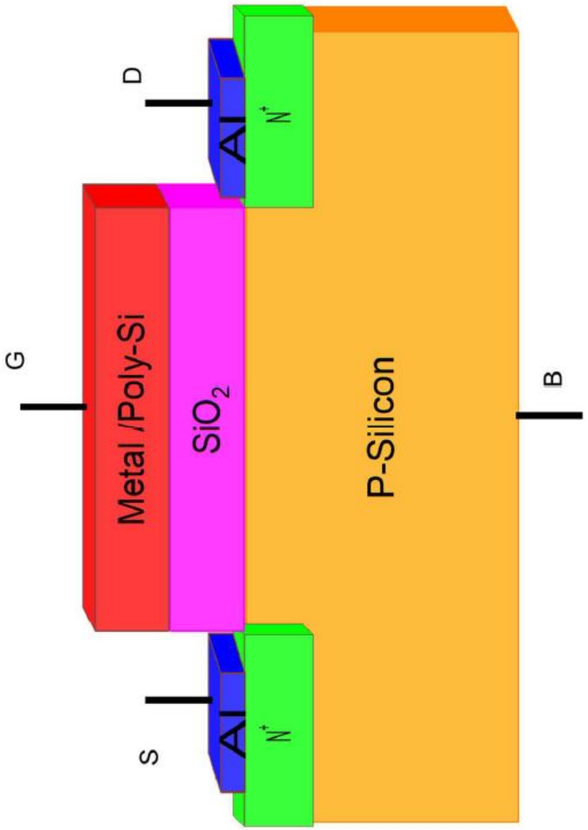
Remember: input of Y is open circuit

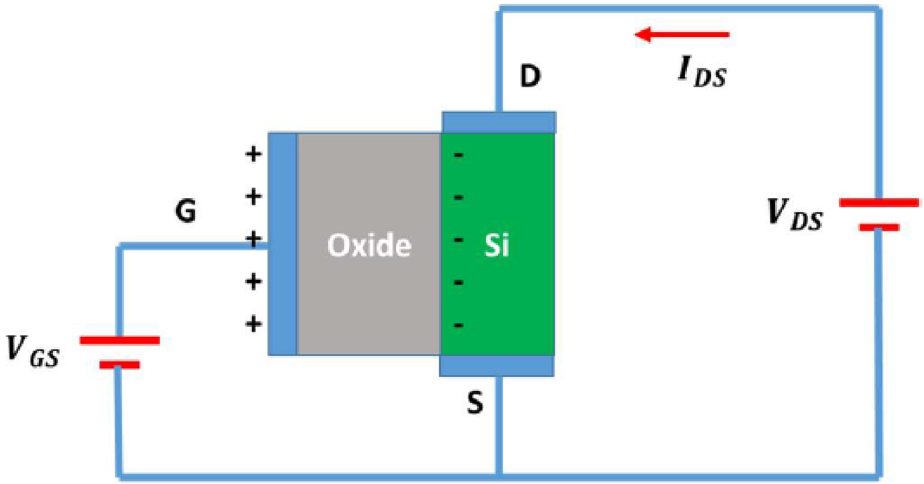
MOSFETs: Workhorse of Semiconductor Industry

MOSFET : Metal Oxide Semiconductor Field effect Transistor

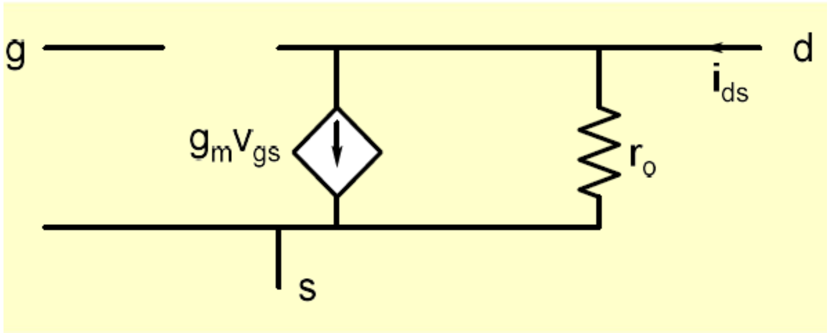






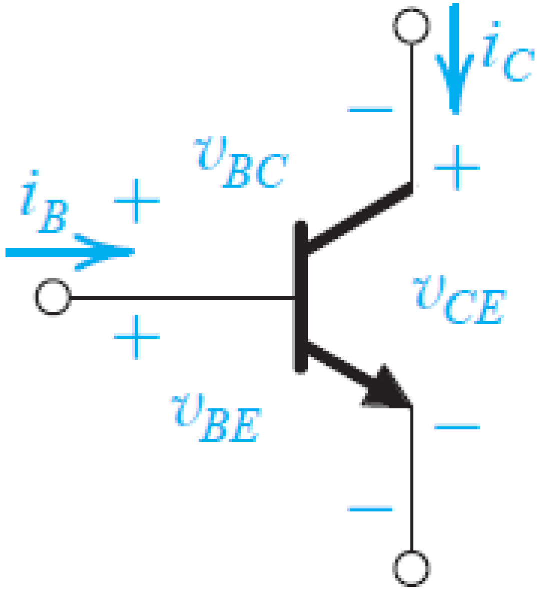


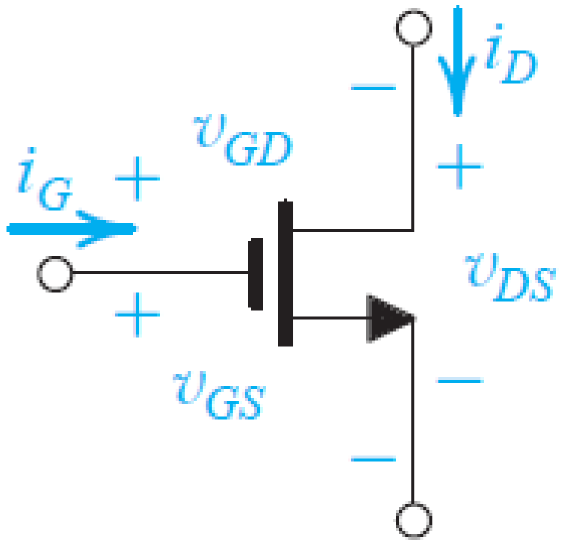
Drain current is controlled by gate voltage



Voltage controlled current source

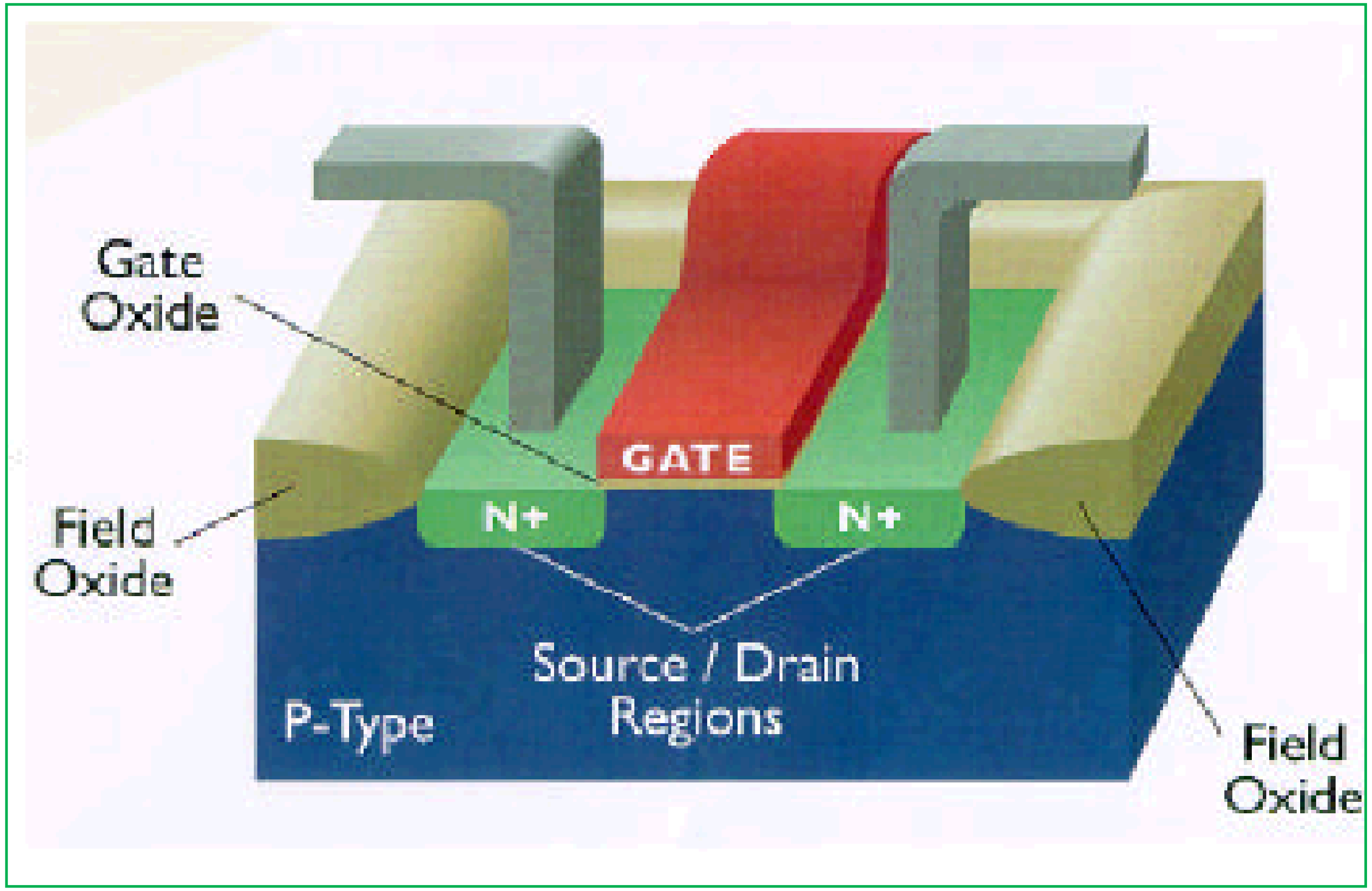
BJT vs. MOSFET

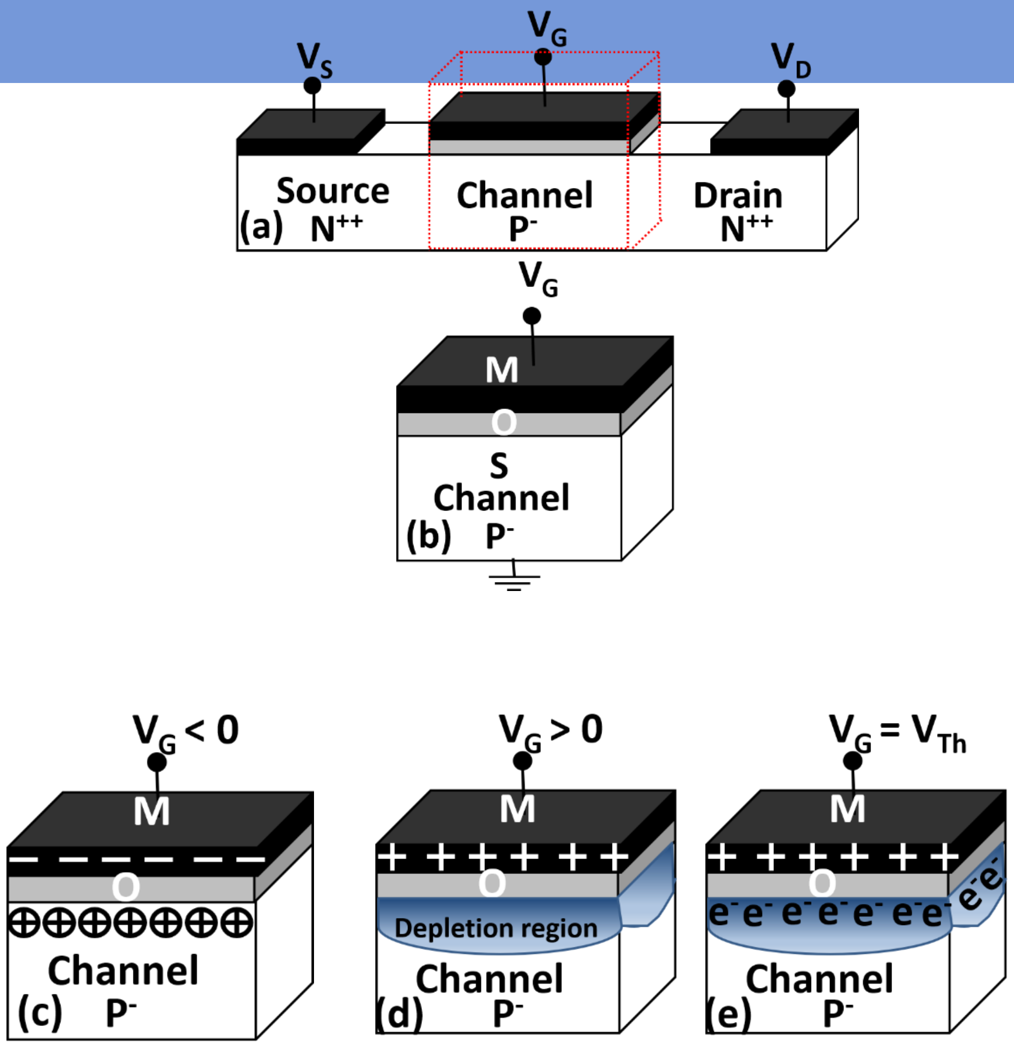




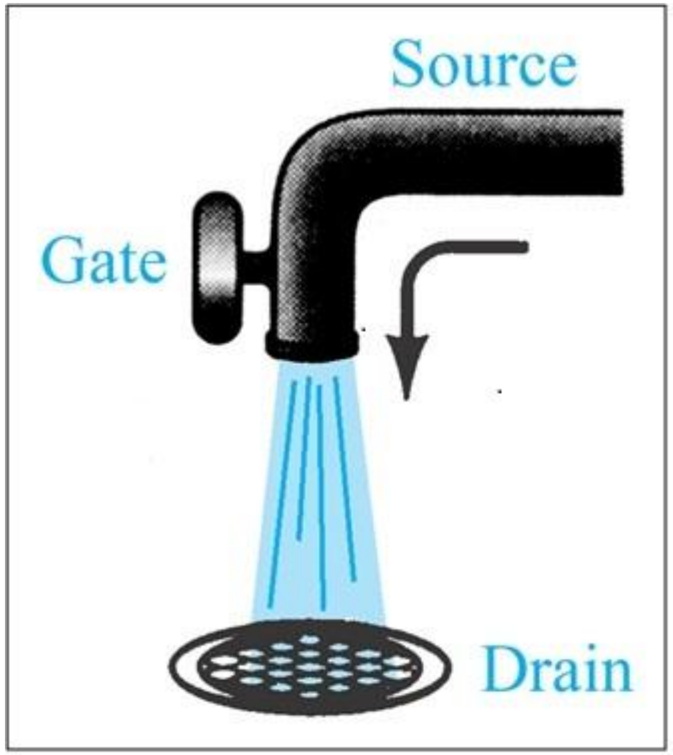
High gain	Low gain
Small caps	Large caps
Static power	Dynamic power

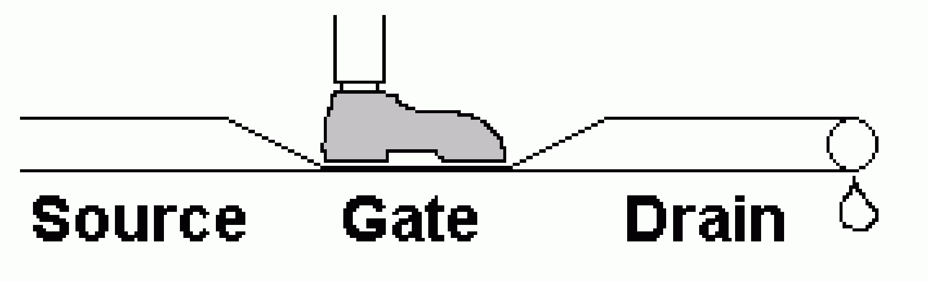
The MOSFET


Gate
Oxide
GATE
N+
N+
Field
Oxide
Source / Drain
Regions
P-Type
Field
Oxide

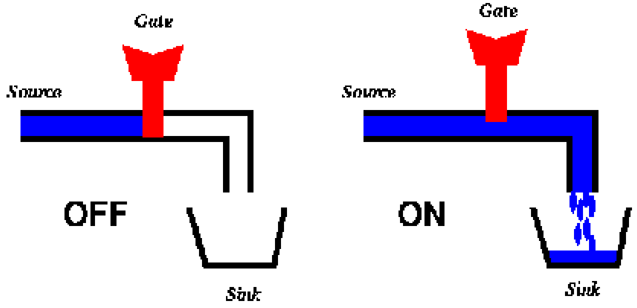

V_S
V_G
V_D
Source
N++
Channel
P-
Drain
N++
(a)
V_G
M
O
S
Channel
(b) P-
V_G < 0
M
O
Channel
(c) P-
V_G > 0
M
O
Depletion region
Channel
(d) P-
V_G = V_Th
M
O
Channel
(e) P-

Water Analogy – V_G control



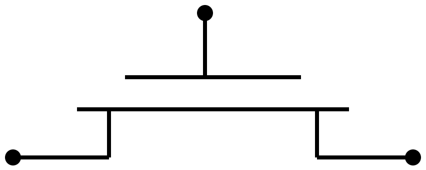


Switch Model of NMOS Transistor



| V_{GS} |

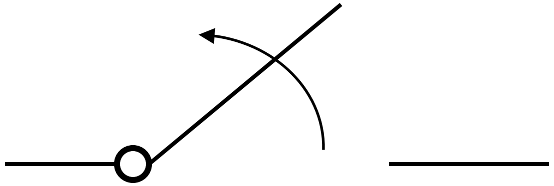
Gate



Source
(of carriers)

Drain
(of carriers)

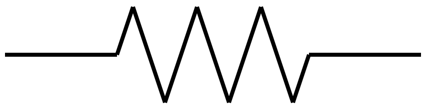
Open (off) (Gate = ‘0’)



| V_{GS} | < | V_T |

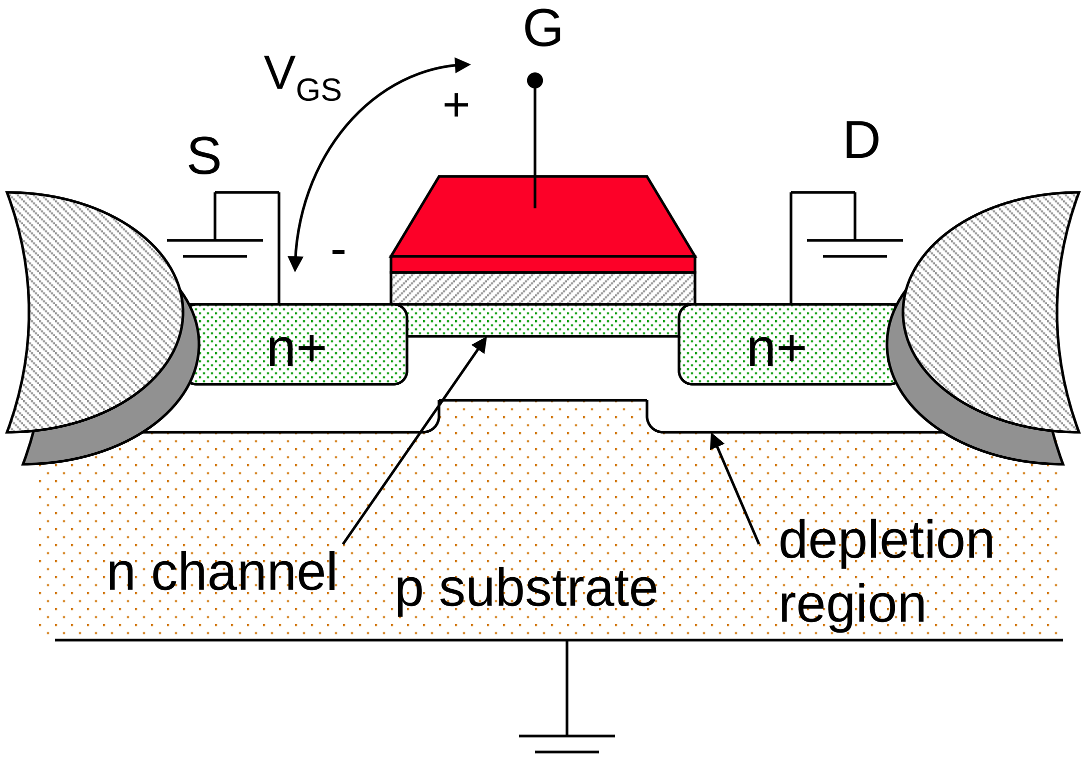
Closed (on) (Gate = ‘1’)

R_{on}



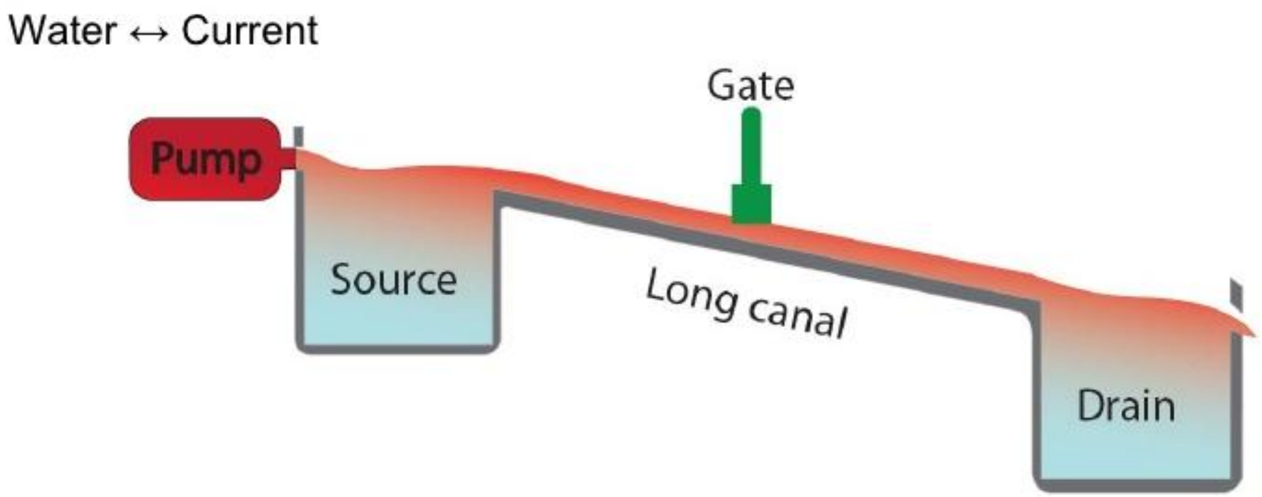
| V_{GS} | > | V_T |

Threshold Voltage Concept



- Conductivity of the channel is modulated by the gate voltage
  - Larger the voltage difference between gate and source, the smaller the resistance of the conducting channel and the larger the current
- The value of V_{GS} where strong inversion occurs is called the threshold voltage, V_T

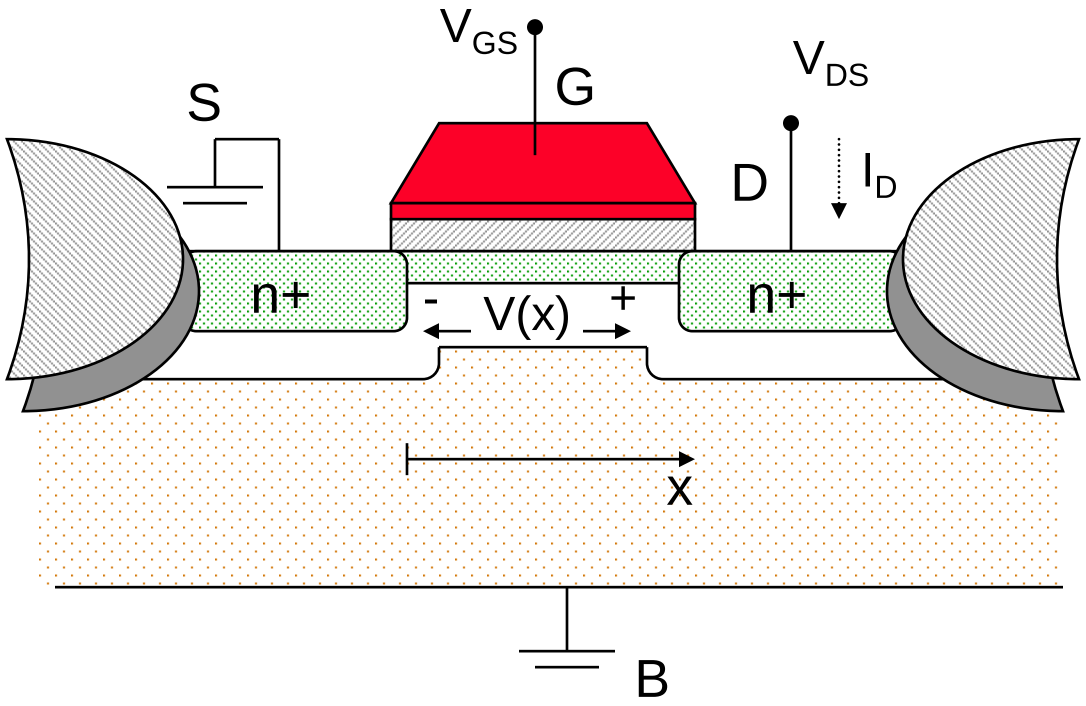
Water Analogy – Effect of V_G and V_{DS}



- When a wall present between source/drain reservoirs is pulled up: water flows (ON)
- Good control over leakage through or over the wall and well set open/closed state.

Transistor in Linear Mode

Assuming $V_{GS} > V_T$



The current is a linear function of both V_{GS} and V_{DS}

Voltage-Current Relation: Linear Mode

For long channel devices

- When $V_{DS} \leq V_{GS} - V_T$

$$\boxed{I_D = k_n^{`} \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{{V_{DS}}^2}{2}\right]}$$

where

$k'_n = \mu_n C_{ox} = \mu_n \varepsilon_{ox}/t_{ox}$ = is the process transconductance parameter (μ_n is the carrier mobility (m^2/Vsec))

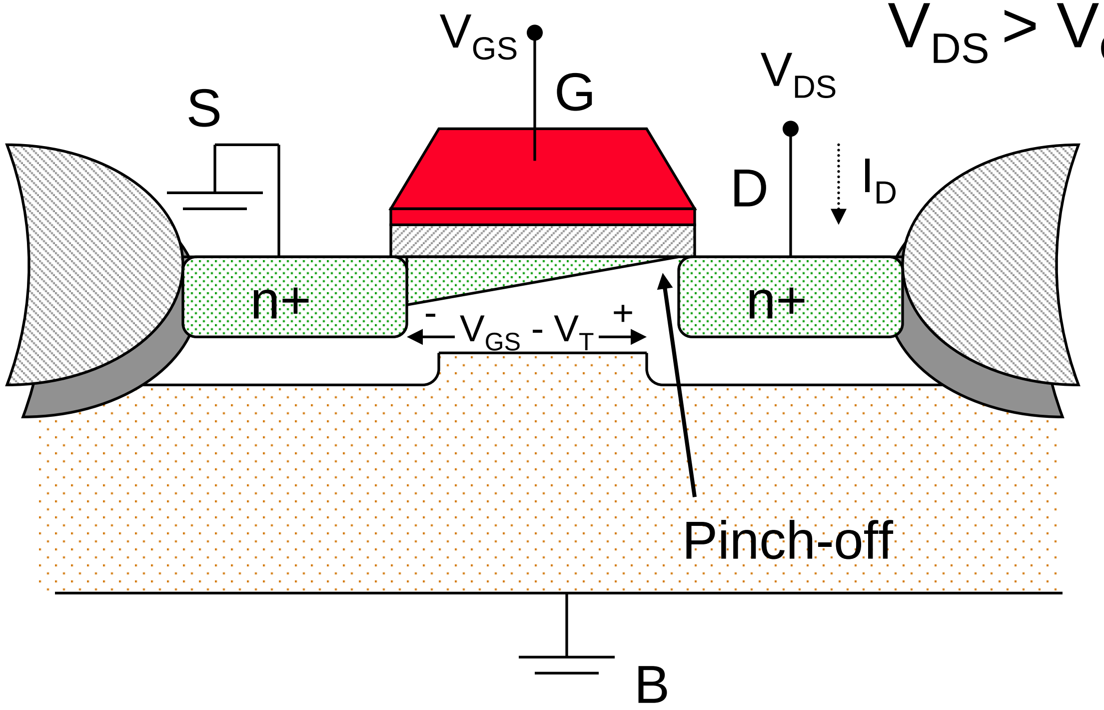
$k_n = k'_n$ W/L is the gain factor of the device

For small V_{DS}, there is a linear dependence between V_{DS} and I_D, hence the name resistive or linear region

Transistor in Saturation Mode

Assuming $V_{GS} > V_T$

$V_{DS} > V_{GS} - V_T$



The current remains constant (saturates).

Voltage-Current Relation: Saturation Mode

For long channel devices

- When $V_{DS} \geq V_{GS} - V_T$

$$\boxed{I_D = k_n^{`} \frac{W}{L}\left[\frac{(V_{GS} - V_T)^2}{2}\right]}$$

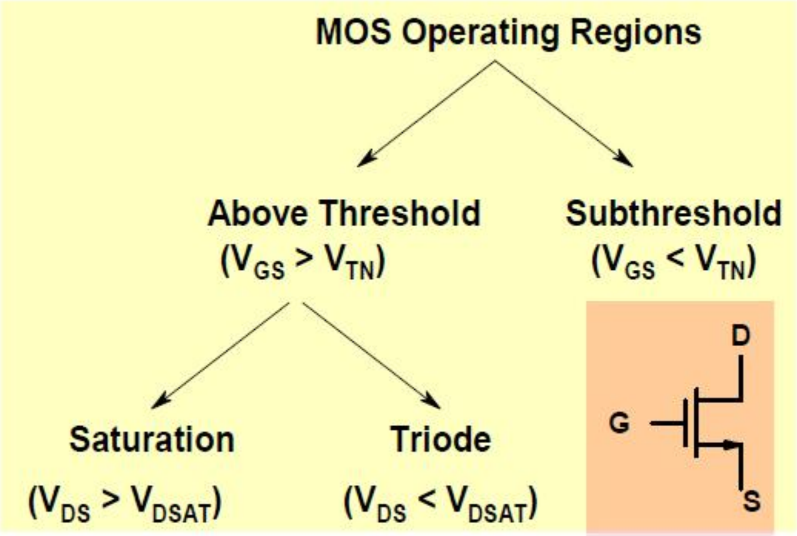
  Voltage difference over the induced channel (from the pinch-off point to the source) remains fixed at $V_{GS} - V_T$

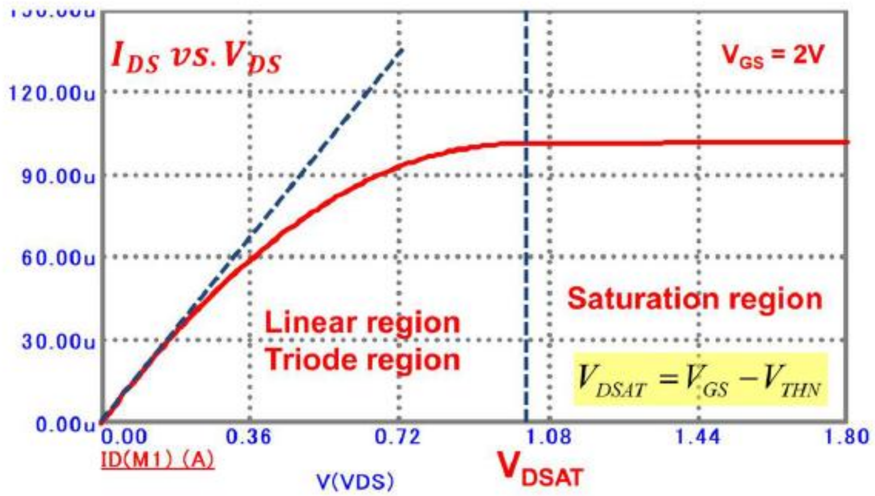
- However, the effective length of the conductive channel is modulated by the applied V_{DS}, so

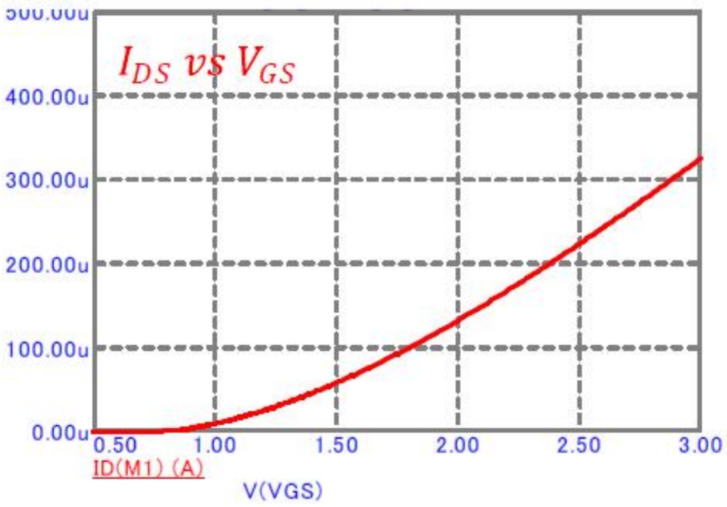
$$I_D = I_D' (1 + \lambda V_{DS})$$

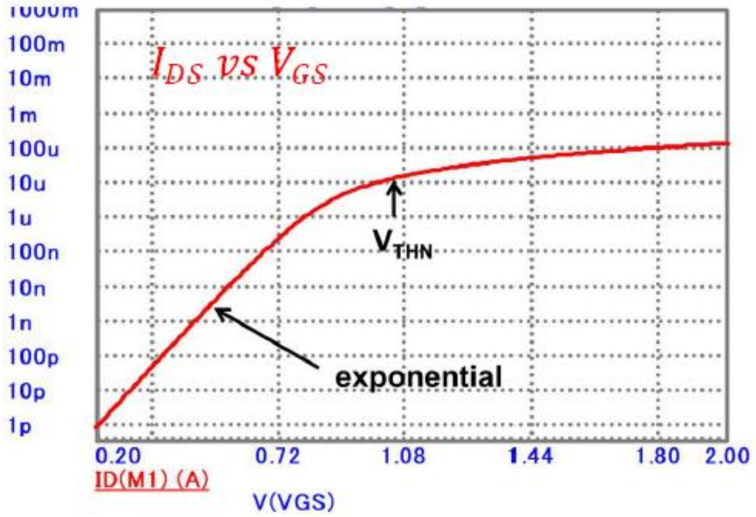
where λ is the channel-length modulation (varies with the inverse of the channel length)

Factors Determining Current

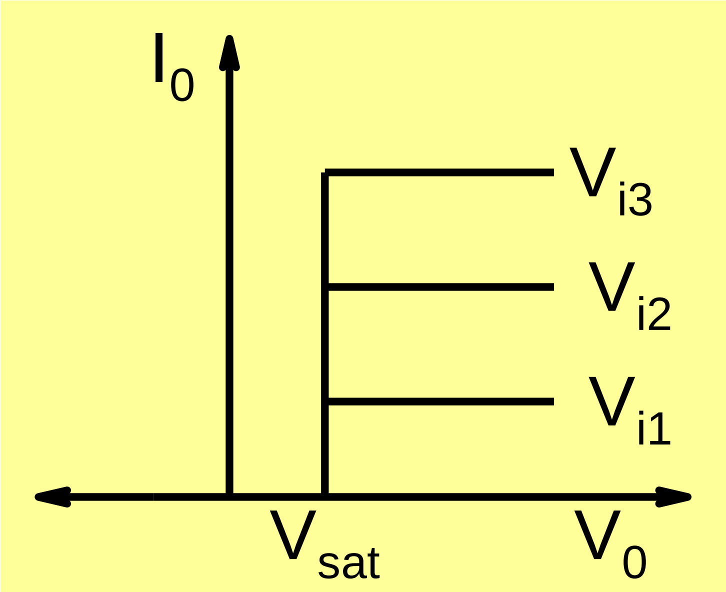


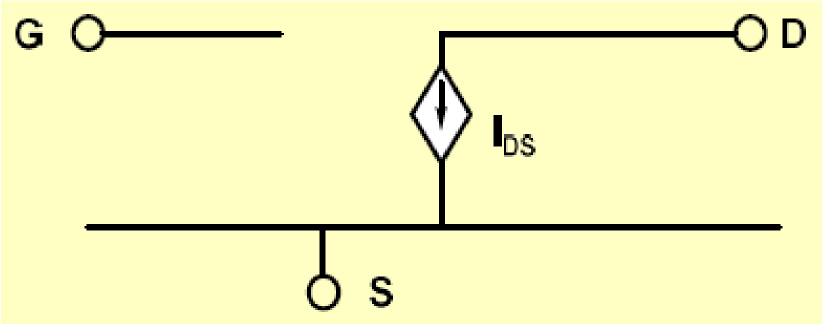






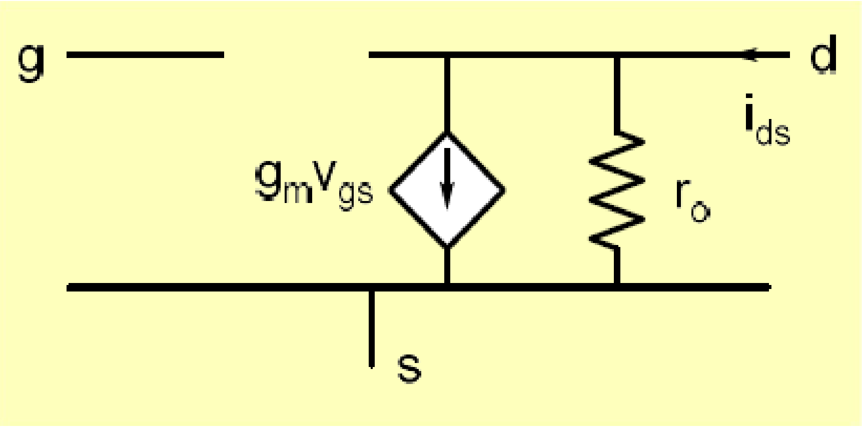
DC and AC model of a MOSFET





$$I_{DS} = \frac{\beta_N}{2}(V_{GS} - V_{THN})^2 \;\; ; \; \beta_N = KP_N \times \frac{W}{L}$$

$$kP_N\text{: } Transconductance\ parameter\ \frac{\mu A}{V^2}$$



$$g_m = \frac{2I_{DSQ}}{V_{GSQ} - V_{THN}} = \sqrt{2I_{DSQ}\beta}$$

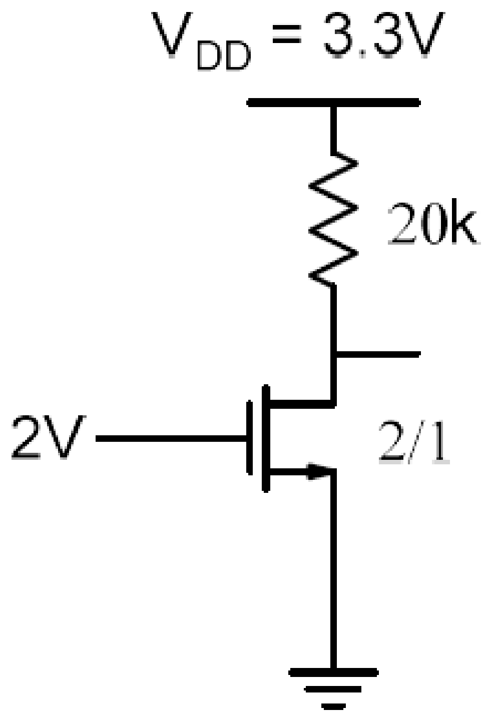
$$r_o = \frac{1}{\lambda_n I_{DSQ}}$$

λ_N *is the channel length modulation parameter*

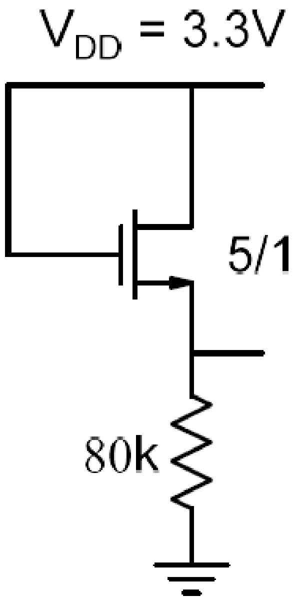
Example 1

$KP_N = 100\mu A/V^2; V_{THN} = 1V; \lambda_n = 0.01V^{-1}$

Determine I_{DS} and V_{DS}



Example 2



$$KP_N = 100\mu A/V^2; V_{THN} = 1V; \lambda_n = 0.01V^{-1}$$

Determine I_{DS} and V_{DS}

$$V_{DS} = V_{GS}$$
$$\Rightarrow V_{DS} > V_{GS} - V_{THN} = V_{DSAT} \Rightarrow \text{Saturation}$$

$$I_{DS} = KP_N \times \frac{W}{L} \times \frac{(V_{GS} - V_{THN})^2}{2}; V_{GS} = 3.3 - I_{DS} \times 80 \times 10^3$$
$$\Rightarrow I_{DS} = 2.48 \times 10^{-5} A; V_{GS} = 1.315V$$

For the other solution VGS = 0.653V which is not possible since it is less than V_{THN}