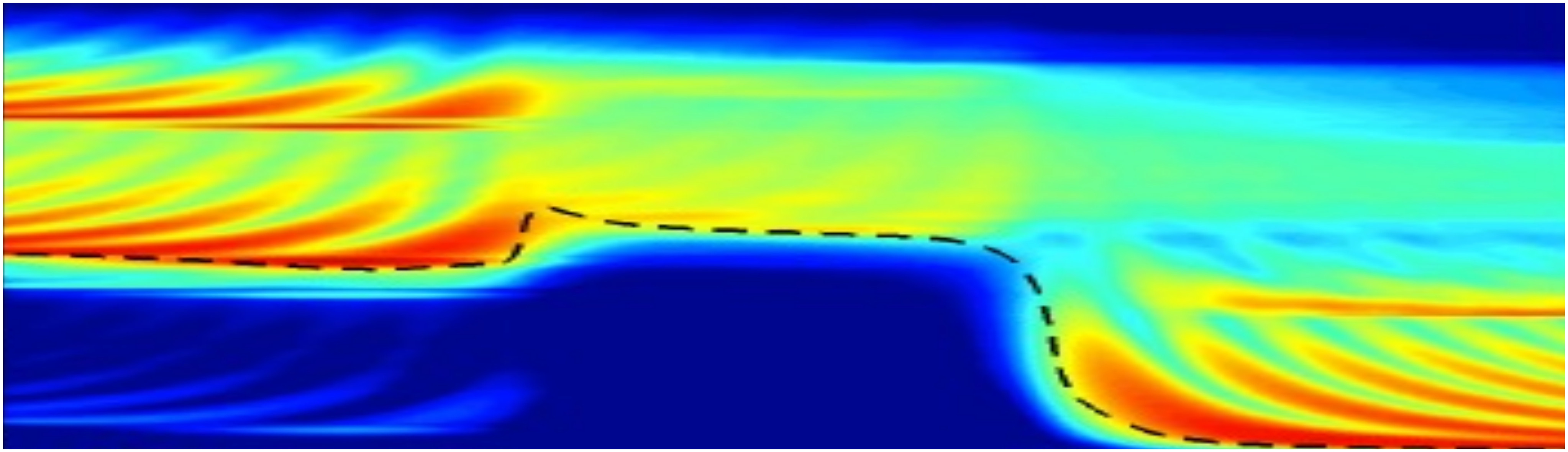

EECS 16B
Designing Information Devices and Systems II
Lecture 10

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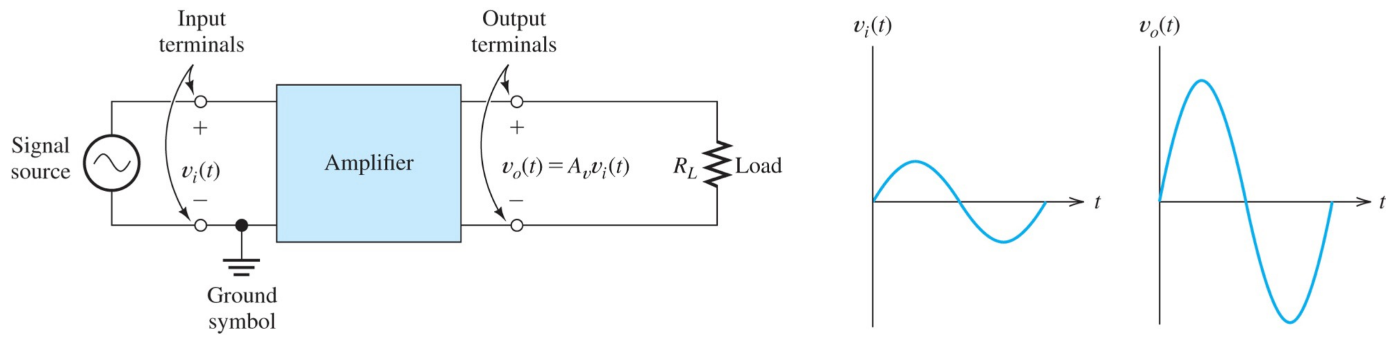
Devices

- Outline
  - Amplifiers and Devices
  - Vector Differential Equations

- Reading-slides

Recap: Active Devices

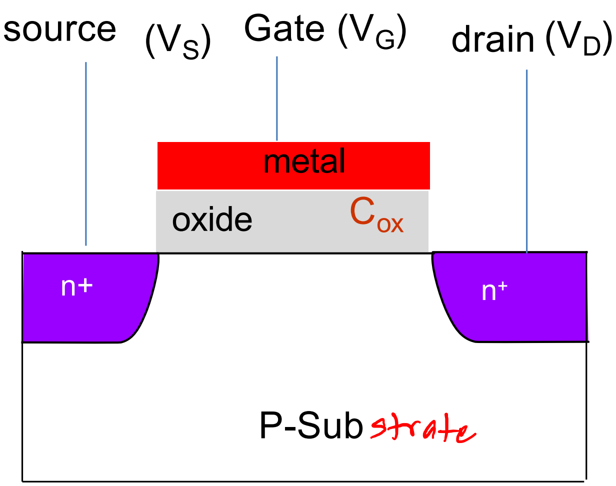


- Active devices are made of semiconductors
- Semi-conductors are materials whose resistance is in between a metal and insulator

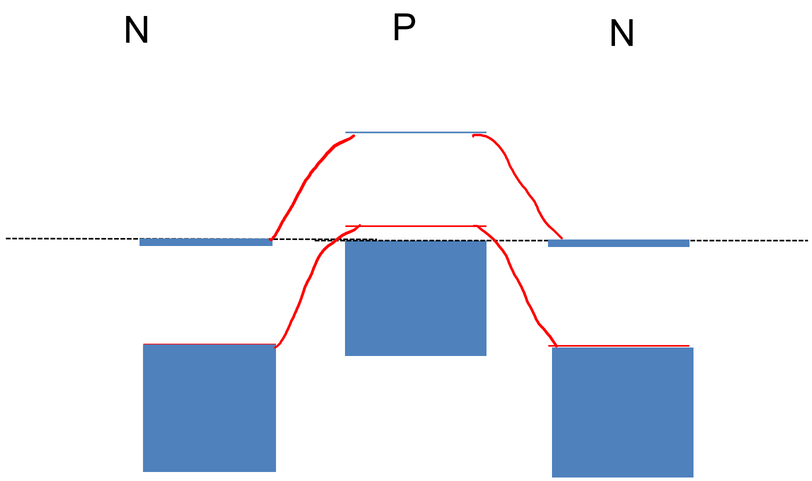
Half

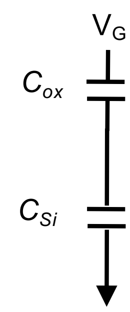
- More interestingly, one is able to change the resistance of the semiconductor materials by using external control such as voltage or current

Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET)



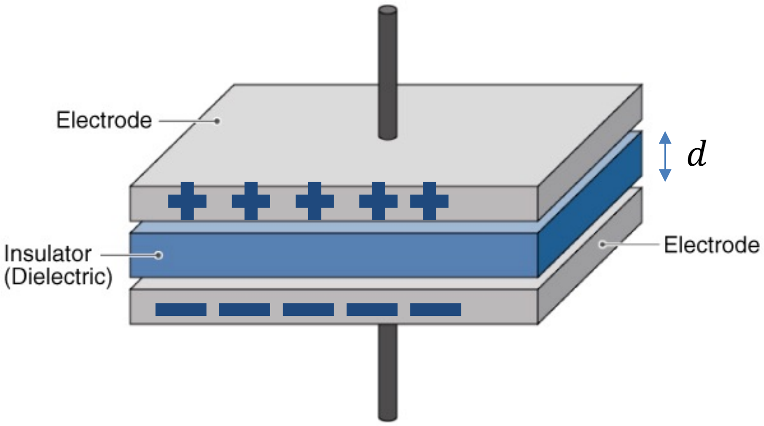
- + or – in the name of n or p type material indicates extent of doping. N+ means doped **heavily** to n type.
- In common MOSFET source and drain voltages are interchangeable

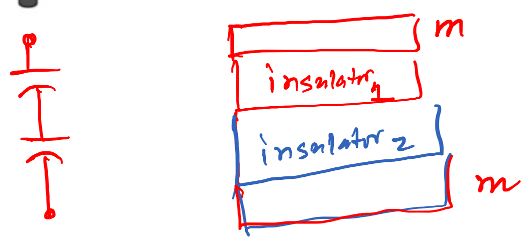


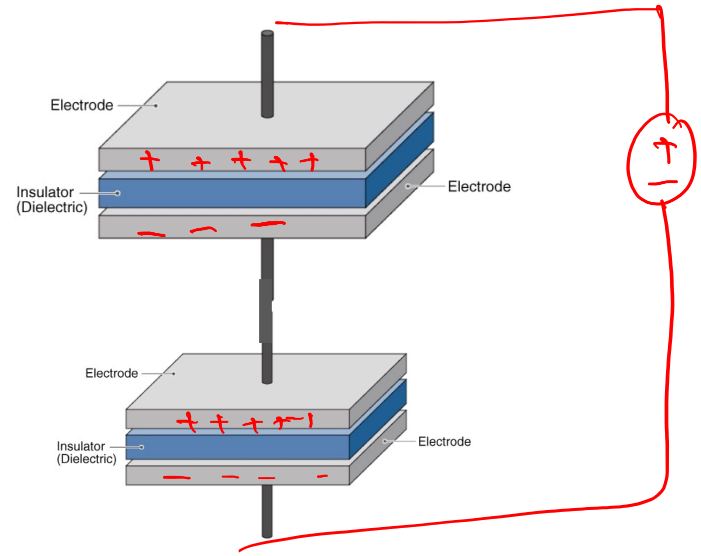


P-type semiconductor in the middle with little to no electrons on the conduction band acts like an insulator

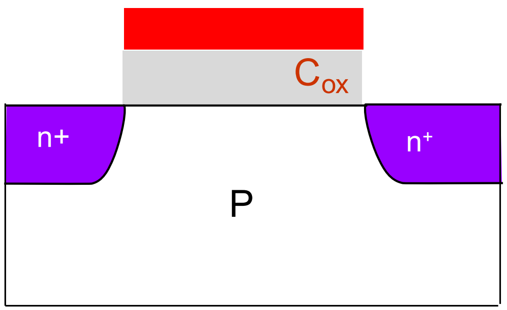
Recap: Capacitors (Review)

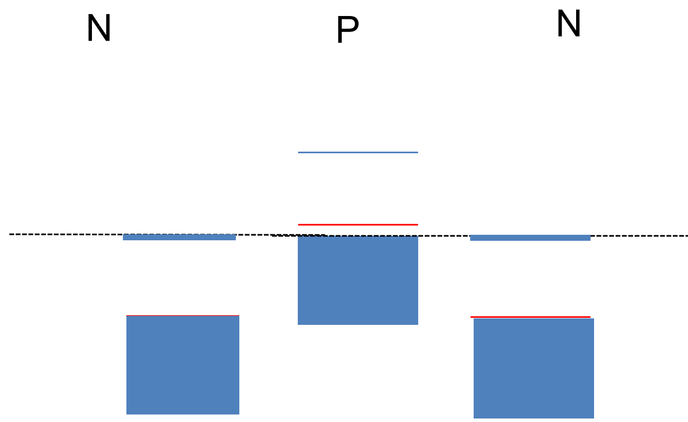


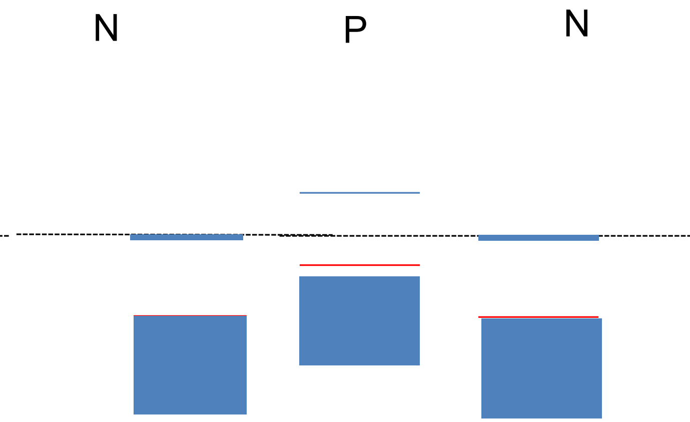


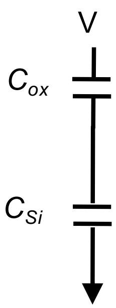


MOSFET

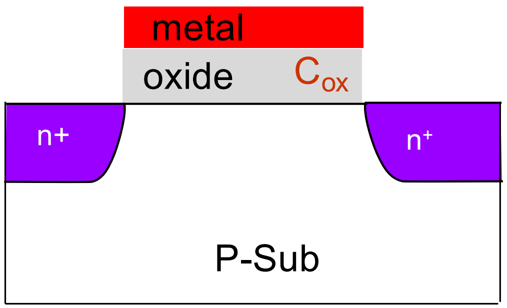


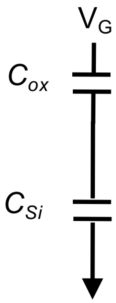


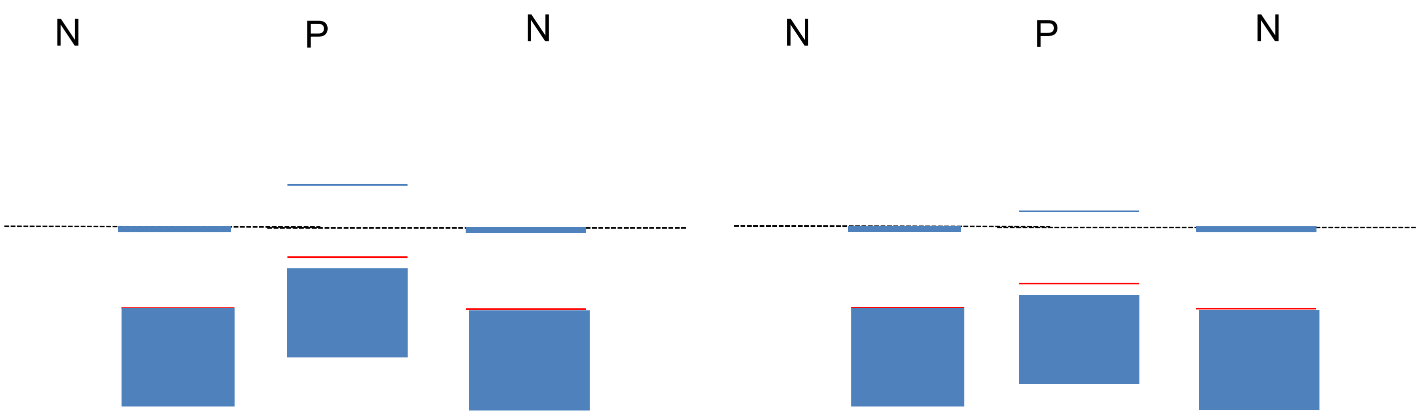




MOSFET

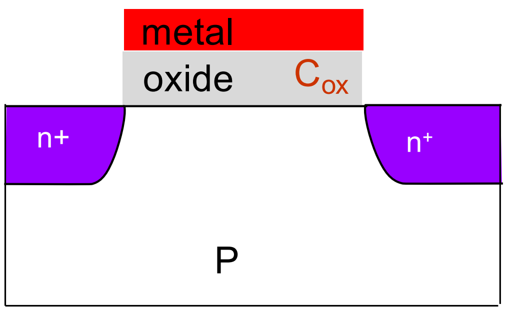


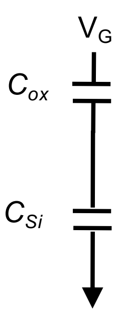


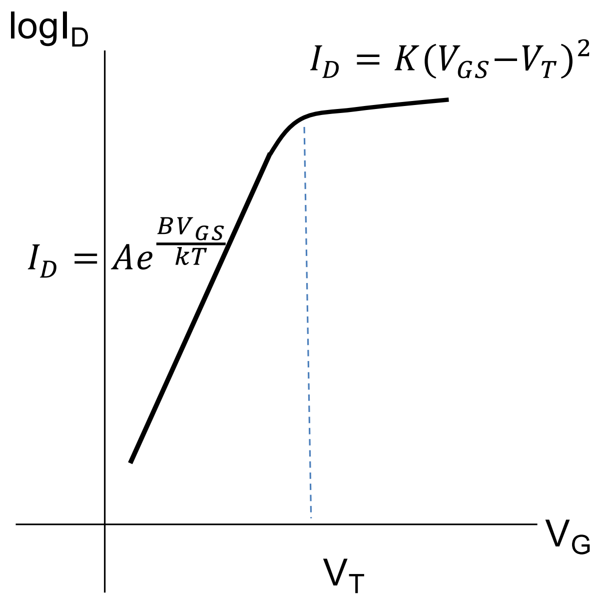


At large gate voltages, one reaches close to maximum charge density achievable in Si. So rate of change in increase in electron density with gate voltage slows down

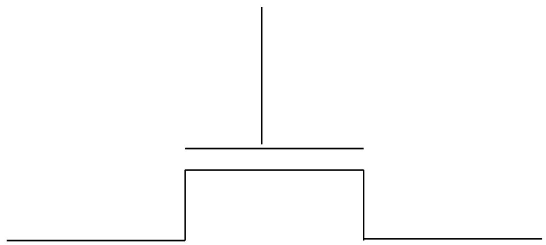
MOSFETs

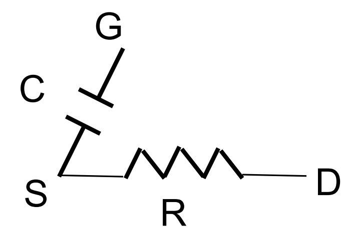






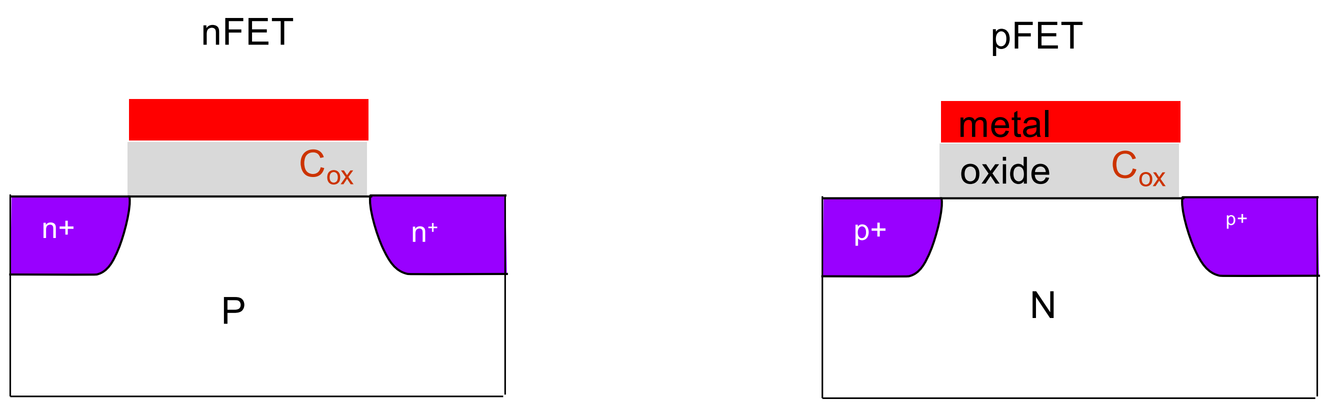
Assuming large V_{DS} is present



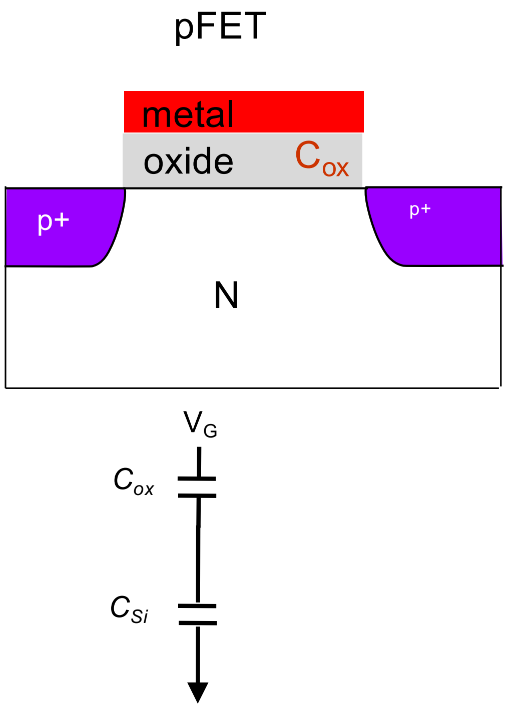


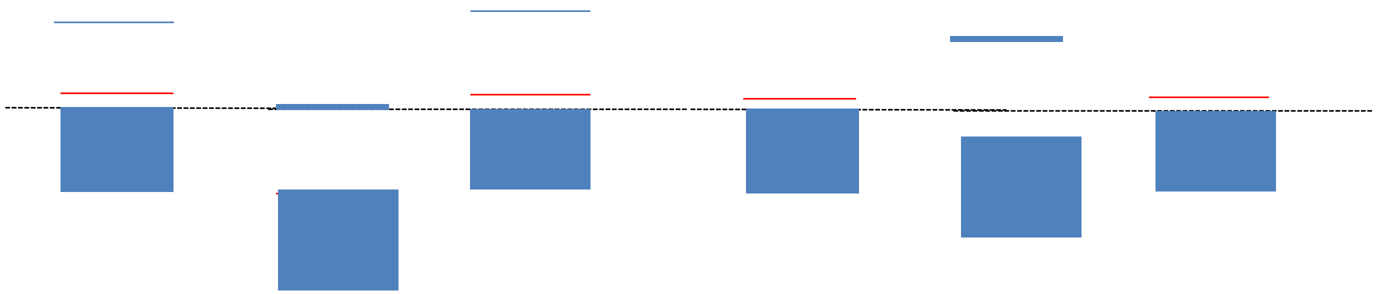
- C is the series combination of Cox and Csi
- $R = I_{DS}/V_{DS}$

nFET vs pFET

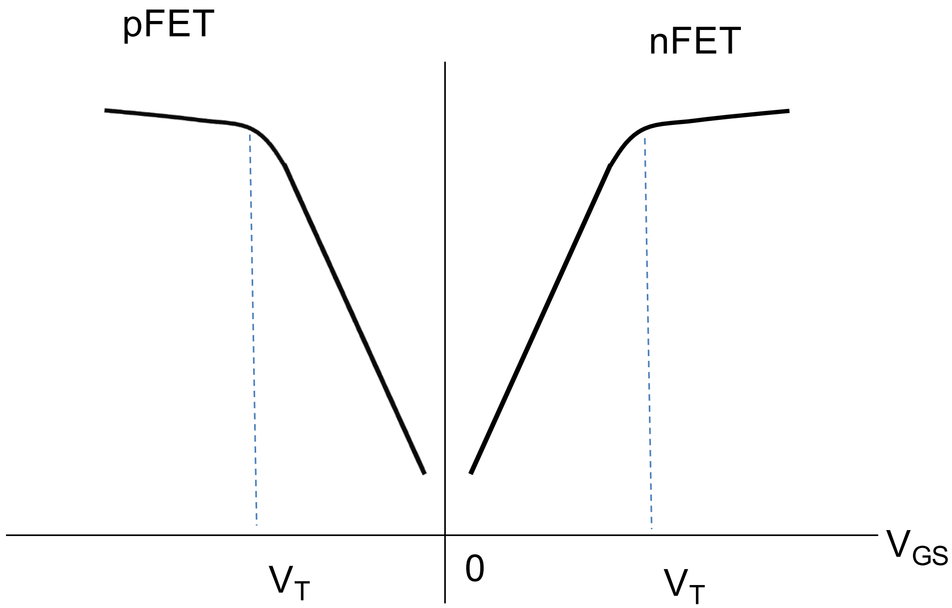


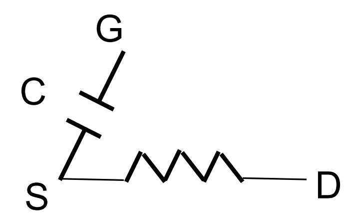
nFET vs pFET





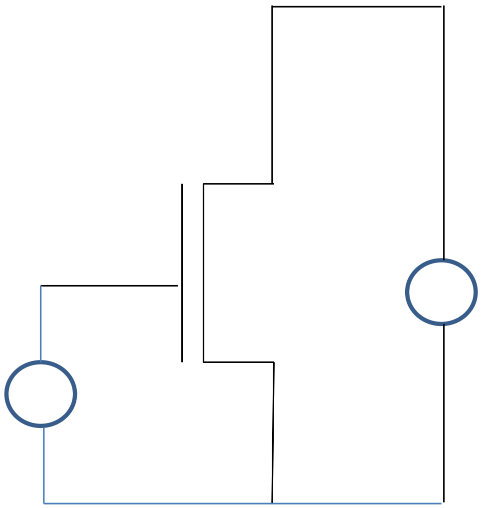
nFET vs pFET





- nFET, V_{GS} and V_T are positive
- pFET, V_{GS} and V_T are negative

FET as an analog amplifier



When $V_{GS}<V_T$

$$I_D = Ae^{\frac{BV_{GS}}{kT}}$$

Small change in V_{GS} changes I_D exponentially

When V_{GS}>VT

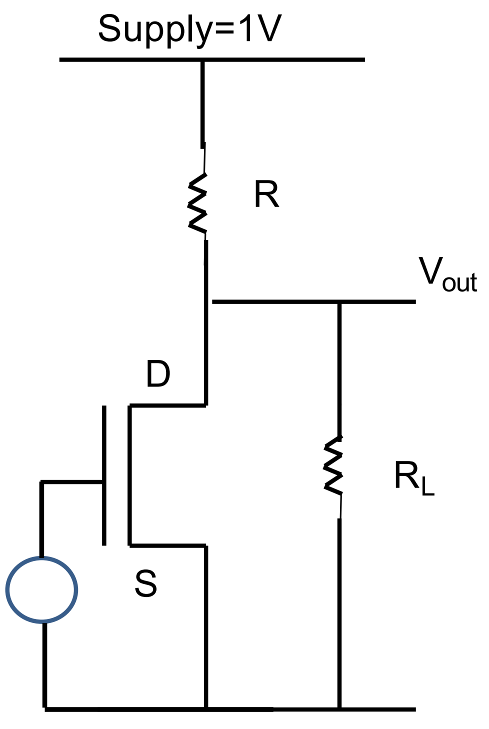
$$I_D = K(V_{GS}-V_T)^2$$

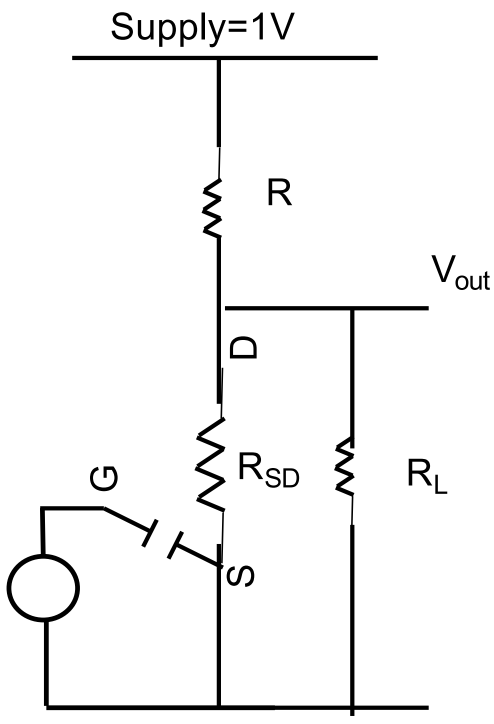
Small change in V_{GS} changes I_D quadratically

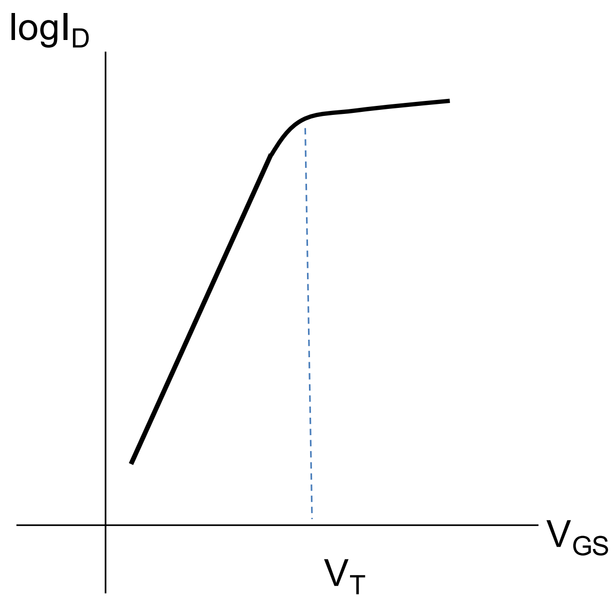
Overall, Large changes in the Drain current can be achieved by changing Gate Voltage

The parameter that is used to quantify the amplification is called **Transconductance** $g_m = \frac{dI_D}{dV_{GS}}$

FET in digital logic



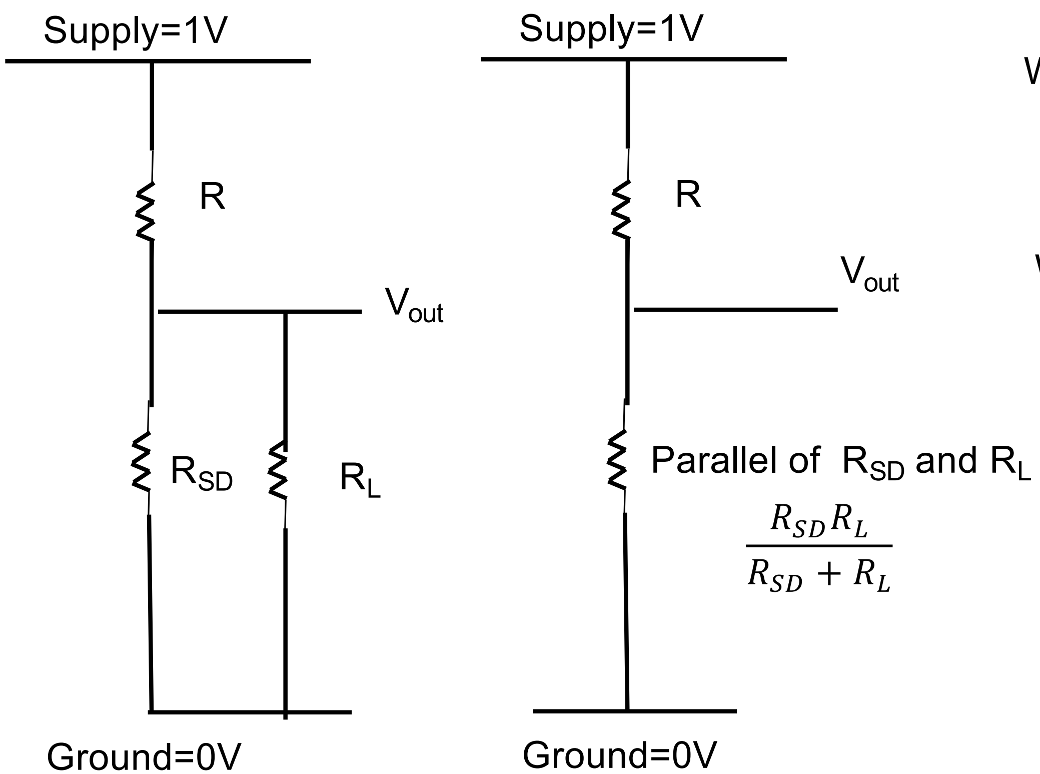




When V_{GS} is High, R_{SD} is low

When V_{GS} is Low, R_{SD} is High

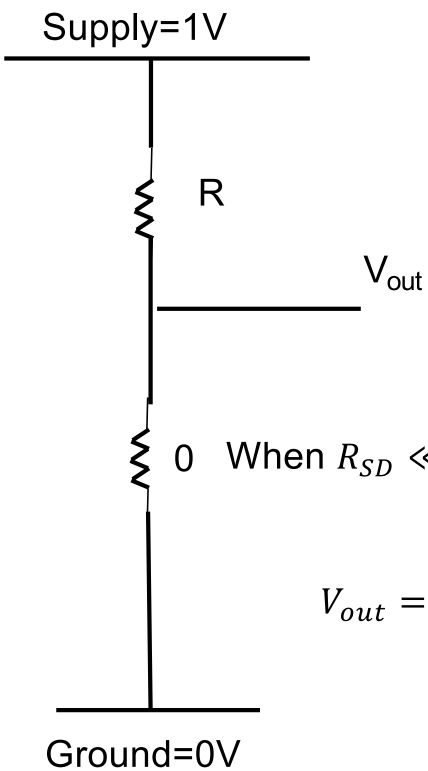
FET in digital logic



When $R_{SD} \ll R_L$; $\frac{R_{SD}R_L}{R_{SD}+R_L} \approx \frac{R_{SD}}{R_L} \approx 0$

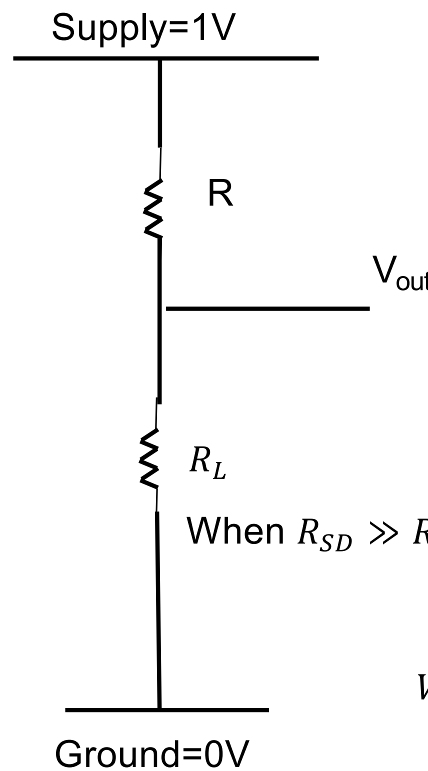
When $R_{SD} \gg R_L$; $\frac{R_{SD}R_L}{R_{SD}+R_L} \approx R_L$

FET in digital logic



When $R_{SD} \ll R_L$ $i.e., V_{GS}$ $is\ high$

$$V_{out} = \frac{0}{R+0} = 0$$

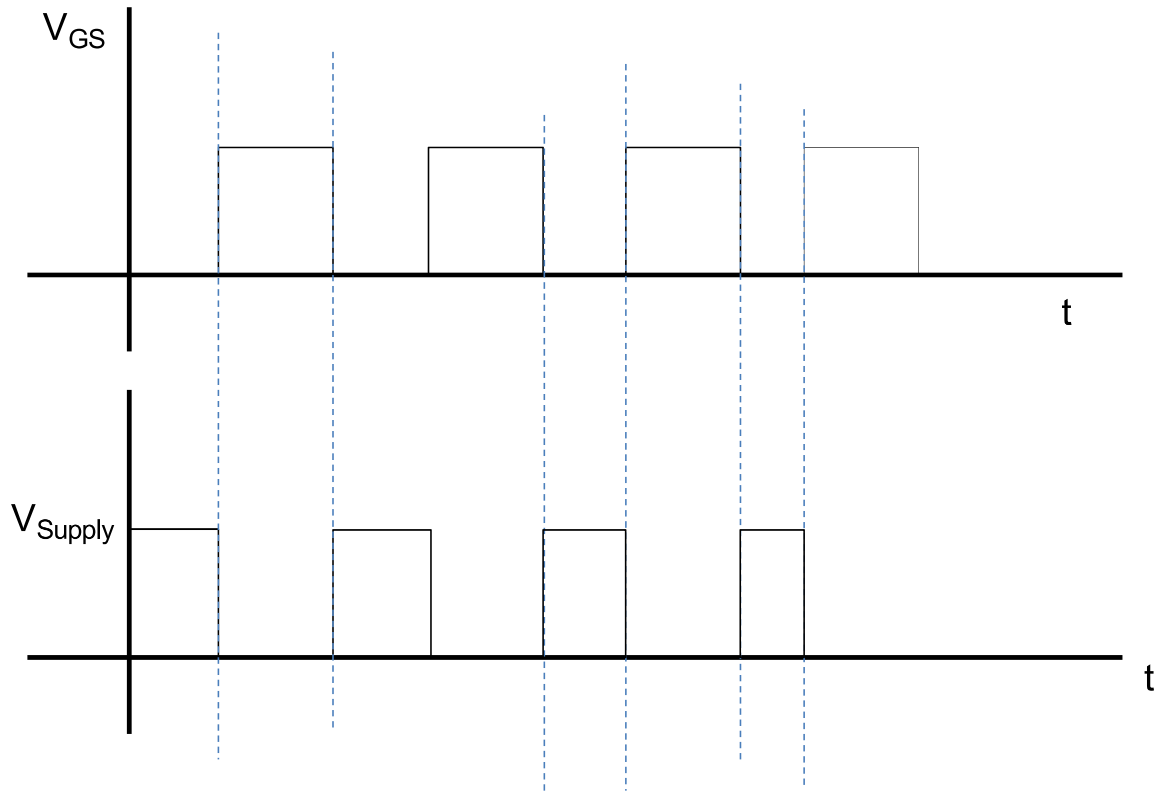


When $R_{SD} \gg R_L$; when V_{GS} $is\ low$

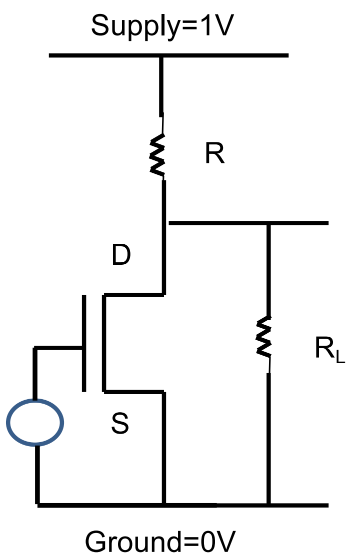
$$V_{out} = \frac{R_L}{R+R_L} V_{supply}$$

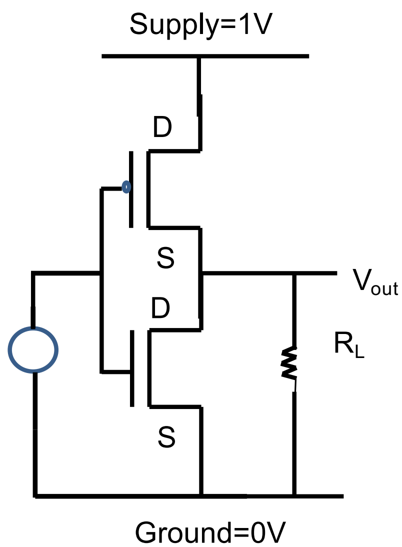
$$\approx V_{supply}\ if\ we\ design\ R \ll R_L$$

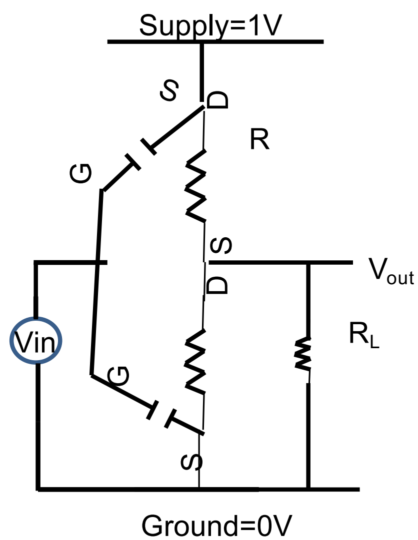
FET in digital logic

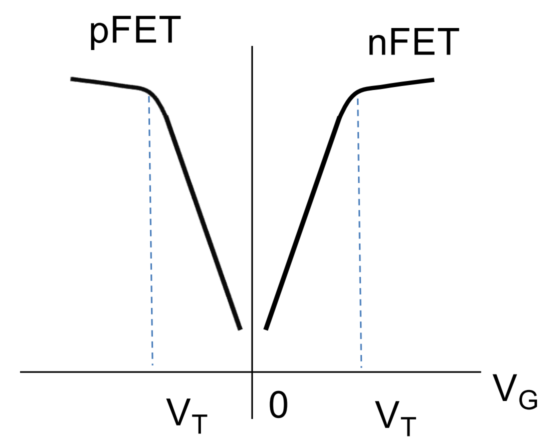


CMOS









Vin=1V

V_{GS} for nFET is HIGH→ R_{SD} is LOW

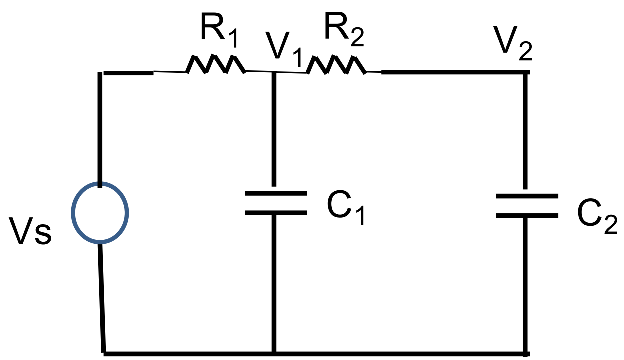
V_{GS} for pFET is LOW→ R_{SD} is high

Vin=0 V

V_{GS} for nFET is LOW→ R_{SD} is HIGH

V_{GS} for pFET is HIGH **NEGATIVE**→ R_{SD} is LOW

Vector Differential Equations



$$V_1 = I_2 R_2 + V_2 = R_2 C_2 \frac{dV_2}{dt} + V_2$$

$$\frac{dV_2}{dt} = \frac{1}{R_2 C_2} V_1 - \frac{1}{R_2 C_2} V_2$$

$$\frac{dV_1}{dt} = -\left(\frac{1}{R_2 C_1} + \frac{1}{R_1 C_1}\right) V_1 + \frac{1}{R_2 C_1} V_2 + \frac{1}{R_1 C_1} V_s$$

$$\frac{dV_2}{dt} = \frac{1}{R_2 C_2} V_2 - \frac{1}{R_2 C_2} V_2$$

$$V_s - V_1 = I R_1 \quad ; I = I_1 + I_2 = C_1 \frac{dV_1}{dt} + C_2 \frac{dV_2}{dt}$$

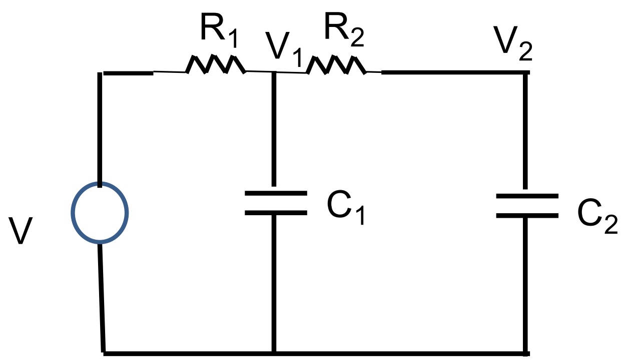
$$V_s - V_1 = \left(C_1 \frac{dV_1}{dt} + C_2 \frac{dV_2}{dt}\right) R_1$$

$$R_2 (V_s - V_1) = \left(R_2 C_1 \frac{dV_1}{dt} + R_2 C_2 \frac{dV_2}{dt}\right) R_1$$

$$\frac{dV_1}{dt} = -\frac{1 + \frac{R_2}{R_1}}{R_2 C_1} V_1 + \frac{1}{R_2 C_1} V_2 + \frac{1}{R_1 C_1} V_s$$

$$\frac{dV_1}{dt} = -\left(\frac{1}{R_2 C_1} + \frac{1}{R_1 C_1}\right) V_1 + \frac{1}{R_2 C_1} V_2 + \frac{1}{R_1 C_1} V_s$$

Vector Differential Equations



$$\frac{dV_1}{dt} = -\left(\frac{1}{R_2C_1} + \frac{1}{R_1C_1}\right)V_1 + \frac{1}{R_2C_1}V_2 + \frac{1}{R_1C_1}V_s$$

$$\frac{dV_2}{dt} = \frac{1}{R_2C_2}V_1 - \frac{1}{R_2C_2}V_2$$

$$\frac{d}{dt}\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} -(\frac{1}{R_2C_1} + \frac{1}{R_1C_1}) & \frac{1}{R_2C_1} \\ \frac{1}{R_2C_2} & \frac{1}{R_2C_2} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{R_1C_1}V_s \\ 0 \end{bmatrix}$$