KTH Information and Communication Technology

IL2218 Analog electronics, advanced course

Bengt Molin

Tel: 08-790 4448

E-post: bengtm@kth.se

EKT – Devices and circuits

Kista, Electrum, elevator C, floor 4

Lecture 1

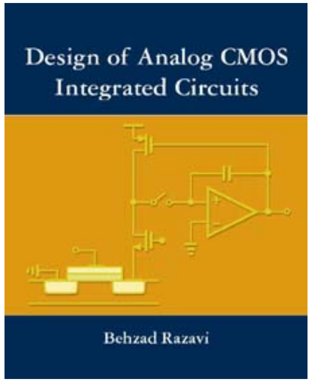
- Changes in the course
- Prerequisite
- Course information
- Course registration
- Student representatives for course evaluation meetings

- Ch 2 Basic MOS device physics

Course changes previous years

- Focus on design in CMOS technology
- Change of course book
  - Razavi, Design of Analog CMOS Integrated Circuits

    Available at student book store



- Change of how the course is organized
- Change of examination

Prerequisite

- Basic course in Electrical circuits
  - Methods to solve for currents and voltage in electrical circuits
- Basic course in Analog electronics
  - Basic transistor based amplifiers
  - Understand transistor models
  - Biasing transistors
  - Small signal models
  - Use of operational amplifiers

Course outline

- Lectures
- Exercises, students solve selected problems from book and demonstrates his or hers solution at the exercise   Students responsible!
- Labs, verify your solutions of selected problems with simulation
- Written exam, first part (questions, short problems) is closed book and second part (analysis and design problems) is open book
- Course web page

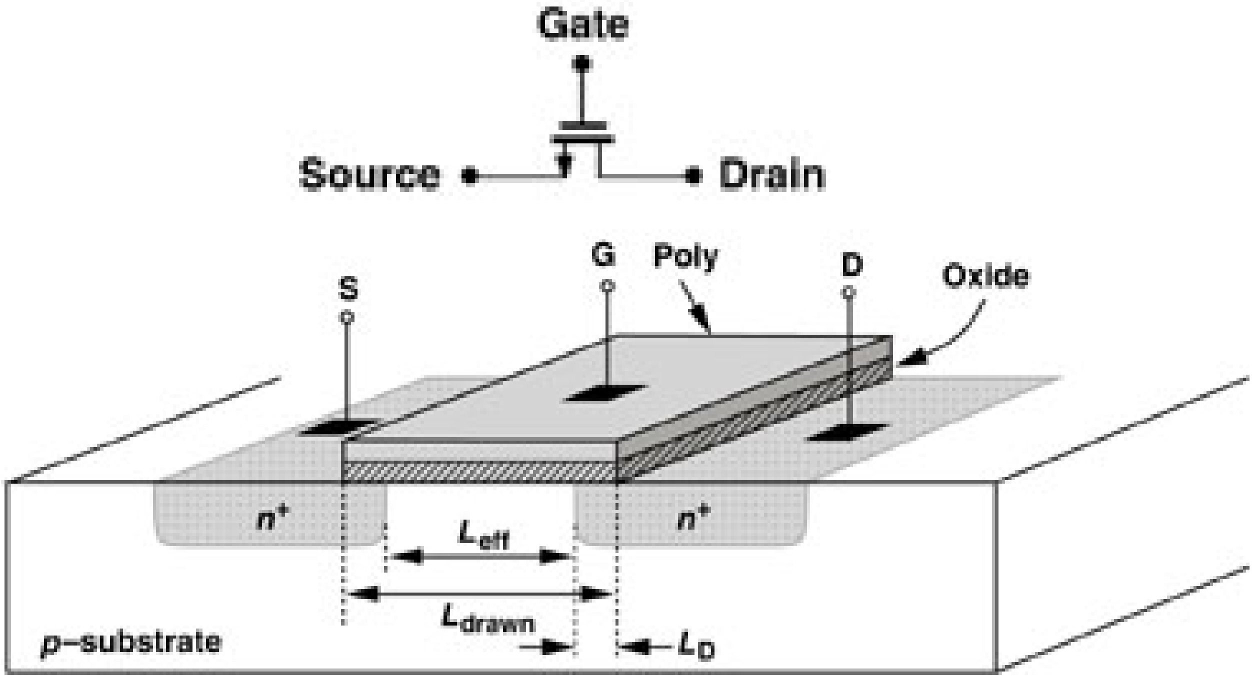
Chapter 1

- Why analog?
  - The nature is analog
  - Analog frontends in digital system
  - Amplification before A/D-conversion
- Why integrated?
  - All in same chip
- Why CMOS?
  - Digital and analog on same chip
  - Device scaling improving MOSFETs
- Why this book?
  - Analog design from both intuitive and rigourous angles

Chapter 2 Basic MOS Device Physics

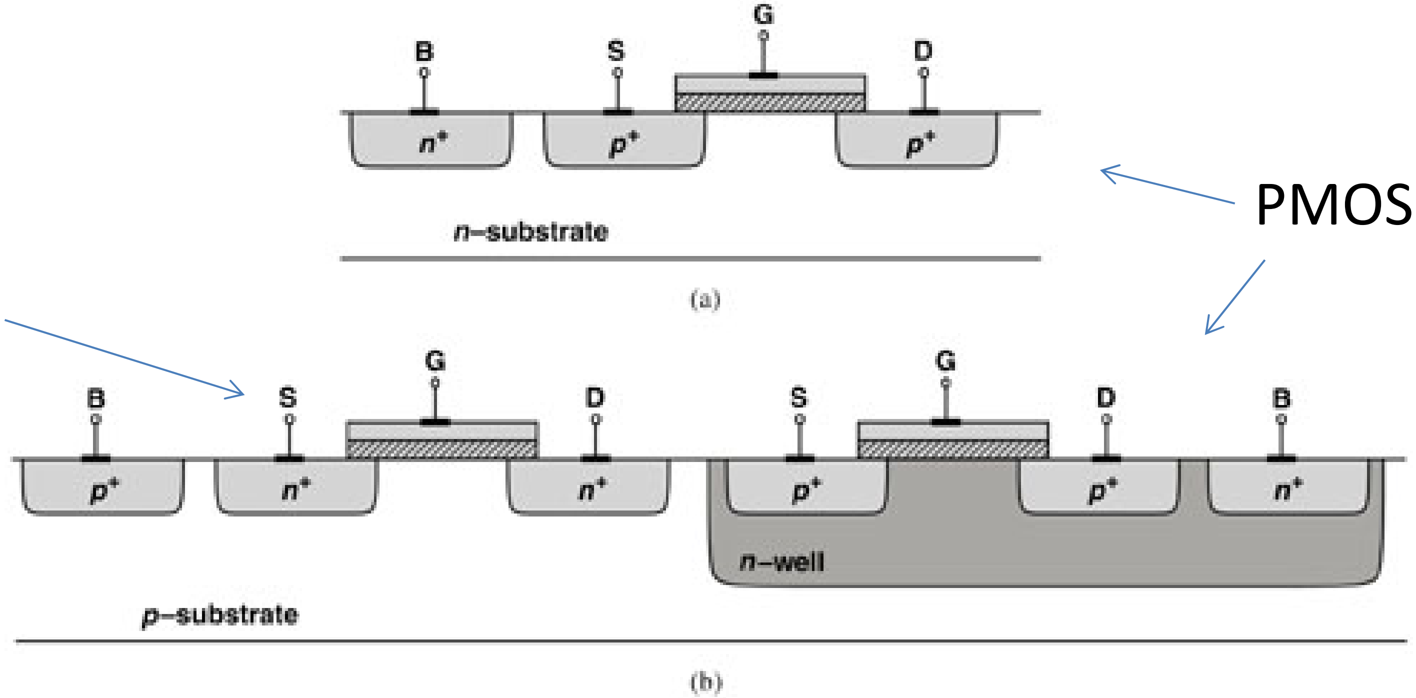
MOS = Metal Oxide Semiconductor

NMOS



$$L_{eff} = L_{drawn} - 2L_D$$

NMOS PMOS CMOS



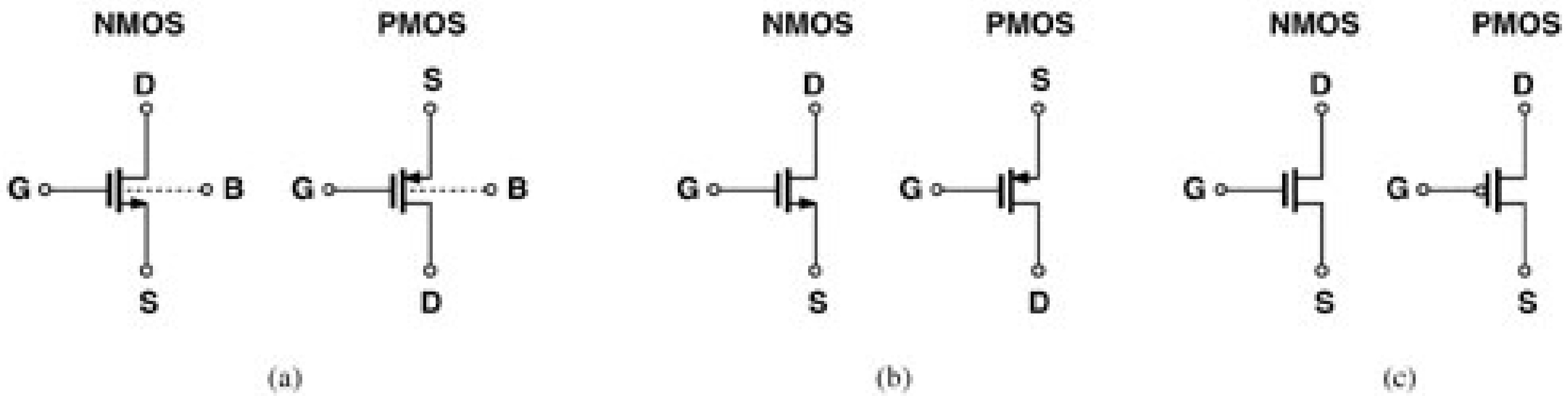
PMOS

NMOS

CMOS = Complementary MOS

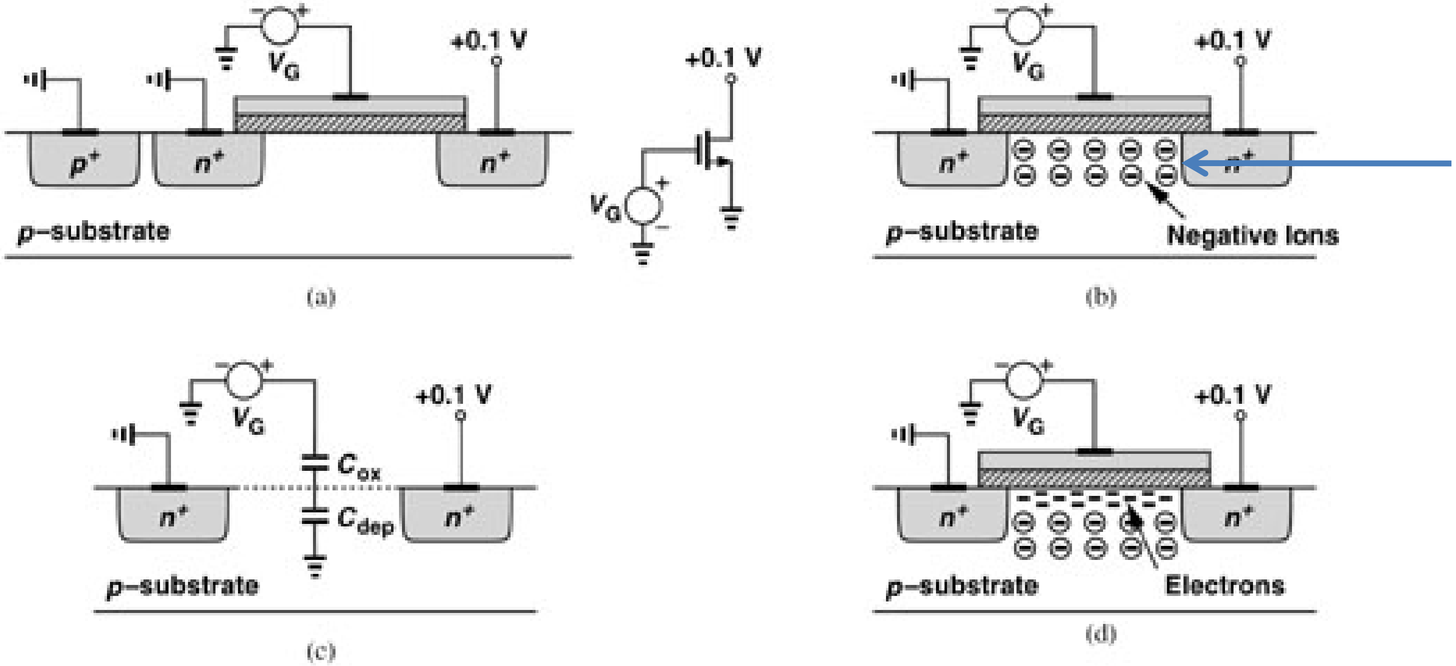
MOS symbols

Four terminal Three terminal Digital



How is terminal body connected?

Threshold Voltage V_{TH}



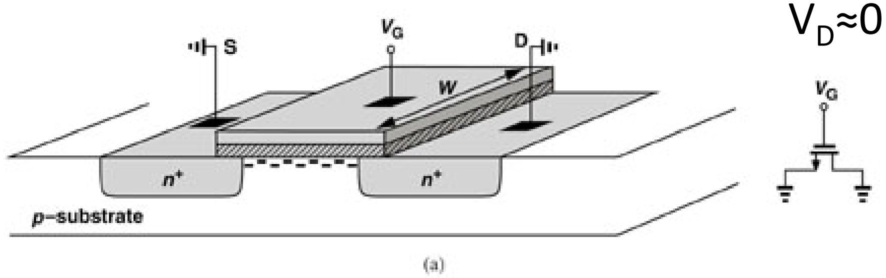
(a) (b) (c) (d)

Depletion

Inversion
Depletion

For $V_G > V_{TH}$ we have inversion and a N-channel from source to drain

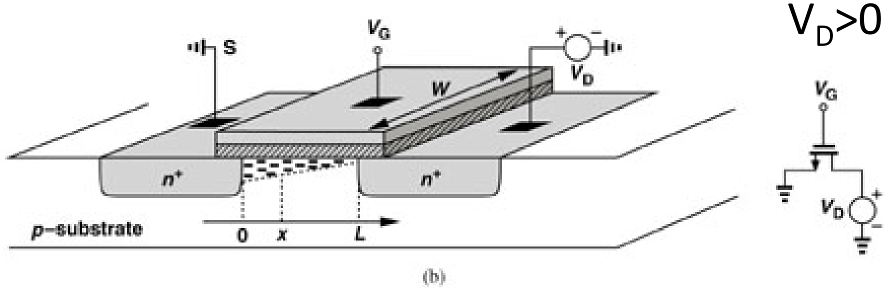
Triode Region



V_D≈0

$$I = Q_d \cdot v$$

$$I_D = \underbrace{C_{ox}\left(V_{GS} - V_{TH}\right)W}_{\text{charge/unit length}} \underbrace{\mu_n \frac{V_{DS}}{L}}_{\text{velocity}}$$



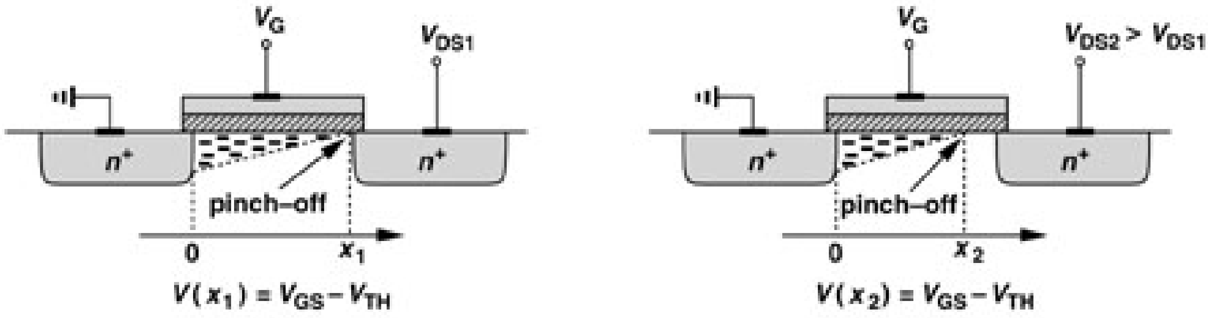
V_D>0

$$I_D = \underbrace{WC_{ox}\left(U_{GS} - V(x) - U_T\right)}_{\text{charge/unit length}} \cdot \underbrace{\mu_n \frac{\overbrace{dV(x)}^{\textit{Electrical field}}}{dx}}_{\text{velocity}}$$

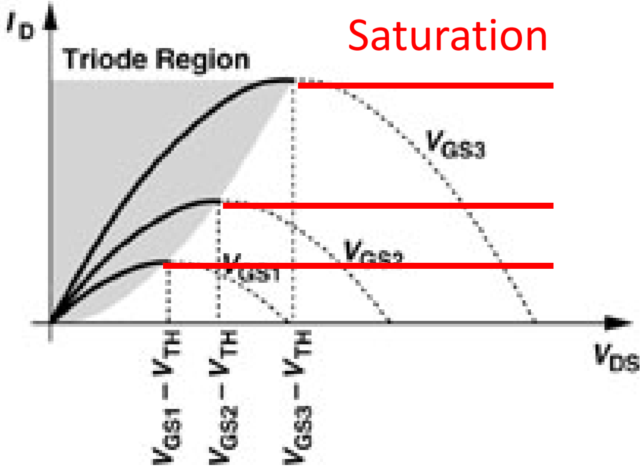
$$I_D = \underbrace{WQ(x)}_{\text{decreases with x}} \cdot \underbrace{\mu_n \frac{dV(x)}{dx}}_{\text{increases with x}}$$

$$\text{If } Q(L) \to 0 \text{ then } \mu_n \frac{dV(L)}{dx} \to \infty$$

I/V Characterics - Triode Region



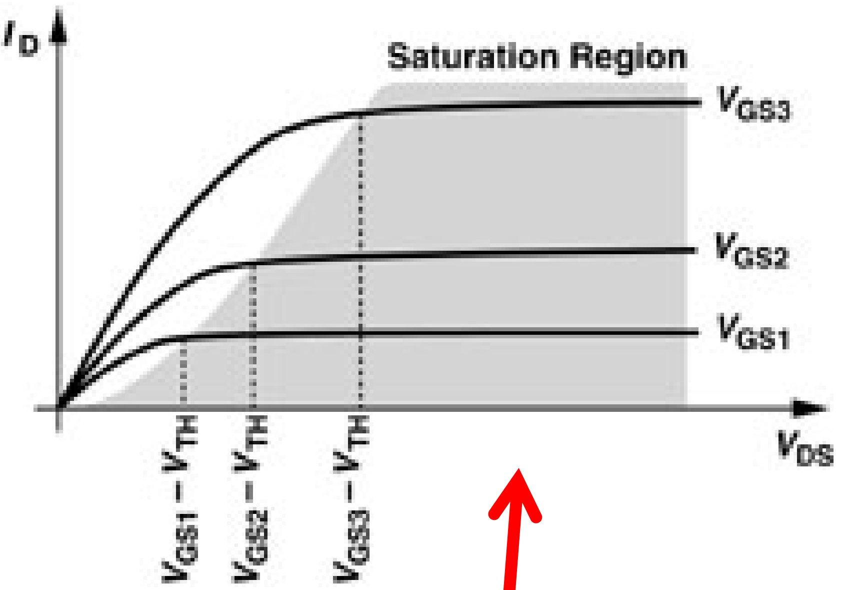
Pinch off =
velocity saturation



$$\int_{x=0}^{L} I_D dx = \int_{V=0}^{V_{DS}} W C_{ox} \mu_n [V_{GS} - V(x) - V_{TH}] dV$$

$$I_D = \mu_n C_{ox} \frac{W}{L} [(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2]$$

Saturation (active) region

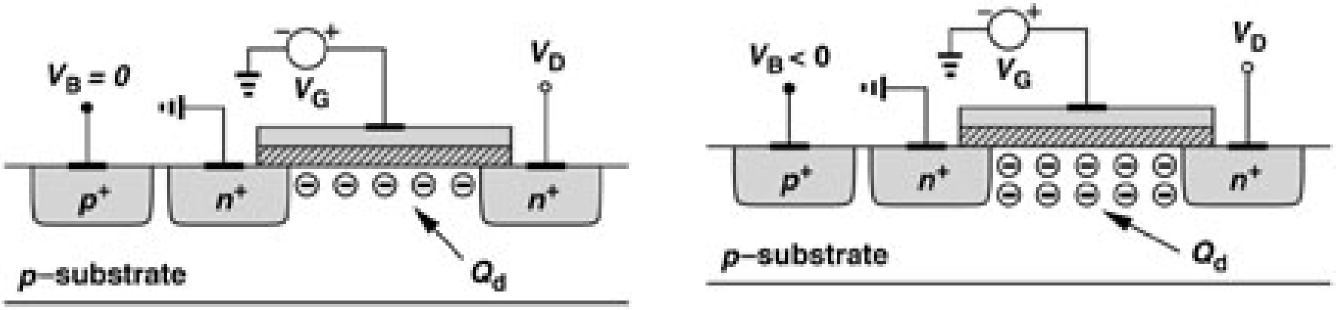


$$V_{DS} > V_{GS} - V_{TH} \qquad (Pinch-off)$$

$$\boxed{I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})^2}$$

Body effect

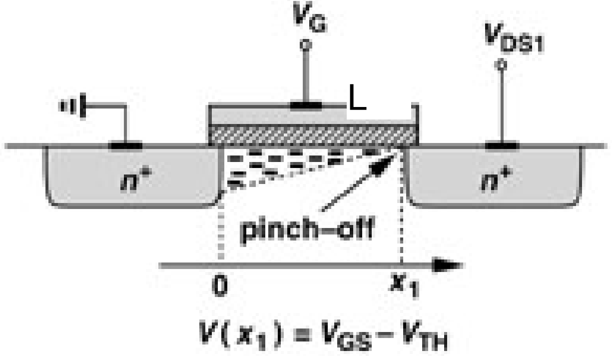
If body potential is different from source potential, i.e. $V_{SB} \neq 0$ the threshold voltage will change. This is called body effect.

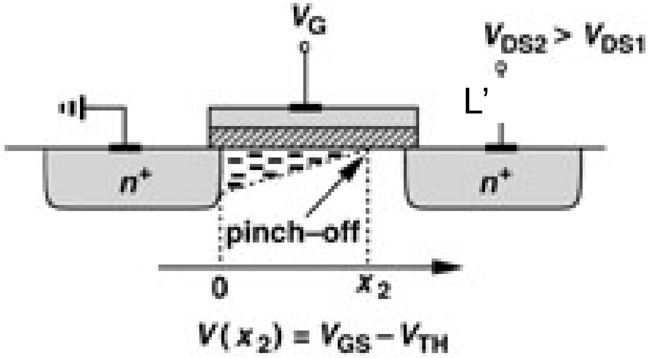


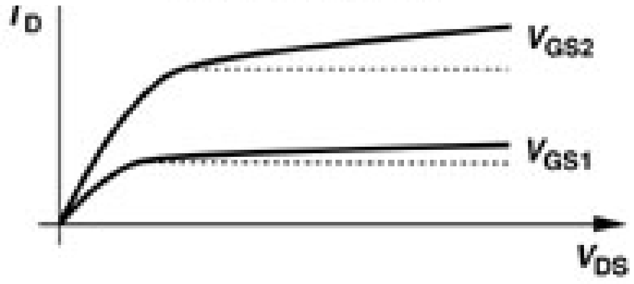
$$V_{TH} = V_{TH0} + \gamma\left(\sqrt{2\Phi_F + V_{SB}} - \sqrt{2\Phi_F}\right), \gamma = \frac{\sqrt{2q\varepsilon_{si}N_{sub}}}{C_{ox}}$$

Channel-Length Modulation

When V_{DS} increases, the channel will be slightly shorter due to depletetion at drain. This will increase the current I_D.



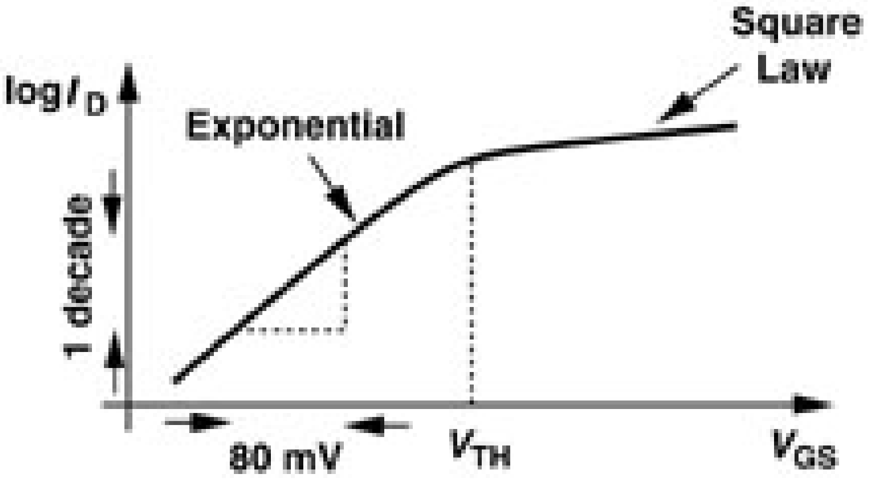




$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$

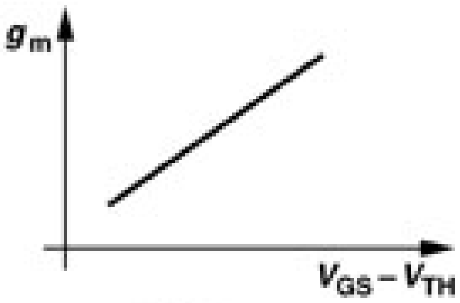
Subthreshold conduction

$$I_D = I_0 \exp\left(\frac{V_{GS}}{\zeta \, kT/q} \right)$$

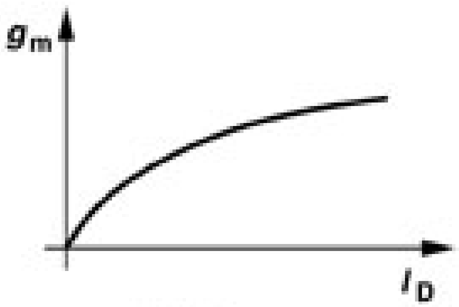


Transconductance

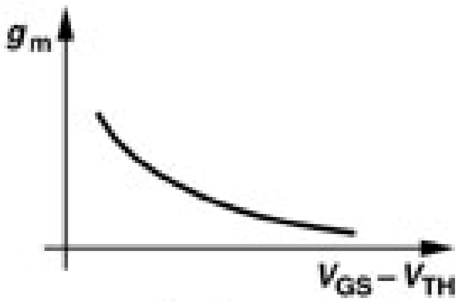
$$g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH}) = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} = \frac{2I_D}{V_{GS} - V_{TH}}$$



W/L Constant



W/L Constant



I_D Constant

Bulk transconductance

Bulk behaves as a second gate

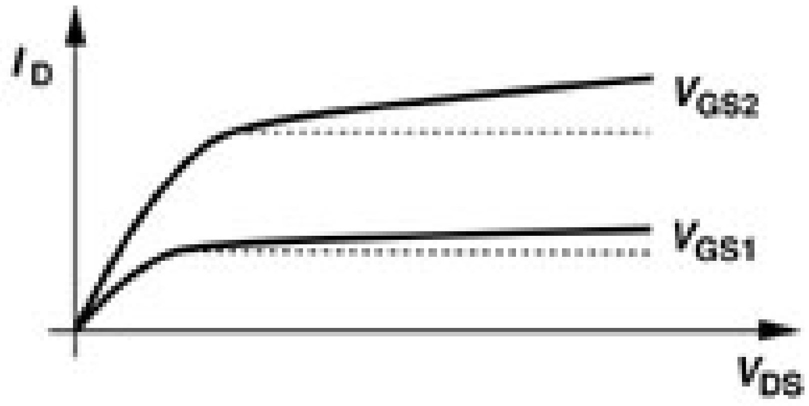
$$g_{mb} = \frac{\partial I_D}{\partial V_{BS}} = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})\left(\frac{-\partial V_{TH}}{\partial V_{BS}}\right)$$

$$\frac{\partial V_{TH}}{\partial V_{BS}} = \frac{-\partial V_{TH}}{\partial V_{SB}} = -\frac{\gamma}{2}(2\Phi_F + V_{SB})^{-1/2}$$

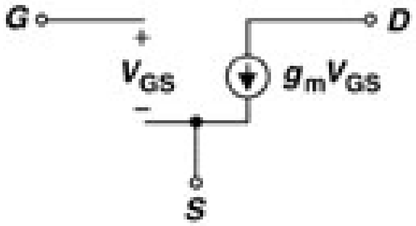
$$g_{mb} = g_m \frac{\gamma}{2\sqrt{2\Phi_F + V_{SB}}} = \eta g_m$$

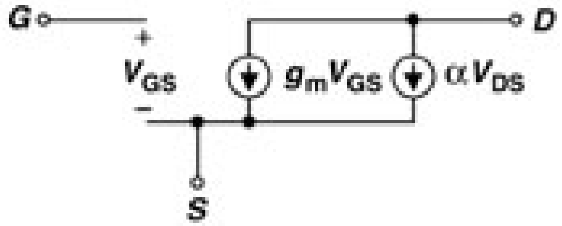
Output resistance

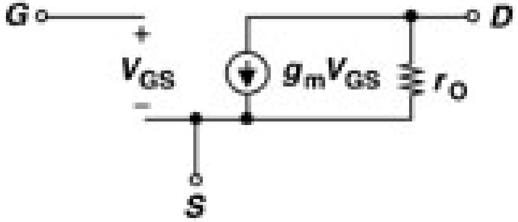
$$r_o = \frac{\partial V_{DS}}{\partial I_D} = \frac{1}{\partial I_D / \partial V_{DS}} = \frac{1}{\frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})^2 \lambda} = \frac{1}{\lambda I_D}$$

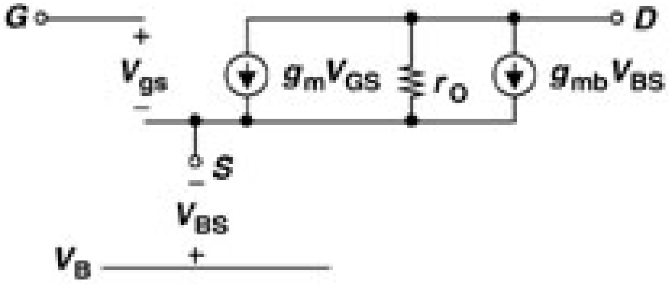


Small signal model

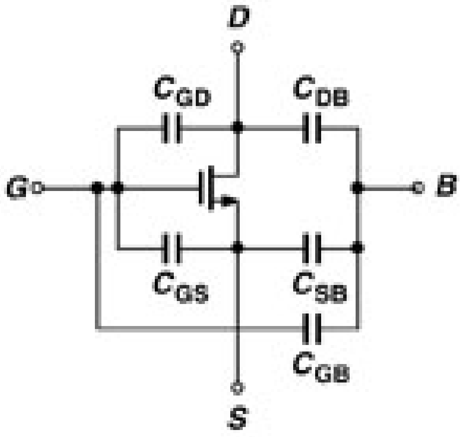


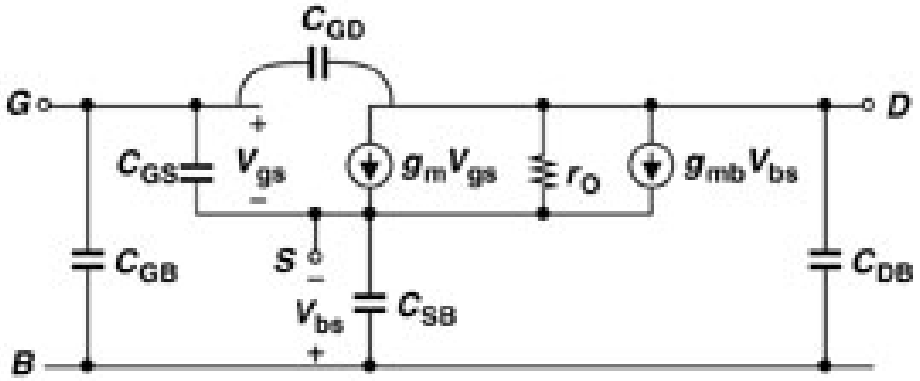




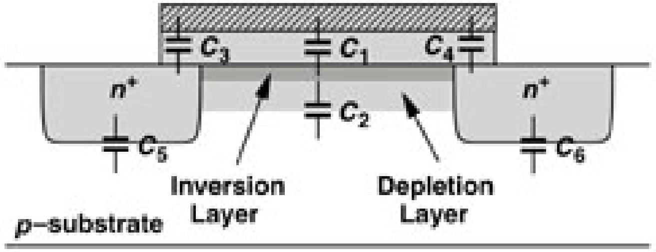


Complete small signal model with capacitances

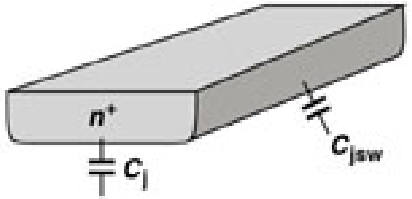




Explain the capacitances!



(a)



(b)

How to make an amplifier out of this?

Any ideas?