ECE 515 - Lecture 3

Thursday, August 30, 2018 11:02 AM

g_m, g_{mb}, r_o

Ac Analysis

① Draw the DC picture
- → short ac sources
- → open ac current

Find Bias points for all devices

② Using DC values from ①, find small-signal parameters (g_m, r_o, etc) for all devices

"Linearization step" • Ac analysis

③ Draw Ac picture
- → replace devices by small signal models
- → short all DC voltage sources

Solve for

↳ open all DC current sources

AC values

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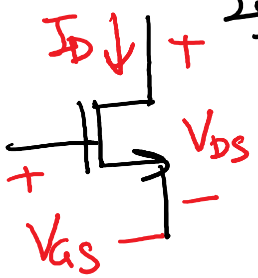
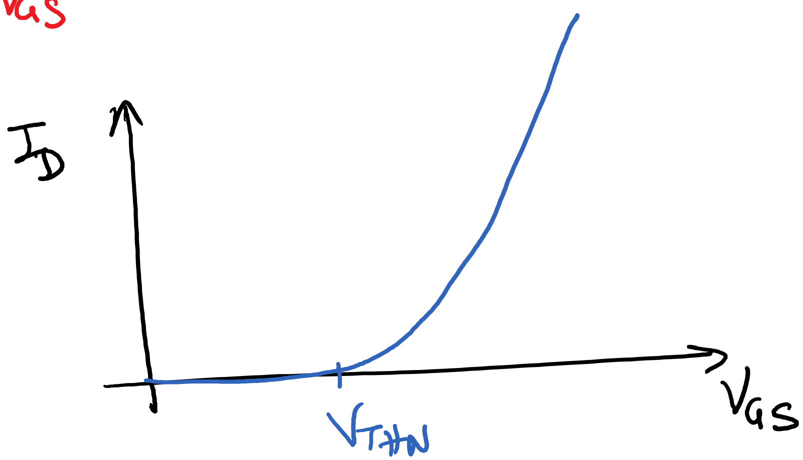
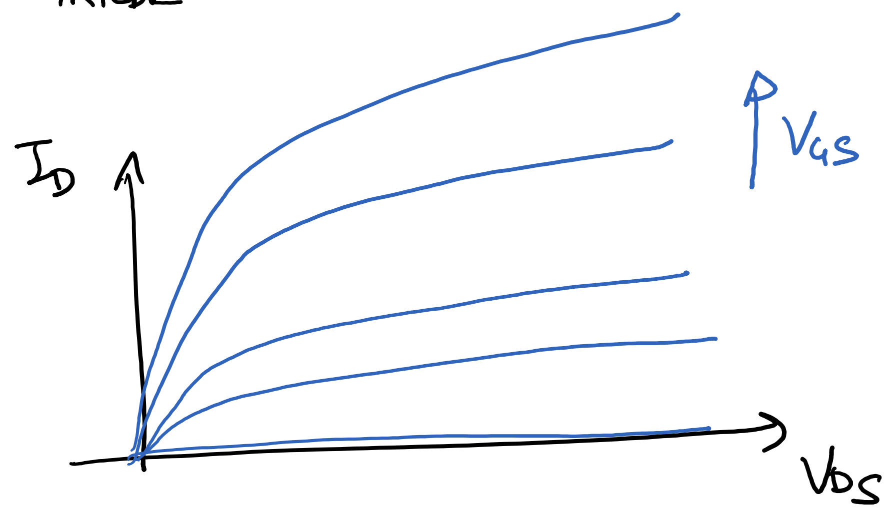
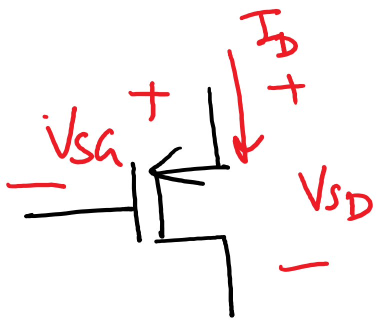
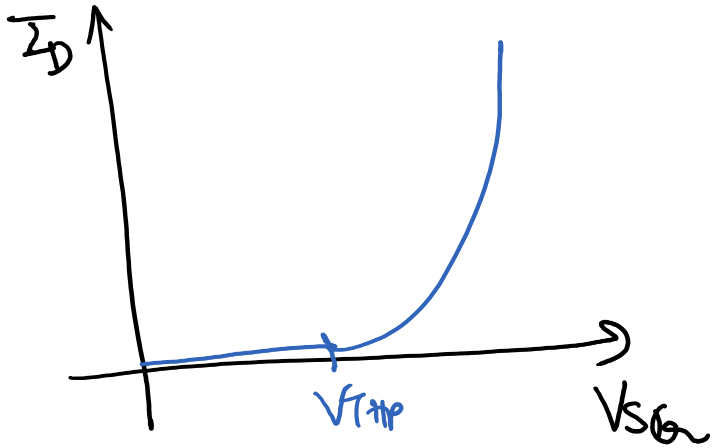


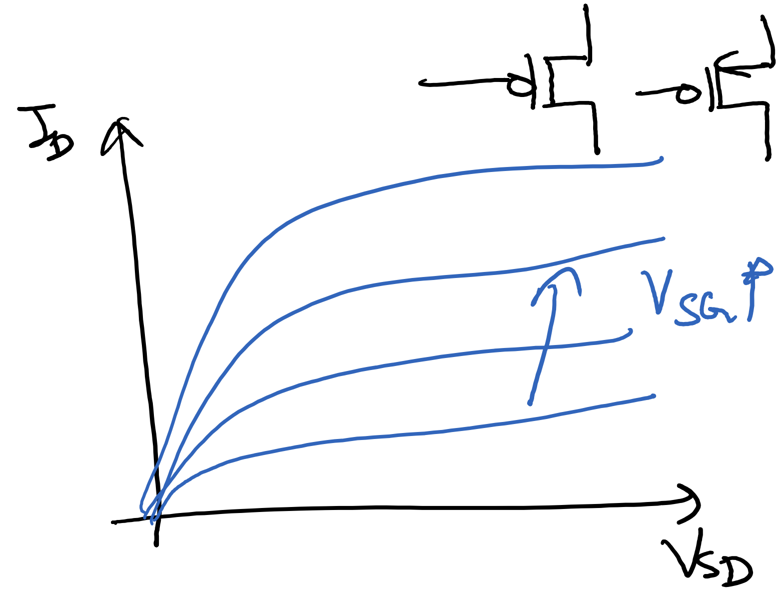
$$I_D = \begin{cases} \frac{1}{2} k'_n \frac{W}{L} \left(V_{GS} - V_{THN}\right)^2 & \text{SAT} \\ k'_n \frac{W}{L} \left(\left(V_{GS} - V_{THN}\right)V_{DS} - \frac{V_{DS}^2}{2}\right) & \text{TRIODE} \end{cases}$$



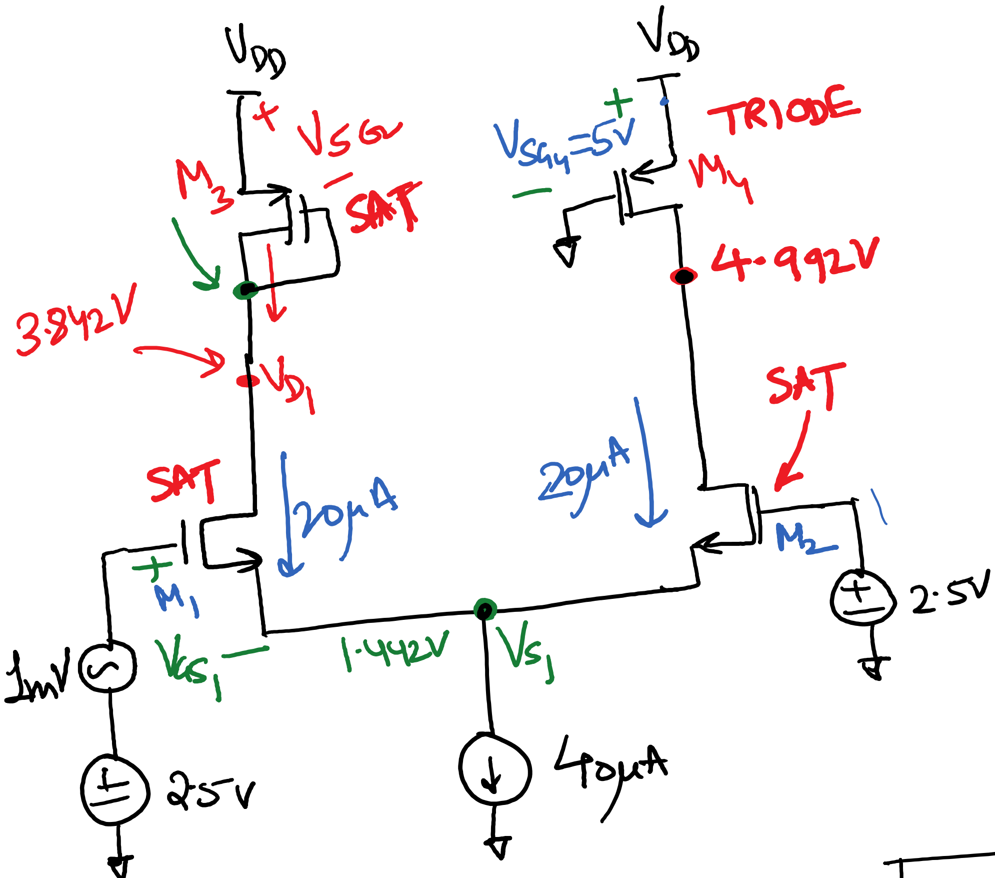








$$I_D = \begin{cases} \frac{1}{2} k'_p \frac{W}{L} \cdot \left(V_{SG} - |V_{THP}|\right)^2 & \text{SAT} \\ k'_p \frac{W}{L} \left[(V_{SG} - V_{THP}) V_{SD} - \frac{V_{SD}^2}{2} \right] & \text{TRIODE} \end{cases}$$



$V_{DD}=5V$ $\quad KP_n=120\frac{\mu A}{V^2}$ $\quad KP_p=40\frac{\mu A}{V^2}$

$V_{THN}=800mV, \quad V_{THP}=900mV$

All NMOS → $\frac{10}{2}$ $\quad L_{min}=1\mu m$

PMOS → $\frac{30}{2}$

Find all voltages & currents

Assume M_1 & M_2 are in SAT

$$V_{GS_1}=\sqrt{\frac{2I_D}{KP_n\frac{W}{L}}}+V_{THN}=\boxed{1.058V}=V_{GS_2}$$

$$V_{S_1}=V_{G_1}-1.058=2.5-1.058=\boxed{1.442V}$$

M_1: $V_{DS_1}=3.842-1.442=2.4V > V_{DS,sat}$ 258 mV

SAT ✓

M_2: $V_{DS_2}=4.992-1.442V=3.55V$

$V_{DS,sat}=V_{GS_2}-V_{THN}=250mV$

M_2 is in SAT ✓

$$V_{SG_3}=\sqrt{\frac{2I_D}{KP_p\,W/L}}+|V_{THP}|=\boxed{1.158V}$$

$$V_{D_1}=5V-V_{SG_3}=\boxed{3.842V}$$

M4

$V_{SG_4} = 5V$ ← most likely in triode

$$I_D = K'_p \frac{W}{L}\left[(V_{SG_4} - V_{THP})V_{SD} - \frac{V_{SD}^2}{2}\right]$$

$$\Rightarrow 20\mu = 40\mu \cdot \frac{30}{2}\left[4.1 \times V_{SD} - \frac{V_{SD}^2}{2}\right]$$

$$\Rightarrow V_{SD_4} = 8.13\ mV$$

$\Rightarrow$

Equivalent circuit

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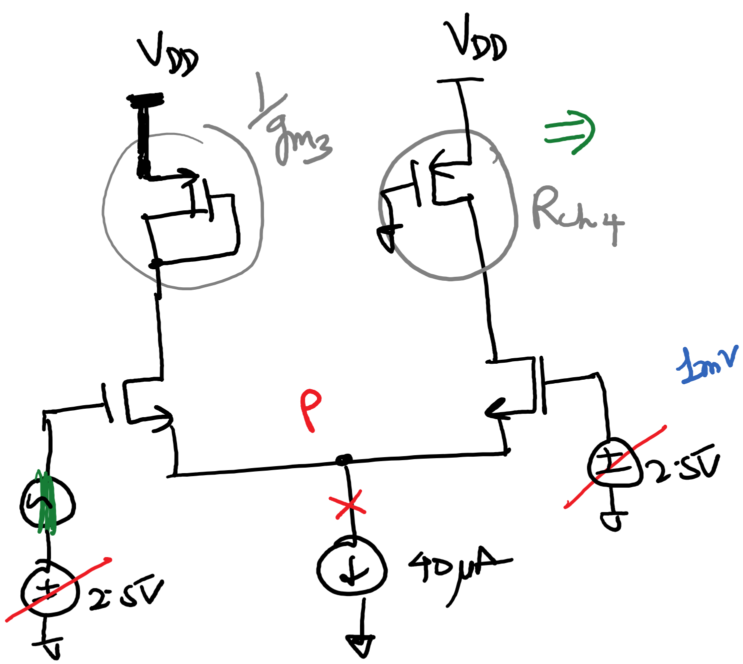
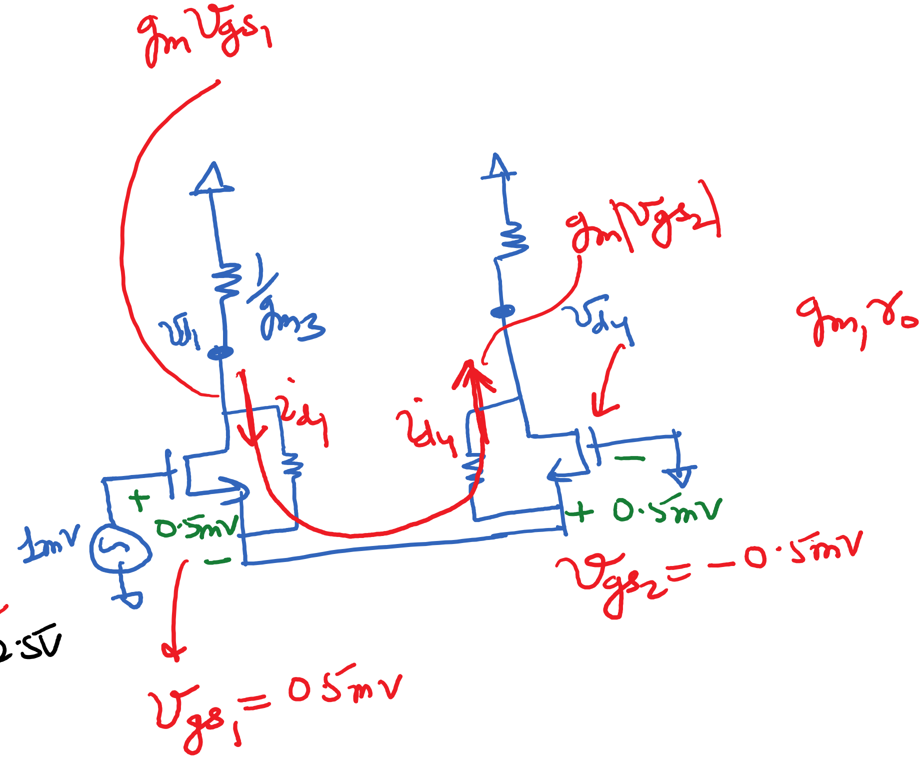
Ac picture

$\gamma = 0$

$\lambda = 0$





$g_{m1} = g_{m2} = \sqrt{2\beta_n I_D} = 150\frac{\mu A}{V}$

$\frac{1}{g_{m3}} = 6.67\,k\Omega$

$R_{ch4} = 407\,\Omega$

$r_o = \frac{1}{\lambda I_{Dsat}} = \infty$

$i_{d1} = i_{d2} = 150\frac{\mu A}{V} \times 0.5mV$

$= 75nA$

$v_{d1} = 0 - 75nA \times \frac{1}{g_{m3}} = -0.5mV$

$v_{d4} = 75nA \times R_{ch} = 0.03mV$

$V_{D_1} = 3.842$ $\qquad v_{d_1} = -0.5mV$

Superposition

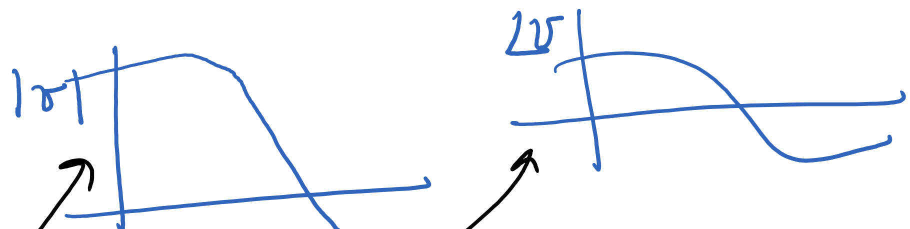
$v_{D_1} = 3.842 - 0.5mV \sin(2\pi f_{in} t)$

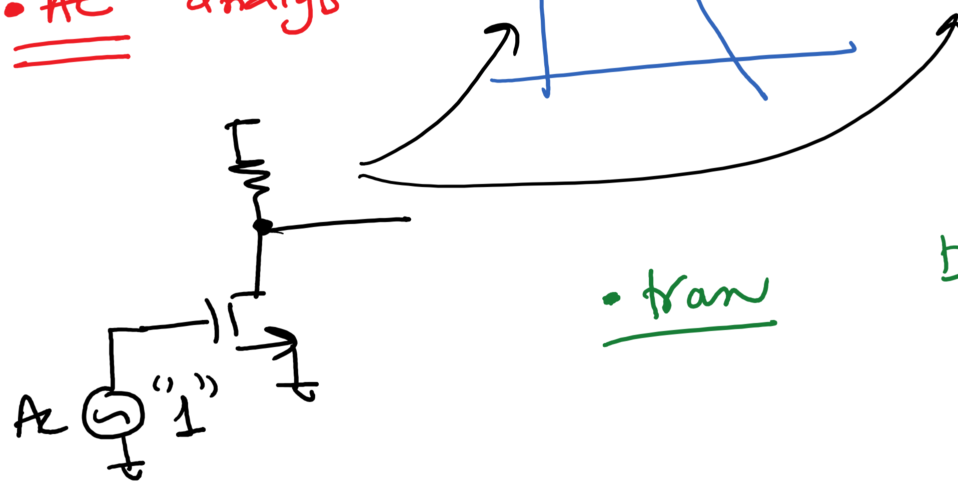
$v_{D_2} = 4.992 + 0.03mV \cdot \sin(2\pi f_{in} t)$

Spectre

- DC analysis ⇒ dc operating point, DC node voltages
- op

- Ac analysis





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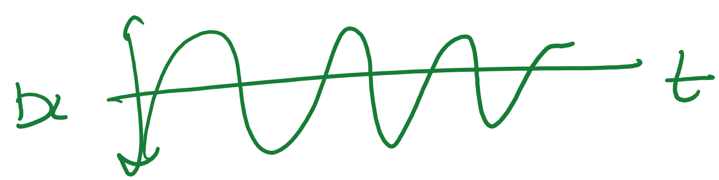
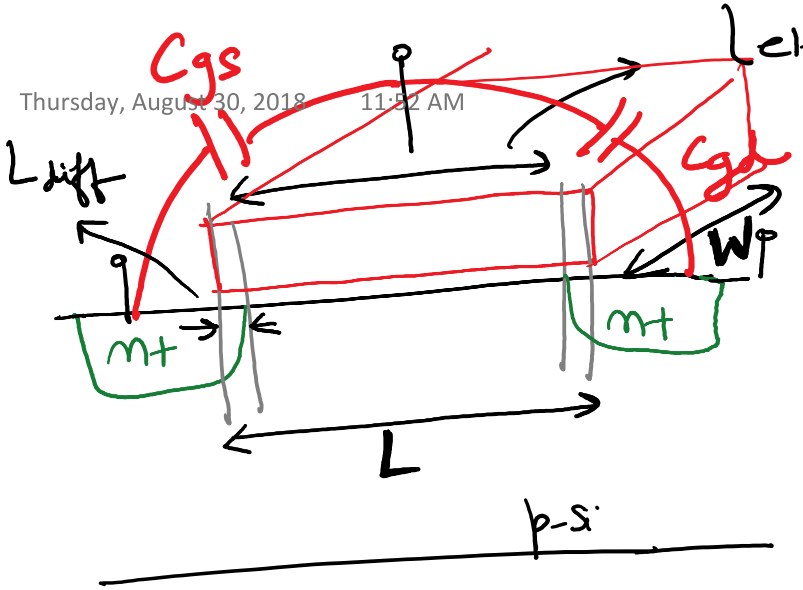
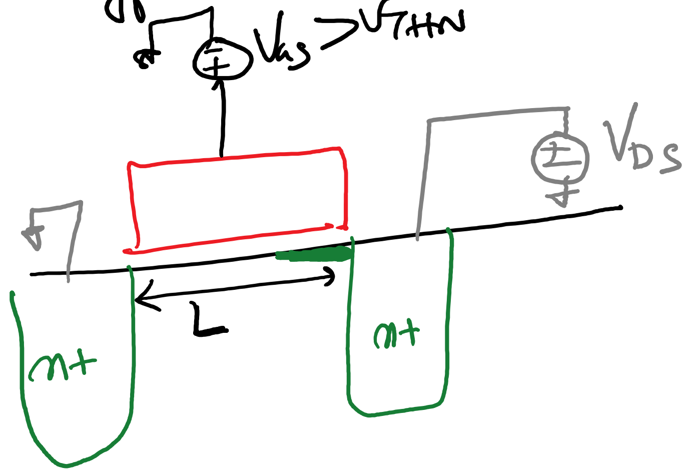


$L_{elec} = L - 2L_{diff}$





* In short-channel technologies. (L < 1μm)

$V_{DS}\uparrow$ $V_{THN}\downarrow$ DIBL

drain induced barrier lowering

* gate oxide are thin

↳ gate oxide leakage

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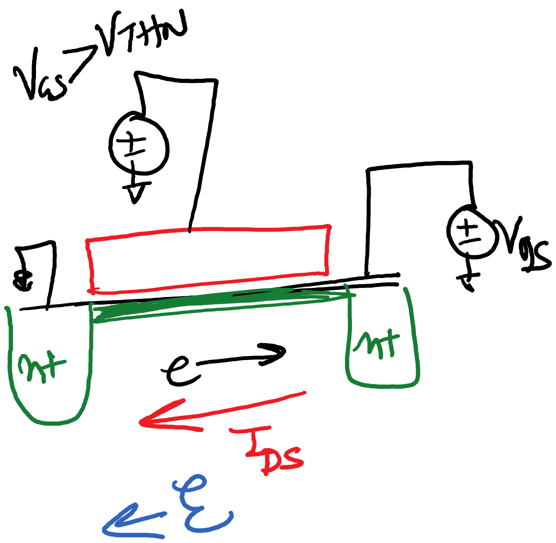
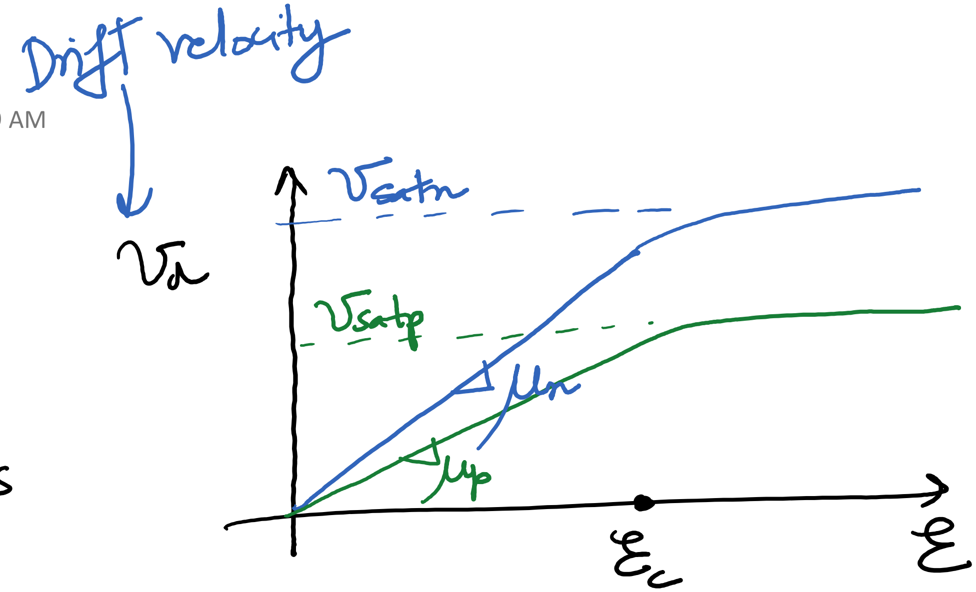




$\mathcal{E} = \frac{V_{DS,sat}}{L}$

$L \downarrow \Rightarrow \mathcal{E} \uparrow$

$v_d = \mu_n \mathcal{E}$

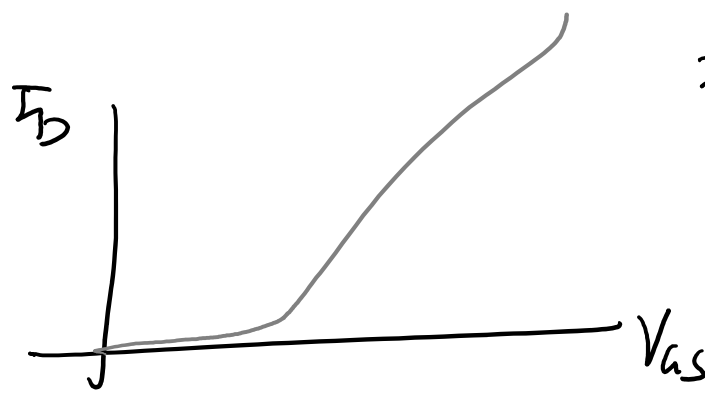
mobility

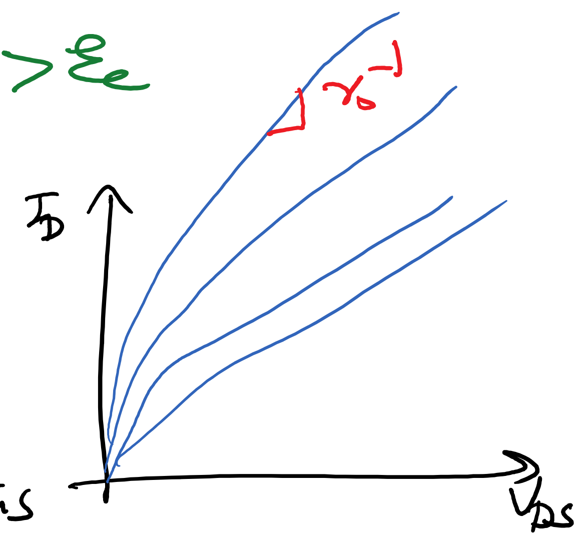
μ_n, μ_p

$\lambda \propto \frac{1}{L}$

Drift velocity is saturated for $\mathcal{E} > \mathcal{E}_c$

$\Downarrow$





output resistance gets smaller as short channel process gm ro t_b with L_b

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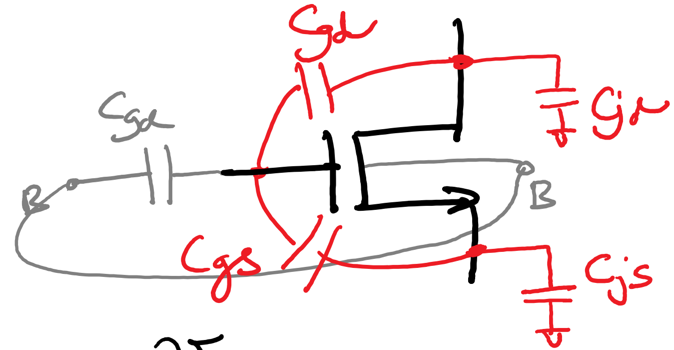
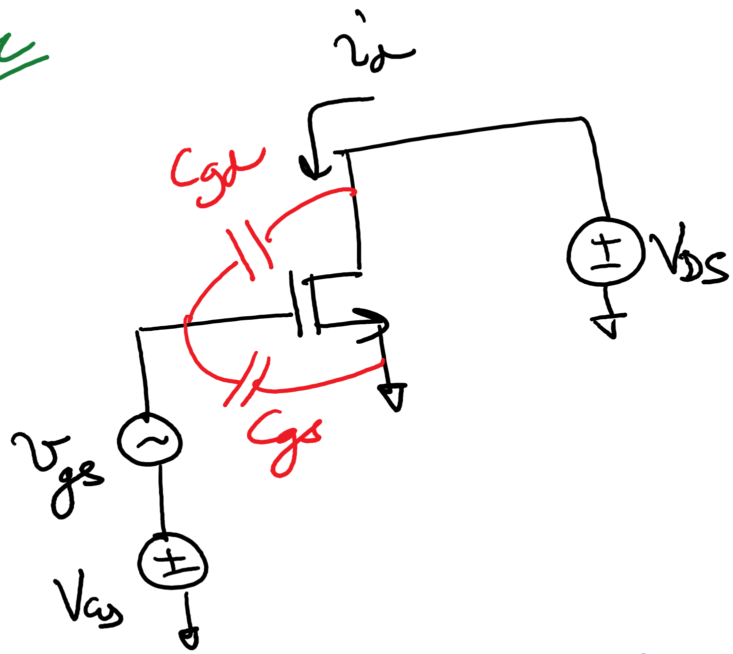
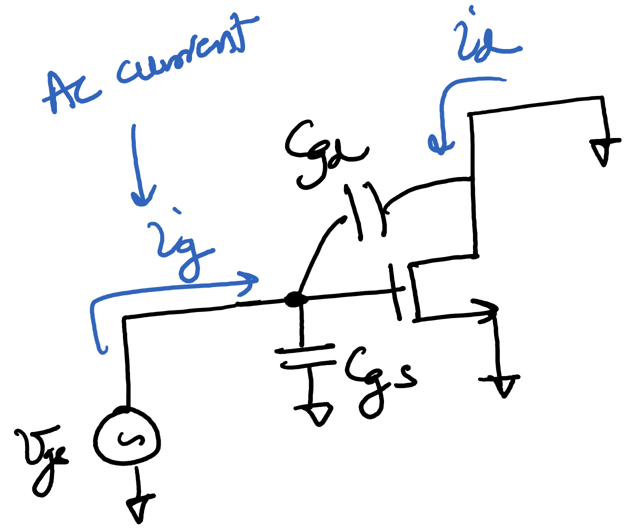
MOSFET Transition frequency, f_T :



$i_d = g_m v_{gs}$

Ac





$v_{gs} = i_g \times \frac{1}{s(C_{gd}+C_{gs})}$ → ①

$i_d = g_m v_{gs}$ → ②

$s \to j\omega$

$\Rightarrow \left|\frac{i_d}{i_g}\right| = \frac{g_m}{s(C_{gd}+C_{gs})} = 1 \Rightarrow f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})}$

$$\Rightarrow \left|\frac{i_d}{i_g}\right| = \frac{g_m}{s(C_{gd}+C_{gs})} = 1 \Rightarrow f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})}$$

$s \rightarrow 2\pi f$

Transition frequency