EE 223 HW2

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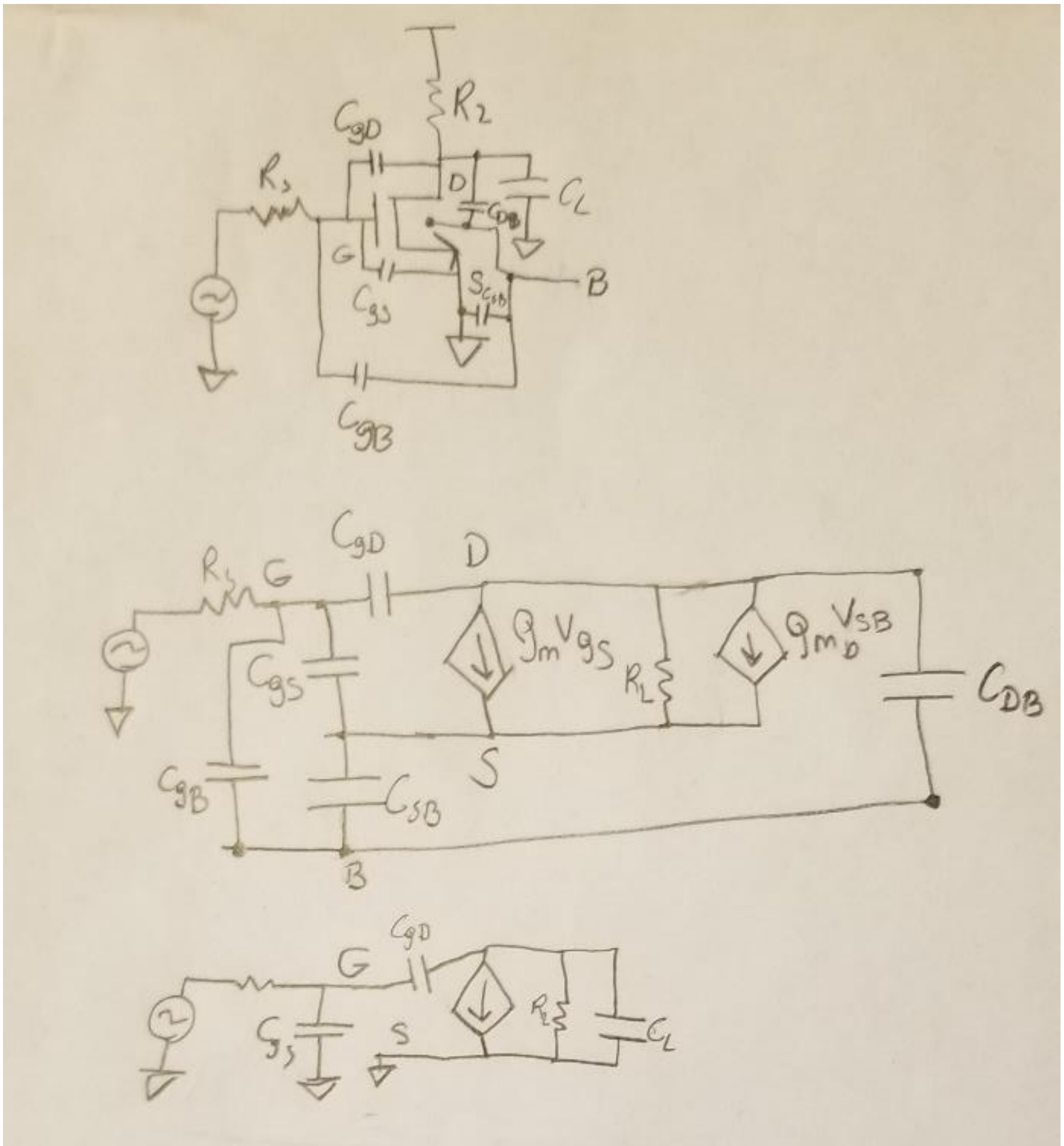
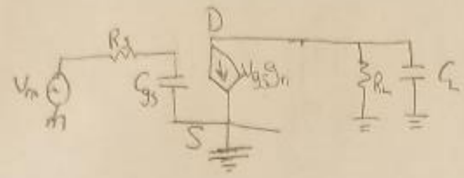
09/29/2018

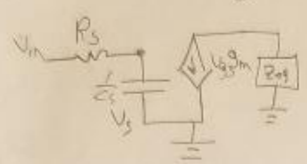
1. MOS Small-Signal Analysis on Common Source Amplifier
    a.



b.

(b)





$$\frac{\frac{1}{sC_{gs}}}{R_s + \frac{1}{sC_{gs}}} V_{in} = V_g$$

$$Z_C = \frac{1}{sC_L}$$

$$\frac{1}{r_o} + \frac{1}{R_L} + \frac{1}{1/sC_L} = \frac{1}{Z_{eq}}$$

$$\frac{1}{R_L} + sC_L$$

$$\frac{[1+sC_L]R_L}{R_L} = \frac{1}{Z_{eq}}$$

$$\frac{R_L}{1 + sC_L R_L} = Z_{eq}$$

$$V_{gs} = V_g - V_s$$

$$V_{gs} = \frac{\frac{1}{sC_{gs}}}{R_s + \frac{1}{sC_{gs}}} V_{in} - \cancel{V_s} 0$$

$$V_{ou} = -g_m V_{gs} Z_{eq}$$

$$= -g_m \left(\frac{\frac{1}{sC_{gs}}}{R_s + \frac{1}{sC_{gs}}} \cdot V_{in} \right) (Z_{eq})$$

$$\frac{V_{out}}{V_{in}} = -g_m \left(\frac{\frac{1}{sC_{gs}}}{R_s + \frac{1}{sC_{gs}}} \right) (Z_{eq})$$

$$= -g_m \left(\frac{\frac{1}{sC_{gs}} \cdot \frac{sC_{gs}}{1}}{\left(R_s + \frac{1}{sC_{gs}}\right) \frac{sC_{gs}}{1}} \right) (Z_{eq})$$

$$= -g_m \left(\frac{1}{sC_{gs}R_s + 1} \right) \left(\frac{R_L}{1 + sC_L R_L} \right)$$

$$= \frac{-g_m R_L}{[sC_{gs}R_s + 1][1 + sC_L R_L]}$$

c.

1c) $$\frac{V_{out}}{V_{in}} = \frac{-g_m R_L}{[S C_{gs} R_s + 1][1 + S C_L R_L]}$$

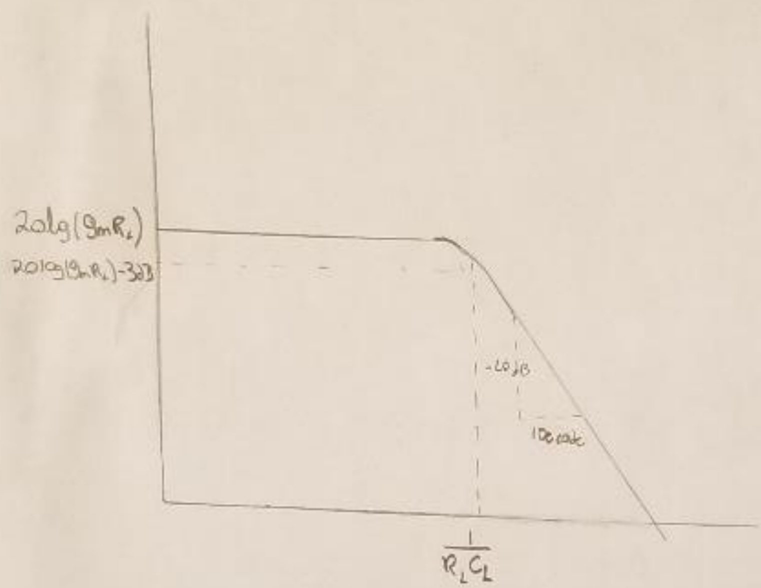
$$A_{DC} = \left.\frac{V_{out}}{V_{in}}\right|_{S \to 0} = \frac{-g_m R_L}{[0 \cdot C_{gs} R_s + 1][1 + 0 \cdot C_L R_L]} = -g_m R_L$$

Two Poles

$$S = \frac{1}{R_S C_{gs}}$$

$$S = \frac{1}{C_L R_L}$$

1D) When $R_L C_L >> R_S C_{gs}$



2. Cadence Spectre Simulation of Common-Source Amplifiers
    a. Schematic and simulation

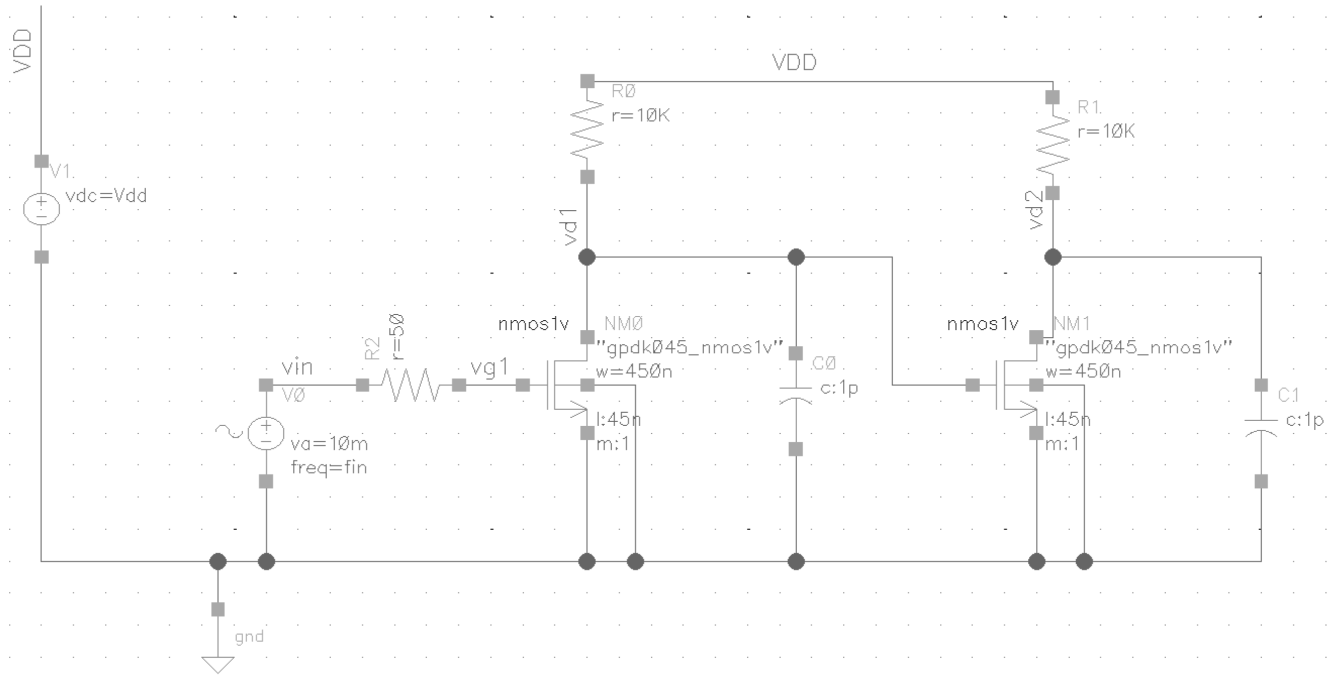


Figure 1: Schematic

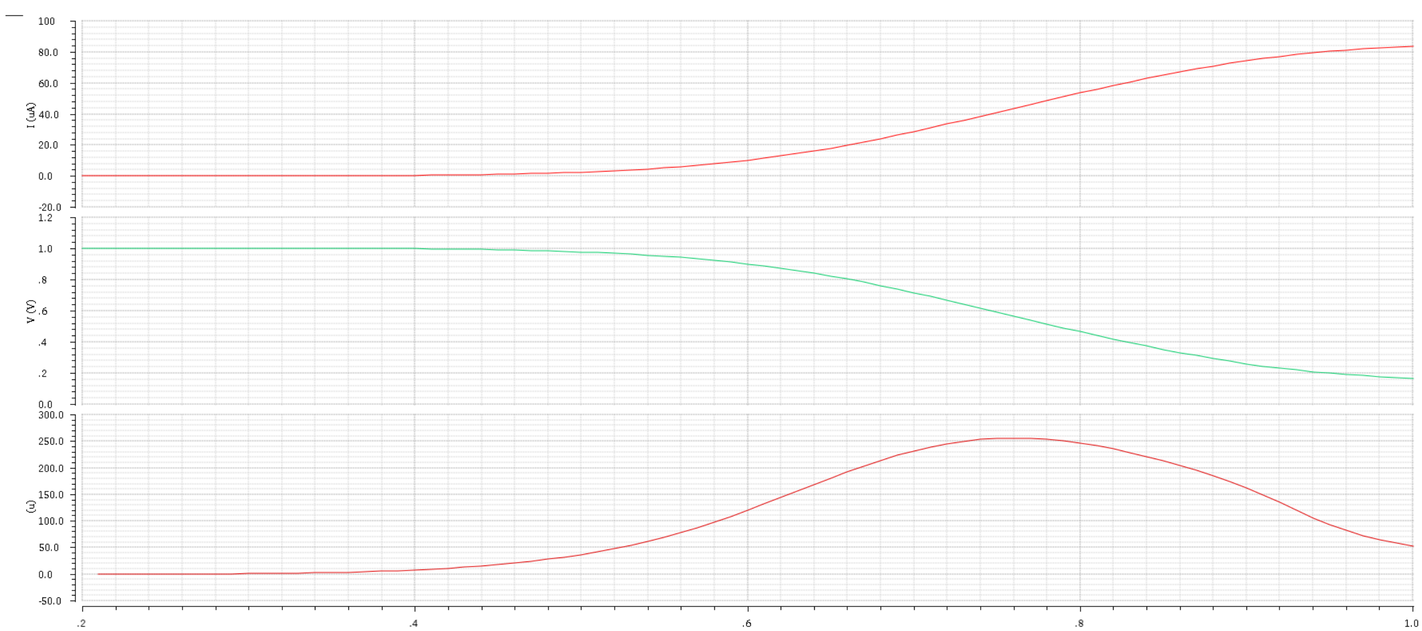


Figure 2: Red curve is Id vs Vg, Green curve is Vd vs Vg and Orange curve is Gm vs Vg.

B.

2b) $g_m = 271.848\,\mu$

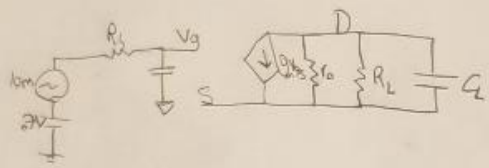
$R_L = 10\,k$

$V_{th} = 619.06\,mV$

$$A = -10\times10^{3} \cdot 271.848\,\mu$$
$$= -(271848\times10^{-3})$$
$$= -2.71848$$

$$A = 20\log(2.71848)$$
$$A = 8.69\,dB$$

2d)



$$\frac{1}{r_o} + \frac{1}{R_L}$$

$$\frac{R_L + r_o}{r_o \cdot R_L} = \frac{1}{R_{eq}} = R_{eq} = \frac{r_o \cdot R_L}{R_L + r_o}$$

2e) $A_1 = \frac{715}{700} = 1.02143 = 20\log(1.02143) = 0.18417\,dB$

$A_2 = \frac{679}{715} = 0.9510$

2f)

$$\omega_{out} = \frac{1}{R_L C_L}$$
$$= \frac{1}{10k \cdot 1\times10^{-12}}$$
$$= \frac{1}{1\times10^{4} \cdot 1\times10^{-12}}$$
$$= \frac{1}{1\times10^{-8}}$$
$$= 1\times10^{8}$$

Actual = 18.1569 MHz

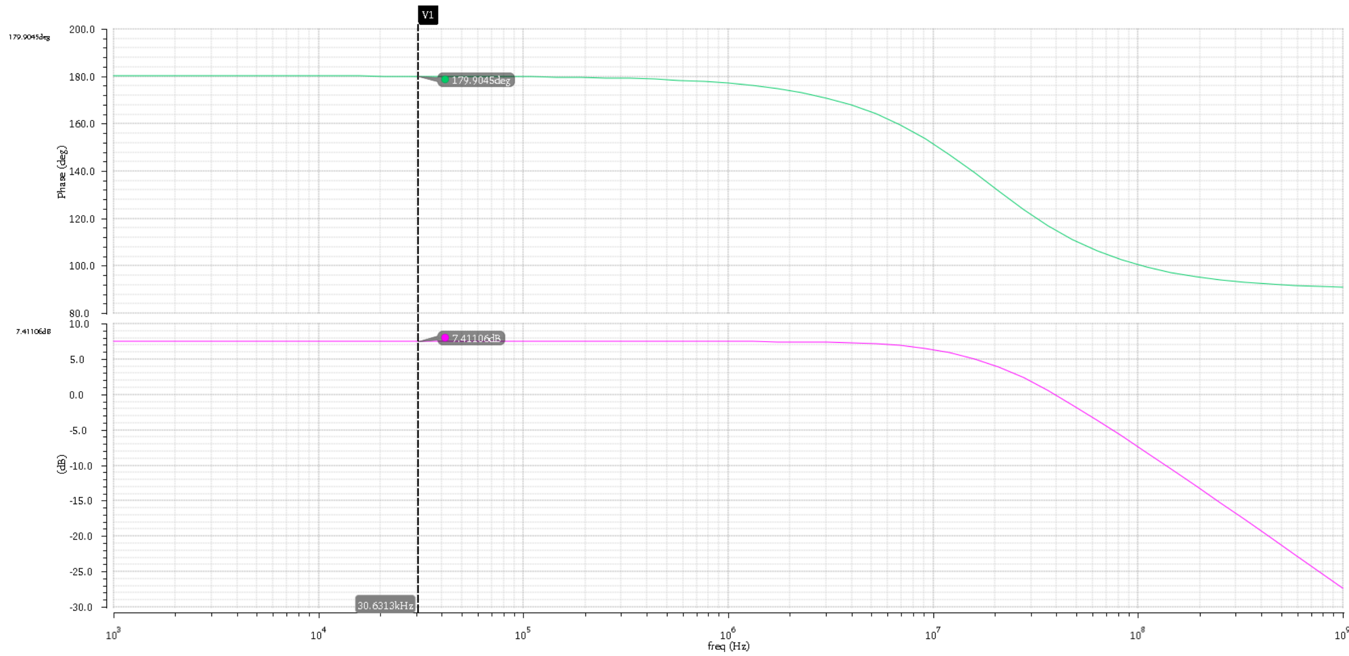


Figure 3: Gain Vs Frequency (pink trace)

b. The reason the calculated result and the simulated result do not agree is because the ro is not infinity. There is a channel length modulation that causes a gain change. This is because ro is in parallel with the load resistance causing the gain to be smaller.

c.

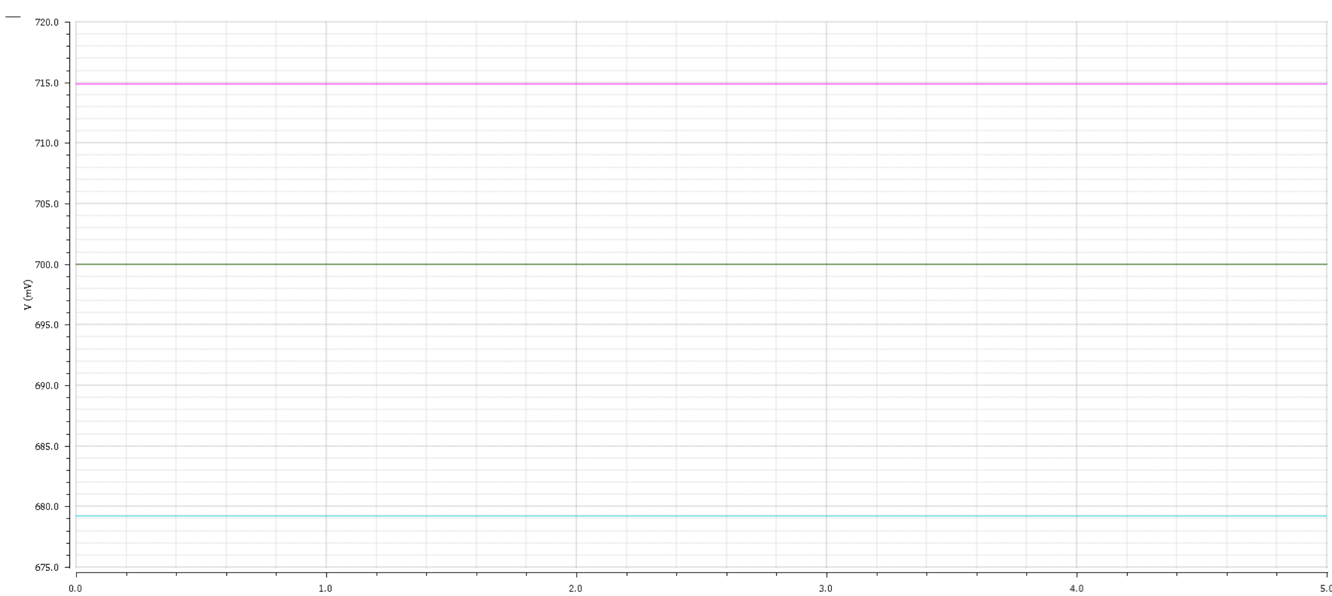


Figure 4: Transient simulation for Vin (Green), Vd1(pink) and Vd2(blue)

d. The results of the calculated poles and the simulated poles do not agree is because the output capacitance is not only the load capacitor. There are other capacitances that contribute to the output capacitance. This causes the pole to take effect at a smaller frequency.

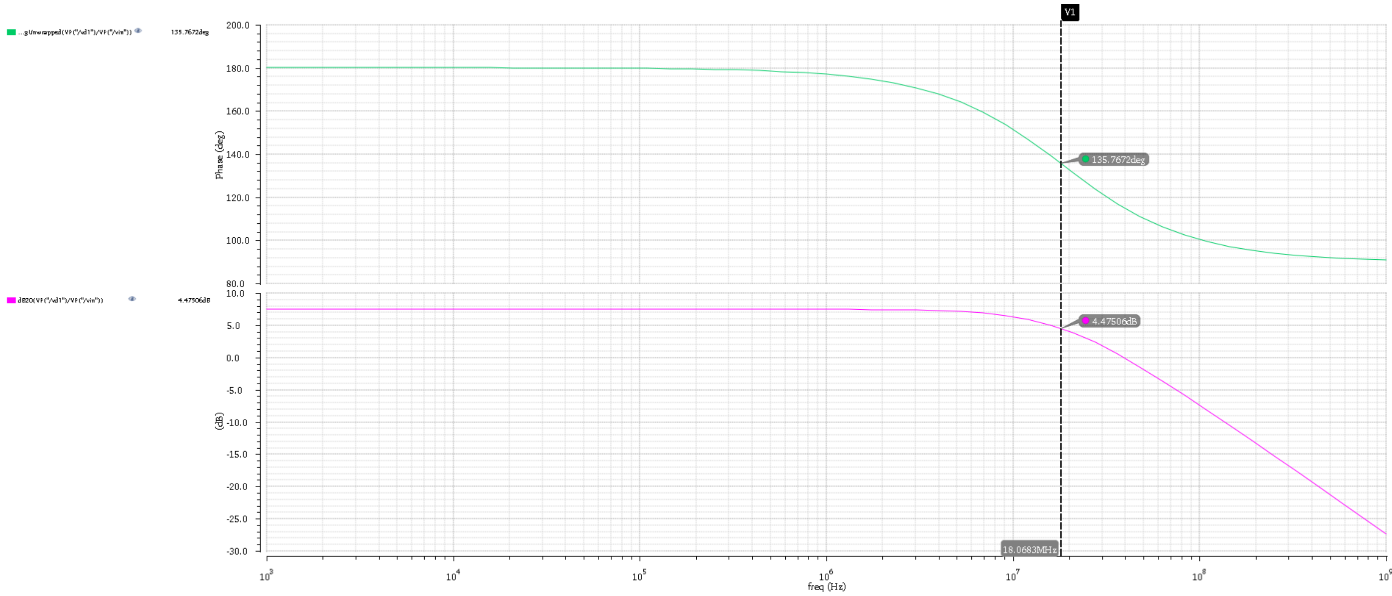
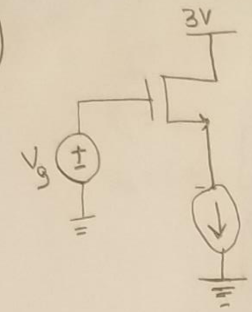


Figure 5: transfer function 3dB point (simulate 18MHZ, Calculated 100MHZ)

3. Body Effect on Threshold Voltage

3)



$V_{T_0} = 0.5V$, $\gamma = 0.4V^{1/2}$ $2\phi_F = 0.9v$, $\mu C_{ox} = 130\,\mu A/V^2$

$\frac{W}{L} = \frac{2\mu}{200n}$

$$V_T = V_{T_0} + \gamma\left(\sqrt{|2\phi_F + V_{SB}|} - \sqrt{|2\phi_F|}\right)$$

$$\gamma = \frac{\sqrt{2q\varepsilon_{si} N_{sub}}}{C_{ox}}$$

$$I_D = \frac{1}{2} k' \frac{W}{L}(V_{gs} - V_{th})^2$$

$$0.6V = 0.5v + (0.4v^{1/2})\left(\sqrt{|0.9v + V_{SB}|} - \sqrt{0.9v}\right)$$

$V_{DD} > V_{gs} - V_{th}$

$$10\mu A = \frac{1}{2}(130\mu A/v^2)\left(\frac{2\mu}{200n}\right)(V_{gs} - V_{Th})^2$$

$$V_T = V_{T_0} + \gamma\sqrt{|2\phi_F + V_{SB}|} - \gamma\sqrt{|2\phi_F|}$$

$$\left(\frac{V_T - V_{T_0} + \gamma\sqrt{|2\phi_F|}}{\gamma}\right)^2 = \left(\frac{\cancel{\gamma}\sqrt{|2\phi_F + V_{SB}|}}{\cancel{\gamma}}\right)^2$$

$$\left(\frac{V_T - V_{T_0} + \gamma\sqrt{|2\phi_F|}}{\gamma}\right)^2 = |2\phi_F + V_{SB}|$$

$$\left(\frac{V_T - V_{T_0} + \gamma\sqrt{|2\phi_F|}}{\gamma}\right)^2 - 2\phi_F = V_{SB} = V_S - \cancel{V_B}^{\,0}$$

$$\left(\frac{.6 - .5 + (0.4)\sqrt{0.9}}{(0.4)}\right)^2 - 0.9 = V_S$$

$$\left(\frac{0.1 + (0.4)(0.94868)}{(0.4)}\right)^2 - 0.9 = V_S$$

$$2.37 - 0.9 = V_S$$

$$1.47 = V_S$$

$V_{DD} + V_{th} > V_{gs}$

$V_{gs} > V_{th}$

$V_g > V_{th} + V_s$

$V_{DD} + V_{th} - V_g > V_s$

$$\sqrt{\frac{2 I_D \cdot L}{K' W}} = \sqrt{(V_{gs} - V_{Th})^2}$$

$$\sqrt{\frac{2 I_D \cdot L}{K' W}} = V_{gs} - V_{th}$$

$$\sqrt{\frac{2 I_D \cdot L}{K' W}} + V_s + V_{th} = V_g$$

$$\sqrt{\frac{2 \cdot 10\times10^{-6} \cdot 200\times10^{-9}}{130\times10^{-6} \cdot 2\times10^{-6}}} + 1.47 + 0.6 = V_g$$

$$\sqrt{\frac{400\times10^{-16}}{260\times10^{-12}}} + 1.47 + 0.6 = V_g$$

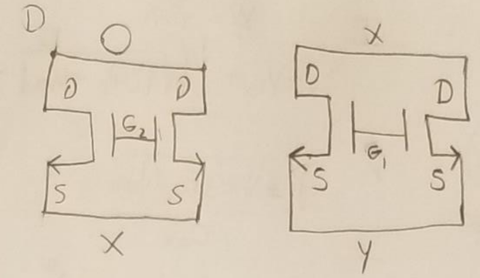
$$\sqrt{\frac{400\times10^{-4}}{260}}$$

$$1.2403\times10^{-4} + 1.47 + 0.6 = V_g$$

$$V_g = 2.07$$

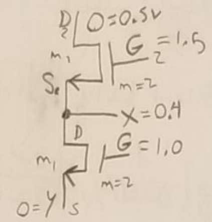
4. Layout & Transistor Capacitors

4)
$V_o = 0.5V$
$V_x = 0.4V$
$V_y = 0V$
$V_{g_1} = 1V$
$V_{g_2} = 1.5V$
$V_{T_0} = 0.7V$
$\gamma = 0$



$V_{Th} = V_{T_0} + \gamma\left(\sqrt{|2\Phi_F - V_{BS}|} - \sqrt{2\Phi_F}\right)$

$V_{Th} = V_{T_0}$ when $\gamma = 0$



b)

$V_{gs_1} > V_{th}$

$V_g - V_{s_{m_1}} > V_{th}$

✓ $1.0 - 0 > .7$

$V_{DS_1} > V_{gs_1} - V_{th}$

✓ $V_D - V_S > .3$

$.4 > .3$

M_1 is in saturation.

$V_{gs_2} > V_{th}$

$V_{g_2} - V_{s_2} > V_{th}$

$1.5 - 0.4 > .7$

✓ $1.1 > .7$

$V_{DS} > V_{g_2} - V_{th}$

$V_D - V_S > (1.1 - .7)$

$0.5 - 0.4 > .4$

✗ $0.1 > 0.4$

M_2 is in linear region.

c) $C_{GC} = W L_{eff} C_{ox}$ $\quad C_{ox} = 7fF/um^2$, $C_{ov} = 1fF/um$, $C_{jw} = 0.01fF/um$ $\quad C_{cb} = 1fF/um^2$ $\quad L_{eff} = 1um - (0.05)2$, $L_{eff} = 0.9$

$C_{gS_{ov}} = W C_{ov}$

$C_{gD_{ov}} = W C_{ov}$

$$\boxed{\begin{gathered} C_{gm_1} = 57fF \\ C_{gm_2} = 83fF \end{gathered}}$$

M_1 is in saturation

$C_{gD} = C_{gDov} = W C_{ov} \Rightarrow 10\lambda(1fF/um) = \frac{10(0.5\,\cancel{um})}{\cancel{um}} \cdot 1fF = 5fF$

$C_{gS} = C_{gSov} + \frac{2}{3} C_{gc} \Rightarrow W C_{ov} + \frac{2}{3}(W L_{eff} C_{ox}) = \frac{10(0.5um \cdot 1fF)}{um} + \frac{2}{3}\frac{\overset{4.5}{\left(10[0.5um] \cdot 0.9um\right)} \cdot 7fF}{\cancel{um^2}} = 5fF + \frac{2}{3}(31.5fF)$

$= 5fF + 21fF$

$= [26fF]2$

$= 52fF$

$C_{gB} = 0$

M_2 is linear region

$C_{gD} = C_{gDov} + \frac{1}{2} C_{gc} = W C_{ov} + \frac{1}{2} W L_{eff} C_{ox} = \frac{10(0.5\,\cancel{um})1fF}{\cancel{um}} + \frac{1}{2}\frac{\left(10[0.5um] \cdot 0.9um\right) \cdot 7fF}{\cancel{um^2}} = 5fF + \frac{1}{2}(31.5fF)$

$C_{gs} = C_{gSov} + \frac{1}{2} C_{gc} = 41.5fF$

$= 5fF + 15.75fF$

$= [20.75]2$

$= 41.5fF$

1d)

$A_S = A_D = WE$ $\qquad C_j = \frac{C_{j0}}{\left(1+\frac{V_{BX}}{\Phi_B}\right)}$ $\qquad C_{jsw}$ $\qquad C_j = 1fF/(um)^2$ $\qquad C_{jsw} = 0.01fF/um$

$P_S = P_D = 2(W+E)$

$C_{SB} = C_{DB} = AC_j + PC_{jsw} = WEC_j + 2(W+E)C_{jsw}$

$$C_Y = \frac{[10\cdot 0.5\cancel{um}][5\cdot 0.5\cancel{um}][1fF]}{(um)^2} + \frac{2(10\cdot 0.5\cancel{um} + 5\cdot 0.5\cancel{um})0.01fF}{\cancel{um}}$$

$C_Y = 5\cdot 2.5\cdot 1fF + 2(7.5)\cdot 0.01fF$

$= 2(12.5fF) + 0.15fF$

$= 25.15fF$

$$C_X = \frac{[10\cdot 0.5\cancel{um}][6\cdot 0.5\cancel{um}][1fF]}{(\cancel{um})^2} + \frac{2[10\cdot 0.5\cancel{um} + 6\cdot 0.5\cancel{um}]0.01fF}{\cancel{um}}$$

$= 2([5\cdot 3]1fF) + 2[5+3]0.01fF$

$= 2(15fF) + 0.16fF$

$= 30.16fF$

$$C_O = \frac{[10\cdot 0.5\cancel{um}][6\cdot 0.5\cancel{um}][1fF]}{(\cancel{um})^2} + \frac{[10\cdot 0.5\cancel{um} + 6\cdot 0.5\cancel{um}]0.01fF}{\cancel{um}}$$

$= [5\cdot 3]1fF + [5+3]0.01fF$

$= 15fF + 0.08fF$

$= 15.08fF$