(1)

Subject .... Date........

Problem Set 1

Problem 1:

a) If the resistivity of Poly-silicon is $10^{-4}\ \Omega.m$ and thickness of Poly-silicon layer is $1\ \mu m$, Calculate the sheet resistance $R_{\square}$

b) If the distance between two metal layers is 100nm and the space between the two metals is filled with silicon oxide ($\varepsilon = 3 * 10^{-11}$ F/m), Calculate the Capacitance Per Unit area

Solution

a)

$$R = \frac{\rho L}{A} = \frac{\rho L}{t * W} = R_{\square} * \frac{L}{W}$$

sheet resistance

$$R_{\square} = \frac{\rho}{t} = \frac{10^{-4}\ \Omega.m}{1\ \mu m} = 100\ \Omega/\square$$

b)

$$C = \frac{\varepsilon A}{t}$$

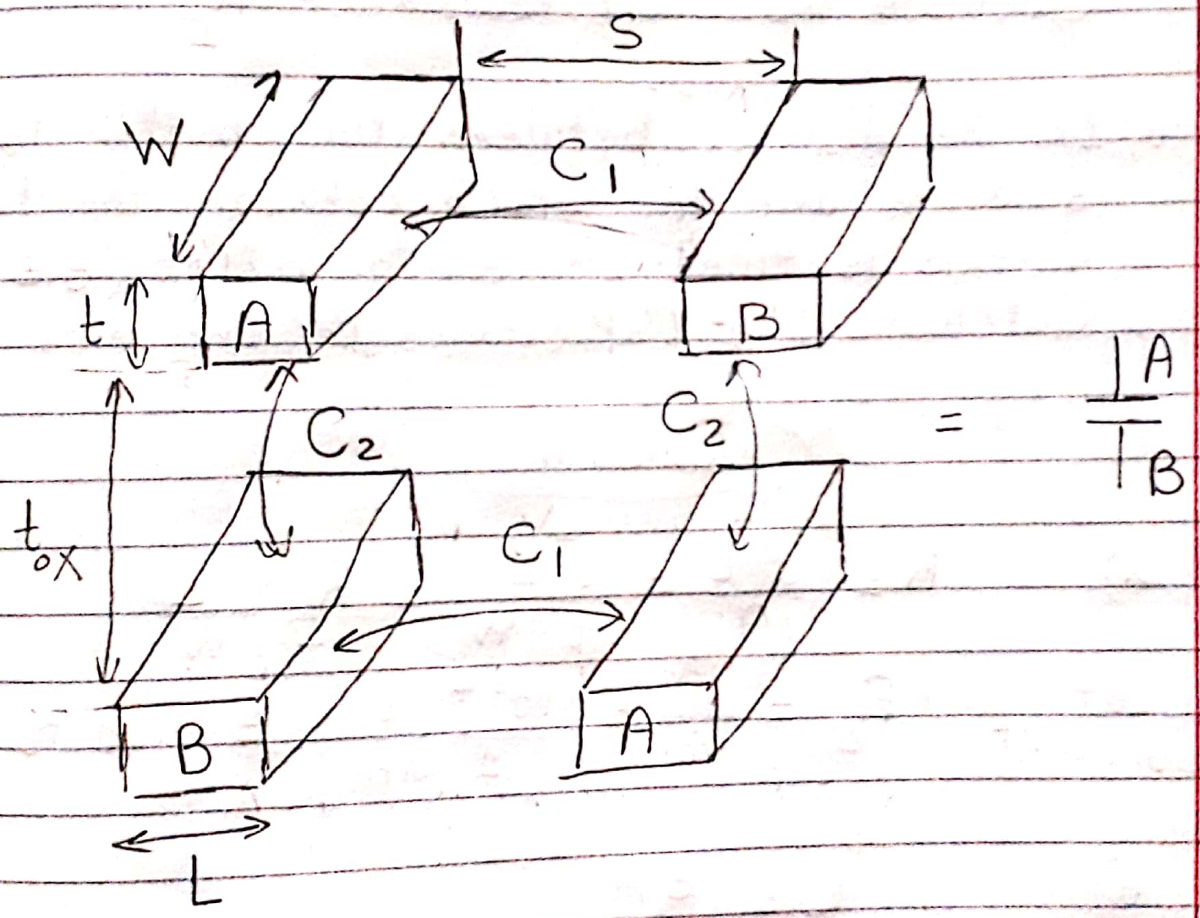
$$\frac{C}{A} = \frac{\varepsilon}{t} = \frac{3 * 10^{-11}\ F/m}{100\ nm} = 0.3\ fF/\mu m^2$$

Capacitance Per Unit area

Scanned with CamScanner

Problem 2:

Find the Value of the Capacitor shown below for $W = 300\,\mu m$, $S = t = t_{ox} = L = 1\,\mu m$, and $\varepsilon = 3 * 10^{-11}$ F/m



$$C_{AB} = 2C_1 + 2C_2$$

$$C_1 = \varepsilon \frac{Wt}{S} \quad \& \quad C_2 = \varepsilon \frac{WL}{t_{ox}}$$

$$\therefore C_{AB} = 2\varepsilon\left(\frac{W\cancel{t}}{\cancel{s}} + \frac{W\cancel{L}}{\cancel{t_{ox}}}\right)$$

$$= 4\varepsilon * W = 4 * 3*10^{-2}\ fF/\mu m * 300\,\mu m$$

$$= 36\ fF$$

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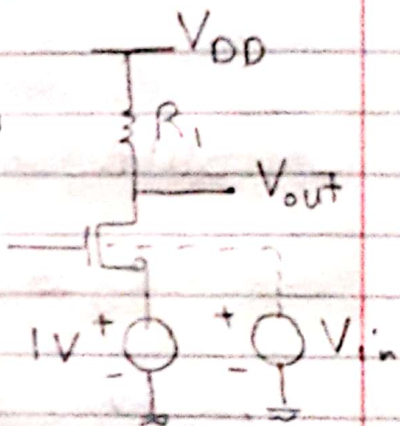
Problem 3:

Sketch V_{out} as a function of V_{in} for the circuit shown with $V_{DD} = 3V$, $\mu_n C_{ox} = 50\ \mu A/V^2$; $V_{TH_0} = 0.8V$, $2\phi_f = 0.7V$, and $\gamma = 0.4\ V^{0.5}$

Solution



(1) $V_{out} = V_{DD} - I_{DS} * R_1 = 3 - I_{DS} R_1$

Assume that the transistor operates in sat region

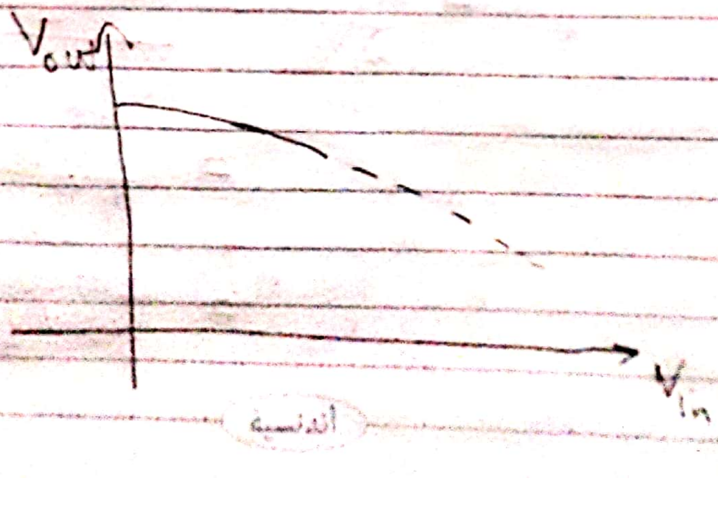
(2) $I_{DS} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th})^2$

$= \frac{1}{2} * 50\ \mu A/V^2 * \frac{W}{L} (1V - V_{th})^2$

(3) $V_{th} = V_{th_0} + \gamma \left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$

$= 0.8 + 0.4 \left(\sqrt{0.7 + 1 - V_{in}} - \sqrt{0.7}\right)$

$V_{in} \uparrow \quad V_{th} \downarrow \quad I_{DS} \uparrow \quad V_{out} \downarrow$



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Problem 4:

An NMos device operating in the sub-threshold region has $\eta = 1.5$. What Variation in V_{GS} results in a tenfold Change in I_D? If $I_D = 10\ \mu A$, Calculate g_m

Solution

In subthreshold region, I_D Can be Written as

$$I_D = I_o \frac{W}{L} e^{\left(\frac{V_{GS} - V_{TH}}{\eta V_T}\right)}$$

$$\therefore V_{GS} = V_{TH} + \eta V_T \ln\left(\frac{I_D}{I_o W/L}\right)$$

$$V_{GS_1} = V_{Th} + \eta V_T \ln\left(\frac{I_{D1}}{I_o W/L}\right)$$

$$V_{GS_2} = V_{Th} + \eta V_T \ln\left(\frac{I_{D2}}{I_o W/L}\right)$$

$$\therefore V_{GS_2} - V_{GS_1} = \eta V_T \ln\left(\frac{I_{D2}}{I_{D1}}\right) = 1.5 * 26\ mV * \ln(10)$$
$$= 89.8\ mV$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{I_o \frac{W}{L} e^{\left(\frac{V_{GS} - V_{TH}}{\eta V_T}\right)}}{\eta V_T}$$

$$= \frac{I_D}{\eta V_T}$$

$$= \frac{10\ \mu A}{1.5 * 26\ mV} = 0.256\ mS$$

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Problem 5:

(a) Show that the transit frequency of a MOS device is given by:

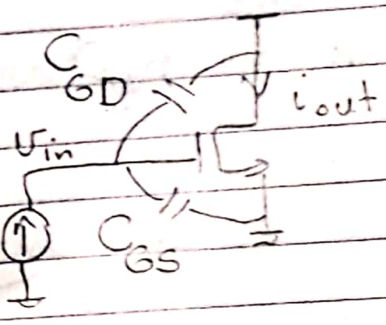
$$f_T = \frac{g_m}{2\pi (C_{GD} + C_{GS})}$$

(b) Calculate the transit frequency for a device in sub-threshold region (weak inversion)

Solution

(a) $i_{out} = g_m v_{in}$

$$= g_m \, i_n * \frac{1}{s(C_{GD}+C_{GS})}$$



$$\therefore \left|\frac{i_{out}}{i_n}\right| = \frac{g_m}{\omega (C_{GD}+C_{GS})}$$

$$@ f_T \longrightarrow \left|\frac{i_{out}}{i_n}\right| = 1$$

$$\therefore f_t = \frac{g_m}{2\pi (C_{GD} + C_{GS})}$$

(b) In sub-threshold: $g_m = \frac{I_D}{\eta V_T}$

$$C_{GD} = C_{GS} = W C_{ov}$$

$$\therefore f_t = \frac{I_D / \eta V_T}{4\pi W C_{ov}} = \frac{I_D}{4\pi \eta V_T W C_{ov}}$$

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

Problem 6:

For the source follower shown, M_1 & M_2 are identical $\mu_n C_{ox} = 50\,\mu A/V^2$, $\left(\frac{W}{L}\right) = \frac{2\,\mu m}{1\,\mu m}$, $V_{Th} = 0.8V$, $V_b = 2V$

$\lambda = 0.02\,V^{-1}$, find:

(a) Gain$\left(\frac{V_{out}}{V_{in}}\right)$ and G_m if $\gamma = 0$ & $\gamma = 0.4$

(b) R_{out} if $\gamma = 0$ & $\gamma = 0.4$

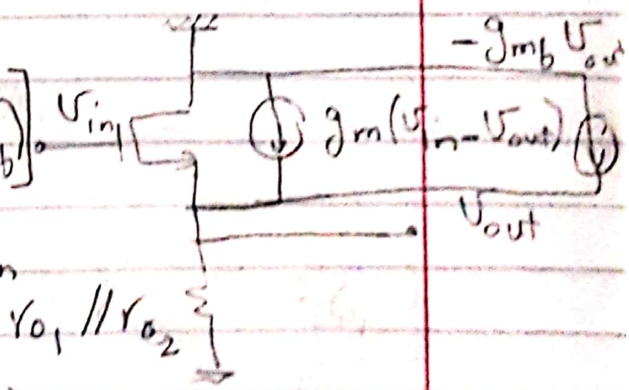
(c) Poles at the input and output. $C_{ox} = 10\,fF/\mu m^2$ and $C_{ov} = 1\,fF/\mu m$

Assume $R_s = 100\,\Omega$ and $C_L = 10\,pF$. Consider C_{gs} and C_{gd} only and use Miller

Solution

(a) Gain:

$$v_{out} = (r_{o_1} // r_{o_2})\left[g_m v_{in} - v_{out}(g_m + g_{mb})\right].$$



$$v_{out}\left[1 + (g_m + g_{mb})(r_{o_1} // r_{o_2})\right] = g_m (r_{o_1} // r_{o_2}) v_{in}$$

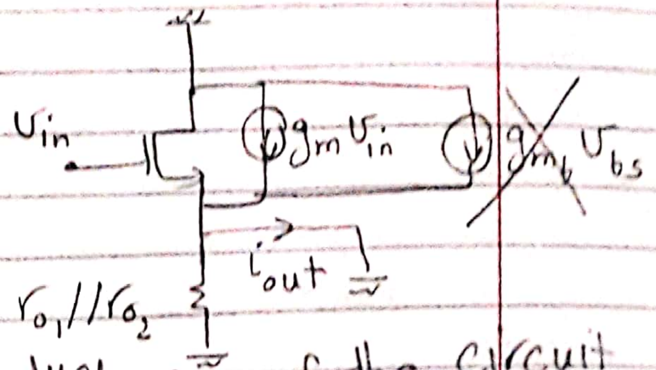
$$\therefore \text{Gain} = \frac{v_{out}}{v_{in}} = \frac{g_m (r_{o_1} // r_{o_2})}{1 + (g_m + g_{mb})(r_{o_1} // r_{o_2})}$$

$$= \frac{g_m}{g_m + g_{mb} + \frac{1}{(r_{o_1} // r_{o_2})}} = \frac{g_m}{g_m + g_{mb} + g_{ds_1} + g_{ds_2}}$$

Gm:

$i_{out} = g_m v_{in}$

$\therefore G_m = \frac{i_{out}}{v_{in}} = g_m$

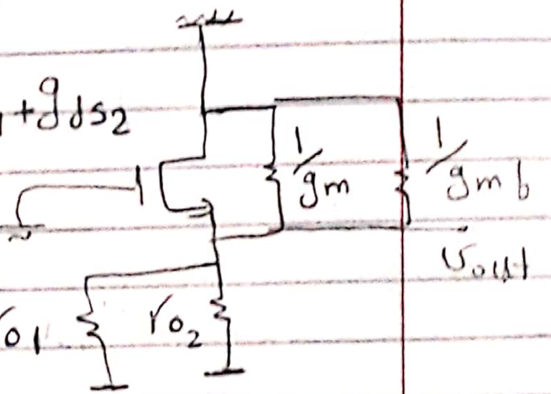


Body effect doesn't affect the overall transconductance of the circuit

(b) Rout:

$G_{out} = g_m + g_{mb} + g_{ds1} + g_{ds2}$

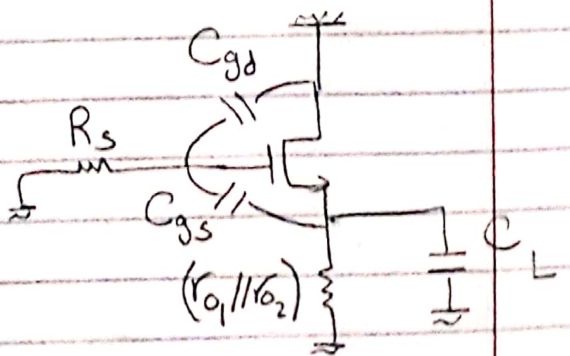
$\therefore R_{out} = \frac{1}{g_m + g_{mb} + g_{ds1} + g_{ds2}}$

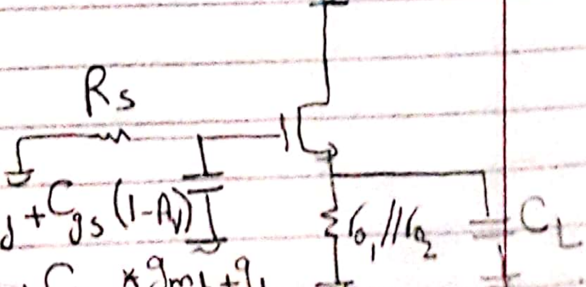


(C)

$\omega_{in} \approx \frac{1}{R_s C_{in}}$

$\omega_{out} \approx \frac{1}{R_{out} C_L}$





$C_{in} = C_{gd} + C_{gs}(1 - A_v)$

$C_{in} = C_{gd} + C_{gs} \times \frac{g_{mb} + g_{ds1} + g_{ds2}}{g_m + g_{mb} + g_{ds1} + g_{ds2}}$