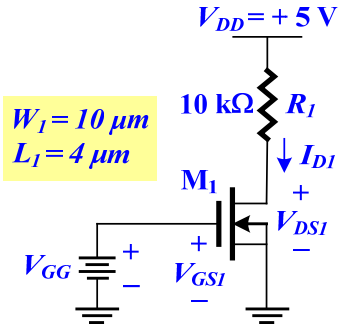
ELECTRÓNICA BÁSICA

El Transistor MOS
Problemas

Problema 1(a)

- M_1 *EOSat*: $V_{GS1} - V_{TON} = V_{DS1}$



$$I_{D1} = \frac{1}{2}\frac{W_1}{L_1}K_n'\left(V_{GS1} - V_{TON}\right)^2$$

$$= \frac{1}{2}\frac{W_1}{L_1}K_n'V_{DS1}^2$$

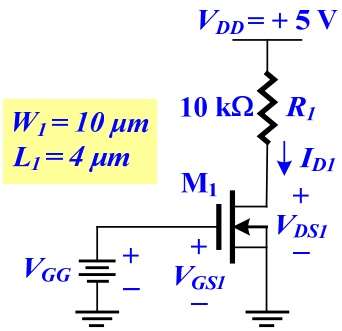
$$= \frac{V_{DD} - V_{DS1}}{R_1}$$

$$V_{DS1}^2 + \frac{5}{7}V_{DS1} - \frac{25}{7} = 0 \quad \rightarrow \quad V_{DS1} = 1.566\,V$$

$$V_{GG} = V_{GS1} = V_{DS1} + V_{TON} = 2.366\,V, \quad I_{D1} = \frac{V_{DD} - V_{DS1}}{R_1} = 343\,\mu A$$

Problema 1(a)

- $V_{GG} = 1\,V, \quad V_{GS1} = 1\,V, \quad M_1 \equiv SAT$:



$$I_{D1} = \frac{1}{2}\frac{W_1}{L_1}K_n'\left(V_{GS1} - V_{TON}\right)^2 = 5.6\ \mu A$$

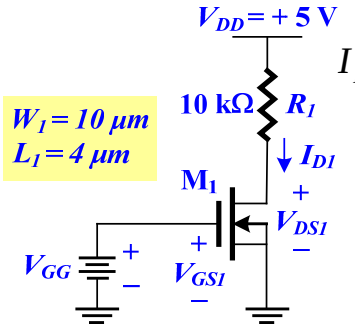
$$V_{DS1} = V_{DD} - I_{D1}R_1 = 4.944\,V$$

Test de saturación :

$$V_{GS1} - V_{TON} = 0.2\,V < V_{DS1} = 4.944\,V$$

Problema 1(a)

- $V_{GG} = 2.5\,V, \quad V_{GS1} = 2.5\,V, \quad M_1 \equiv Lin$:



$$I_{D1} = \frac{W_1}{L_1}K_n'\left(\left(V_{GS1} - V_{TON}\right)V_{DS1} - \frac{1}{2}V_{DS1}^2\right) = \frac{V_{DD} - V_{DS1}}{R_1}$$

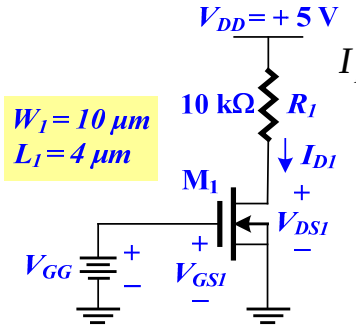
$$V_{DS1}^2 - \left(\frac{5}{7} + 3.4\right)V_{DS1} + \frac{25}{7} = 0$$

$$\rightarrow \quad V_{DS1} = 1.244\,V \quad \rightarrow \quad I_{D1} = 375.6\ \mu A$$

Test de zona lineal : $V_{GS1} - V_{TON} = 1.7\,V > V_{DS1} = 1.244\,V$

Problema 1(a)

- $V_{GG} = 4\,V, \quad V_{GS1} = 4\,V, \quad M_1 \equiv Lin:$



$$I_{D1} = \frac{W_1}{L_1} K_n' \left((V_{GS1} - V_{TON}) V_{DS1} - \frac{1}{2} V_{DS1}^2 \right)$$

$$= \frac{V_{DD} - V_{DS1}}{R_1}$$

$$V_{DS1}^2 - \left(\frac{5}{7} + 6.4 \right) V_{DS1} + \frac{25}{7} = 0$$

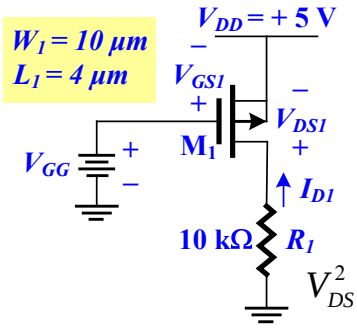
$$\rightarrow \quad V_{DS1} = 0.543\,V \quad \rightarrow \quad I_{D1} = 445.7\ \mu A$$

Test de zona lineal : $V_{GS1} - V_{TON} = 3.2\,V > V_{DS1} = 0.543\,V$

ResPrB.I-5

Problema 1(b)

- M_1 *EOSat*: $V_{GS1} - V_{TOP} = V_{DS1}$



$$I_{D1} = -\frac{1}{2} \frac{W_1}{L_1} K_p' \left(V_{GS1} - V_{TOP} \right)^2$$

$$= -\frac{1}{2} \frac{W_1}{L_1} K_p' V_{DS1}^2 = -\frac{V_{DD} + V_{DS1}}{R_1}$$

$$V_{DS1}^2 - \frac{80}{43} V_{DS1} - \frac{400}{43} = 0, \quad V_{DS1} = -2.258\,V$$

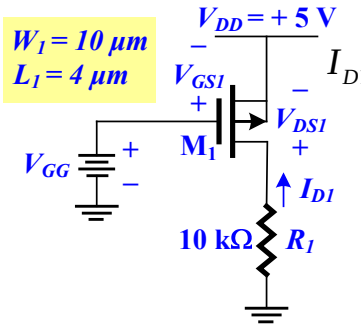
$$V_{GS1} = V_{DS1} + V_{TOP} = -3.158\,V, \quad V_{GG} = V_{DD} + V_{GS1} = 1.842\,V$$

$$I_{D1} = -\frac{V_{DD} + V_{DS1}}{R_1} = -274 \mu A, \quad I_{DP1} = -I_{D1} = 274 \mu A$$

ResPrB.I-6

Problema 1(b)

- $V_{GG} = 1\,V, \quad V_{GS1} = -4\,V, \quad M_1 \equiv LIN$:



$$I_{D1} = -\frac{W_1}{L_1} K_p' \left((V_{GS1} - V_{TOP}) V_{DS1} - \frac{1}{2} V_{DS1}^2 \right)$$

$$= -\frac{V_{DD} + V_{DS1}}{R_1}$$

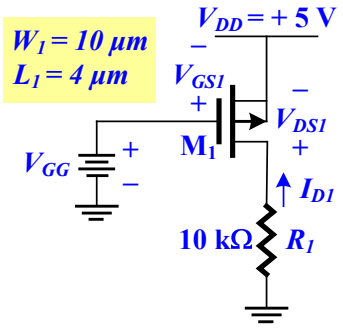
$$V_{DS1}^2 + \left(6.2 + \frac{80}{43} \right) V_{DS1} + \frac{400}{43} = 0$$

$$\rightarrow \quad V_{DS1} = -1.395\,V \quad , \quad I_{D1} = -360.5\,\mu A$$

Test de zona lineal : $V_{GS1} - V_{TOP} = -3.1 < V_{DS1} = -1.395$

Problema 1(b)

- $V_{GG} = 2.5\,V, \quad V_{GS1} = -2.5\,V, \quad M_1 \equiv SAT$:



$$I_{D1} = -\frac{1}{2} \frac{W_1}{L_1} K_p' \left(V_{GS1} - V_{TOP} \right)^2$$

$$= -\frac{V_{DD} + V_{DS1}}{R_1}$$

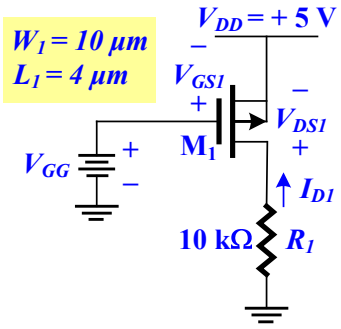
$$\frac{430}{8} 2.56 = 500 + 100 V_{DS1}$$

$$\rightarrow \quad V_{DS1} = -3.624\,V \quad , \quad I_{D1} = -137.6\,\mu A$$

Test de saturacion : $V_{GS1} - V_{TOP} = -1.6\,V > V_{DS1} = -3.624\,V$

Problema 1(b)

- $V_{GG} = 4\,V, \quad V_{GS1} = -1\,V, \quad M_1 \equiv SAT$:



$$I_{D1} = -\frac{1}{2}\frac{W_1}{L_1}K_p'\left(V_{GS1} - V_{TOP}\right)^2$$

$$= -\frac{V_{DD} + V_{DS1}}{R_1}$$

$$\frac{430}{8}0.01 = 500 + 100V_{DS1}$$

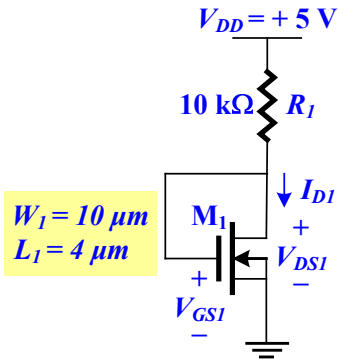
$$\rightarrow \quad V_{DS1} = -4.994\,V \quad , \quad I_{D1} = -0.54\,\mu A$$

Test de saturación : $V_{GS1} - V_{TOP} = -0.1\,V > V_{DS1} = -4.994\,V$

ResPrB.I-9

Problema 2(a)

- $V_{GS1} = V_{DS1} \quad \rightarrow \quad M_1 \equiv SAT$



$$I_{D1} = \frac{1}{2}\frac{W_1}{L_1}K_n'\left(V_{GS1} - V_{TON}\right)^2$$

$$= \frac{V_{DD} - V_{GS1}}{R_1}$$

$$V_{GS1}^2 - \left(1.6 - \frac{5}{7}\right)V_{GS1} + 0.64 - \frac{25}{7} = 0$$

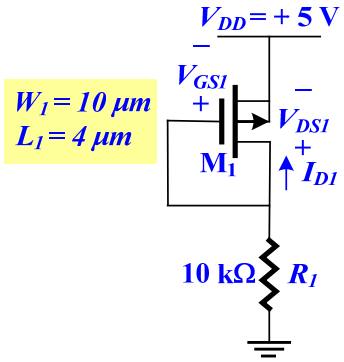
$$\rightarrow \quad V_{GS1} = V_{DS1} = 2.21\,V$$

$$\rightarrow \quad I_{D1} = \frac{V_{DD} - V_{DS1}}{R_1} = 279\,\mu A$$

ResPrB.I-10

Problema 2(b)

- $V_{GS1} = V_{DS1} \quad \rightarrow \quad M_1 \equiv SAT$



$$I_{D1} = -\frac{1}{2}\frac{W_1}{L_1}K_p'\left(V_{GS1} - V_{TOP}\right)^2$$

$$= -\frac{V_{DD} + V_{GS1}}{R_1}$$

$$V_{GS1}^2 + \left(1.8 - \frac{80}{43}\right)V_{GS1} + 0.81 - \frac{400}{43} = 0$$

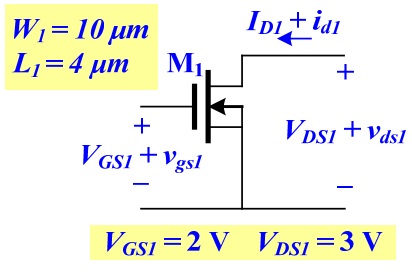
$$\rightarrow \quad V_{GS1} = V_{DS1} = -2.884\,V$$

$$\rightarrow \quad I_{D1} = \frac{-V_{DD} - V_{DS1}}{R_1} = -211.6\,\mu A$$

Problema 3(a)

- $M_1 \equiv SAT : V_{GS1} - V_{TON} = 1.2\,V < V_{DS1} = 3\,V$

$$I_{D1} = \frac{1}{2}\frac{W_1}{L_1}K_n'\left(V_{GS1} - V_{TON}\right)^2\left(1 + \lambda_n V_{DS}\right) = 204\ \mu\text{A}$$



$$g_m = \sqrt{2\frac{W}{L}K_n' I_{D1}\left(1 + \lambda_n V_{DS1}\right)}$$

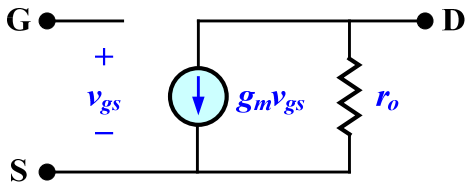
$$= 340\,\mu\text{A/V}$$

$$g_{ds} = \frac{\lambda_n I_{D1}}{\left(1 + \lambda_n V_{DS1}\right)} = 0.806\ \mu\text{A/V}$$

$$r_{ds} = g_{ds}^{-1} = 1.24\,\text{M}\Omega$$

Problema 3(a)

- Circuito equivalente de pequeña señal en LF:



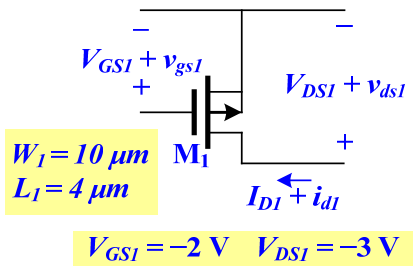
$$g_m = 340\,\mu\text{A/V} \qquad r_o = 1.24\,\text{M}\Omega$$

ResPrB.I-13

Problema 3(b)

- $M_1 \equiv SAT : V_{GS1} - V_{TOP} = -1.1\,V > V_{DS1} = -3\,V$

$$I_{D1} = -\frac{1}{2}\frac{W_1}{L_1}K_p'\left(V_{GS1} - V_{TOP}\right)^2\left(1 - \lambda_p V_{DS}\right) = -66.4\ \mu\text{A}$$



$$g_m = \sqrt{2\frac{W}{L}K_p'\left|I_{D1}\right|\left(1 - \lambda_p V_{DS1}\right)}$$
$$= 120.7\,\mu\text{A/V}$$

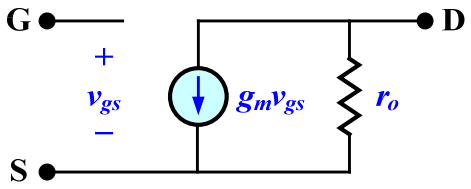
$$g_{ds} = \frac{\lambda_p\left|I_{D1}\right|}{\left(1 - \lambda_p V_{DS1}\right)} = 0.455\,\mu\text{A/V}$$

$$r_{ds} = g_{ds}^{-1} = 2.2\,\text{M}\Omega$$

ResPrB.I-14

Problema 3(b)

- Circuito equivalente de pequeña señal en LF:



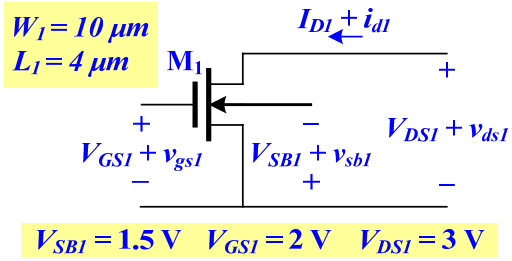
$$g_m = 120.7\,\mu\text{A/V} \qquad r_o = 2.2\,\text{M}\Omega$$

ResPrB.I-15

Problema 3(c)

- $$V_{TN} = V_{TNO} + \gamma_n\left(\sqrt{2\Phi_F + V_{SB}} - \sqrt{2\Phi_F}\right) = 1.123\,V$$

$$M_1 \equiv SAT : V_{GS1} - V_{TN} = 0.877\,V < V_{DS1} = 3\,V$$



$$I_{D1} = \frac{1}{2}\frac{W_1}{L_1}K_n'\left(V_{GS1} - V_{TN}\right)^2\left(1 + \lambda_n V_{DS}\right) = 108.9\ \mu\text{A}$$

ResPrB.I-16

Problema 3(c)

- Modelo pequeña señal:

$$g_m = \sqrt{2\frac{W}{L}K_n' I_{D1}\left(1+\lambda_n V_{DS1}\right)} = 248.4\,\mu\text{A/V}$$

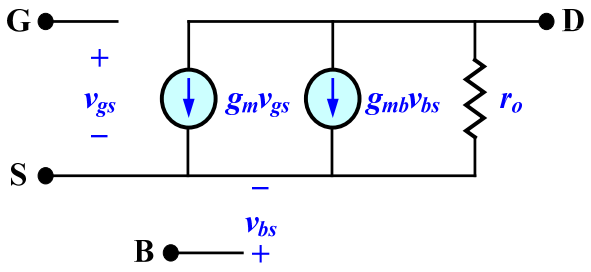
$$g_{mb} = \frac{\gamma_n g_m}{2\sqrt{2\Phi_F + V_{SB}}} = 41.87\ \mu\text{A/V}$$

$$g_{ds} = \frac{\lambda_n I_{D1}}{\left(1+\lambda_n V_{DS1}\right)} = 0.43\ \mu\text{A/V}, \quad r_{ds} = g_{ds}^{-1} = 2.32\,\text{M}\Omega$$

ResPrB.I-17

Problema 3(c)

- Circuito equivalente de pequeña señal:



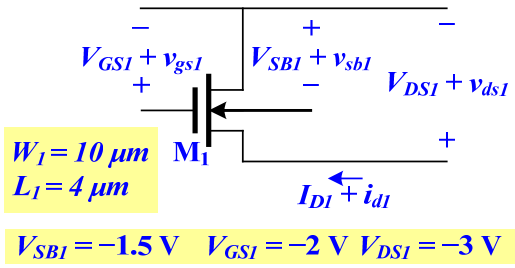
$$g_m = 248.4\,\mu\text{A/V} \qquad g_{mb} = 41.87\ \mu\text{A/V} \qquad r_o = 2.32\,\text{M}\Omega$$

ResPrB.I-18

Problema 3(d)

- $$V_{TN} = V_{TP} - \gamma_p\left(\sqrt{2|\Phi_F| - V_{SB}} - \sqrt{2|\Phi_F|}\right) = -1.273\,V$$

$$M_1 \equiv SAT : V_{GS1} - V_{TP} = -0.727\,V > V_{DS1} = -3\,V$$



$V_{SB1} = -1.5$ V $V_{GS1} = -2$ V $V_{DS1} = -3$ V

$$I_{D1} = -\frac{1}{2}\frac{W_1}{L_1}K_p'\left(V_{GS1} - V_{TP}\right)^2\left(1 - \lambda_p V_{DS}\right) = -29\ \mu\text{A}$$

Problema 3(d)

- Modelo pequeña señal:

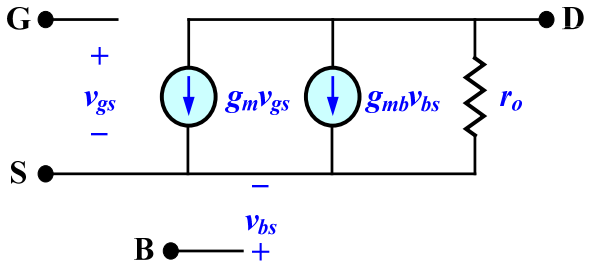
$$g_m = \sqrt{2\frac{W}{L}K_p'|I_{D1}|\left(1 - \lambda_p V_{DS1}\right)} = 79.7\,\mu\text{A/V}$$

$$g_{mb} = \frac{\gamma_p\, g_m}{2\sqrt{2|\Phi_F| - V_{SB}}} = 15.7\ \mu\text{A/V}$$

$$g_{ds} = \frac{\lambda_p|I_{D1}|}{\left(1 - \lambda_p V_{DS1}\right)} = 0.2\ \mu\text{A/V}, \quad r_{ds} = g_{ds}^{-1} = 5\,\text{M}\Omega$$

Problema 3(d)

- Circuito equivalente de pequeña señal:

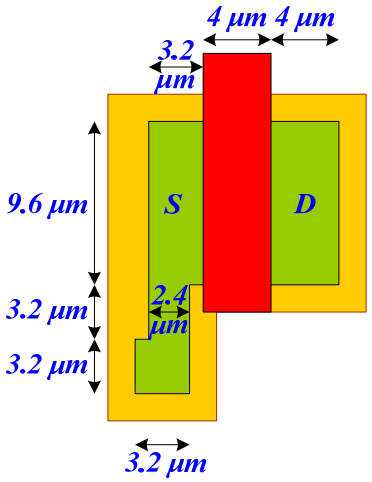


$g_m = 79.7\,\mu\text{A/V}$ $\quad g_{mb} = 15.7\,\mu\text{A/V}$ $\quad r_o = 5\,\text{M}\Omega$

ResPrB.I-21

Problema 4(a)

- Parámetros de geometría:



$W = 9.6\,\mu\text{m}$

$L = 4\,\mu\text{m}$

$A_S = 48.64\,\mu\text{m}^2$

$P_S = 40\,\mu\text{m}$

$A_D = 38.4\,\mu\text{m}^2$

$P_D = 27.2\,\mu\text{m}$

ResPrB.I-22

Problema 4(a)

- Capacidades de puerta (M saturado):

$$C_{gs} = \frac{2}{3} WLC_{ox} + WC_{gso} = 46.2 \text{ fF}$$

$$C_{gd} = WC_{gdo} = 1.92 \text{ fF} \qquad C_{gb} = LC_{gbo} = 0.4 \text{ fF}$$

- Capacidades de drenador y fuente:

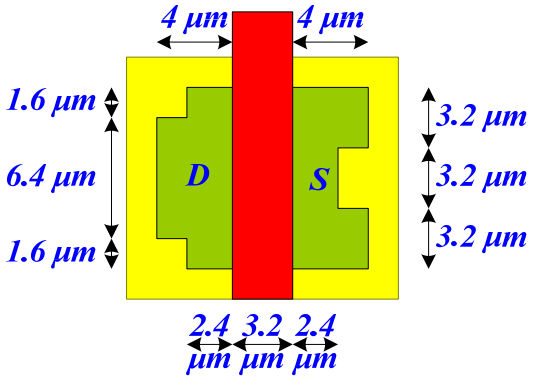
$$C_{db} = \frac{C_j A_D}{\left(1 + \left(V_{DB}/\phi_B\right)\right)^{m_j}} + \frac{C_{jsw} P_D}{\left(1 + \left(V_{DB}/\phi_B\right)\right)^{m_{jsw}}} = 10 \text{ fF}$$

$$C_{sb} = \frac{C_j A_S}{\left(1 + \left(V_{SB}/\phi_B\right)\right)^{m_j}} + \frac{C_{jsw} P_S}{\left(1 + \left(V_{SB}/\phi_B\right)\right)^{m_{jsw}}} = 20 \text{ fF}$$

ResPrB.I-23

Problema 4(b)

- Parámetros de geometría:



$$W = 9.6\,\mu\text{m}$$

$$L = 3.2\,\mu\text{m}$$

$$A_S = 33.28\,\mu\text{m}^2$$

$$P_S = 30.4\,\mu\text{m}$$

$$A_D = 33.28\,\mu\text{m}^2$$

$$P_D = 27.2\,\mu\text{m}$$

ResPrB.I-24

Problema 4(b)

- Capacidades de puerta (M saturado):

$$C_{gs} = \frac{2}{3} WLC_{ox} + WC_{gso} = 37.35 \text{ fF}$$

$$C_{gd} = WC_{gdo} = 1.92 \text{ fF} \qquad C_{gb} = LC_{gbo} = 0.32 \text{ fF}$$

- Capacidades de drenador y fuente:

$$C_{db} = \frac{C_j A_D}{\left(1 + \left(\left|V_{DB}/\phi_B\right|\right)\right)^{m_j}} + \frac{C_{jsw} P_D}{\left(1 + \left(\left|V_{DB}/\phi_B\right|\right)\right)^{m_{jsw}}} = 9.156 \text{ fF}$$

$$C_{sb} = \frac{C_j A_S}{\left(1 + \left(\left|V_{SB}/\phi_B\right|\right)\right)^{m_j}} + \frac{C_{jsw} P_S}{\left(1 + \left(\left|V_{SB}/\phi_B\right|\right)\right)^{m_{jsw}}} = 14.187 \text{ fF}$$