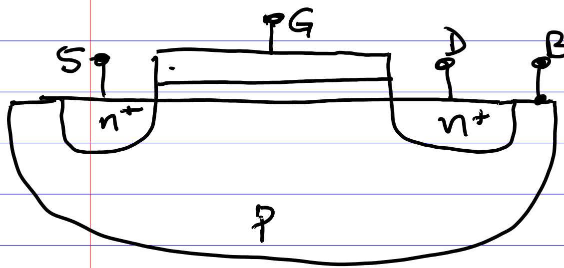
Electrónica Fundamental

Trasistor MOS

Práctico 5

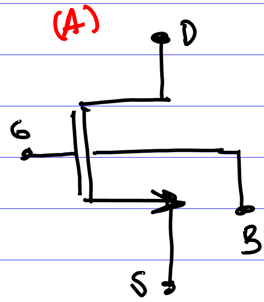
Dispositivo MOS

- canal n

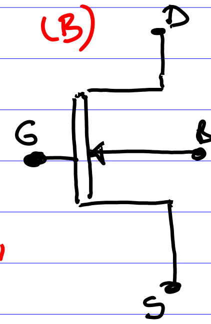


símbolos

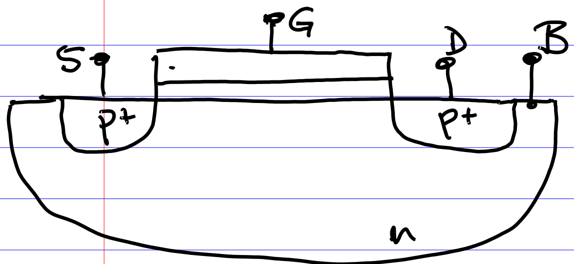
(A)



(B)

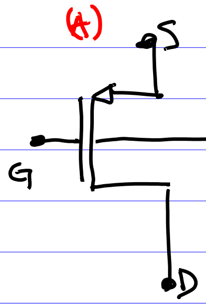


- canal p

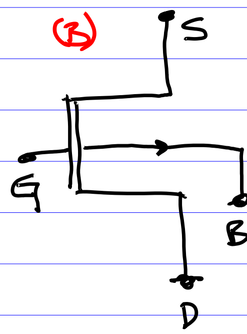


símbolos

(A)

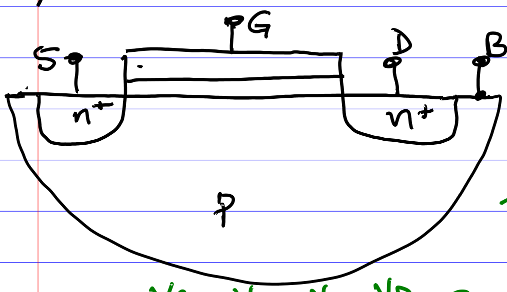


(B)



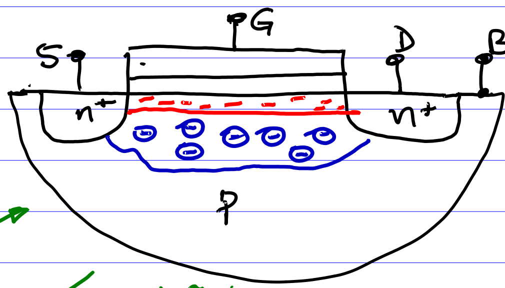
Regiones de Operación

(0) transistor cortado



$V_G = V_D = V_S = V_B = 0$

(1) Zona lineal

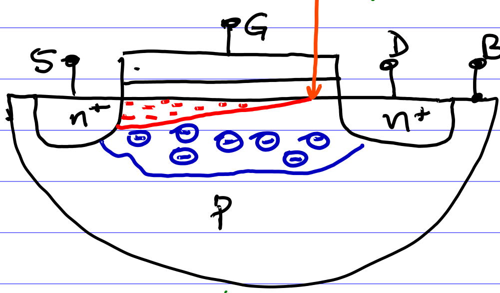


$V_D \cong V_B = V_S = 0$

$V_G > 0 \qquad (V_G > V_{t0})$

(2) Zona Saturación

V_p



V_p: Votage de Pinch-off

Voltge en el canal en el cual la carga de inversión se anula.

$V_B = V_S = 0$

$V_G > 0 \qquad (V_G > V_{t0})$

$V_p = f(V_{GB})$

$$V_p = \frac{V_{GB} - V_{t0}}{1+\delta}$$

Ver hoja ec. transistor MOS

Parámetros generales:

μ: Movilidad de los portadores (electrones para nMOS y huecos para pMOS)

C_{ox}: Capacidad del óxido por unidad de área (igual a ε_{ox}/t_{ox}, siendo ε_{ox} la constante dieléctrica del óxido y t_{ox} el espesor del óxido)

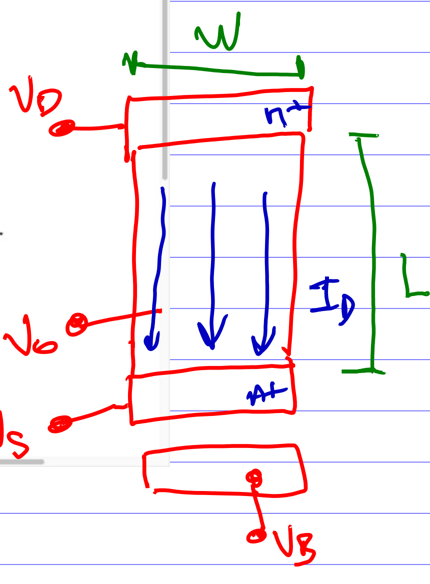
W: ancho del canal

L: largo del canal

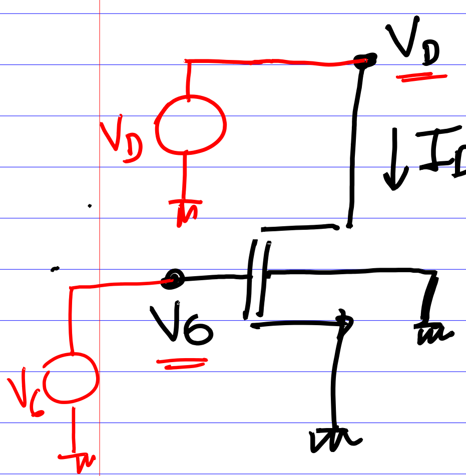
$$\beta = \mu . C_{ox} . \frac{W}{L}$$

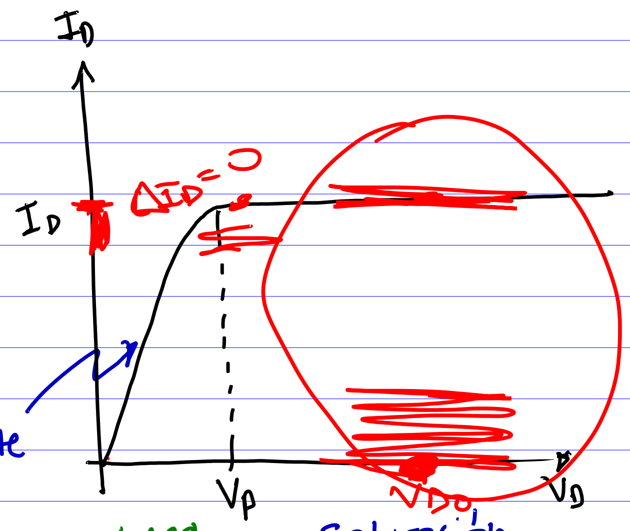
V_{t0}: tensión umbral a tensión source sustrato nula

δ: parámetro de linealización del efecto de sustrato; ((1+δ) también es denominado λ y n).



Ensayo NMOS



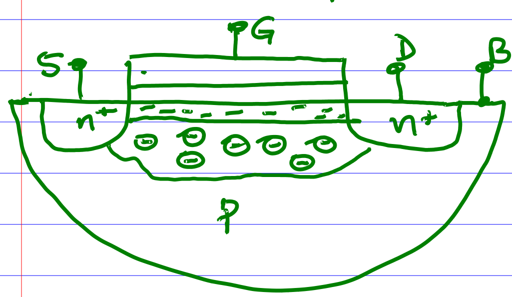


pendiente $\propto \frac{1}{R_{DS}}$

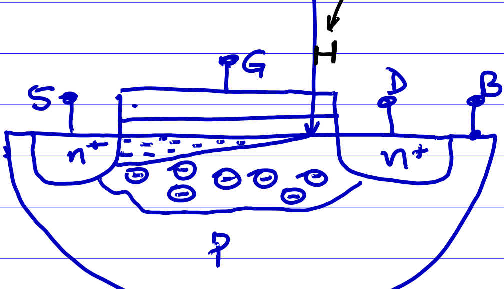
lineal — saturación

Existe carga de inversion (Q_i) de source (S) a drain (D)

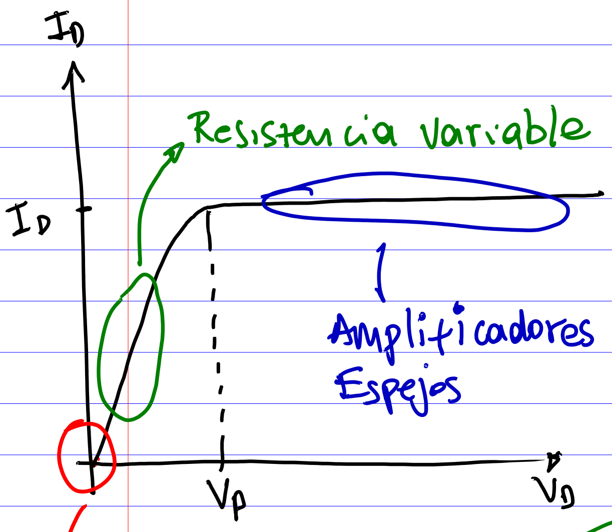
Existe región del canal para la cual "no hay" Q_i



V_p



Ecuaciones



Resistencia variable

Amplificadores
Espejos

$V_p < V_D$

Zona Lineal:

$$I_D = \beta\left[(V_G - V_{t0}).(V_D - V_S) - \frac{(1+\delta)}{2}\left(V_D^{\,2} - V_S^{\,2}\right)\right]$$

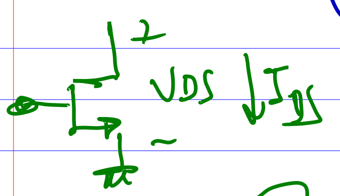
Condiciones: $V_S < V_P \Leftrightarrow V_G > V_{t0} + (1+\delta).V_S$

$V_D < V_P$

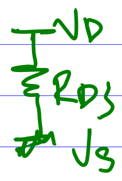
Ver hoja de ecuaciones

llaves analogicas

$\hookrightarrow I_D \simeq \beta\,(V_{GB} - V_{t0})\,V_{DS}$



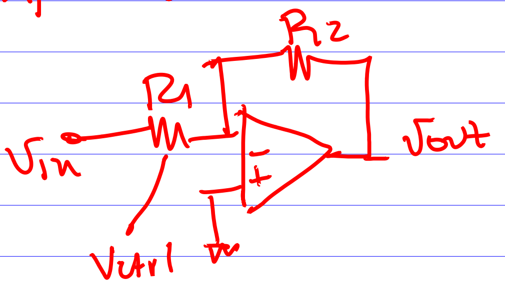
$R_{DS} = \frac{V_{DS}}{I_{DS}} \cong \frac{1}{\beta(V_{GB} - V_{t0})}$



$\left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{DS}\cong 0} = \beta\,(V_{GB} - V_{t0})$ // R_{DS}

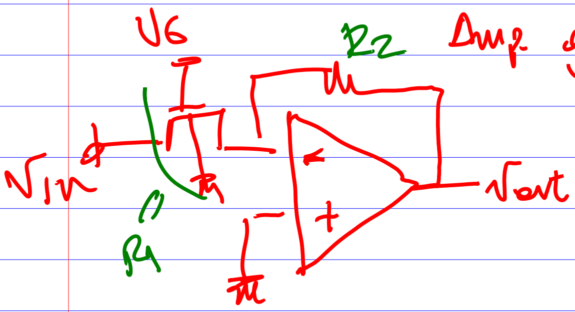
$R_{DS} = f(V_{GB})$

Aplicación

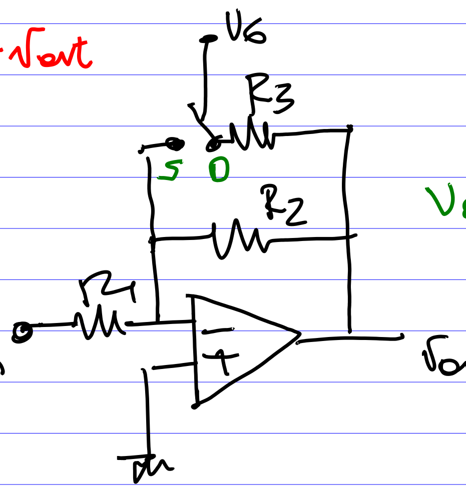


$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$

$\hookrightarrow f(V_{ctrl})$



Amp. ganancia variable



Ejemplo 2

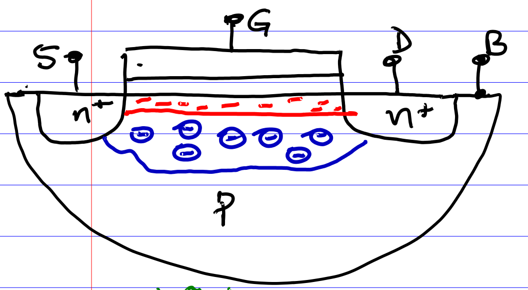
Amp ganancia variable

Usando llave

$V_G > V_{t0} \rightarrow$ Gain $= -\frac{R_3 \| R_2}{R_1}$

$V_G < V_{t0}$

Gain $= -\frac{R_2}{R_1}$



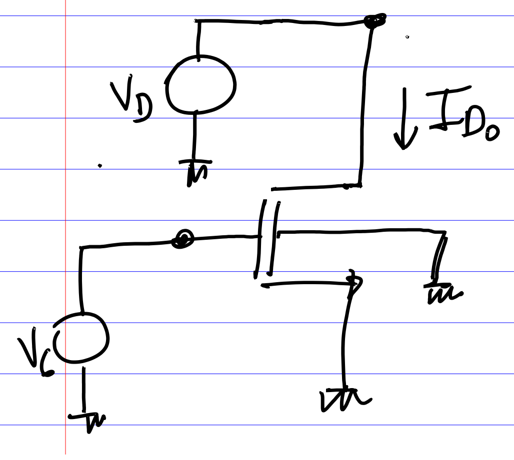
$V_D \cong V_B = V_S = 0$
$V_G > 0$ $(V_G > V_{t0})$

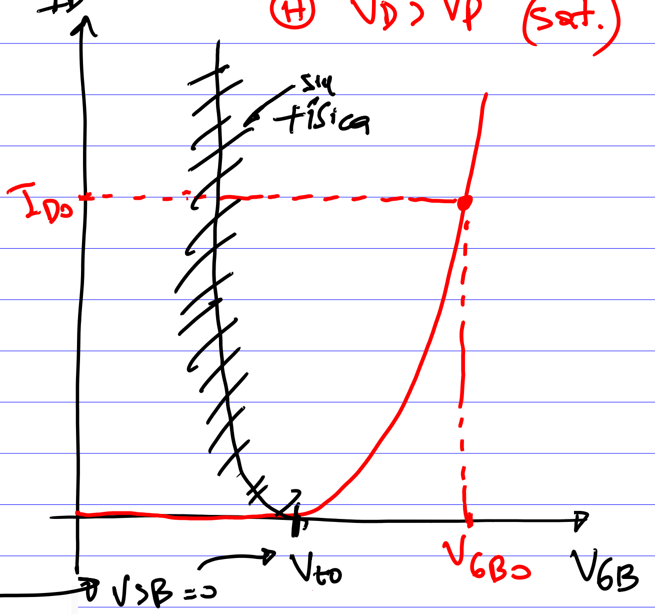
Bulk = vss

$\Rightarrow R_{on} \ll R_3$

$\hookrightarrow$ como diseñador

Ensayo NMOS (II)





(+) $V_D > V_P$ (Sat.)

Zona Saturación:

$$I_D = \frac{\beta}{2(1+\delta)}\left(V_G - V_{t0} - (1+\delta).V_S\right)^2$$

I_D no depende de V_D

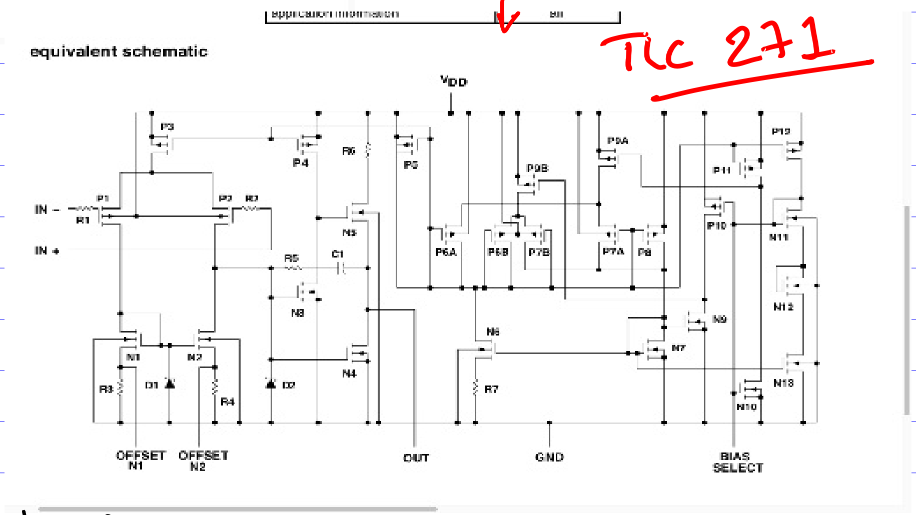
↓

Amplificación

Condiciones: $V_S < V_P \Leftrightarrow V_G > V_{t0} + (1+\delta).V_S)$

$\underline{V_D \geq V_P}$

TLC 271



Hoja de ecuaciones.

3 sets de ecuaciones para

$I_D = f(V_G, V_S, V_B, V_D)$

- NMOS Referido a V_B (1)
- NMOS Ref. a V_S (2)
- PMOS Ref. a V_B. (3)

Ejemplo pasar de (1) a (2)

$$I_D = \frac{\beta}{2(1+\delta)}\left(V_{GB} - V_{to} - (1+\delta)V_{SB}\right)^2 \quad \text{de (1)} \quad @ \text{Sat}$$

↓ cambio variable

$$I_D = \frac{\beta}{2(1+\delta)}\Big(\underbrace{V_{GB} - V_{SB}}_{=V_{GS}} - \underbrace{(V_{to} + \delta V_{SB})}_{=V_T}\Big)^2$$

$$I_D = \frac{\beta}{2(1+\delta)}\left(V_{GS} - V_T\right)^2 \quad \text{de (2)} \quad @ \text{Sat}.$$

Ejercicio 2 (5.56)

El objetivo de este ejercicio es estudiar y ejercitar las ecuaciones del transistor MOS en circuitos sencillos. Los circuitos mostrados en las Figuras 2.1, 2.2 y 2.3 se caracterizan por $V_{t0} = 0.8V$, $\beta = 0.5mA/V^2$ y $\delta = 0$.

(a) Calcule cuánto valen V_1 y V_5

(b) Muestre que el transistor de la Figura 2.3 siempre está saturado y calcule el valor de V_6.

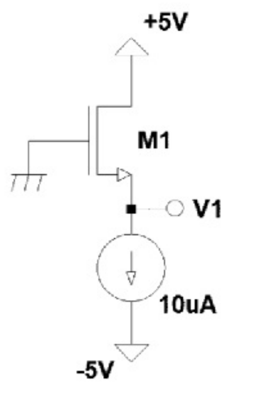


Figura 2.1

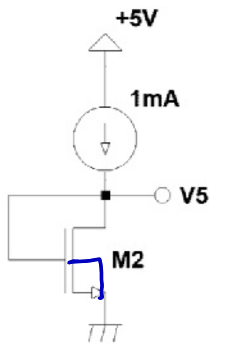


Figura 2.2

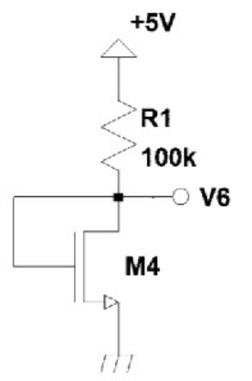
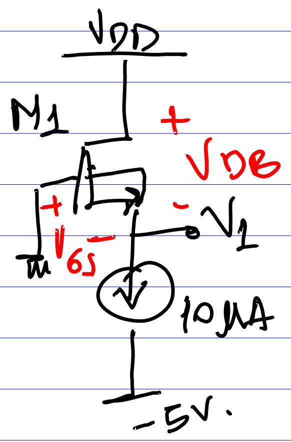


Figura 2.3

$V_{t0} = 0.8V$

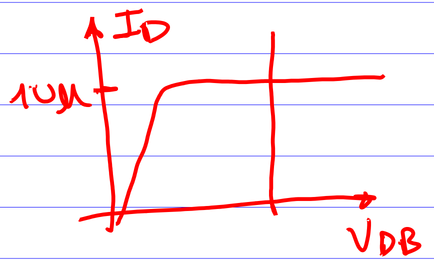
$\beta = 0.5 \frac{mA}{V^2}$

$\delta = 0$



$V_G = 0$

$V_D = V_{DD}$



(H) M1: Saturado?

$I_D = \frac{\beta}{2(1+\cancel{\delta})}\left(V_{GB} - V_{t0} - \cancel{(1+\delta)V_{SB}}\right)^2$, $\delta = 0$, $V_{SB} = 0$

$$\boxed{I_D = \beta/2\,(V_{GB} - V_{t0})^2}$$

M1: Saturado?

- $V_P > V_{SB} = 0$

$V_{GB} > V_{t0} = 0.8V$

$V_{GB} = V_G - V_B$, $V_G = 0$

$V_P = \frac{V_{GB} - V_{t0}}{1+\delta} = V_{GB} - V_{t0}$ → $V_P = \sqrt{\frac{2I_D}{\beta}} > 0$

⇒ $\boxed{V_P > V_{SB}}$ *

cond. de canal.

$V_P < V_{DB}$?

$V_P = V_{GB} - V_{t0} \overset{?}{<} V_{DB} \Rightarrow -V_{t0} < V_{DB} - V_{GB} = \underbrace{V_D}_{V_{DD}} - \cancel{V_B} - (\underbrace{V_G}_{0} - \cancel{V_B})$

⇒ $-V_{t0} < V_{DD}$ ✓ → $\boxed{V_P < V_{DB}}$ **

* y ** ⇒ de saturación OK!

$V_1 = ?$

→ $I_D = \frac{\beta}{2}(V_{GB} - V_{t0})^2$ → $V_{GB} = \underbrace{V_{t0}}_{0.8V} + \underbrace{\sqrt{\frac{2I_D}{\beta}}}_{200mV}$

$V_{GB} = 1V$.

→ $\boxed{V_1 = V_G - V_{GB} = -1V}$

termino de verificar que M1 está saturado

$V_{DB} = V_{DD} - V_1 = 6V$

$V_P = 200mV$

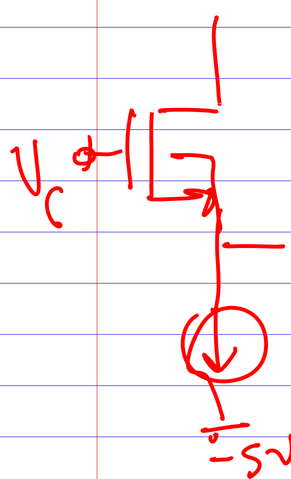
→ $V_{DB} > V_P$ OK!

M1 Saturado

Duda surgida en clase → Porqué $V_1 = V_G - V_{GB}$?

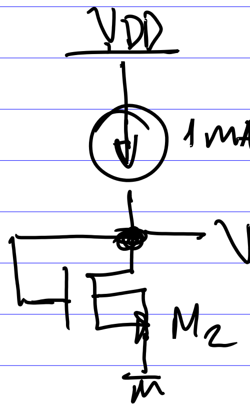
$V_1 = V_G - \underbrace{V_{GB}}_{V_G - V_B} = \cancel{V_G} - \cancel{V_G} + V_B$

→ $V_1 = V_B$



$V_1 = V_B$

(ii)



$M_2: V_D = V_G$

↳ M_2: "Diodo"

M_2 saturado!!

$-V_P < V_{DB}$

$$V_P = \frac{V_{GB}-V_{to}}{1+\cancel{\delta}} = \underbrace{V_{GB}}_{\overset{||}{V_{DB}}} - V_{to} = V_{DB} - V_{to}$$

$$V_{DB} \overset{?}{>} V_P = V_{DB} - V_{to}$$

↳ $\cancel{V_{DB}} > \cancel{V_{DB}} - V_{to}$ → $\boxed{V_{to} > 0}$

Uso ecs. Ref. a Bulk!!

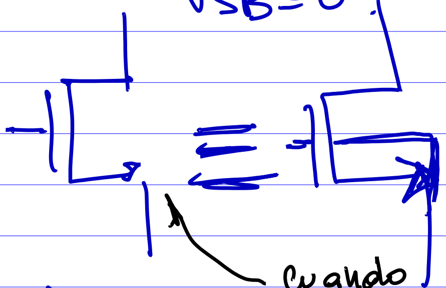
$$I_D = \frac{\beta}{2(1+\cancel{\delta})}\left(V_{GB} - V_{to} - (1+\cancel{\delta})\cancel{V_{SB}}\right)^2$$

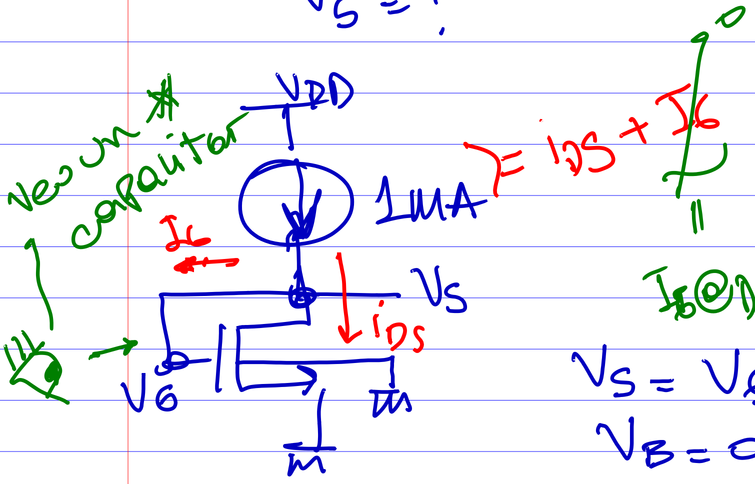
↳ $I_D = \frac{\beta}{2}(V_{GB}-V_{to})^2$

$V_S = V_{GB}$

$V_S = ?$

$V_{SB} = 0$?





$I_G @ DC = 0$

$V_S = V_G = V_G - V_B = V_{GB}$

$V_B = 0$

$V_{GB} = V_S$? —

$\Rightarrow I_D = \frac{\beta}{2}(V_{GB}-V_{to})^2$

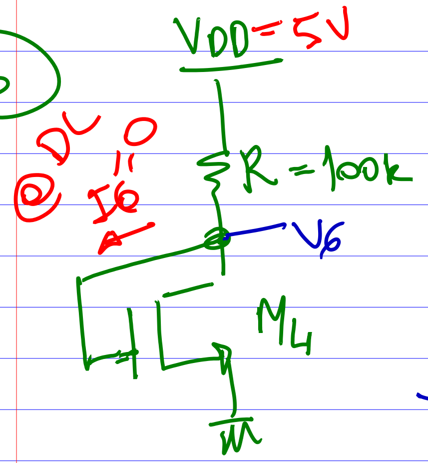
↓

$$V_{GB} = \underbrace{V_{to}}_{\overset{||}{0.8}} + \underbrace{\sqrt{\frac{2I_D}{\beta}}}_{2V}$$

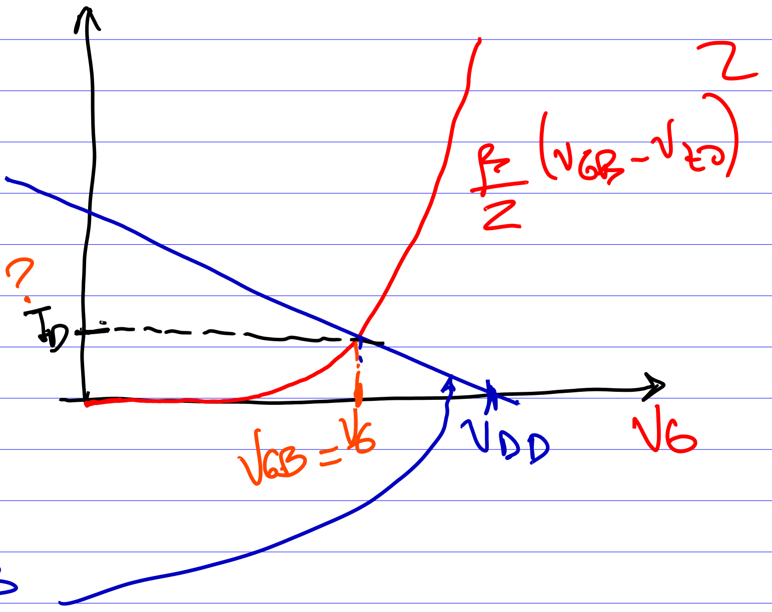
$\boxed{V_{GB} = 2{,}8V}$

→ $\boxed{V_S = 2{,}8V}$

(b)



M_4: Seguro saturado



$$I_D=\frac{\beta}{2}(V_{GB}-V_{t0})^2$$

$$I_R=\frac{V_{DD}-V_{GB}}{R}$$

$$\Rightarrow \quad V_{DD}=RI_D+V_{GB}$$

$$I_D=\frac{\beta}{2}(V_{GB}-V_{t0})^2$$

$$V_{DD}=\frac{R\beta}{2}(V_{GB}-V_{t0})^2+V_{GB}$$

$$V_{DD}=\frac{R\beta}{2}V_{GB}^2-(R\beta V_{t0})V_{GB}+\frac{R\beta}{2}V_{t0}^2+V_{GB}$$

Dimensiones! $\left[R\beta V_{GB}^2\right]=\frac{V}{\cancel{A}}\frac{\cancel{A}}{\cancel{V^2}}\cancel{V^2}$

$$\underbrace{(R\beta)}_{a}V_{GB}^2+\underbrace{2(1-R\beta V_{t0})}_{b}V_{GB}+\underbrace{R\beta V_{t0}^2-2V_{DD}}_{c}=0$$

$\Rightarrow$

$a=50V^{-1}$

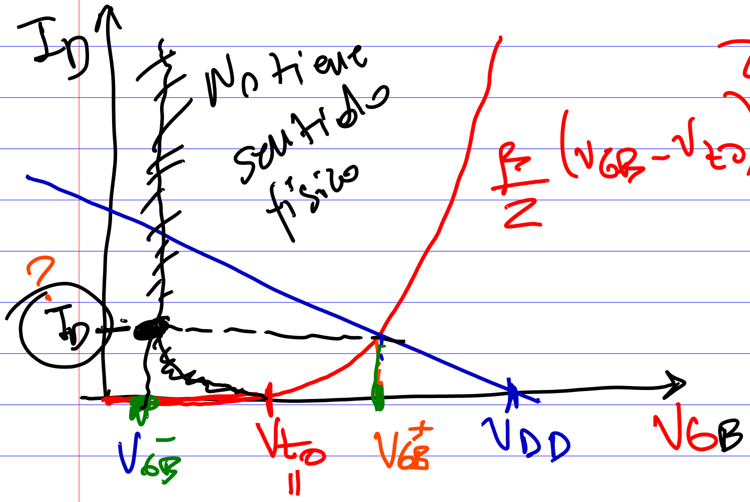
$b=-78$

$c=22V$

$\rightarrow V_{GB}=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$

$V_{GB}^{+}=1{,}19V$

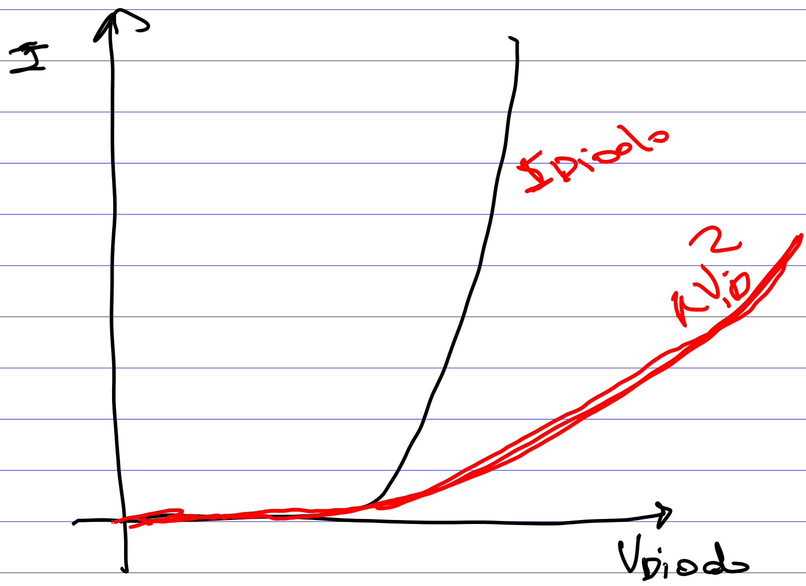
$V_{GB}^{-}=369mV$

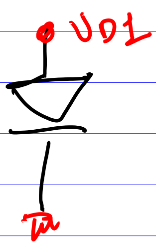


$V_{GB}^+ = 1.19V$

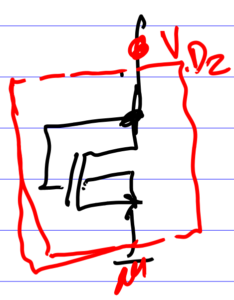
$V_{GB}^- = 369mV$

$$I_D = \frac{\beta}{2}(V_{GB} - V_{t0})^2, \quad V_{t0} = 0.8V$$

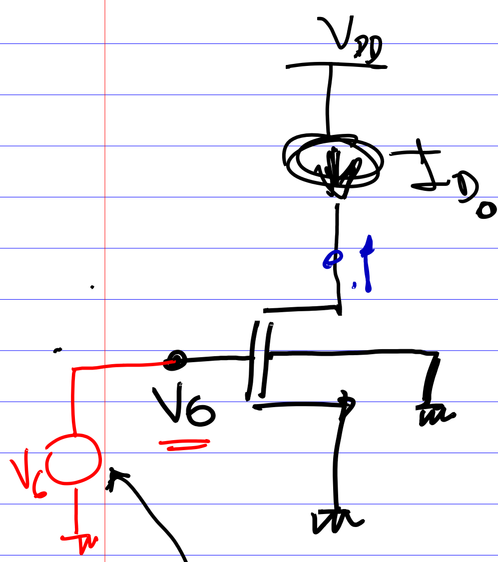


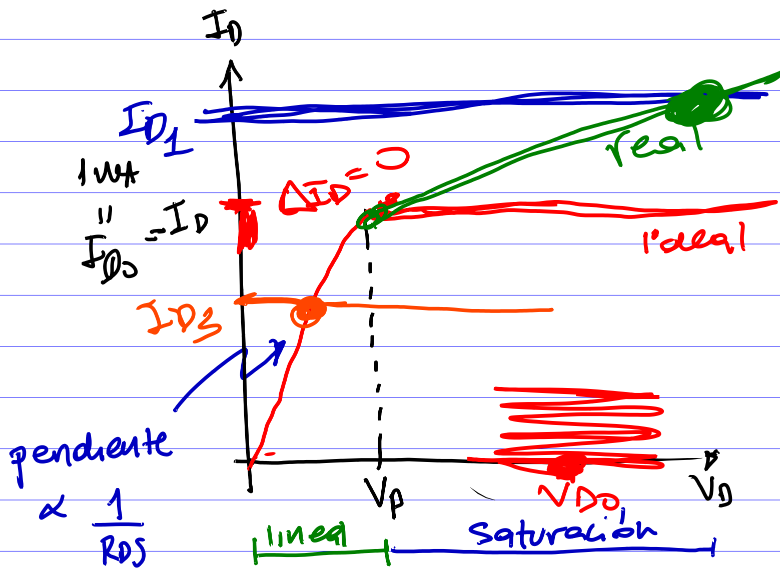


$$I_{Diodo} = I_S\left(e^{\frac{V_{diodo}}{nU_t}} - 1\right)$$



Experimento



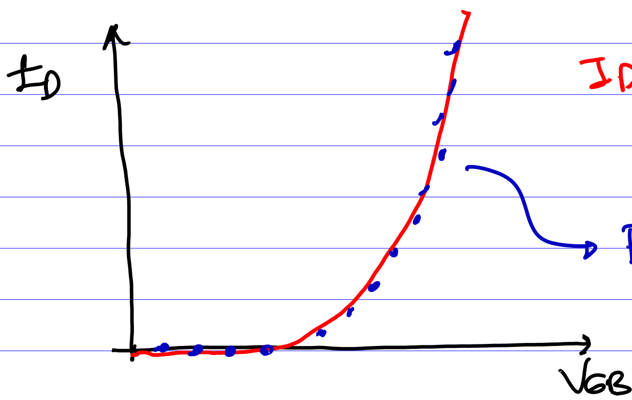


si $V_{GB} = cte$

$\hookrightarrow V_p = cte$

$$V_p = \frac{V_{GB} - V_{t_0}}{1+\delta}$$

Duda de Lab



$$I_D = \frac{\beta}{2(1+\delta)}(V_{GB} - V_{t_0})^2$$

ptos extaidos del spice