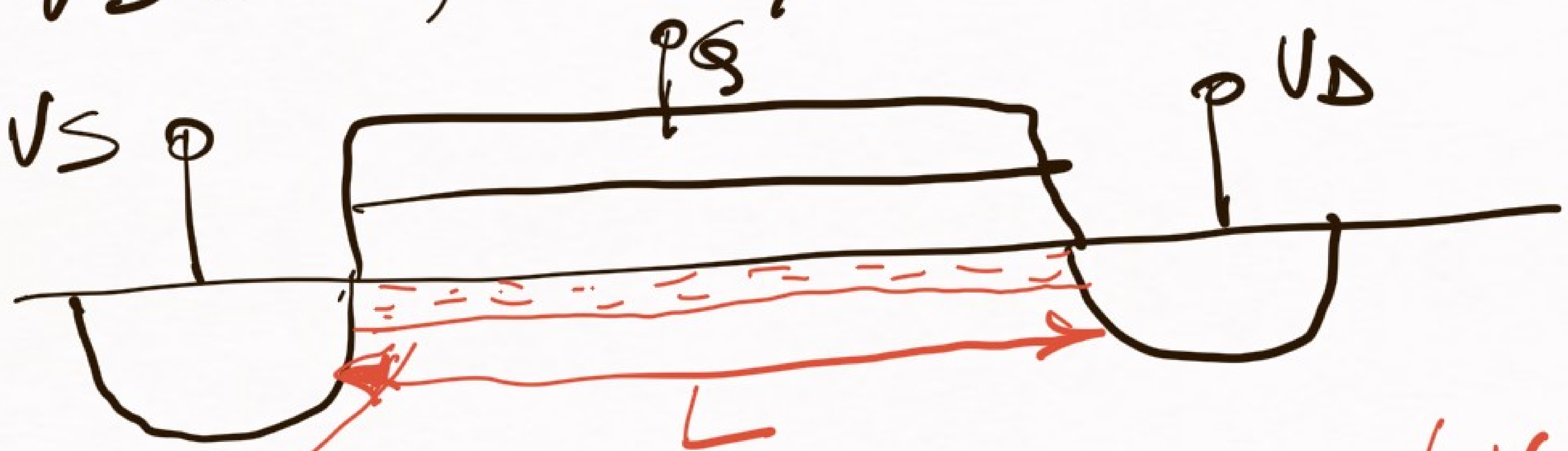
# Ec. Tr. MOS en zona lineal

14/4/21

Tensiones referidas al sustrato: $V_G = V_{GB}$, $V_S = V_{SB}$, $V_D = V_{DB}$.

(I) $V_S = V_D$, $V_G$ / ∃ $Q_i$

$V_{ch} = V_S = V_D = cte$




$$Q_{i_t} = -W \cdot L \cdot C_{ox} \left( V_G - V_{t0} - (1+\delta) V_{ch} \right)$$

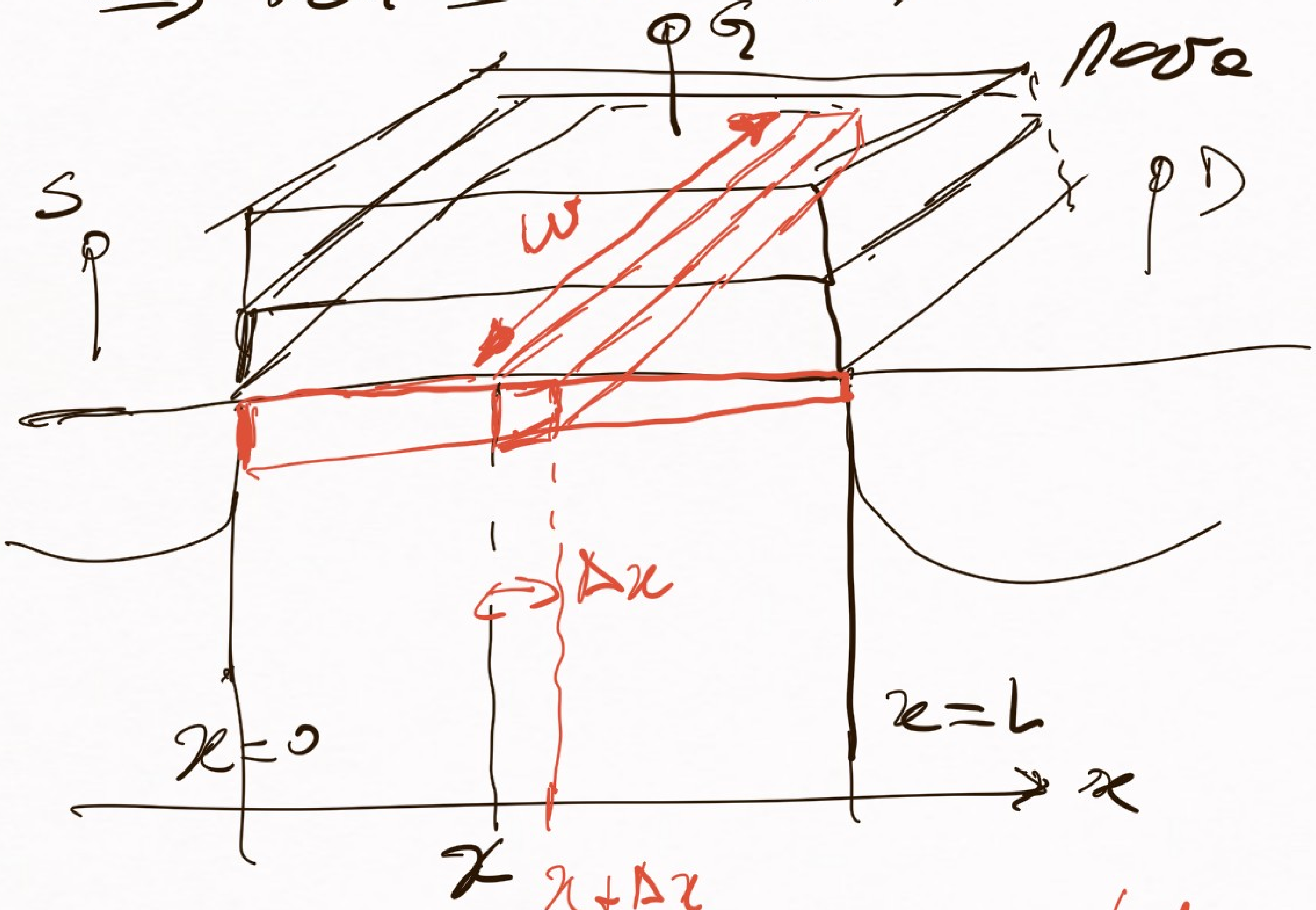
$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}, \qquad V_{ch} = V_S = V_D$$

carga de inversión total en el canal

② $V_S \neq V_D$ , $V_D > V_S$

$\Rightarrow V_{ch} = V_{ch}(x)$ , $V_S \leq V_{ch}(x) \leq V_D$

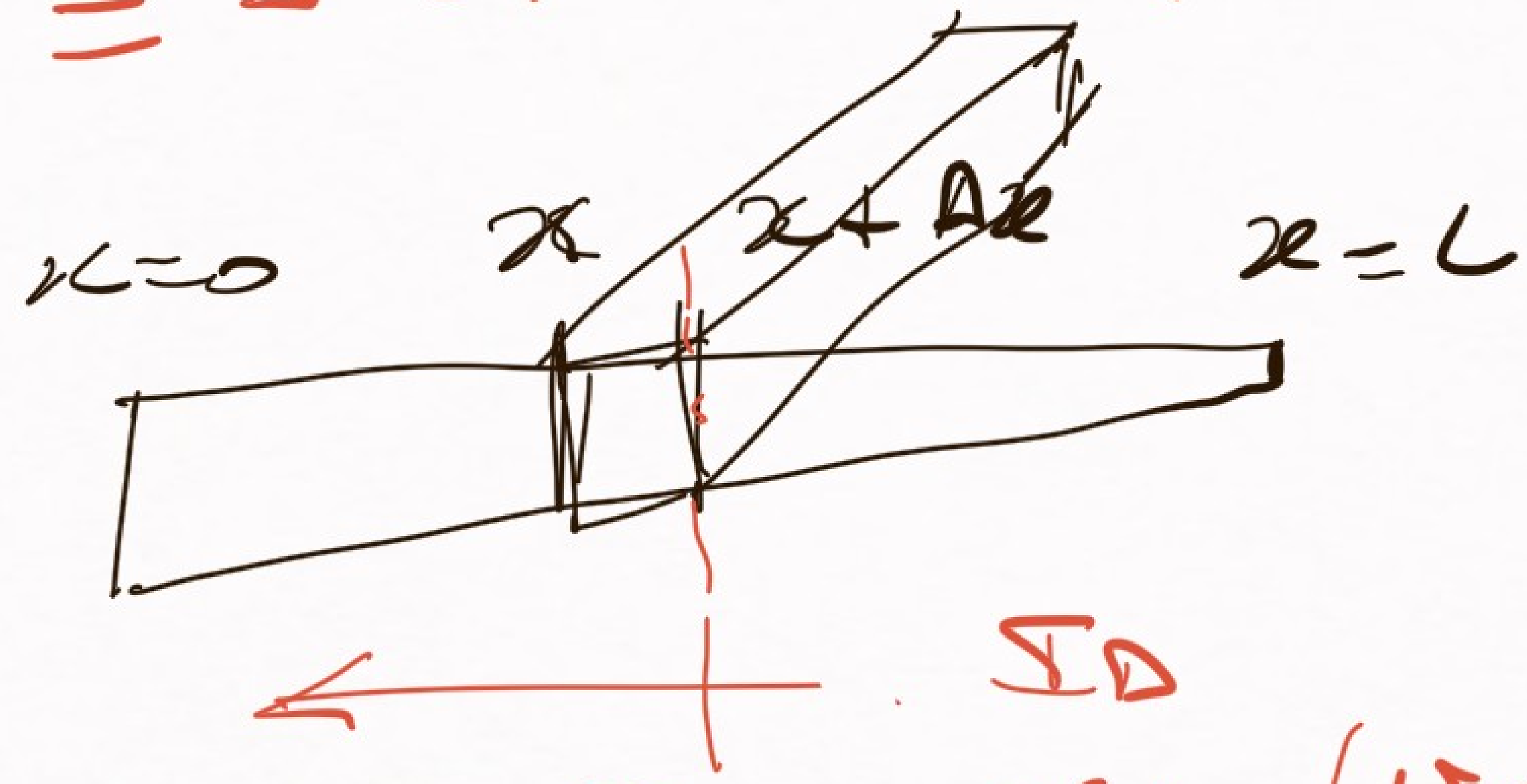
pour $0 \leq x \leq L$




Q barre entre $x$ et $x+\Delta x$ $= - W . \Delta x . C_{ox} . \left( V_G - V_{to} - (1+\delta) V_{ch}(x) \right)$

$Q_i$ barra entre $x$ y $x+\Delta x$ $= -W \cdot \Delta x \cdot C_{ox}\left(V_G - V_{T0} - (1+\delta)\, V_{ch}(x)\right)$

$\underline{I_D\ ?}$




$$I_D = \frac{\Delta Q}{\Delta t} = \underbrace{\frac{\Delta Q}{\Delta x}}_{=\frac{Q_{i\,barra}}{\Delta x}} \cdot \underbrace{\frac{\Delta x}{\Delta t}}_{= v_d}$$

($v_d$: Velocidad de los portadores)

$$\Rightarrow I_D = -W \cdot \underbrace{C_{ox} \cdot \left(V_G - V_{T0} - (1+\delta)\, V_{ch}(x)\right)}_{} \cdot \underbrace{v_d(x)}_{= \mu \cdot E}$$

$$-\frac{Q_{i\,barra}}{\Delta x \cdot W} = Q_i(x)$$

$$I_D = Q_i(x) \cdot W \cdot v_d(x) = Q_i(x) \cdot W \cdot \mu \cdot E(x) =$$

$$= Q_i(x) \cdot W \cdot \mu \cdot \left(-\frac{dV_{ch}(x)}{dx}\right)$$

$$I_D = -\mu \cdot C_{ox} \cdot W \cdot \left(V_G - V_{t0} - (1+\delta)\, V_{ch}(x)\right) \cdot \left(-\frac{dV_{ch}}{dx}\right)$$

Integramos a lo largo del canal (entre $x=0$ y $x=L$ o $V_{ch}=V_S$ y $V_{ch}=V_D$) a ambos lados de la igualdad

$$\underbrace{\int_0^L I_D\, dx}_{\parallel} = \mu\, C_{ox} \cdot W \int_0^L \left(V_G - V_{t0} - (1+\delta)\, V_{ch}(x)\right) \frac{dV_{ch}}{dx}\, dx$$

$$\boxed{I_D \cdot L = \mu\, C_{ox} \cdot W \int_{V_S}^{V_D} \left(V_G - V_{t0} - (1+\delta)\, V_{ch}\right) dV_{ch}}$$

$$I_D = \underbrace{\mu \cdot C_{ox} \cdot \frac{W}{L}}_{\beta} \cdot \int_{V_S}^{V_D} \left(V_G - V_{t0} - (1+\delta) V_{ch}\right) dV_{ch}$$

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

Ec. tr. MOS en ~~zona~~ lineal (con tensiones referidas al sustrato (B))

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

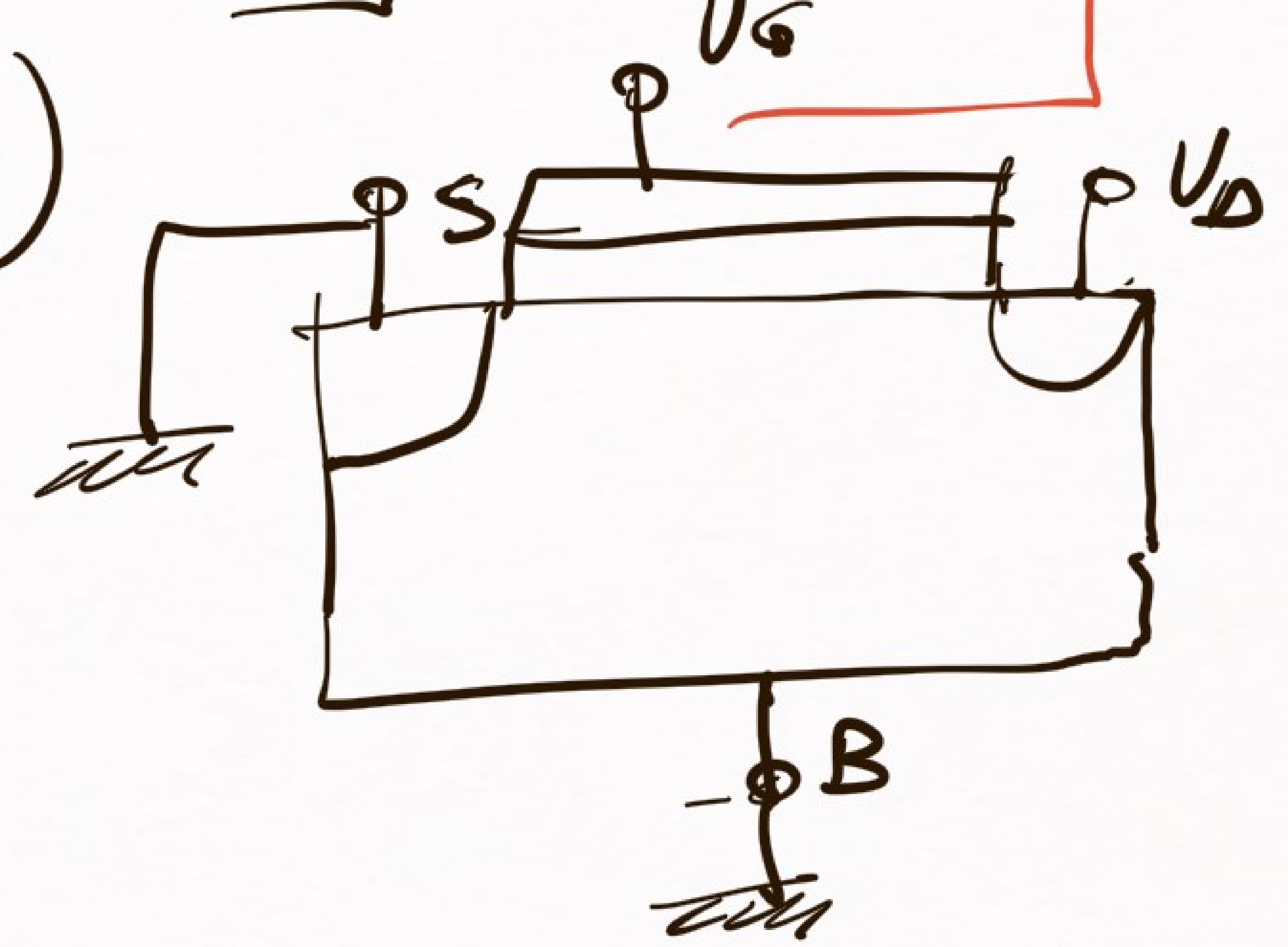
$\underbrace{V_D < V_P} \iff V_D < \frac{V_G - V_{t0}}{(1+\delta)}$

$V_P = \frac{V_G - V_{t0}}{(1+\delta)}$

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

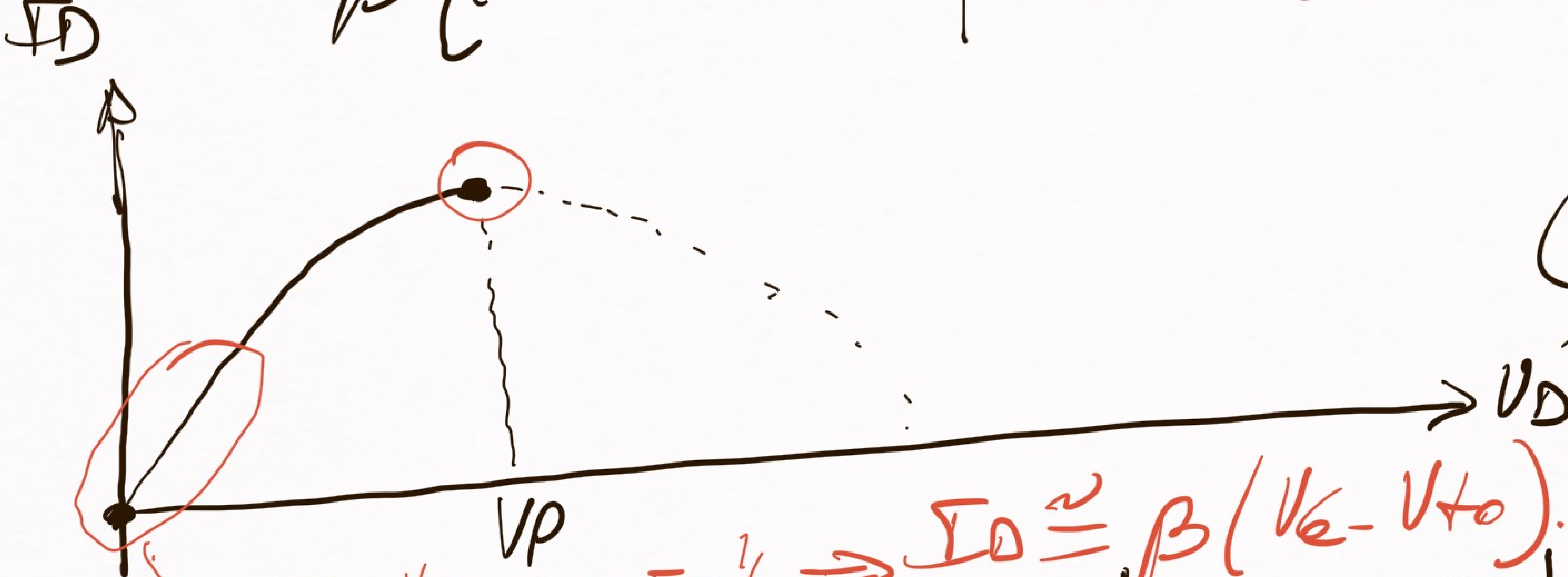
$$\boxed{I_D = \beta\left[(V_G - V_{to}) - \frac{(1+\delta)}{2}(V_D + V_S)\right](V_D - V_S)}$$

$\boxed{\text{Caso } V_S = 0}$ (S y B conectados)



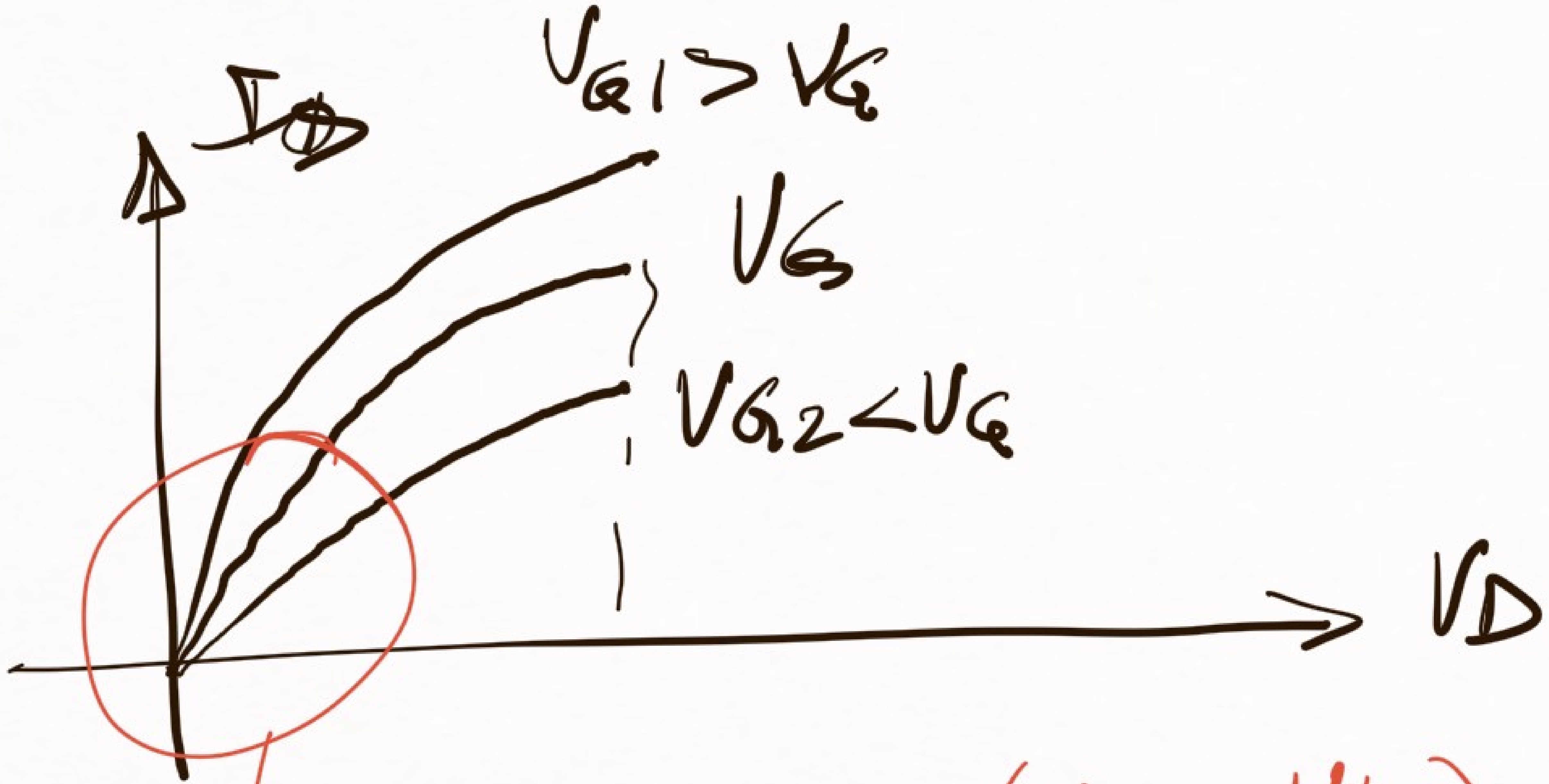

$$\Rightarrow I_D = \beta\left[V_G - V_{to} - \frac{(1+\delta)}{2}V_D\right]\cdot V_D$$

$$= \beta\left[(V_G - V_{to})V_D - \frac{1+\delta}{2}\cdot V_D^2\right]$$




$0 = (V_D - V_S) = V_D$

$V_D$ "pequeño" $\Rightarrow I_D \cong \underbrace{\beta(V_G - V_{to})}_{\frac{1}{R_{ON}}}\cdot V_D$




$$I_D \cong \beta(V_G - V_{t0}) \cdot V_D$$

$$I_D = \frac{1}{R_{ON}} \cdot V_D \quad , \quad R_{ON} = \frac{1}{\beta(V_G - V_{t0})}$$

El tr. en zona lineal para $V_D$ pequeño ($<< V_p$) $\rightarrow$ se aprox. una R controlada (pequeña) por $\underline{V_G}$

## Ec. tr. MOS en saturación, $V_S < V_P$

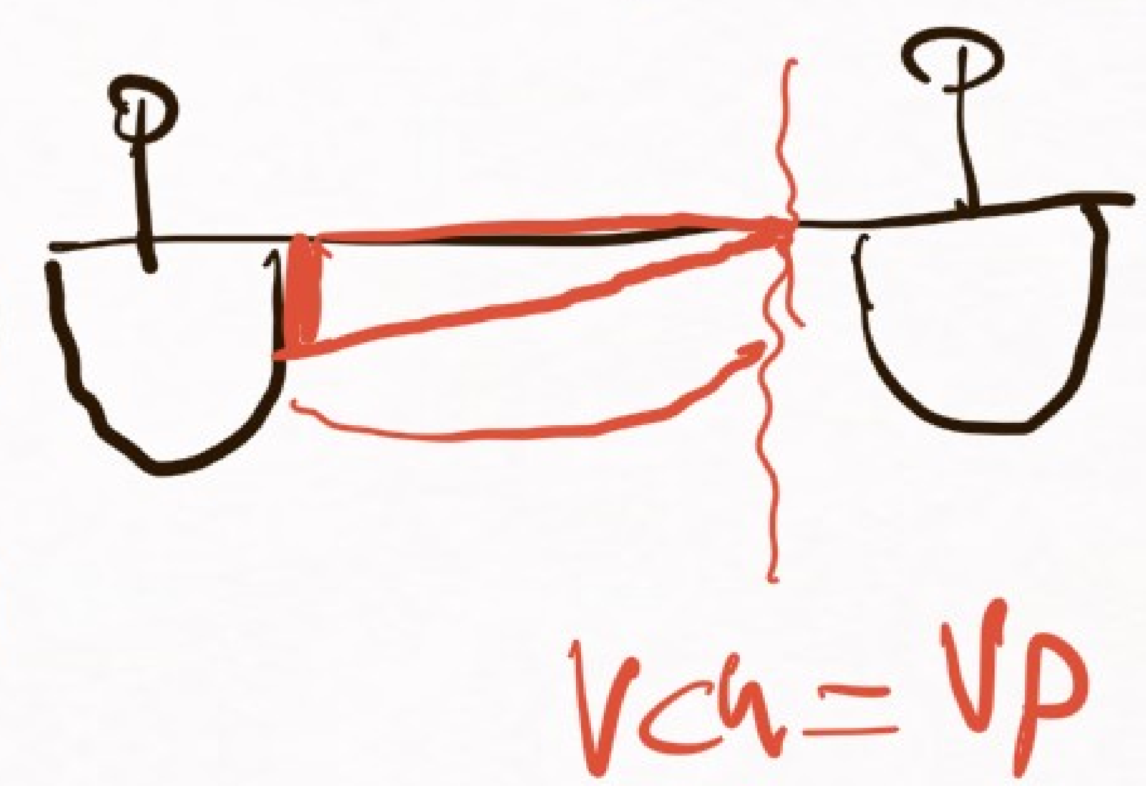
$V_S < V_D < V_P$


perfil de carga trapezoidal y op. en zona lineal

$V_S < V_D = V_P$


perfil de carga triangular y frontera entre zona lineal y saturación.

$V_S < V_D$, $V_D > V_P$




Operación en saturación

$$I_{Dsat} = I_{Dlim}\Big|_{V_D = V_P}$$

$I_{Dsat} = I_{Dlim} \Big|_{V_D = V_P}$

Ec. en saturación

cuentos

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

$$V_S < V_P \iff V_G > V_{to} + (1+\delta) V_S$$

$$V_D > V_P \iff V_D > \frac{V_G - V_{to}}{(1+\delta)}$$

$$V_P = \frac{V_G - V_{to}}{(1+\delta)}$$

Ec. en corte.

$$I_D = 0, \quad \begin{cases} V_S > V_p \Leftrightarrow V_G < V_{to} + (1+\delta) V_S \\ V_D > V_p \Leftrightarrow V_D > \dfrac{V_G - V_{to}}{(1+\delta)} \end{cases}$$

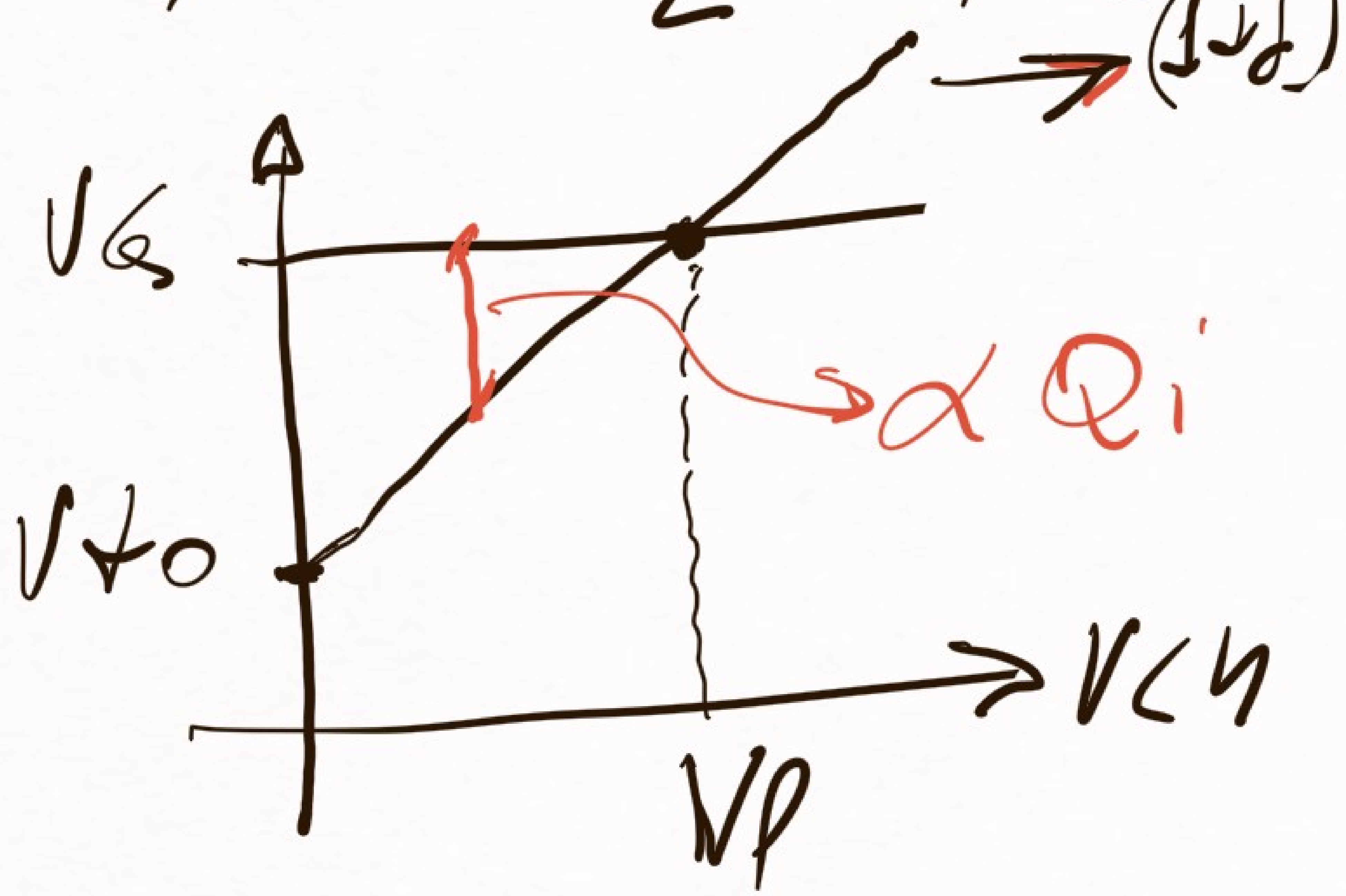
$Q_i = 0$ en todo el canal

y no hay corriente.

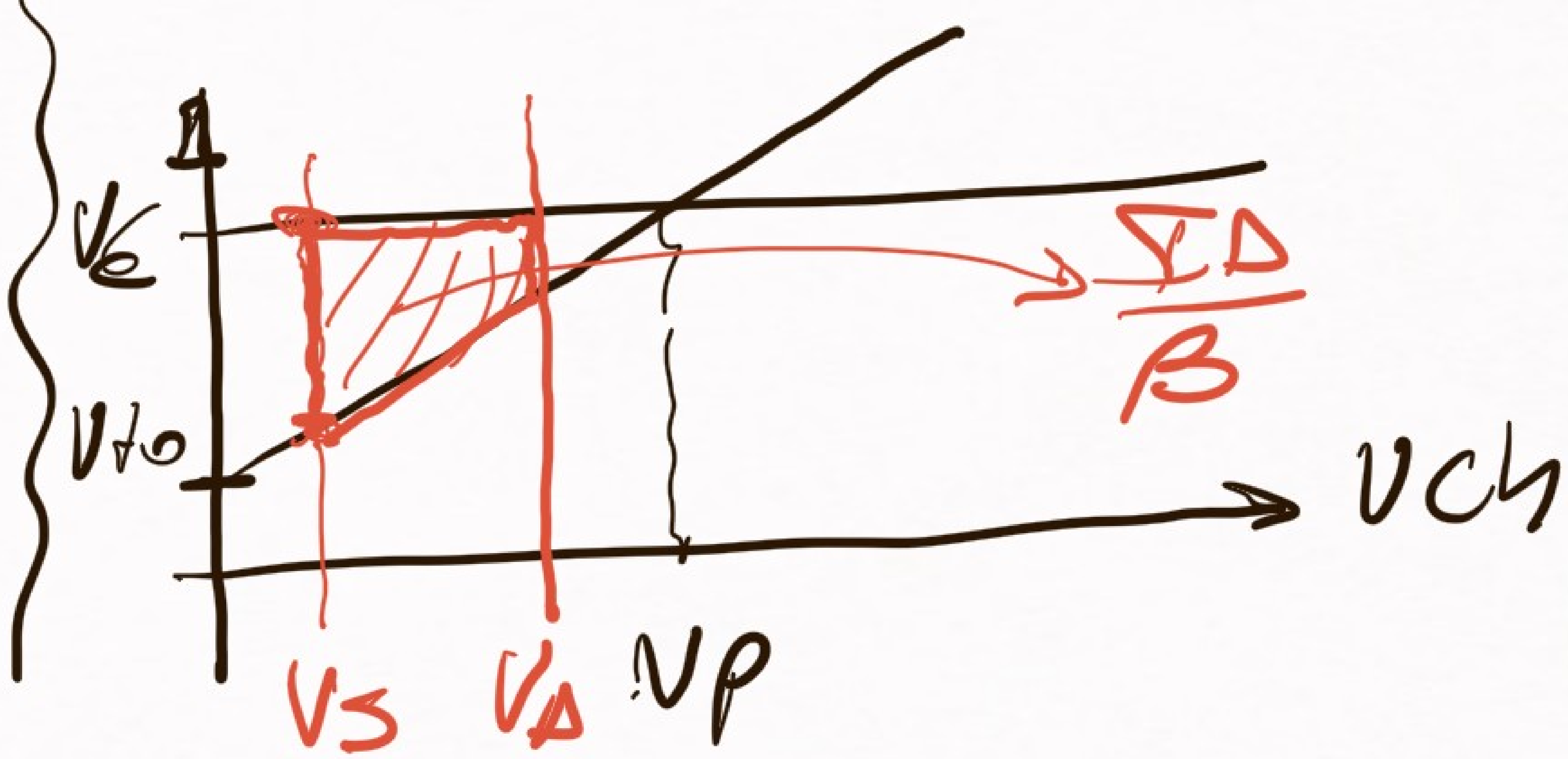
## Rep. Gráfica de las ecs. del transistor MOS.

## Diagrama de Jespers – Memelink

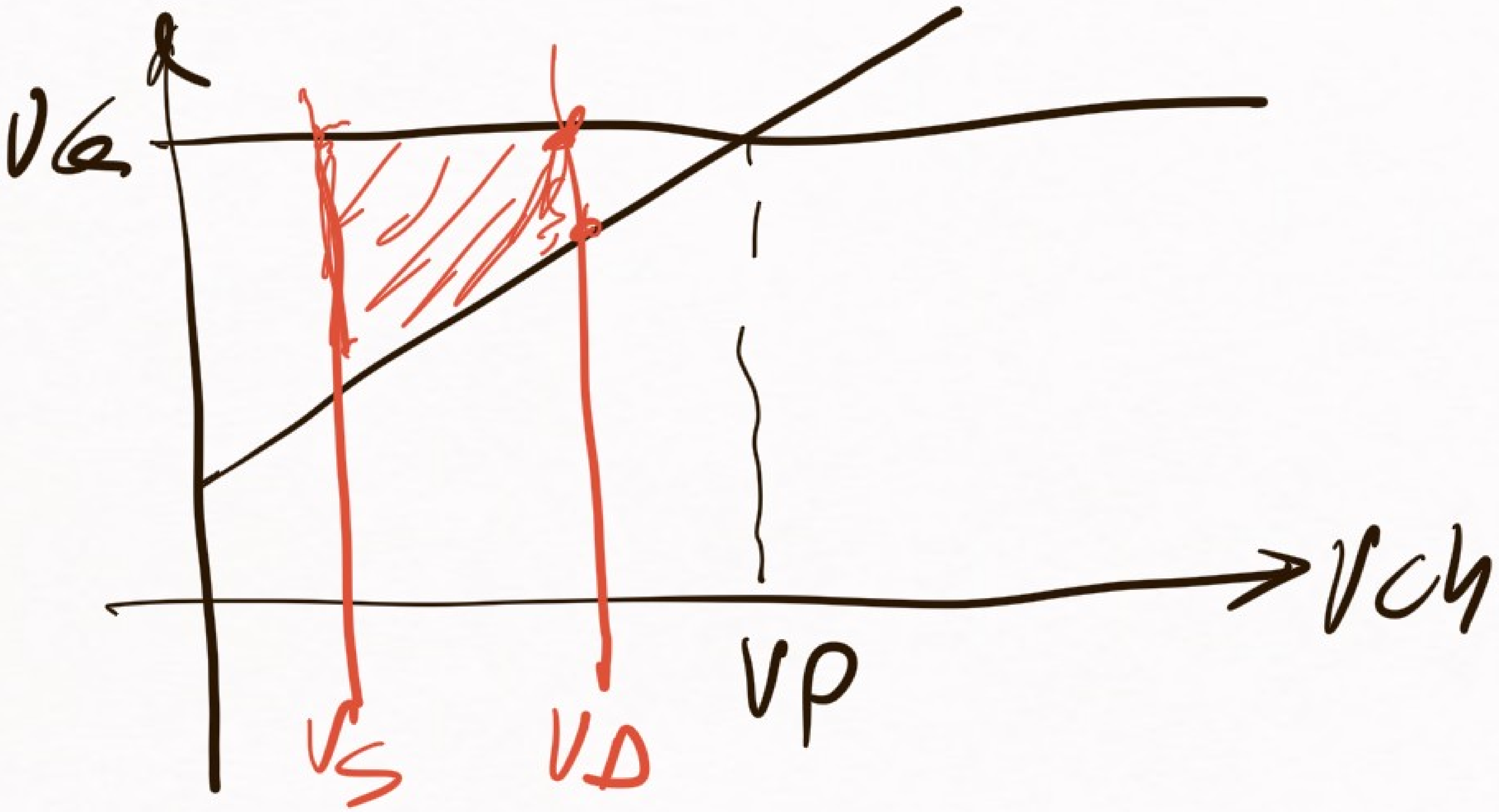
$$I_D = \underbrace{\beta}_{= \mu \cdot C_{ox} \cdot \frac{W}{L}} \int_{V_S}^{V_D} \underbrace{\left(V_G - \left(V_{to} - (1+\delta) V_{ch}\right)\right)}_{\propto Q_i} dV_{ch}$$




Z. lineal: $V_S < V_P$, $V_D < V_P$



## Z. lineal:

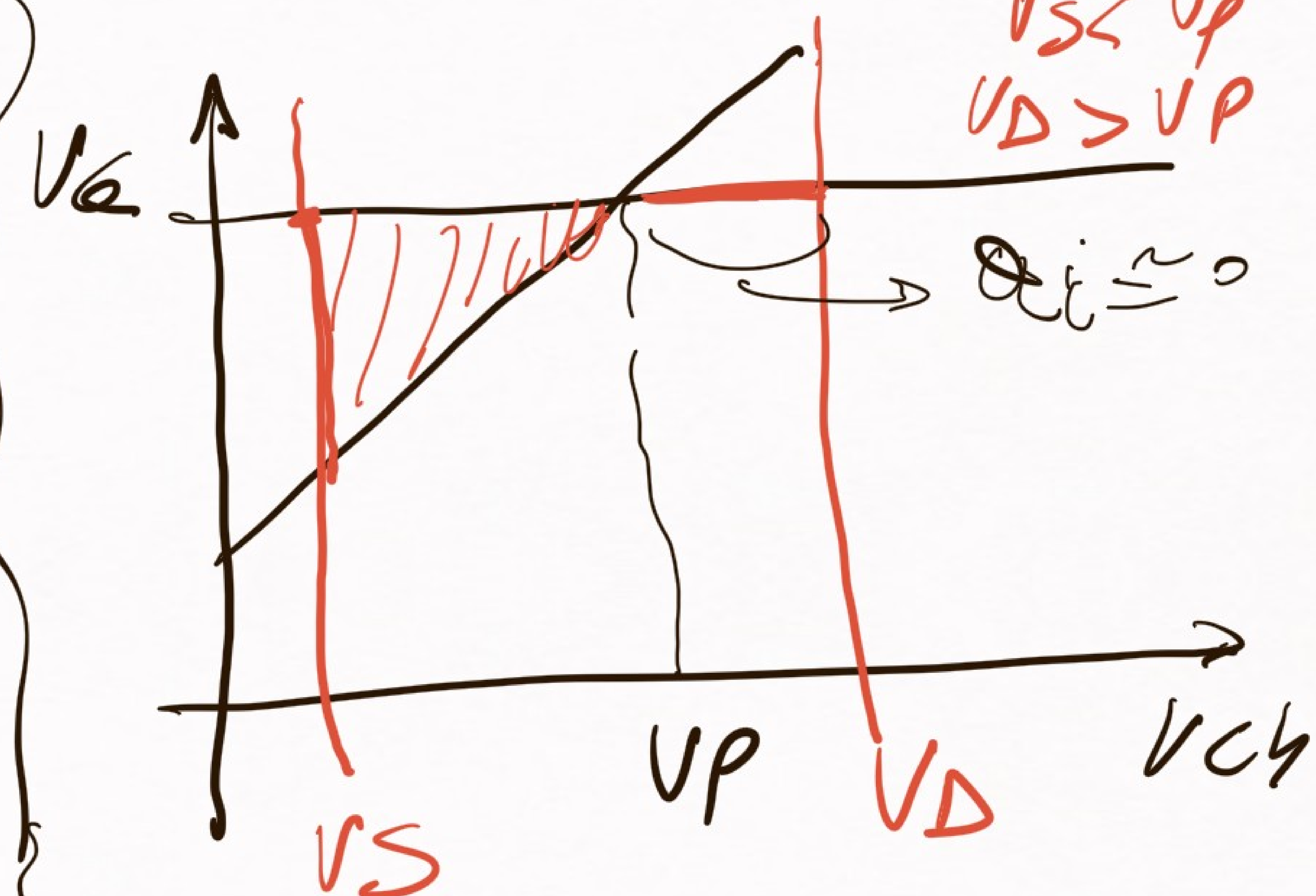



$I_D = \beta$. área del trapecio

$V_S < V_P$
$V_D < V_P$

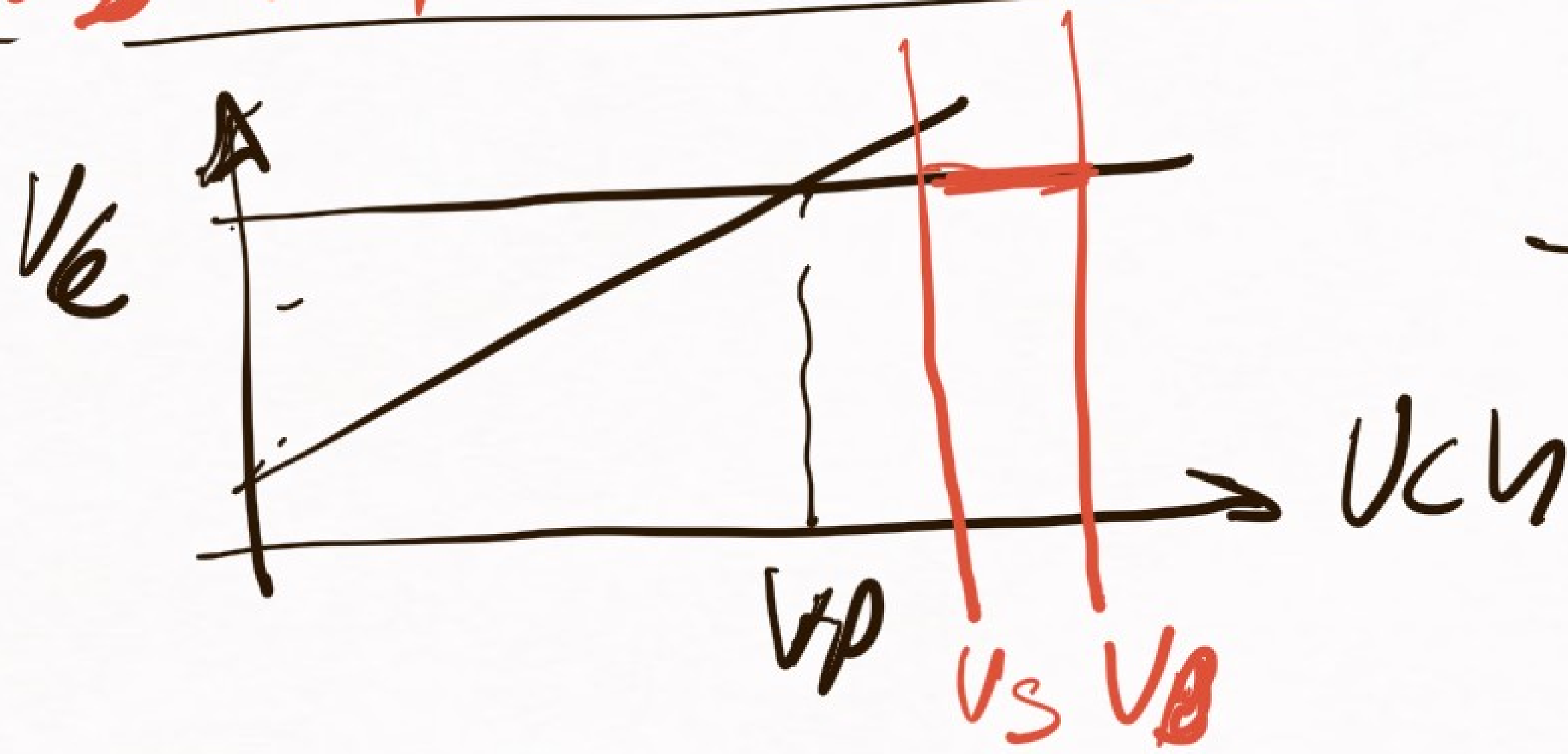
## Saturación:

$V_S < V_P$
$V_D > V_P$



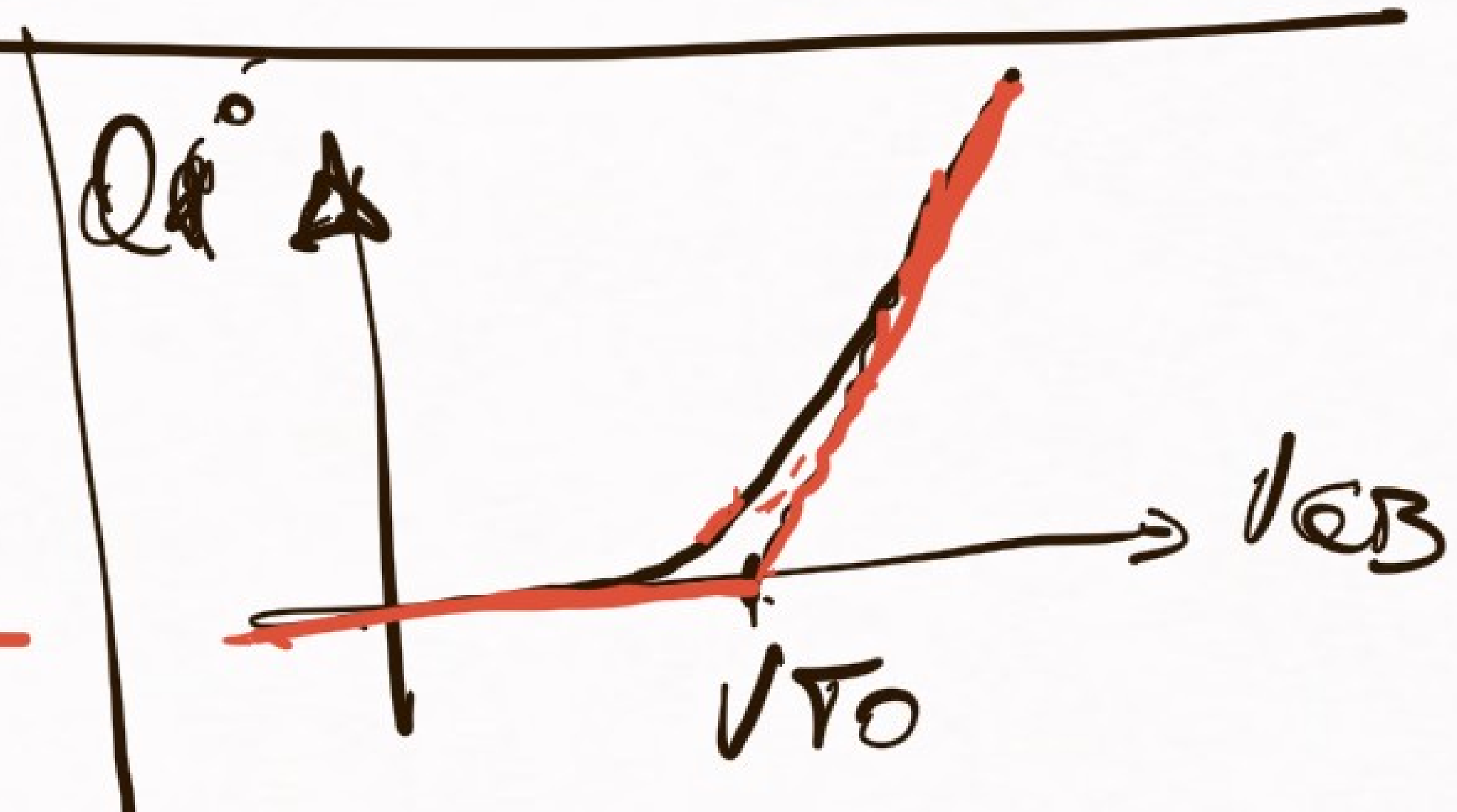

$I_D = \beta$. área del triángulo

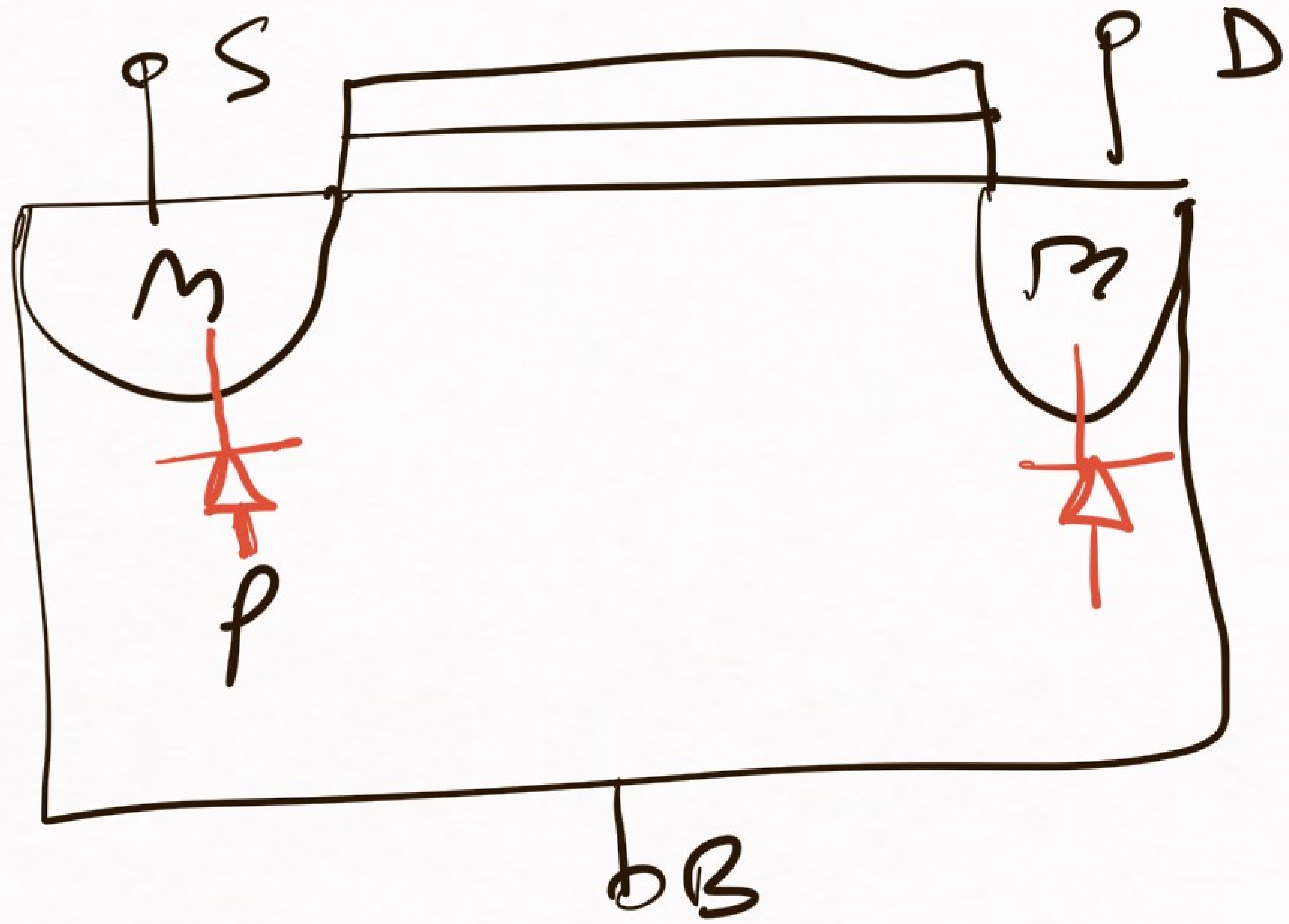
## Corte




$I_D = 0$

$V_S > V_P$
$V_D > V_P$






$V_{SB} > 0$

$V_{DB} > 0$