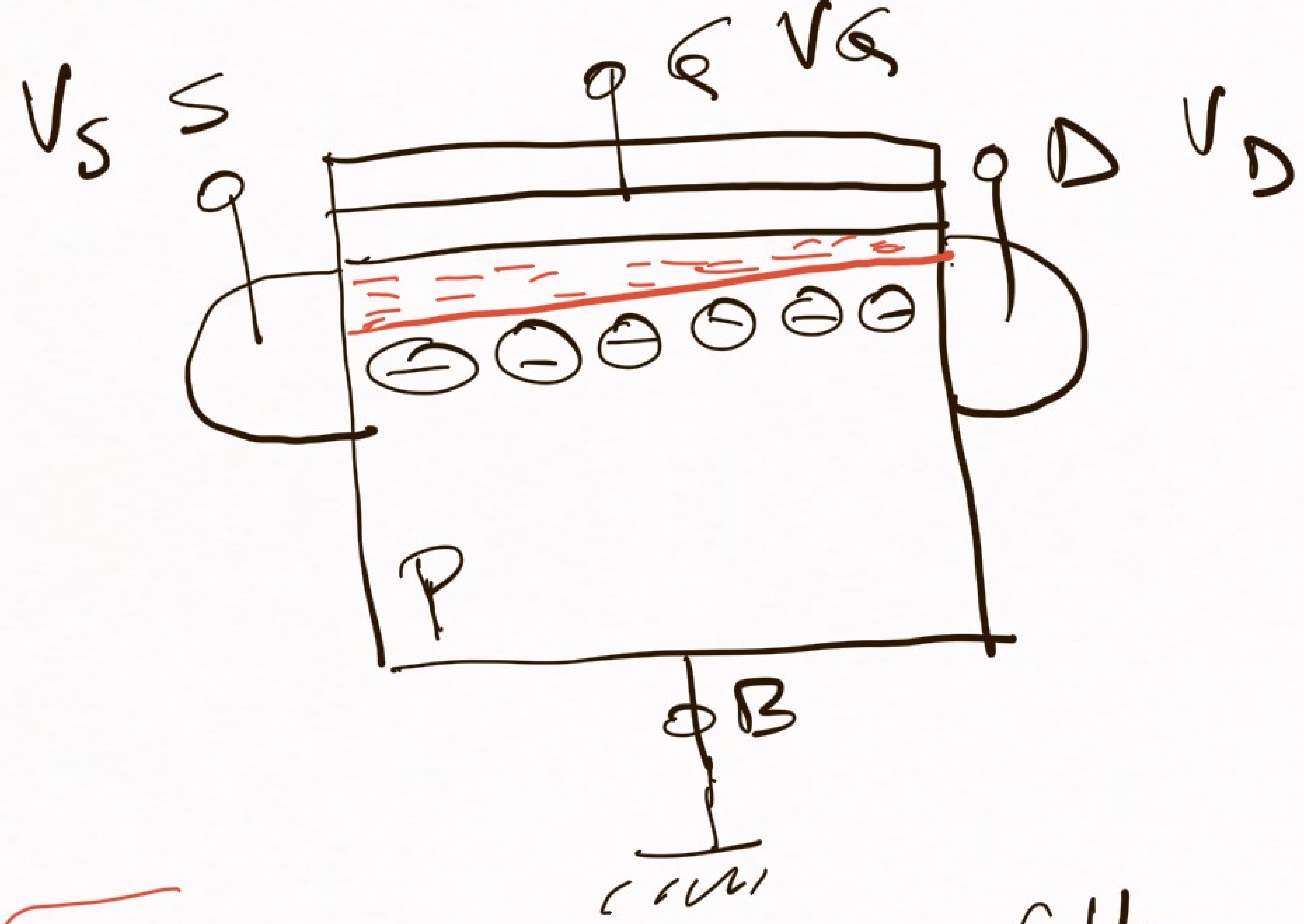
27/4

Ecs. del transistor MOS



$$\left.\begin{array}{l} V_S < V_P \\ V_D < V_P \end{array}\right]$$ Zona lineal

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

$$(V_D > V_S)$$

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

⇒ Ec. tr. MOS en zona lineal referida al sustrato:

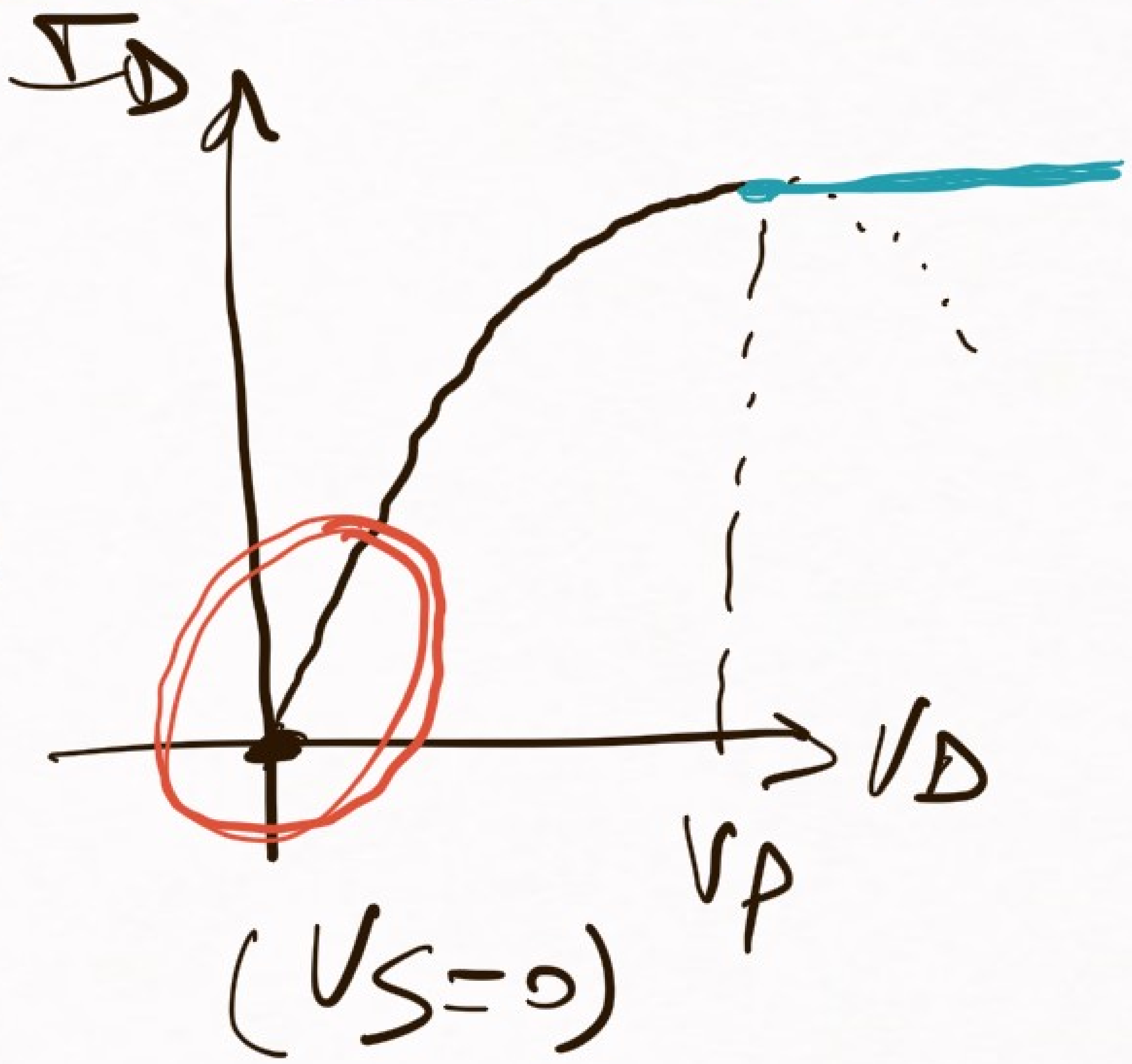
$$\boxed{I_D = \beta\left((V_G - V_{to})(V_D - V_S) - \frac{(1+\delta)}{2}\left(V_D^2 - V_S^2\right)\right)}$$

$V_S < V_p$, $V_D < V_p$, $V_p = \dfrac{V_G - V_{to}}{1+\delta}$

$$V_G > V_{to} + (1+\delta)\,V_S$$

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

$\gg$



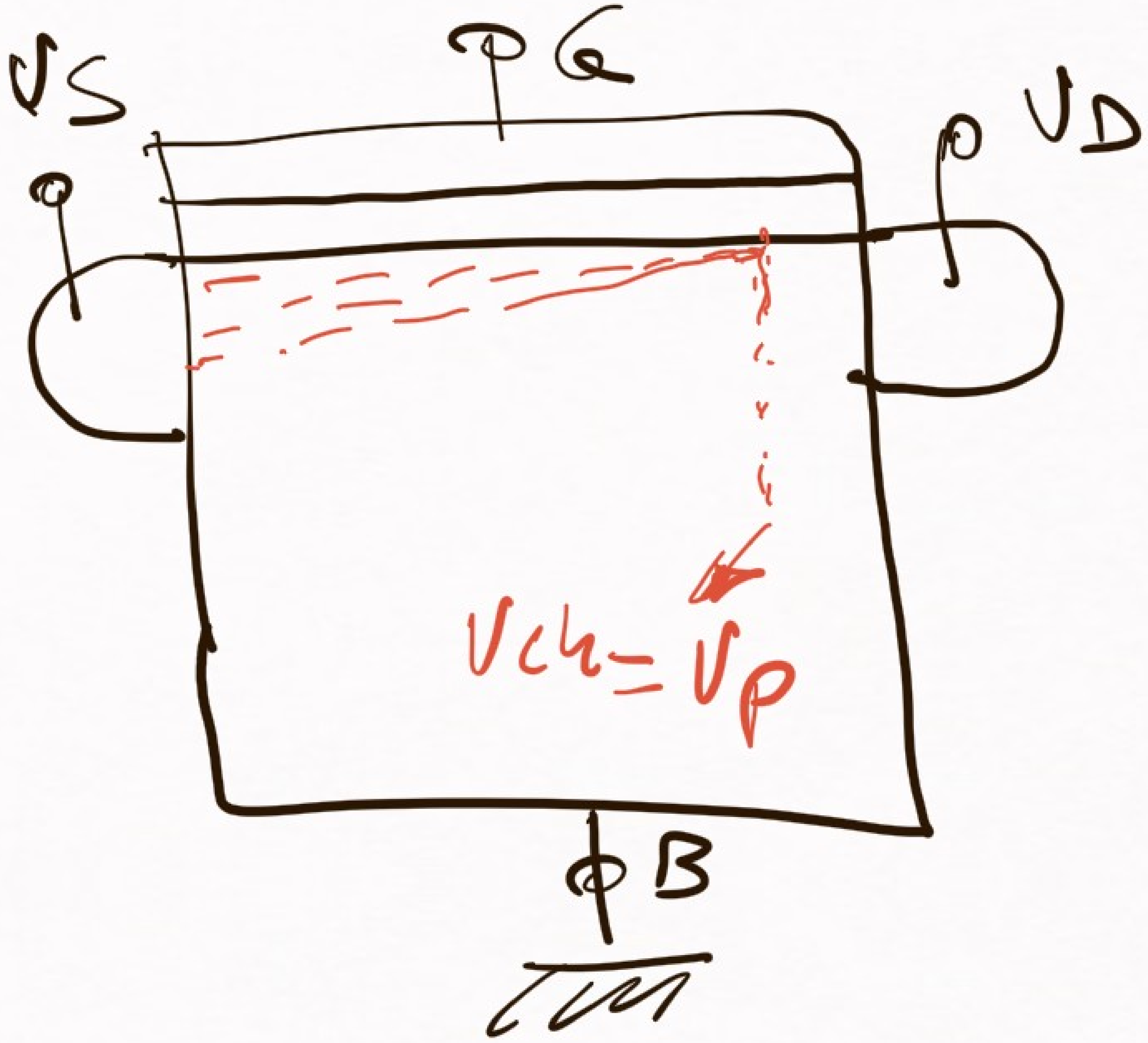
$$\Rightarrow I_D \cong \underbrace{\beta(V_G - V_{to})}(V_D - V_S)$$

$\longrightarrow 1/R_{ON}$

$$R_{ON} = \frac{1}{\beta(V_G - V_{to})}$$

Ec. en saturación.

$V_S < V_P$, $\underline{V_D > V_P}$



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

cuentos

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

$V_S < V_P$, $V_D > V_P$, $V_P = \dfrac{V_G - V_{to}}{(1+\delta)}$

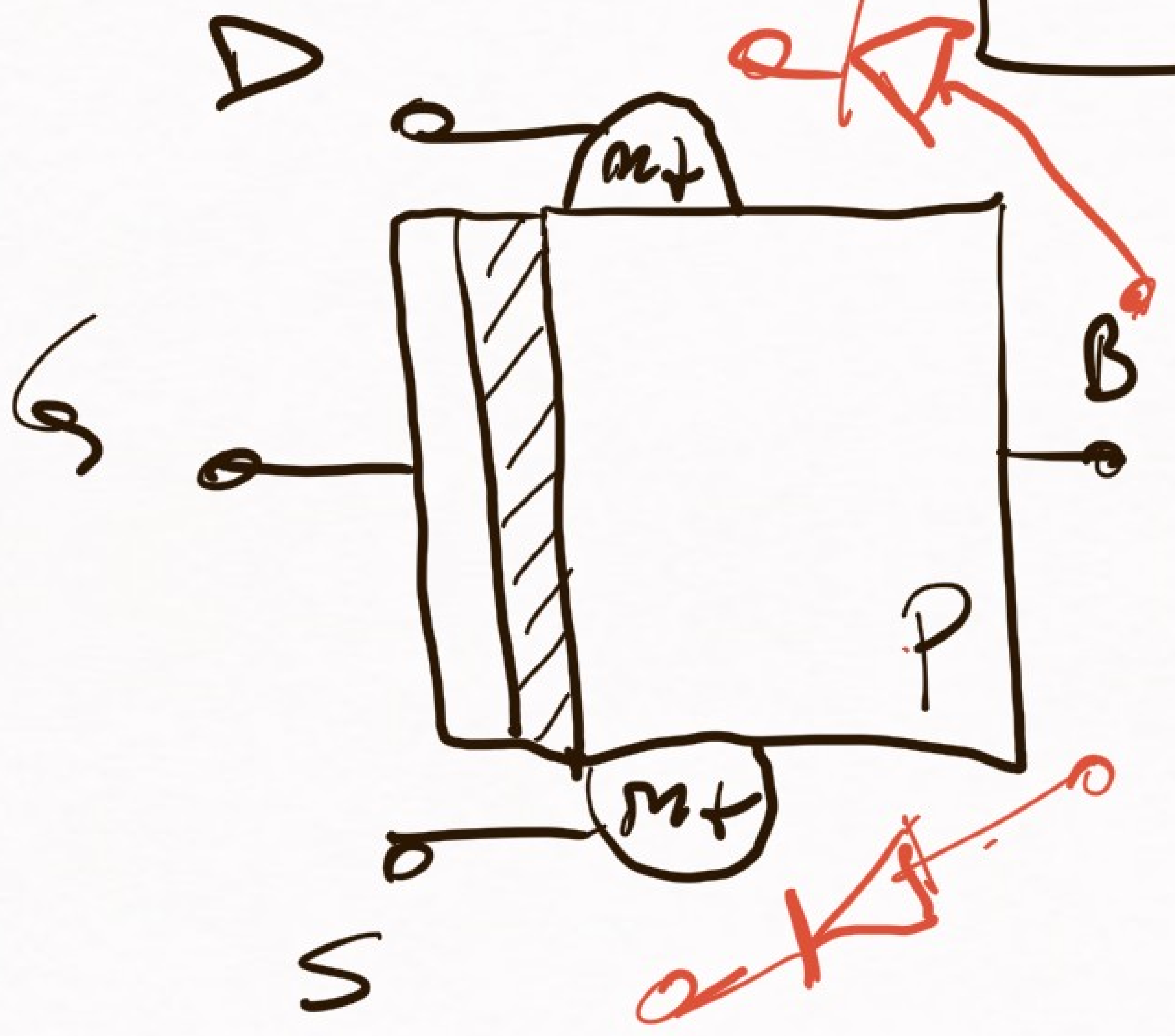
$\Leftrightarrow V_G > V_{to} + (1+\delta)V_S$

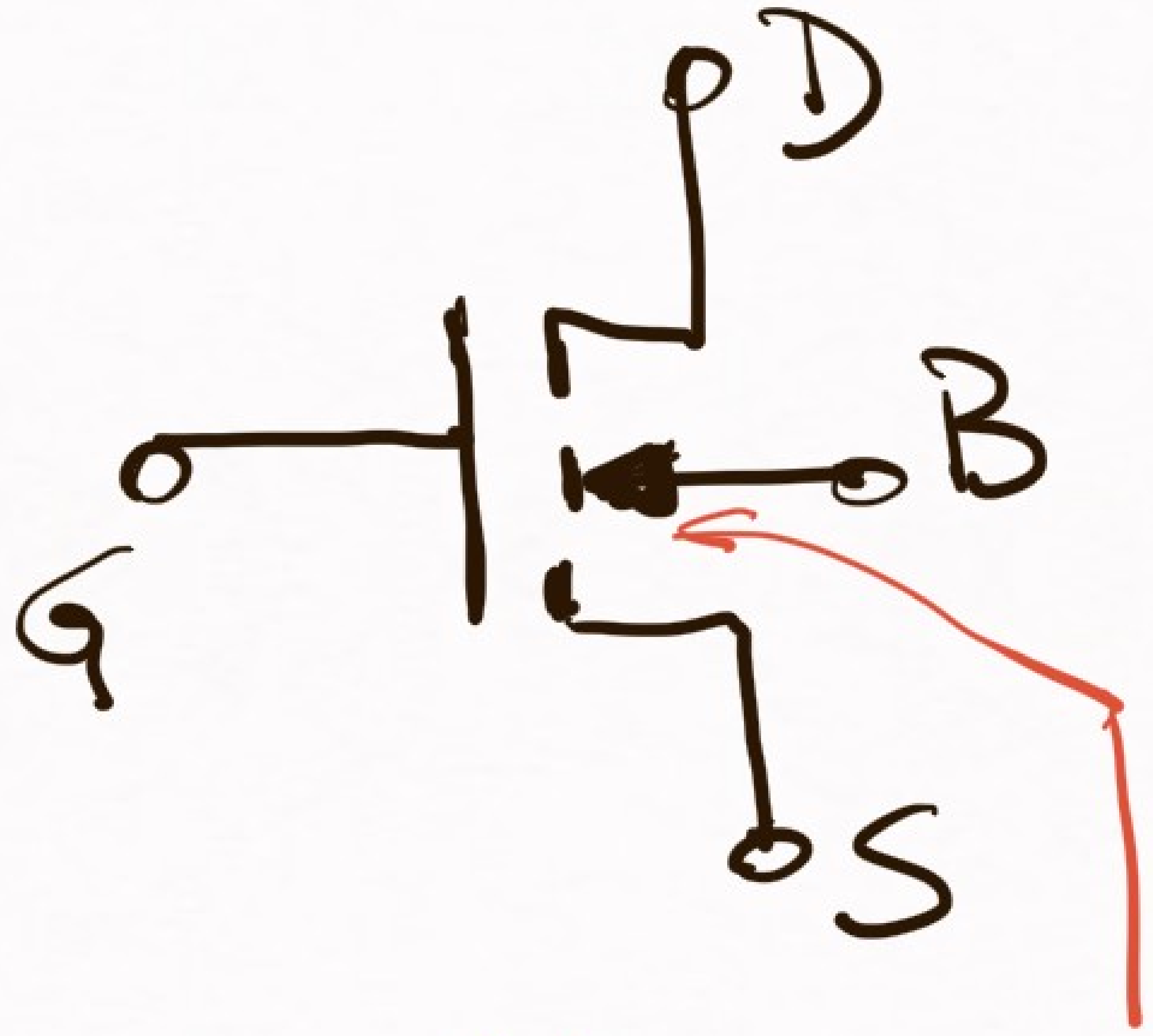
Ec. en corte:

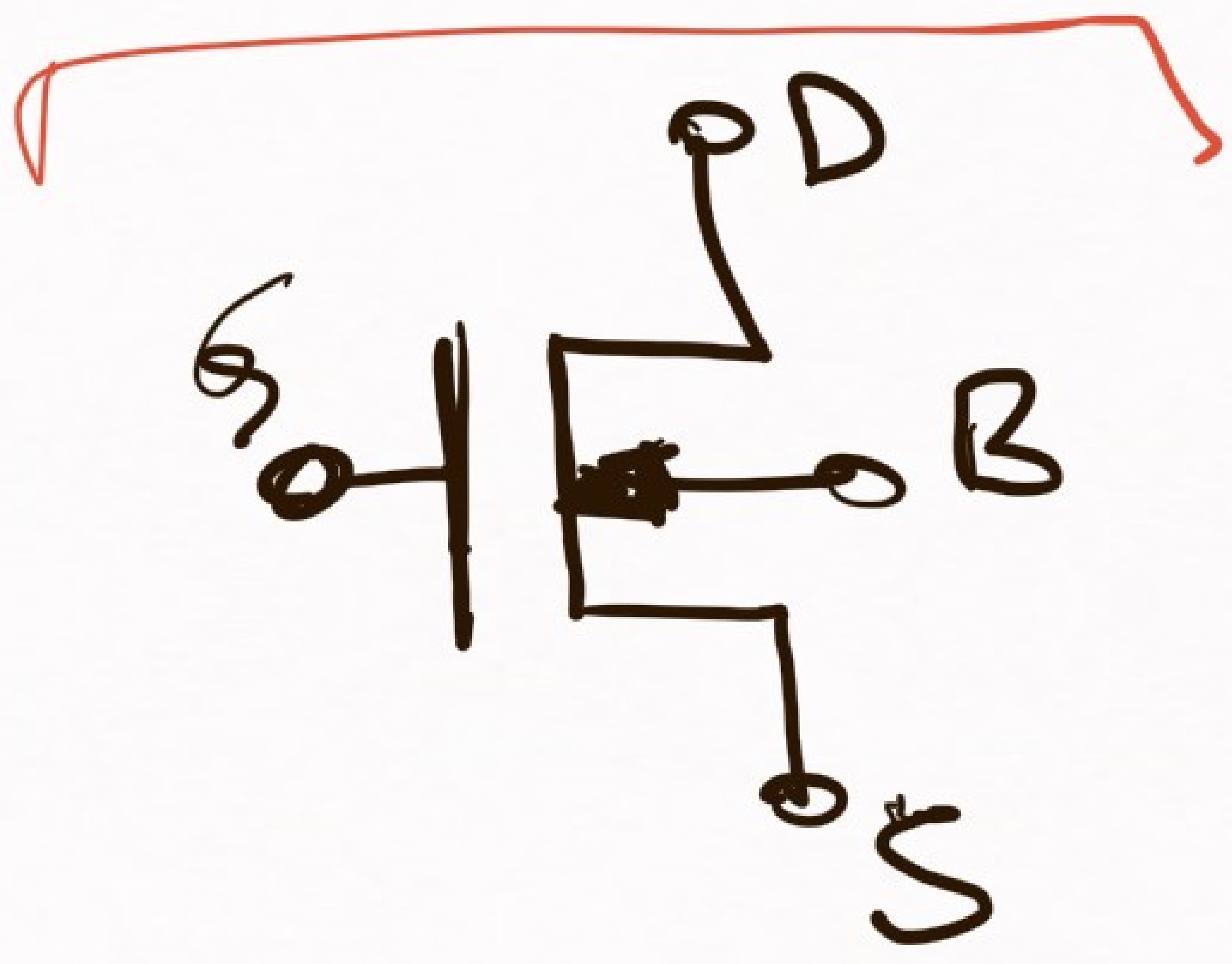
$$\underline{I_D = 0}\ ,\ \underbrace{V_S > V_P\ ,\ V_D > V_P}_{\rightarrow\ Q_i \simeq 0 \text{ en todo el canal}}$$

$$\underbrace{V_G < V_{T0} + (1+\delta)\, V_S}$$

Simbolo de circuito del transistor nMOS

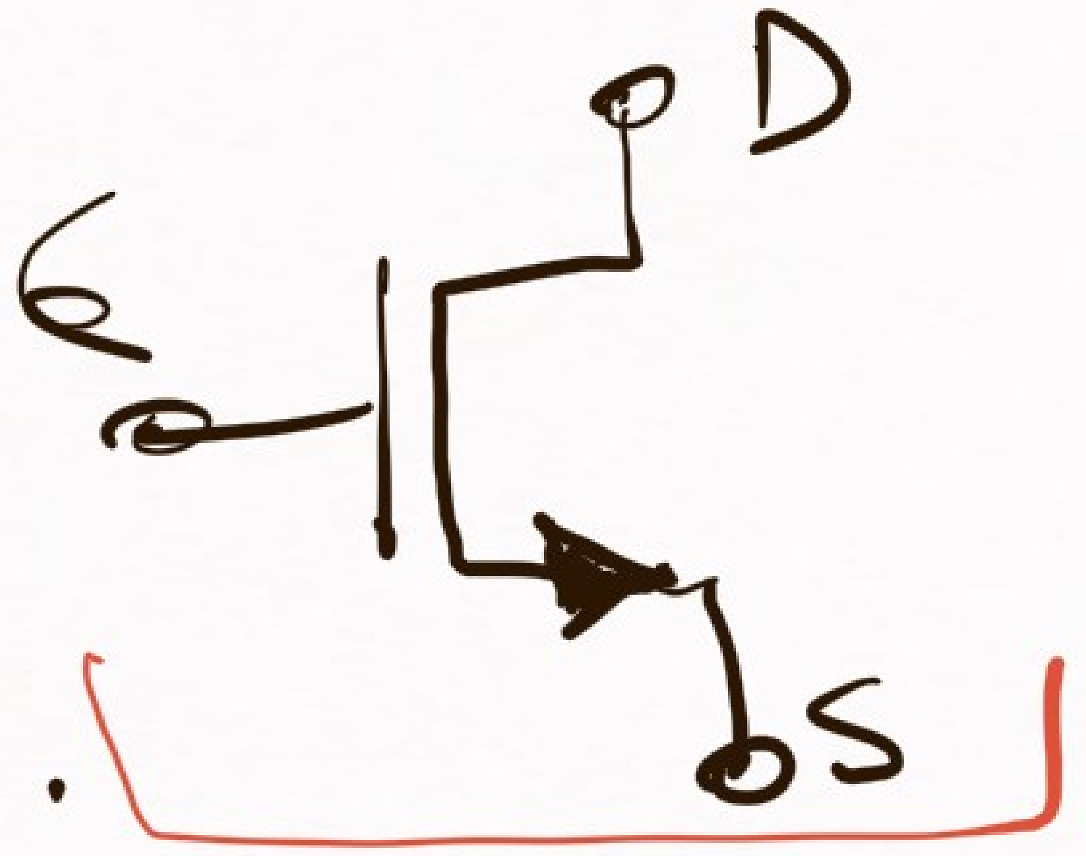




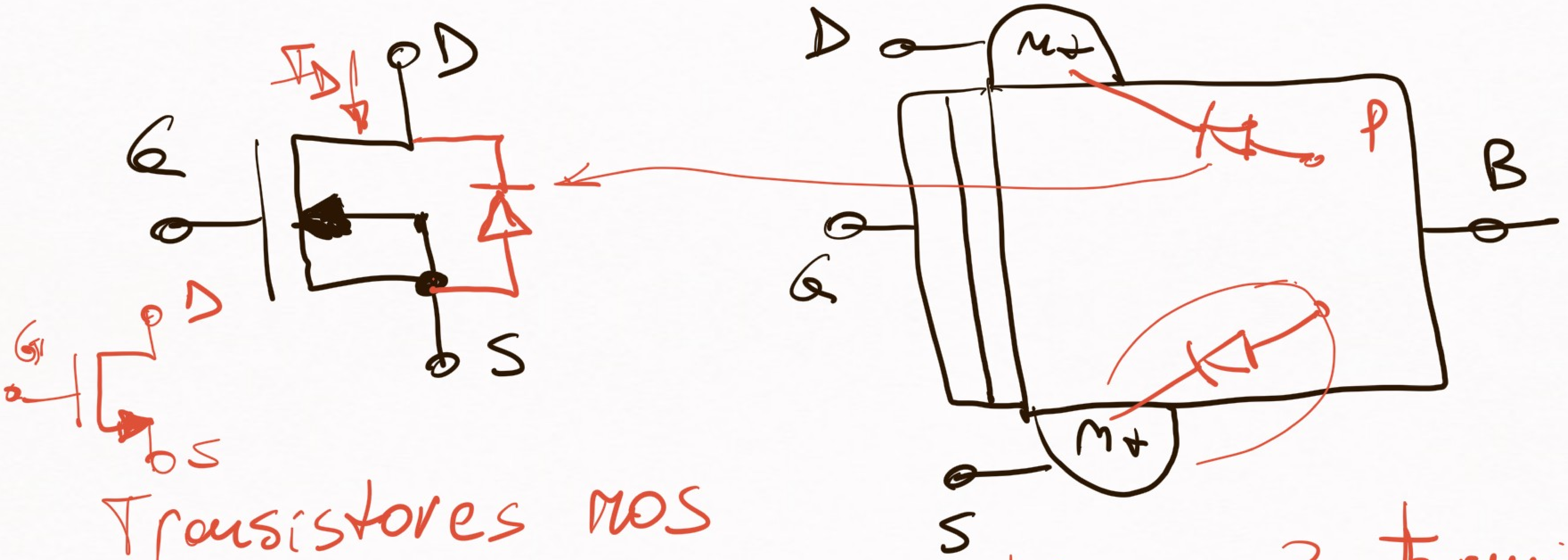


flecha apunta en el sentido directo de la juntura B - S (o B-D)

Sin conexión explícita del sustrato



Transistores nMOS discretos



Transistores MOS discretos:

- tienen 3 terminales
- No son simétricos respecto a S y D
- Tienen el diodo D-B en "antiparalelo"

Ejs de circuitos con transistor nMOS

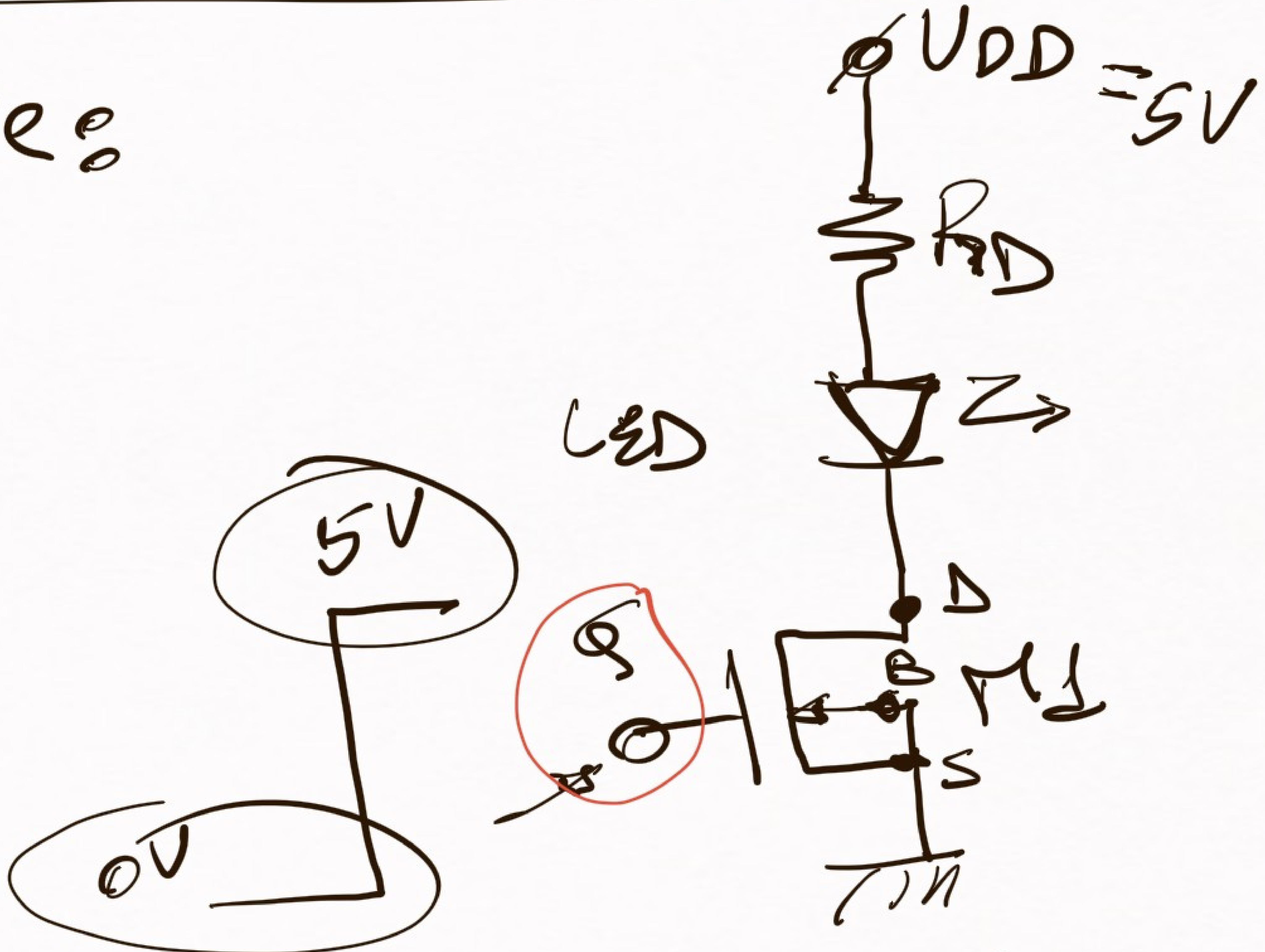
1) Uso como llave:

M1: $V_{to} = 1.5 V$

$\gamma = 0.3$

$\beta = 0.1 A/V^2$

LED: $V_{FLED} = 1.4 V$

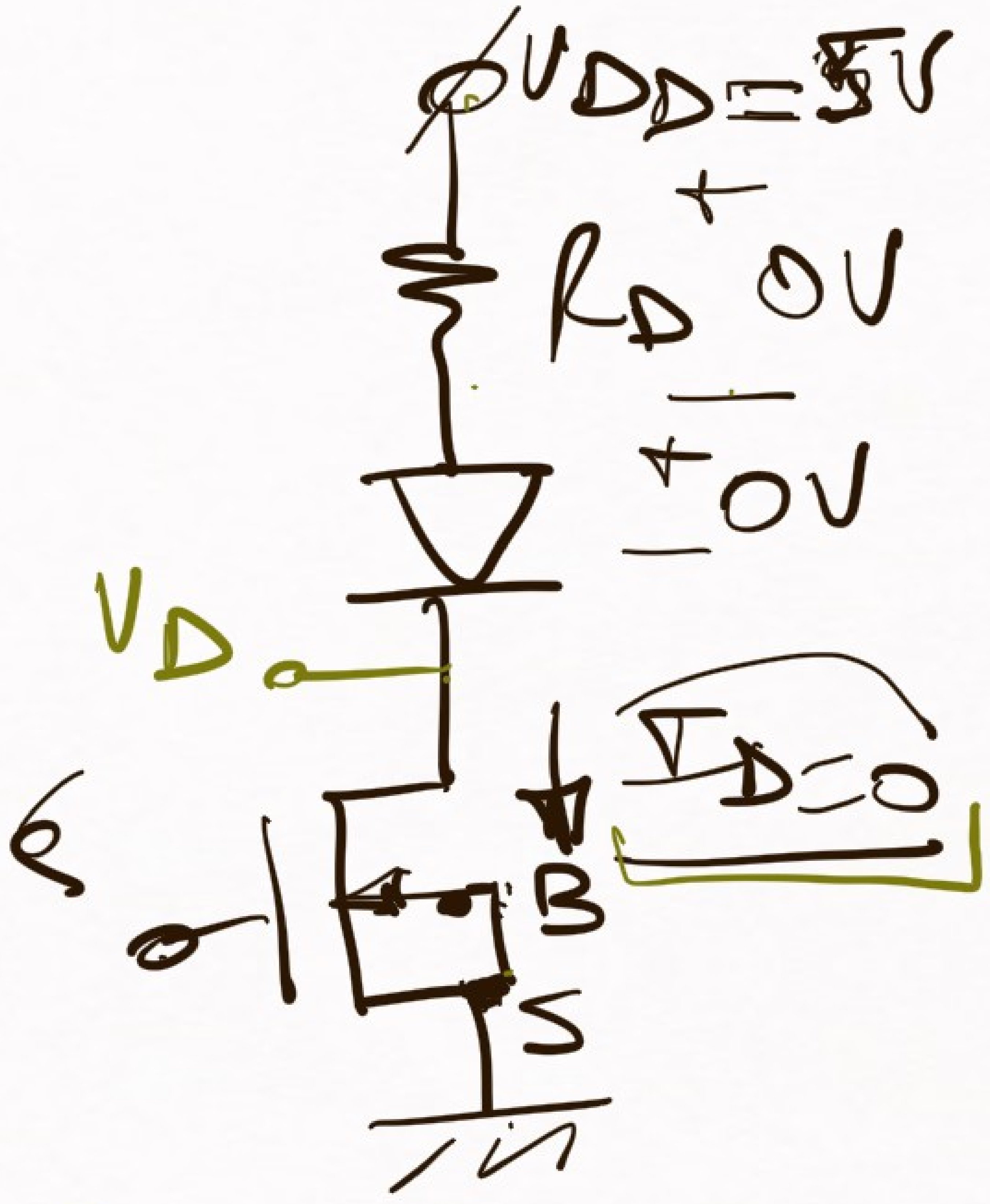


Diseñar RD para que $I_{LED} = 10 mA$

1) $V_G = 0 \Rightarrow$ Ⓗ M1 cortado

$\boxed{I_D = 0} \Rightarrow I_{LED} = 0$

(LED apagado)



$\Rightarrow$ verifico si solución es coherente con la Ⓗ:

$V_S > V_P$, $V_D > V_P$

$\parallel$

$V_{SB} = 0$

$$\frac{\overset{=V_{GB}=0}{V_G} - V_{t0}}{(1+\delta)} = \frac{-1.5V}{1.3}$$

$$V_D = V_{DD} - \underbrace{R_D \cdot I_D}_{0} - \underbrace{V_{LED}}_{0}$$

$V_D \overset{?}{>} V_P$, $V_D = 5V > \frac{0-1.5}{1.3}$ ✓

2) $\underline{V_G = 5V}$ → Trans en zona lineal?

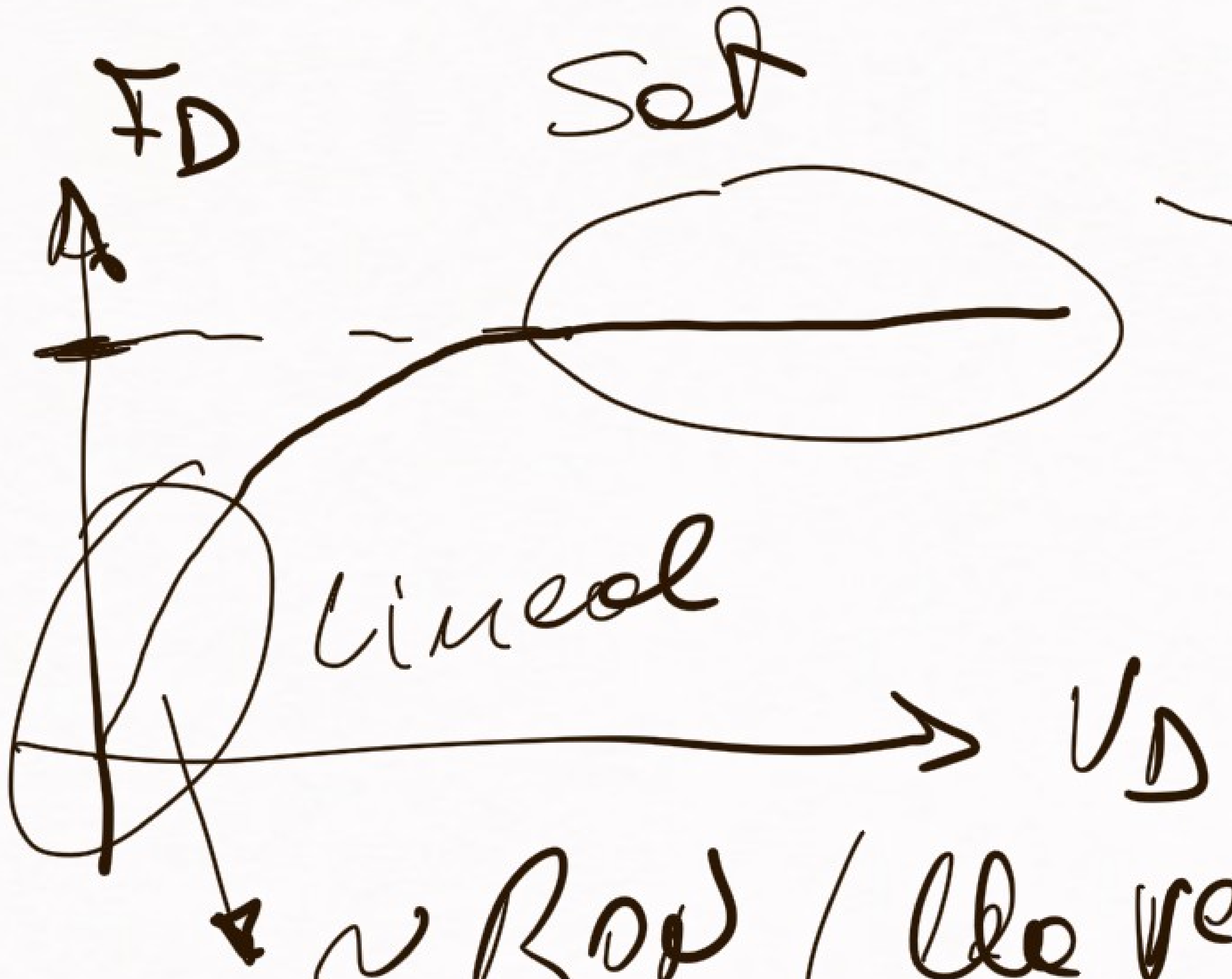
$V_S < V_P$, $\underline{V_D < V_P}$

MIE
Ron

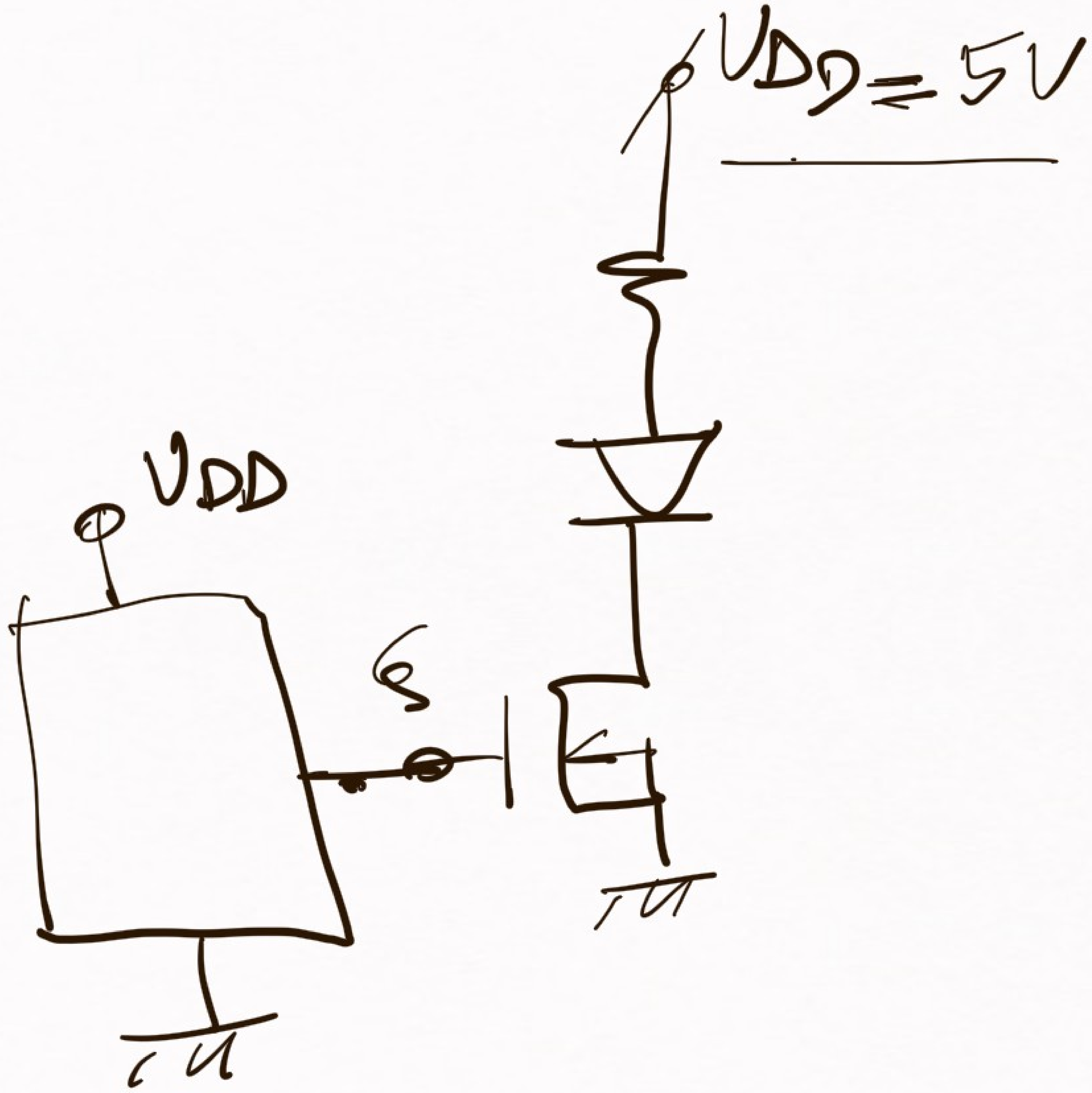
→ trans en saturación?

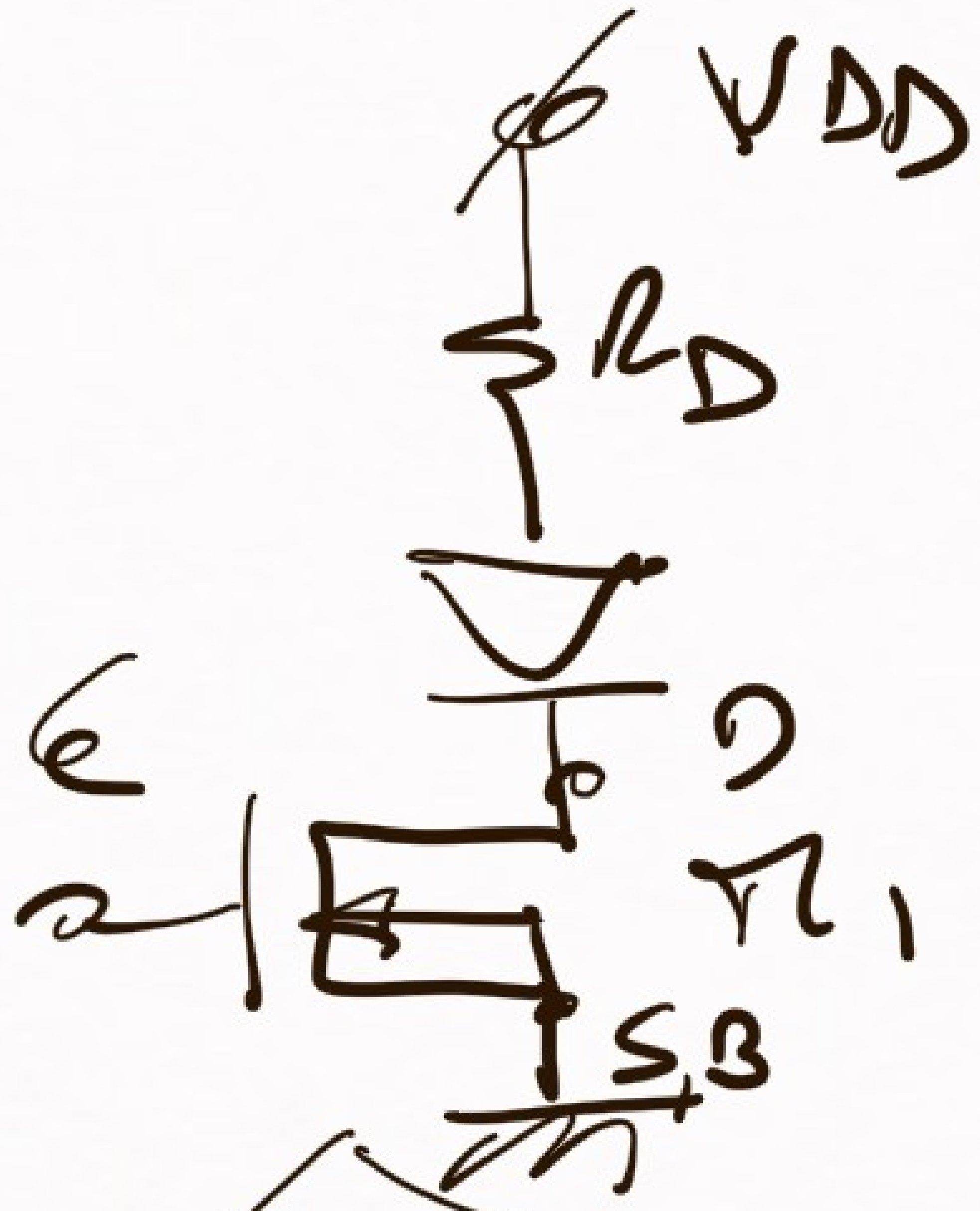
$V_S < V_P$, $\underline{V_D > V_P}$

→ transistor $\cong$ fuente de corriente

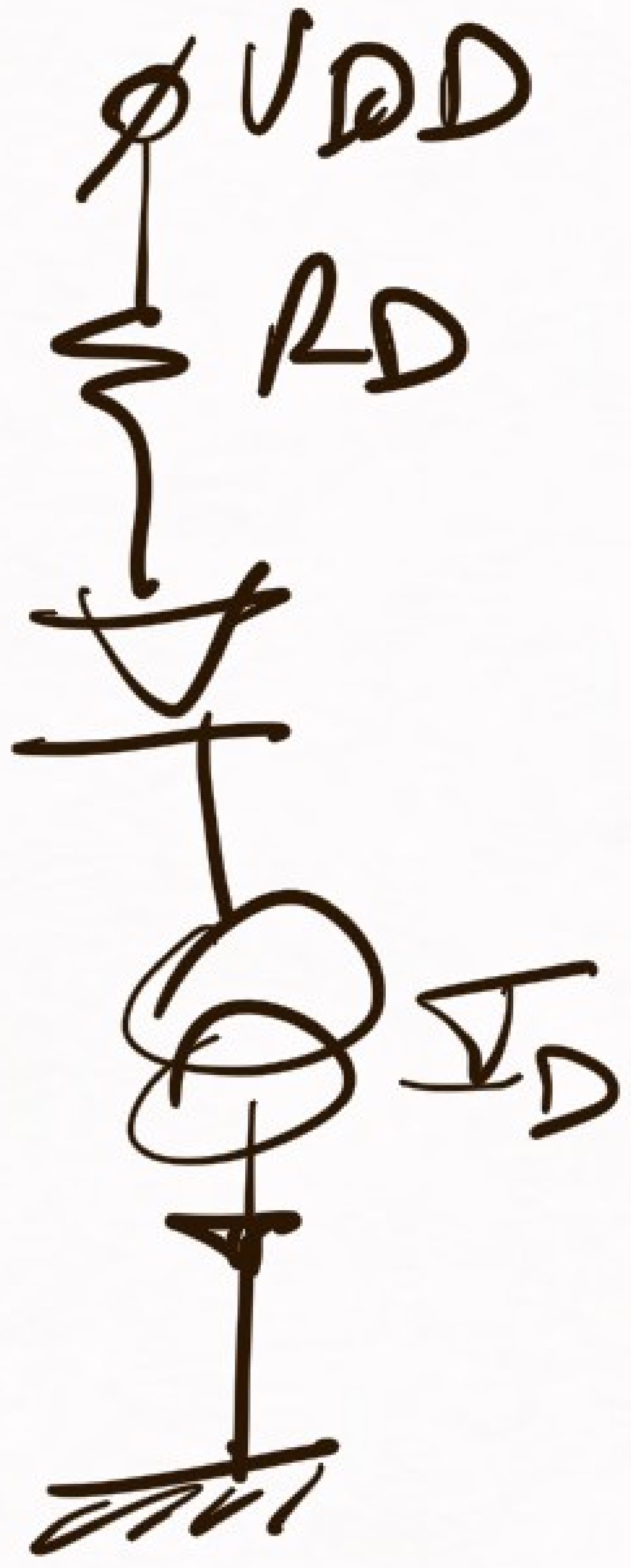


$\sim$ Ron (llave cerrada)


VDD = 5V
VDD
G



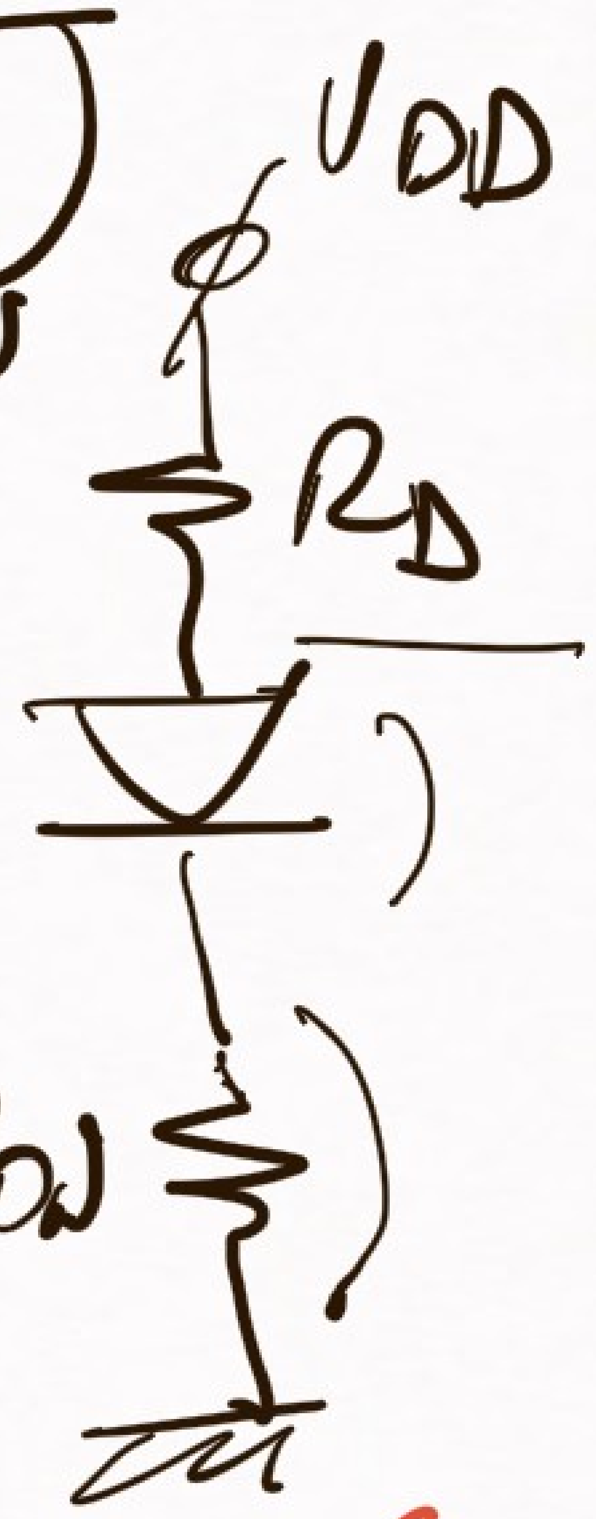
M1 en saturación:



$$I_D = f(V_G, \underbrace{V_{to}, \beta, \delta}_{\text{dispersión}})$$

M1 en zona lineal

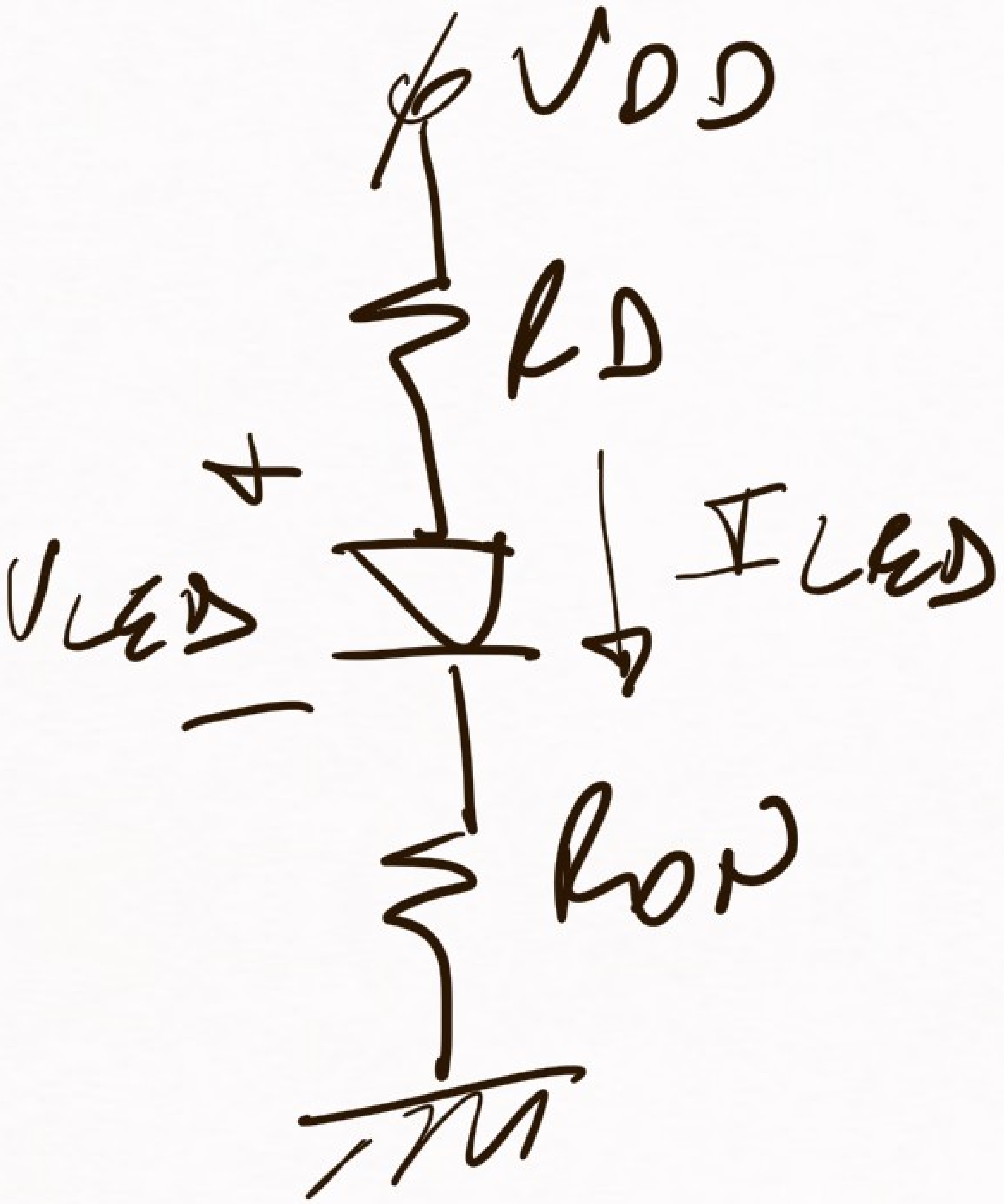
$V_D << V_P$



$f(V_G, \beta, V_{to}) = R_{ON}$

Si $R_{ON} << R_D$

⇒ corriente fijada por R_D



$$I_{LED} = \frac{V_{DD} - V_{LED}}{R_D + R_{ON}} \quad \circledast$$

Si $R_{ON} << R_D$

$$\Rightarrow \boxed{I_{LED} \simeq \frac{V_{DD} - V_{LED}}{R_D}}$$

$$R_{ON} = \frac{1}{\beta(V_G - V_{to})} = \frac{1}{0.1(5 - 1.5)} = \underline{2.9\,\Omega}$$

$\circledast$ $\underline{V_D << V_P}$

Usando (*)

$$\underbrace{I_{LED}}_{\substack{\shortparallel \\ 10mA}} = \frac{\overset{5V}{V_{DD}} - \overset{1.4V}{V_{LED}}}{R_D + R_{ON}} \Rightarrow \underbrace{R_D + R_{ON} = 360\Omega}$$

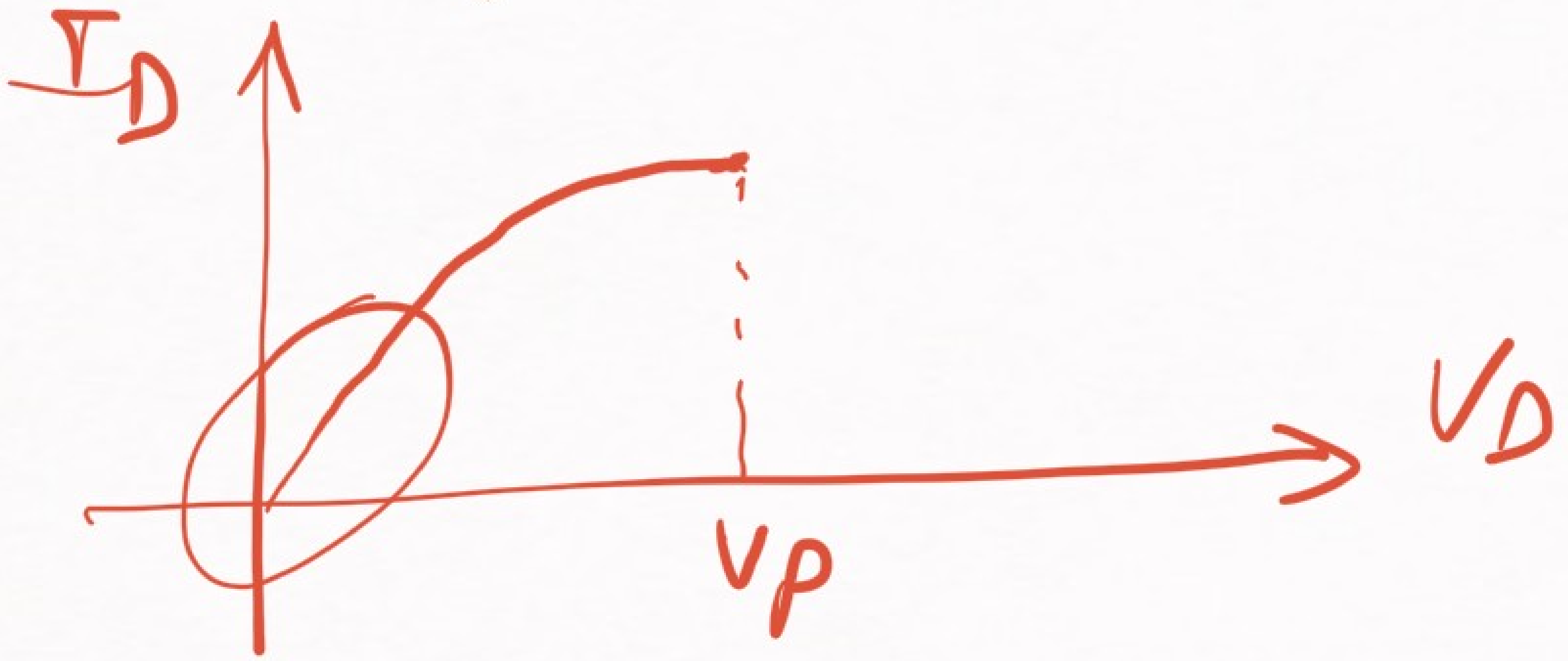
$\Rightarrow R_D = 357\Omega$ (desprezando R_{ON}

$$\Rightarrow \underbrace{R_D \cong 360\Omega}$$

Verifico Ⓗ: Zona lineal: $V_S < V_P$

$$\underbrace{\cancel{V_D < V_P}}$$

$$\underbrace{V_D << V_P}$$



Verifico Ⓗ:

$$V_S < V_P \Leftrightarrow \underbrace{V_G}_{\overset{||}{5V}} \overset{\checkmark}{>} \underbrace{V_{T0}}_{\overset{||}{1.5V}} + (1+\delta)\underbrace{V_S}_{\overset{||}{V_{SB}=0}}$$

$$\overset{\checkmark}{V_D << V_P} = \frac{5V - 1.5V}{1.3} = \frac{3.5}{1.3} = 2.7V$$

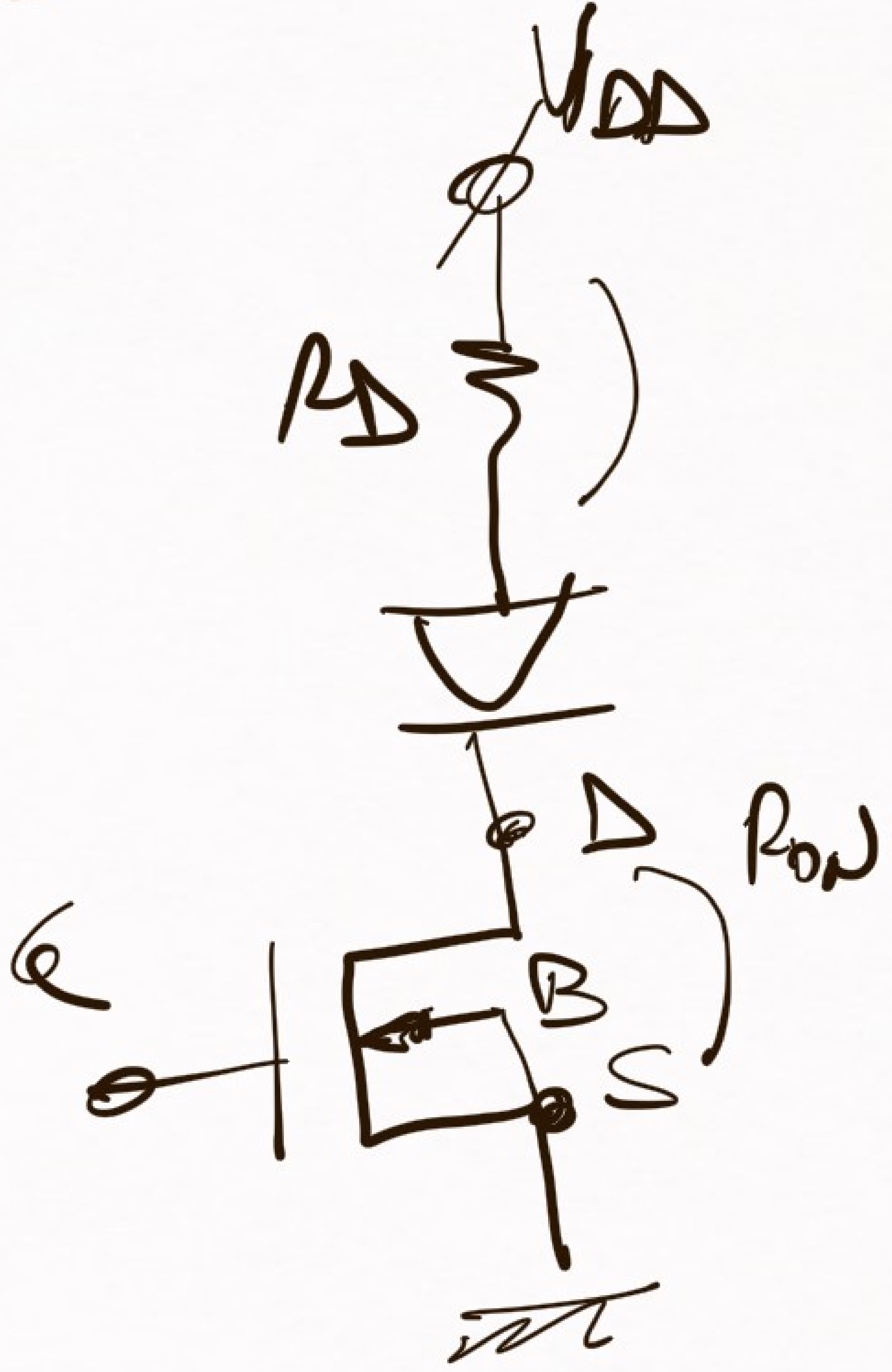
$$\Updownarrow$$

$$V_D = V_{DD} - R_D \cdot I_D - V_{LED} =$$

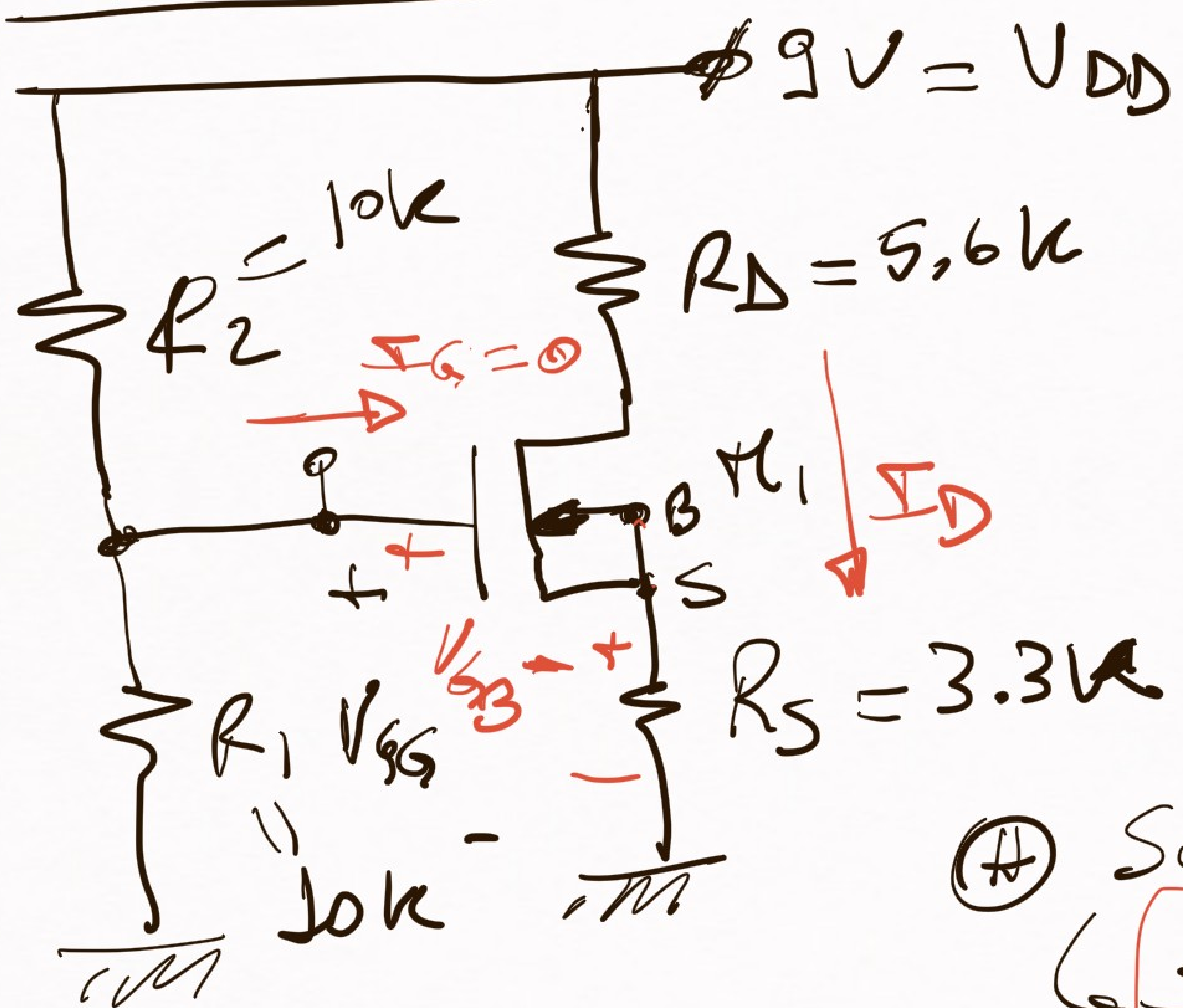
$$= \underbrace{(V_{DD} - V_{LED})}_{\rightarrow \underline{\underline{3.6V}}} \cdot \frac{R_{ON}}{R_D + R_{ON}} =$$

$$= \underline{\underline{29\,mV}}$$

$$\rightarrow \boxed{R_D = 360\Omega}$$



Ej. en saturación:



M1: $V_{to} = 1V$

$\gamma \cong 0$

$\beta = 1 mA/V^2$

I_D?

Ⓐ Saturación

$$I_D = \frac{\beta}{2(1+\delta)}\left(V_{GB} - V_{to} - \underbrace{(1+\delta)V_{SB}}_{0}\right)^2$$

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

$$V_{GG} = \frac{R_1}{R_1 + R_2} \cdot V_{DD} = 4.5V$$

$$V_{GG} = V_{GB} + R_S \cdot I_D$$

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

$$V_{GG} = 4.5\,V$$

$$V_{GG} = V_{GB} + R_S \cdot I_D$$

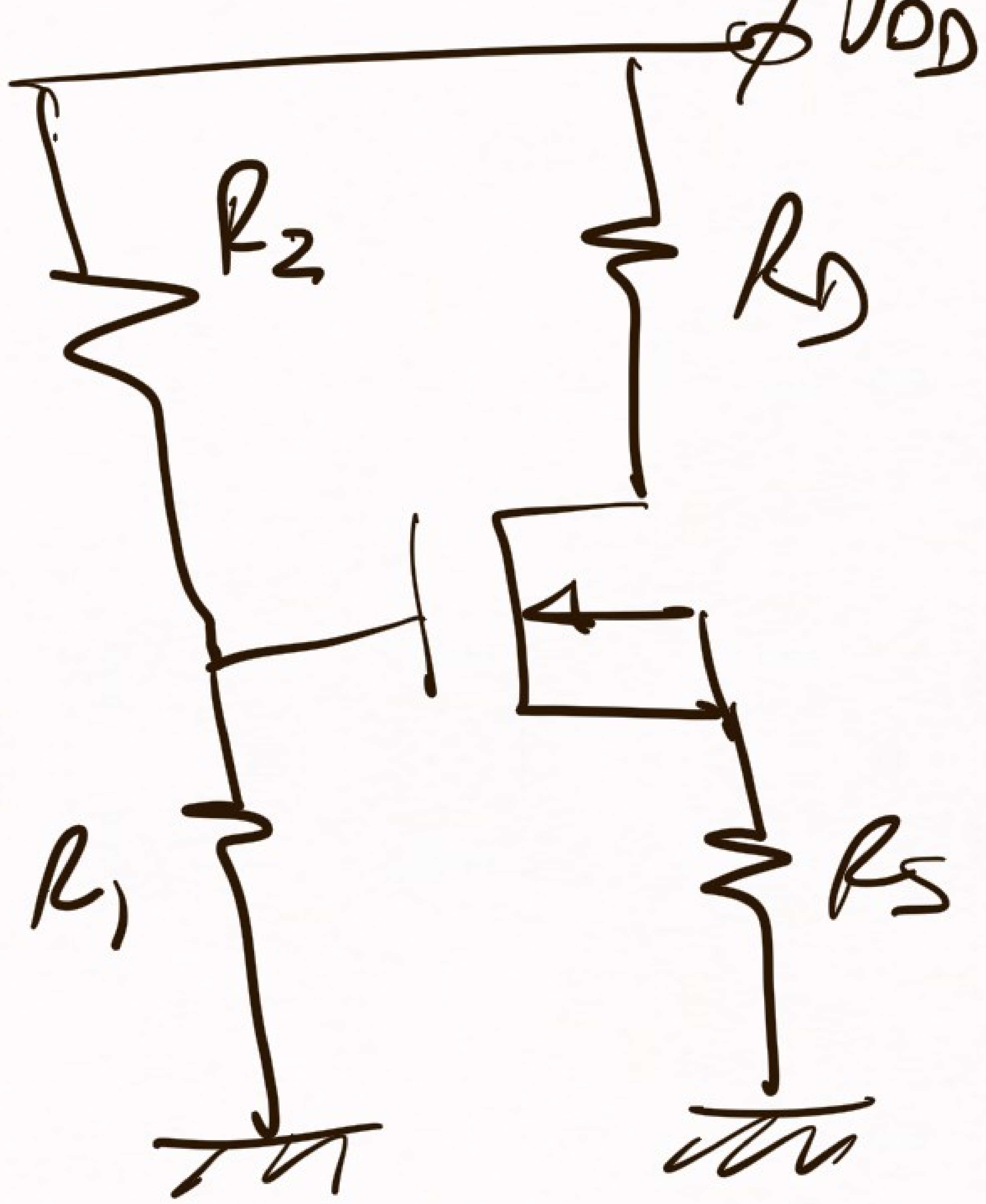
$$4{,}5\,V = V_{GB} + \frac{R_S \cdot \beta}{2(1+\delta)}\left(V_{GB} - V_{t0}\right)^2$$

↳ Ec. de 2do grado

$$\Rightarrow V_{GB} = \begin{cases} 2.18\,V \\ -0.79\,V \end{cases}$$

transistor no va a estar saturado

$V_S < V_P$, $\underbrace{V_G > V_{t0} + (1+\delta)V_S}$ → no se cumple



$$V_D \overset{?\,\checkmark}{>} V_P = 1.18V$$

$$\|$$

$$V_{DB}$$

$$V_{DB} = V_{DD} - \overbrace{R_D I_D}^{= 3.22V} - \underbrace{R_S I_D}_{\substack{\| \\ 2.32V}} =$$

$$= \underline{2.76V}$$