Transistores

13/5/21

Digital

* Llave abierta
  → zona de corte
* Llave cerrada
  → zona lineal

Analógico

* Fuente de corriente controlada
  → zona saturación
  → Amplificador

Ec. en saturación:

$$i_D = \frac{\beta}{2(1+\delta)}\left(V_{GB} - V_{t0} - (1+\delta)V_{SB}\right)^2\left(1 + \frac{V_{DB}}{V_A}\right)$$

→ característica no lineal.

Modelo de pequeña señal

→ Dispositivo no lineal operando con pequeñas variaciones (pequeña amplitud AC) entorno a un punto fijo de su característica (punto DC)

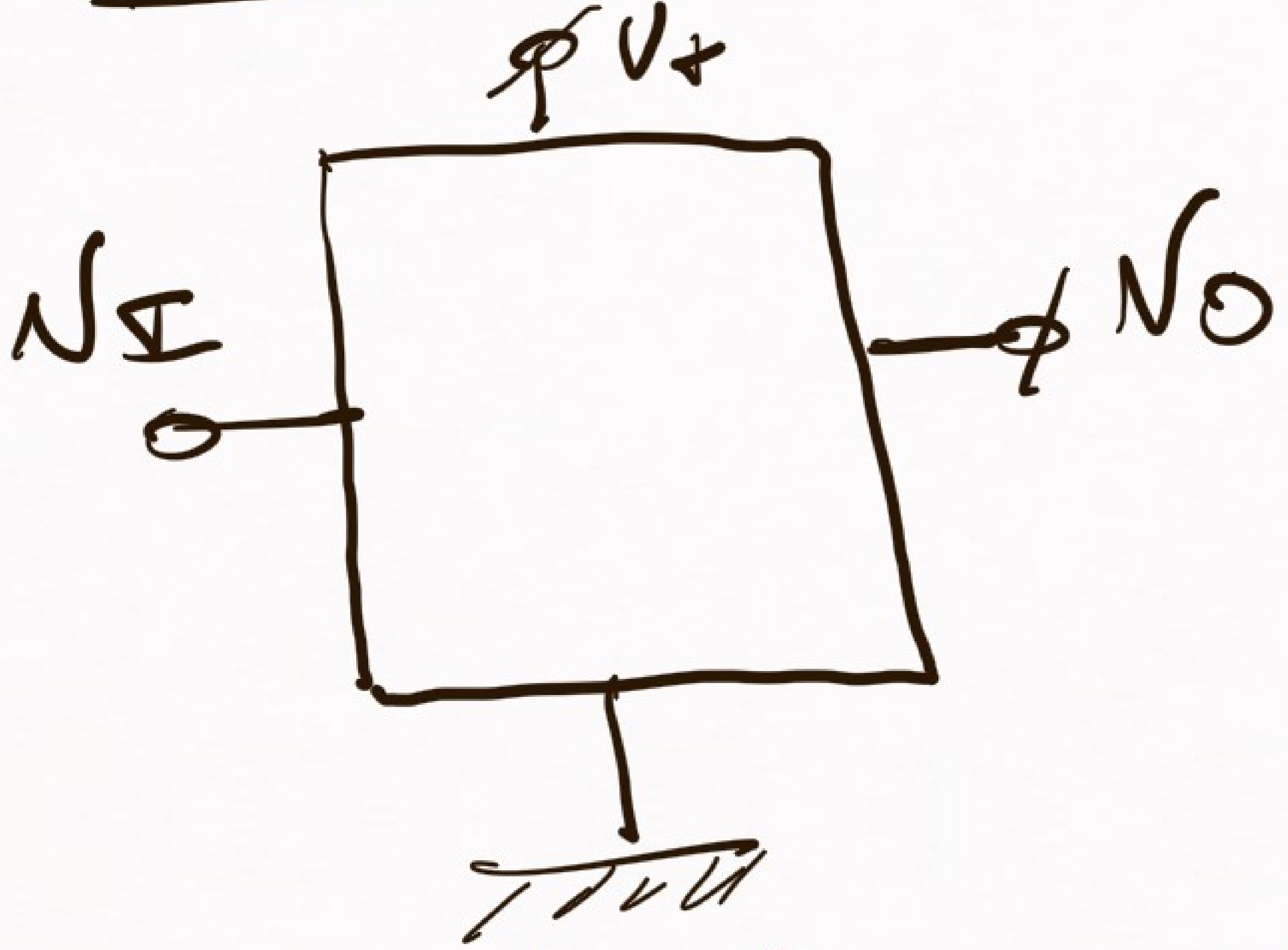
↳ Aproximamos con característica lineal este caso.

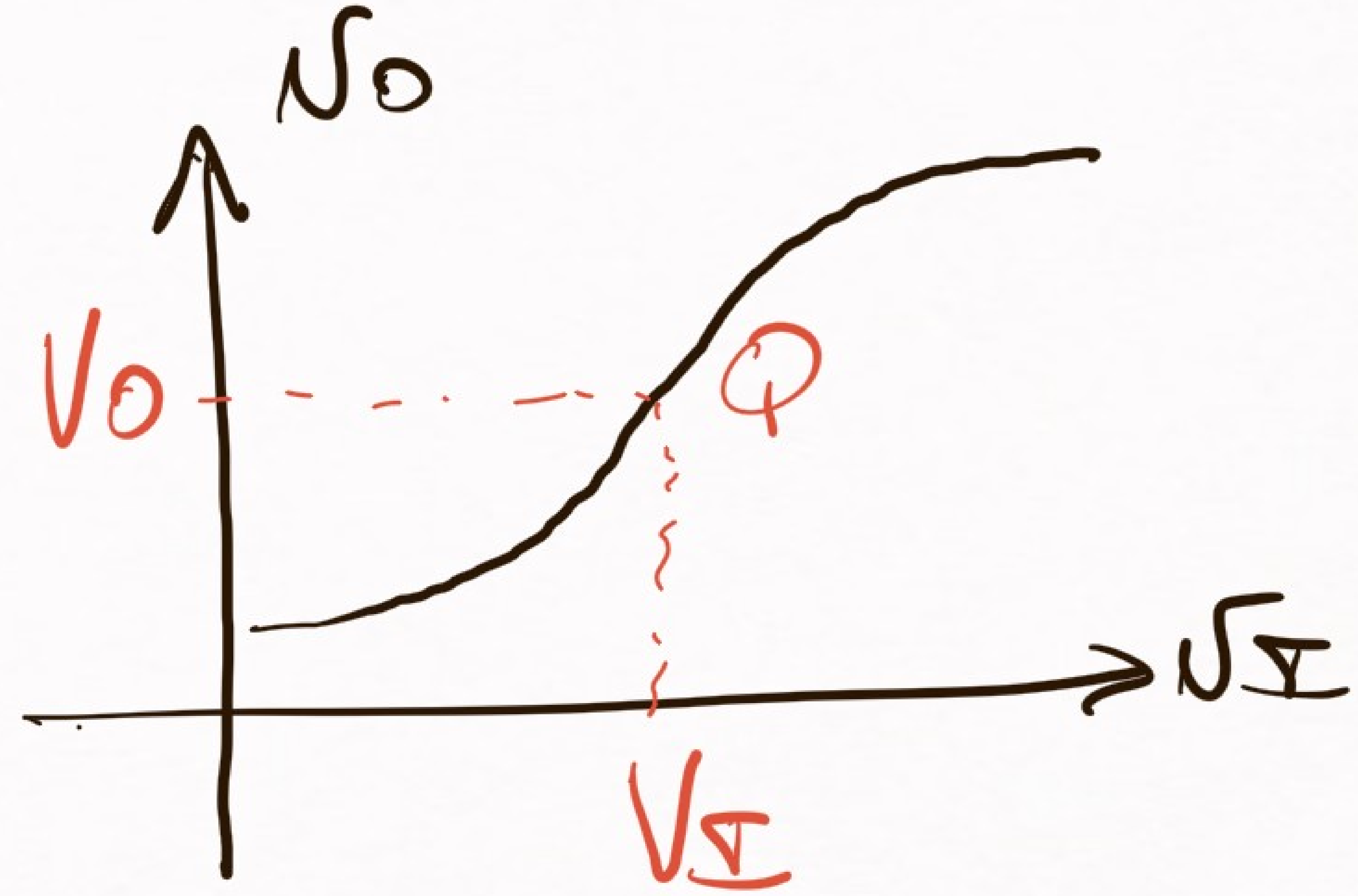
1) Caso gral., "abstracto"

2) T. MOS con $V_{SB}=0$

3) T. MOS en general.

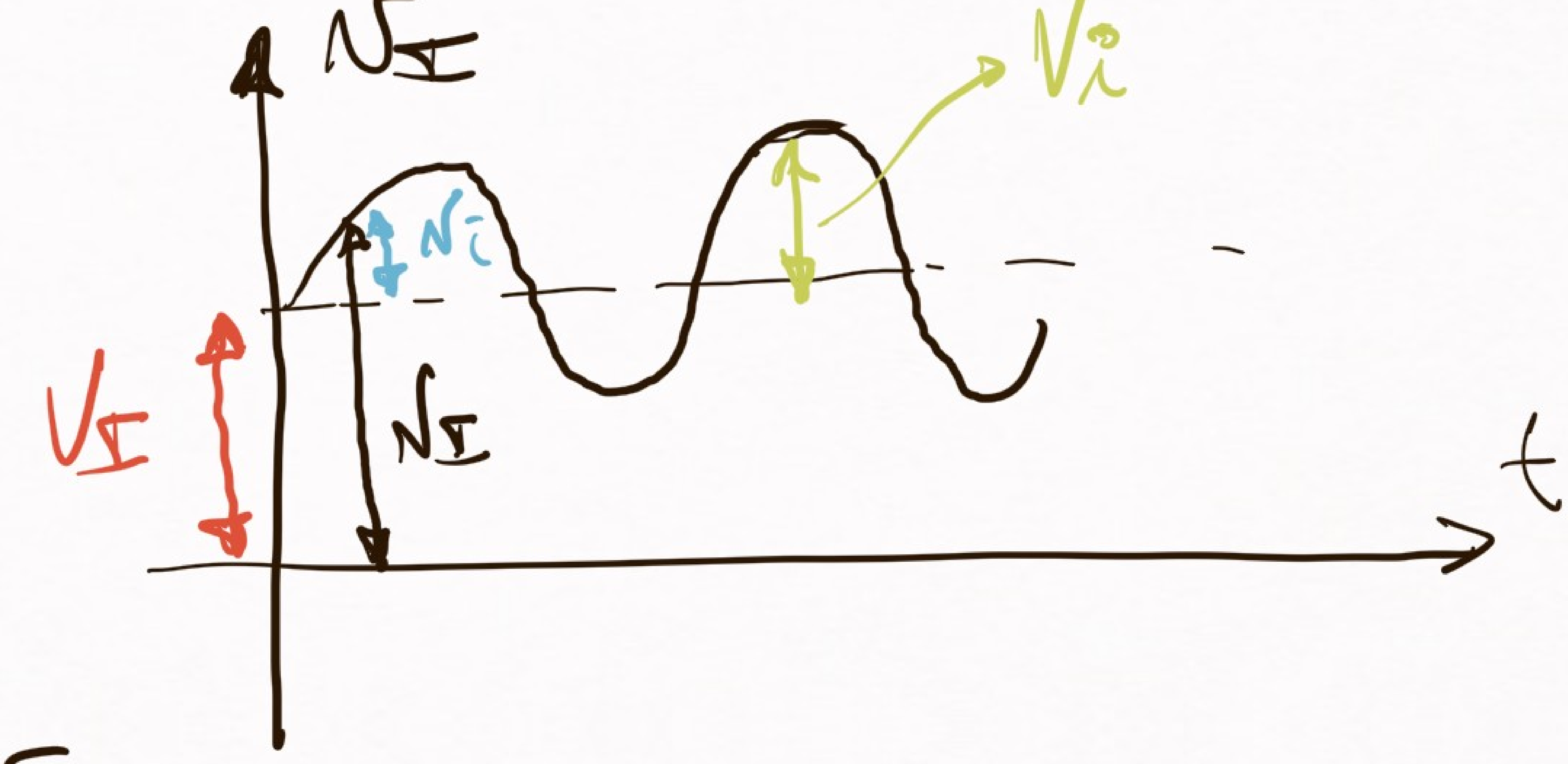
Caso General.





Q: punto de operación o punto de polarización ("bias point") o punto de reposo.

Nomenclatura:

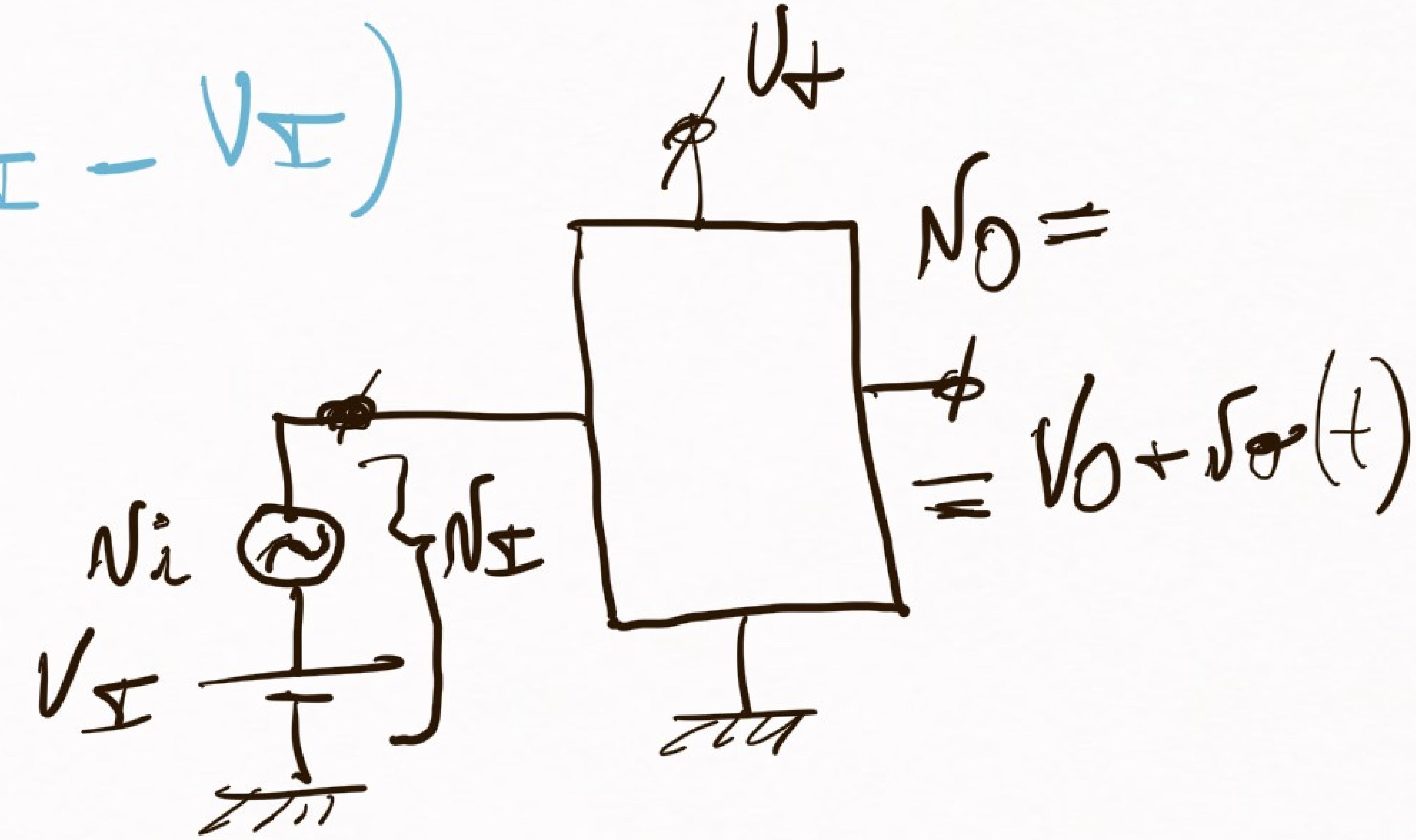


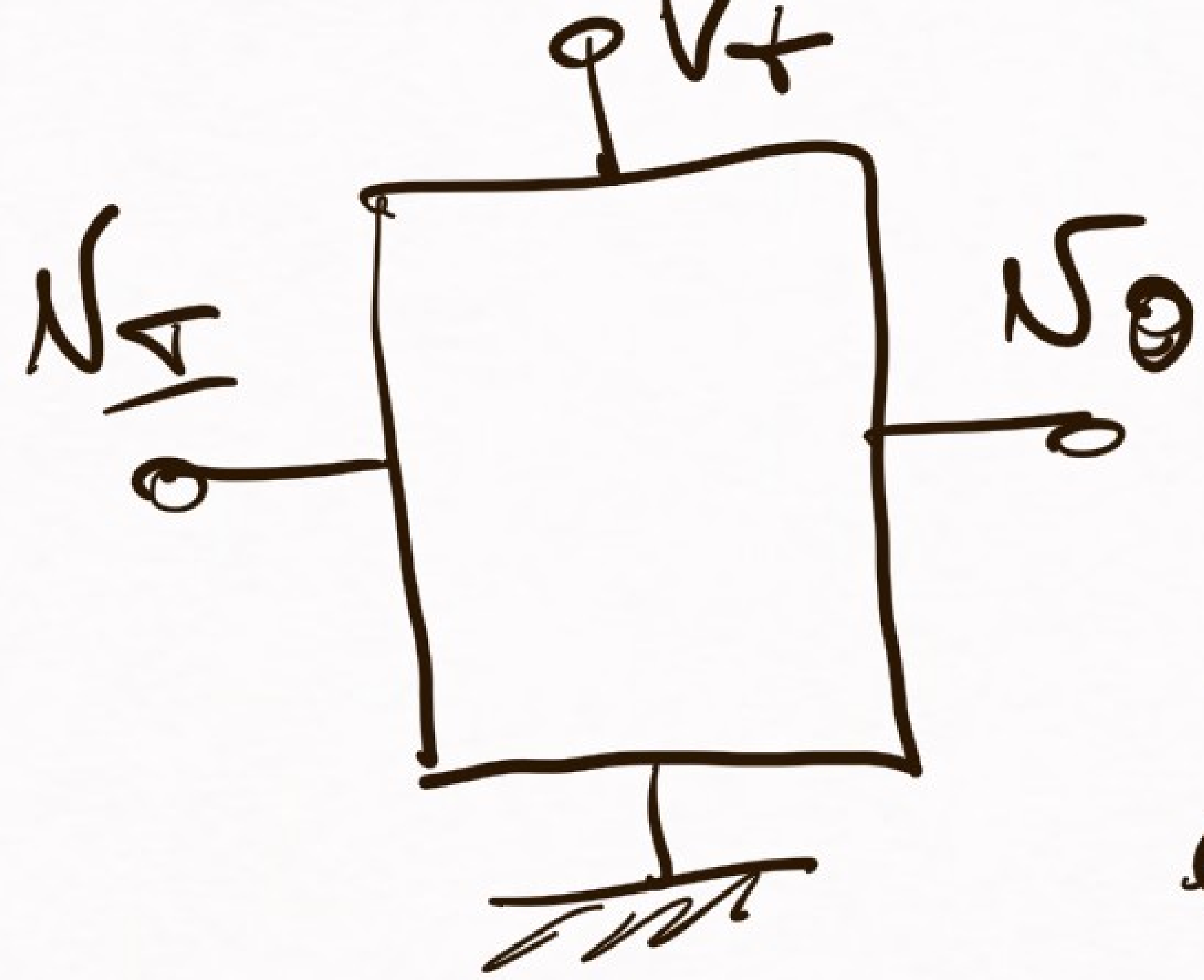
Señal total: v_I

Comp. DC: V_I

Comp. AC: $v_i = (v_I - V_I)$

(Amplitud de AC: V_i)





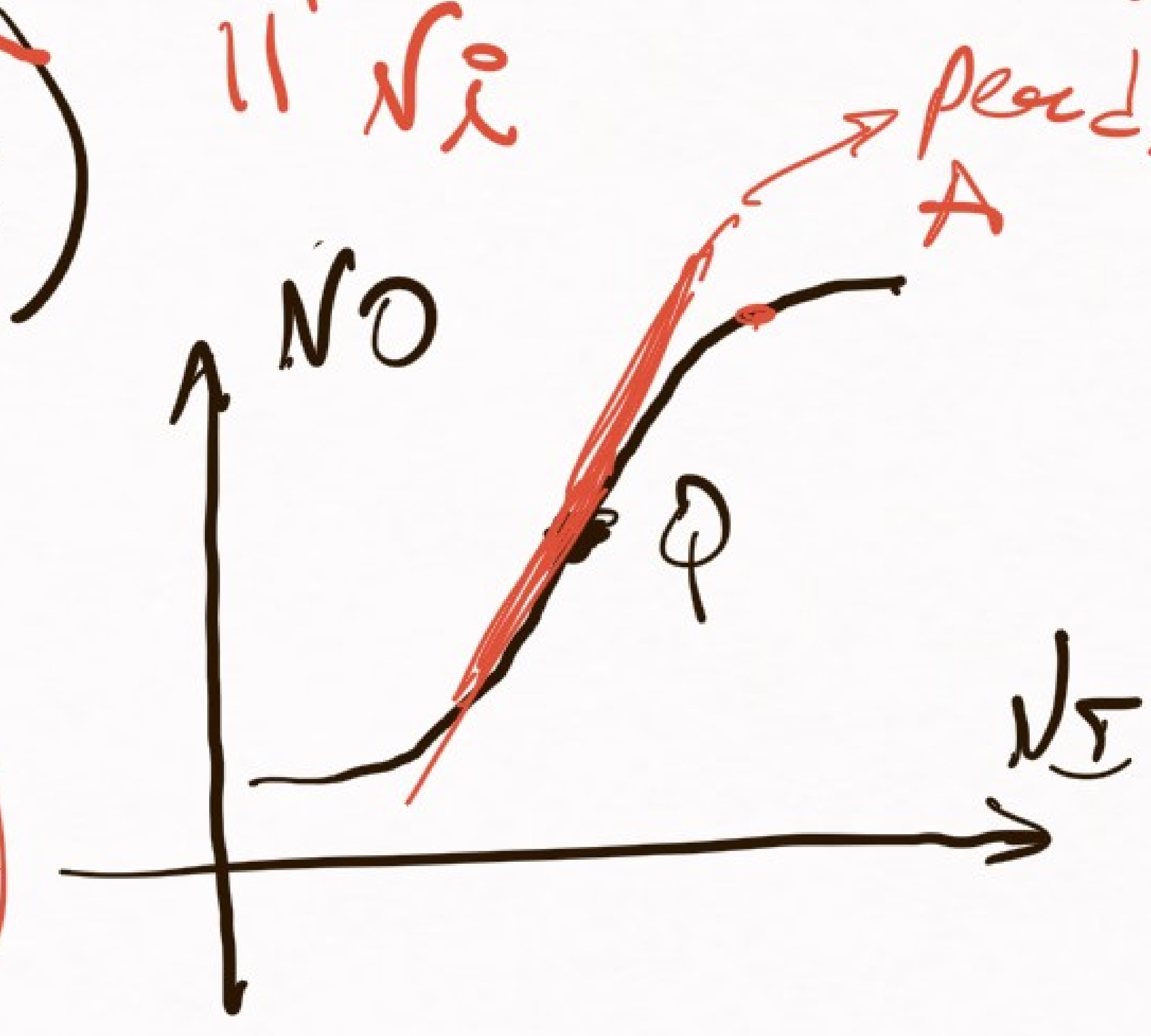
$\underbrace{v_O(v_I) \text{ no lineal}}$

$\Rightarrow$ Desarrollo de Taylor en torno a $Q(v_I = V_I,\ v_O = V_O)$

$$f(x) = f(x_0) + \frac{df}{dx}\bigg|_{x=x_0}(x - x_0)$$

$$v_O \simeq \underbrace{v_O(V_I)}_{\text{(salida DC)} = V_O} + \underbrace{\frac{dv_O}{dv_I}\bigg|_{v_I=V_I}}_{= \text{"}A\text{"}} \cdot \underbrace{(v_I - V_I)}_{\text{(AC entrada)} \,=\, v_i}$$

$A(Q) = A(V_I)$



$$\boxed{v_O \simeq V_O + A(V_I)\cdot v_i}$$

en modo AC

Aplicación del modelo de peq. señal

(x superposición): ($v_O = V_O + A(V_I) \cdot v_i$)

1) Componente DC: V_O: Análisis DC

$\Rightarrow$ fuentes independientes de AC $= 0$

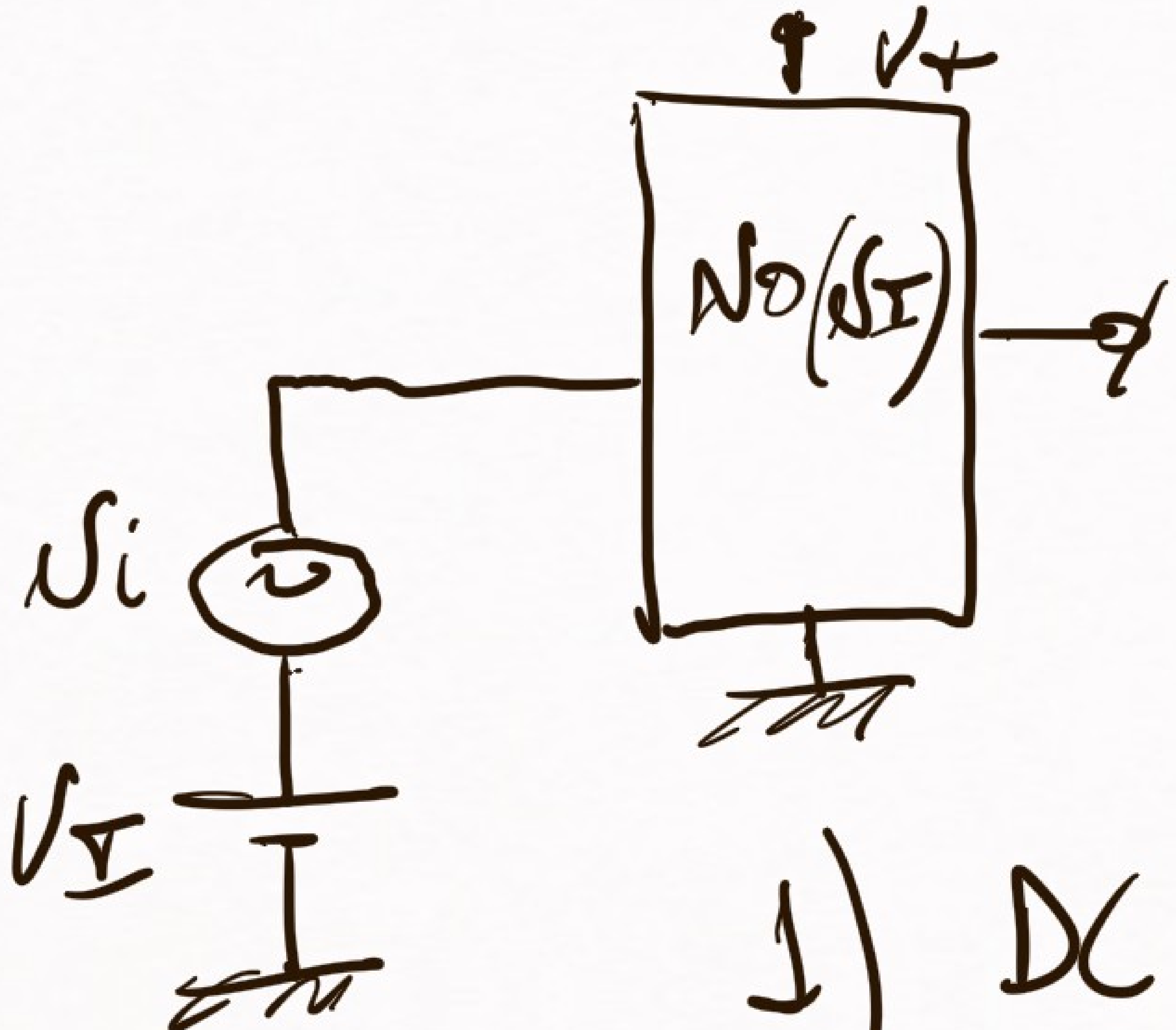
C: circuito abierto, L: cortocircuito

2) Calcular los parámetros del modelo de pequeña señal: $A(V_I)$

3) Componente AC: $A(V_I) \cdot v_i$: Análisis AC

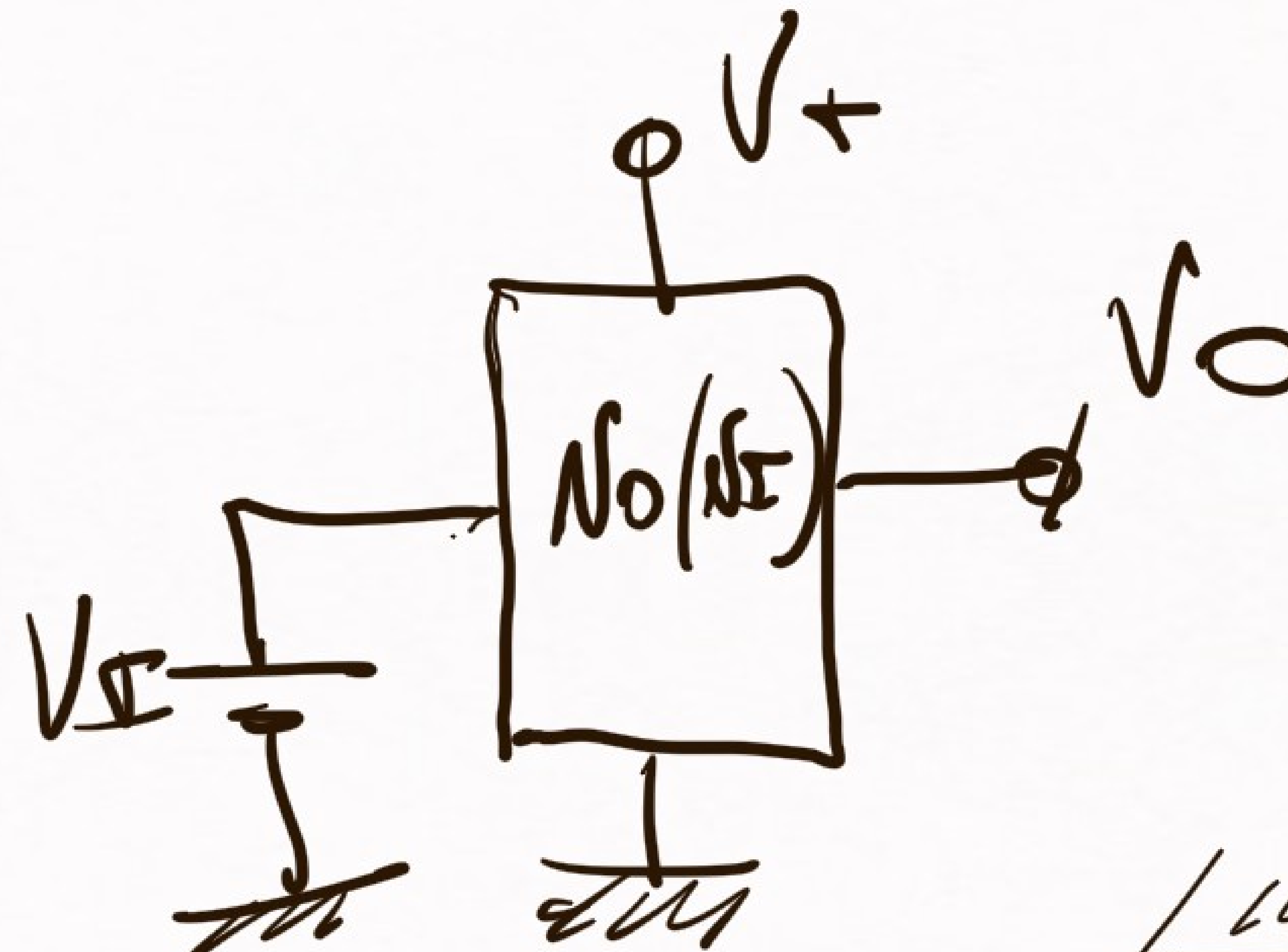
$\Rightarrow$ Fuentes DC independientes $= 0$

($V_I = 0$, $V_+ = 0$)

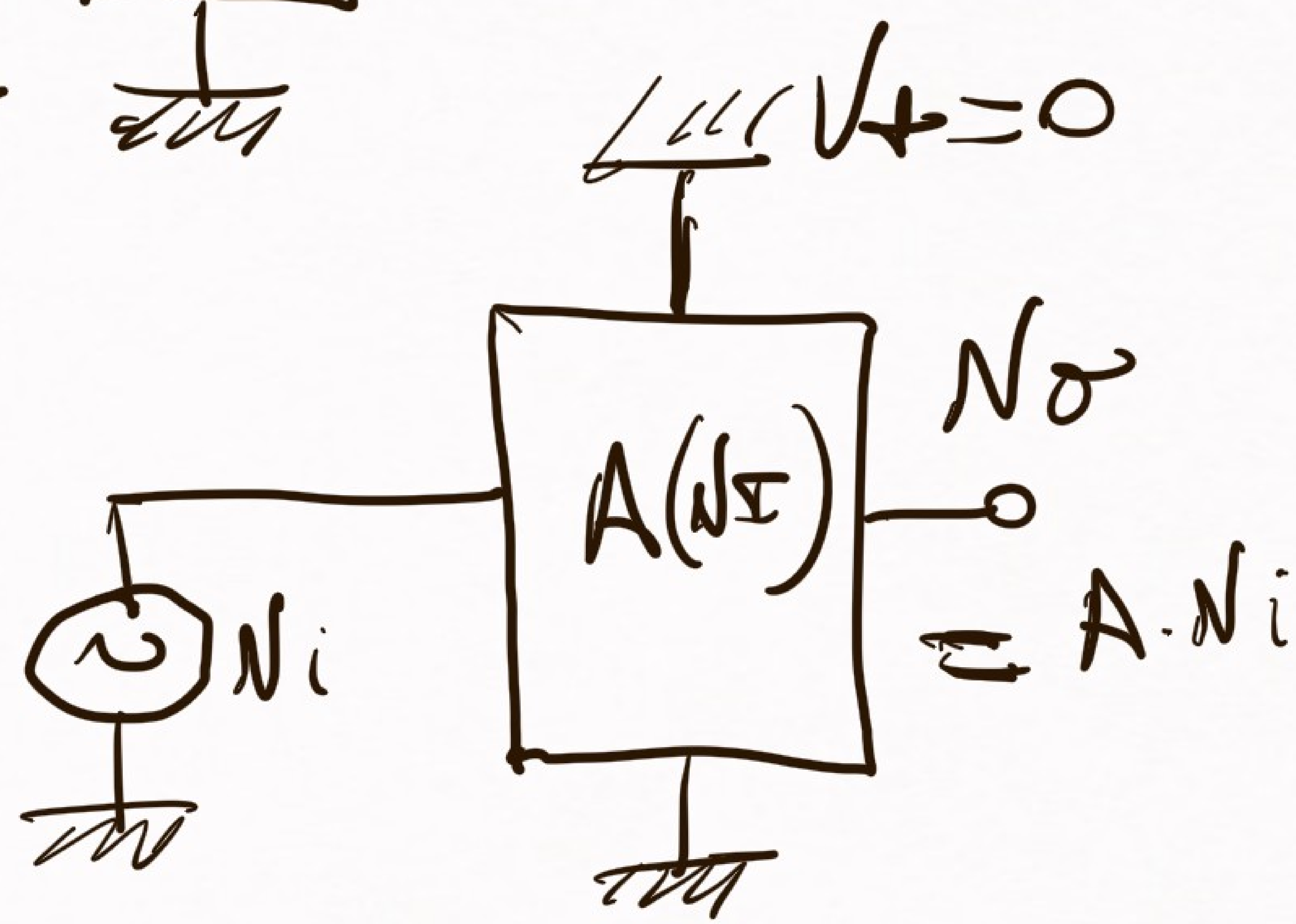


$v_O = V_O + v_o$

1) DC
($v_i = 0$)



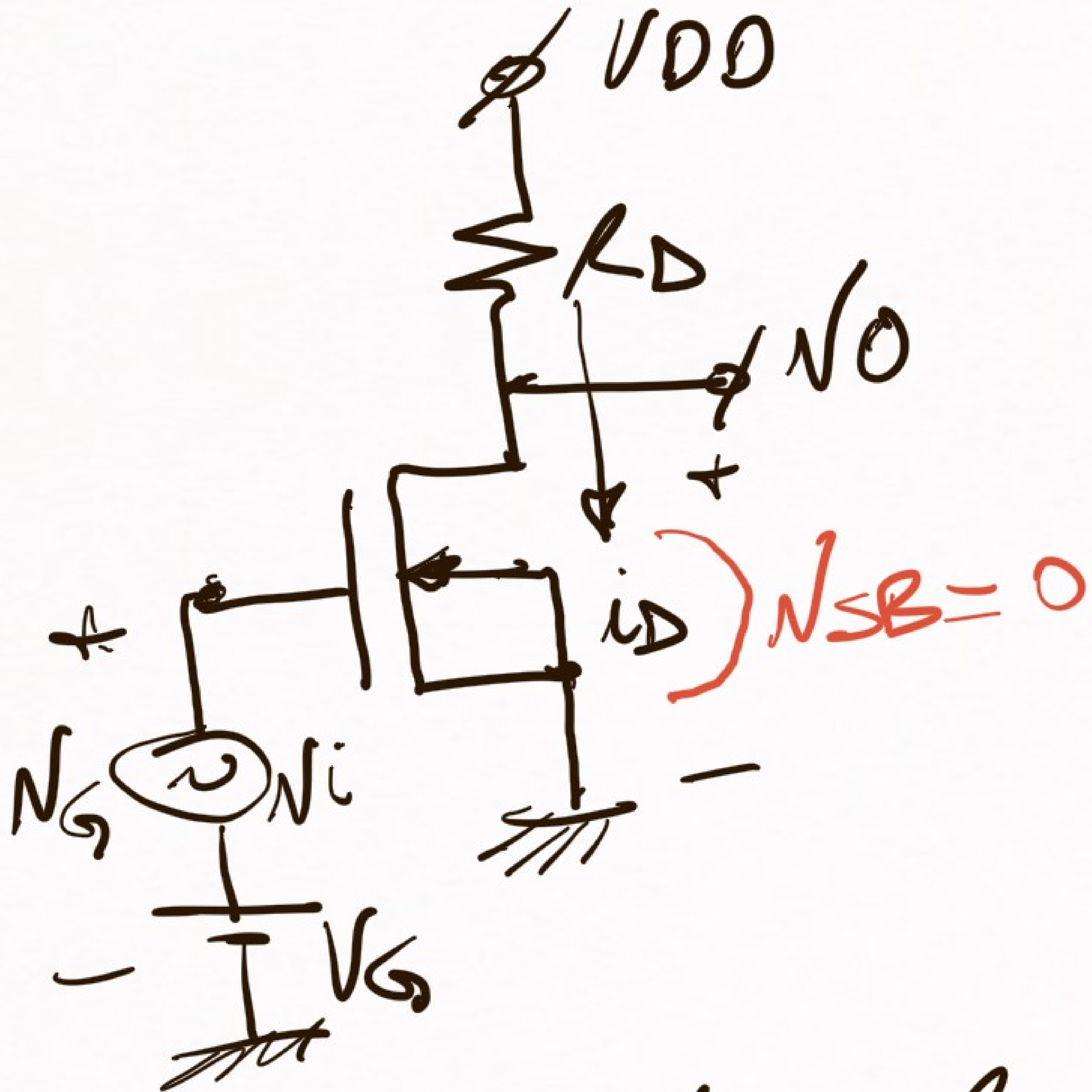
2,3) AC
($V_I = 0$, $V_+ = 0$)



Sustituimos por modelo de peq. señal

Tr. MOS como amplificador

Configuración source común



(H) Tensiones aplicadas y RD son tales que el transistor opere en saturación.

$$i_D = \frac{\beta}{2(1+\delta)} \cdot (v_G - V_{to})^2$$

(despreciando efecto de modulación de largo de canal)

$$v_O = V_{DD} - R_D \cdot i_D$$

linealizamos $i_D(v_G)$

$$\underbrace{i_D}_{total} = \underbrace{I_D}_{DC} + \underbrace{\left.\frac{\partial i_D}{\partial v_G}\right|_{V_G}}_{g_m} \cdot \underbrace{(v_G - V_G)}_{v_g}$$

$v_g = v_i$

v_g (AC)

$\rightarrow$ g_m: transconductancia de gate.

$$i_D = \frac{\beta}{2(1+\delta)}(v_G - V_{to})^2$$

$i_D \rightarrow I_D$, $v_G \rightarrow V_G$

$$\left.\frac{\partial i_D}{\partial v_G}\right|_{V_G} = \frac{\beta}{(1+\delta)}(V_G - V_{to}) = \sqrt{\frac{2\beta \cdot I_D}{(1+\delta)}} = g_m$$

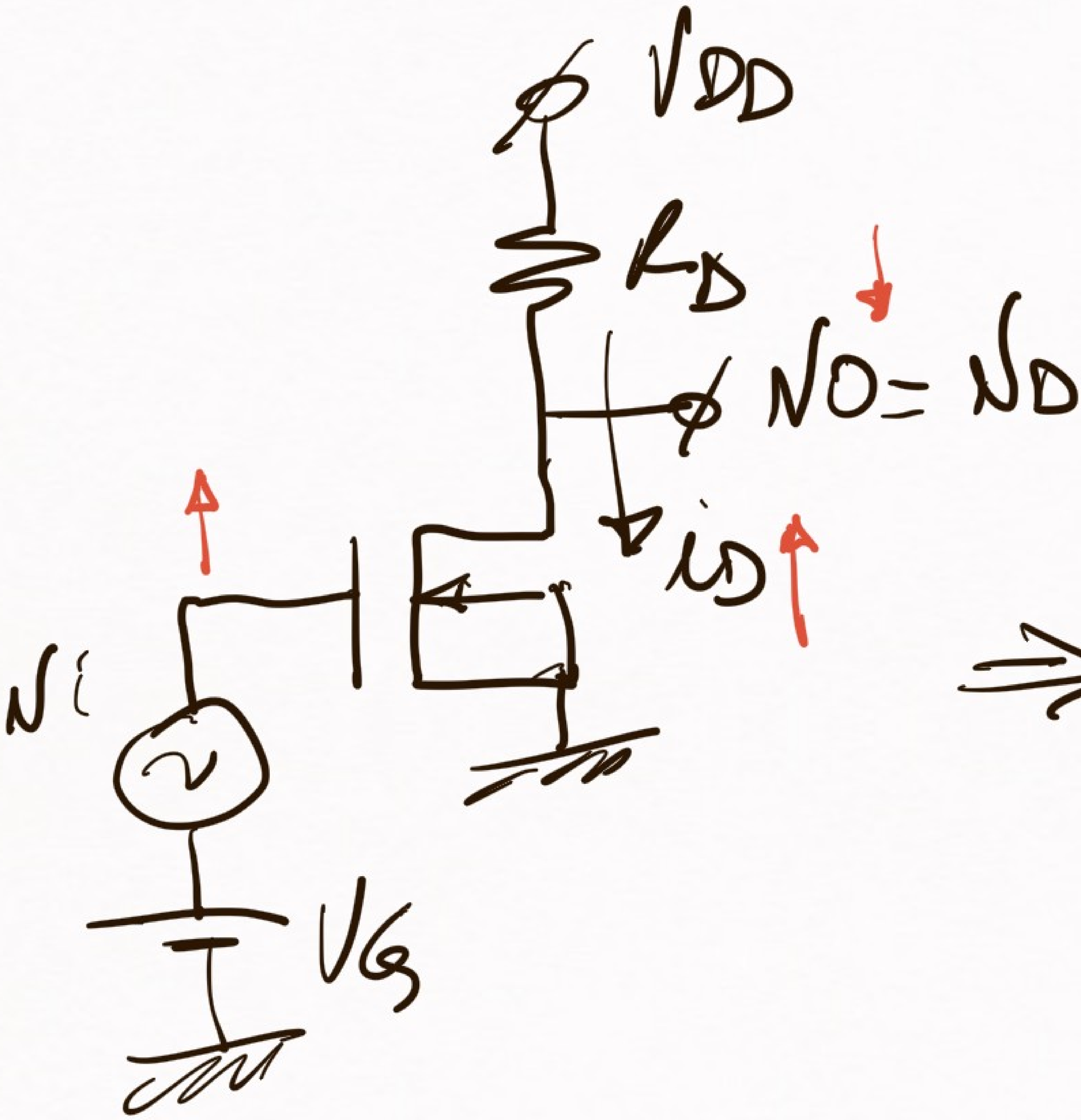
$$i_D = I_D + g_m \cdot v_g = I_D + g_m \cdot v_i$$

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

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

$$g_m = \frac{\beta}{(1+\delta)}\left(V_G - V_{to}\right) = \frac{\sqrt{\beta}\,\cancel{\beta}}{\cancel{(1+\delta)}\,\sqrt{1+\delta}}\sqrt{\frac{2\,\cancel{(1+\delta)}\,I_D}{\cancel{\beta}}} =$$

$$= \sqrt{\frac{2\beta I_D}{1+\delta}}$$

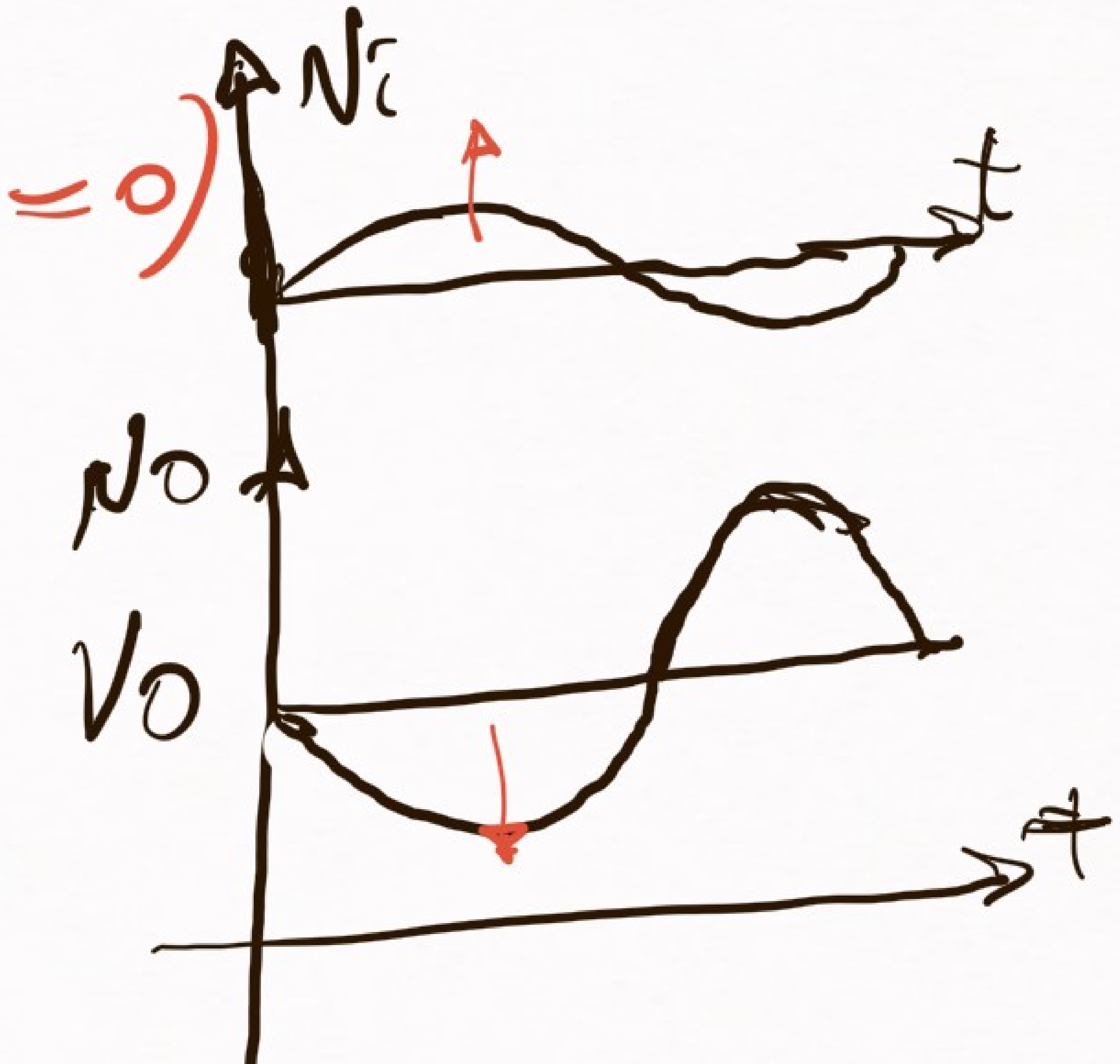


$$i_D \cong I_D + g_m \cdot v_i$$

$$v_O = V_{DD} - R_D \cdot i_D$$

$$\Rightarrow v_O = \underbrace{V_{DD} - R_D I_D}_{V_O} - \underbrace{R_D \cdot g_m \cdot v_i}_{v_o}$$

$$V_O = v_O(@\, v_i = 0)$$



$\Rightarrow$ ganancia: $\dfrac{v_o}{v_i} = -g_m \cdot R_D$

$$v_O = V_O - \underbrace{g_m \cdot R_D}_{\text{ganancia}} \cdot v_i$$

Ej: $R_D = 1.8k$, $I_D = 1\,mA$

$\beta = 2mA/V^2$, $\delta = 0.5$, $V_{t0} = 1V$

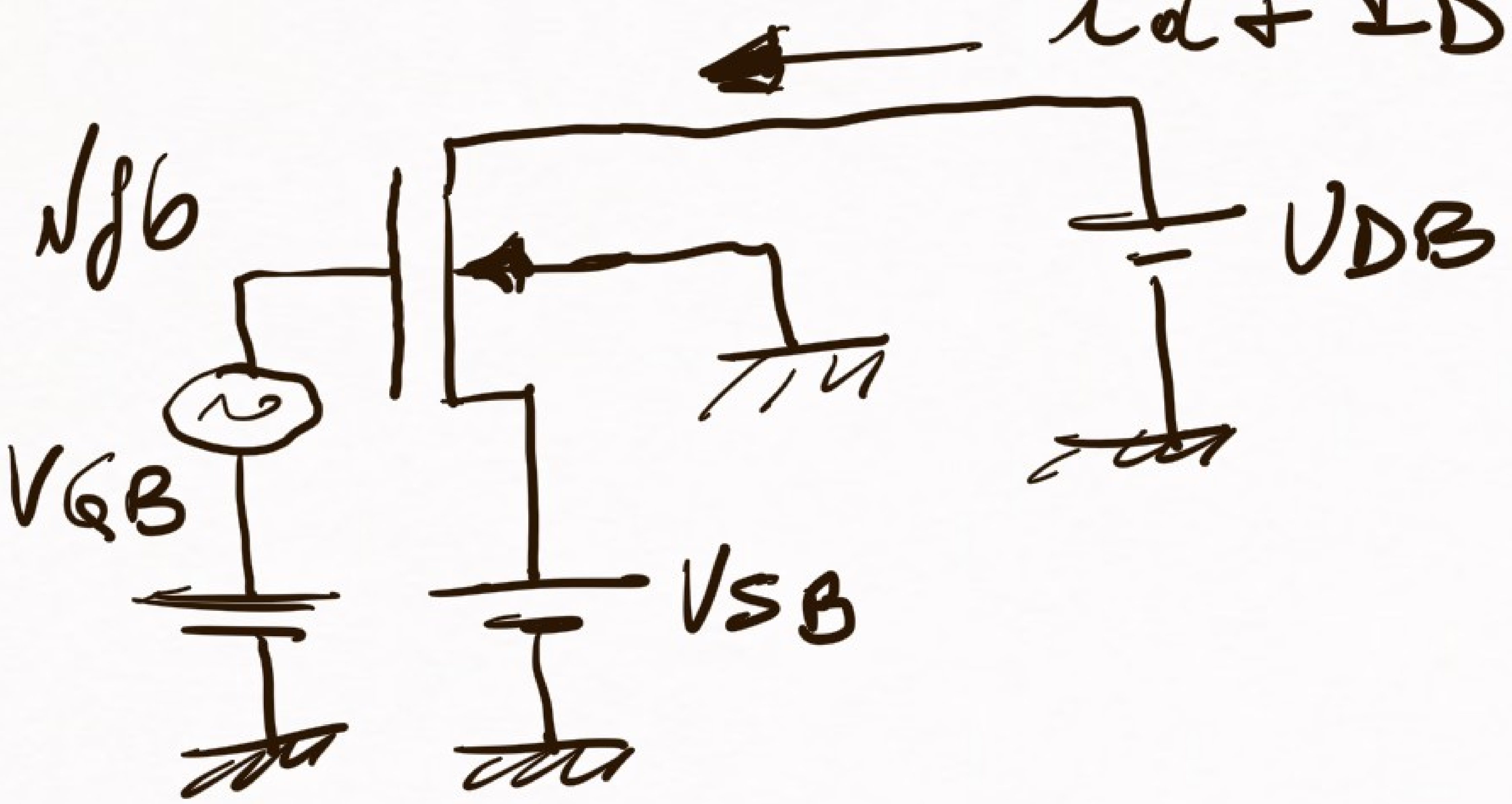
$\Rightarrow g_m = \sqrt{\dfrac{2\beta I_D}{(1+\delta)}} = 1.6\ mS\ (mA/V) =$

$1.6\times10^{-3}\ S$

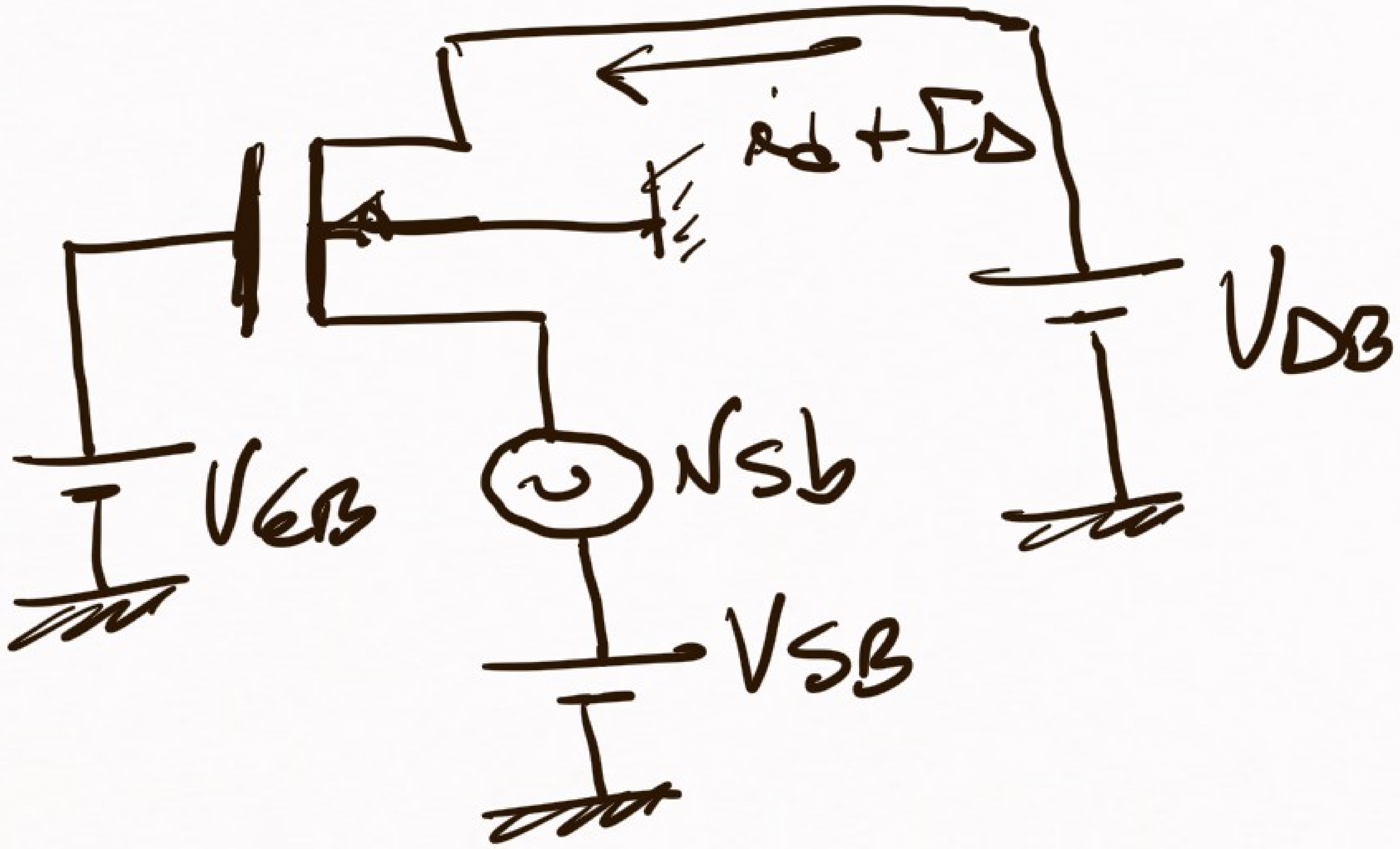
$\Rightarrow$ ganancia $= -g_m \cdot R_D = \underline{-2.9\ V/V}$

Modelo de pequeña señal y baja frecuencia del transistor MOS referido al sustrato.

$$i_D = f(v_{GB}, v_{SB}, v_{DB})$$

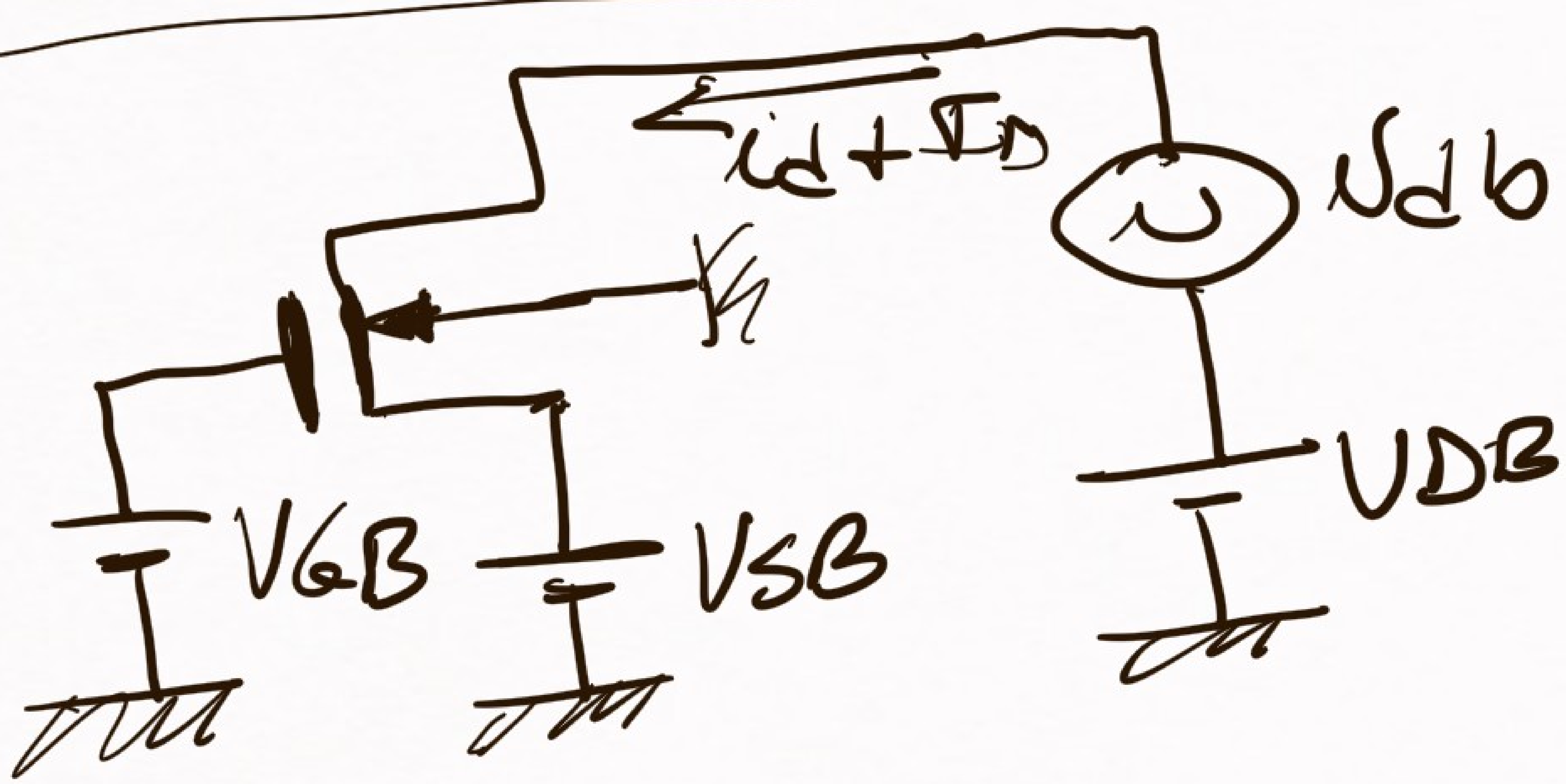


$$i_d = \underbrace{\left.\frac{\partial i_D}{\partial v_{GB}}\right|_{V_{GB}, V_{SB}, V_{DB}}}_{= g_m} \cdot v_{gb}$$



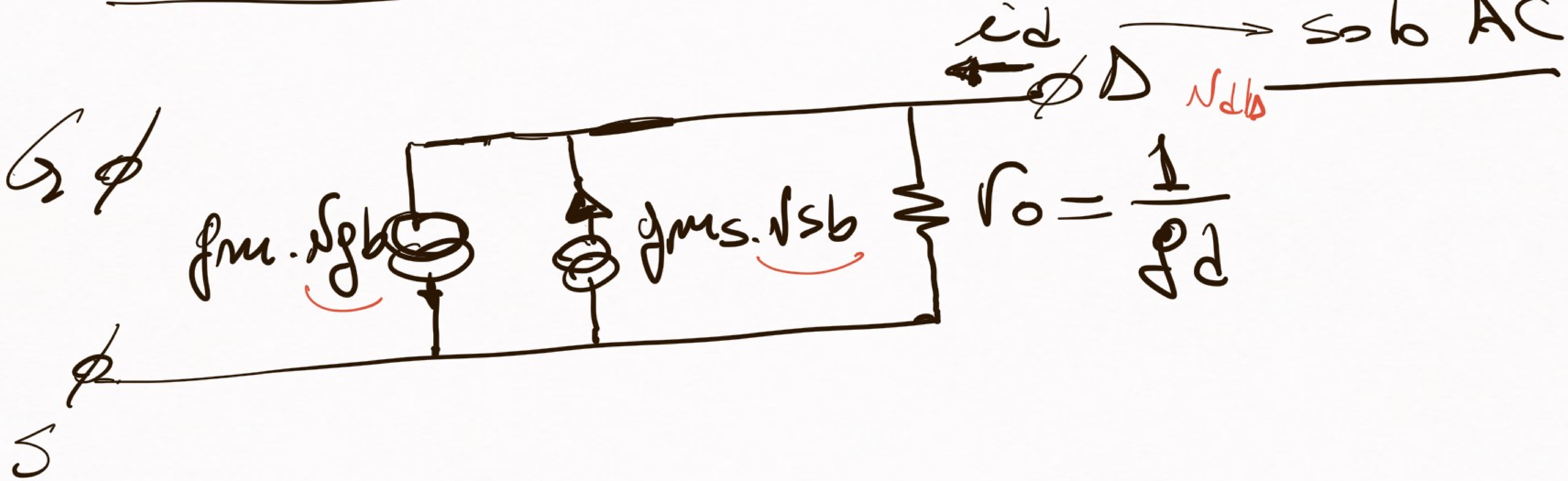
$$i_d = \underbrace{\left.\frac{\partial i_D}{\partial v_{SB}}\right|_{V_{GB}, V_{SB}, V_{DB}}}_{= -g_{ms}} \cdot v_{sb}$$

transconductance de source



$$i_d = \underbrace{\left.\frac{\partial i_D}{\partial v_{DB}}\right|_{V_{GB}, V_{SB}, V_{DB}}}_{= g_d = \frac{1}{r_o}} \cdot v_{db}$$

⇒ Modelo de peq. señal y baja frec. referido al sustrato:



$$i_D = \frac{\beta}{2(1+\delta)}\left(V_{GB} - V_{t0} - (1+\delta)V_{SB}\right)^2 \cdot \left(1 + \frac{V_{DB}}{V_A}\right)$$

solo a los
efectos de calc. g_d

$$g_m = \frac{\partial i_D}{\partial V_{GB}} = \sqrt{\frac{2\beta}{(1+\delta)} \cdot I_D}$$

$$g_{ms} = -\frac{\partial i_D}{\partial V_{SB}} =$$

$$= -\frac{\beta}{(1+\delta)}\left(-(1+\delta)\right) \cdot \left(V_{GB} - V_{t0} - (1+\delta)V_{SB}\right) =$$

$$= \sqrt{2\beta(1+\delta) I_D} = (1+\delta) \cdot g_m$$

$$\boxed{g_d = \frac{\partial i_D}{\partial v_{DB}} = \frac{I_D}{V_A}}$$

$$i_D = \frac{\beta}{2(1+\delta)} \left(v_{GB} - V_{t0} - (1+\delta)\, v_{SB}\right)^2 \left(1 + \frac{v_{DB}}{V_A}\right)$$

$$\boxed{g_m = \sqrt{\frac{2\beta I_D}{(1+\delta)}}} \quad , \quad \boxed{g_{ms} = (1+\delta)\, g_m}$$