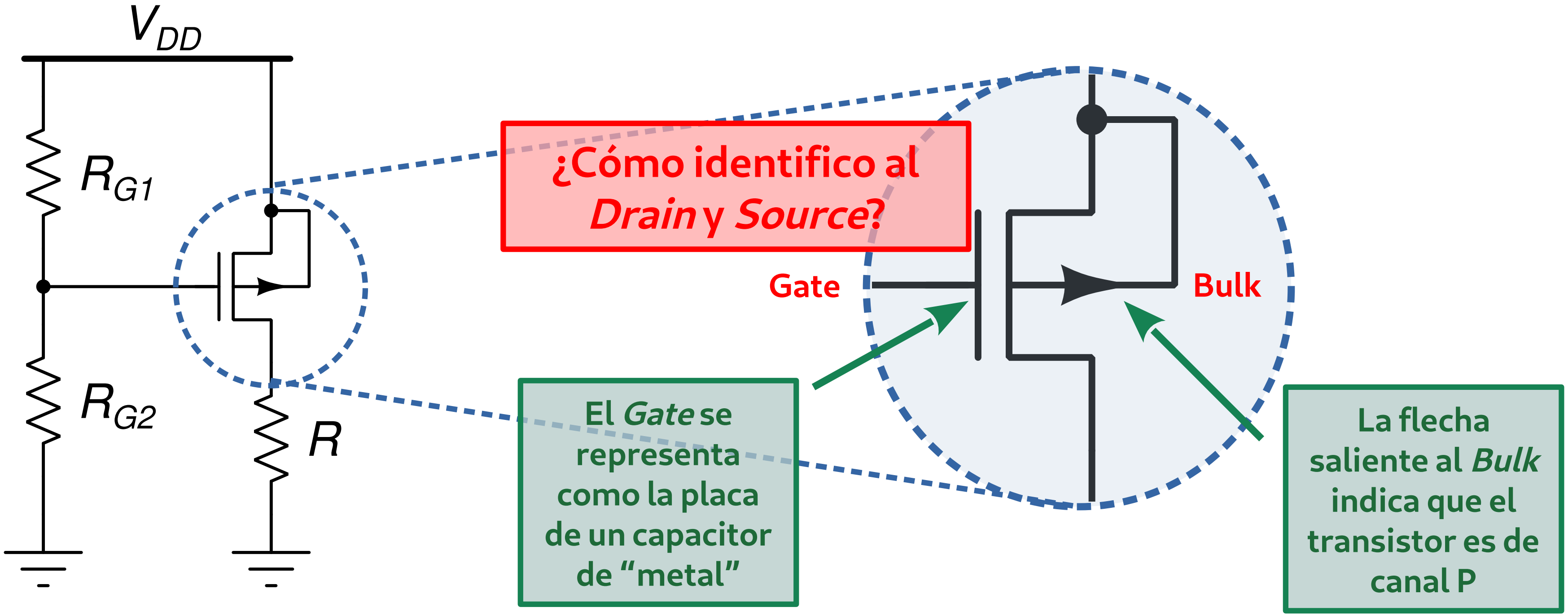
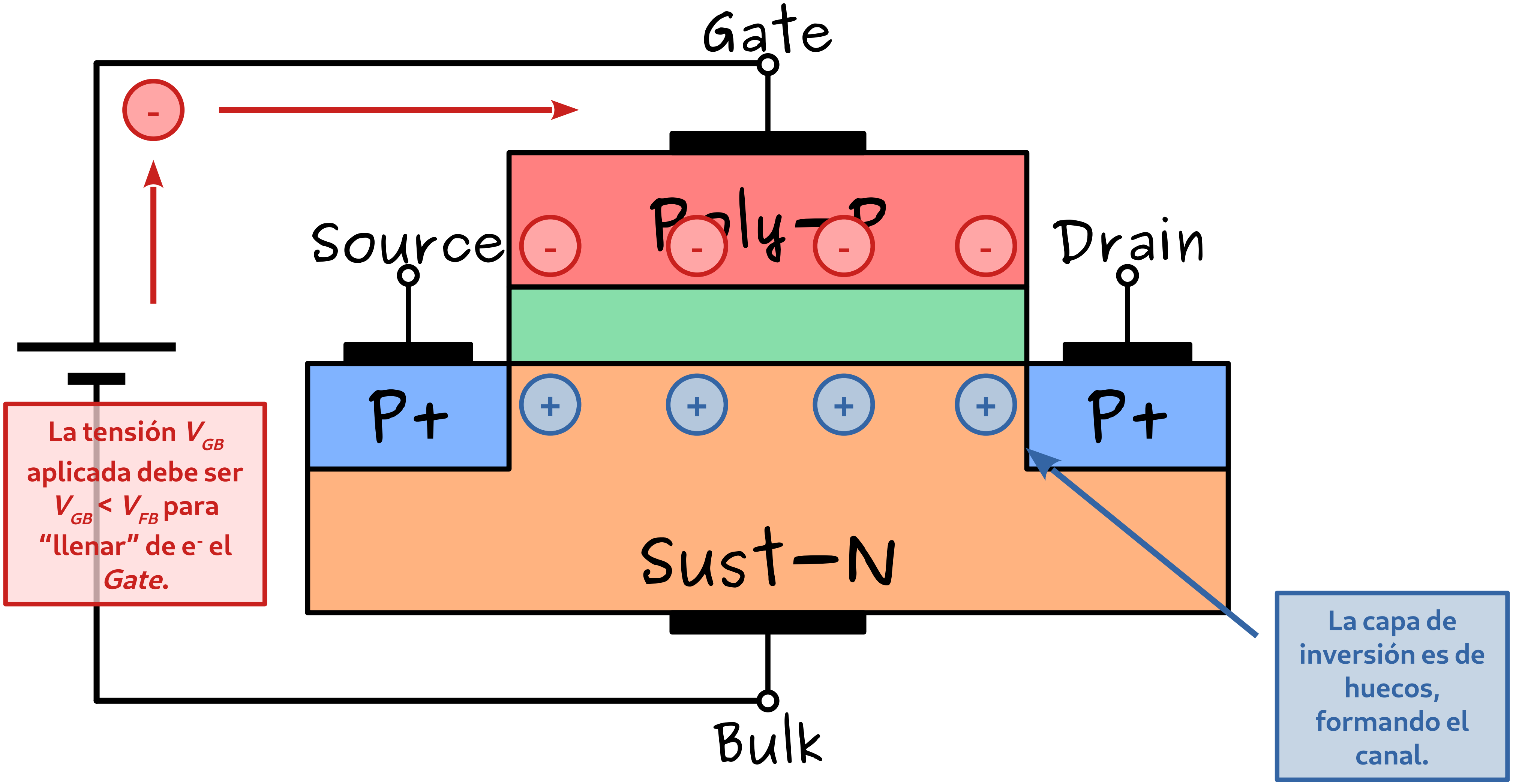
Transistor MOS

Transistor Canal P: Polarización

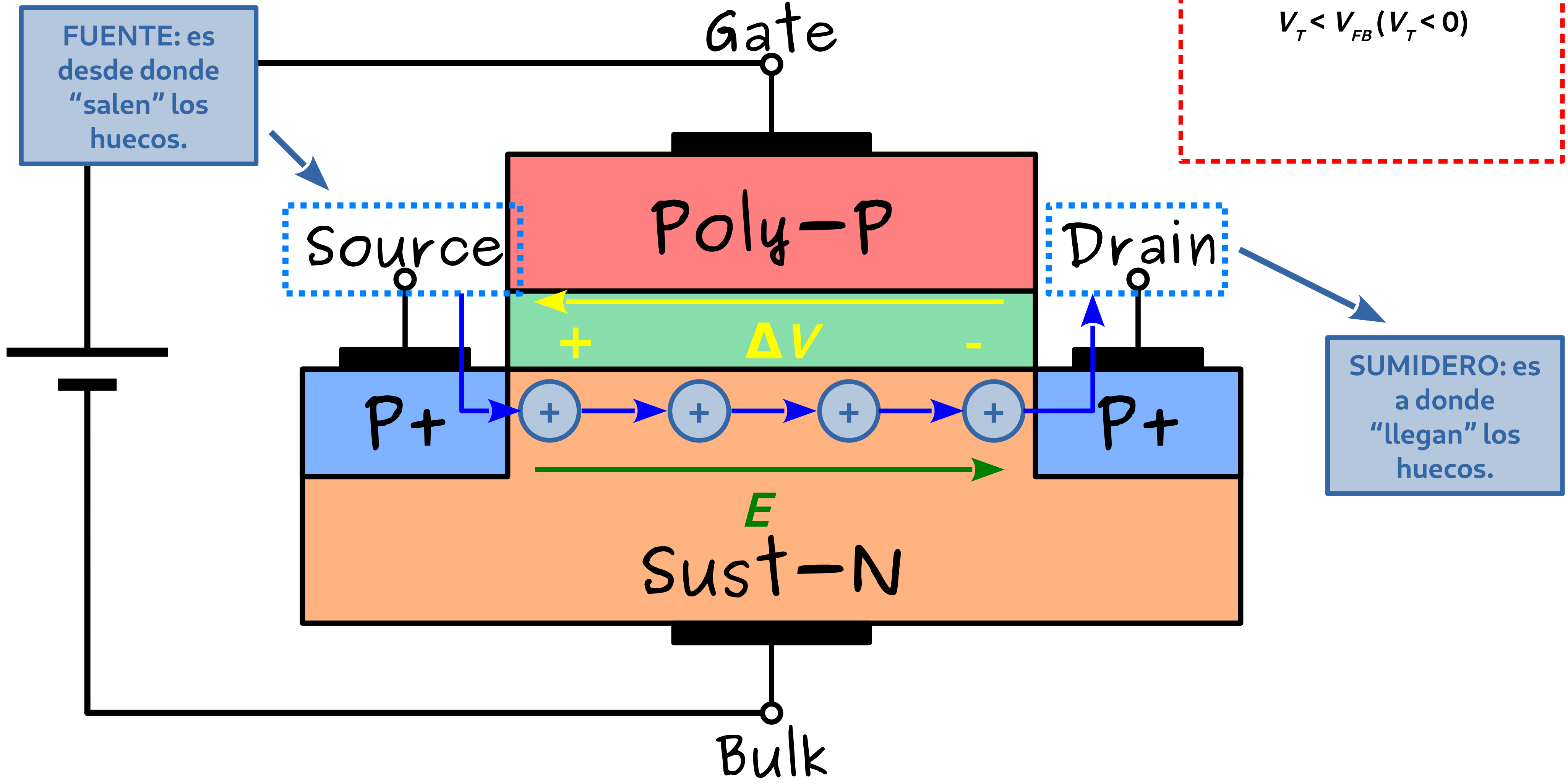
Un transistor MOS de canal P con parámetros V_T = -0,8 V; $\mu_p C'_{ox}$ = 80 μA/V²; W = 500 μm; L = 10 μm y λ = 0,03 V^{-1}; forma parte del siguiente circuito donde V_{DD} = 3.3 V; R_{G1} = 1.3 kΩ; R_{G2} = 2.0 kΩ y R = 1.0 kΩ.

- Hallar el punto de polarización del transistor.
- Hallar el rango de R para que el transistor se encuentre en régimen de saturación.

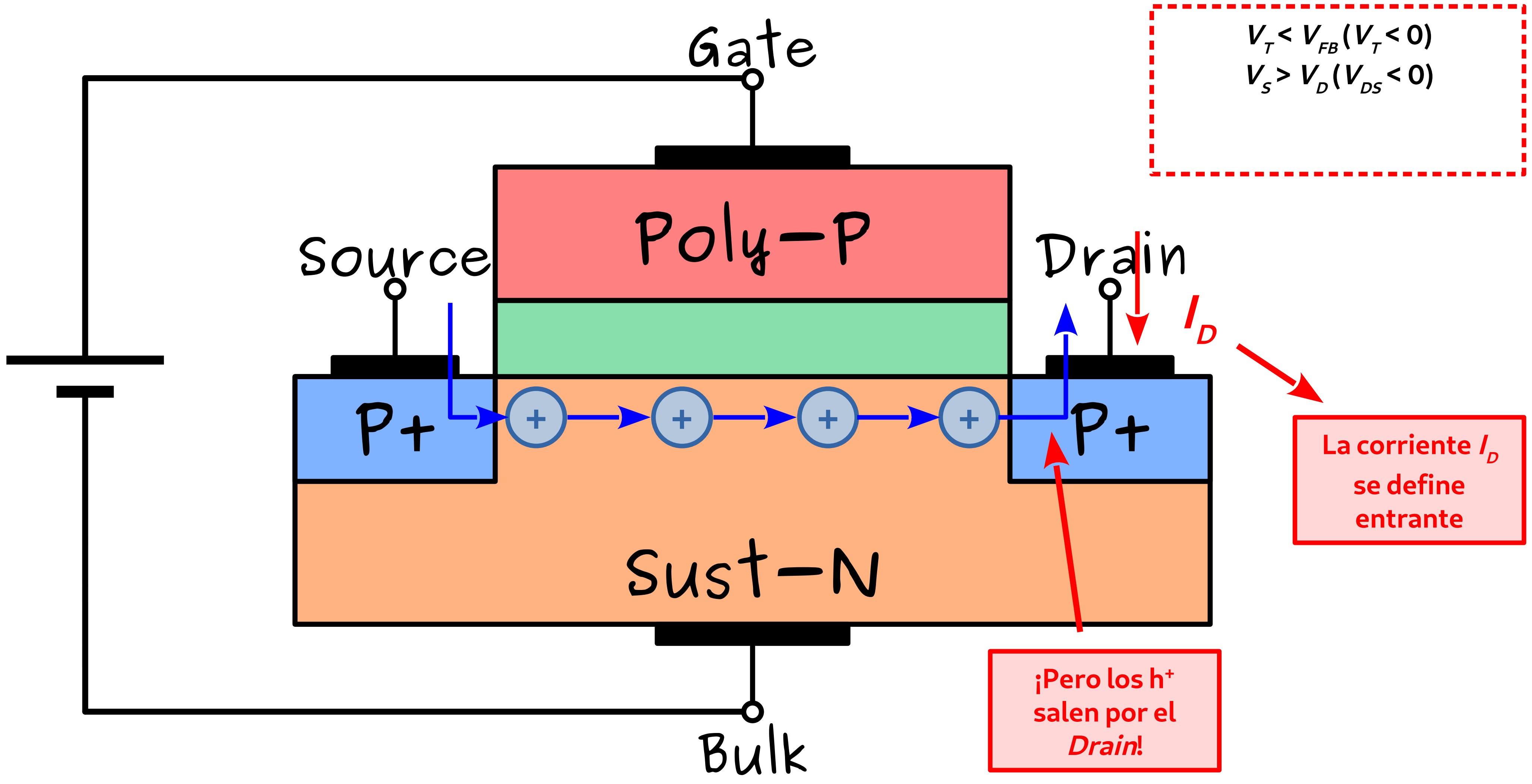



Gate
Poly-P
Source
Drain
P+
P+
Sust-N
Bulk
La tensión V_{GB} aplicada debe ser $V_{GB} < V_{FB}$ para "llenar" de e^- el *Gate*.
La capa de inversión es de huecos, formando el canal.

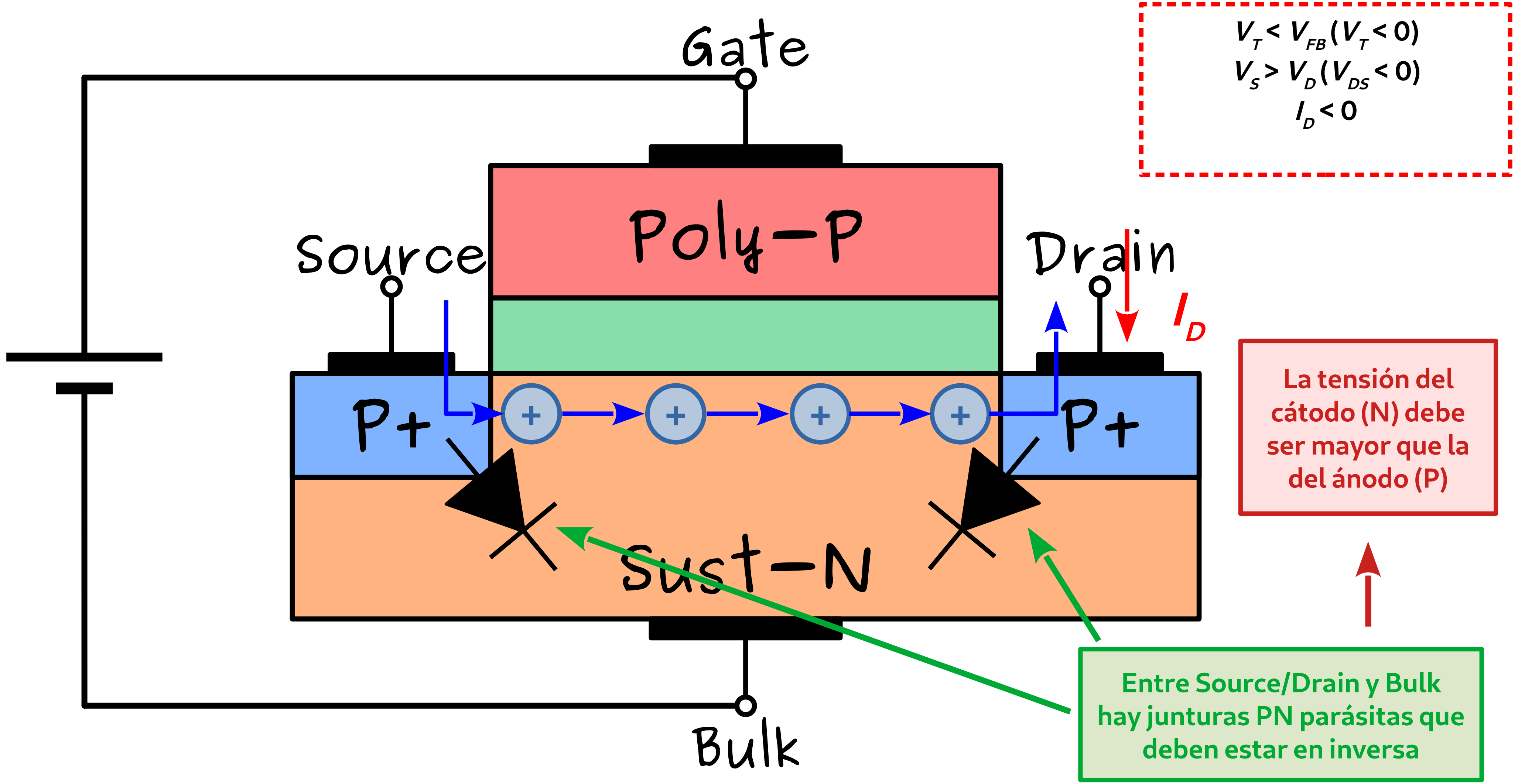
$V_T < V_{FB} (V_T < 0)$



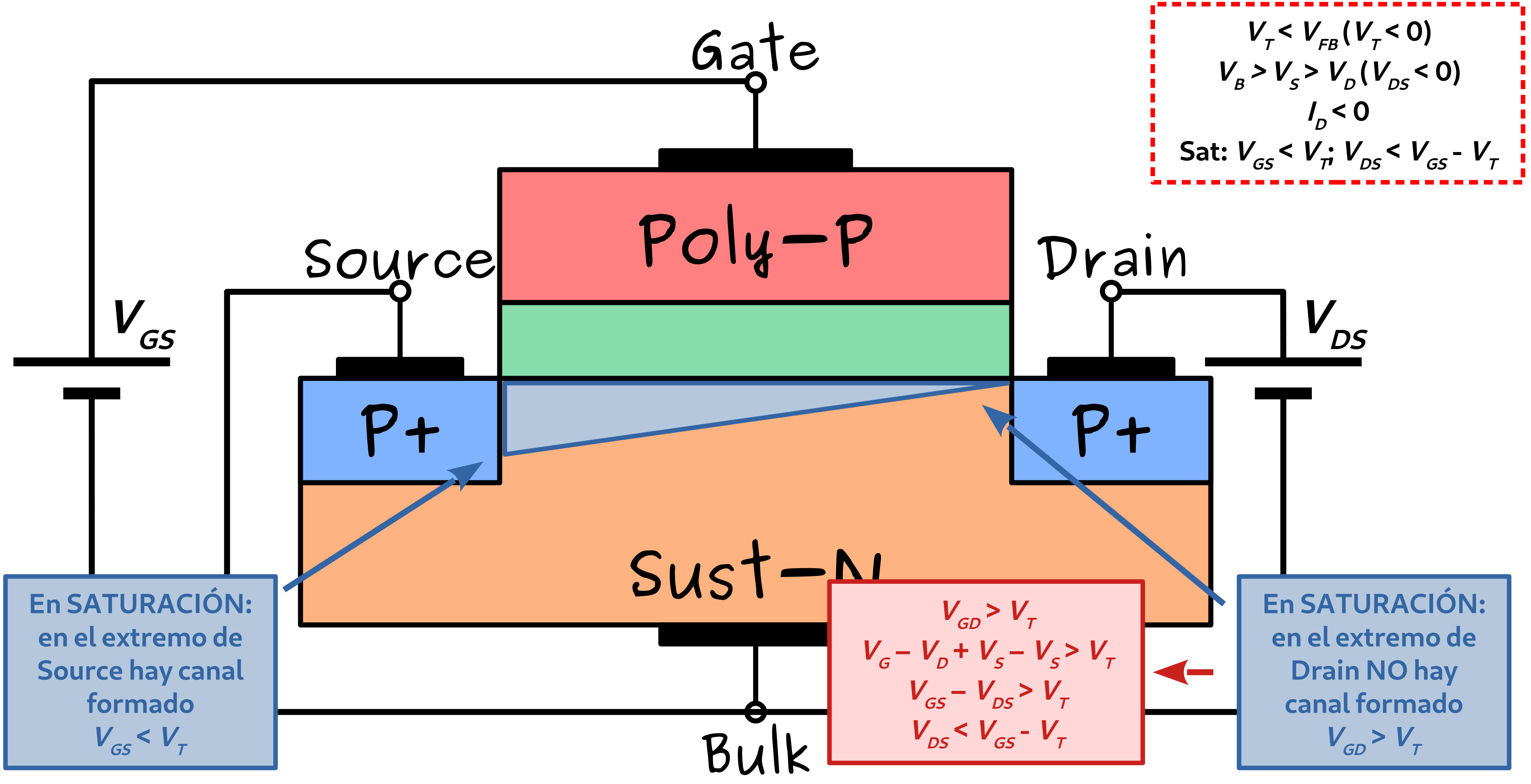
FUENTE: es desde donde "salen" los huecos.
Gate
Source
Drain
Poly-P
+
ΔV
-
P+
+
+
+
+
P+
E
Sust-N
Bulk
SUMIDERO: es a donde "llegan" los huecos.



Gate
Poly-P
Source
Drain
I_D
P+
P+
Sust-N
Bulk
$V_T < V_{FB} (V_T < 0)$
$V_S > V_D (V_{DS} < 0)$
La corriente I_D se define entrante
¡Pero los h⁺ salen por el *Drain*!

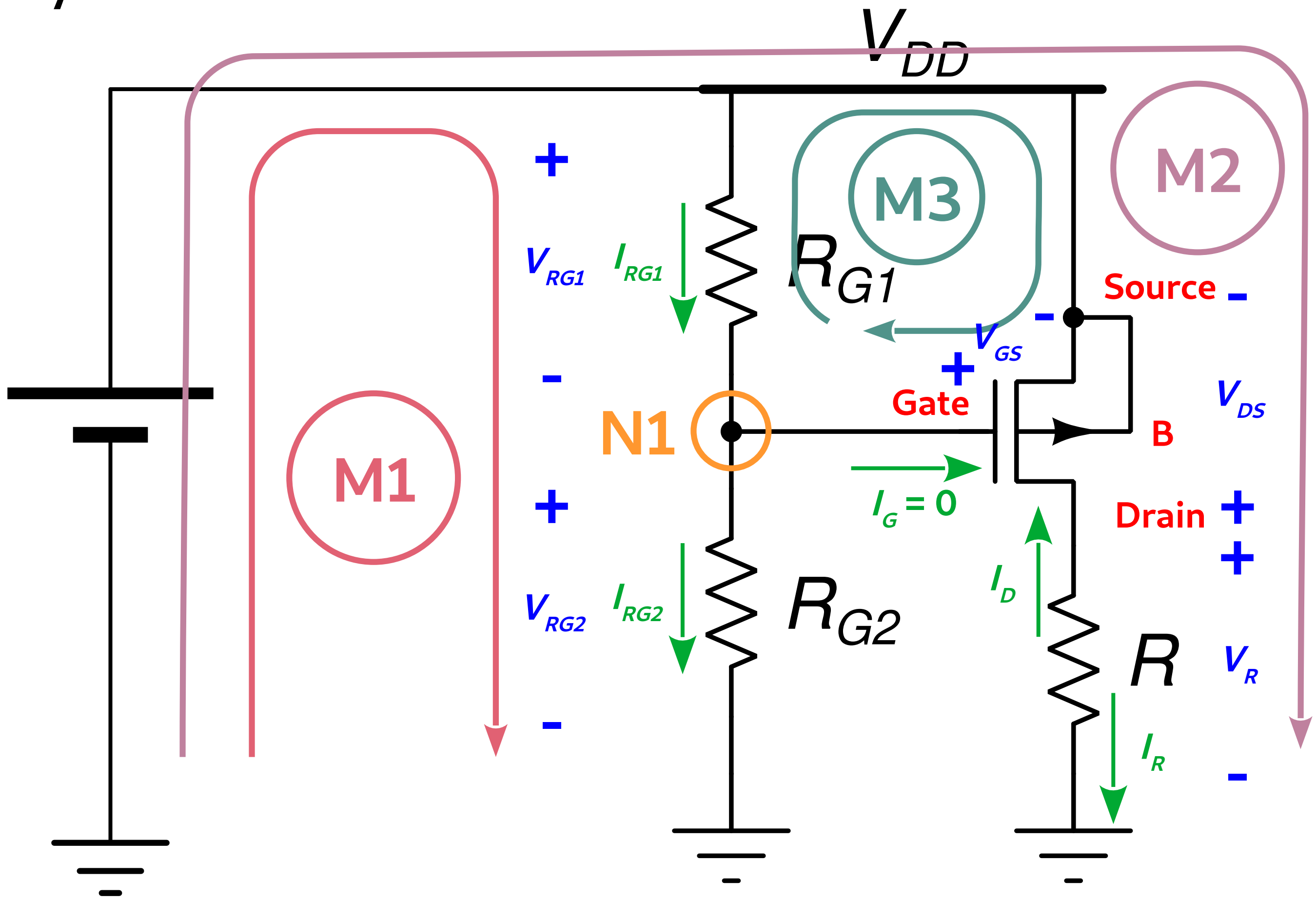


Gate
Poly-P
Source
Drain
I_D
P+
P+
Sust-N
Bulk
$V_T < V_{FB} (V_T < 0)$
$V_S > V_D (V_{DS} < 0)$
$I_D < 0$
La tensión del cátodo (N) debe ser mayor que la del ánodo (P)
Entre Source/Drain y Bulk hay junturas PN parásitas que deben estar en inversa



Gate
Poly-P
Source
Drain
V_{GS}
V_{DS}
P+
P+
Sust-N
Bulk
$V_T < V_{FB} (V_T < 0)$
$V_B > V_S > V_D (V_{DS} < 0)$
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$
En SATURACIÓN: en el extremo de Source hay canal formado
$V_{GS} < V_T$
$V_{GD} > V_T$
$V_G - V_D + V_S - V_S > V_T$
$V_{GS} - V_{DS} > V_T$
$V_{DS} < V_{GS} - V_T$
En SATURACIÓN: en el extremo de Drain NO hay canal formado
$V_{GD} > V_T$

Leyes de Kirchoff



$V_T < V_{FB}\ (V_T < 0)$

$V_B > V_S > V_D\ (V_{DS} < 0)$

$I_D < 0$

Sat: $V_{GS} < V_T;\ V_{DS} < V_{GS} - V_T$

<u>Transistor MOS canal P</u>

$V_T = -0{,}8\ V$

$\mu_p C'_{ox} = 80\ \mu A/V^2$

$W = 500\ \mu m;\ L = 10\ \mu m$

$\lambda = 0{,}03\ V^{-1}$

$V_{DD} = 3.3\ V;\ R = 1.0\ k\Omega$

$R_{G1} = 1.3\ k\Omega;\ R_{G2} = 2.0\ k\Omega$

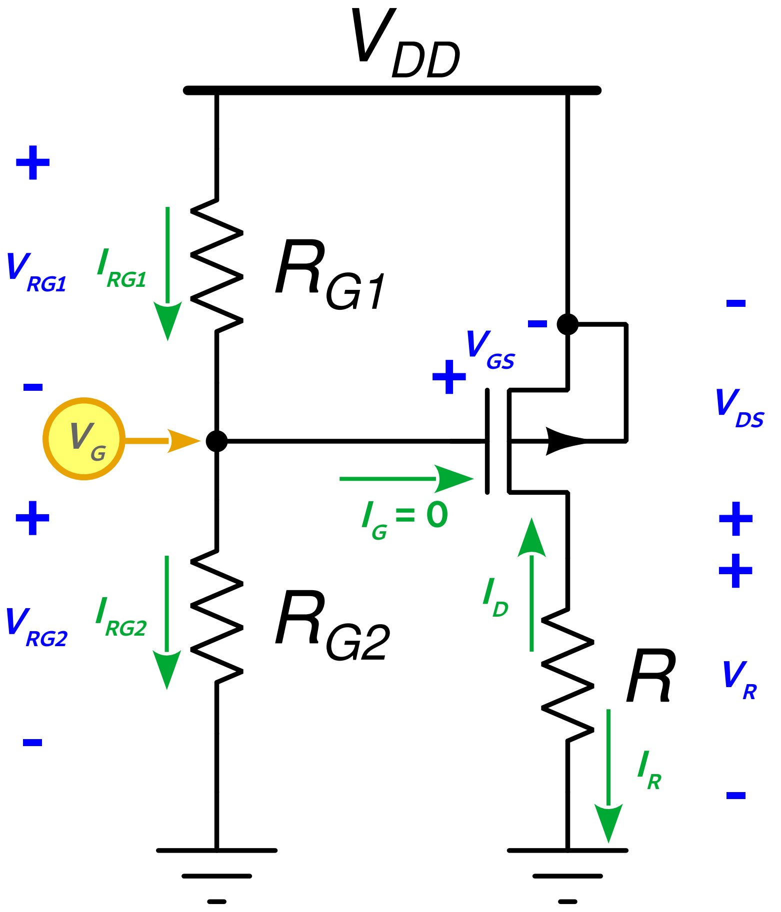
M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_R = 0$

N1: $I_{RG1} = I_{RG2} + I_G = I_{RG2}$

M3: $V_{R1} + V_{GS} = 0$

Resolvemos la "malla de entrada"...



M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_{R} = 0$

N1: $I_{RG1} = I_{RG2} = I_{RG}$

M3: $V_{R1} + V_{GS} = 0$

De M1 y N1 despejamos:

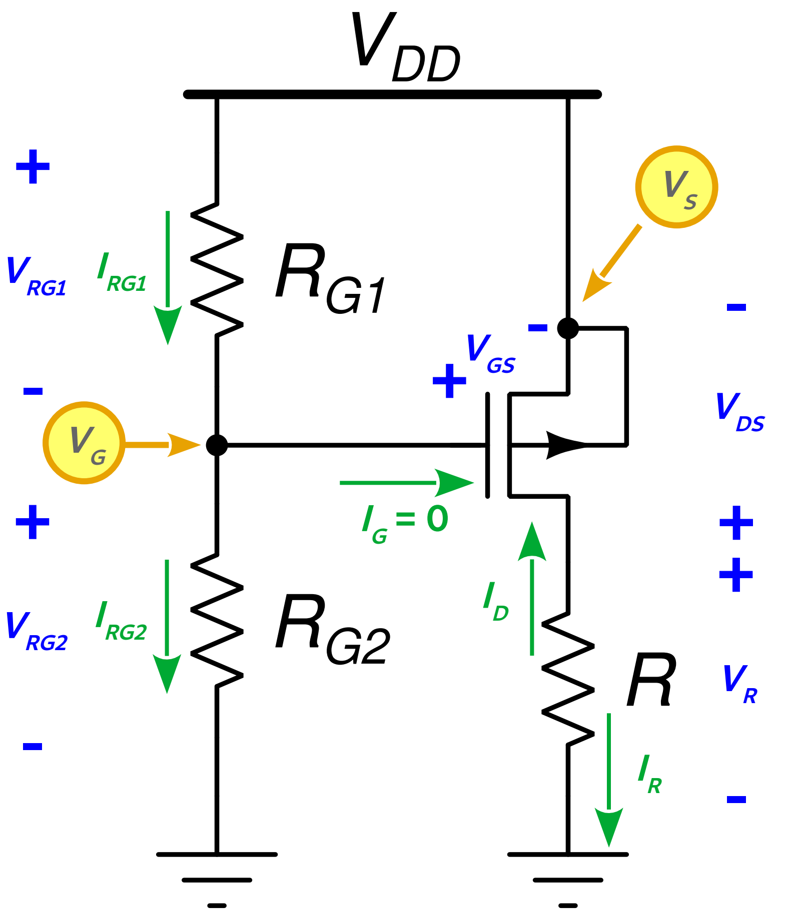
$$V_{DD}=V_{RG1}+V_{RG2}$$
$$V_{DD}=I_{RG1}R_{G1}+I_{RG2}R_{G2}$$
$$V_{DD}=I_{RG}(R_{G1}+R_{G2})$$
$$I_{RG}=\frac{V_{DD}}{R_{G1}+R_{G2}}$$

$$V_G=V_{RG2}=I_{RG2}R_{G2}$$
$$V_G=V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}}$$
$$V_G=2\ \mathrm{V}$$

$V_T < V_{FB}$ ($V_T < 0$)
$V_B > V_S > V_D$ ($V_{DS} < 0$)
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

Transistor MOS canal P
$V_T = -0{,}8$ V
$\mu_p C'_{ox} = 80\ \mu A/V^2$
$W = 500\ \mu m$; $L = 10\ \mu m$
$\lambda = 0{,}03\ V^{-1}$
$V_{DD} = 3.3$ V; $R = 1.0$ kΩ
$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

Resolvemos la “malla de entrada”...



M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_{R} = 0$

N1: $I_{RG1} = I_{RG2} = I_{RG}$

M3: $V_{R1} + V_{GS} = 0$

$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} = 2\ \mathrm{V}$$

Pero ¡OJO! V_G no es V_{GS}

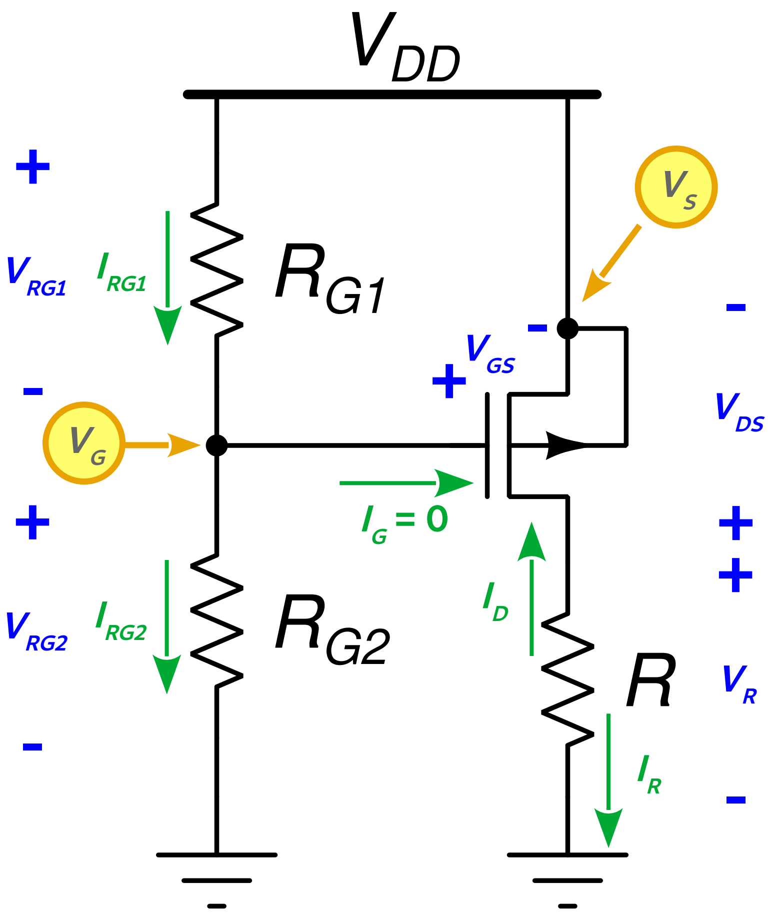
$$V_{GS} = V_G - V_S = V_G - V_{DD}$$
$$V_{GS} = 2\ \mathrm{V} - 3.3\ \mathrm{V} = -1.3\ \mathrm{V}$$

$$V_{GS} = -V_{RG1}$$
$$V_{GS} = -V_{DD}\frac{R_{G1}}{R_{G1}+R_{G2}} = -1.3\ \mathrm{V}$$

$V_T < V_{FB}$ ($V_T < 0$)
$V_B > V_S > V_D$ ($V_{DS} < 0$)
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

Transistor MOS canal P
$V_T = -0{,}8$ V
$\mu_p C'_{ox} = 80\ \mu A/V^2$
$W = 500\ \mu m$; $L = 10\ \mu m$
$\lambda = 0{,}03\ V^{-1}$
$V_{DD} = 3.3$ V; $R = 1.0$ kΩ
$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

Calculamos la corriente del transistor…



M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_R = 0$

N1: $I_{RG1} = I_{RG2} = I_{RG}$

M3: $V_{R1} + V_{GS} = 0$

$$V_G = V_{DD} \frac{R_{G2}}{R_{G1}+R_{G2}} = 2 \text{ V}$$

$$V_{GS} = -1.3 \text{ V} < V_T$$

$V_T < V_{FB}$ $(V_T < 0)$
$V_B > V_S > V_D$ $(V_{DS} < 0)$
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

Transistor MOS canal P
$V_T = -0{,}8$ V
$\mu_p C'_{ox} = 80\ \mu A/V^2$
$W = 500\ \mu m$; $L = 10\ \mu m$
$\lambda = 0{,}03\ V^{-1}$
$V_{DD} = 3.3$ V; $R = 1.0$ kΩ
$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

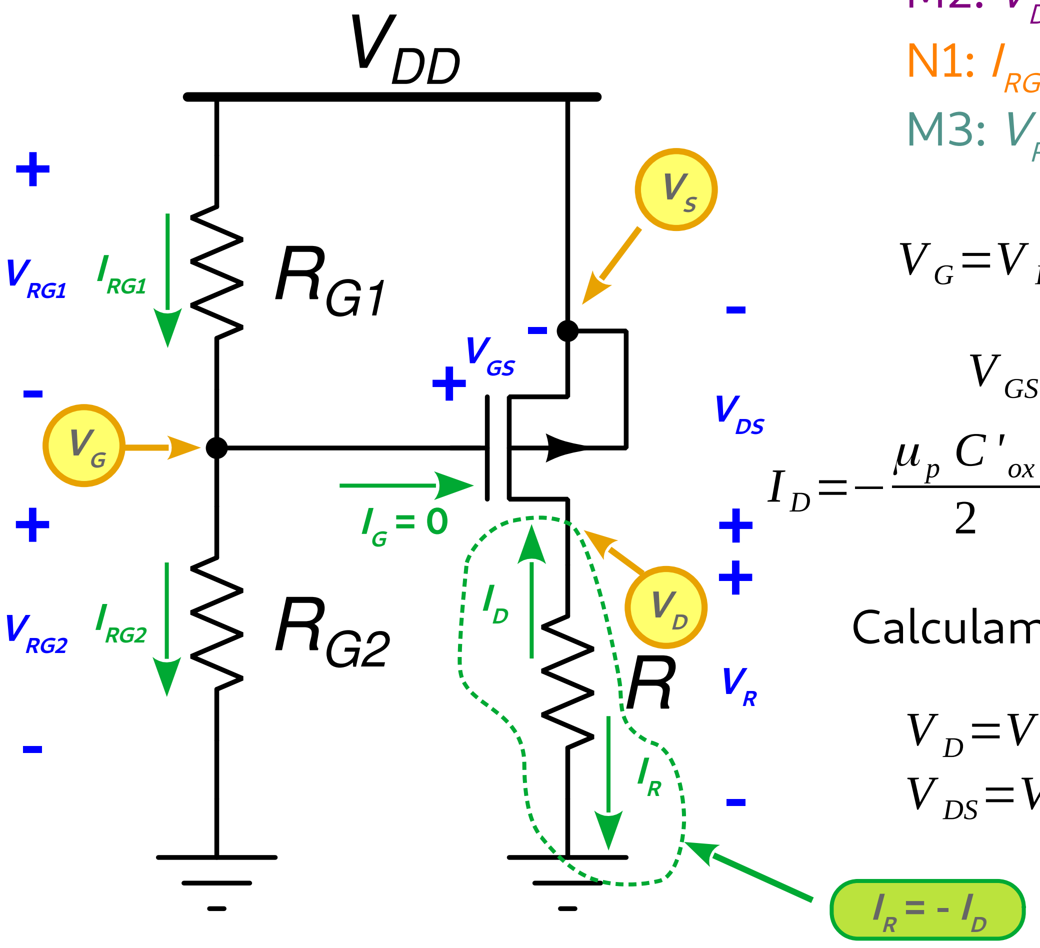
Suponemos saturación y efecto de modulación del largo del canal despreciable…

$$I_D = -\frac{\mu_p C'_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2 = -0.5 \text{ mA}$$

… ¡luego debemos corroborarlo!

Ya casi terminamos…

Resolvemos para V_{DS}...



M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_R = 0$

N1: $I_{RG1} = I_{RG2} = I_{RG}$

M3: $V_{R1} + V_{GS} = 0$

$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} = 2\ \mathrm{V}$$

$$V_{GS} = -1.3\ \mathrm{V} < V_T$$

$$I_D = -\frac{\mu_p C'_{ox}}{2}\frac{W}{L}(V_{GS}-V_T)^2 = -0.5\ \mathrm{mA}$$

$V_T < V_{FB}$ ($V_T < 0$)
$V_B > V_S > V_D$ ($V_{DS} < 0$)
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

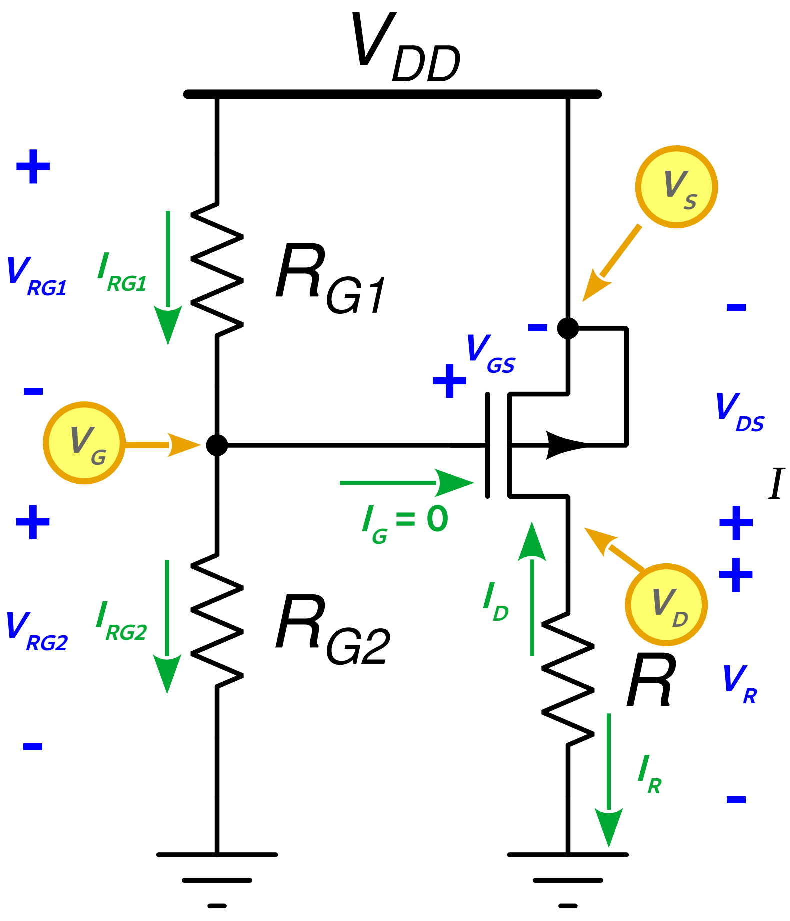
Transistor MOS canal P
$V_T = -0,8$ V
$\mu_p C'_{ox} = 80\ \mu A/V^2$
$W = 500\ \mu m$; $L = 10\ \mu m$
$\lambda = 0,03\ V^{-1}$
$V_{DD} = 3.3$ V; $R = 1.0$ kΩ
$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

Calculamos la tensión de *Drain*:

$$V_D = V_R = I_R \cdot R = -I_D \cdot R = 0.5\ \mathrm{mA} \cdot 1\ \mathrm{k\Omega} = 0.5\ \mathrm{V}$$

$$V_{DS} = V_D - V_S = V_D - V_{DD} = 0.5\ \mathrm{V} - 3.3\ \mathrm{V} = -2.8\ \mathrm{V}$$

Verificamos...



M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_{R} = 0$

N1: $I_{RG1} = I_{RG2} = I_{RG}$

M3: $V_{R1} + V_{GS} = 0$

$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} = 2\ \text{V}$$

$$V_{GS} = -1.3\ \text{V} < V_T$$

$$I_D = -\frac{\mu_p C'_{ox}}{2}\frac{W}{L}(V_{GS}-V_T)^2 = -0.5\ \text{mA}$$

$V_T < V_{FB}$ $(V_T < 0)$
$V_B > V_S > V_D$ $(V_{DS} < 0)$
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

Transistor MOS canal P

$V_T = -0{,}8$ V
$\mu_p C'_{ox} = 80\ \mu\text{A/V}^2$
$W = 500\ \mu$m; $L = 10\ \mu$m
$\lambda = 0{,}03\ \text{V}^{-1}$
$V_{DD} = 3.3$ V; $R = 1.0$ kΩ
$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

Verificamos saturación...

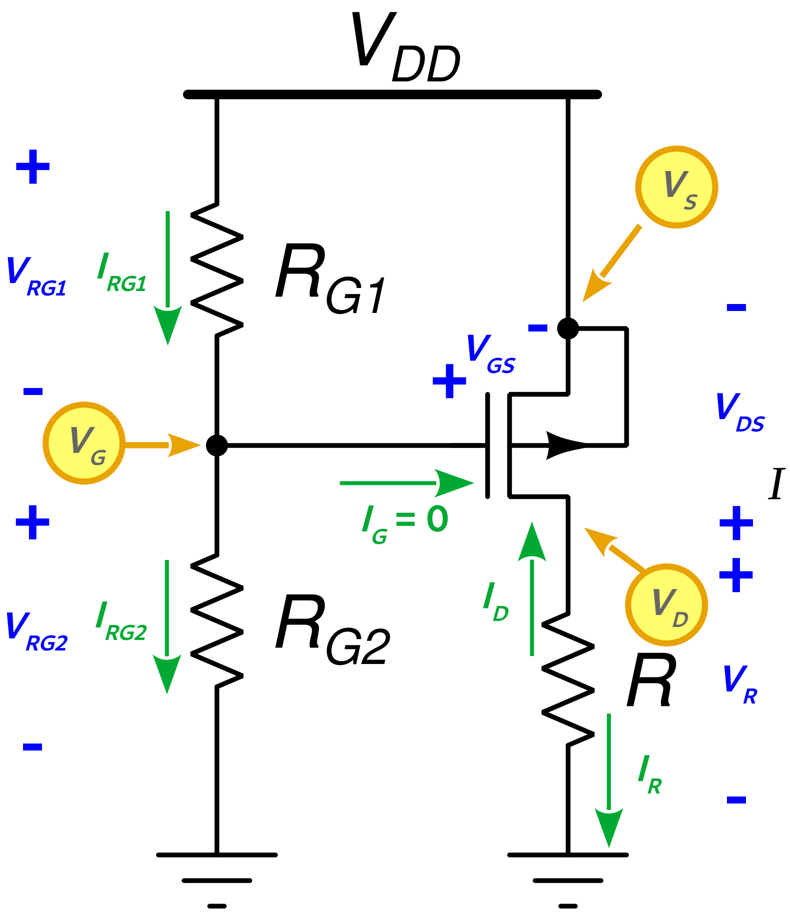
$$V_{DS} = -2.8\ \text{V} < V_{GS} - V_T = -0.5\ \text{V}$$

...y EMLC despreciable...

$$1 - \lambda V_{DS} = 1 - 0.03\ \text{V}^{-1}(-2.8\ \text{V}) =$$
$$= 1 + 0.03 \times 2.8 = 1.084 \approx 1$$

→ **Aceptando 10% de error**

En resumen...



M1: $V_{DD} - V_{RG1} - V_{RG2} = 0$

M2: $V_{DD} + V_{DS} - V_R = 0$

N1: $I_{RG1} = I_{RG2} = I_{RG}$

M3: $V_{R1} + V_{GS} = 0$

$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} = 2\ \text{V}$$

$$V_{GS} = -1.3\ \text{V} < V_T$$

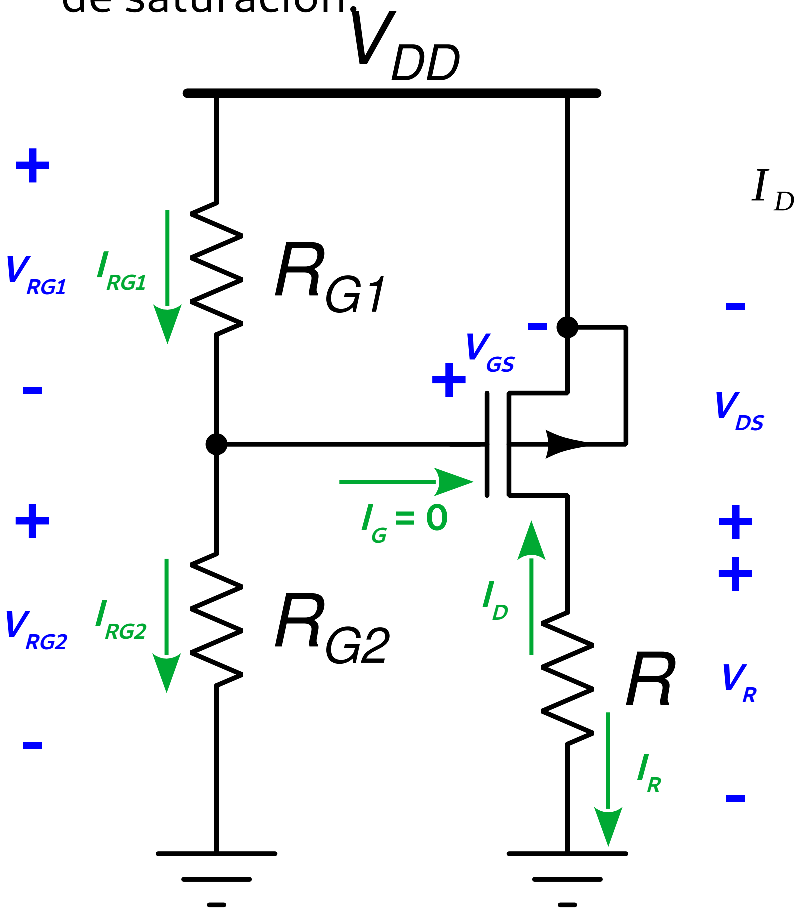
$$I_D = -\frac{\mu_p C'_{ox}}{2}\frac{W}{L}(V_{GS}-V_T)^2 = -0.5\ \text{mA}$$

$$V_{DS} = -2.8\ \text{V} < V_{DS_{sat}}$$

$V_T < V_{FB}$ ($V_T < 0$)
$V_B > V_S > V_D$ ($V_{DS} < 0$)
$I_D < 0$
Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

Transistor MOS canal P
$V_T = -0{,}8$ V
$\mu_p C'_{ox} = 80\ \mu A/V^2$
$W = 500\ \mu m$; $L = 10\ \mu m$
$\lambda = 0{,}03\ V^{-1}$
$V_{DD} = 3.3$ V; $R = 1.0$ kΩ
$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

- Hallar el rango de R para que el transistor se encuentre en régimen de saturación.



$$V_{GS} = -1.3\ \text{V} < V_T$$

$$I_D = -\frac{\mu_p C'_{ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2 = -0.5\ \text{mA}$$

$$V_{DS} < V_{DS_{sat}}$$

$$V_D = I_R \cdot R = -I_D \cdot R$$
$$V_{DS} = V_D - V_S = -I_D \cdot R - V_{DD}$$

Condiciones:

$V_T < V_{FB}$ $(V_T < 0)$

$V_B > V_S > V_D$ $(V_{DS} < 0)$

$I_D < 0$

Sat: $V_{GS} < V_T$; $V_{DS} < V_{GS} - V_T$

<u>Transistor MOS canal P</u>

$V_T = -0{,}8$ V

$\mu_p C'_{ox} = 80\ \mu\text{A/V}^2$

$W = 500\ \mu\text{m}$; $L = 10\ \mu\text{m}$

$\lambda = 0{,}03\ \text{V}^{-1}$

$V_{DD} = 3.3$ V; $R = 1.0$ kΩ

$R_{G1} = 1.3$ kΩ; $R_{G2} = 2.0$ kΩ

Si $R = 0 \Rightarrow V_D = 0 \Rightarrow V_{DS} = -V_S = -V_{DD} < V_{DS_{sat}}$

Si $V_{DS} = V_{DS_{sat}} \Rightarrow R = \dfrac{V_{DD} + V_{DS}}{-I_D}$

$$R = \frac{3.3\ \text{V} - 0.5\ \text{V}}{0.5\ \text{mA}} = 5.6\ \text{k}\Omega$$

$$0 < R < 5.6\ \text{k}\Omega$$