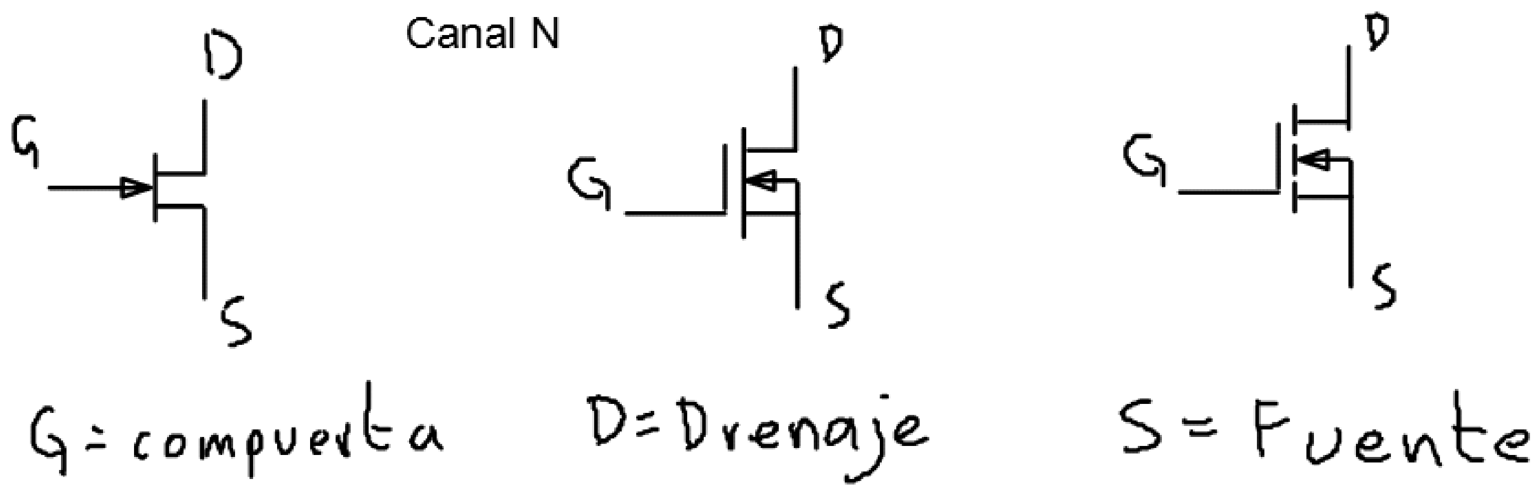
Amplificadores monoetapa con transistores tipo FET

- Unipolares
  - Canal N
  - Canal P

- Tipos
  - JFET
  - MOSFET tipo decremental
  - MOSFET tipo incremental

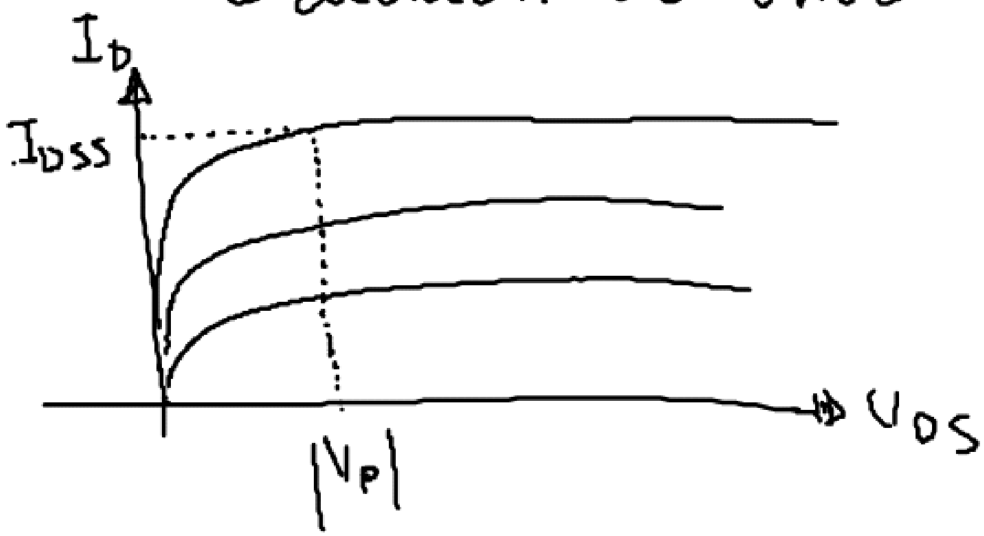
Canal N



- Variables de interés I_D, V_{GS}
- Variable de control V_{GS}
- Relación no lineal entre variables de salida y entrada
  - JFET y MOSFET tipo decremental

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

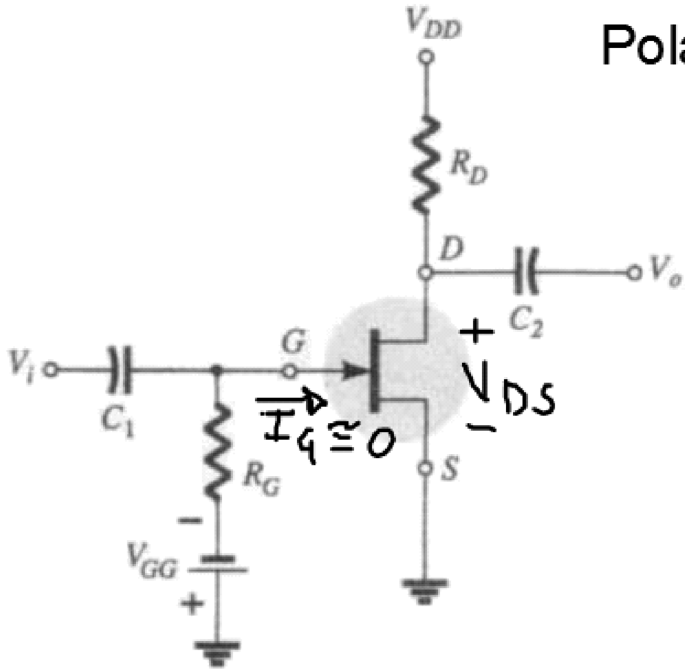
Ecuación de Shockley

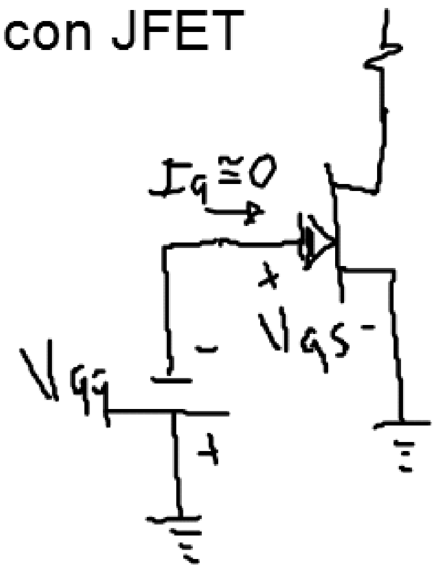


  - MOSFET tipo incremental

$$\boxed{I_D = K\left(V_{GS} - V_T\right)^2}$$

Polarización fija con JFET



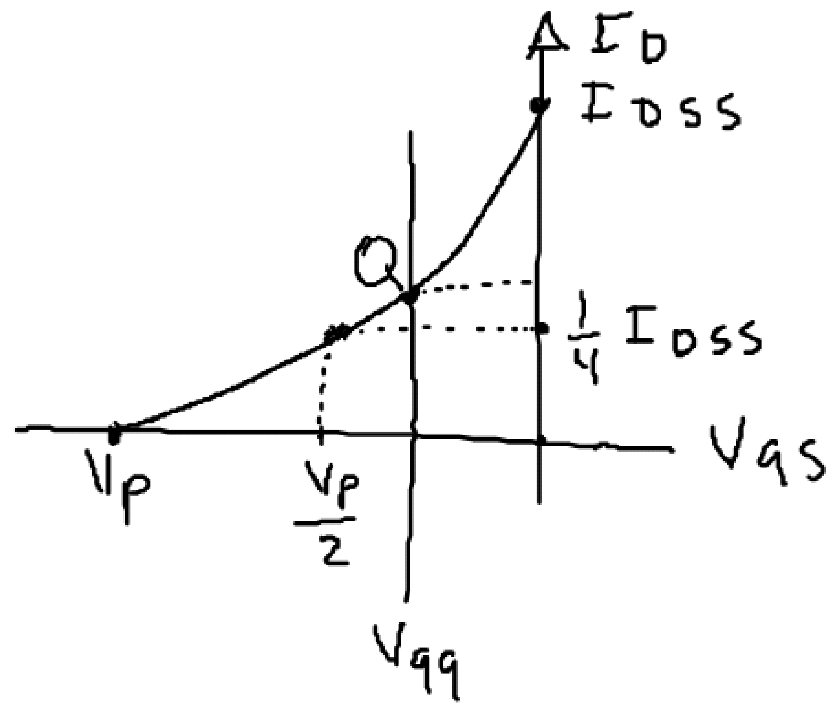


$$\boxed{V_{GG} = -V_{GS}}$$

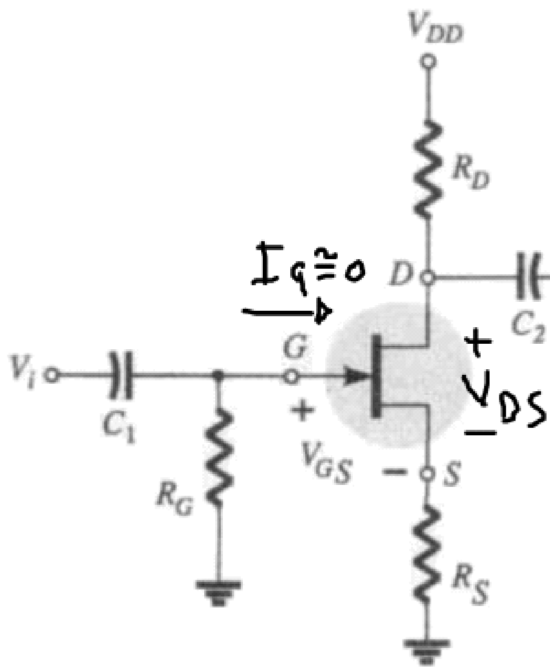
Ecuación de Shockley

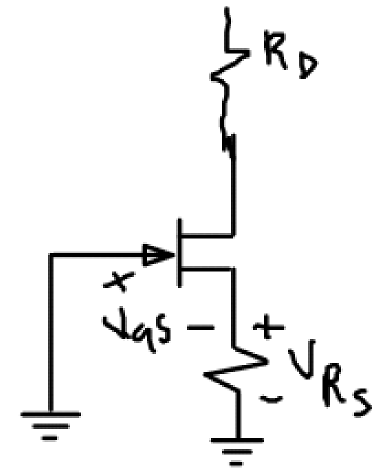
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$V_{DS} = V_{DD} - I_D R_D$$



Autopolarización con JFET



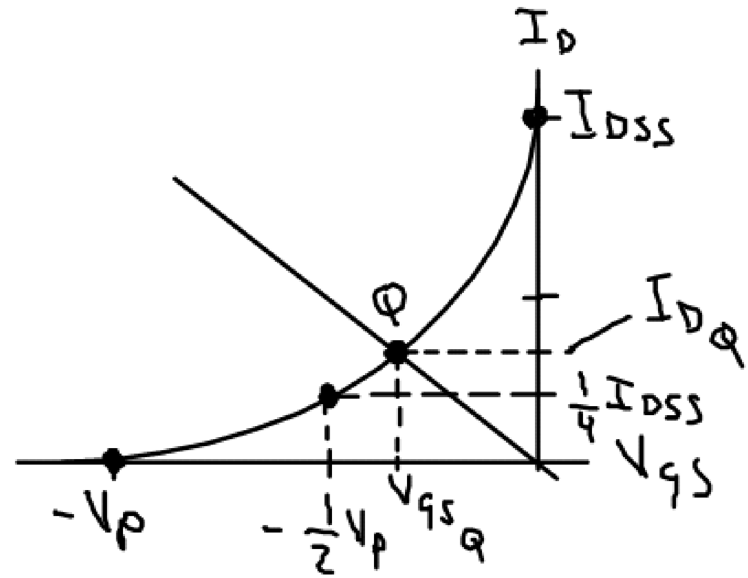


$$\boxed{V_{GS} = -V_{R_S}}$$

$$V_{R_S} = I_S R_S$$

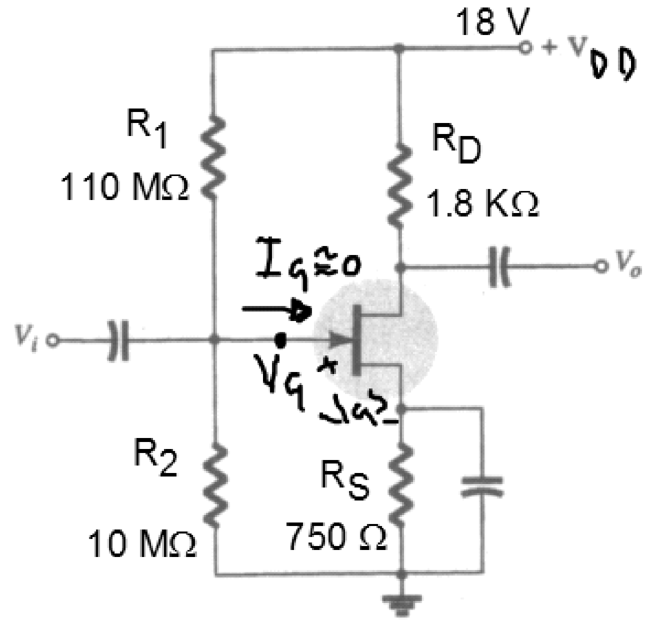
pero $I_S \cong I_D$

$$\boxed{V_{GS} = -I_D R_S}$$

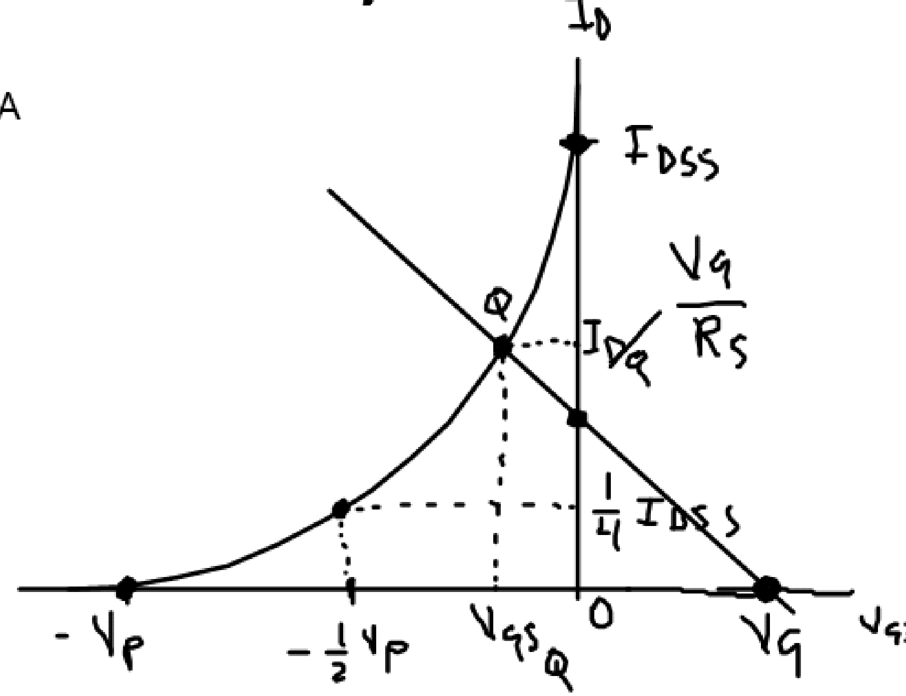


$$\boxed{V_{DS} = V_{DD} - I_D (R_S + R_D)}$$

Polarización por división de voltaje



$I_{DSS} = 6$ mA
$V_P = -3$ V

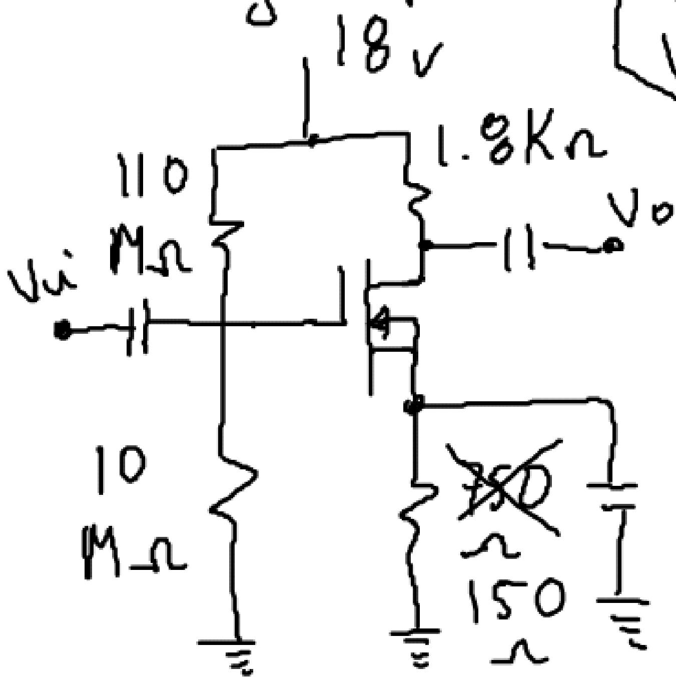


$$V_g = V_{R_2} = \frac{R_2}{R_1 + R_2} V_{DD}$$

$$V_g = V_{gs} + V_{R_s} \quad \text{pero} \quad V_{R_s} = I_S R_s \cong I_D R_s$$

$$V_g = V_{gs} + I_D R_s \Rightarrow \boxed{V_{gs} = V_g - I_D R_s}$$

Ejemplo



$$\boxed{\begin{aligned} I_{DSS} &= 6\,mA \\ V_p &= -3V \end{aligned}}$$

$$V_g = \frac{10}{120}(18)$$

$$\boxed{V_g = 1.5V}$$

$$V_{gs} = V_g - I_D R_S$$

$$V_{gs} = 1.5 - I_D(\cancel{750}\ 150)$$

$$I_D = I_{DSS}\left(1 - \frac{V_{gs}}{V_p}\right)^2$$

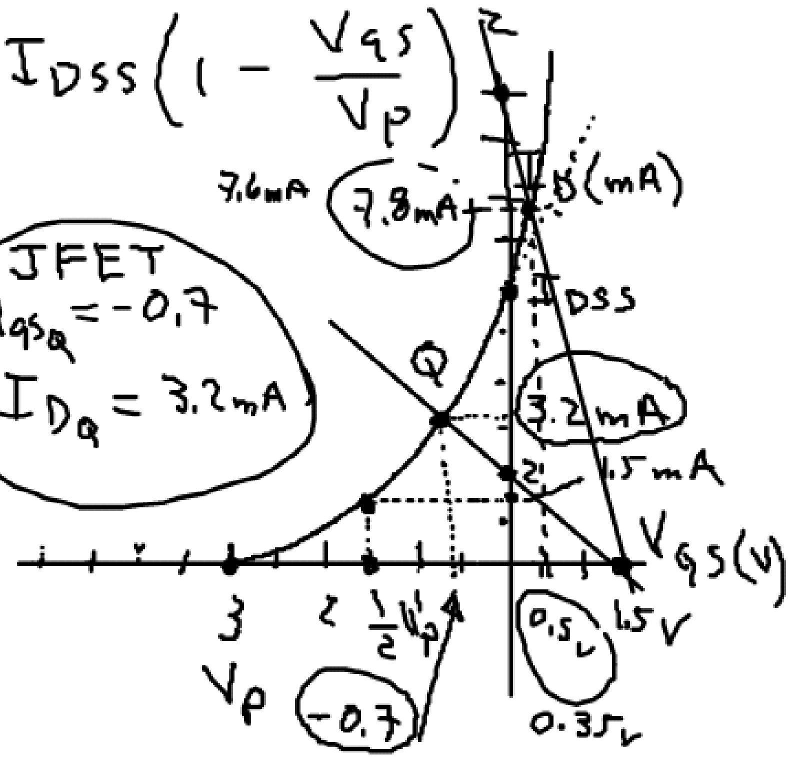
$$V_g = \frac{R_2}{R_1+R_2} V_{DD} = 1.5V$$

$$\boxed{V_{gs} = V_g - I_D R_s}$$

$$V_{gs} = 1.5 - I_D(\cancel{750}\ 150)$$

$$I_D = I_{DSS}\left(1 - \frac{V_{gs}}{V_p}\right)^2$$

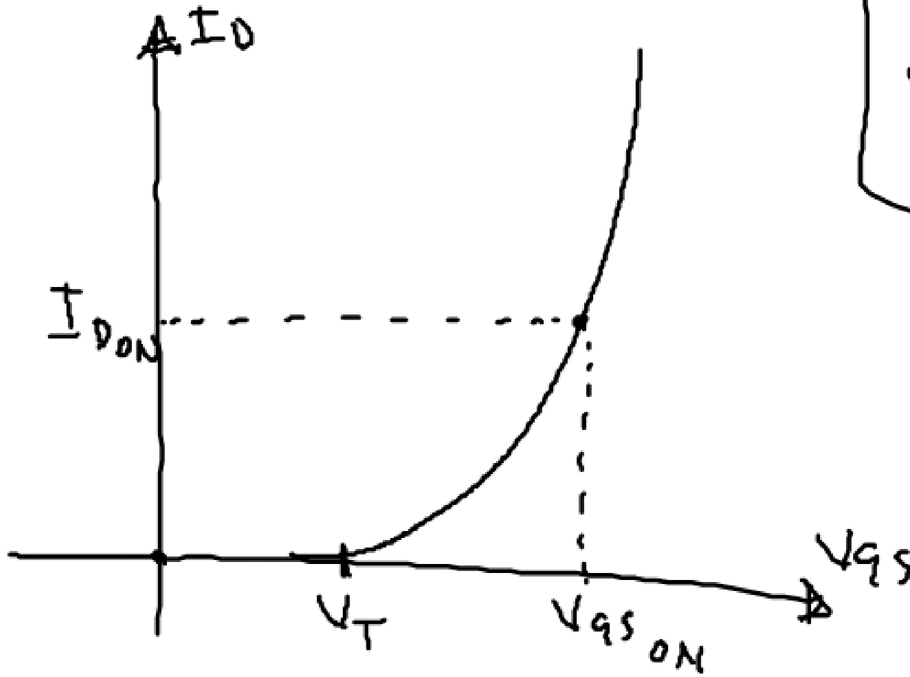
JFET
$V_{gs_Q} = -0.7$
$I_{D_Q} = 3.2\,mA$



Mosfet tipo incremental

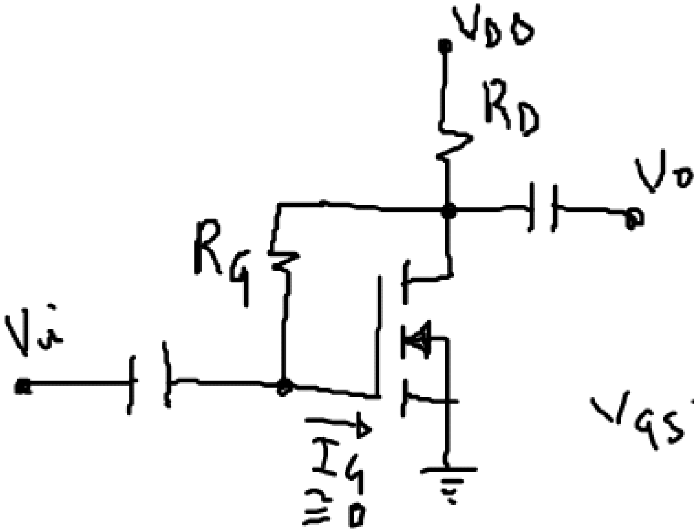
$$I_D = k\left(V_{GS} - V_T\right)^2$$

$I_{D\,ON}$
$V_{GS\,ON}$
V_T



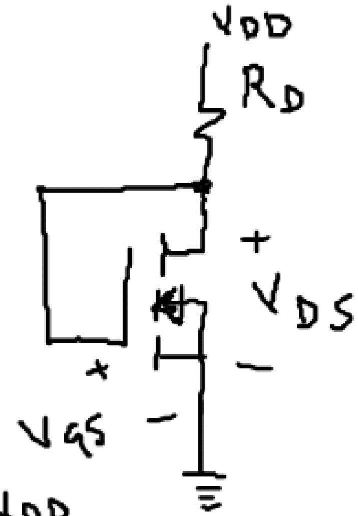
$$\boxed{k = \frac{I_{D\,ON}}{\left(V_{GS\,ON} - V_T\right)^2}} \quad \left[\frac{A}{V^2}\right]$$

Polarización por realimentación



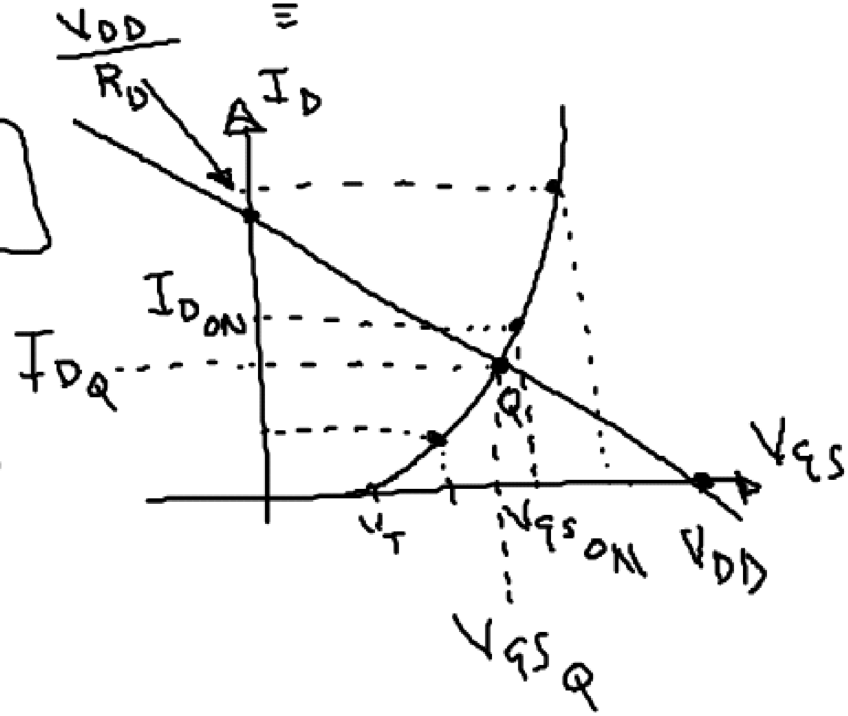
$V_{GS} = V_{DS}$

$\Rightarrow$

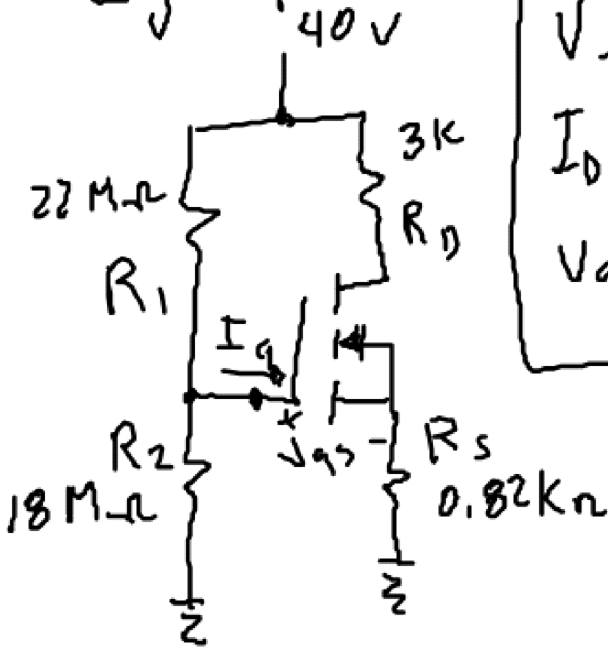


$$\boxed{V_{GS} = V_{DS} = V_{DD} - I_D R_D}$$

$$\boxed{I_D = k\left(V_{GS} - V_T\right)^2}$$



Ejemplo:



$$\boxed{\begin{aligned} V_T &= 5\,V \\ I_{D_{ON}} &= 3\,mA \\ V_{GS_{ON}} &= 10\,V \end{aligned}}$$

$$K = \frac{I_{D_{ON}}}{(V_{GS_{ON}} - V_T)^2}$$

$$\boxed{K = 0.12 \times 10^{-3}\ \frac{A}{V^2}}$$

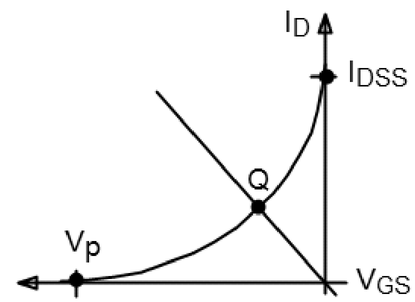
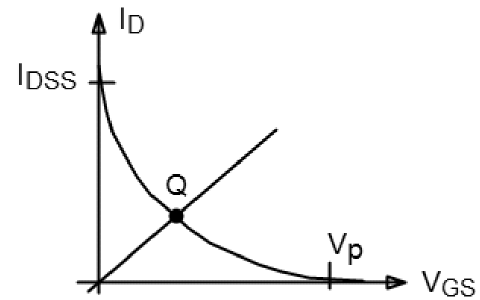
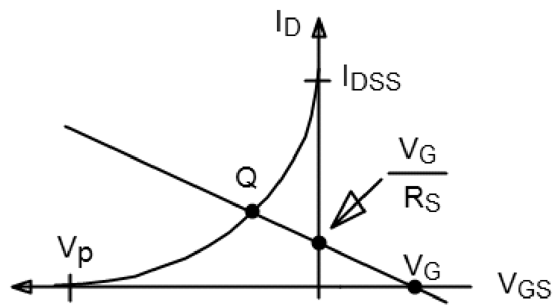
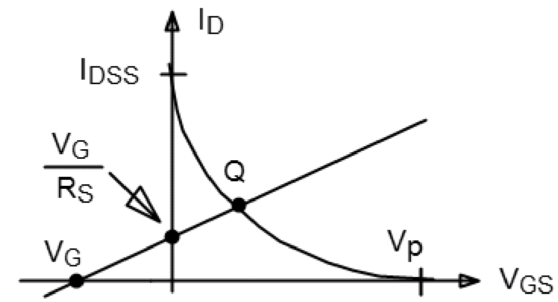
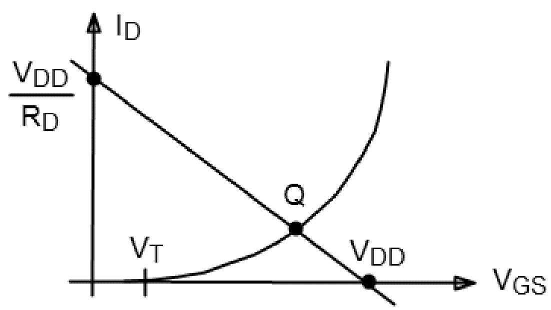
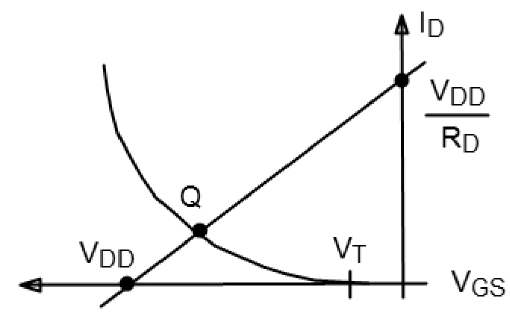
$$V_G = \frac{R_2}{R_1 + R_2} V_{DD} = 18\,V$$

$$V_G = V_{GS} + V_{R_S}$$

$$V_{GS} = V_G - I_D R_S$$

$$\boxed{V_{GS} = 18 - I_D(820)}$$

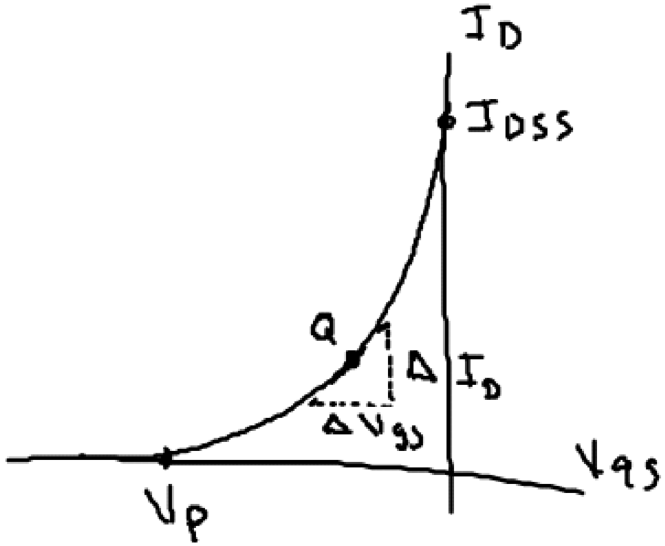
$$I_D = K\left(V_{GS} - V_T\right)^2$$

Transistor tipo FET	Canal N	Canal P
Autopolarización ➲ JFET ➲ Mosfet tipo decremental		
División de voltaje ➲ JFET ➲ Mosfet tipo decremental		
➲ Mosfet tipo incremental		

Análisis en AC para amplificadores monoetapa a base de transistores tipo FET

Factor de transconductancia (g_m)

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \quad [\text{Siemens ó mho}]$$



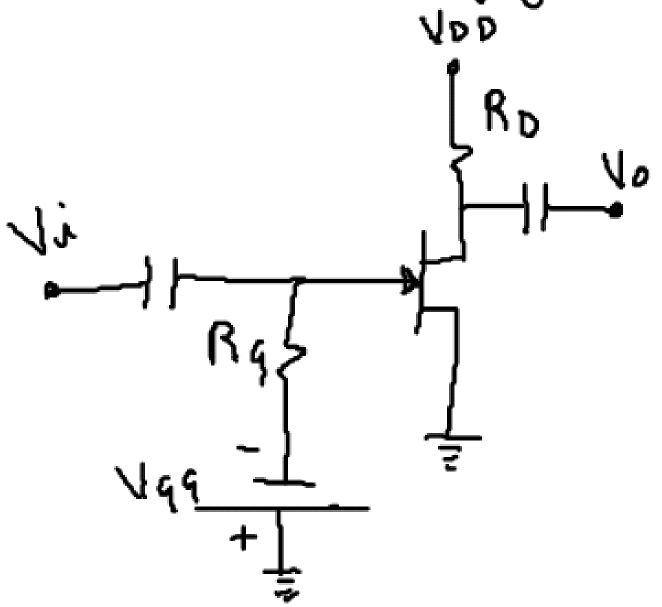
$$g_m = \left.\frac{\Delta I_D}{\Delta V_{GS}}\right|_{\text{punto Q}} = \left.\frac{d I_D}{d V_{GS}}\right|_{\text{punto Q}}$$

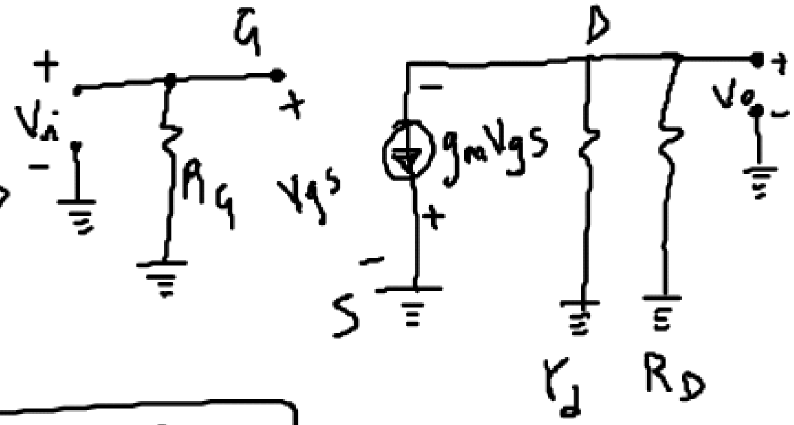
$$g_m = \frac{d}{dV_{GS}}\left[I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2\right]$$

$$\boxed{g_m = \frac{2 I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right] \quad \text{Siemens ó mho}}$$

$$\boxed{g_m = y_{fs}} \qquad \boxed{r_d = \frac{1}{y_{os}}}$$

Polarización fija





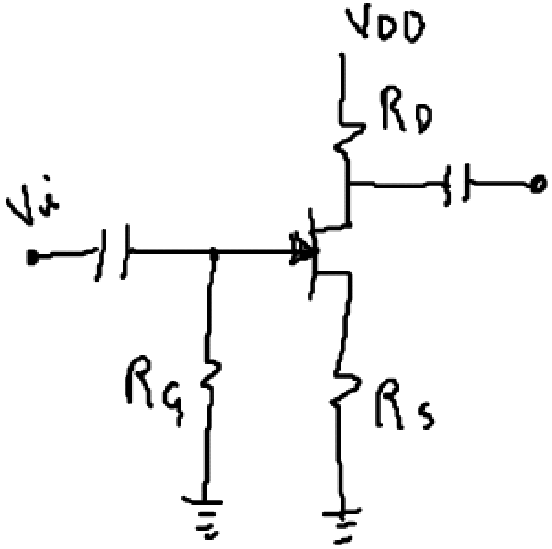
$$\boxed{Z_i = R_g}$$

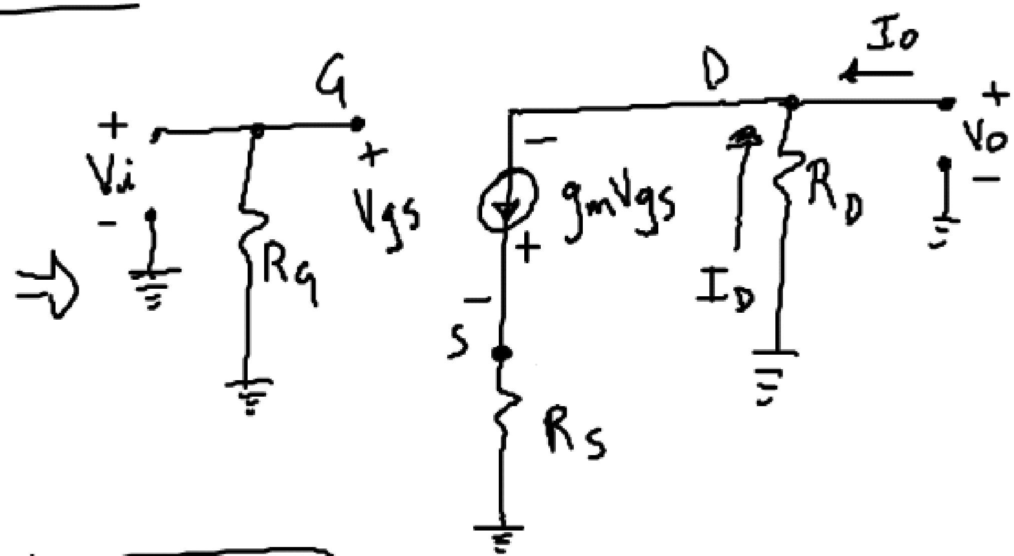
$$\boxed{Z_o = r_d \parallel R_D}$$

$$A_v = \frac{V_o}{V_i} = -\frac{g_m V_{gs} (r_d \parallel R_D)}{V_{gs}}$$

$$\boxed{A_v = -g_m (r_d \parallel R_D)}$$

Autopolarización





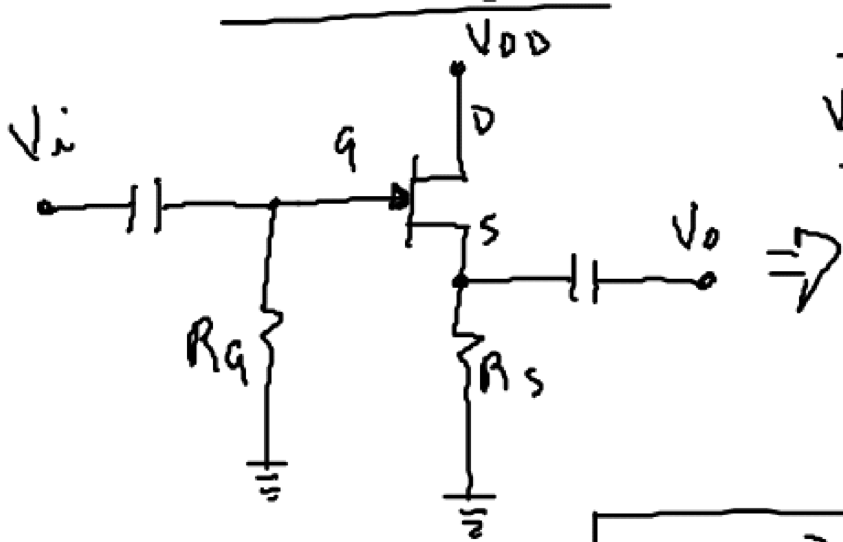
$$\boxed{Z_i = R_g}$$

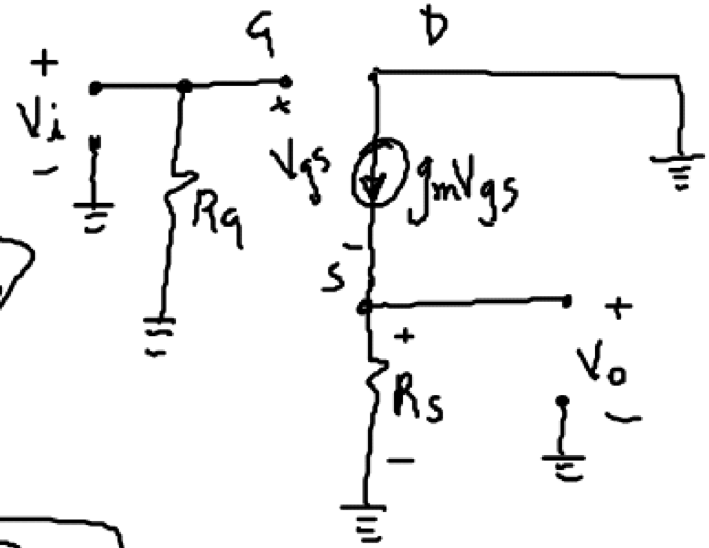
$$\boxed{Z_o = R_D}$$

$$A_v = \frac{V_o}{V_i} = -\frac{g_m V_{gs} R_D}{V_{gs} + V_{R_s}} = -\frac{g_m V_{gs} R_D}{V_{gs} + g_m V_{gs} R_s}$$

$$\boxed{A_v = -\frac{g_m R_D}{1 + g_m R_s}}$$

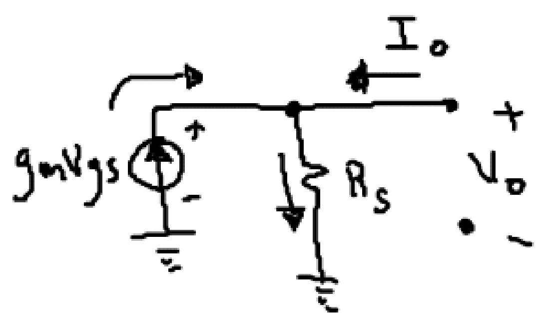
Fuente seguidor





$$\boxed{Z_i = R_G}$$

Para Z_o

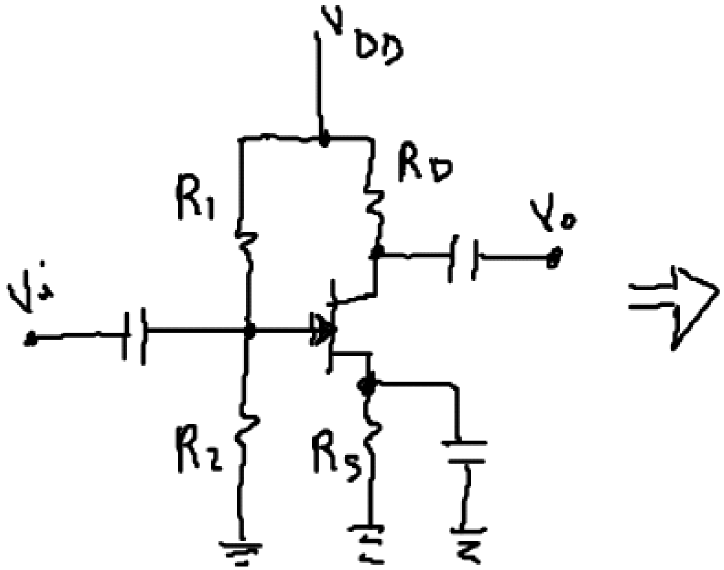


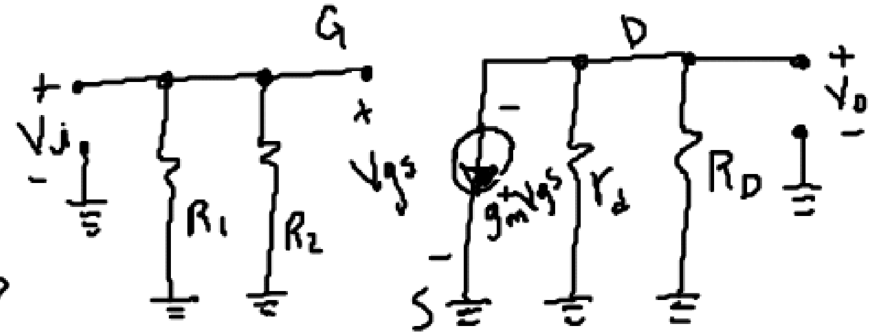
$$V_{gs} = -V_{R_S} = -V_o$$

$$I_o + g_mV_{gs} = I_{R_s} = \frac{V_o}{R_s}$$

$$I_o = \frac{V_o}{R_s} - g_mV_{gs} = \frac{V_o}{R_s} + g_mV_o = V_o\left[\frac{1}{R_s} + g_m\right]$$

Divisor de voltaje





$$\boxed{Z_i = R_1 \| R_2}$$

$$\boxed{Z_o = r_d \| R_D}$$

$$A_v = \frac{V_o}{V_i} = -\frac{g_m V_{gs} (r_d \| R_D)}{V_{gs}}$$

$$\boxed{A_v = -g_m (r_d \| R_D)}$$

Análisis en AC con Mosfet tipo incremental

$$I_D = K(V_{GS} - V_T)^2$$

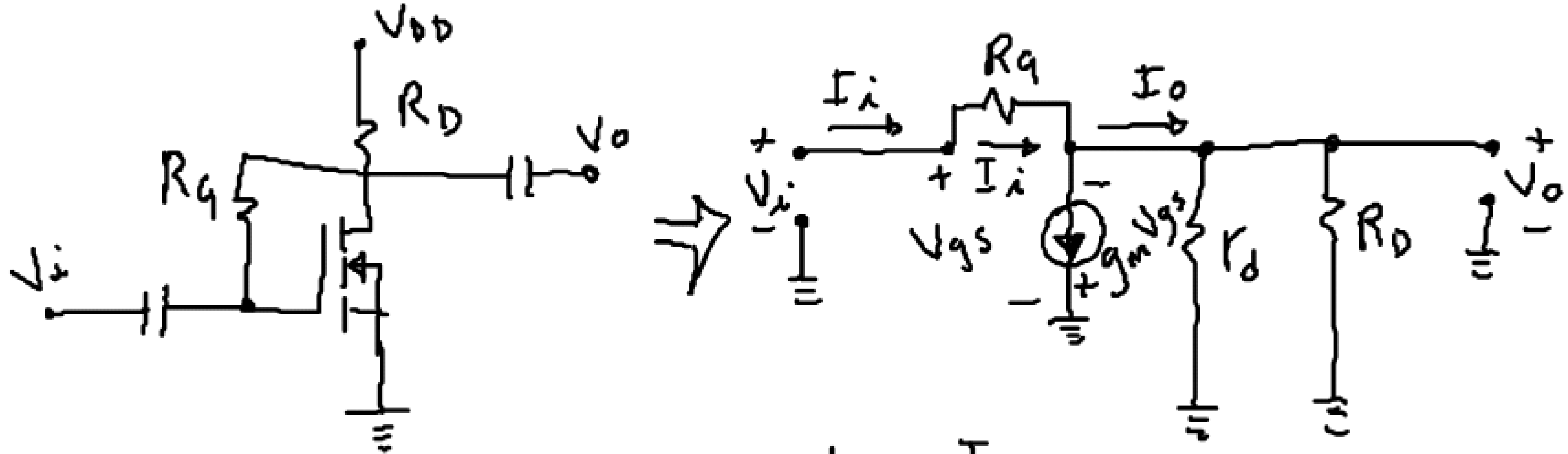
$$\boxed{V_{GS_T} = V_T}$$

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$g_m = \frac{d I_D}{d V_{GS}} = \frac{d}{d V_{GS}}\left(K(V_{GS} - V_T)^2\right)$$

$$\boxed{g_m = 2K(V_{GS} - V_T)}$$

Realimentación del drenaje



$$Z_i = \frac{V_i}{I_i}$$

$$I_i = g_m V_{gs} + I_o$$

donde $I_o = \dfrac{V_o}{r_d \| R_D}$

entonces

$$I_i = g_m V_{gs} + \frac{V_o}{r_d \| R_D} \Rightarrow V_o = I_i (r_d \| R_D) - g_m V_{gs} (r_d \| R_D)$$

$$V_i = V_{gs}$$

$$V_{R_G} = I_i R_G = V_i - V_o$$

$$I_i R_G = V_i - I_i (r_d \| R_D) + g_m V_i (r_d \| R_D)$$

$$\boxed{Z_i = \frac{V_i}{I_i} = \frac{R_G + (r_d \| R_D)}{1 + g_m (r_d \| R_D)}}$$

$$\boxed{Z_o = R_G \| r_d \| R_D}$$

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{g_m V_{gs} (r_d \| R_D)}{V_{gs}} = -g_m (r_d \| R_D)}$$

para $R_G >> R_D$

de otra manera:

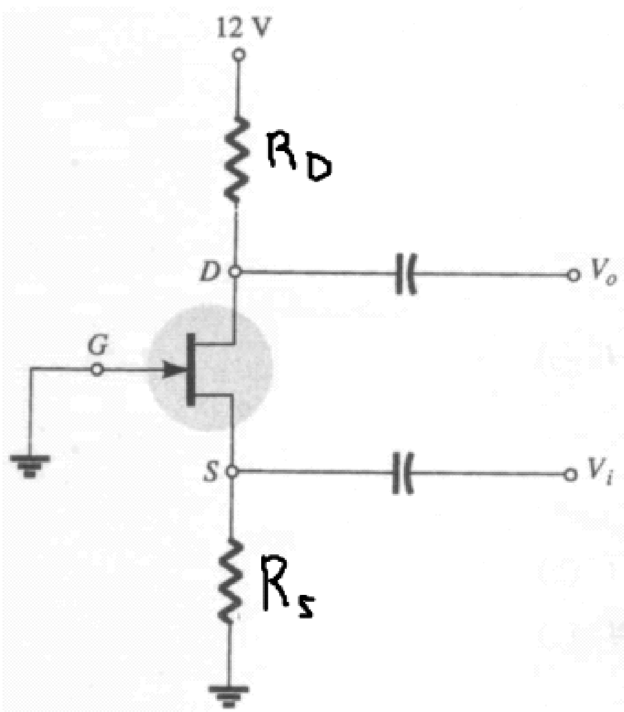
$$I_i R_G = V_i - V_o$$

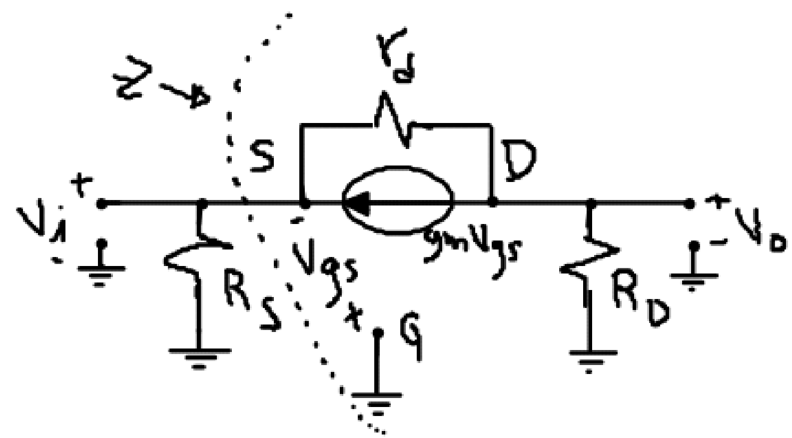
$$g_m V_i R_G + \frac{V_o R_G}{(r_d \| R_D)} = V_i - V_o$$

$$V_o \left(1 + \frac{R_G}{r_d \| R_D}\right) = V_i (1 - g_m R_G)$$

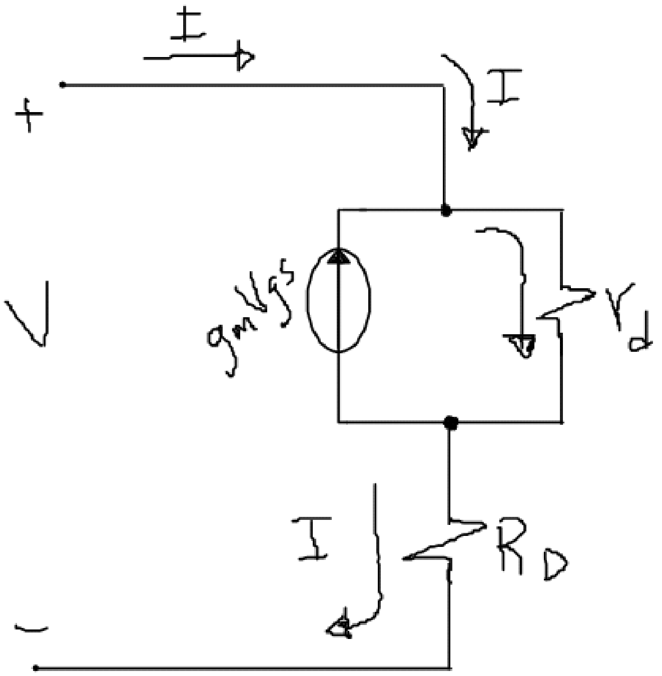
$$A_v = \frac{V_o}{V_i} = \frac{1 - g_m R_q}{1 + \dfrac{R_q}{(r_d || R_D)}} = \frac{\dfrac{1}{R_q} - g_m}{\dfrac{1}{R_q} + \dfrac{1}{r_d || R_D}}$$

Compuerta común





$V_i = V_{R_s} = -V_{gs} = V$ $\quad Z_i = \dfrac{V_i}{I_i}$



$$I_{r_d} = I + g_m V_{gs}$$

$$V_{r_d} = I_{r_d} r_d = r_d (I + g_m V_{gs})$$

$$V = V_{r_d} + I R_D$$

$$V = r_d (I + g_m V_{gs}) + I R_D$$

$$V = r_d I + r_d g_m V_{gs} + I R_D$$

pero $V = -V_{gs}$

$$V = r_d I - r_d g_m V + I R_D$$

$$\boxed{Z = \frac{V}{I} = \frac{r_d + R_D}{1 + g_m r_d}}$$

$$\boxed{Z_i = R_S \| Z}$$

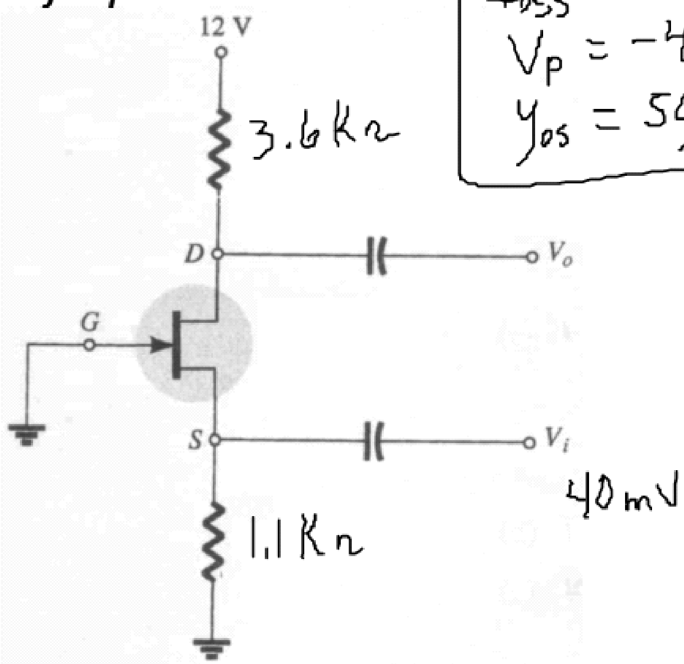
$$\boxed{Z_o = r_d \| R_D}$$

si $r_d \gg R_D$ y $r_d g_m \gg 1$

$$\boxed{Z \simeq \frac{1}{g_m}}$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs} R_D}{-V_{gs}} = g_m R_D}$$

Ejemplo



$I_{DSS} = 10\,mA$

$V_p = -4V$

$y_{os} = 50\mu S$

Considerar: $V_{GS_Q} = -2.2\,V$

$I_{D_Q} = 2.03\,mA$

$$g_m = \frac{2 I_{DSS}}{|V_p|}\left(1 - \frac{V_{GS_Q}}{V_p}\right)$$

$$g_m = \frac{2(10mA)}{4}\left(1 - \frac{(-2.2)}{(-4)}\right)$$

$$\boxed{g_m = 2.25\ mS}$$

$$\boxed{r_d = \frac{1}{y_{os}} = \frac{1}{50\mu S} = 20K\Omega}$$

$$Z_i = R_S \| \left(\frac{r_d + R_D}{1 + g_m r_d}\right) = 1.1K\Omega \| \left(\frac{20k + 3.6K}{1+(2.25mS)(20k)}\right)$$

$$\boxed{Z_i = 349.86\,\Omega}$$

$$Z_o = r_d \| R_D = 20K\Omega \| 3.6K\Omega$$

$$\boxed{Z_o = 3.05\,K\Omega}$$

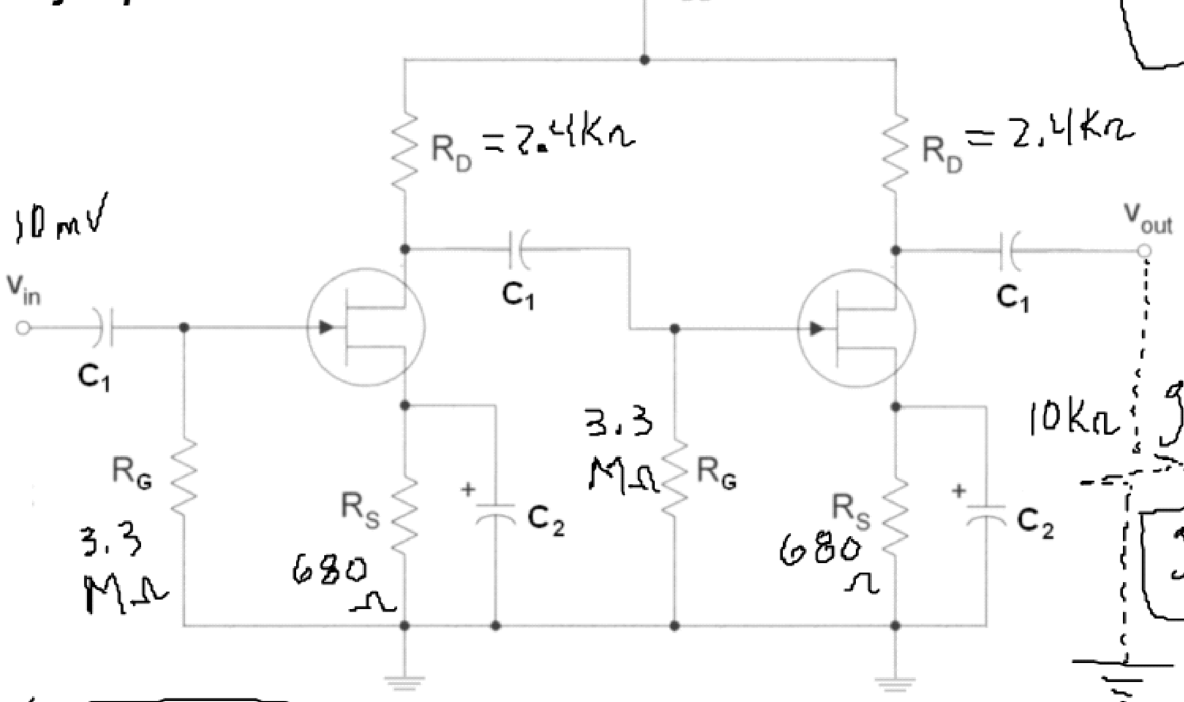
$$A_v = g_m R_D = (2.25\,mS)(3.6\,K\Omega)$$

$$\boxed{A_v = 8.1}$$

$$\boxed{V_o = A_v V_i = 324\,mV}$$

Conexión en cascada

Ejemplo 1



$$\boxed{\begin{aligned} I_{DSS} &= 10\,mA \\ V_p &= -4V \end{aligned}}$$

$$\boxed{\begin{aligned} V_{GS_Q} &= -1.9V \\ I_{D_Q} &= 2.8\,mA \end{aligned}}$$

$$g_m = \frac{2 I_{DSS}}{|V_p|}\left(1 - \frac{V_{gs}}{V_p}\right)$$

$$\boxed{g_m = 2.625\ mS}$$

$$\boxed{Z_i = 3.3\,M\Omega}$$

$$\boxed{Z_o = 2.4K\Omega}$$

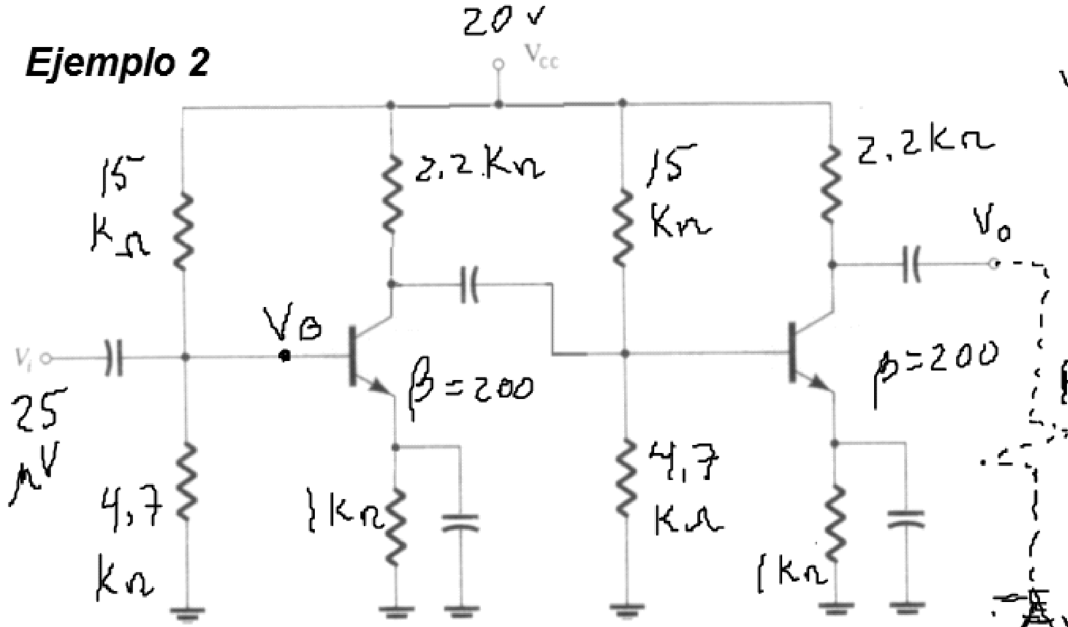
$$A_v = A_{v_1} A_{v_2} \quad \text{pero} \quad A_{v_1} = -g_m(R_{D_1} \| R_{G_2})$$

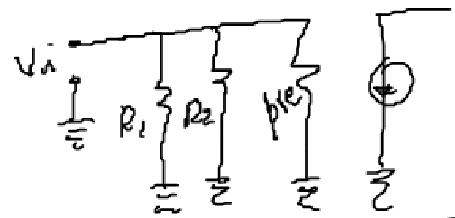
$$A_{v_2} = -g_m R_{D_2}$$

$$\boxed{A_v = 39.66}$$

$$\boxed{V_o = A_v V_i = 396.6\ mV}$$

Ejemplo 2





$$\boxed{Z_i = R_1 \| R_2 \| \beta r_e}$$

$$\boxed{Z_i = 953.6\,\Omega}$$

$$\boxed{Z_o = R_C = 2.2\,k\Omega}$$

$$V_B = 4{,}7\,V = V_{BE} + V_{RE}$$

$$I_E = 4\,mA$$

$$r_e = \frac{26\,mV}{I_E} = 6.5\,\Omega$$

$$A_V = A_{V1} A_{V2}$$

$$A_{V1} = -\frac{2.2\,k\Omega \| 15\,k\Omega \| 4{,}7\,k\Omega \| (200)(6.5)}{6.5}$$

$$A_{V1} = -102.3$$

$$A_{V2} = -\frac{2.2\,k\Omega}{6.5} = -338.46$$

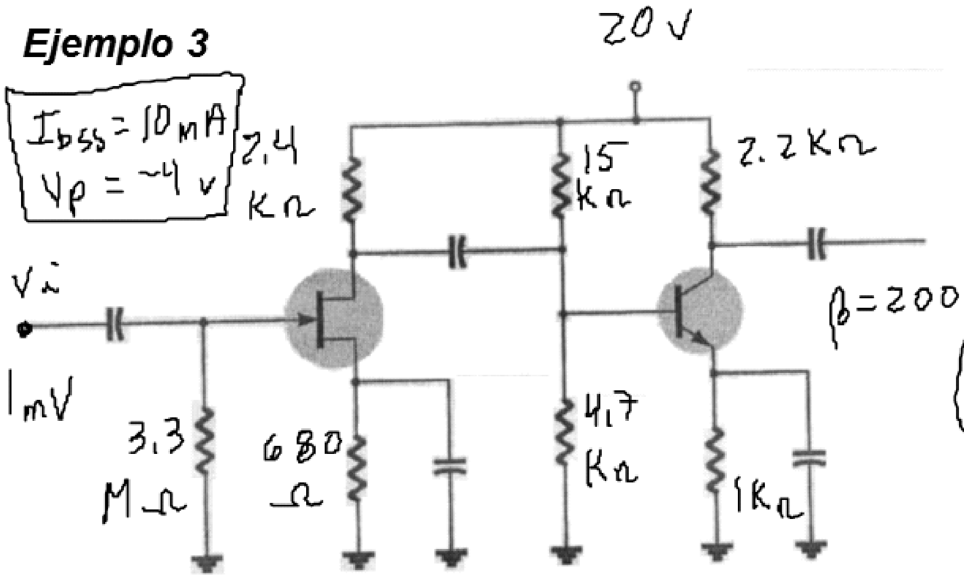
$$A_V = A_{V1} A_{V2} = 34624$$

$$\boxed{V_o = A_V V_i = (34624)(25\,\mu V) = 0.866\,V}$$

Ejemplo 3

$I_{DSS} = 10\,mA$

$V_P = -4\,v$



$V_{GS_Q} = -1.9\,v$

$I_{D_Q} = 2.8\,mA$

$I_E = 4\,mA$

$r_e = 6.5\,\Omega$

$A_V = A_{V_1} A_{V_2}$

$$g_m = \frac{2 I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$\boxed{g_m = 2.6\,mS}$$

$Z_i = R_G = 3.3\,M\Omega$

$Z_o = R_C = 2.2\,K\Omega$

$A_{V_1} = -2.6\,mS\,[2.4\,k\Omega \,\|\, 15\,K\Omega \,\|\, 4.7\,K\Omega \,\|\, (200)(6.5)]$

$$\boxed{A_{V_1} = -1.77}$$

$$A_{V_2} = -\frac{2.2\,K\Omega}{6.5\,\Omega}$$

$$\boxed{A_{V_2} = -338.46}$$

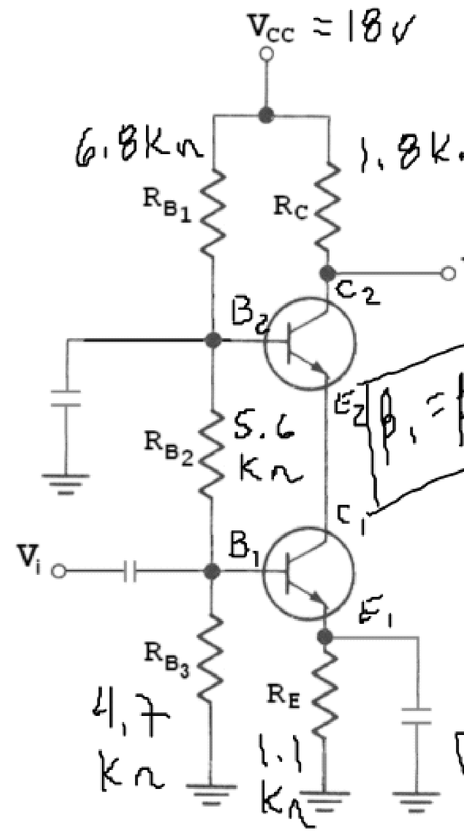
$$\boxed{A_V = A_{V_1} A_{V_2} = 599}$$

$V_o = A_V V_i = (599)(1\,mV)$

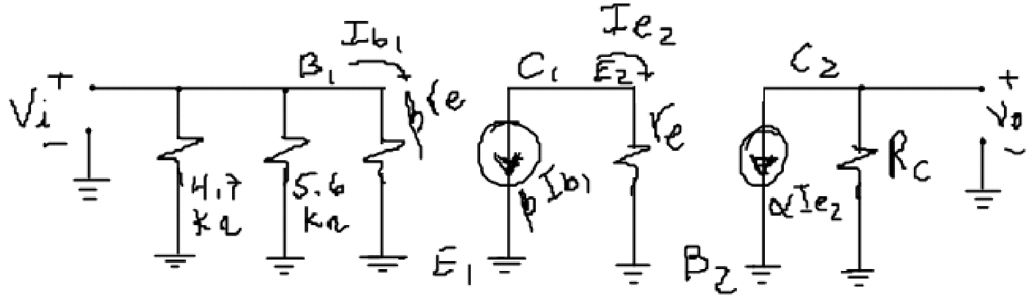
$$\boxed{V_o = 0.6\,V}$$

Conexión cascodo

Ejemplo 1



$\boxed{\beta_1 = \beta_2 = 200}$



$$V_{B_1} = \frac{R_{B_3}}{R_{B_3} + R_{B_2} + R_{B_1}} V_{CC}$$

$$V_{B_1} = V_{BE_1} + V_{RE} \quad \text{pero} \quad V_{RE} = I_E R_E$$

$$\boxed{I_{E_1} = \frac{V_{B_1} - V_{BE_1}}{R_E} = 3.86\,mA}$$

$$\boxed{r_e = \frac{26\,mV}{I_E} = 6.73\,\Omega}$$

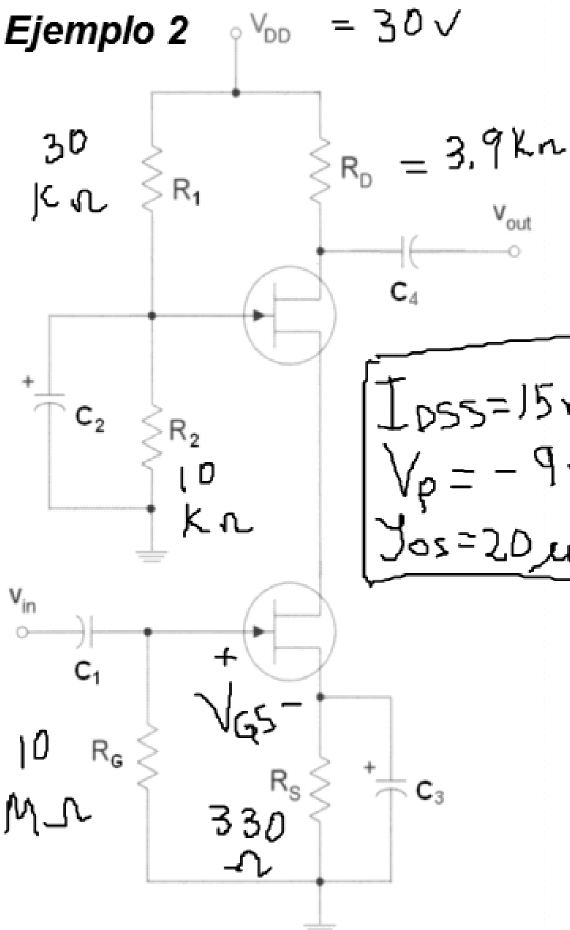
$$Z_i = 4.7\,k\Omega \parallel 5.6\,k\Omega \parallel (200)(6.73)$$

$$\boxed{Z_i = 881.9\,\Omega}$$

$$\boxed{Z_o = R_C = 1.8\,k\Omega}$$

$$\boxed{A_v = A_{v_1} A_{v_2} = (-1)(267.4) = -267.4}$$

Ejemplo 2



$$I_{DSS} = 15\,mA$$
$$V_p = -9\,V$$
$$y_{os} = 20\,\mu S$$

$$I_{DQ} = 7.68\,mA$$
$$V_{GSQ} = -2.53\,V$$

$$r_d = \frac{1}{y_{os}} = \frac{1}{20\,\mu S} = 50\,k\Omega$$

$$g_m = \frac{2 I_{DSS}}{|V_p|}\left(1 - \frac{V_{GSQ}}{V_p}\right) = 2.39\ mS$$

$$Z_i = R_G = 10\,M\Omega$$

$$Z_o = R_D = 3.9\,k\Omega$$

$$A_{V_1} = -g_m\left(\frac{1}{g_m}\right) = -1$$

$$A_{V_2} = g_m R_D = 9.32$$

$$A_V = A_{V_1} A_{V_2} = (-1)(9.32) = -9.32$$

$$V_{GS} = -V_{R_S} = -I_D R_S$$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$