Etapas Básicas de Amplificación

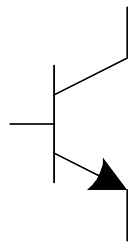
(Parte 1)

Dr. J.E. Rayas Sánchez

Etapas Básicas de Amplificación

- Emisor Común (EC)
- Base Común (BC)
- Colector Común (CC, Seguidor de Emisor)
- Degeneración de Emisor (DE)
- Fuente Común (SC)
- Compuerta Común (GC)
- Drenaje Común (DC, Seguidor de Fuente)
- CC-EC, CC-CC, y Darlington
- Cascode
- Diferenciales

Modelos del BJT en Señal Grande (repaso)

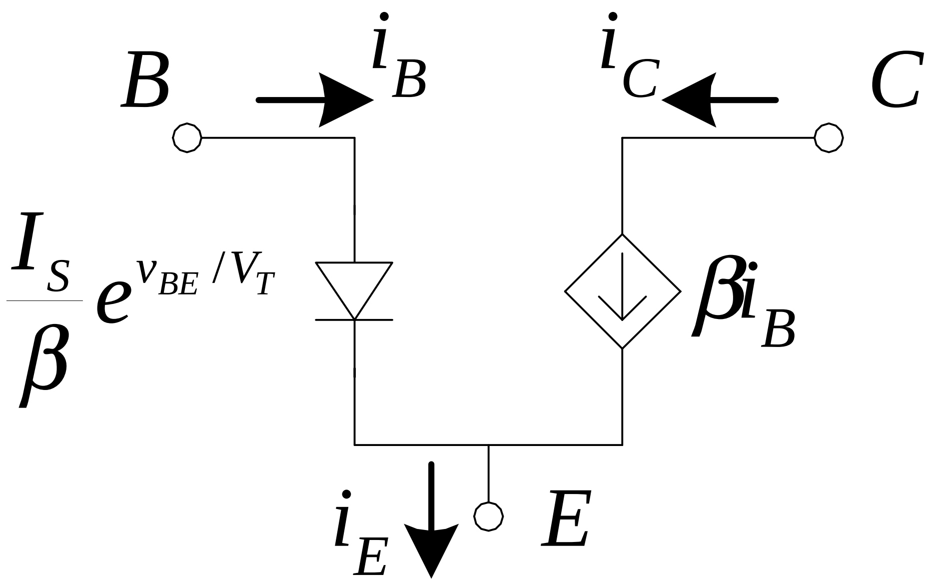


$$i_C = \beta i_B \qquad i_E = i_B(1+\beta) = \frac{i_C}{\beta/(1+\beta)} = \frac{i_C}{\alpha}$$

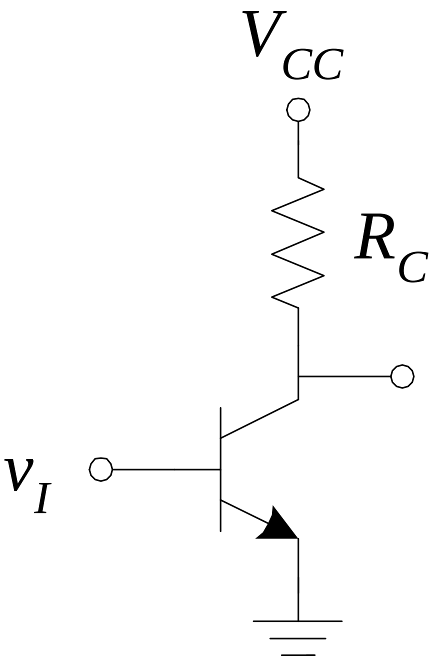
$$i_B = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_E = \frac{I_S}{\alpha} e^{v_{BE}/V_T}$$

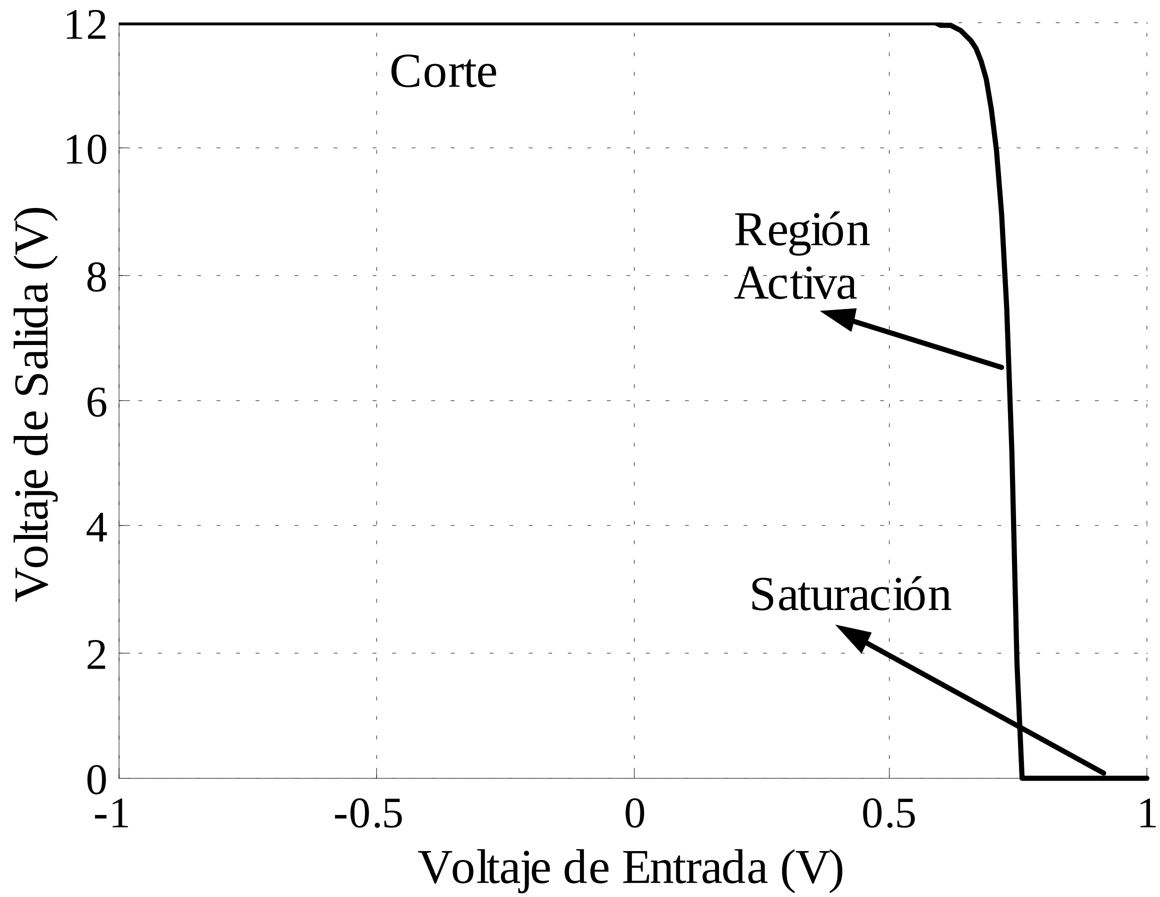


Emisor Común – Señal Grande



$$i_C = I_S e^{v_I / V_T}$$

$$v_O = \begin{cases} V_{CC} - i_C R_C & \text{si } i_C R_C \le V_{CC} \\ 0 & \text{si } i_C R_C > V_{CC} \end{cases}$$



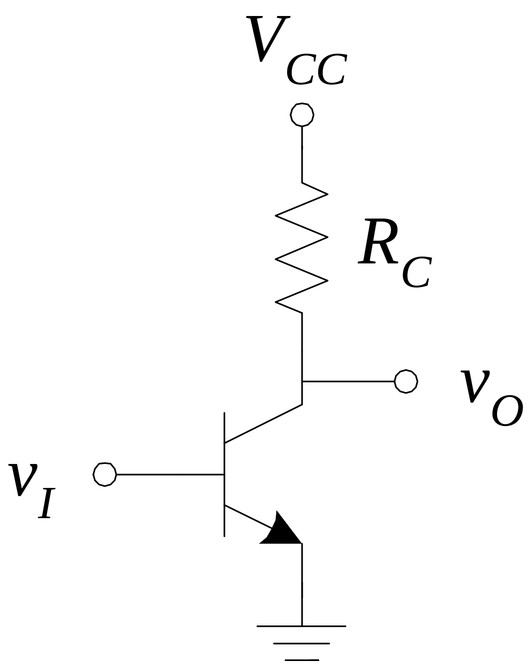
$V_{CC} = 12\text{V}$

$R_C = 1\text{K}\Omega$

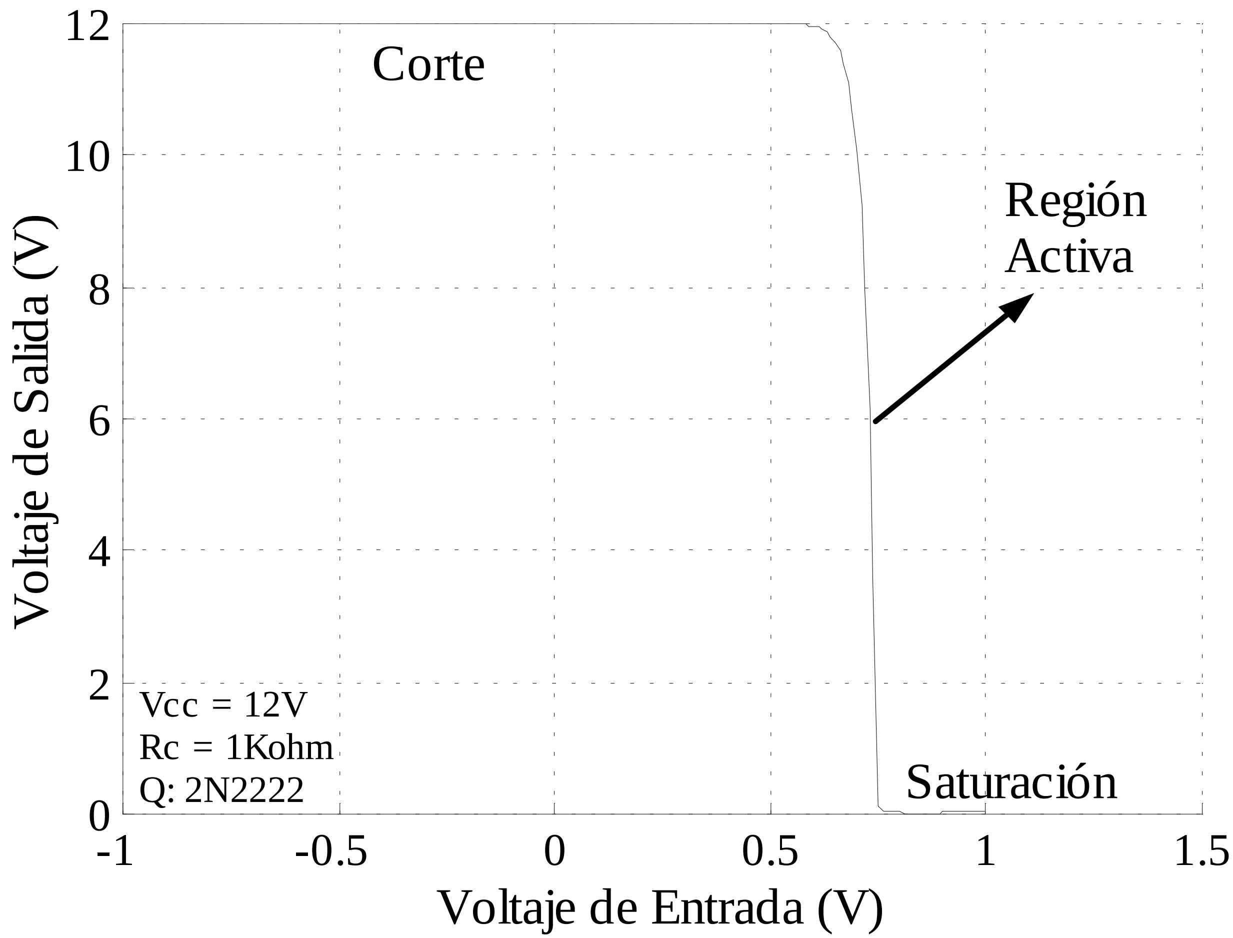
$I_S = 1\times10^{-15}\text{A}$

$V_T = 25\text{mV}$

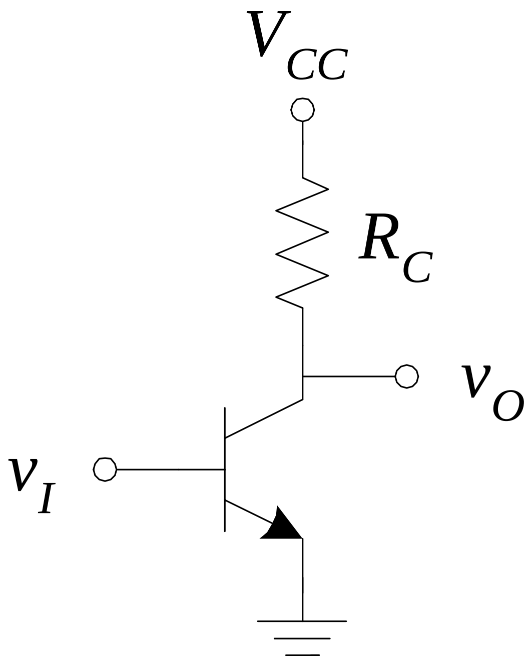
Emisor Común – Señal Grande (cont.)



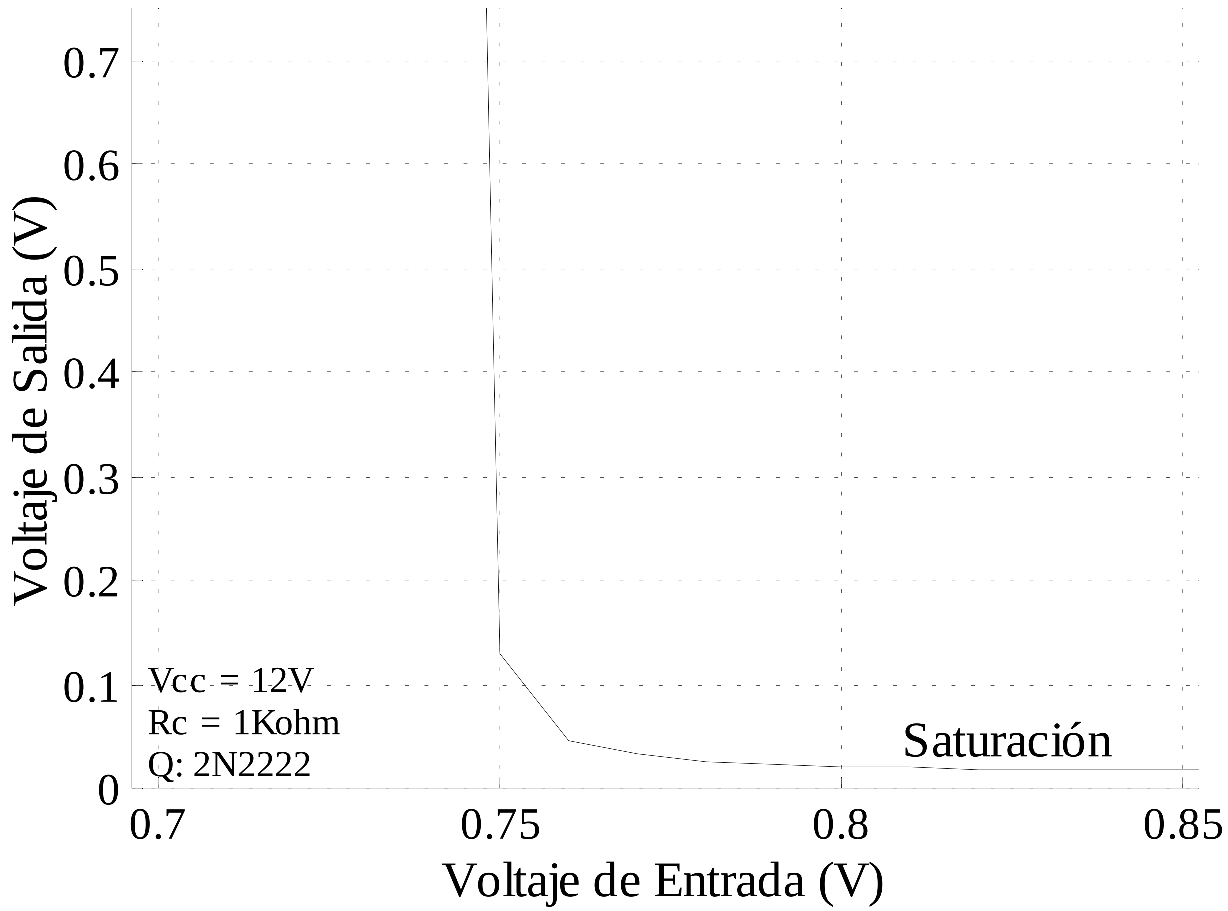
Simulación en Spice:



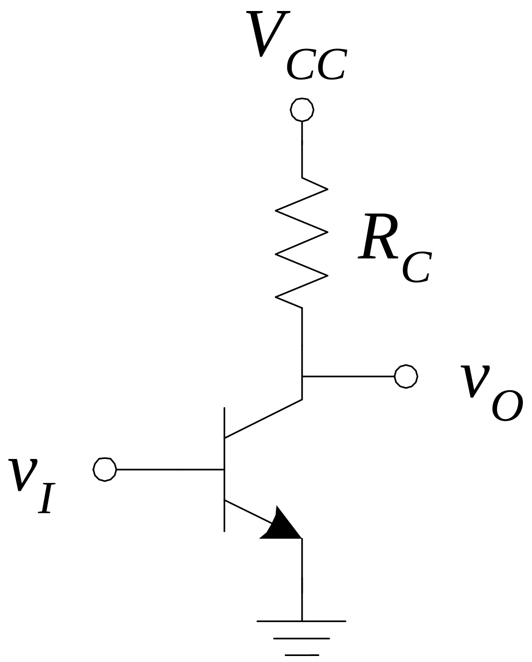
Emisor Común – Señal Grande (cont.)



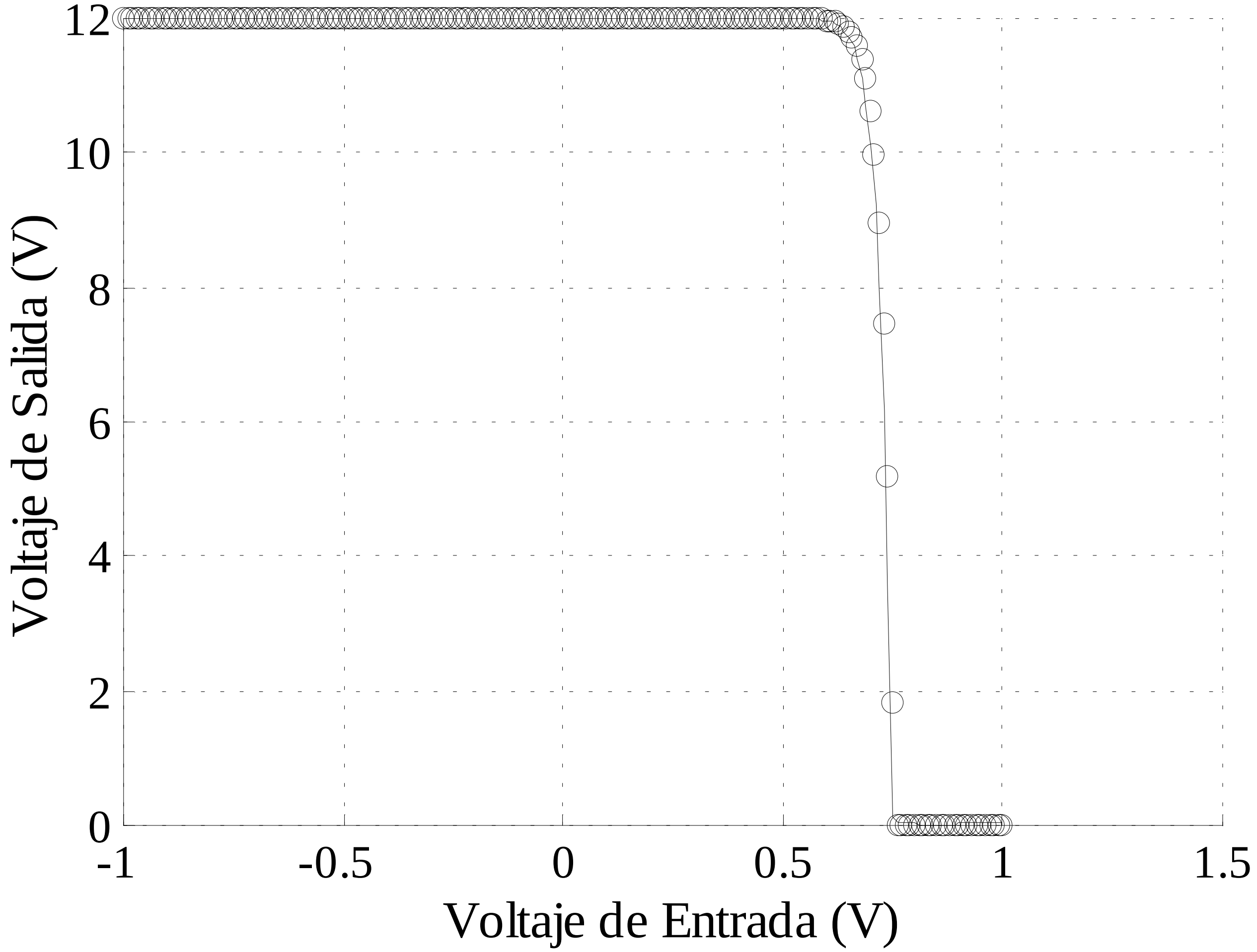
Simulación en Spice:



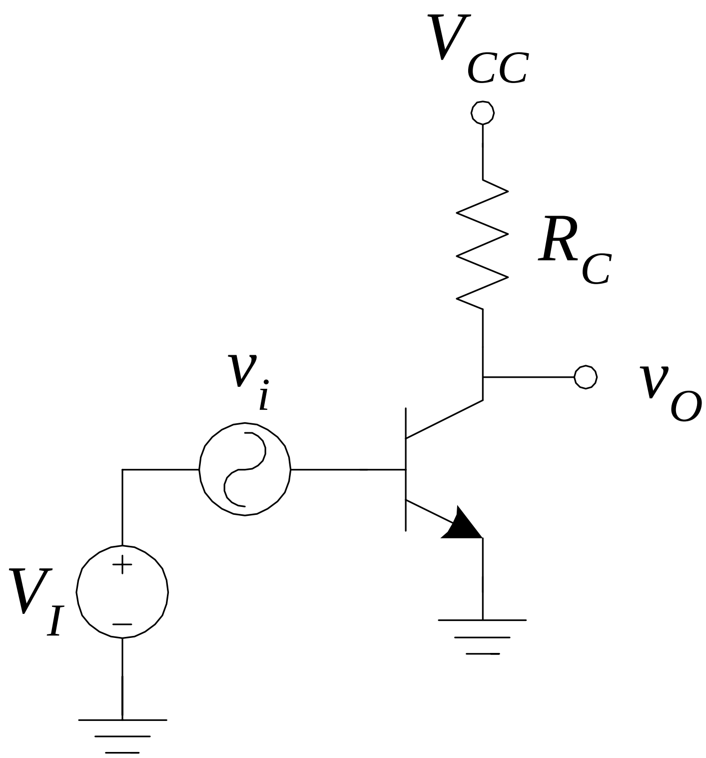
Emisor Común – Señal Grande (cont.)



Spice (–) VS modelo analítico (o):



Emisor Común – Señal Pequeña



$$v_O = V_{CC} - I_S R_C e^{(V_I + v_i)/V_T}$$

$$v_O = V_{CC} - I_{CQ} R_C e^{v_i/V_T}$$

usando $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$

y suponiendo que $v_i << V_T$

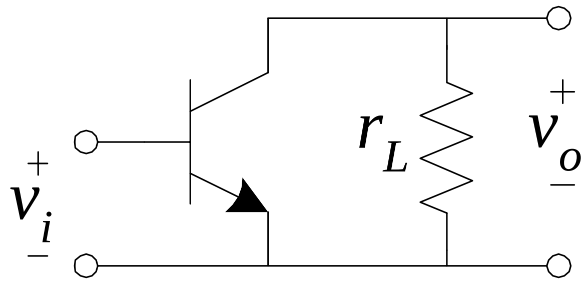
$$v_O = V_{CC} - I_{CQ} R_C (1 + v_i / V_T)$$

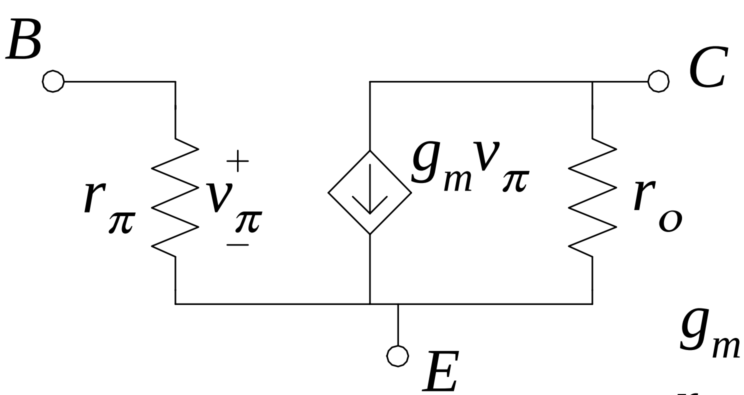
$$v_O = (V_{CC} - I_{CQ} R_C) - \frac{I_{CQ}}{V_T} R_C v_i$$

$$v_O = (V_{CC} - I_{CQ} R_C) - g_m R_C v_i$$

Emisor Común – Señal Pequeña (cont.)

$(v_i << V_T)$





$g_m = I_C/V_T$

$r_\pi = \beta/g_m$

$r_o = V_A/I_C$

$$Z_{in} = \frac{v_i}{i_i} = r_\pi = \frac{\beta}{g_m}$$

$$v_o = -g_m v_\pi (r_L \parallel r_o)$$

$$A_v = \frac{v_o}{v_i} = -g_m (r_L \parallel r_o)$$

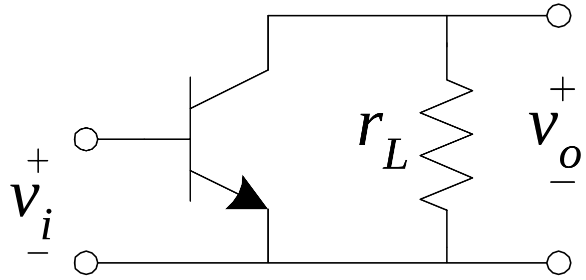
$$i_L = -g_m v_\pi (r_L \parallel r_o) / r_L$$

$$i_i = \frac{v_i}{r_\pi}$$

$$A_i = \frac{i_L}{i_i} = -g_m r_\pi (r_L \parallel r_o) / r_L$$

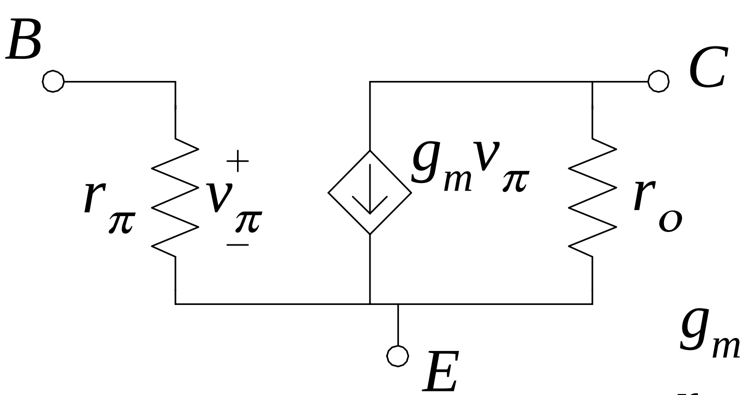
Emisor Común – Señal Pequeña (cont.)

$(v_i << V_T)$



$$Z_o = \left.\frac{v_o}{-i_o}\right|_{v_i=0}$$

$$Z_o = r_o$$



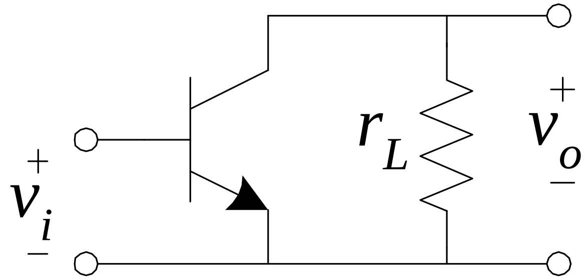
$$g_m = I_C/V_T$$

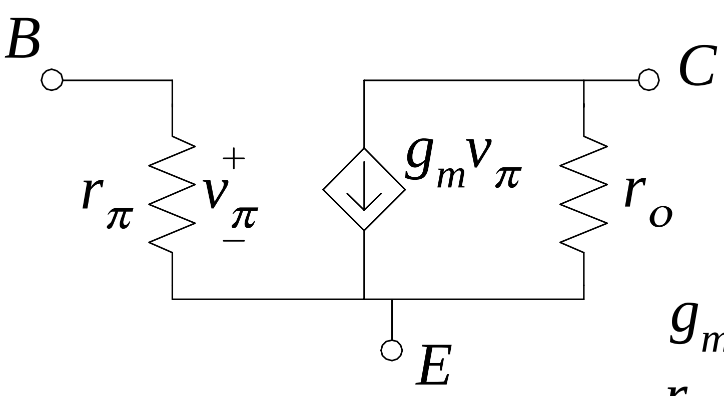
$$r_\pi = \beta/g_m$$

$$r_o = V_A/I_C$$

Emisor Común – Señal Pequeña (resumen)

$(v_i << V_T)$





$$g_m = I_C/V_T$$

$$r_\pi = \beta/g_m$$

$$r_o = V_A/I_C$$

$$Z_{in} = \frac{v_i}{i_i} = r_\pi = \frac{\beta}{g_m}$$

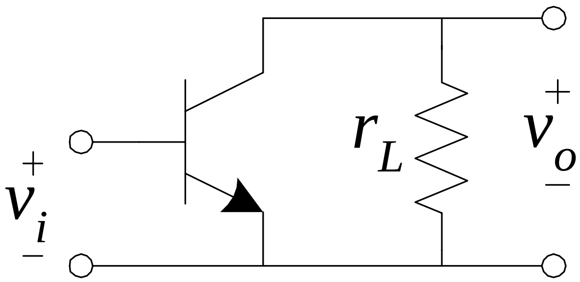
$$A_v = \frac{v_o}{v_i} = -g_m(r_L \parallel r_o)$$

$$A_i = \frac{i_L}{i_i} = -g_m r_\pi (r_L \parallel r_o)/r_L$$

$$Z_o = r_o$$

Máxima A_V del Emisor Común

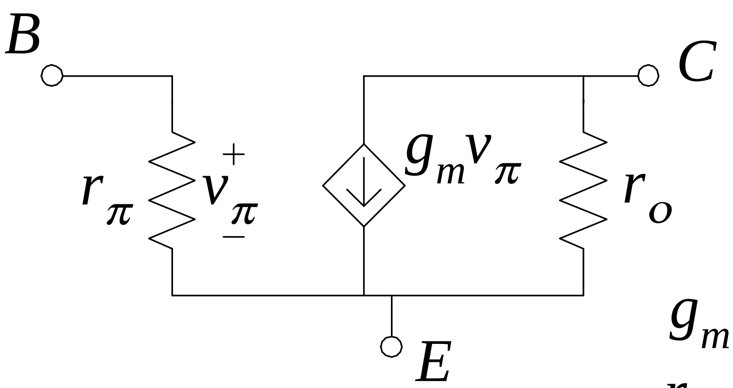
$(v_i << V_T)$



$$A_v = \frac{v_o}{v_i} = -g_m(r_L \parallel r_o)$$

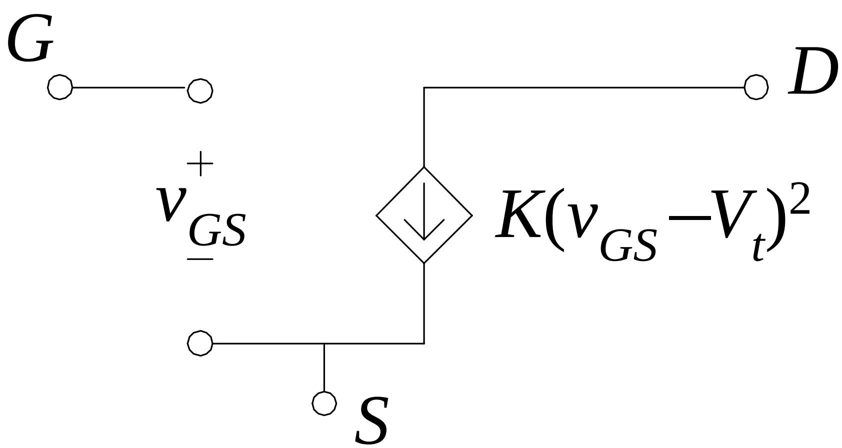
$$|A_{v_{max}}| = g_m r_o / 2$$

$$|A_{v_{max}}| = \frac{V_A}{2V_T}$$



$$g_m = I_C/V_T$$
$$r_\pi = \beta/g_m$$
$$r_o = V_A/I_C$$

Modelo del FET para Señal Grande (repaso)



- E-MOSFET

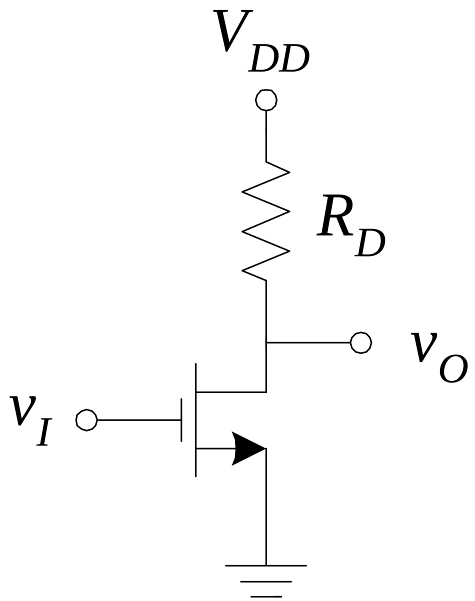
$$K=\frac{1}{2}\mu_n C_{OX}\left(\frac{W}{L}\right)$$

- JFET

$$K=I_{DSS}/V_P^2$$

$$V_t=V_P$$

Fuente Común – Señal Grande



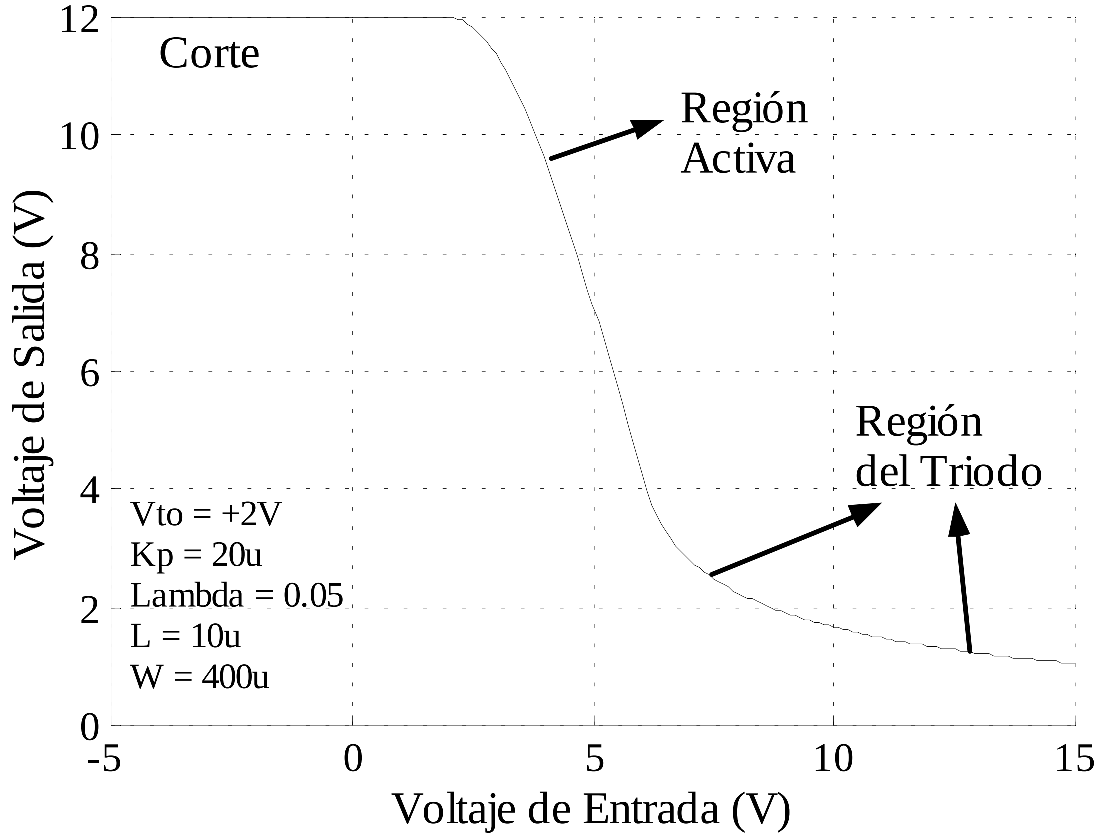
$$i_D = K(v_{GS} - V_t)^2 \qquad v_O = V_{DD} - KR_D(v_{GS} - V_t)^2$$

(siempre que $v_O > V_{GS} - V_t$ y $V_{GS} > V_t$)

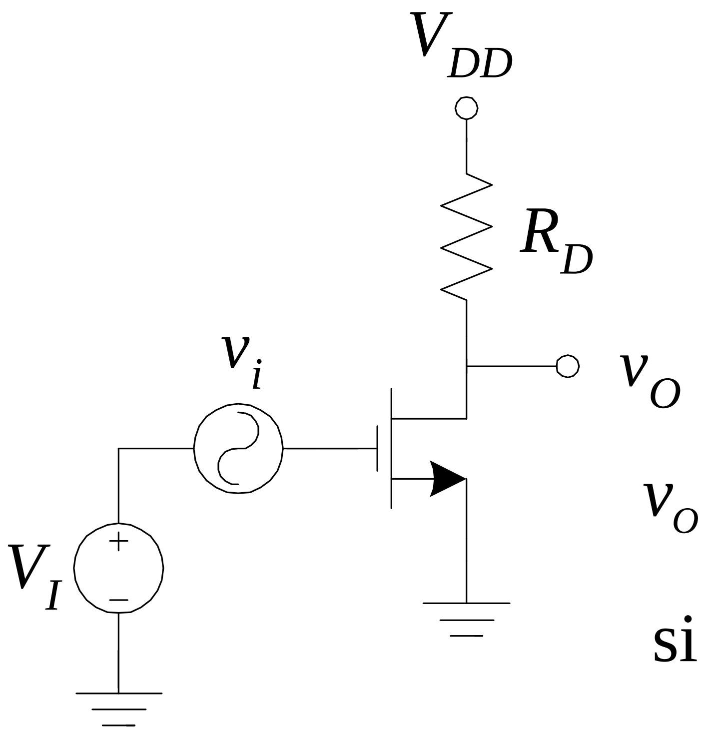
$V_{DD} = 12\text{V}$

$R_D = 1\text{K}\Omega$

Spice →



Fuente Común – Señal Pequeña



$$v_O = V_{DD} - KR_D(v_{GS} - V_t)^2$$

$$v_O = V_{DD} - KR_D(V_I + v_i - V_t)^2$$

$$v_O = V_{DD} - KR_D[(V_I - V_t)^2 + 2(V_I - V_t)v_i + v_i^2]$$

$$\text{si } \; v_i << 2(V_I - V_t) = 2(V_{GS} - V_t)$$

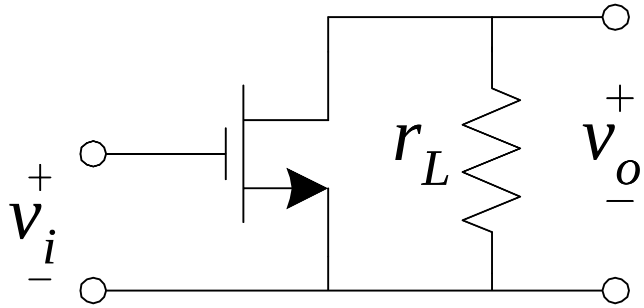
$$v_O = V_{DD} - KR_D[(V_{GS} - V_t)^2 + 2(V_{GS} - V_t)v_i]$$

$$v_O = V_{DD} - I_{DQ}R_D - 2K(V_{GS} - V_t)R_D v_i$$

$$v_O = V_{DD} - I_{DQ}R_D - g_m R_D v_i$$

Fuente Común – Señal Pequeña (cont.)

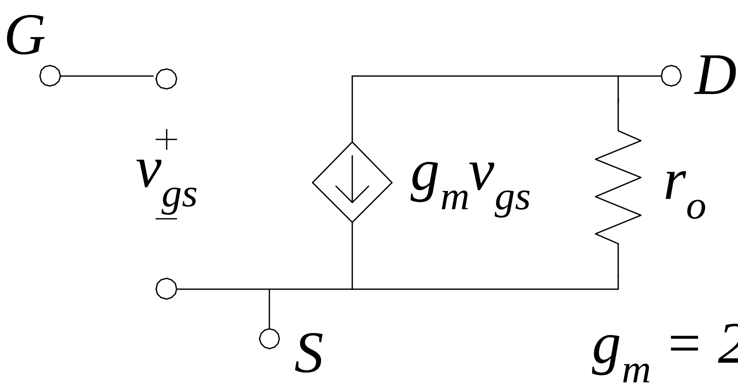
$(v_i << 2(V_{GS} - V_t))$



$$Z_{in} = \frac{v_i}{i_i} = \infty$$

$$A_v = \frac{v_o}{v_i} = -g_m (r_L \parallel r_o)$$

$$Z_o = r_o$$

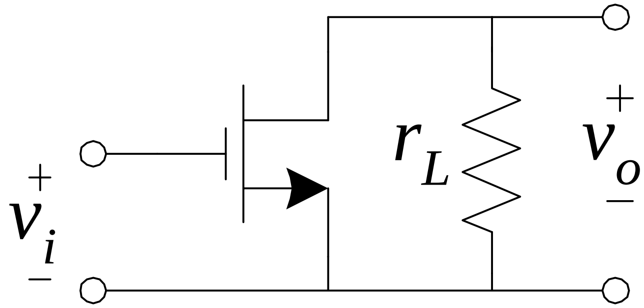


$g_m = 2K(V_{GS} - V_t)$

$r_o = V_A/I_D = 1/\lambda I_D$

Máxima A_V del Fuente Común

$(v_i << 2(V_{GS} - V_t))$



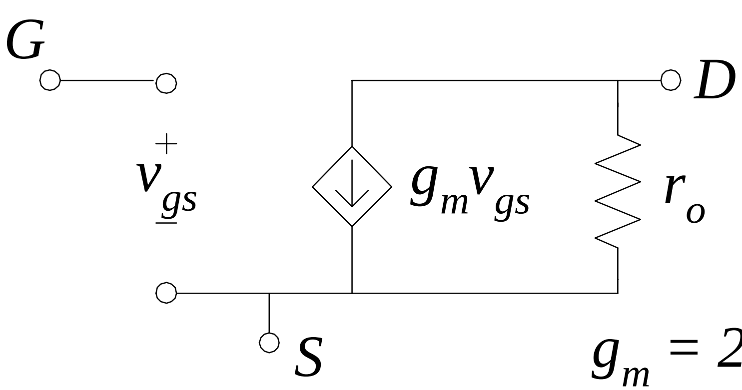
$$A_v = \frac{v_o}{v_i} = -g_m(r_L \parallel r_o)$$

$$|A_{v_{max}}| = g_m r_o / 2$$

$$|A_{v_{max}}| = K(V_{GS} - V_t)V_A / I_D$$

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

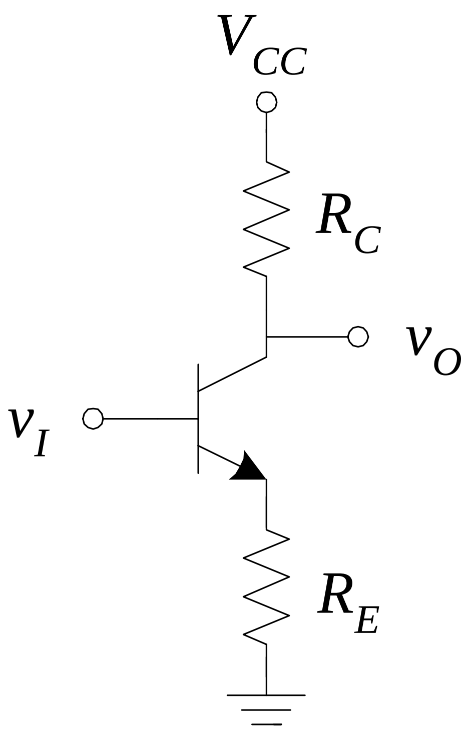
$$|A_{v_{max}}| = V_A \sqrt{K / I_D}$$



$g_m = 2K(V_{GS} - V_t)$

$r_o = V_A / I_D = 1/\lambda I_D$

Degeneración de Emisor – Señal Grande

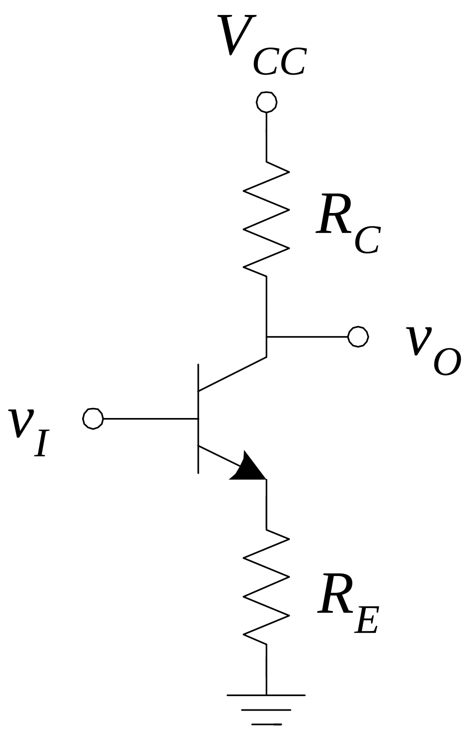


$$i_C = I_S e^{v_{BE}/V_T} \qquad v_{BE} = v_I - (i_C/\alpha)R_E$$

$$i_C e^{(i_C R_E)/(\alpha V_T)} = I_S e^{v_I/V_T} \quad \text{(Ecuación Implícita)}$$

$$v_O = \begin{cases} V_{CC} - i_C R_C & \text{si } i_C(R_E/\alpha + R_C) \le V_{CC} \\ i_C R_E & \text{si } i_C(R_E/\alpha + R_C) > V_{CC} \end{cases}$$

Degeneración de Emisor – Señal Grande (cont.)



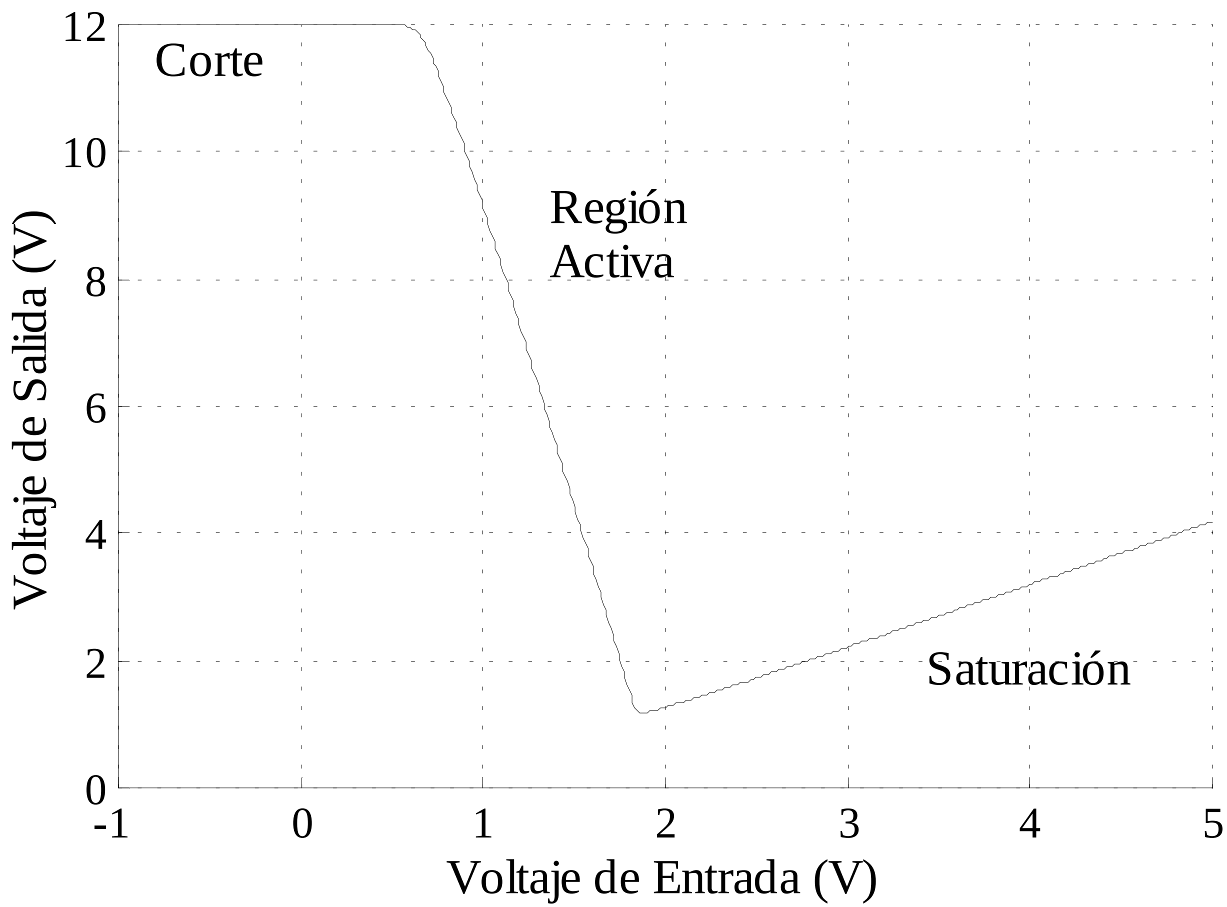
$V_{CC} = 12V$

$R_E = 100\Omega$

$R_C = 1K\Omega$

Q: 2N2222

Simulación en Spice:



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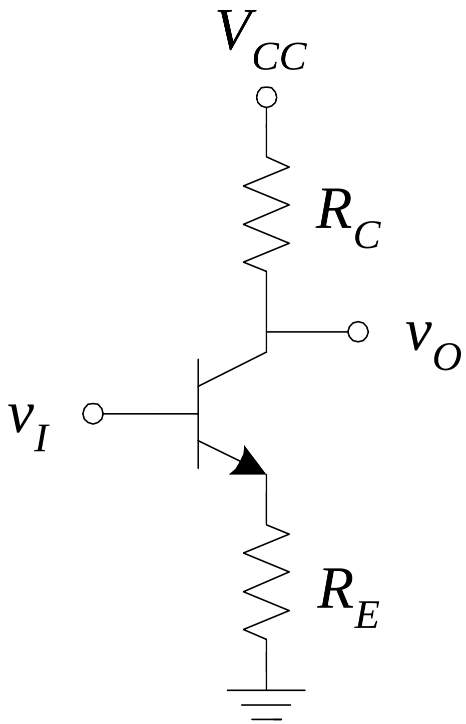
Degeneración de Emisor – Señal Grande (cont.)



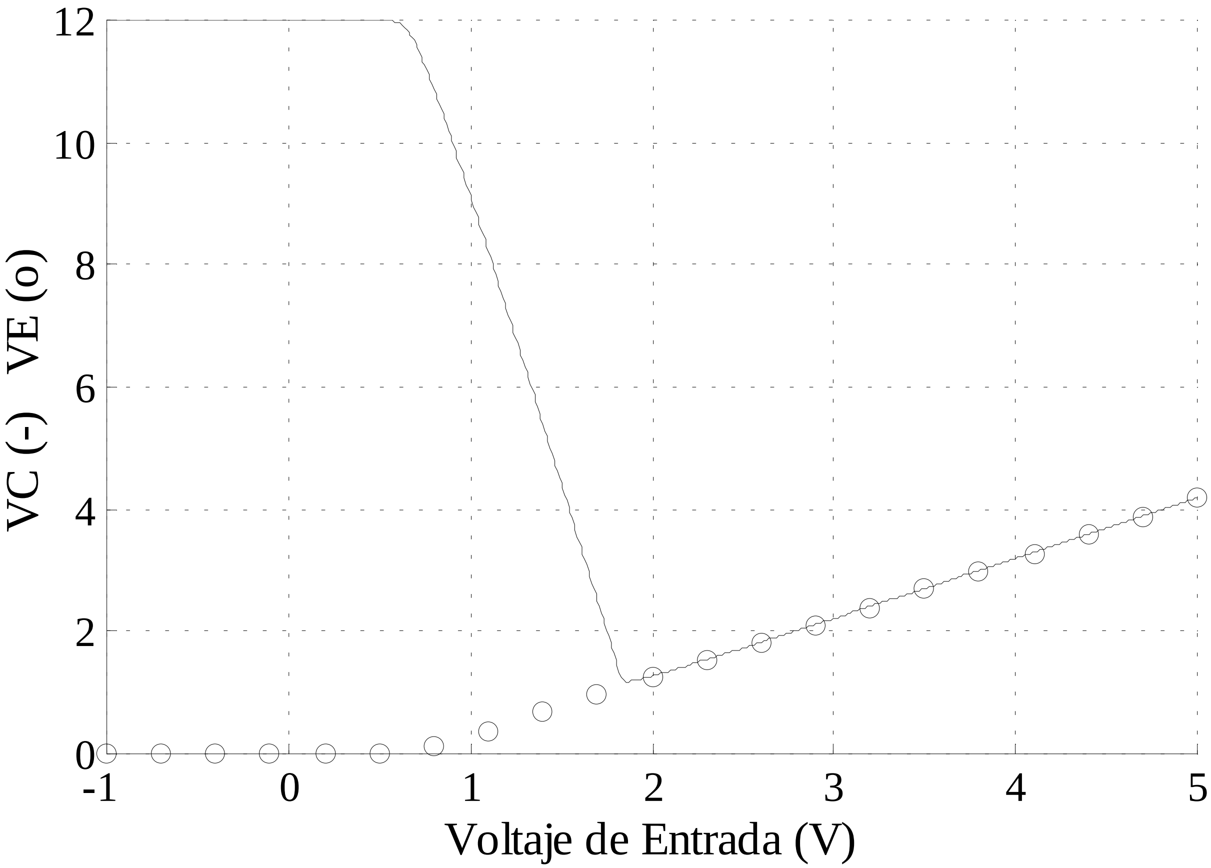
V_{CC} = 12V

R_E = 100Ω

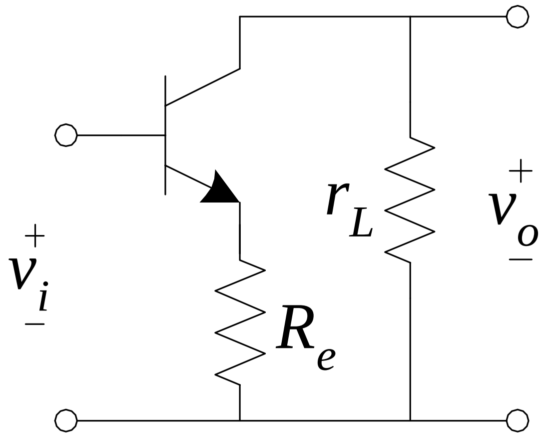
R_C = 1KΩ

Q: 2N2222

Simulación en Spice:



Degeneración de Emisor – Señal Pequeña

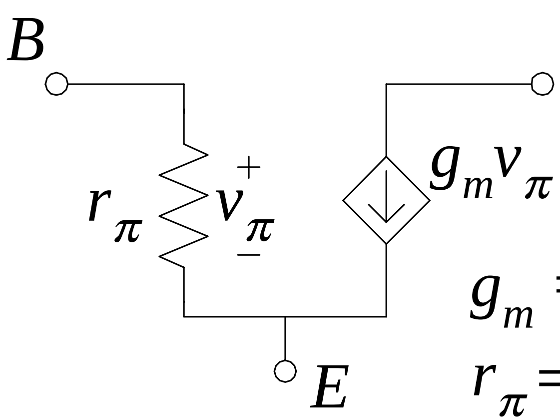


$$v_o = -g_m v_\pi r_L$$

$$v_i = v_\pi + (v_\pi / r_\pi + g_m v_\pi) R_e$$

$$v_i = v_\pi [1 + (1/r_\pi + g_m) R_e] \approx v_\pi (1 + g_m R_e)$$

$$A_v = \frac{v_o}{v_i} = \frac{-g_m r_L}{1 + g_m R_e}$$



$$g_m = I_C / V_T$$

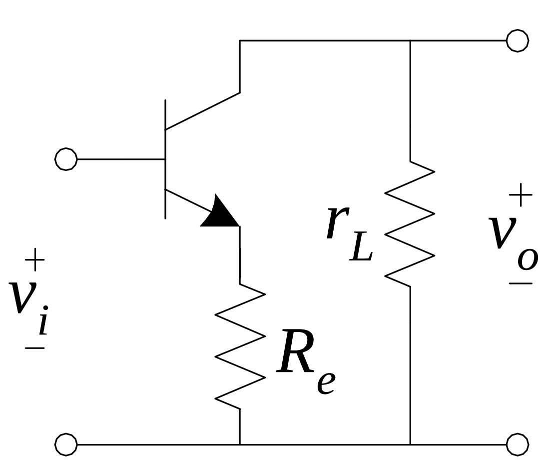
$$r_\pi = \beta / g_m$$

$$i_i = \frac{v_\pi}{r_\pi} \qquad v_i = v_\pi (1 + g_m R_e)$$

$$Z_{in} = \frac{v_i}{i_i} = r_\pi (1 + g_m R_e) = r_\pi + \beta R_e$$

$$A_i = \frac{i_L}{i_i} = \frac{-g_m v_\pi}{v_\pi / r_\pi} = -g_m r_\pi = -\beta$$

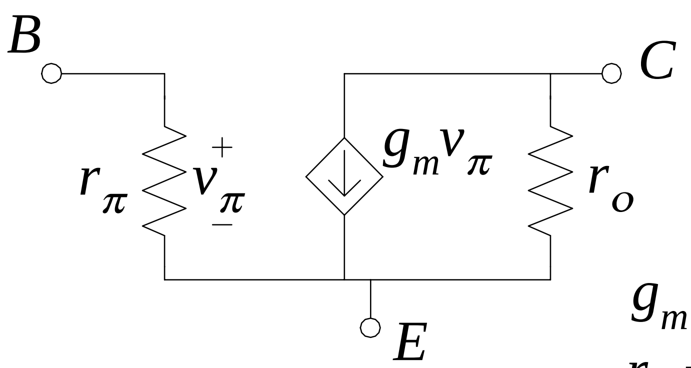
Degeneración de Emisor – Señal Pequeña (cont.)



$$Z_o = \left.\frac{v_o}{-i_o}\right|_{v_i=0}$$

$$v_o = (-i_o - g_m v_\pi) r_o - v_\pi = -i_o r_o - v_\pi (1 + g_m r_o)$$

$$i_o = \frac{v_\pi}{(r_\pi \,||\, R_e)}$$



$$Z_o = r_o + (r_\pi \,||\, R_e)(1 + g_m r_o)$$

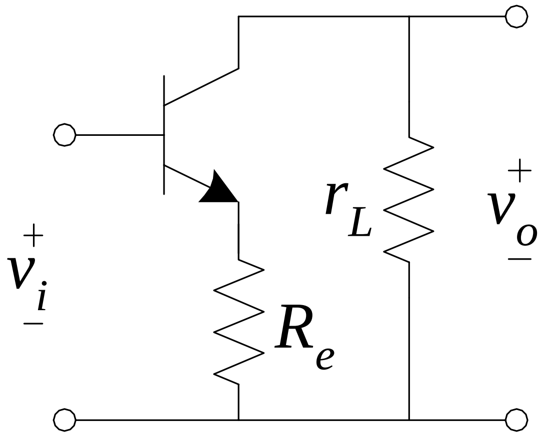
$$Z_o \approx r_o [1 + g_m (r_\pi \,||\, R_e)]$$

$g_m = I_C/V_T$

$r_\pi = \beta/g_m$

$r_o = V_A/I_C$

Degeneración de Emisor – Señal Peq. (resumen)



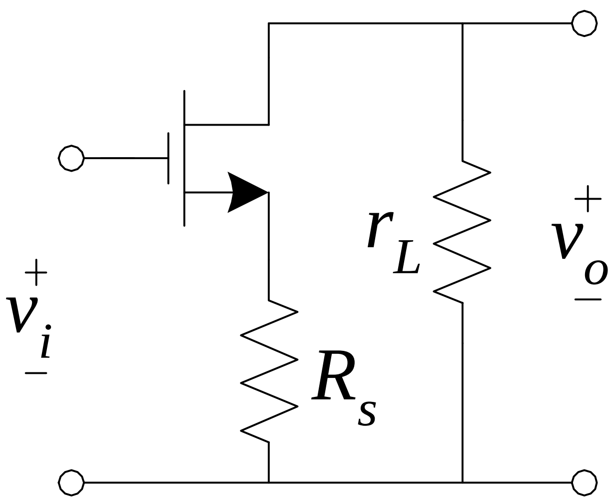
$$A_v = \frac{v_o}{v_i} = \frac{-g_m r_L}{1 + g_m R_e}$$

$$Z_{in} = \frac{v_i}{i_i} = r_\pi + \beta R_e$$

$$A_i = \frac{i_L}{i_i} = -g_m r_\pi = -\beta$$

$$Z_o \approx r_o[1 + g_m(r_\pi \parallel R_e)]$$

Degeneración de Fuente – Señal Pequeña

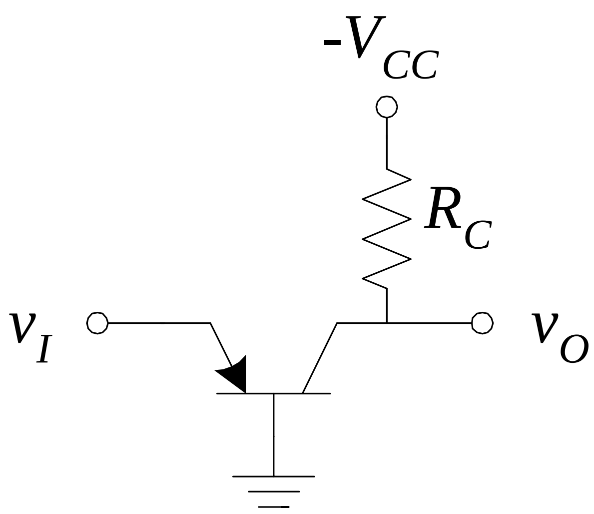


$$A_v = \frac{v_o}{v_i} = \frac{-g_m r_L}{1 + g_m R_s}$$

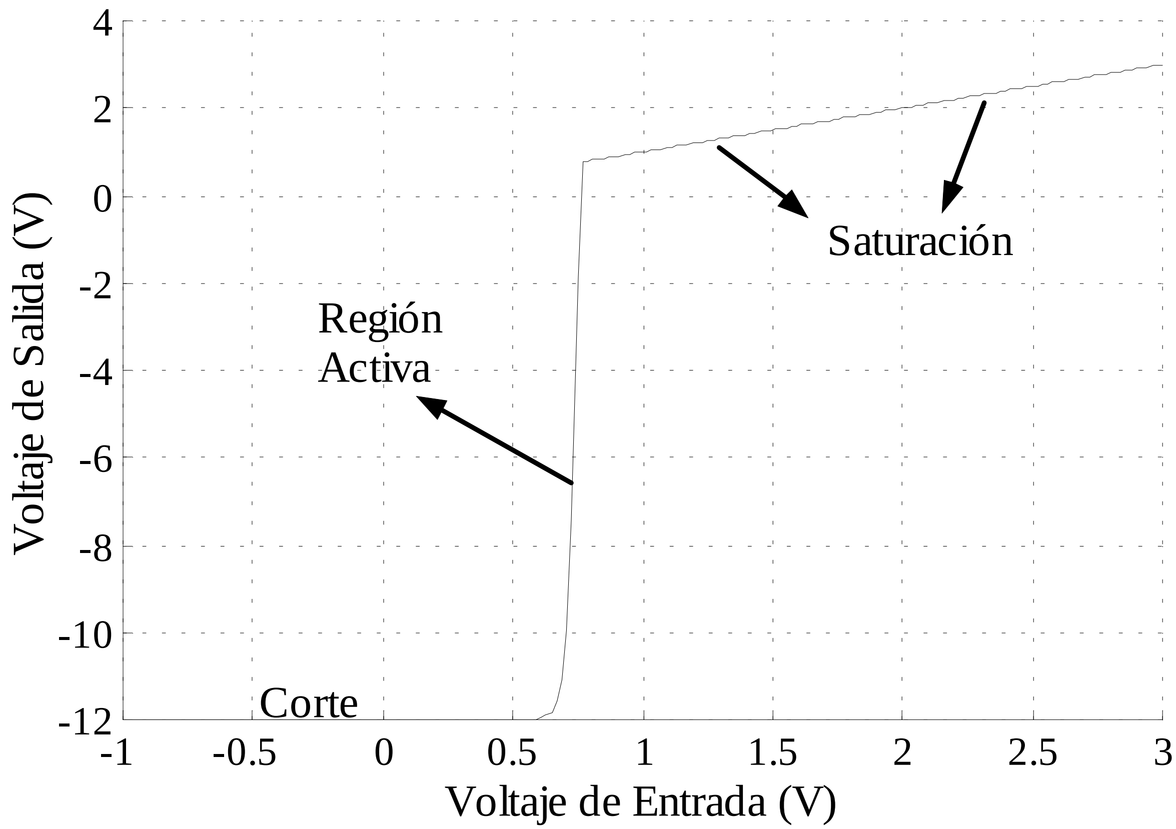
$$Z_{in} = \infty$$

$$Z_o \approx r_o [1 + g_m R_s]$$

Base Común – Señal Grande



$$i_C = I_S e^{v_I/V_T} \quad v_O = \begin{cases} -V_{CC} + i_C R_C & \text{si } v_O \le V_{CB_{on}} \\ v_I & \text{si } v_O > V_{CB_{on}} \end{cases}$$



$V_{CC} = 12\text{V}$

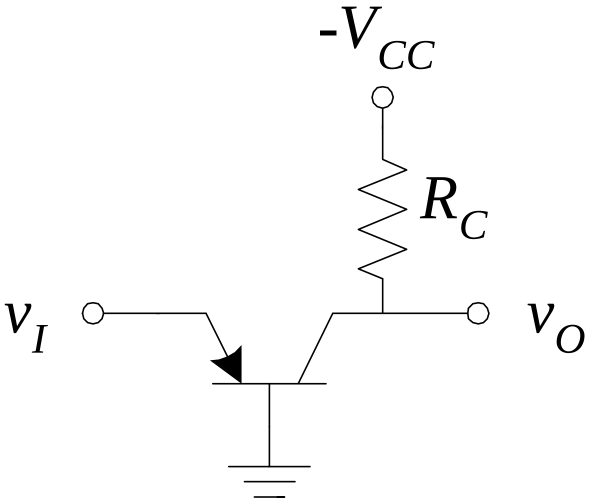
$R_C = 1\text{K}\Omega$

$I_S = 1\times10^{-15}\text{A}$

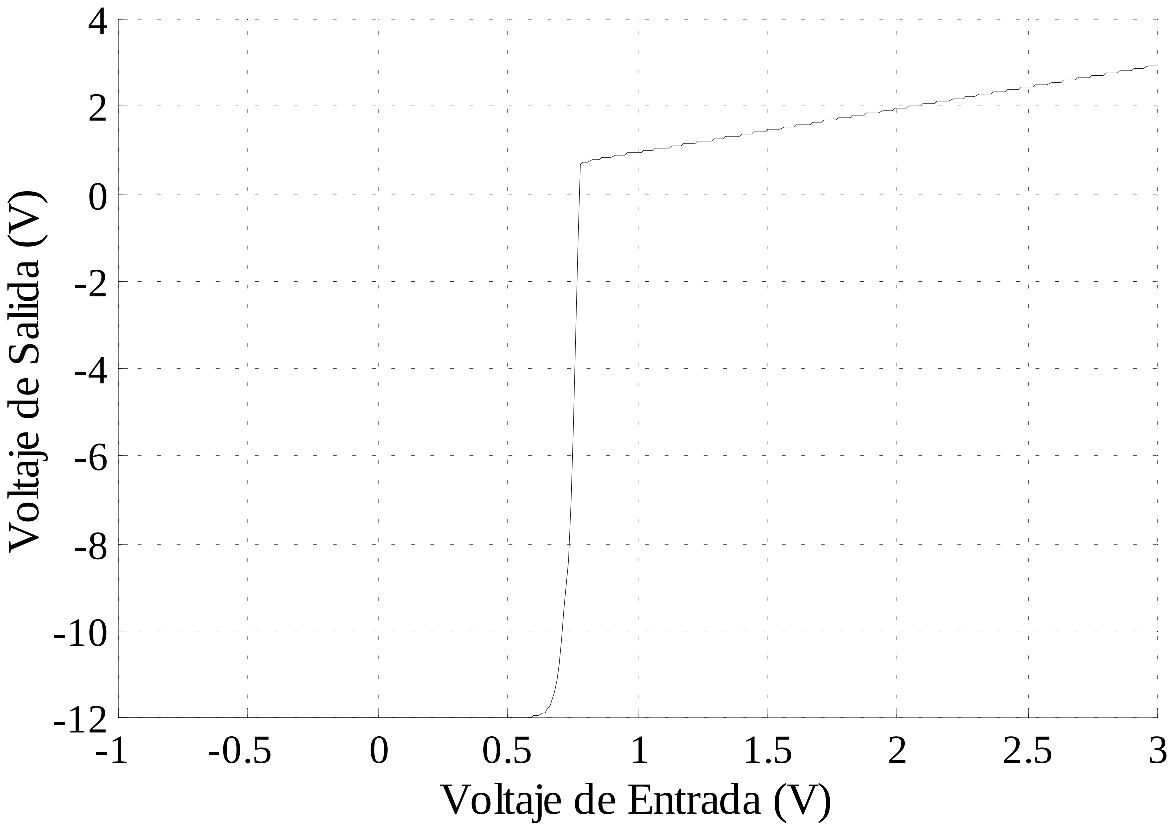
$V_T = 25\text{mV}$

$V_{CBon} = 0.7\text{V}$

Base Común – Señal Grande (cont.)



Simulación en Spice:

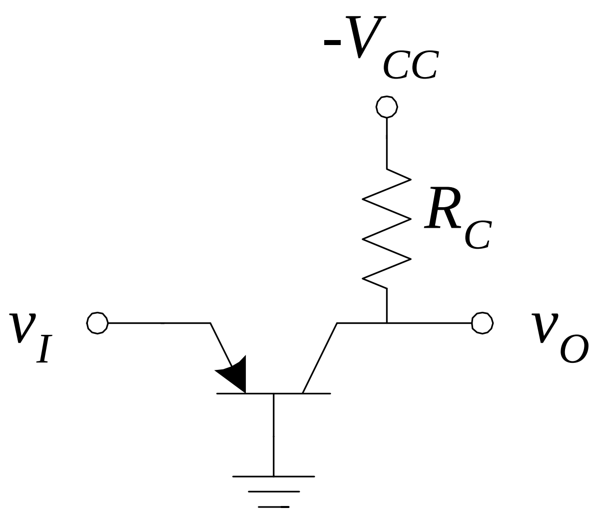


$V_{CC} = 12\text{V}$

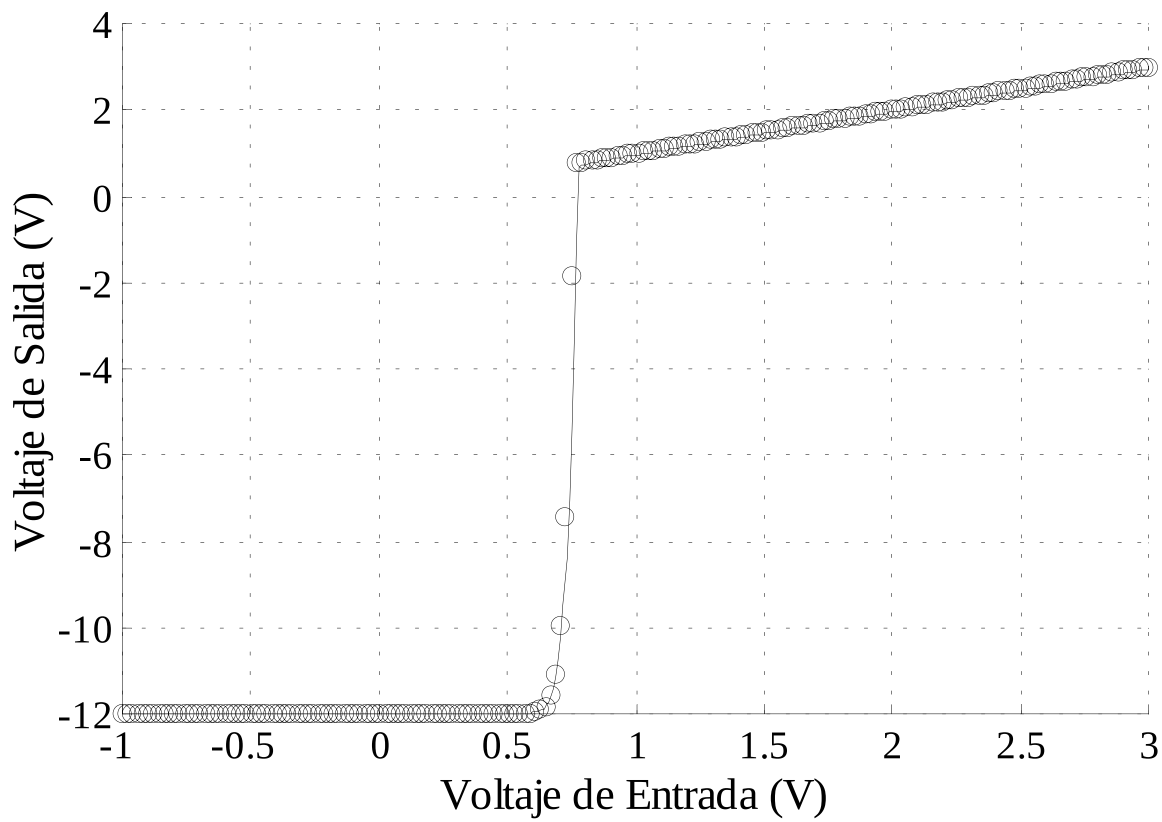
$R_C = 1\text{K}\Omega$

Q : 2N3906

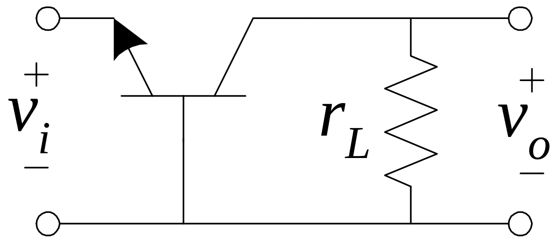
Base Común – Señal Grande (cont.)



Spice (–) VS modelo analítico (o):



Base Común – Señal Pequeña



Se puede demostrar que:

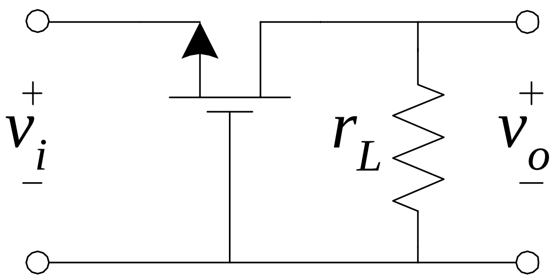
$$A_v = \frac{v_o}{v_i} = g_m r_L$$

$$Z_{in} = r_\pi \parallel \frac{1}{g_m} \approx \frac{1}{g_m}$$

$$A_i = \frac{i_o}{i_i} = \alpha$$

$$Z_o = r_o$$

Compuerta Común – Señal Pequeña



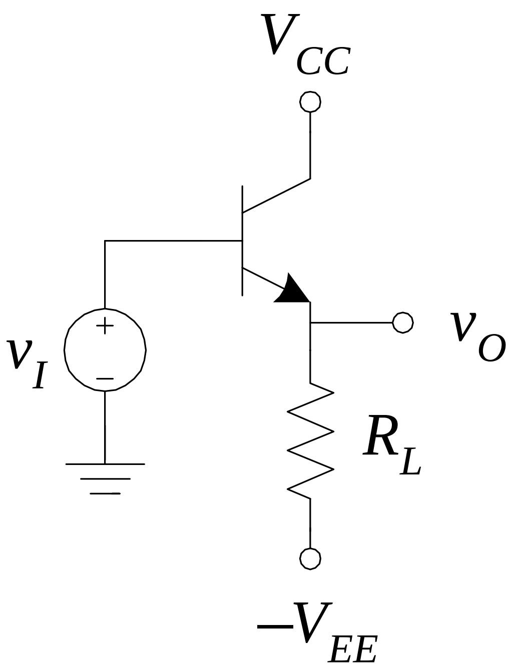
Se puede demostrar que:

$$A_v = \frac{v_o}{v_i} = g_m r_L$$

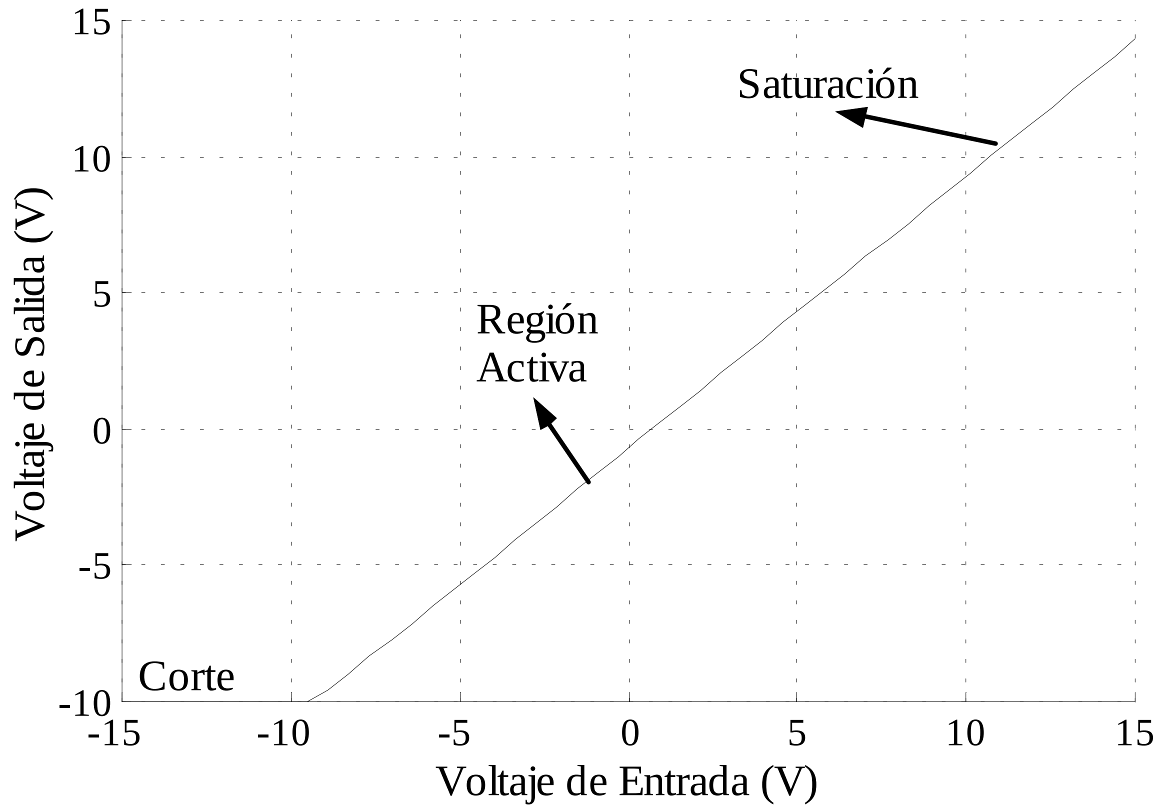
$$Z_{in} = \frac{1}{g_m}$$

$$Z_o = r_o$$

Colector Común – Señal Grande



$$v_O = \begin{cases} v_I - v_{BE} & \text{si } v_I \geq -V_{EE} + 0.7 \\ -V_{EE} & \text{si } v_I < -V_{EE} + 0.7 \end{cases}$$



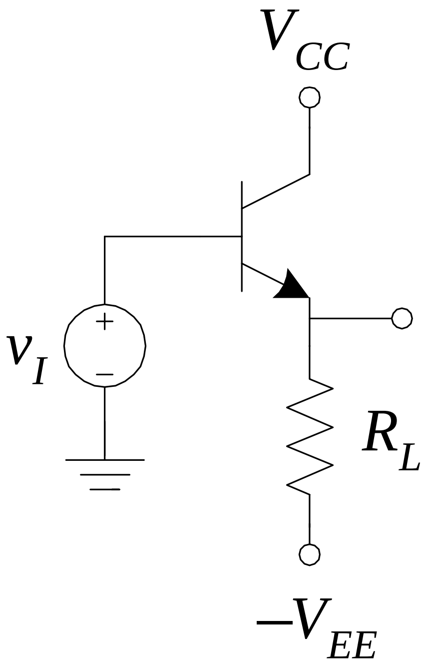
$V_{CC} = 10\text{V}$

$V_{EE} = 10\text{V}$

$R_L = 100\Omega$

$v_{BE} = 0.7\text{V}$

Colector Común – Señal Grande (cont.)



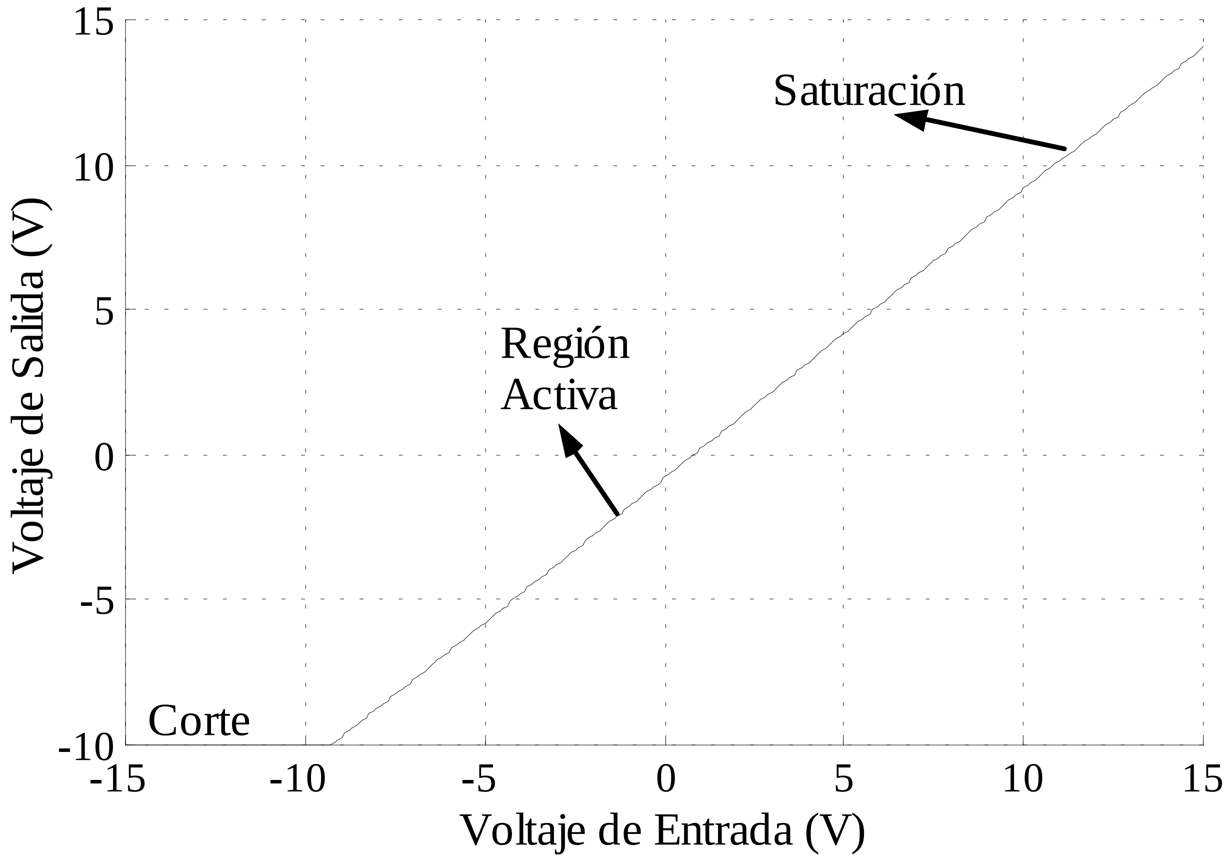
V_{CC} = 10V

V_{EE} = 10V

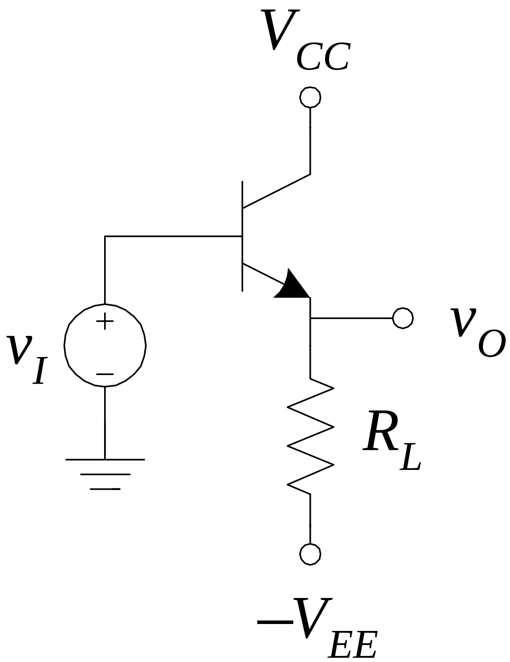
R_L = 100Ω

Q: 2N2222

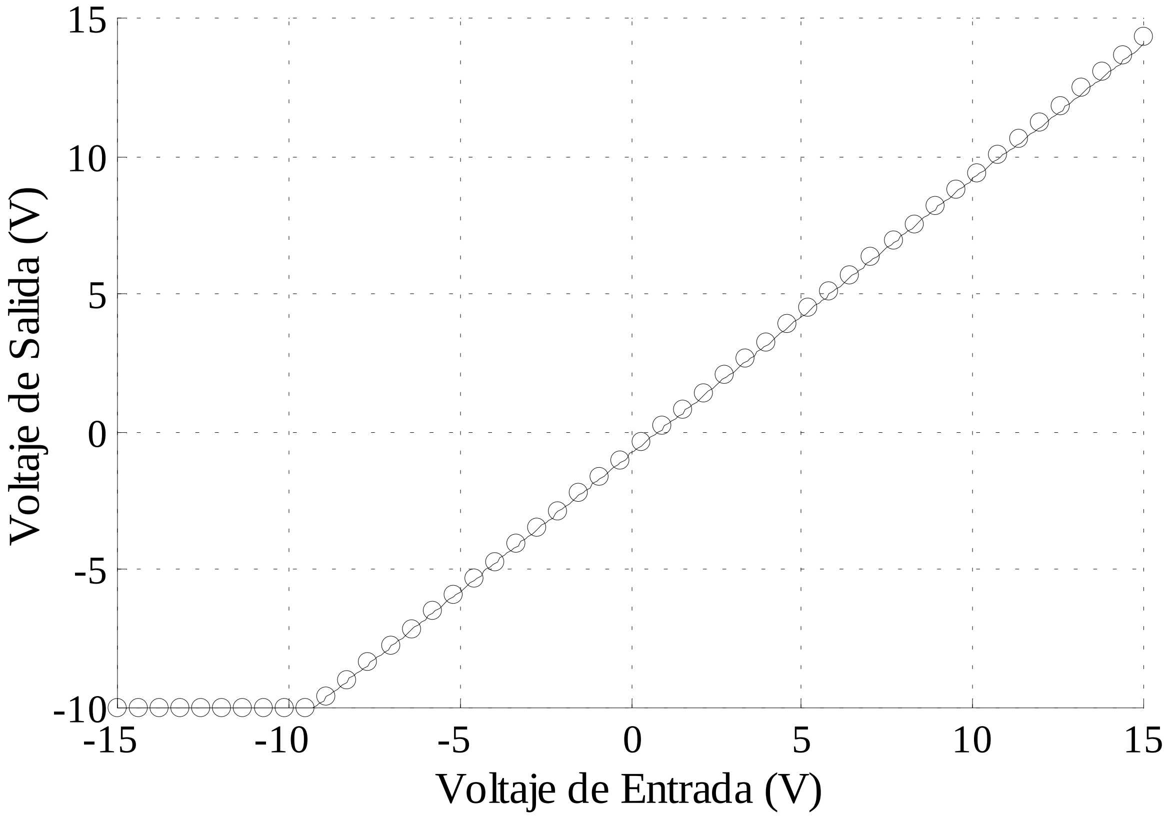
Simulación en Spice:



Colector Común – Señal Grande (cont.)



Spice (–) VS modelo analítico (o):



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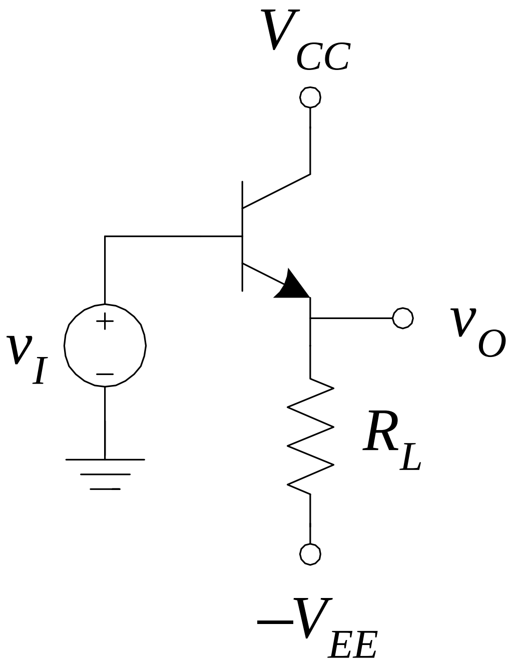
Colector Común – Señal Grande (cont.)



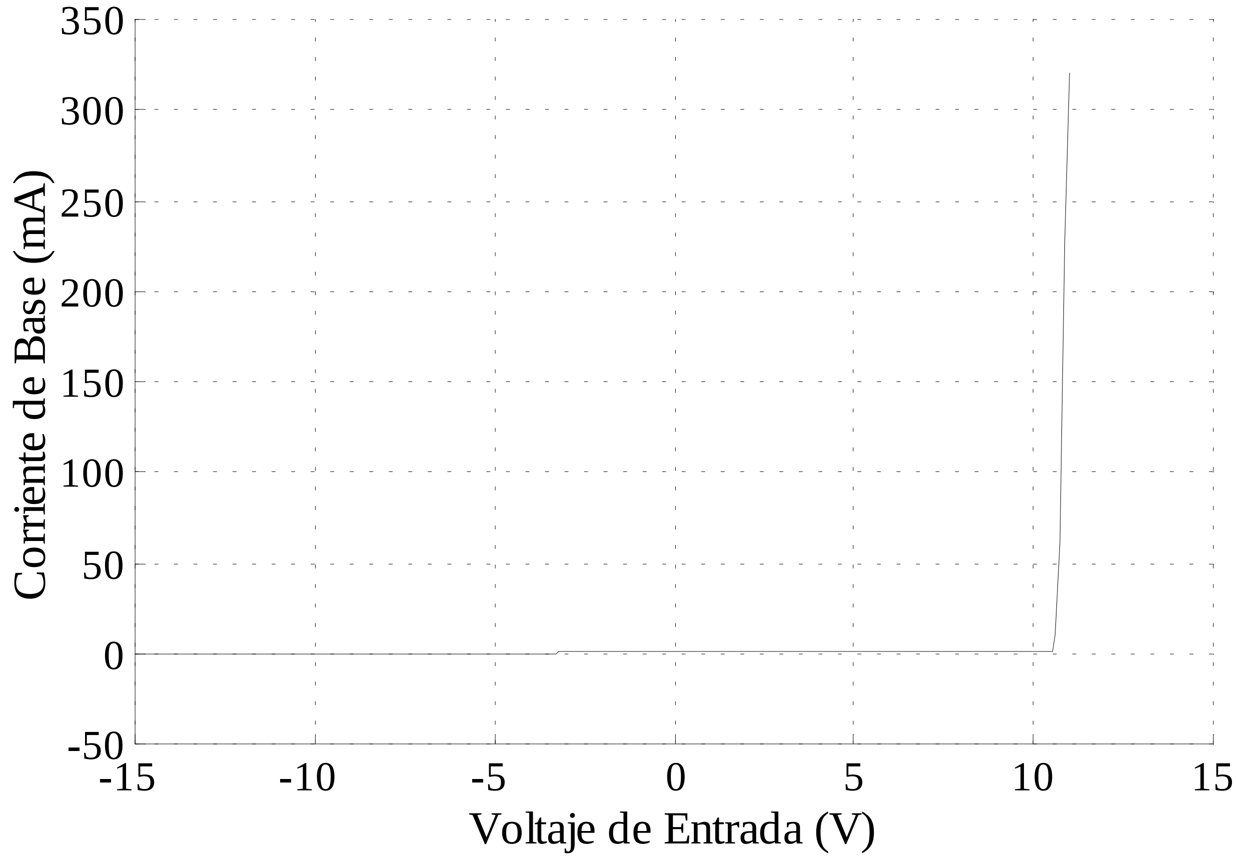
V_{CC} = 10V

V_{EE} = 10V

R_L = 100Ω

Q: 2N2222

Simulación en Spice:



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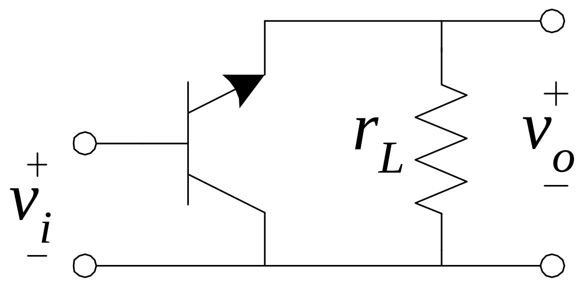
Colector Común – Señal Pequeña



Se puede demostrar que:

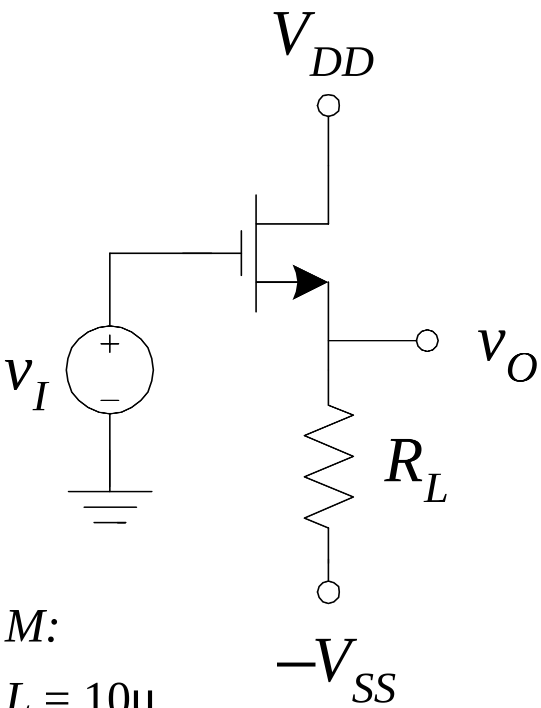
$$Z_{in} = r_\pi + (1+\beta)(r_L \parallel r_o)$$

$$A_v = \frac{(1+\beta)(r_L \parallel r_o)}{r_\pi + (1+\beta)(r_L \parallel r_o)} \approx \frac{g_m r_L}{1+g_m r_L} \approx 1$$

$$A_i = \frac{1+\beta}{1+r_L / r_o}$$

$$Z_o = r_o \parallel \frac{r_\pi}{1+\beta}$$

Drenaje Común – Señal Grande



M:

$L = 10\mu$

$W = 400\mu$

$V_{to} = +2V$

$K_p = 20\mu$

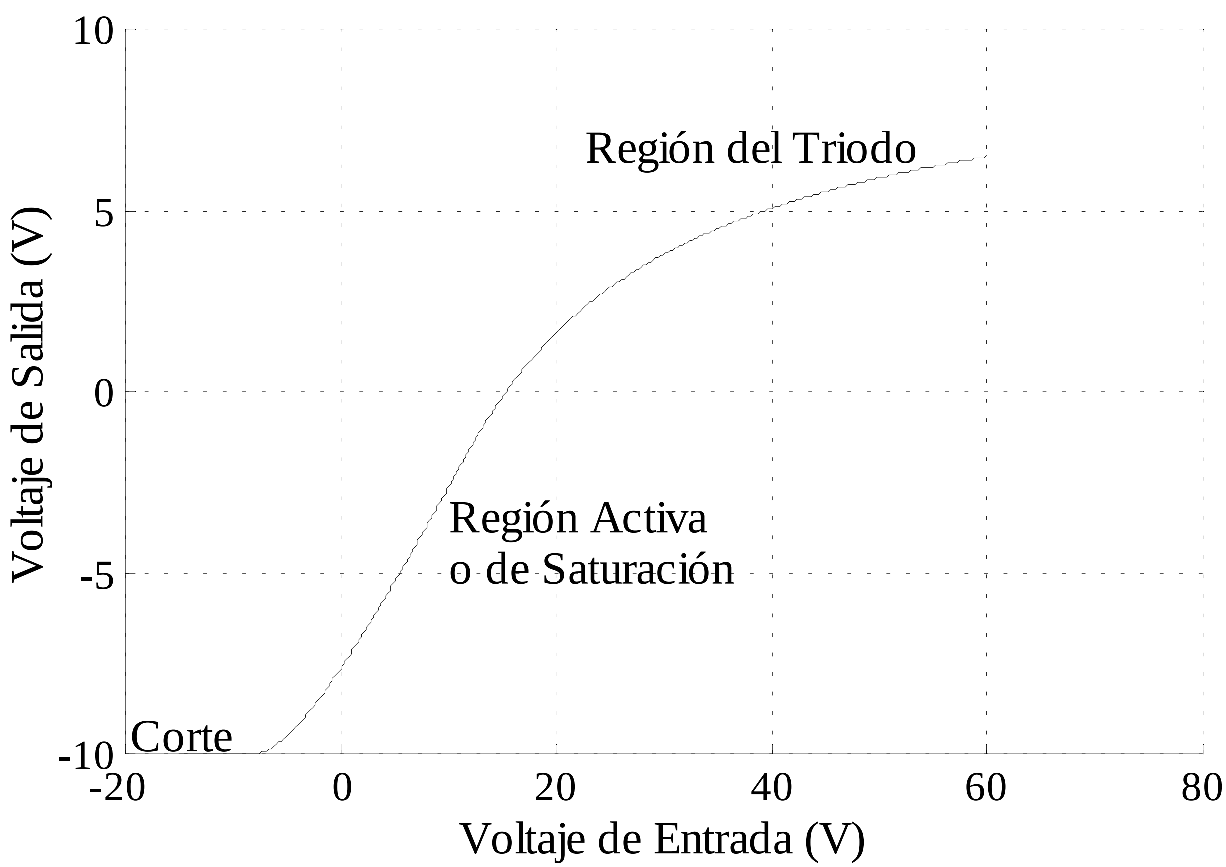
$\lambda = 0.05$

$V_{DD} = 10V$

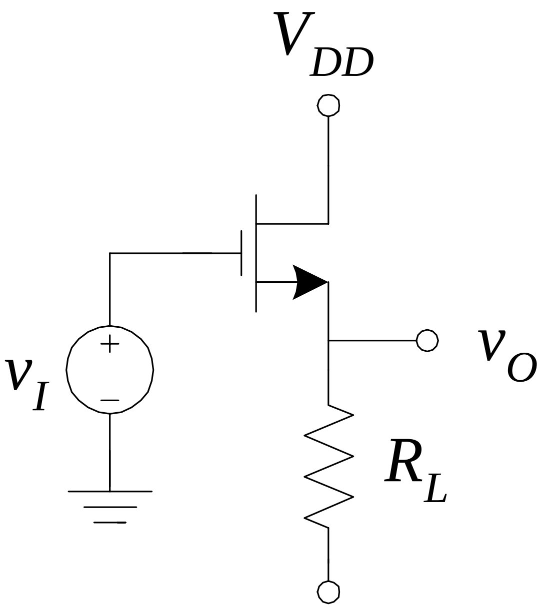
$V_{SS} = 10V$

$R_L = 100\Omega$

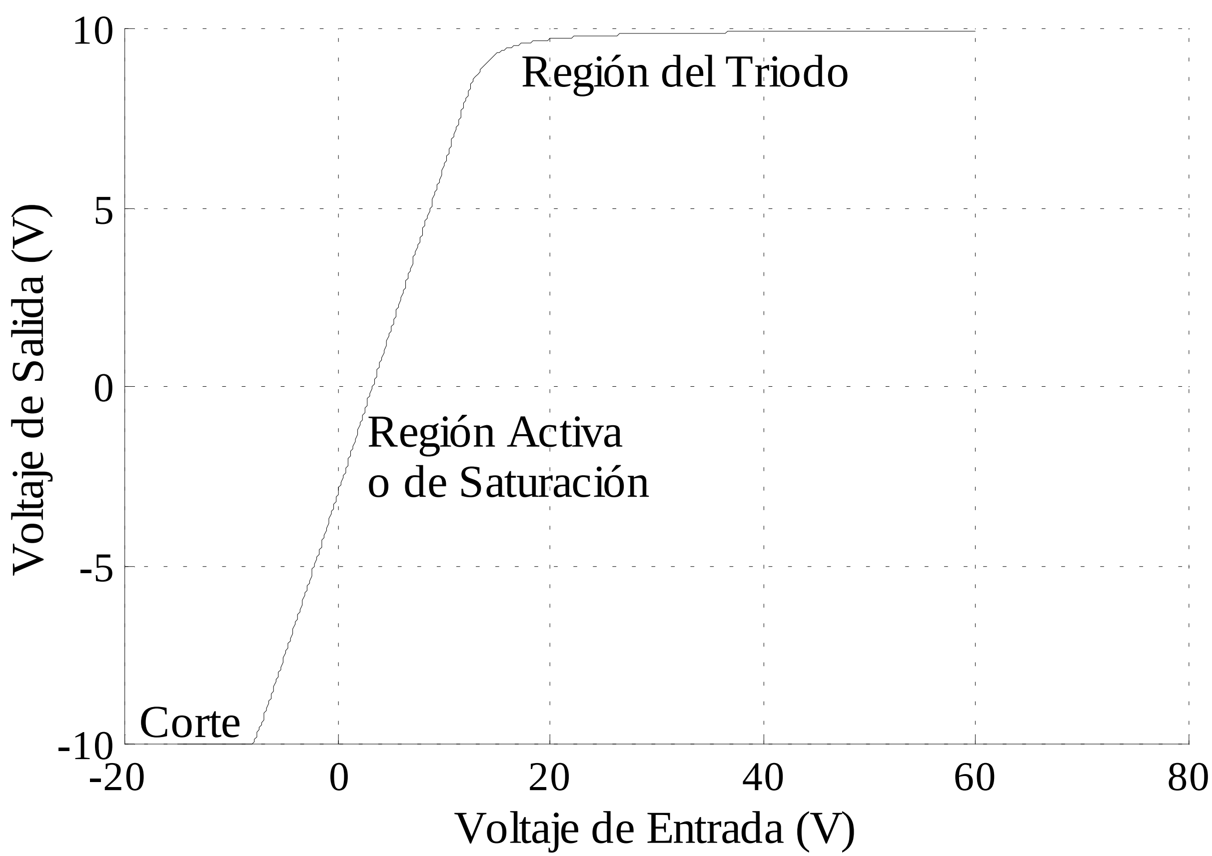
Simulación en Spice:



Drenaje Común – Señal Grande (cont.)



Simulación en Spice:



M:

$L = 10\mu$

$W = 400\mu$

$V_{to} = +2V$

$K_p = 20\mu$

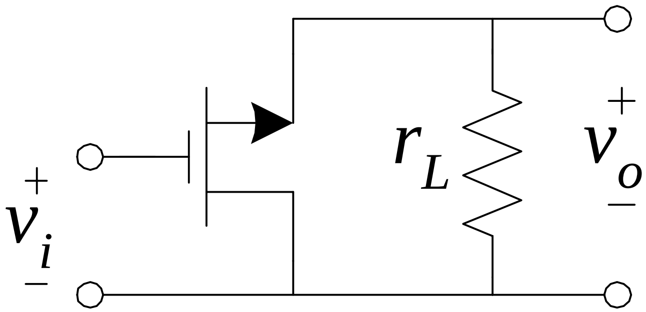
$\lambda = 0.05$

$V_{DD} = 10V$

$V_{SS} = 10V$

$R_L = 10K\Omega$

Drenaje Común – Señal Pequeña



$$A_v = \frac{g_m(r_L \parallel r_o)}{1 + g_m(r_L \parallel r_o)} \approx 1$$

$$Z_{in} = \infty$$

$$Z_o = r_o \parallel \frac{1}{g_m}$$