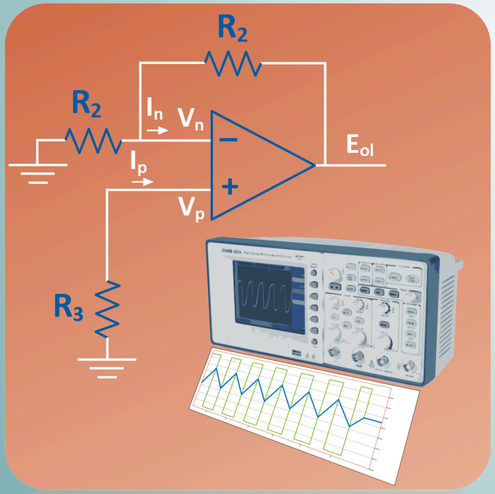
Electrónica Básica

Tema B.3.
Amplificadores Básicos



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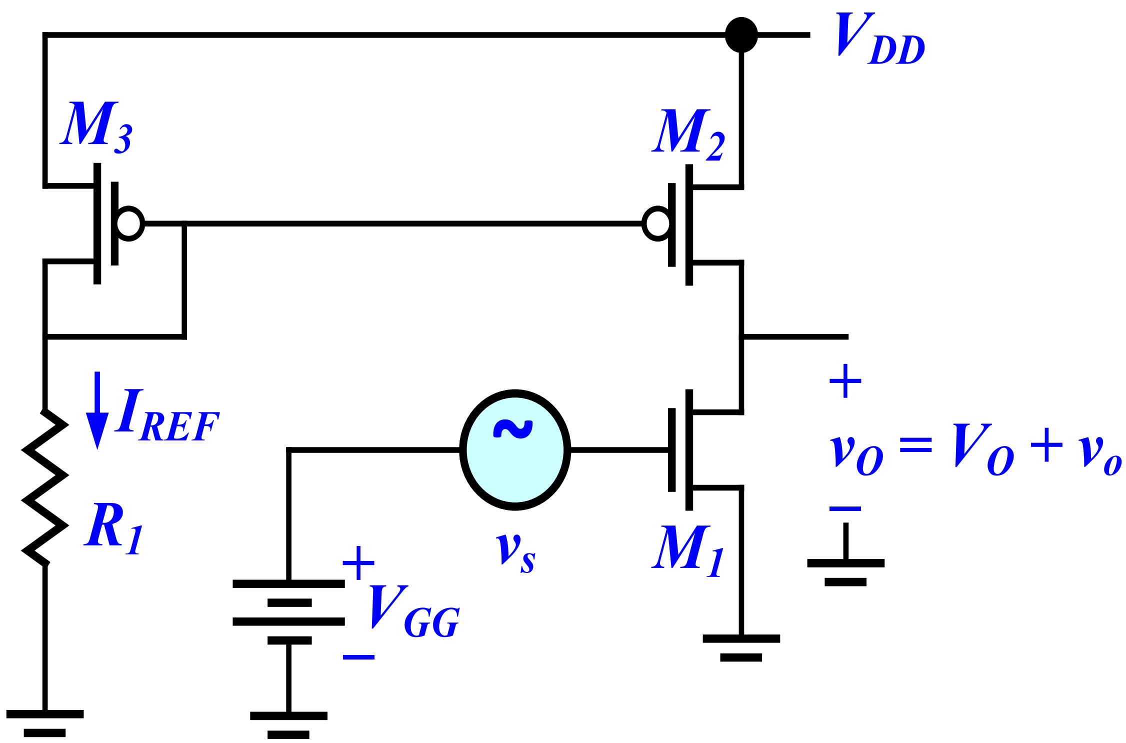
DPTO. DE ELECTRÓNICA Y COMPUTADORES

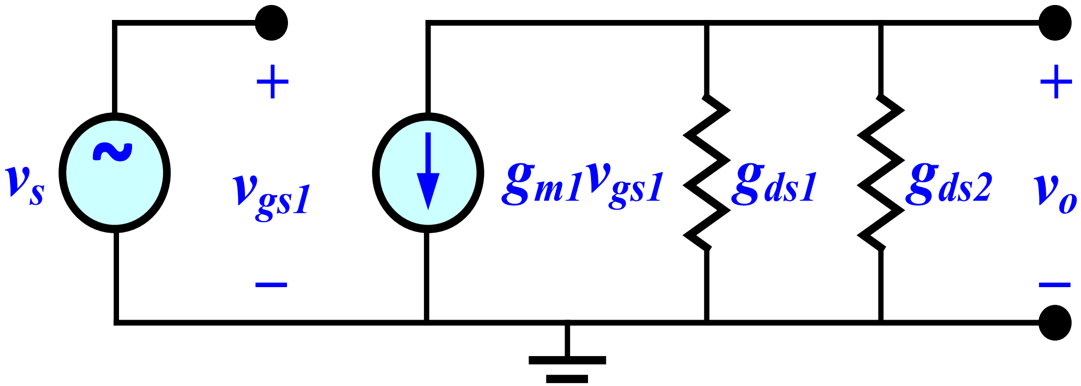
Amplificador Fuente Común

- Amplificador NMOS con fuente de corriente PMOS:



Amplificador Fuente Común

- Circuito equivalente de pequeña señal:

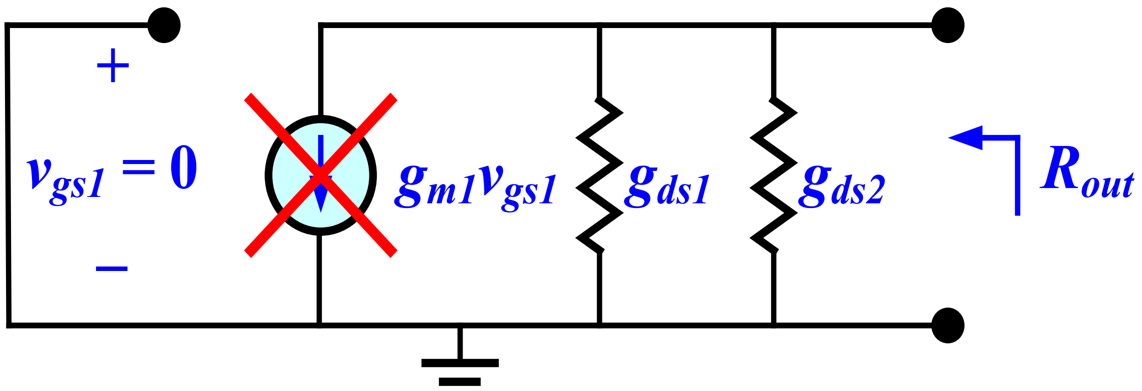


- Ganancia de tensión:

$$A_v = \frac{v_o}{v_s} = \frac{-g_{m1}}{g_{ds1} + g_{ds2}}$$

Amplificador Fuente Común

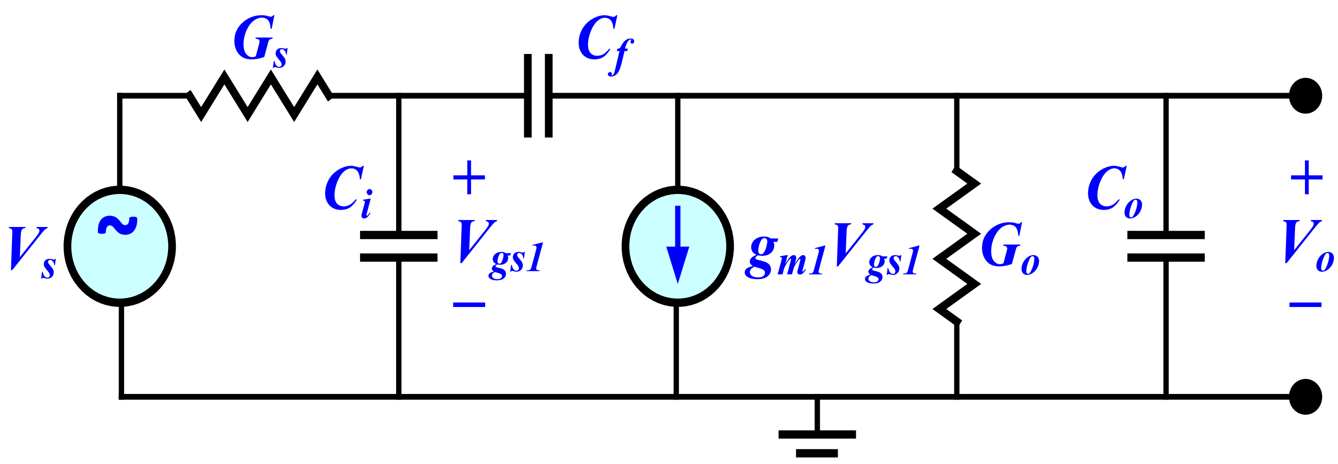
- Resistencia de salida:



$$R_{out} = \frac{1}{g_{ds1} + g_{ds2}}$$

Amplificador Fuente Común

- Circuito de pequeña señal en alta frecuencia:

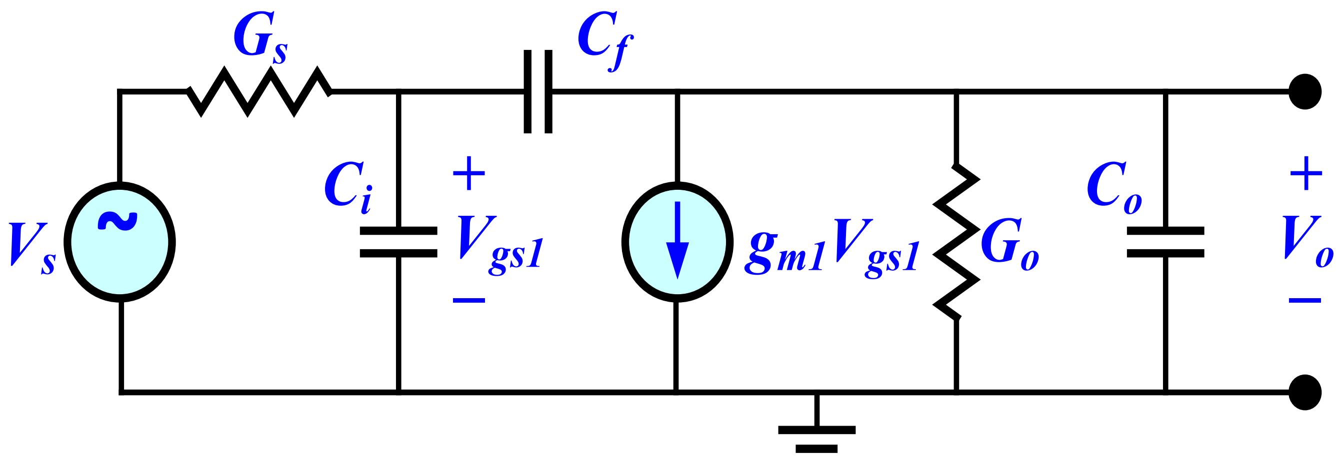


$$G_o = g_{ds1} + g_{ds2} \quad , \quad C_i = C_{gs1} + C_{gb1}$$

$$C_f = C_{gd1} \quad , \quad C_o = C_{gd2} + C_{db1} + C_{db2}$$

Amplificador Fuente Común

- Respuesta en alta frecuencia:



$$\frac{V_o(s)}{V_s(s)} = \frac{R_o\left(sC_f - g_{m1}\right)}{b_2 s^2 + b_1 s + 1}$$

$$b_2 = R_s R_o \left(C_i C_o + C_i C_f + C_o C_f\right)$$

$$b_1 = R_s\left(1 + g_{m1} R_o\right) C_f + R_s C_i + R_o\left(C_o + C_f\right)$$

Amplificador Fuente Común

- Aproximación de polo dominante:

$$D(s) = b_2 s^2 + b_1 s + 1 = \left(1 - \frac{s}{p_1}\right)\left(1 - \frac{s}{p_2}\right) = \frac{s^2}{p_1 p_2} - s\left(\frac{1}{p_1} + \frac{1}{p_2}\right) + 1$$

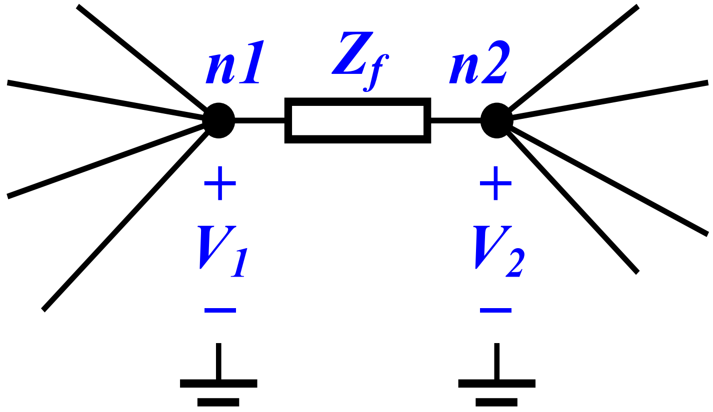
$$|p_2| >> |p_1| \quad \Rightarrow \quad D(s) \cong \frac{s^2}{p_1 p_2} - \frac{s}{p_1} + 1$$

$$p_1 ; \quad -\frac{1}{b_1} = -\frac{1}{R_s\left(1 + g_{m1} R_o\right) C_f + R_s C_i + R_o\left(C_o + C_f\right)}$$

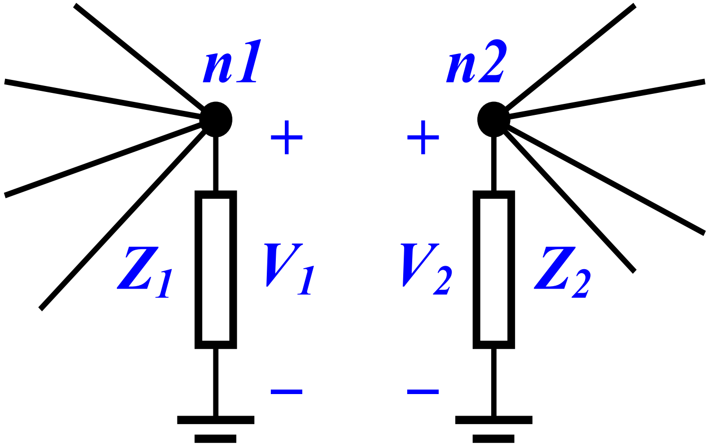
$$p_2 ; \quad -\frac{b_1}{b_2} = -\frac{R_s\left(1 + g_{m1} R_o\right) C_f + R_s C_i + R_o\left(C_o + C_f\right)}{R_s R_o\left(C_i C_o + C_i C_f + C_o C_f\right)}$$

Teorema de Miller

- Circuito general con una impedancia flotante:



- Equivalente Miller:

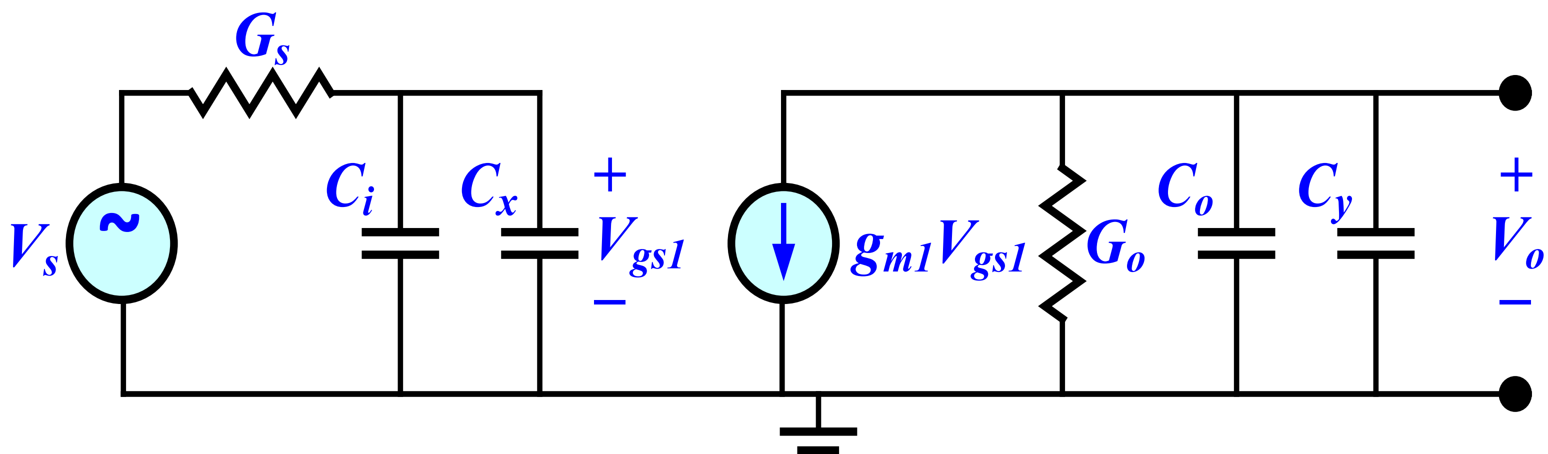


$$\frac{V_1 - V_2}{Z_F} = \frac{V_1}{Z_1} \rightarrow Z_1 = \frac{Z_F}{1 - A_v}$$

$$\frac{V_1 - V_2}{Z_F} = -\frac{V_2}{Z_2} \rightarrow Z_2 = \frac{Z_F}{1 - \frac{1}{A_v}}$$

Amplificador Fuente Común

- Aproximación Miller:



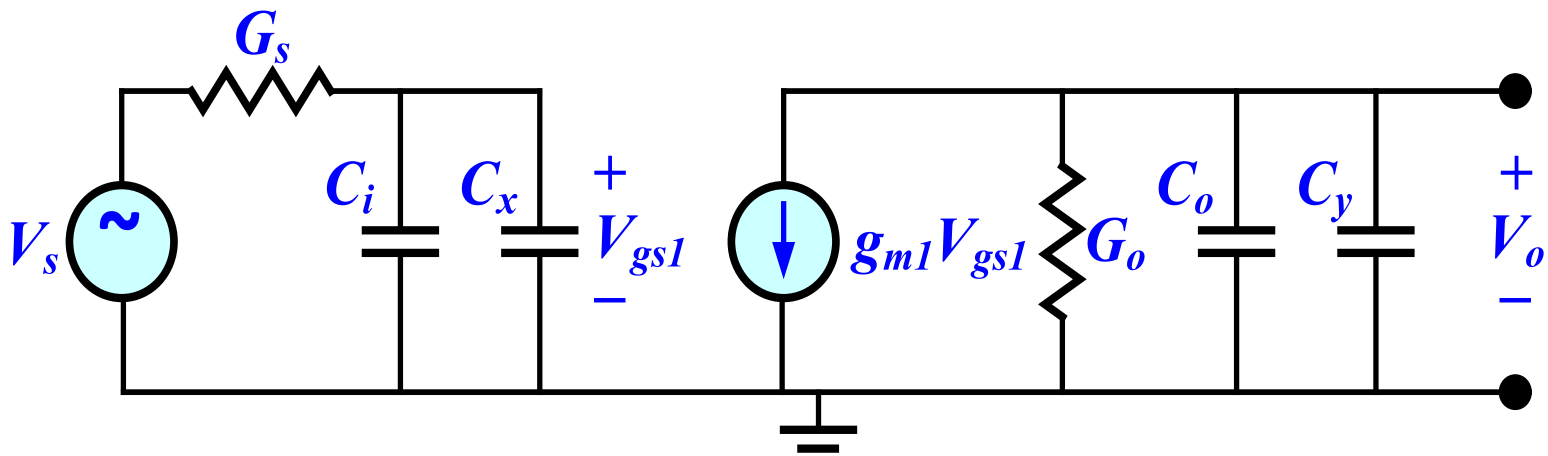
$$A_v(s) = \frac{V_o(s)}{V_{gs1}(s)} \quad ; \quad A_{v0} = A_v(s)\Big|_{s\to 0} = -g_{m1}R_o$$

$$C_x \; ; \; (1 - A_{v0})C_f = (1 + g_{m1}R_o)C_f$$

$$C_y \; ; \; \left(1 - \frac{1}{A_{v0}}\right)C_f = \left(1 + \frac{1}{g_{m1}R_o}\right)C_f$$

Amplificador Fuente Común

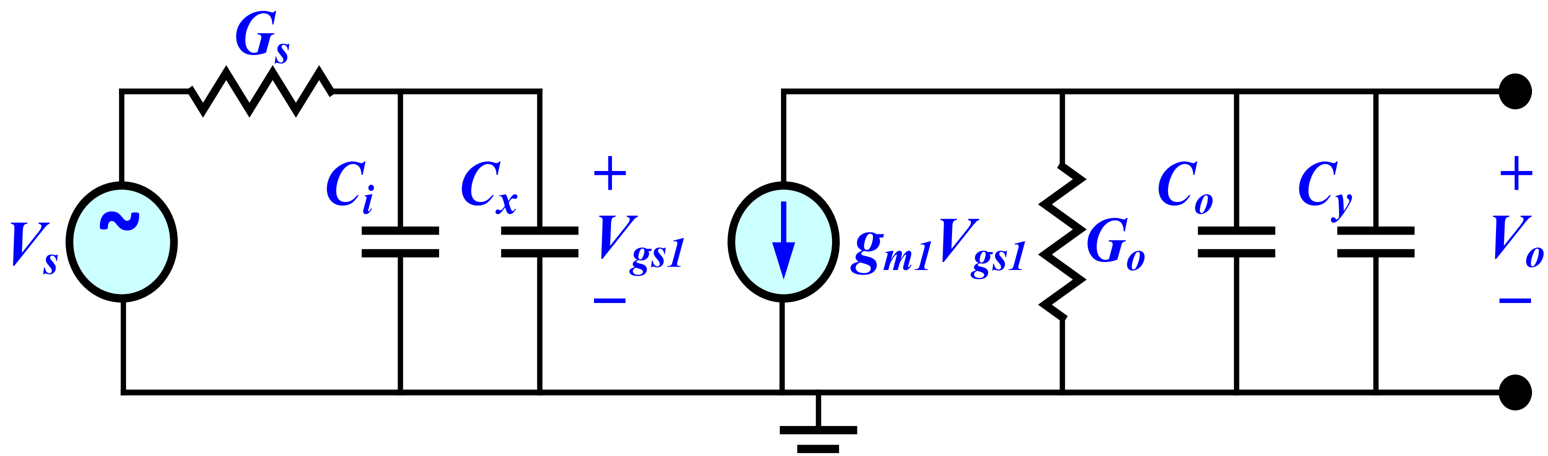
- Aproximación Miller:



$$\frac{V_o(s)}{V_s(s)} = \frac{-g_{m1}R_o}{\left(1+R_s\left(C_i+C_x\right)s\right)\left(1+R_o\left(C_o+C_y\right)s\right)}$$

Amplificador Fuente Común

- Aproximación Miller:

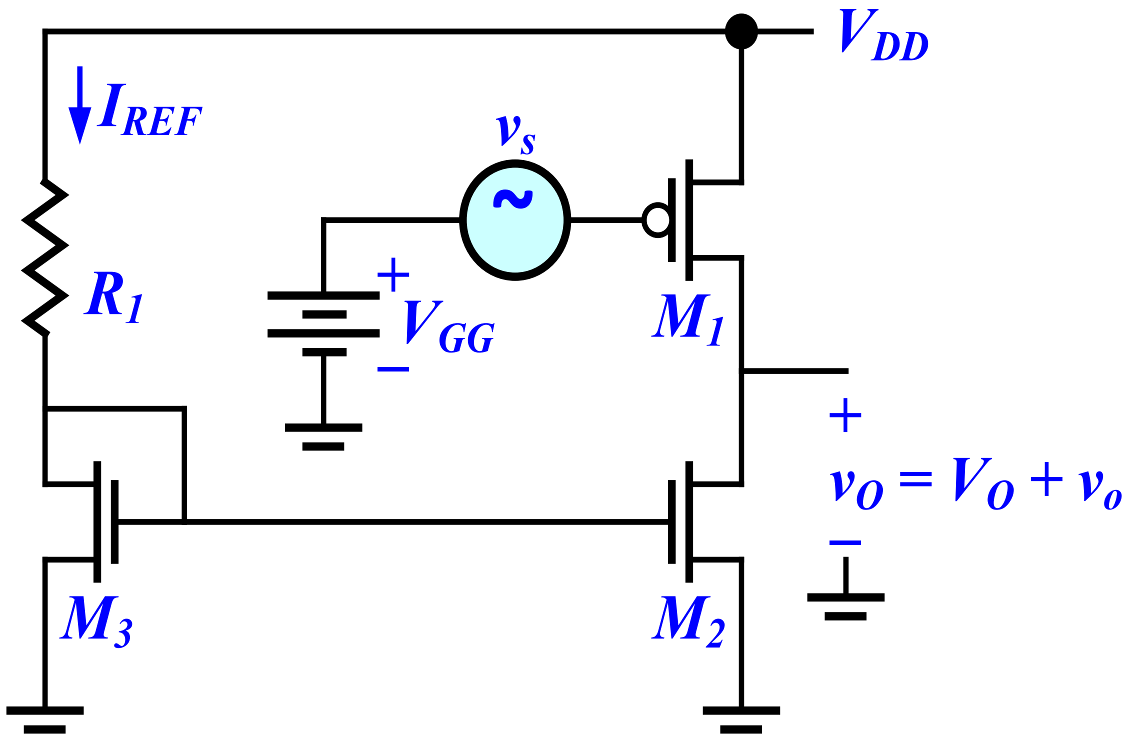


$$p_1 = -\frac{1}{R_s C_i + R_s \left(1 + g_{m1} R_o\right) C_f}$$

$$p_2 = -\frac{1}{R_o C_o + R_o \left(1 + \frac{1}{g_{m1} R_o}\right) C_f}$$

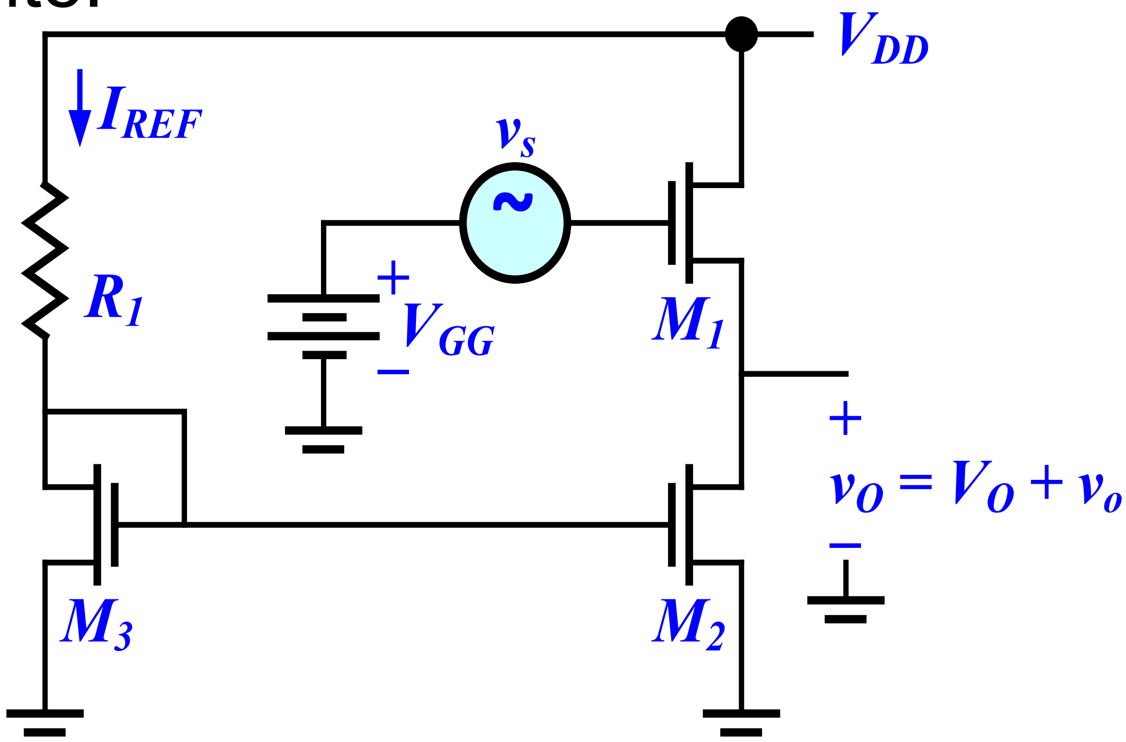
Amplificador Fuente Común

- Amplificador PMOS con fuente de corriente NMOS:



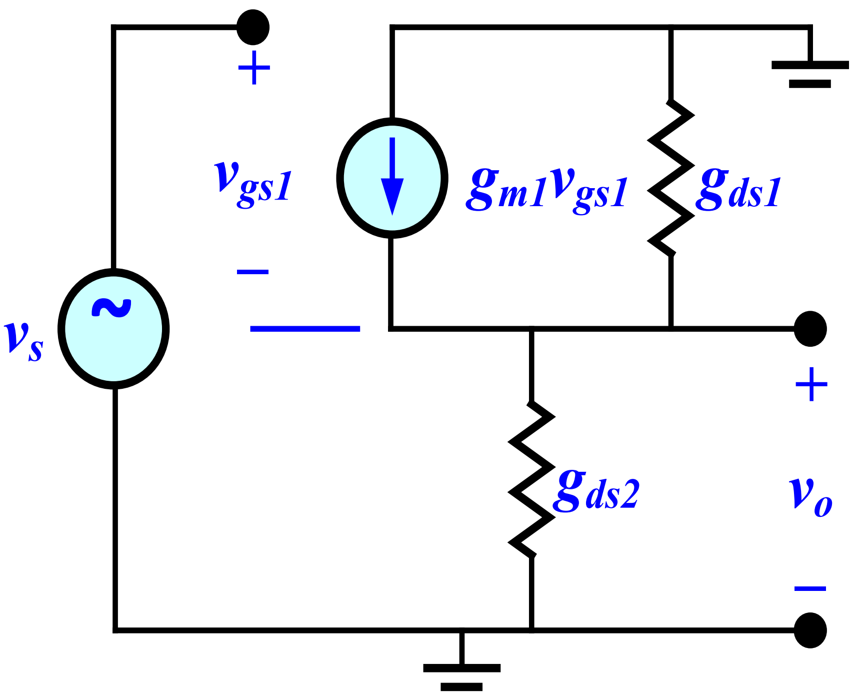
Seguidor de Fuente

- Seguidor de fuente NMOS con fuente de corriente:



Seguidor de Fuente

- Circuito equivalente de pequeña señal:



$$v_{gs1} = v_s - \frac{g_{m1}v_{gs1}}{g_{ds1} + g_{ds2}}$$

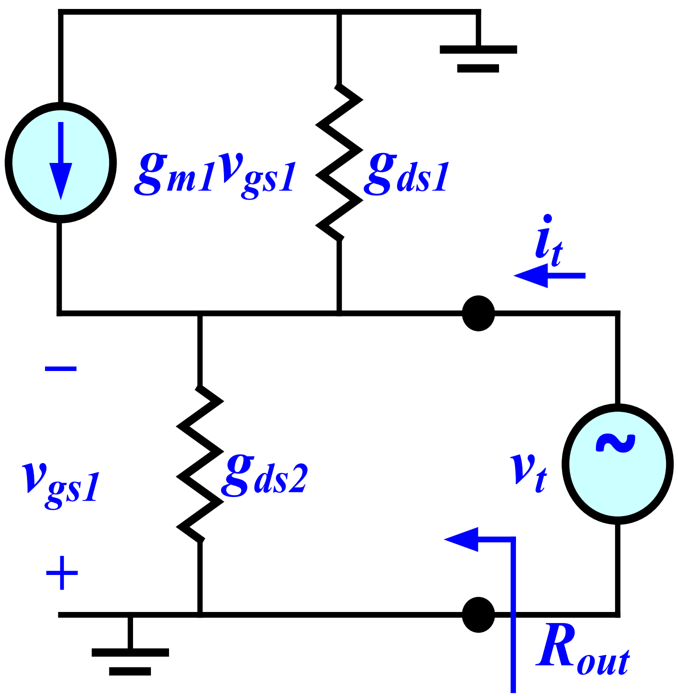
$$v_{gs1} = \frac{g_{ds1} + g_{ds2}}{g_{m1} + g_{ds1} + g_{ds2}} v_s$$

$$v_o = \frac{g_{m1}v_{gs1}}{g_{ds1} + g_{ds2}}$$

- Ganancia de tensión: $A_v = \dfrac{v_o}{v_s} = \dfrac{g_{m1}}{g_{m1} + g_{ds1} + g_{ds2}}$

Seguidor de Fuente

- Resistencia de salida de pequeña señal:



$$i_t = \left(g_{ds1} + g_{ds2}\right) v_t - g_{m1} v_{gs1}$$

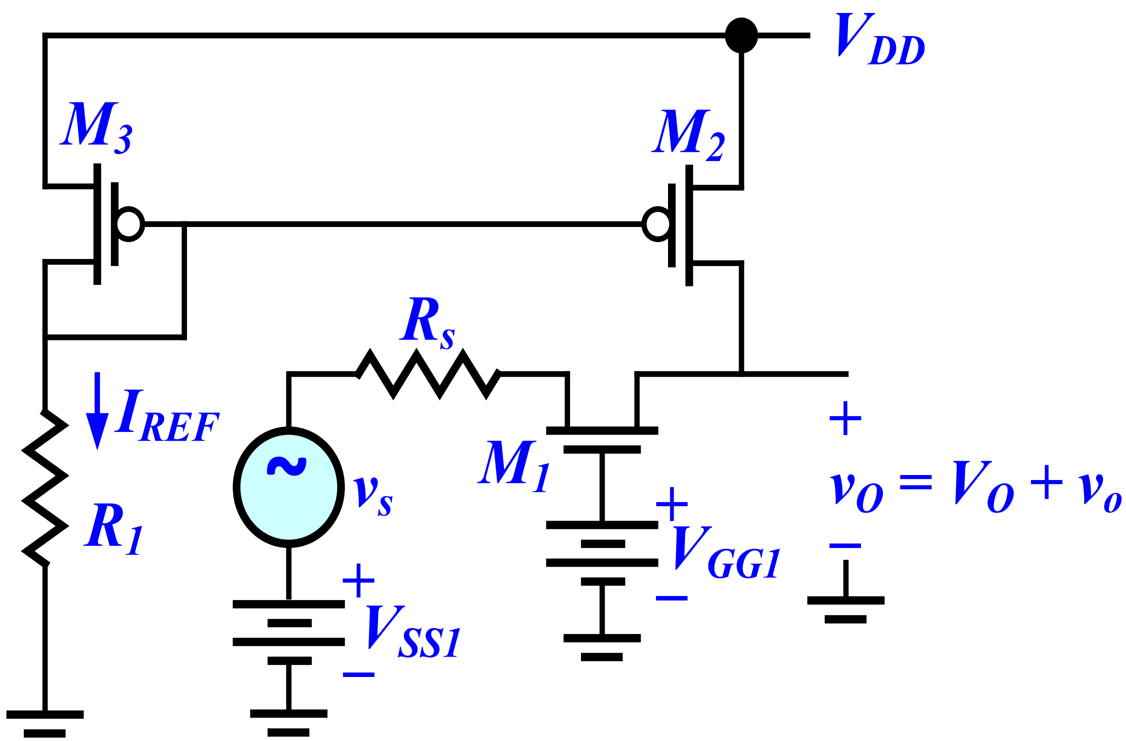
$$i_t = \left(g_{m1} + g_{ds1} + g_{ds2}\right) v_t$$

$$R_{out} = \frac{v_t}{i_t} = \frac{1}{g_{m1} + g_{ds1} + g_{ds2}}$$

$$R_{out} \; ; \; \frac{1}{g_{m1}}$$

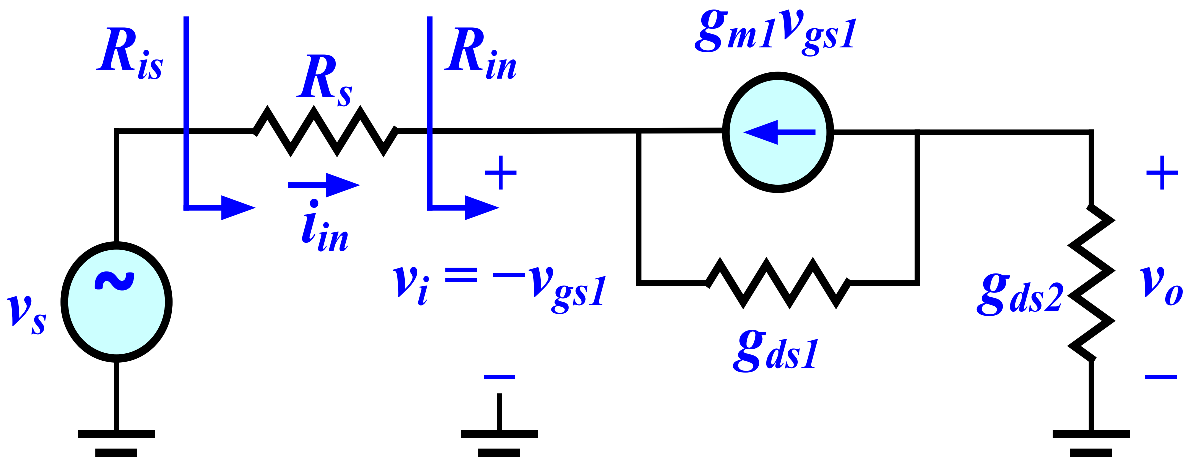
Amplificador Puerta Común

- Amplificador puerta común NMOS con fuente de corriente PMOS:



Amplificador Puerta Común

- Circuito equivalente de pequeña señal:



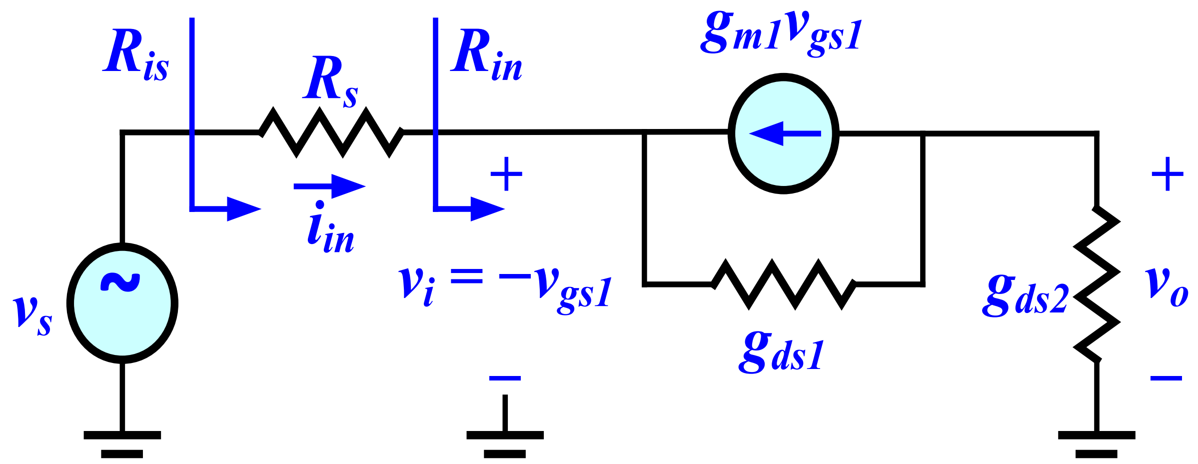
$$-v_o g_{ds2} = g_{m1} v_{gs1} + g_{ds1}\left(v_o + v_{gs1}\right)$$

$$\left(g_{m1} + g_{ds1}\right) v_i = \left(g_{ds1} + g_{ds2}\right) v_o$$

- Ganancia de tensión: $A_v = \dfrac{v_o}{v_i} = \dfrac{g_{m1} + g_{ds1}}{g_{ds1} + g_{ds2}}$

Amplificador Puerta Común

- Resistencia de entrada:

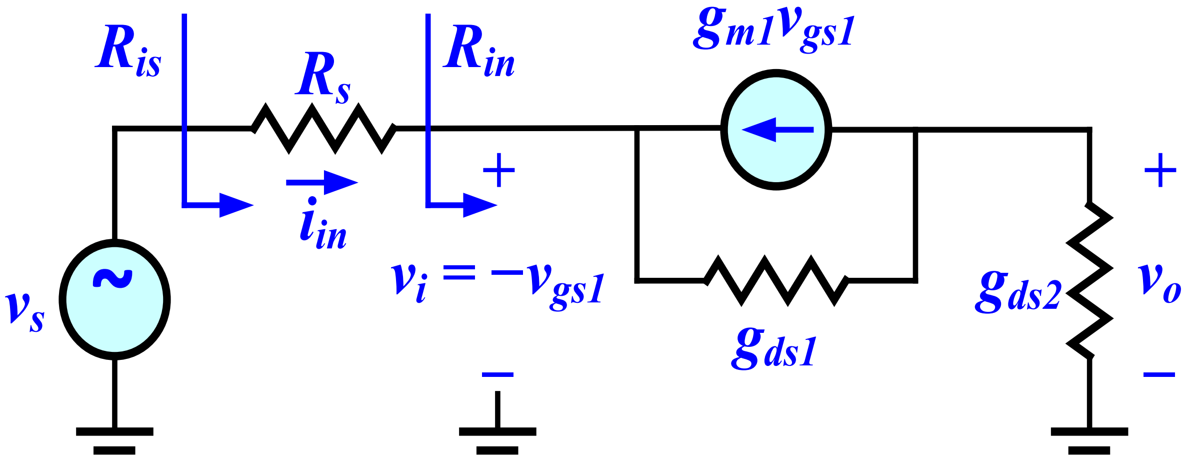


$$i_{in} = g_{m1}v_{in} + g_{ds1}(1 - A_v)v_{in} \quad \Rightarrow \quad R_{in} = \frac{v_{in}}{i_{in}} = \frac{g_{ds1} + g_{ds2}}{(g_{m1} + g_{ds1})g_{ds2}}$$

$$R_{is} = \frac{v_s}{i_{in}} = R_s + \frac{g_{ds1} + g_{ds2}}{(g_{m1} + g_{ds1})g_{ds2}}$$

Amplificador Puerta Común

- Ganancia de tensión respecto de la fuente v_s:

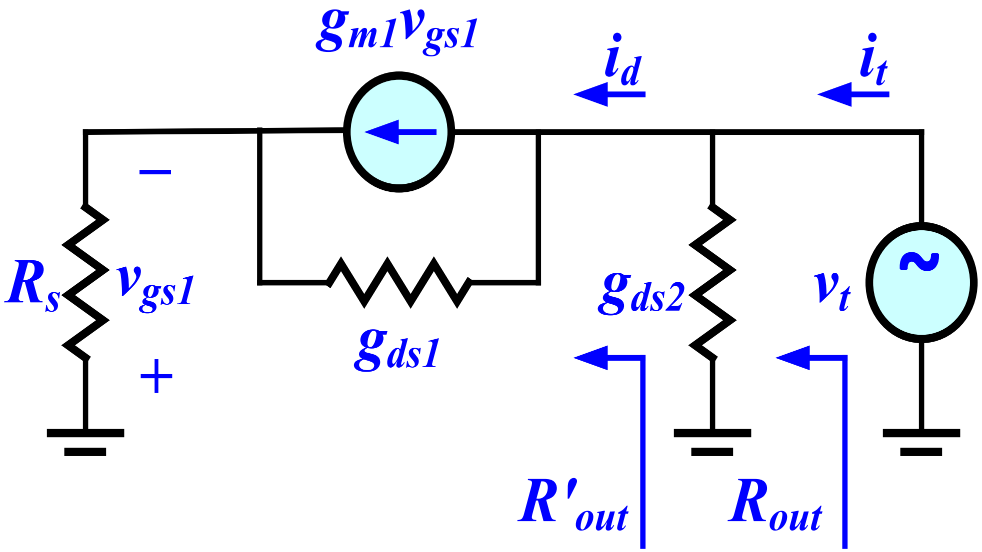


$$v_o = i_{in}\frac{1}{g_{ds2}} = \frac{v_s}{R_{is}}\frac{1}{g_{ds2}} = v_s\frac{g_{m1}+g_{ds1}}{g_{ds1}+g_{ds2}+g_{ds2}\left(g_{m1}+g_{ds1}\right)R_s}$$

$$A_{vs} = \frac{v_o}{v_s} = \frac{g_{m1}+g_{ds1}}{g_{ds1}+g_{ds2}+g_{ds2}\left(g_{m1}+g_{ds1}\right)R_s}$$

Amplificador Puerta Común

- Resistencia de salida:



$$i_d = g_{m1}v_{gs1} + g_{ds1}\left(v_t + v_{gs1}\right)$$

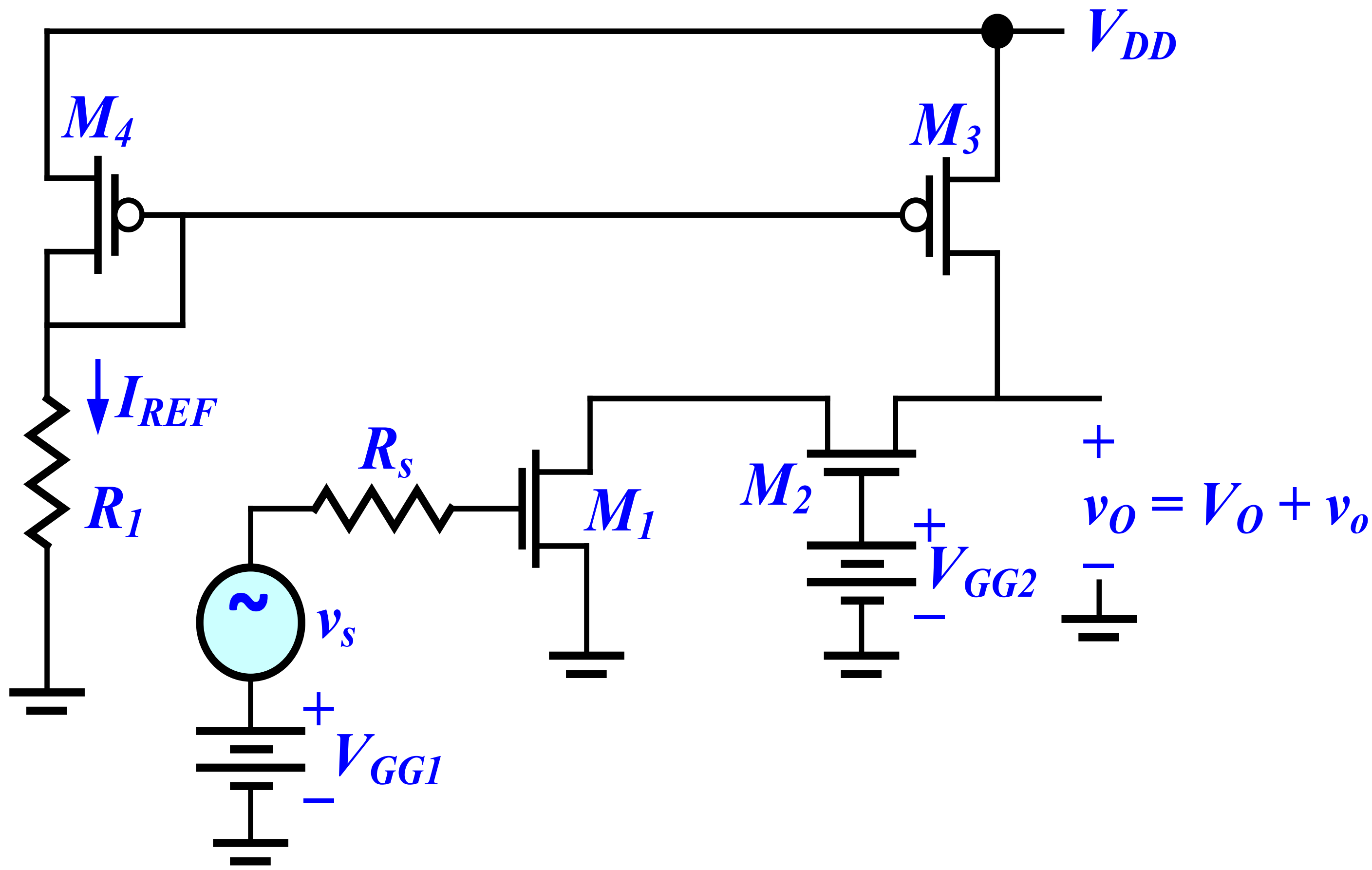
$$v_{gs1} = -R_s i_d$$

$$g_{ds1}v_t = \left(1 + g_{m1}R_s + g_{ds1}R_s\right)i_d$$

$$R'_{out} = \frac{v_t}{i_d} = g_{ds1}^{-1}\left(1 + g_{m1}R_s\right) + R_s \qquad R_{out} = \frac{v_t}{i_t} = g_{ds2}^{-1} \parallel R'_{out}$$

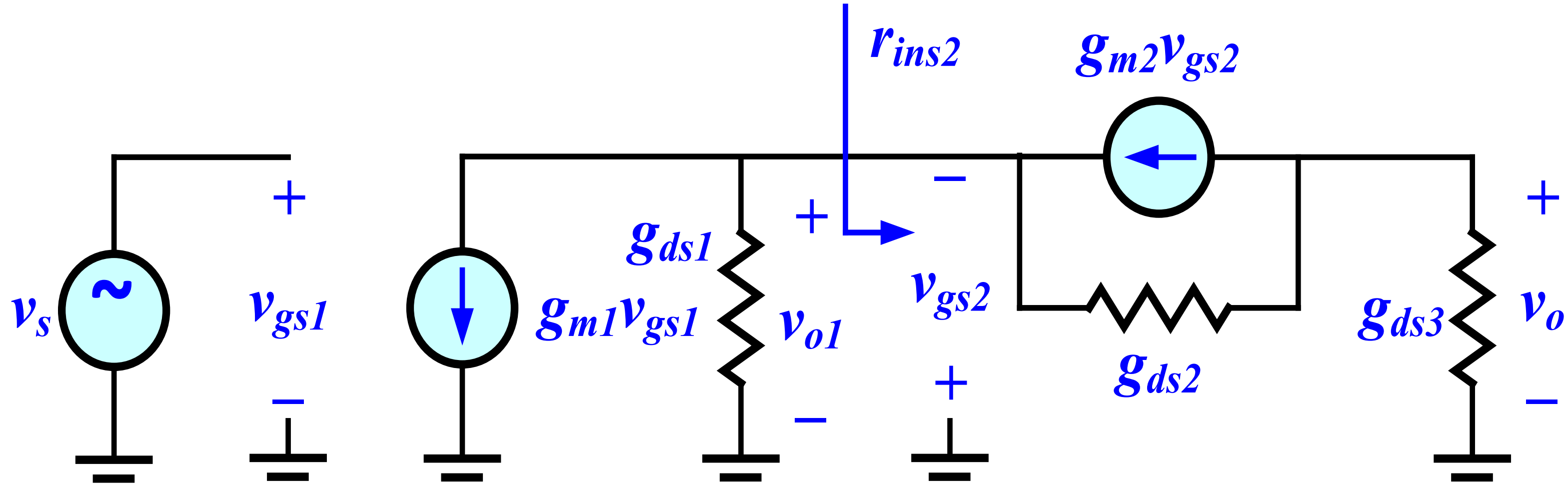
Amplificador Cascode

- Esquema del circuito:



Amplificador Cascode

- Circuito de pequeña señal simplificado:

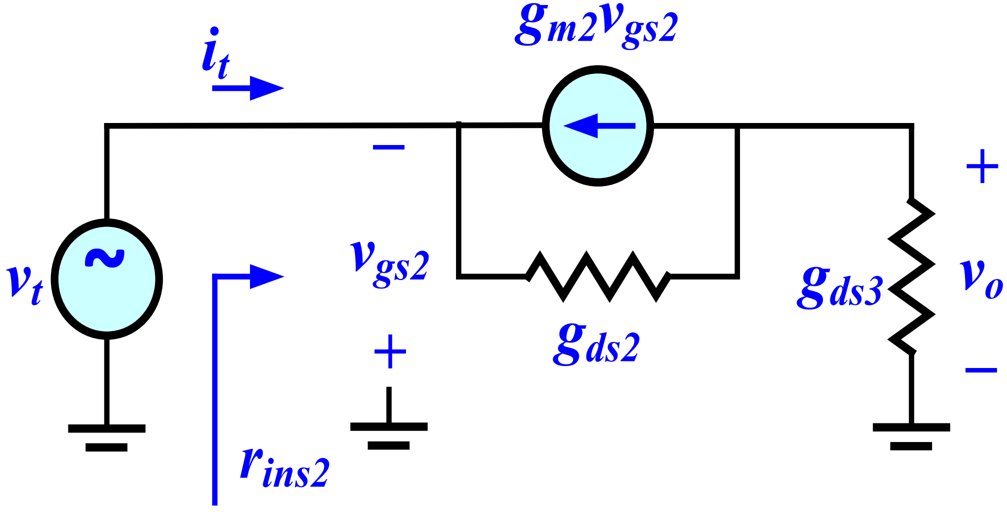


$$A_{v1} = \frac{v_{o1}}{v_s} = -g_{m1}\left(r_{ds1} \| r_{ins2}\right) \qquad A_{v2} = \frac{v_o}{v_{o1}} = \frac{g_{m2} + g_{ds2}}{g_{ds3} + g_{ds2}}$$

$$A_v = \frac{v_o}{v_s} = \frac{v_{o1}}{v_s}\frac{v_o}{v_{o1}} = A_{v1}A_{v2}$$

Amplificador Cascode

- Resistencia de entrada de la segunda etapa (CG):



$$r_{ins2} = \frac{v_t}{i_t} = \frac{g_{ds2} + g_{ds3}}{\left(g_{m2} + g_{ds2}\right) g_{ds3}} \; ; \; \frac{1}{g_{m2}}\left(1 + \frac{g_{ds2}}{g_{ds3}}\right)$$

Amplificador Cascode

- Ganancia de tensión:

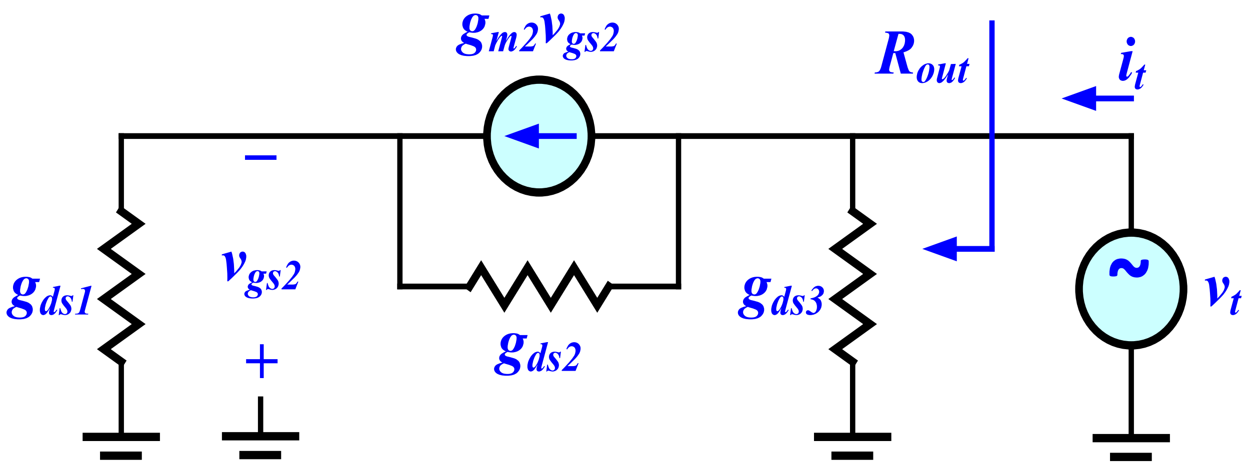
$$A_{v1} = \frac{v_{d1}}{v_{in}} = -g_{m1}\left(r_{ds1} \left\| \frac{g_{ds2} + g_{ds3}}{\left(g_{m2} + g_{ds2}\right) g_{ds3}} \right. \right) \; ; \quad -\frac{g_{m1}}{g_{m2}}\left(1 + \frac{g_{ds2}}{g_{ds3}}\right)$$

$$A_{v2} = \frac{g_{m2} + g_{ds2}}{g_{ds3} + g_{ds2}} \; ; \quad \frac{g_{m2}}{g_{ds3} + g_{ds2}}$$

$$A_v = A_{v1} A_{v2} \; ; \quad -\frac{g_{m1}}{g_{m2}}\left(1 + \frac{g_{ds2}}{g_{ds3}}\right)\frac{g_{m2}}{g_{ds3} + g_{ds2}} = -\frac{g_{m1}}{g_{ds3}}$$

Amplificador Cascode

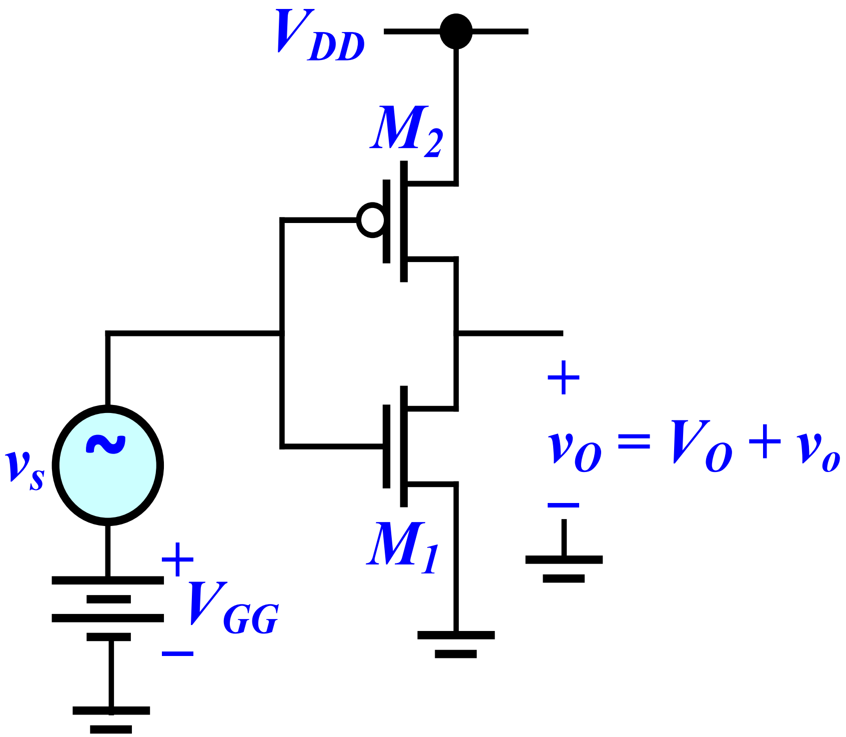
- Resistencia de salida:

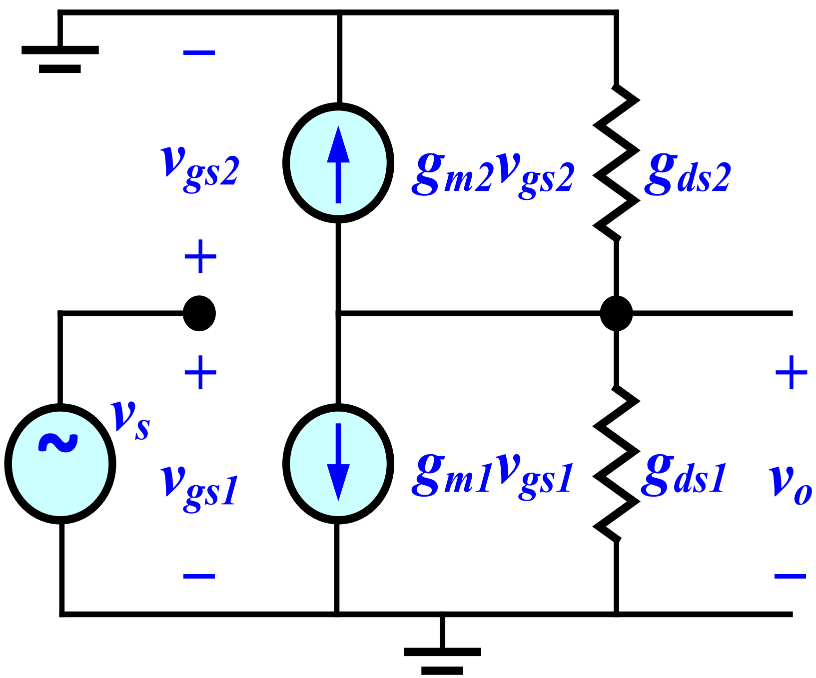


$$R_o = \left(g_{ds1}^{-1} + g_{ds2}^{-1} + g_{m2} g_{ds1}^{-1} g_{ds2}^{-1}\right) \| g_{ds3}^{-1} \; ; \; g_{ds3}^{-1} = r_{ds3}$$

Inversor CMOS

- Ganancia de tensión y resistencia de salida:





$$A_v = \frac{v_o}{v_s} = -\frac{g_{m1} + g_{m2}}{g_{ds1} + g_{ds2}}$$

$$R_{out} = g_{ds1}^{-1} \parallel g_{ds2}^{-1}$$