Espejos de Corriente y Cargas Activas

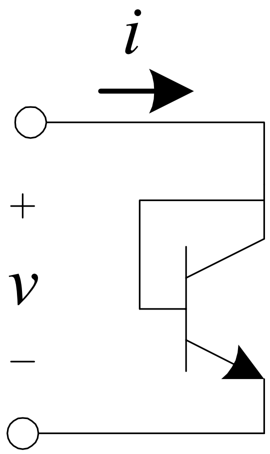
Algunas de las figuras de esta presentación fueron tomadas de la página de internet de los autores del texto:

A.S. Sedra and K.C. Smith, *Microelectronic Circuits*. New York, NY: Oxford University Press, 1998.

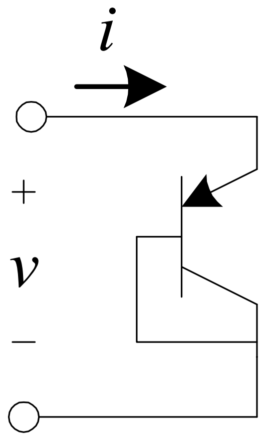
Polarización en Circuitos Integrados (CIs)

- Los circuitos de polarización con muchas resistencias y capacitores son inadecuados para CIs
- Es mucho más fácil fabricar transistores que resistencias y capacitores en un CI
- Las características internas de los transistores en un CI pueden igualarse más fácilmente

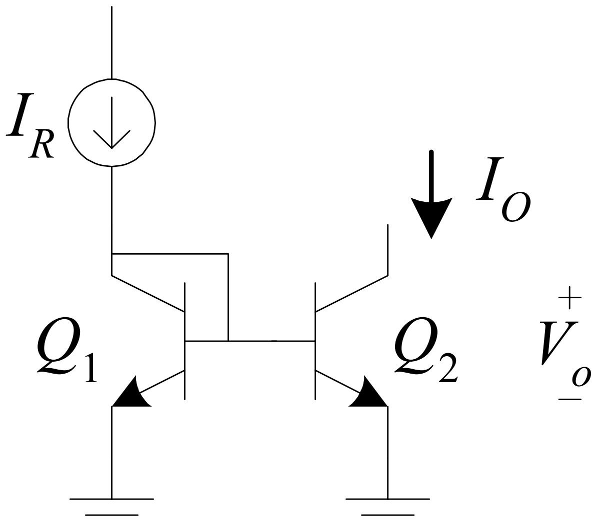
Transistor Conectado como Diodo



$$i = \frac{I_S}{\alpha} e^{v/V_T}$$



Espejo de Corriente con BJTs

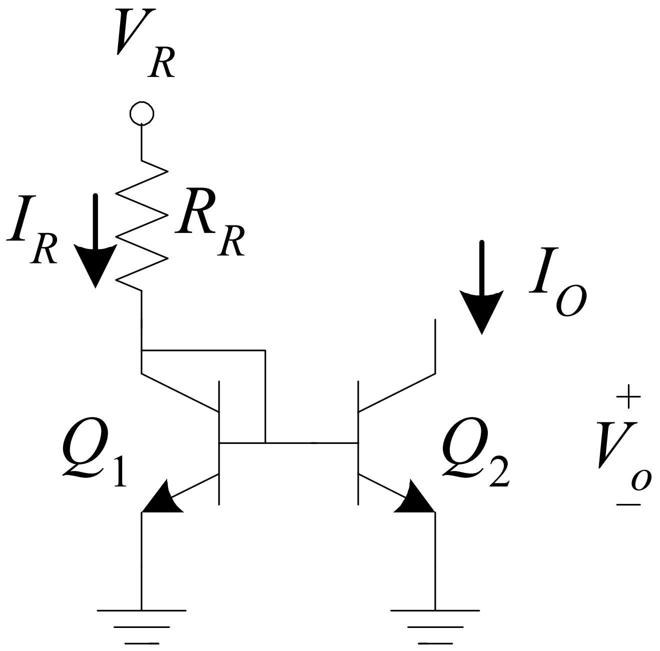


$$I_R = I_S e^{\frac{V_{BE}}{\eta V_T}}$$

$$I_O = I_S e^{\frac{V_{BE}}{\eta V_T}}$$

$$I_O = I_R$$

Fuente de Corriente con BJTs



$$I_O = I_R$$

$$I_R = \frac{V_R - V_{BE}}{R_R}$$

Generadores de Fuentes de Corriente

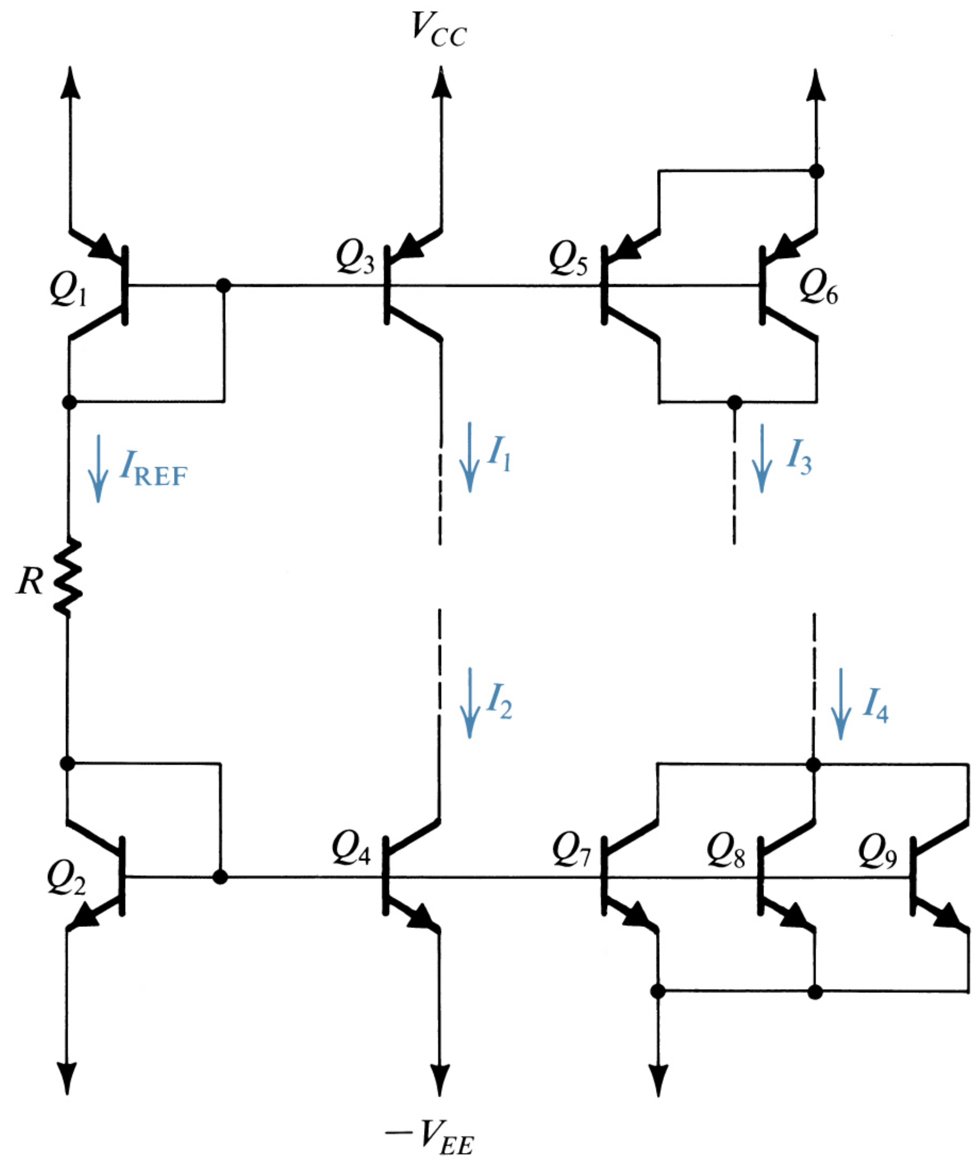
$$I_{REF} = \frac{V_{CC} + V_{EE} - V_{EB1} - V_{BE2}}{R}$$

$$I_1 \approx I_{REF}$$

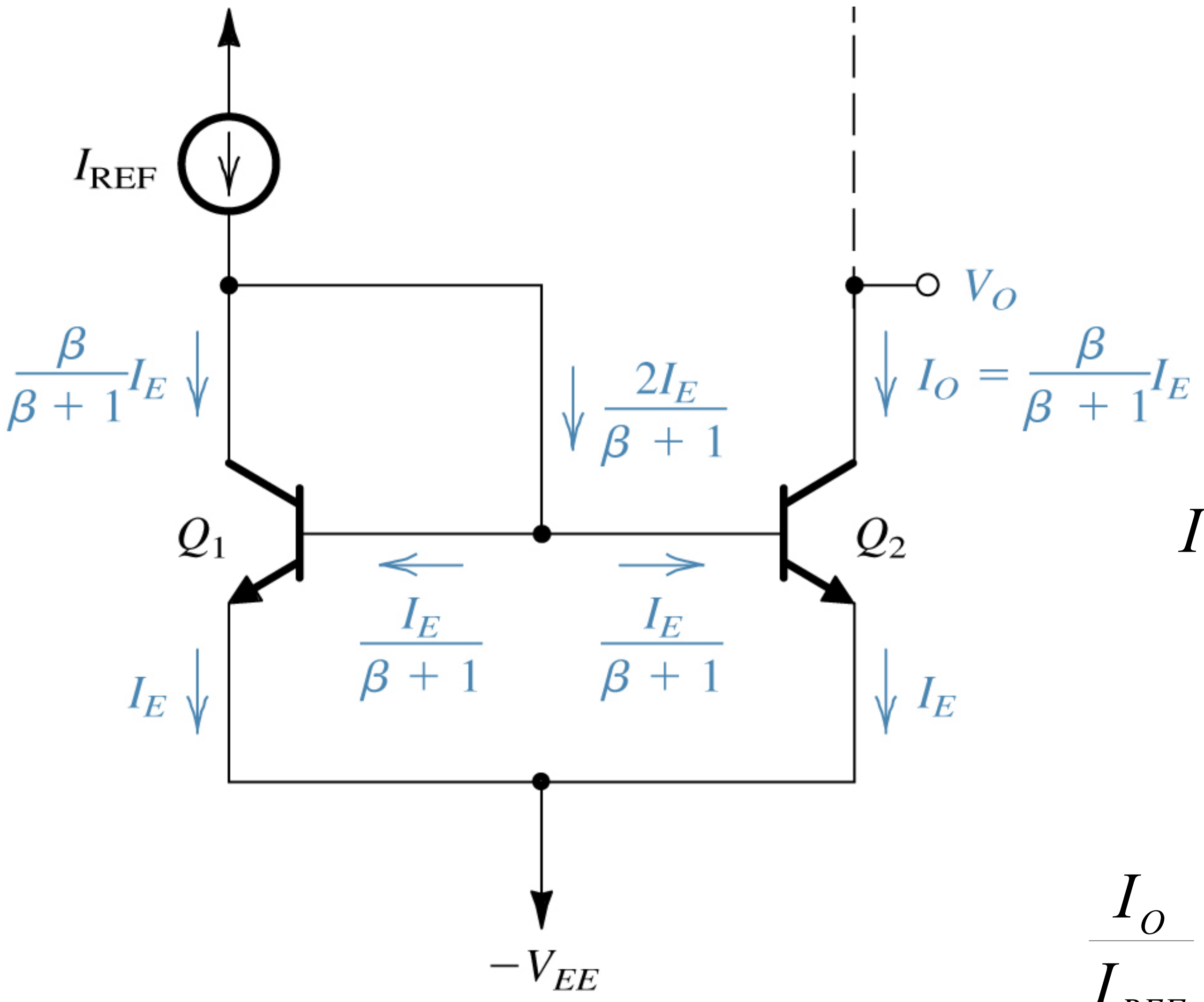
$$I_2 \approx I_{REF}$$

$$I_3 \approx 2I_{REF}$$

$$I_4 \approx 3I_{REF}$$



Efectos de la β en el Espejo de Corriente



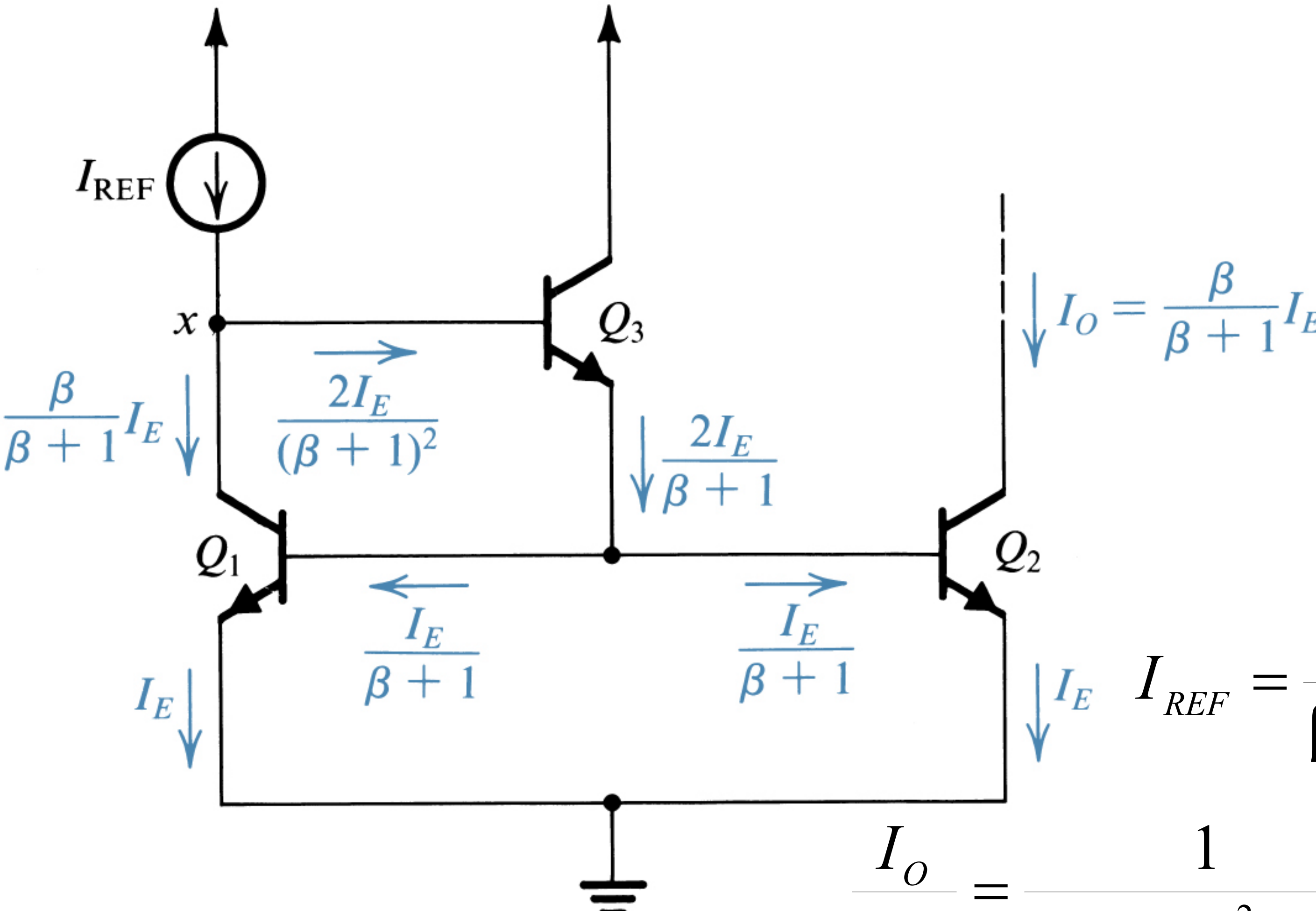
$$I_E = \frac{I_S}{\alpha} e^{v_{BE}/V_T}$$

$$I_{REF} = \frac{\beta I_E}{\beta+1} + \frac{2I_E}{\beta+1}$$

$$I_{REF} = \frac{\beta+2}{\beta+1} I_E$$

$$\frac{I_O}{I_{REF}} = \frac{\beta}{\beta+2} = \frac{1}{1+2/\beta}$$

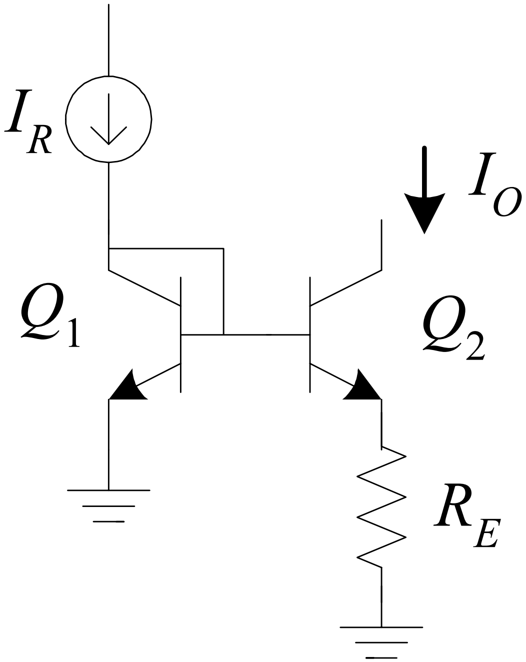
Espejo de Corriente con Amplificación de β



$$I_{REF} = \frac{\beta I_E}{\beta+1} + \frac{2I_E}{(\beta+1)^2}$$

$$\frac{I_O}{I_{REF}} = \frac{1}{1+2/(\beta^2+\beta)} \approx \frac{1}{1+2/\beta^2}$$

Espejo de Corriente tipo Widlar

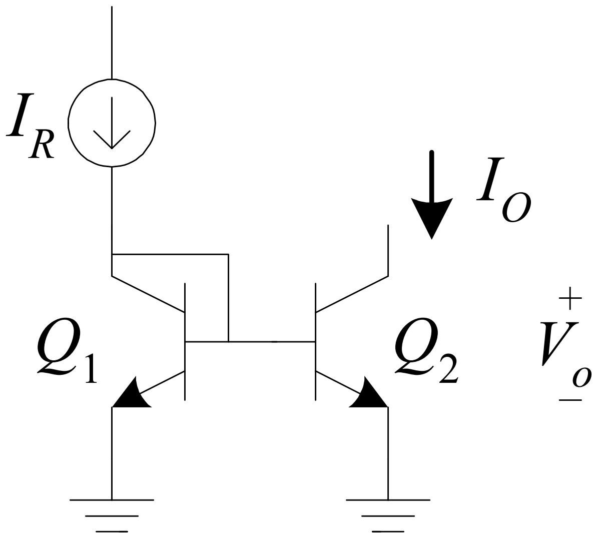


$$V_{BE1} - V_{BE2} - I_O R_E = 0$$

$$V_T \ln \frac{I_R}{I_S} - V_T \ln \frac{I_O}{I_S} - I_O R_E = 0$$

$$V_T \ln \frac{I_R}{I_O} = I_O R_E$$

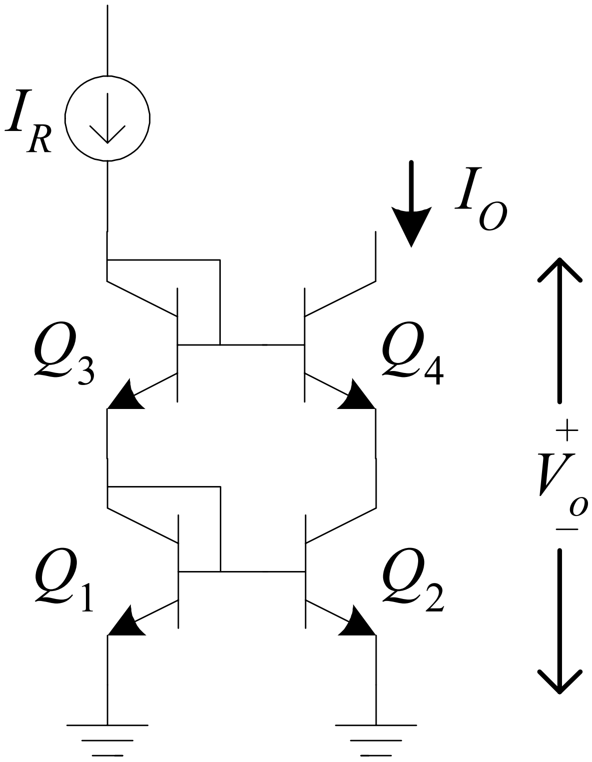
Efectos del Voltaje Early



$$I_R = I_S e^{\frac{V_{BE}}{\eta V_T}} \left(1 + \frac{V_{BE}}{V_A}\right) \qquad I_O = I_S e^{\frac{V_{BE}}{\eta V_T}} \left(1 + \frac{V_O}{V_A}\right)$$

$$\frac{I_O}{I_R} = \frac{1 + \frac{V_O}{V_A}}{1 + \frac{V_{BE}}{V_A}} \approx 1 + \frac{V_O}{V_A}$$

Fuente de Corriente Cascode con BJTs



$$V_{C3E1} = 2V_{BE}$$

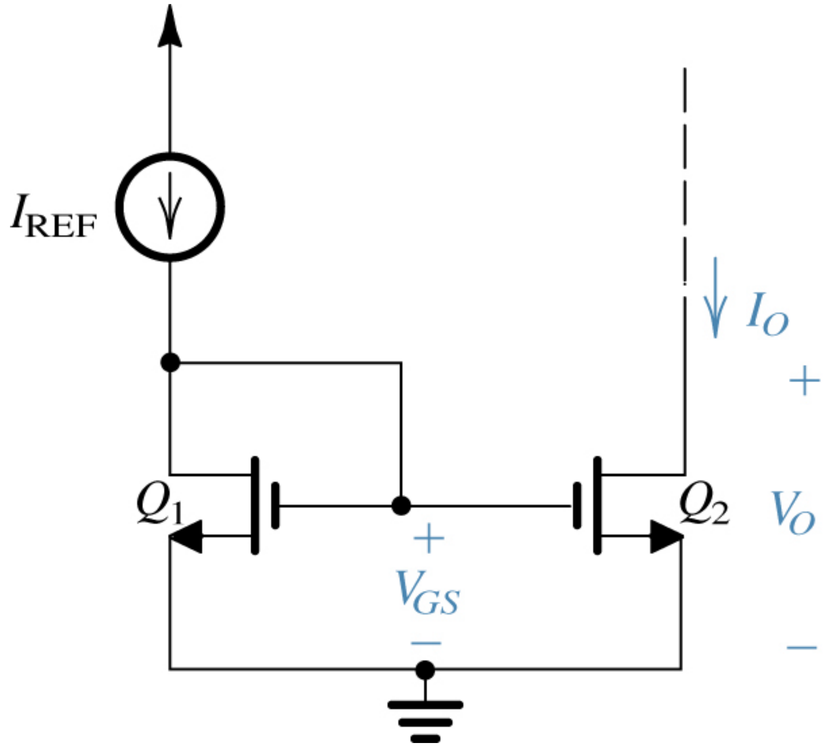
$$V_{C3E1} = V_{BE} + V_{CE2} = 2V_{BE}$$

$$V_{CE2} = V_{BE}$$

luego, el efecto Early se minimiza,

$$I_O \approx I_R$$

Espejo de Corriente E-MOS



$$I_{REF} = K_1(V_{GS} - V_t)^2$$

$$I_O = K_2(V_{GS} - V_t)^2$$

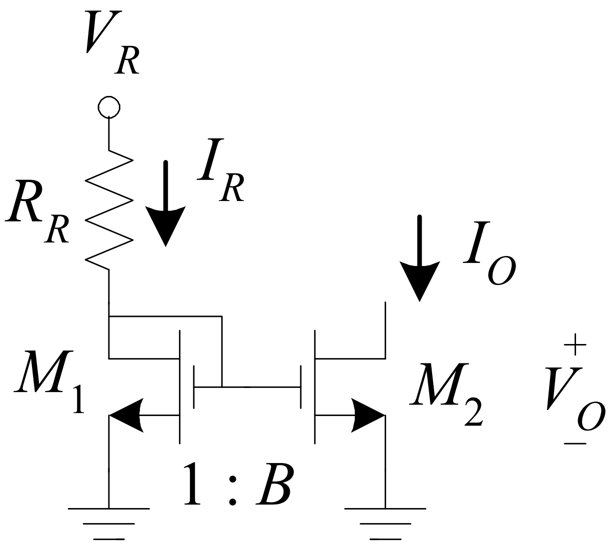
$$I_O = I_{REF}\left(\frac{K_2}{K_1}\right)$$

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

$$I_O = I_{REF}\left(\frac{W_2 / L_2}{W_1 / L_1}\right)$$

$$I_O = BI_{REF} \qquad B = \frac{W_2 / L_2}{W_1 / L_1}$$

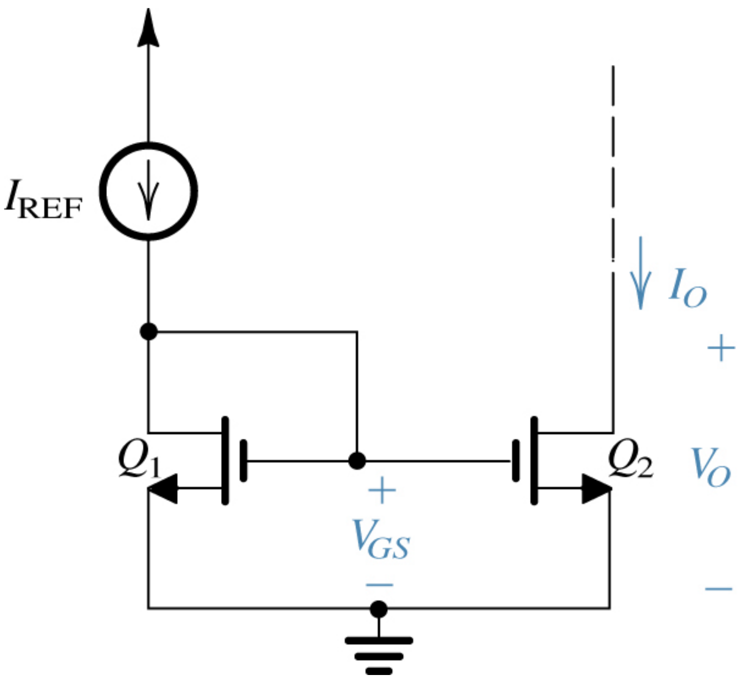
Fuente de Corriente E-MOS



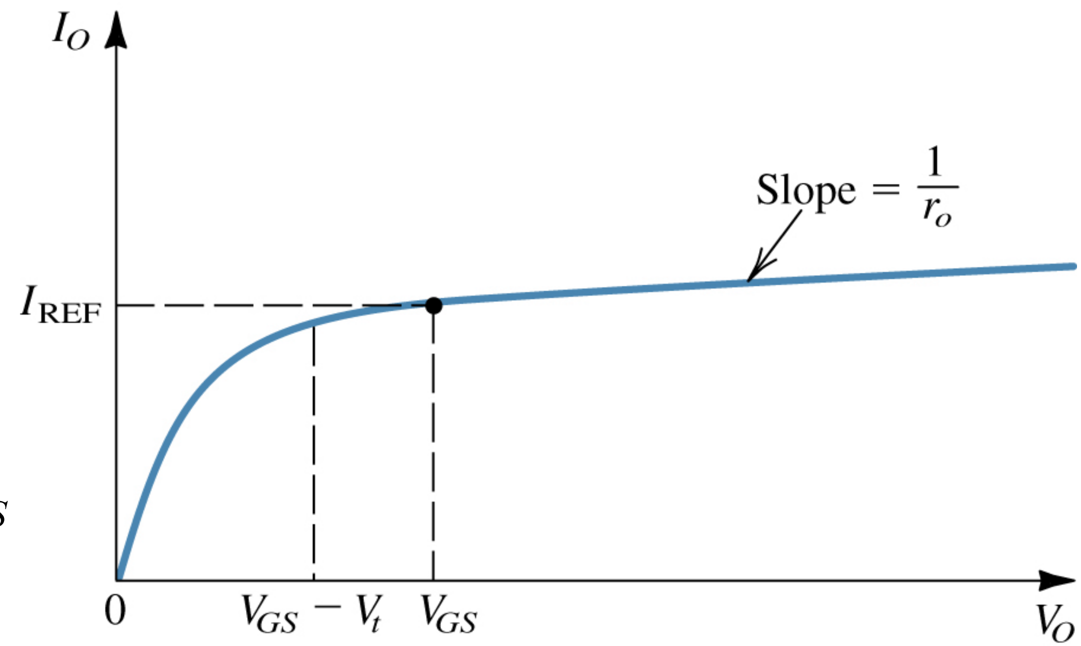
$$I_O = BI_R \qquad B = \frac{W_2 / L_2}{W_1 / L_1}$$

$$I_R = \frac{V_R - V_{GS}}{R_R} = K_1 (V_{GS} - V_{t1})^2$$

Espejo de Corriente E-MOS (cont.)



si $B = \dfrac{W_2 / L_2}{W_1 / L_1} = 1$

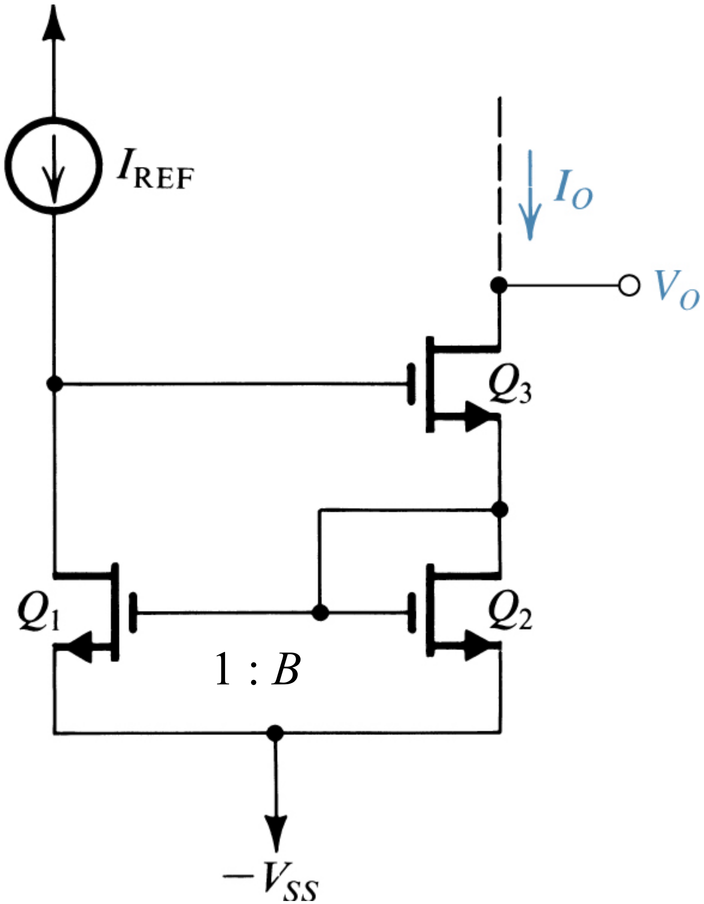


como $V_{DS2} = V_O \neq V_{DS1} = V_{GS}$

$I_O \approx BI_{REF}$

(efecto de la modulación de la longitud del canal)

Espejo de Corriente E-MOS tipo Wilson



Q_1 y Q_2 forman el espejo de corriente

$$I_{REF} = I_{DS1}$$

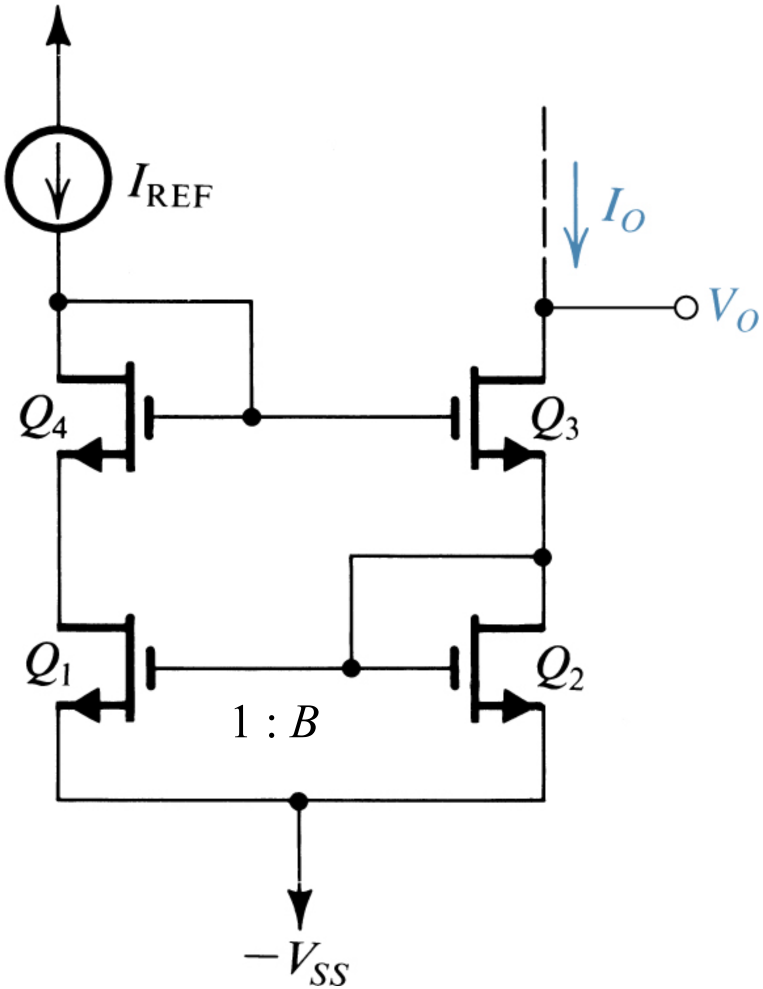
$$I_O = I_{DS3} = I_{DS2}$$

$$V_{DS1} = 2V_{GS}$$

$$V_{DS2} = V_{GS}$$

$$I_O = BI_{REF}$$

Espejo de Corriente tipo Wilson modificada



Q_1 y Q_2 forman el espejo de corriente ($K_1 = K_4$, $K_2 = K_3$)

$$I_{REF} = I_{DS4} = I_{DS1}$$

$$I_O = I_{DS3} = I_{DS2}$$

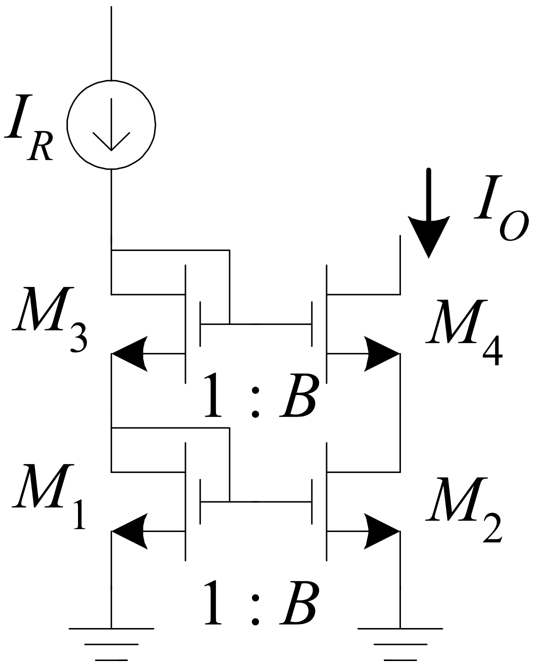
$$V_{DS2} = V_{GS}$$

$$V_{D4S1} = 2V_{GS} \qquad V_{DS4} = V_{GS}$$

$$V_{DS1} = V_{D4S1} - V_{DS4} = V_{GS}$$

$$I_O = BI_{REF}$$

Espejo de Corriente tipo Cascode



M_1 y M_2 forman el espejo de corriente ($K_1 = K_3, K_2 = K_4$)

$$I_R = I_{DS3} = I_{DS1}$$

$$I_O = I_{DS4} = I_{DS2}$$

$$V_{DS1} = V_{GS}$$

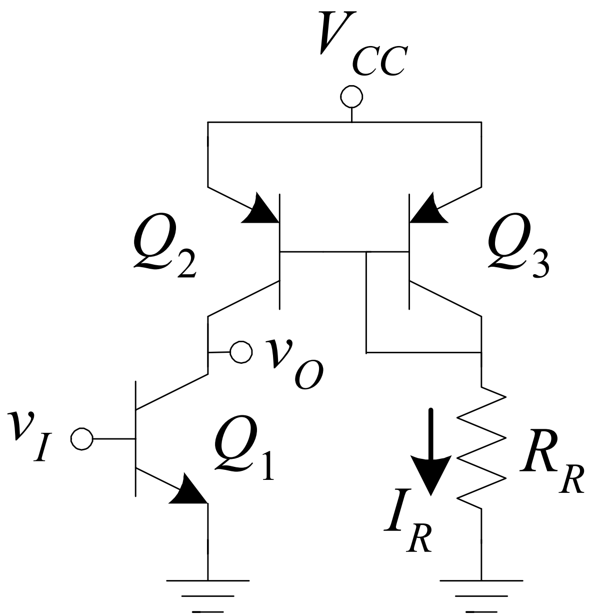
$$V_{D3S1} = 2V_{GS} \qquad V_{DS3} = V_{GS}$$

$$V_{D3S1} = V_{GS} + V_{DS2} = 2V_{GS}$$

$$V_{DS2} = V_{GS}$$

$$I_O = BI_{REF}$$

Emisor Común con Carga Activa



$$\frac{I_{C2}}{I_R} = 1 + \frac{V_{CC} - v_O}{V_{AP}} \qquad I_R = \frac{V_{CC} - V_{EB3}}{R_R}$$

$$I_{C2} = I_{C1} = I_{S1} e^{\frac{v_I}{\eta V_T}} \left(1 + \frac{v_O}{V_{AN}}\right)$$

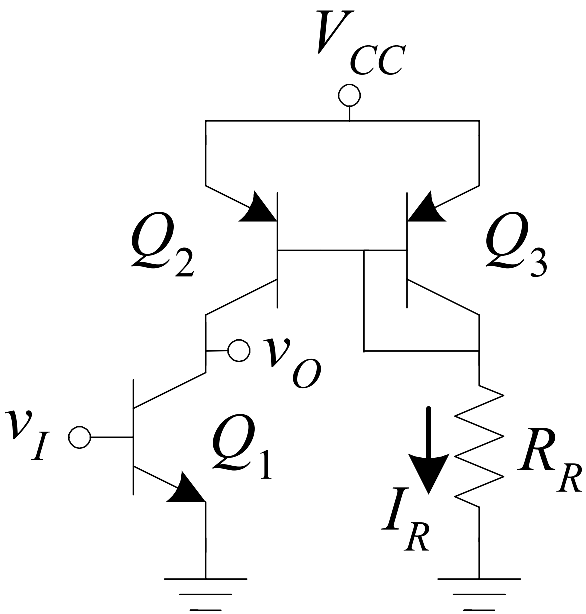
$$I_{S1} e^{\frac{v_I}{\eta V_T}} \left(1 + \frac{v_O}{V_{AN}}\right) = I_R \left(1 + \frac{V_{CC} - v_O}{V_{AP}}\right)$$

Para señal pequeña:

$$\frac{v_o}{v_i} = -g_{m1}(r_{o1} \parallel r_{o2})$$

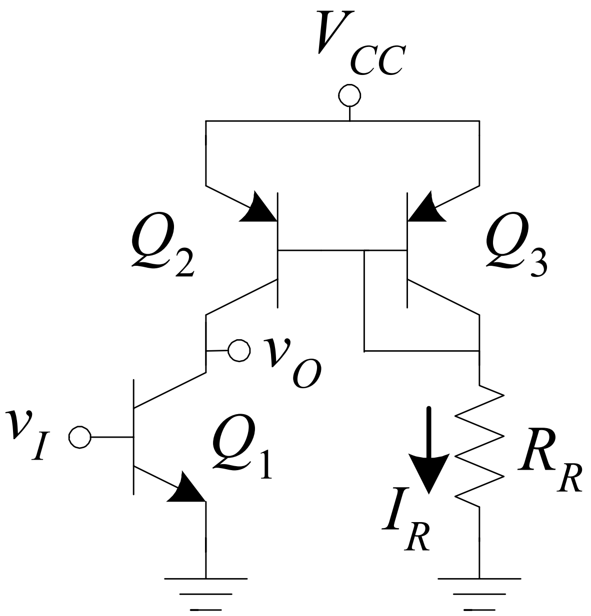
$$v_O = \frac{I_R + (V_{CC}/V_{AP}) - I_{S1} e^{\frac{v_I}{\eta V_T}}}{(I_R/V_{AP}) + I_{S1} e^{\frac{v_I}{\eta V_T}} / V_{AN}}$$

Emisor Común con Carga Activa (cont)

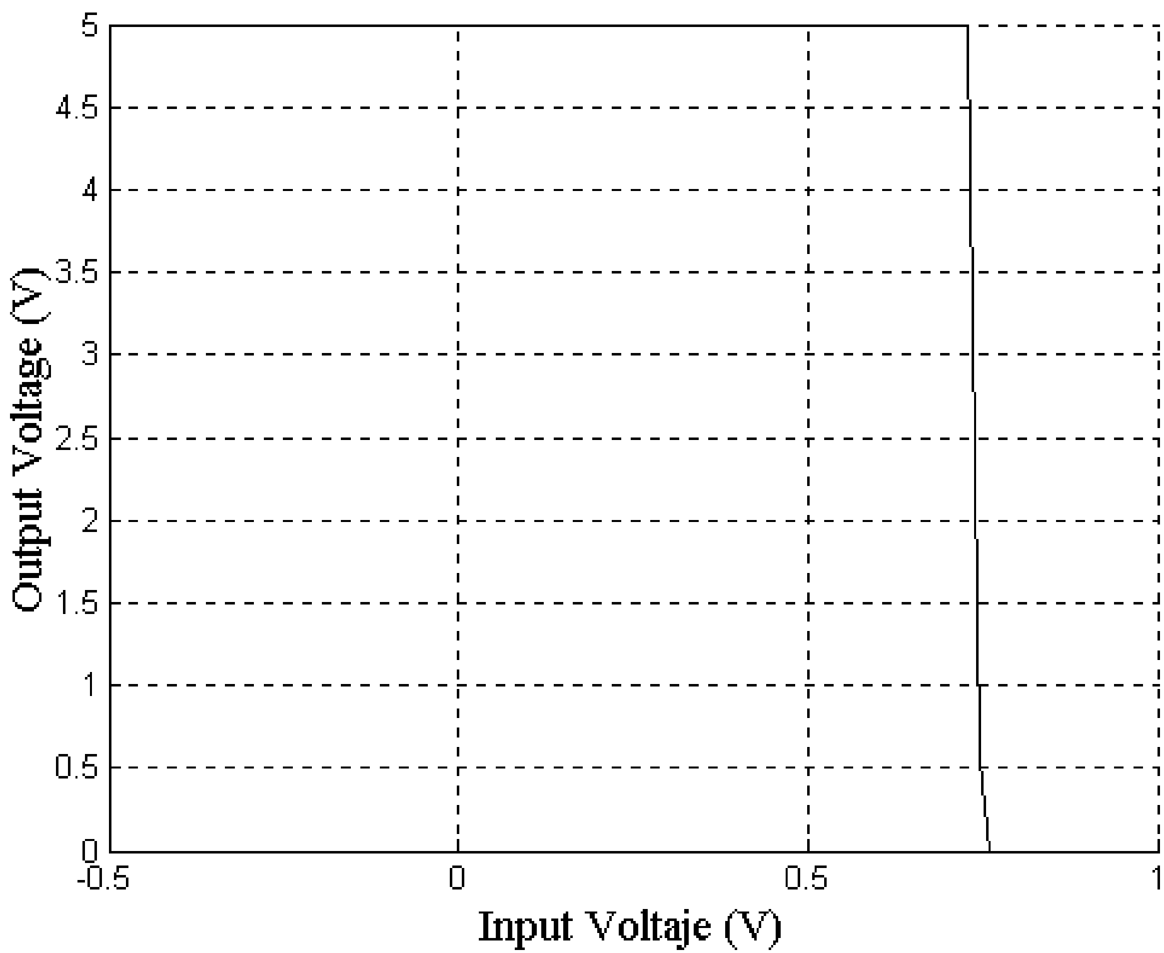


$$v_O = \begin{cases} 0 \text{ si } v_O < 0 \\ \dfrac{I_R + (V_{CC}/V_{AP}) - I_{S1} e^{\frac{v_I}{\eta V_T}}}{(I_R/V_{AP}) + I_{S1} e^{\frac{v_I}{\eta V_T}} / V_{AN}} \text{ si } 0 \le v_O \le V_{CC} \\ V_{CC} \text{ si } v_O > V_{CC} \end{cases}$$

Emisor Común con Carga Activa (cont)



I_{s1} = 15e-15A
V_T = 25mV
V_{EB3} = 0.7V
V_{CC} = 5V
R_R = 1K
η = 1
V_{AN} = 80V
V_{AP} = 40V



Amp. Dif. BJT con Carga Activa

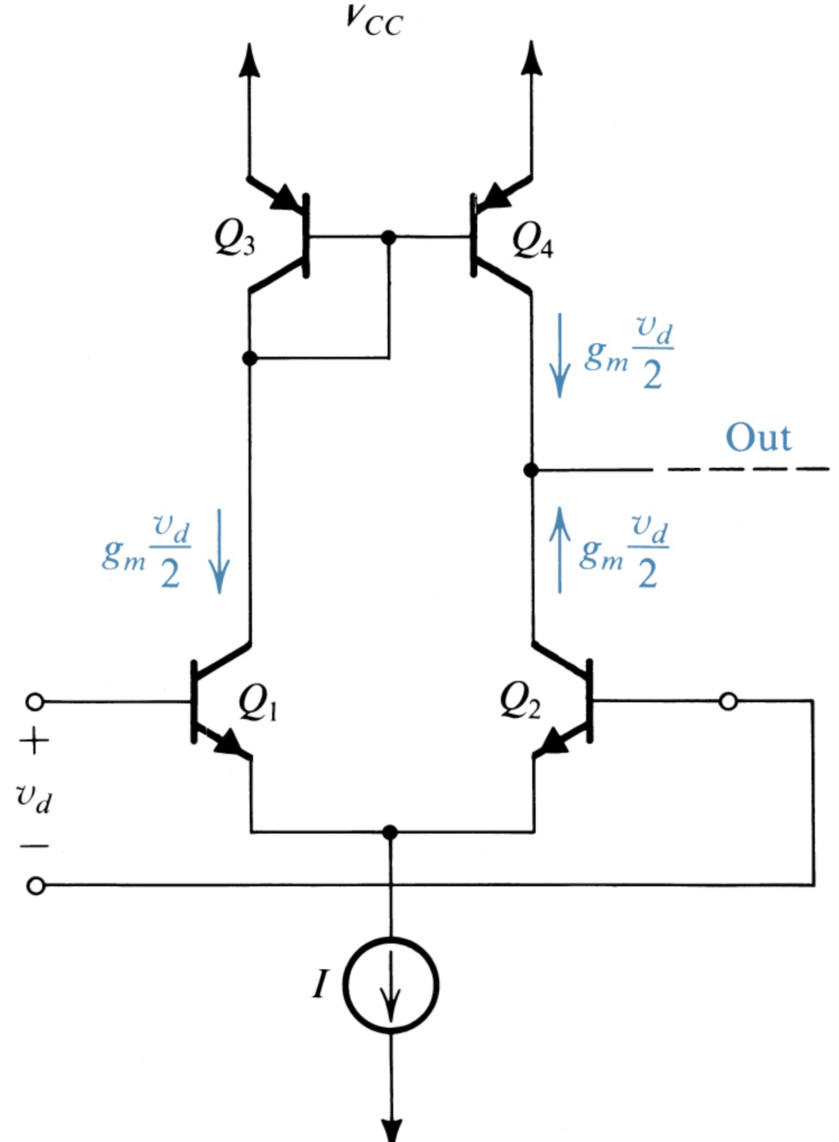
$$I_O = 0$$

$$i_o = g_m v_d$$

$$v_o = g_m v_d R_o$$

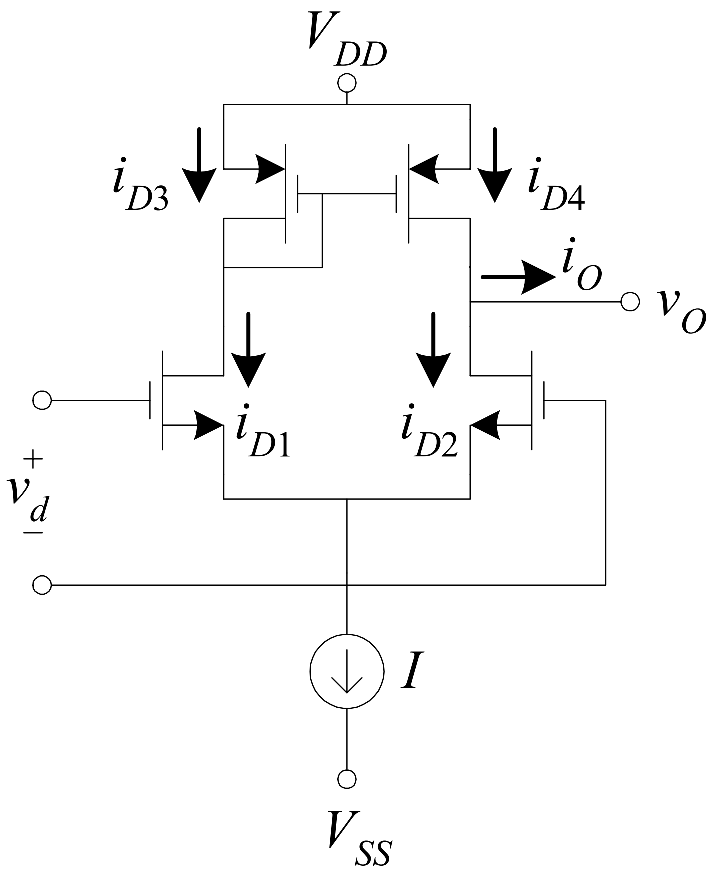
$$R_o = r_{o2} \parallel r_{o4} = \frac{r_o}{2}$$

$$\frac{v_o}{v_d} = \frac{1}{2} g_m r_o = \frac{V_A}{2V_T}$$



Dr. J.E. Rayas Sánchez

Amp. Diferencial CMOS con Carga Activa



para la polarización ($v_d = 0$):

$$I_{D1} = I_{D3} = I_{D4} = I_{D2} = I/2, \qquad I_O = 0$$

para la señal ($V_{DD} = V_{SS} = I = 0$):

$$i_{d1} = g_m(v_d/2) \qquad i_{d2} = g_m(-v_d/2)$$

$$i_{d1} = i_{d3} = i_{d4} \qquad i_o = i_{d4} - i_{d2} = g_m v_d$$

$$v_o = i_o(r_{o4} \parallel r_{o2}) = g_m v_d \frac{r_o}{2} \qquad r_o = \frac{V_A}{I/2}$$

$$g_m = 2K(V_{GS} - V_t) = \frac{I}{V_{GS} - V_t} \qquad A_V = \frac{V_A}{V_{GS} - V_t}$$