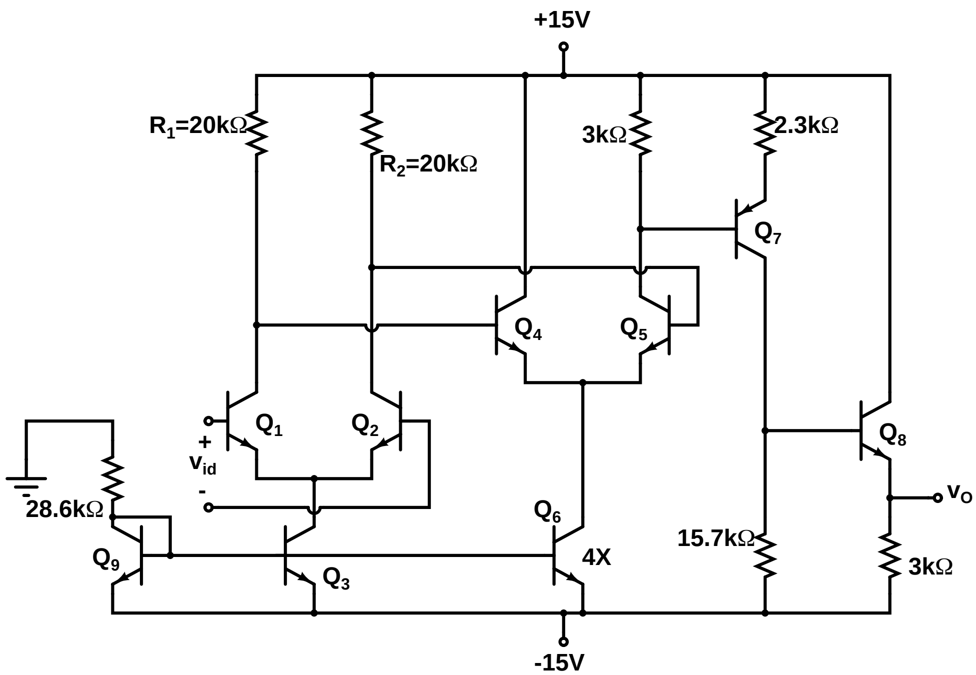
Ejemplo 1

El siguiente diagrama muestra el circuito con los valores correctos de resistencia.



Análisis D.C.

$$I_{CQ9} \simeq \frac{14.3V}{28.6k\Omega} = 0.5mA = I_{C_{Q3}} = \frac{1}{4} I_{C_{Q6}}$$

$$I_{C_{Q1}} = I_{C_{Q2}} = 0.25mA$$

$$I_{C_{Q4}} = I_{C_{Q5}} = 1mA$$

$$V_{C_{Q5}} = +15V - 1k\Omega \times 1mA = 12V$$

$$V_{E_{Q7}} = V_{C_{Q5}} + 0.7V = 12.7V$$

$$I_{E_{Q7}} \simeq I_{C_{Q7}} = \frac{+15V - 12.7V}{2.3k\Omega} = 1mA$$

$$V_{B_{Q8}} \simeq -15V + 15.7k\Omega \times 1mA = 0.7V$$

$$V_{E_8} \simeq V_{B_{Q8}} - 0.7V = 0V$$

$$I_{C_{Q8}} \simeq \frac{15V}{3k\Omega} = 5mA$$

Parametros

$$g_{m_{Q1}} = g_{m_{Q2}} = \frac{0.25mA}{25mV} = 10mA/V$$

$$g_{m_{Q4}} = g_{m_{Q5}} = g_{m_{Q7}} = \frac{1mA}{25mV} = 40mA/V$$

$$r_{\pi_{Q4}} = r_{\pi_{Q5}} = r_{\pi_{Q7}} = \frac{\beta}{g_m} = \frac{100}{40mA/V} = 2.5k\Omega$$

$$g_{m_{Q8}} = \frac{5mA}{25mV} = 200mA/V$$

Ganancias

$$\begin{aligned} A_1 &= \frac{v_{C_{Q1}} - v_{C_{Q2}}}{v_{id}} \\ &= -g_{m_{Q1,Q2}}(20k\Omega \| r_{\pi_{Q4,Q5}}) \\ &= -10mA/V \times 20k\Omega \| 2.5k\Omega = -10mA/V \times 2222 \\ &= -22.2V/V \end{aligned}$$

$$\begin{aligned} A_2 &= \frac{v_{C_{Q5}}}{v_{C_{Q1}} - v_{C_{Q2}}} \\ &= \frac{1}{2} g_{m_{Q5}} (3k\Omega \| (r_{\pi_{Q7}} + (\beta + 1)R_4) \\ &\simeq \frac{1}{2} g_{m_{Q5}} 3k\Omega \\ &= \frac{1}{2} \times 40mA/V \times 3k\Omega \\ &= 60V/V \end{aligned}$$

$$\begin{aligned} A_3 &= \frac{v_{C_{Q7}}}{v_{C_{Q5}}} \\ &= -\frac{g_{m_{Q7}} R_{c_{Q7}}}{1 + g_{m_{Q7}} R_{e_{Q7}}} \\ &= -\frac{40mA/V \times 15.7k\Omega \| (r_{\pi_{Q8}} + (\beta + 1)R_6)}{1 + 40mA/V \times 2.3k\Omega} \\ &= -\frac{40mA/V \times 15.7k\Omega \| (500\Omega + 101 \times 3k\Omega)}{93} \\ &= -\frac{40mA/V \times 15.7k\Omega \| (500\Omega + 101 \times 3k\Omega)}{93} \\ &= -\frac{597}{93} = -6.4V/V \end{aligned}$$

$$A_4 = \frac{v_{C_{Q7}}}{v_{E_{Q8}}} = +\frac{g_{m_{Q8}} R_6}{1 + g_{m_{Q8}} R_6} \simeq 1V/V$$

La ganancia total es:

$$A = -22.2 \times 60 \times -6.4 \times 1 \simeq \boxed{8568V/V}$$

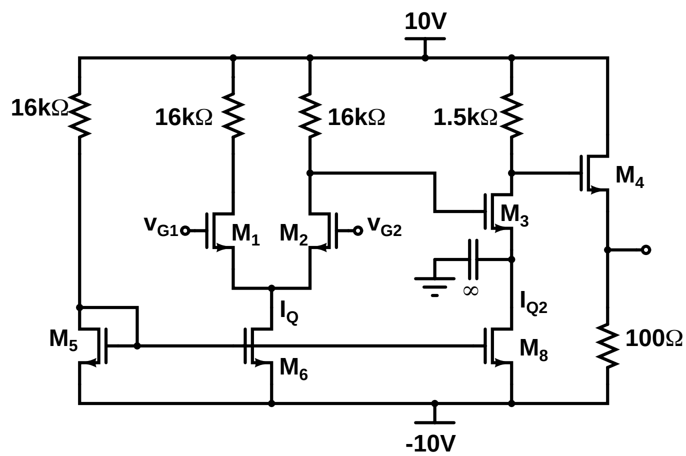
Resistencia de entrada:

$$R_i = 2 \times r_{\pi_{Q1}} = 2 \times \frac{100}{10mA/V} \simeq \boxed{20k\Omega}$$

Resistencia de salida:

$$R_o \simeq R_6 \| \frac{r_{\pi_{Q8}} + R_5}{\beta + 1} = 3k\Omega \| \frac{500\Omega + 15.7k\Omega}{101} = \boxed{152\Omega}$$

Ejemplo 2



El circuito tiene varios problemas. Los parametros eran: $k'_n = 20\mu A/V^2$, $|V_{th}| = 1V$, $\lambda = 0$, $(W/L)_1 = (W/L)_2 = (W/L)_3 = 10$, $(W/L)_4 = 150$,$(W/L)_5 = (W/L)_6 = 30$, $(W/L)_8 = 120$.

Análisis D.C.

Corriente en M_5

$$I_{D_{M5}} = \frac{20V - V_{GS_{M5}}}{16k\Omega} = (10\mu A/V^2)(10)(v_{GS_{M5}} - 1)^2$$

$$v_{GS_{M5}} = 2.89V$$

$$I_{D_{M5}} = 1.07mA$$

$$I_{D_{M1}} = I_{D_{M2}} = 0.535mA$$

$$I_{D_{M8}} = I_{D_{M3}} = \frac{120}{30} 1.07mA = 4.28mA$$

$$V_{D_{M3}} = 10V - 4.28mA \times 1.5k\Omega = 3.58V$$

For M_4,

$$i_{D_{M4}} = \frac{3.58V - V_{GS_{M5}} + 10V}{100\Omega} = (10\mu A/V^2)(150)(v_{GS_{M4}} - 1)^2$$

$$V_{GS_{M4}} = 7.4V$$

$$I_{D_{M4}} = 61.7mA$$

Parametros

$$g_{m_{M1}} = g_{m_{M2}} = 2\sqrt{\frac{1}{2}k_n'(W/L)_{M1}I_{D_{M1}}} = 2\sqrt{(10\mu A/V^2)(10)0.535mA} = 0.46mA/V$$

$$g_{m_{M3}} = 2\sqrt{(10\mu A/V^2)(10)4.28mA} = 1.3mA/V$$

$$g_{m_{M4}} = 2\sqrt{(10\mu A/V^2)(150)61.7mA} = 19.2mA/V$$

Ganancias

$$A_1 = \frac{1}{2}g_{m_{M2}}16k\Omega = 3.68V/V$$

$$A_2 = -g_{m_{M3}}1.5k\Omega = -1.95V/V$$

$$A_3 = \frac{g_{m_{M4}}100\Omega}{1 + g_{m_{M4}}100\Omega} = 1.92/2.92 = 0.67V/V$$

$$A = 3.68 \times -1.95 \times 0.67 = 4.8V/V$$

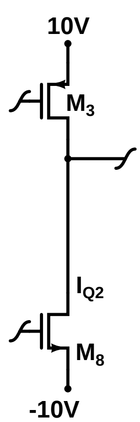
La resitencia de entrada es $R_i = \infty$ y la de salida es $R_o = 100\Omega \| \frac{1}{g_{m_{M4}}} = 100\Omega \| 52\Omega = 34\Omega$.

Ejemplo 3

Para mejorar el ultimo amplificador se pueden hacer varios cambios.

Segunda etapa

La segunda etapa puede sustituirse por la siguiente:



con ganancia igual a

$$A_2 = -g_{m_{M3}}(r_{o_{M3}} \| r_{o_{M8}})$$

Como $r_o = 1/\lambda I_Q$ y $g_m = 2\sqrt{\frac{1}{2}k'(W/L)I_Q}$,

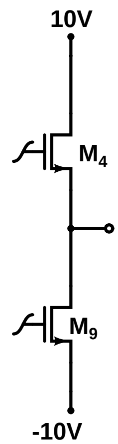
$$\begin{aligned} A_2 &= -2\sqrt{\frac{1}{2}k_p'(W/L)_{M3}I_{Q_{M3}}} \times \frac{1}{I_{Q_{M3}}(\lambda_{M8} + \lambda_{M3})} \\ &= -\frac{2}{\lambda_{M8} + \lambda_{M3}} \times \sqrt{\frac{1}{2}\frac{k_p'(W/L)_{M3}}{I_{Q_{M3}}}} \end{aligned}$$

Si suponemos que $\lambda_p = .02V^{-1}$, $\lambda_n = .01V^{-1}$, $k'_p = 10\mu A/V^2$ y cambiamos $(W/L)_{M8}$ a 30 para reducir $I_{Q_{M3}}$ a $100\mu A$,

$$A_2 = -\frac{2}{.02 + .01V^{-1}} \times \sqrt{\frac{5\mu A/V^2 \times 10}{100\mu A}} = -47.14V/V$$

Tercera etapa

La tercera etapa puede construirse como sigue,



donde M_9 es parte del espejo de corriente y fija $I_{Q_{M4}}$ en $100\mu A$. La ganancia de la etapa 3 es

$$A_3 = \frac{g_{m_{M4}}(r_{o_{M4}} \| r_{o_{M9}})}{1 + g_{m_{M4}}(r_{o_{M4}} \| r_{o_{M9}})}$$

Si $g_{m_{M4}} = 2\sqrt{\frac{1}{2}k'_n(W/L)I_Q} = 2\sqrt{10\mu A/V^2 \times 150 \times 100\mu A} = 774.6\mu A/V$ y $r_{o_{M4}} = r_{o_{M9}} = \frac{1}{.01V^{-1}100\mu A} = 1M\Omega$,

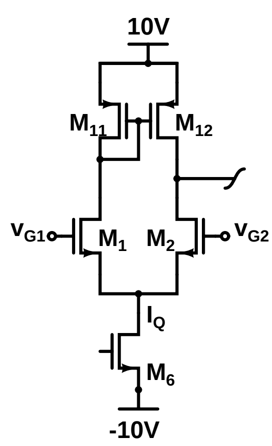
$$A_3 = \frac{774.6\mu A/V \times 0.5M\Omega}{1 + 774.6\mu A/V \times 0.5M\Omega)} \simeq= 1$$

y

$$R_o \simeq \frac{1}{g_{m_{M4}}} = \frac{1}{774.6\mu A/V} = 1290\Omega$$

Primera etapa

Podemos cambiar las resistencia conectada a M_2 por una carga activa,



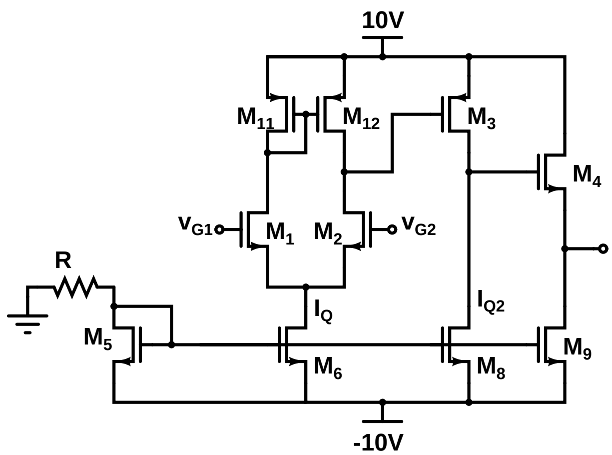
con ganancia

$$A_1 = \frac{v_{d_{m2}}}{v_{g_{M2}} - v_{g_{m1}}} = -g_{m_{M2}}(r_{o_{M2}} \| r_{o_{M12}})$$

Si fijamos $I_{Q_{M6}}$ en $100\mu A$, $I_{Q_{M2}} = 50\mu A$ y

$$\begin{aligned} A_1 &= -\frac{2}{\lambda_{M2} + \lambda_{M12}} \times \sqrt{\frac{1}{2}\frac{k_n'(W/L)_{M2}}{I_{Q_{M2}}}} \\ &= -\frac{1}{.01 + .02V^{-1}} \times \sqrt{\frac{10\mu A/V^2 \times 10}{50\mu A}} \\ &= -94.3 \end{aligned}$$

El circuito completo es



Note que $V_{SD_{M11}} = V_{SG_{M12}}$ debe ser igual a $V_{SD_{M12}}$ si los dos transistores están apareados (*matched*). En tal caso $(W/L)_{M3} = 2(W/L)_{M12}$ pues $V_{SG_{M3}} = V_{SD_{M12}} = V_{SG_{M12}}$ e $I_{D_{M3}} = 2I_{D_{M12}}$, así que $(W/L)_{M12,M11}$ debe ser 5.

La ganancia total es

$$A = -94.3 \times -47.14 \times 1 = 4445V/V$$

Para escoger R, observe que $I_{Q_{M5}} = 0.1mA = 10\mu A/V^2 \times 30 \times (9 - 0.1mA \times R)^2$, así que

$$R = \frac{9V - \sqrt{0.1mA \div 0.3mA/V^2}}{0.1mA} = 84.2k\Omega$$

Note que el terminal marcado como V_{G2} es la entrada no-invertidora del amplificador.