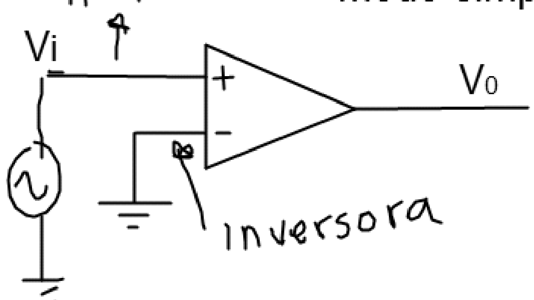
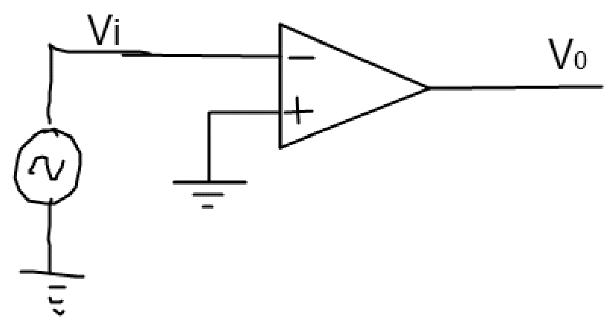
# Amplificador operacional

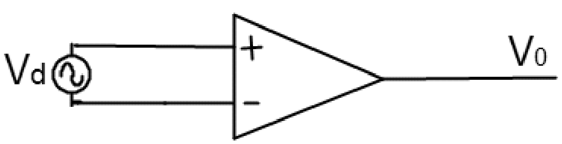
- Amplificador diferencial
- Muy alta ganancia
- Alta impedancia de entrada
- Baja impedancia de salida

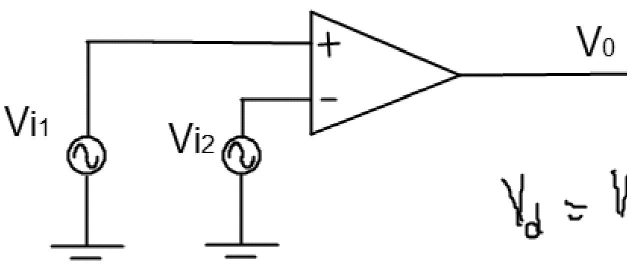
## Modo simple



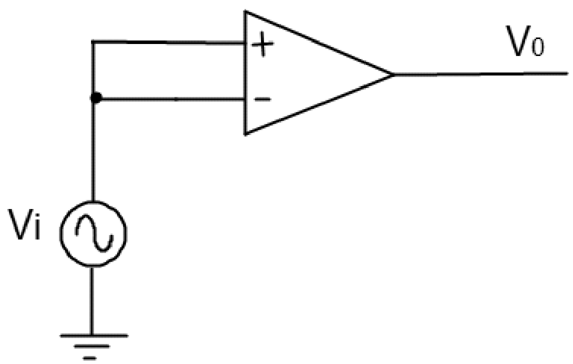

## Modo diferencial



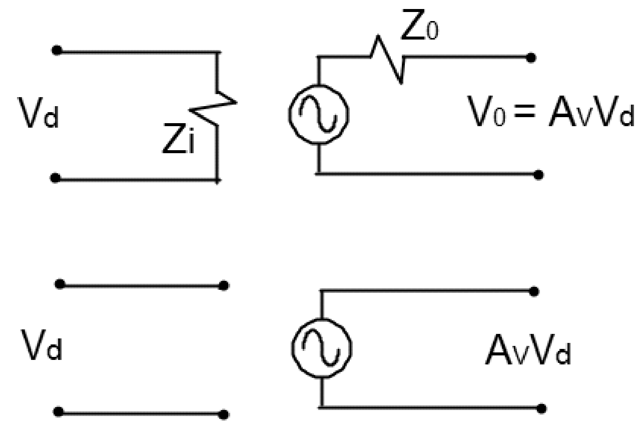




$V_d = V_{i1} - V_{i2}$

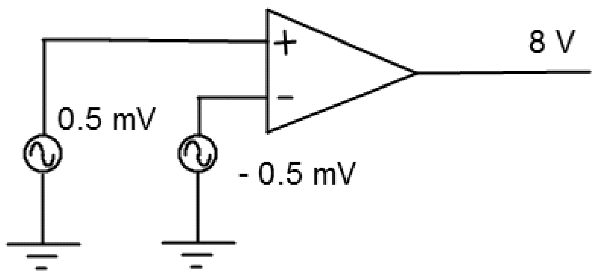
Modo común

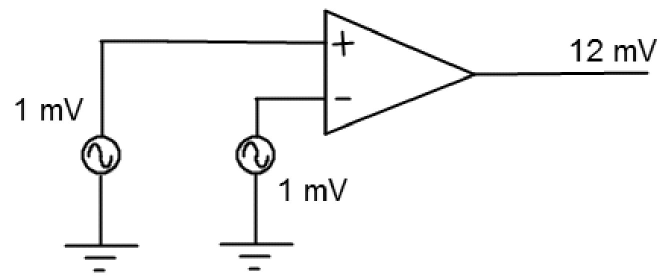



Modelo ideal



Ejemplo: Obtener la RRMC




$$V_o = A_d V_d = 8\,v$$

$$V_d = V_{i_1} - V_{i_2} = 0.5\,mV - (-0.5\,mV)$$

$$V_d = 1\,mV$$

$$A_d = \frac{V_o}{V_d} = \frac{8\,V}{1\,mV} = 8000$$

$$V_o = A_c V_{ic} = 12\,mV$$

$$V_{ic} = \frac{1}{2}\left(V_{i_1} + V_{i_2}\right) = 1\,mV$$

$$A_c = \frac{V_o}{V_{ic}} = \frac{12\,mV}{1\,mV} = 12$$

$$RRMC = \frac{A_d}{A_c} = \frac{8000}{12} = 666.7$$

$$RRMC = 20\log(666.7) = 56.48\,dB$$

Ejemplo: Si $V_{i1} = 150\mu V$, $V_{i2} = 140\mu V$ y $A_d = 4000$. Obtener $V_O$ para una RRMC de:

a) 100

b) $10^5$

Solución

$$V_{i.c} = \frac{1}{2}(150\mu V + 140\mu V) = 145\mu V$$

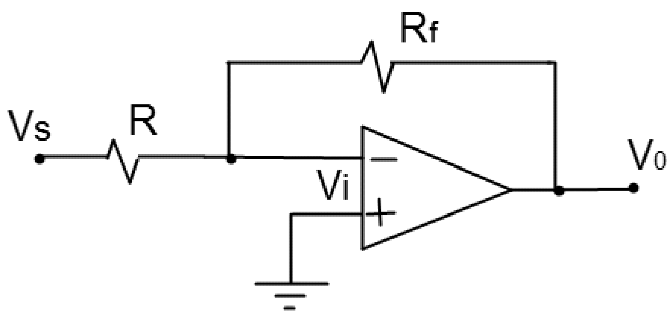
$$V_d = 150\mu V - 140\mu V = 10\mu V$$

a) $$V_o = (4000)(10\mu V)\left(1 + \frac{1}{100}\frac{145\mu V}{10\mu V}\right)$$

$$V_o = 45.8\ mV$$

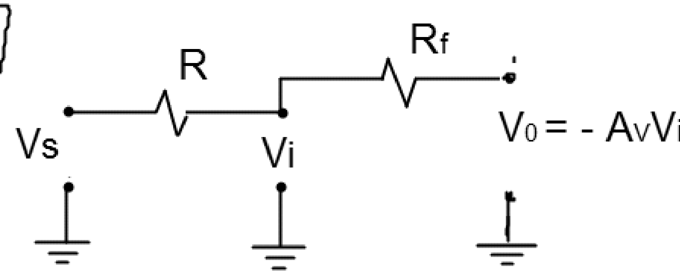
b) $$V_o = (4000)(10\mu V)\left(1 + \frac{1}{10^5}\frac{145\mu V}{10\mu V}\right) = 40\ mV$$

Amplificador inversor




Conexiones básicas

$$\boxed{\frac{V_0}{V_s} = -\frac{R_f}{R}}$$




$$V_{i_1} = \frac{R_f}{R+R_f} V_s$$

$$V_{i_2} = \frac{R}{R+R_f}\left(-A_v V_i\right)$$

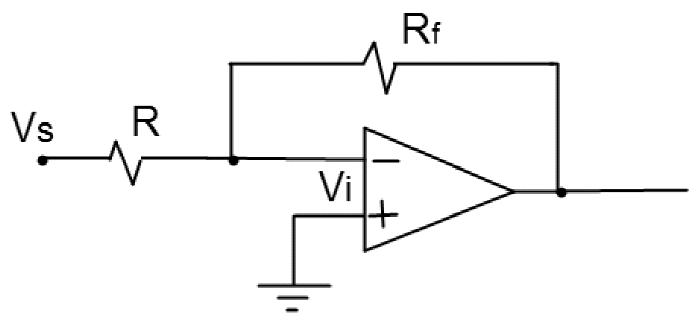
$$V_i = V_{i_1} + V_{i_2} = \frac{R_f}{R+R_f} V_s + \frac{R}{R+R_f}\left(-A_v V_i\right)$$

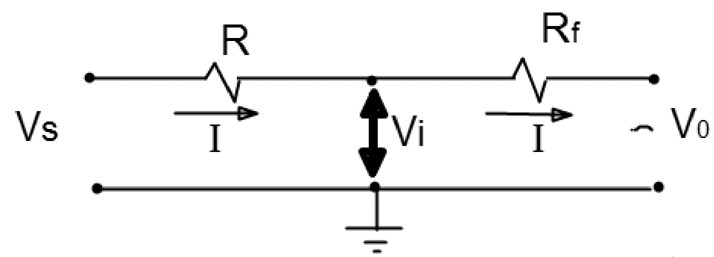
$$V_i\left(1 + \frac{R}{R+R_f} A_v\right) = \frac{R_f}{R+R_f} V_s$$

$$V_i = \frac{R_f V_s}{(R+R_f)\left(1 + \frac{R}{R+R_f} A_v\right)}$$

$$V_i = \frac{R_f V_s}{R(1+A_v) + R_f}$$

Concepto de tierra virtual




10      −10

$A = 200000$

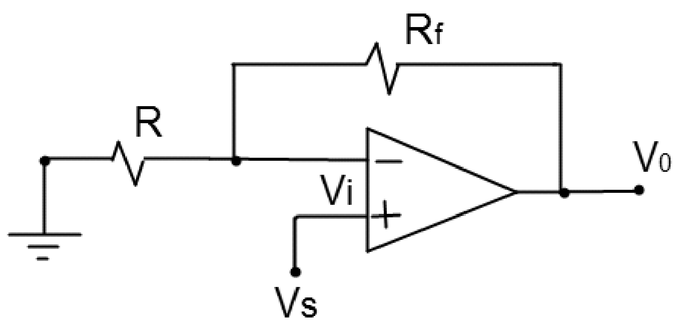
$V_i = 50\,\mu V$

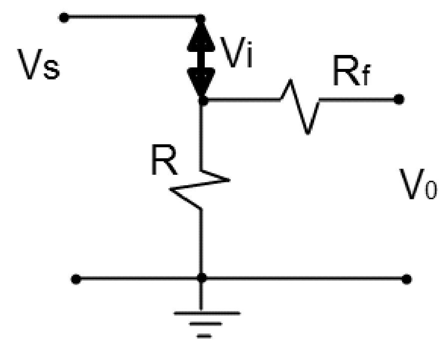
$$I = \boxed{\frac{V_s}{R} = -\frac{V_o}{R_f}}$$

$$\Downarrow$$

$$\boxed{\frac{V_o}{V_s} = -\frac{R_f}{R}}$$

## Amplificador no inversor

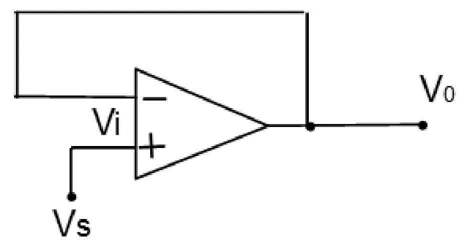


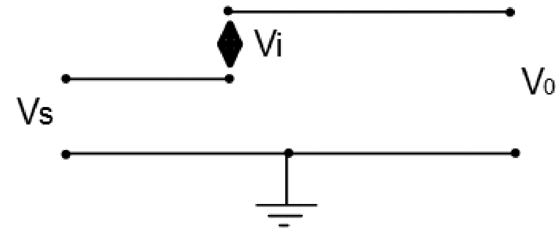




$$V_s = \frac{R}{R + R_f} V_0$$

$$\boxed{\frac{V_0}{V_s} = \frac{R + R_f}{R} = 1 + \frac{R_f}{R}}$$

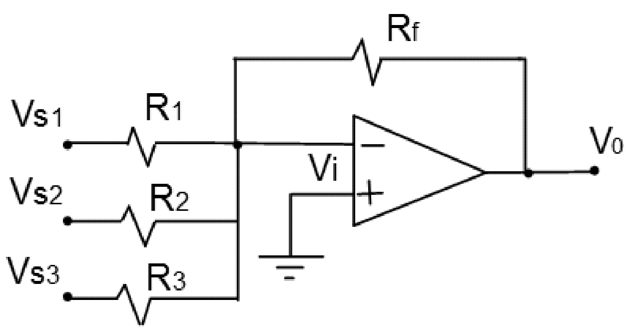
## Seguidor Unitario

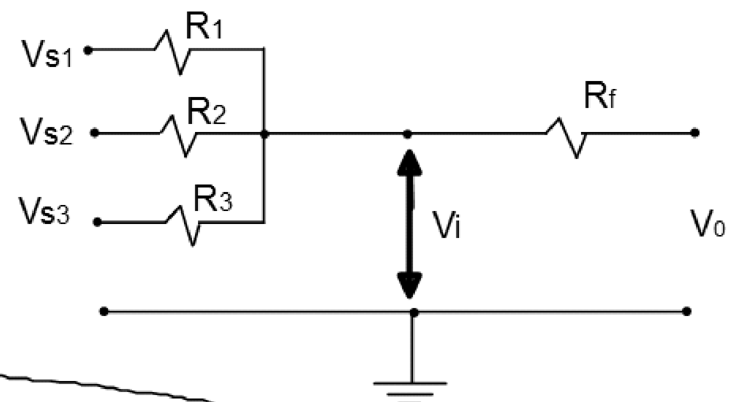



$$\boxed{V_s = V_o} \Rightarrow \boxed{\frac{V_o}{V_s} = 1}$$

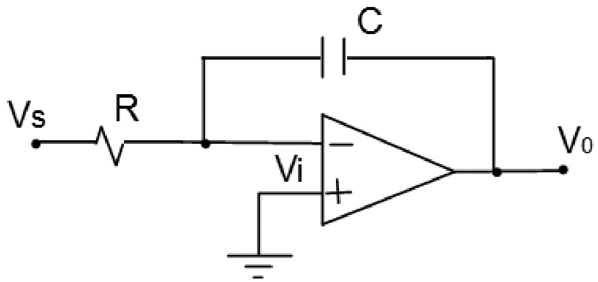
## Amplificador sumador

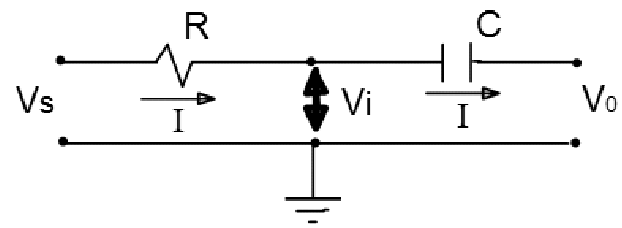



$$\boxed{V_o = -\left(\frac{R_f}{R_1}V_{s_1} + \frac{R_f}{R_2}V_{s_2} + \frac{R_f}{R_3}V_{s_3} + \dots\right)}$$

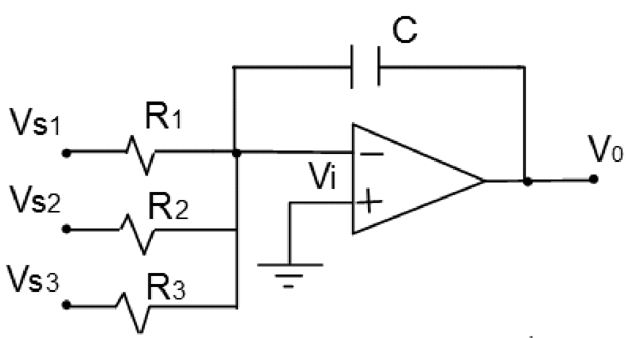
Amplificador integrador



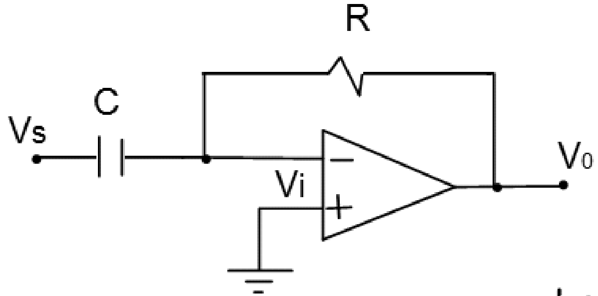

$$I = \frac{V_s}{R} = C\frac{dV_o}{dt}$$

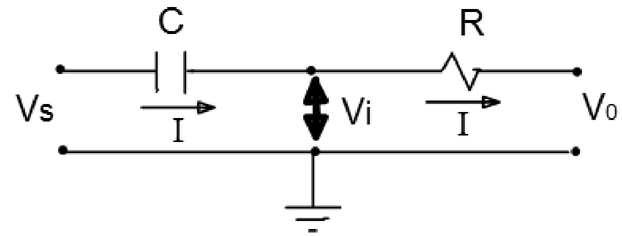
$$\boxed{V_o = -\frac{1}{RC}\int V_s(t)\,dt}$$




$$V_o = -\left(\frac{1}{R_1C}\int V_{s_1}(t)\,dt + \frac{1}{R_2C}\int V_{s_2}(t)\,dt + \frac{1}{R_3C}\int V_{s_3}(t)\,dt\right)$$

Amplificador diferenciador




$$I = C\frac{dV_s}{dt} = \frac{V_0}{R}$$

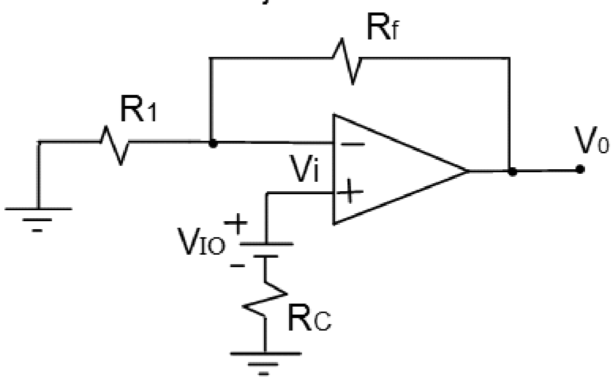
$$\boxed{V_0 = -RC\frac{dV_s(t)}{dt}}$$

# Especificaciones de los amplificadores operacionales

## Parámetros de desvío de DC

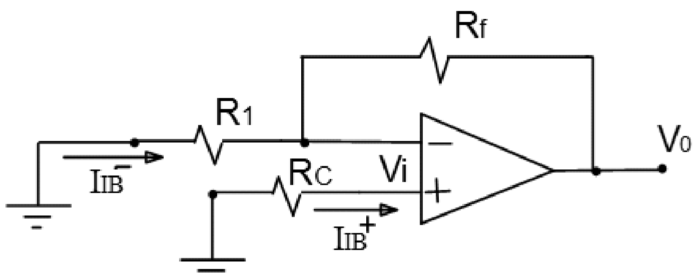
- Desvío de voltaje
- Desvío de corriente

Desvío de voltaje




$$\boxed{V_{o_1} = \left(1 + \frac{R_f}{R_1}\right) V_{IO}}$$

Desvío de corriente $I_{IO} = I_{IB}^{+} - I_{IB}^{-}$

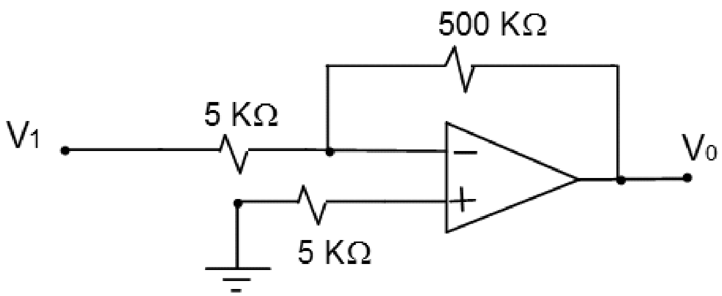



$$V_{o_2} = -I_{IB}^{-} R_1 \left(\frac{R_f}{R_1}\right) + I_{IB}^{+} R_C \left(1 + \frac{R_f}{R_1}\right)$$

considerando que

$$R_1 = R_C$$

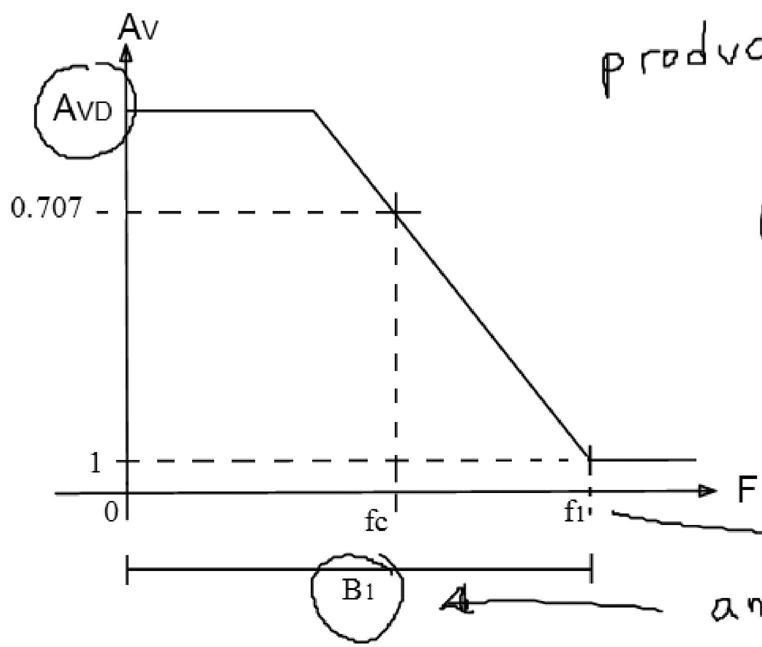
Ejemplo: Considerar $V_{IO} = 4mV$, $I_{IO} = 150nA$




$$V_o(\text{desvío}) = 4mV\left(1 + \frac{500}{5}\right) + $$
$$+ 150nA(500k\Omega)$$
$$V_o(\text{desvío}) = 0.479\ V$$

Parámetros de frecuencia

Ganancia y ancho de banda




producto ganancia – ancho de banda

$$\boxed{f_1 = A_{VD} f_c}$$

frecuencia de ganancia unitaria

ancho de banda de ganancia unitaria

Velocidad de respuesta, SR

Velocidad màxima a la que puede cambiar la salida del amplificador, en $V/\mu s$

$$SR = \frac{\Delta V_o}{\Delta t}$$

Frecuencia máxima de señal

Si $V_o = K \operatorname{sen}(\underline{2\pi f}\, t)$

la tasa de cambio màximo de voltaje es

$$2\pi f K \quad \left[\frac{V}{S}\right]$$

para prevenir distorsión a la salida:

$$2\pi f K \leq SR \longrightarrow f \leq \frac{SR}{2\pi K} \quad [Hz]$$

$$\omega K \leq SR \longrightarrow \omega \leq \frac{SR}{K} \quad [rad]$$

Ejemplos:

Considerar un amplificador operacional con una rapidez en la respuesta *SR* = $2v/\mu s$, obtener $A_{CL}$ máximo cuando la señal de entrada varía $0.5v$ en $10\mu s$.

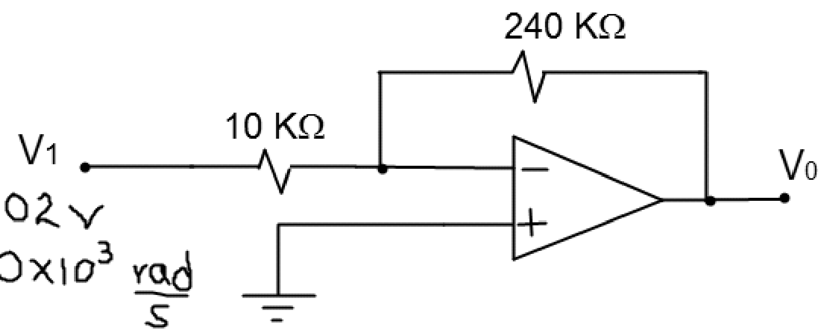
*Solución:*

Si $V_o = A_{CL}V_i$ entonces $\frac{\Delta Vo}{\Delta t} = A_{CL} \frac{\Delta V_i}{\Delta t}$ es decir: $\frac{2v}{\mu s} = A_{CL} \frac{0.5v}{10\mu s}$

por tanto: $A_{CL} = \frac{20v\mu s}{0.5v\mu s} = 40$

Ejemplo:

Determinar frecuencia máxima (ancho de banda) del siguiente circuito considerando que SR = 0.5 v/μs




0.02 v

$\omega = 300 \times 10^3 \ \frac{rad}{s}$

$$A_{CL} = -\frac{240\,k\Omega}{10\,k\Omega} = |-24| = 24$$

$$K = V_0 = 24(0.02\ v) = 0.48\ v$$

$$\omega \leq \frac{0.5\ v/\mu s}{0.48\ v} = \frac{500000\ v/s}{0.48\ v} \cong 1 \times 10^6\ \frac{rad}{s}$$

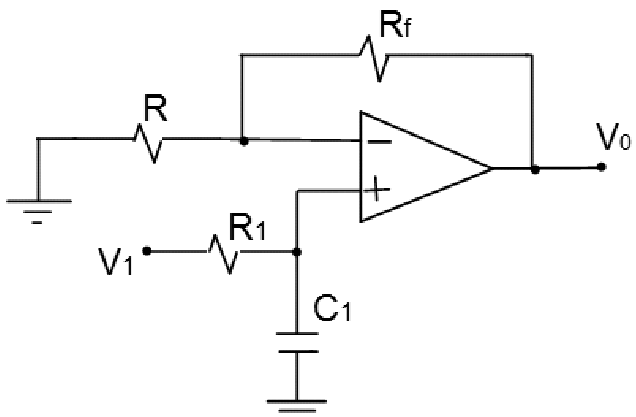
$$f \leq \frac{500000\ v/s}{3\ v} \cong 167\ kHz$$

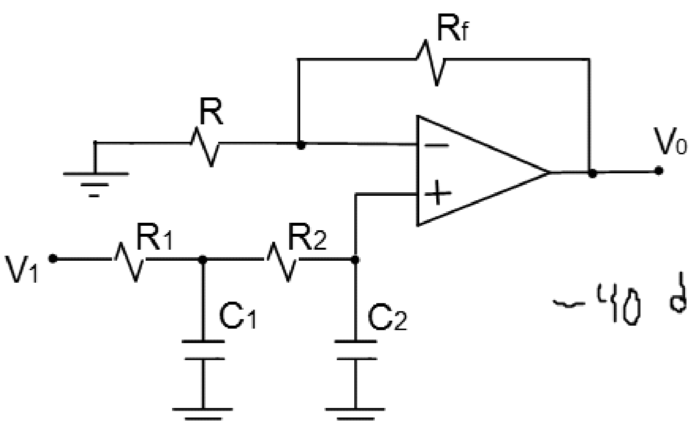
## Aplicaciones de los amplificadores operacionales

### Filtros activos

#### Paso bajas

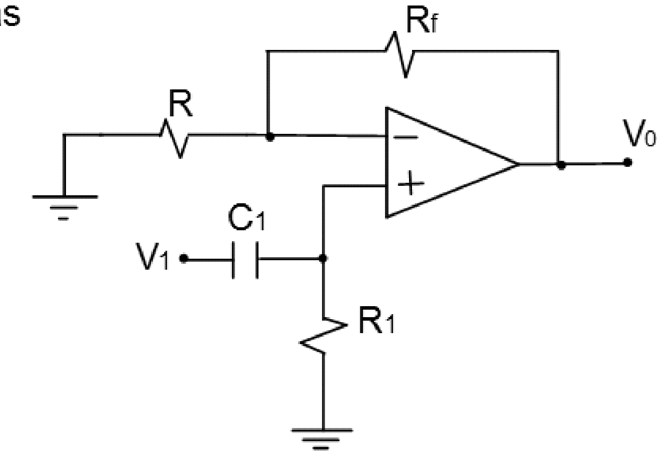
−20 dB/década

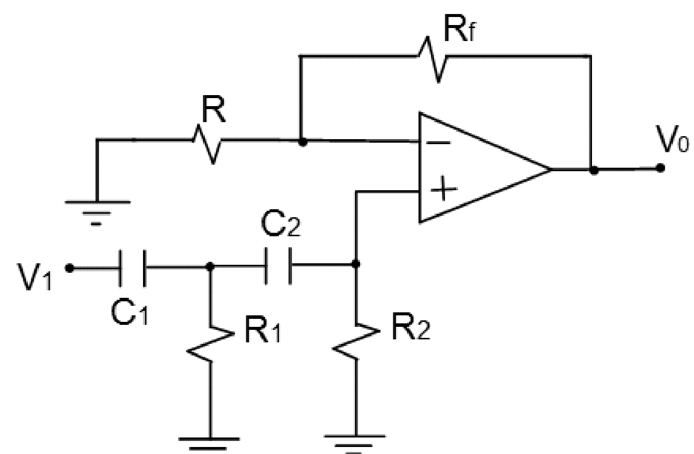


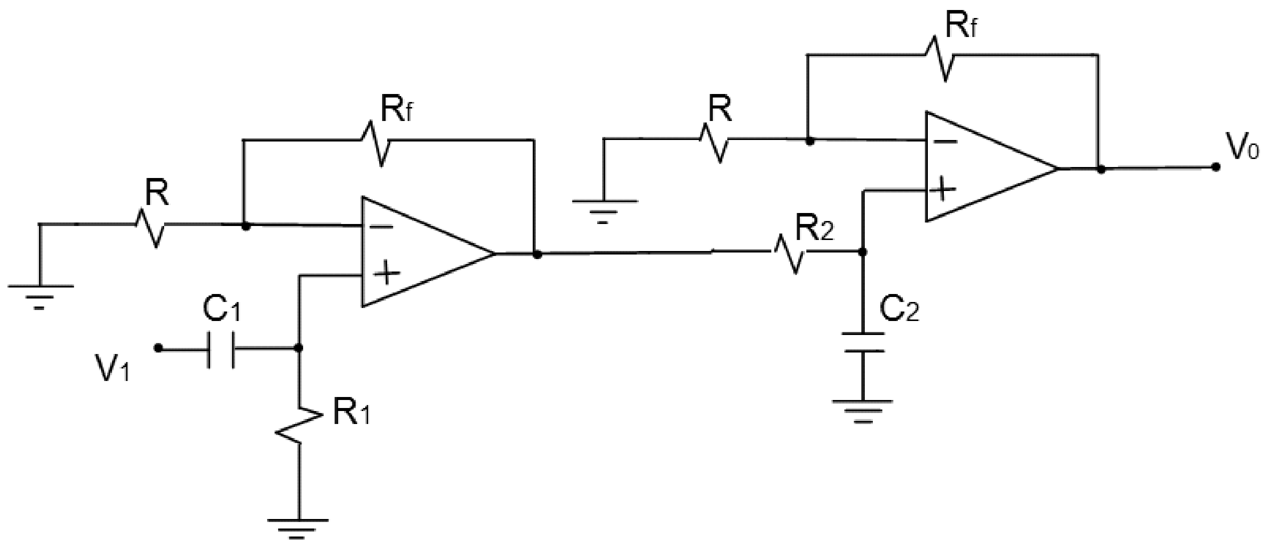

−40 dB/década

#### Paso altas

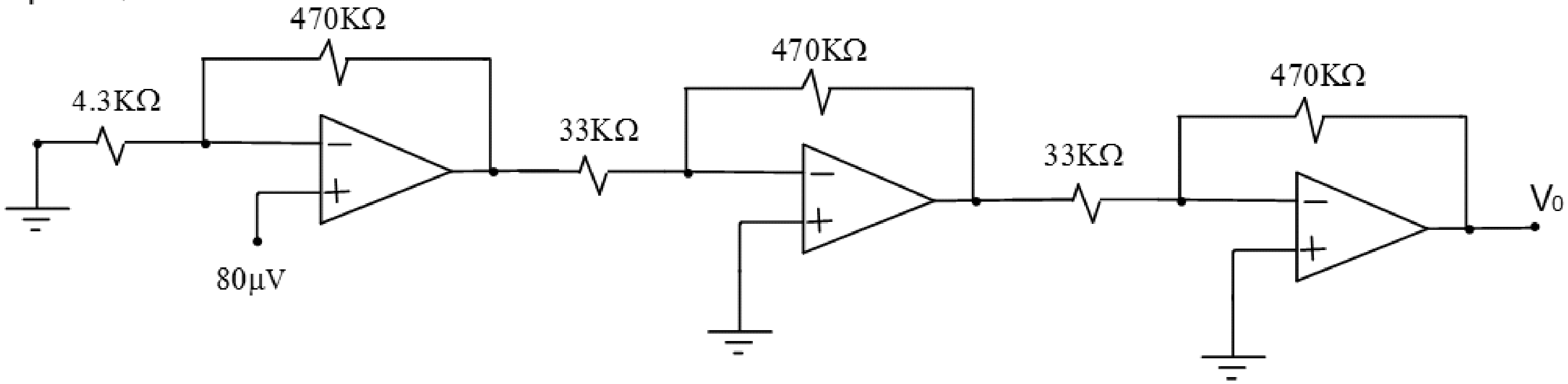


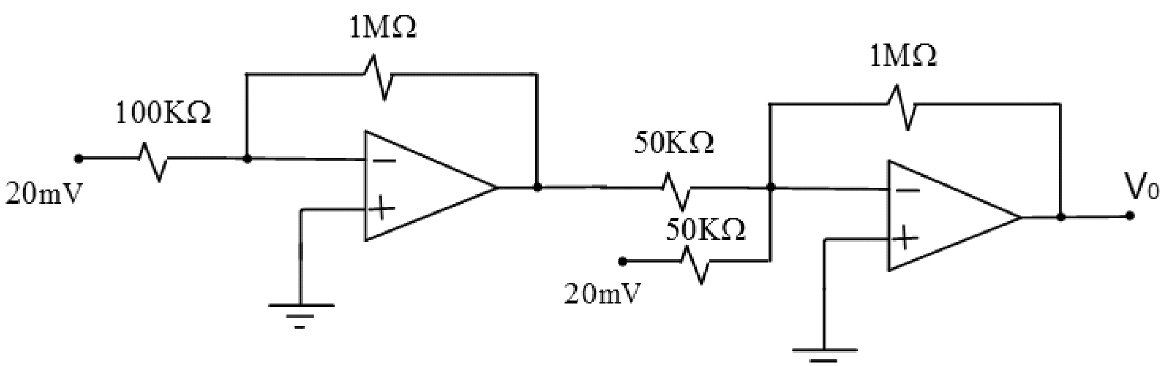
Paso banda



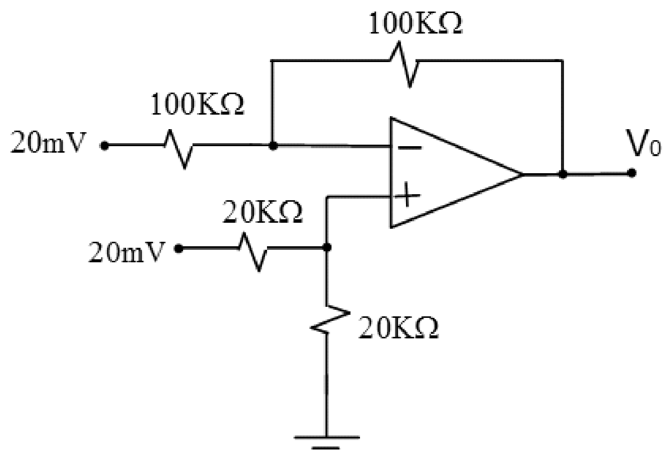
Ejemplo: (1)




Ejemplo: (2)



Ejemplo:




$V_o = V_{o1} + V_{o2}$

inversor

no inversor

Inversor

$V_{o1} = 20mV(-1) = -20mV$

No inversor

$V_{o2} = 10mV(1+1) = 20mV$

$\boxed{V_o = 0\,v}$