TEMA 5: AMPLIFICADOR OPERACIONAL Y CIRCUITOS DE APLICACIÓN

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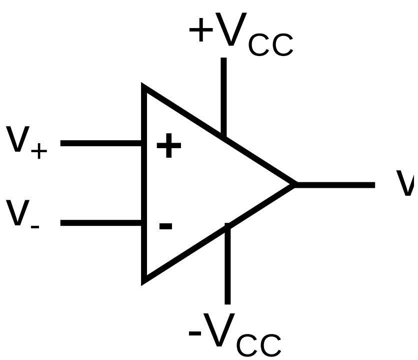
- Filtros activos como aplicación lineal de AO

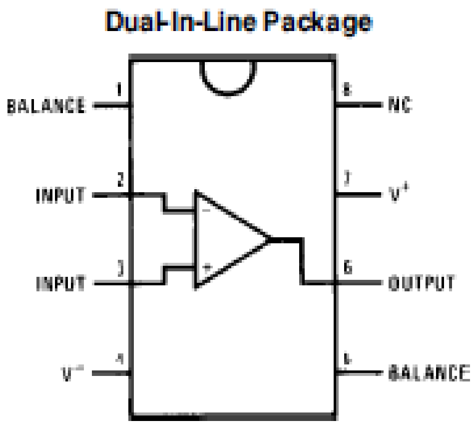
EL AMPLIFICADOR OPERACIONAL IDEAL

AO: Amplificador de tensión integrado con entrada diferencial

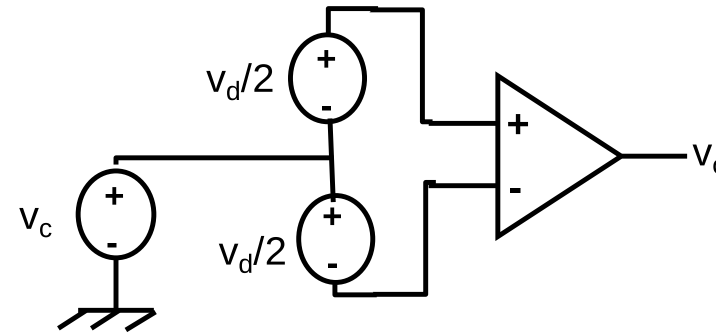
Símbolo



Encapsulado (DIP8)



Ganancia:
Modo común y modo diferencial



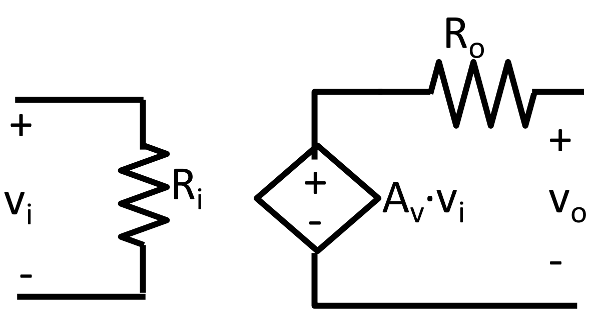
$$v_o = A_{vd}\cdot v_d + A_{vc}\cdot v_c$$

$$\Rightarrow v_o = A_{vd}\cdot(v_+ - v_-) + A_{vc}\cdot\left(\frac{v_+ + v_-}{2}\right)$$

Amplificador operacional ideal

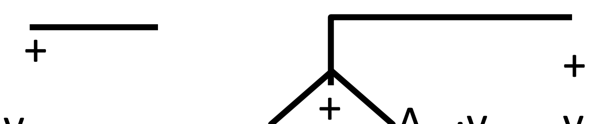
Respuesta a frecuencias medias	Respuesta en frecuencia	Velocidad de respuesta

Amplificador de tensión



AO IDEAL

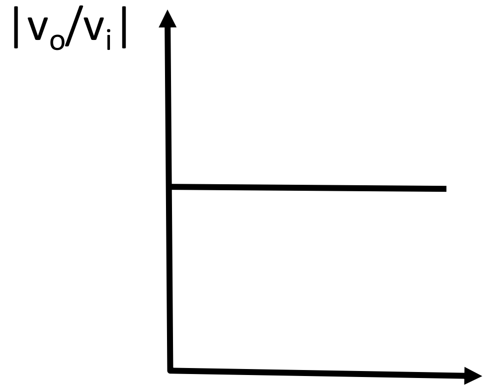
$R_o = 0$

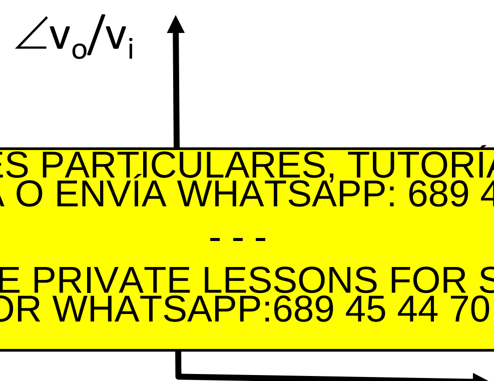


$A_{vc} = 0$

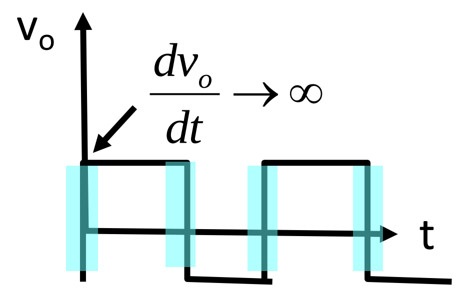
CMRR = 20·log (A$_{vd}$/A$_{vc}$) → ∞

BW→∞



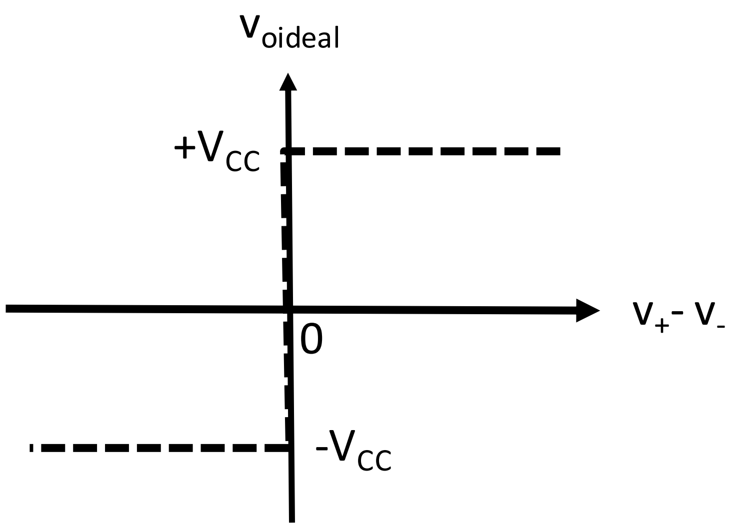


$$\left.\frac{dv_o}{dt}\right|_{max} \to \infty$$



Amplificador operacional ideal

Función de transferencia



Resumen Características

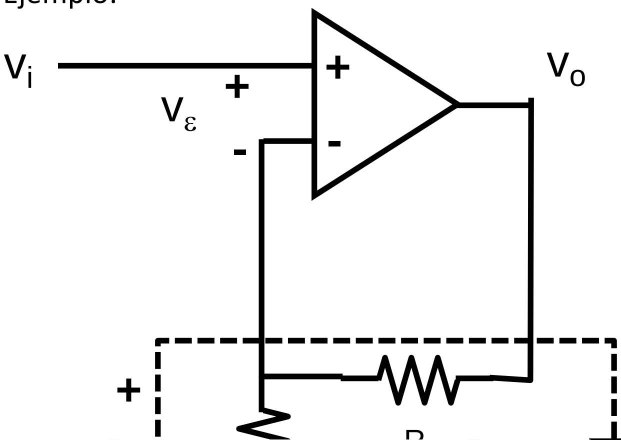
Parámetro	AO ideal	AO real
Ri	∞ (⇒$i_+ = i_- = 0$)	0.1-5MΩ (par BJT) >10^{10} (par FET)
Ro	0	20-200Ω
Avd	∞	10^5-10^6V/V
CMRR	∞	80-120dB
BW	∞	1-10MHz (BW ganancia unidad)
$(dv_o/dt)_{max}$	∞	1V/μs-30V/μs
$(V_+-V_-)DC$	0	$V_{..}$≈1.5mV (BJT)

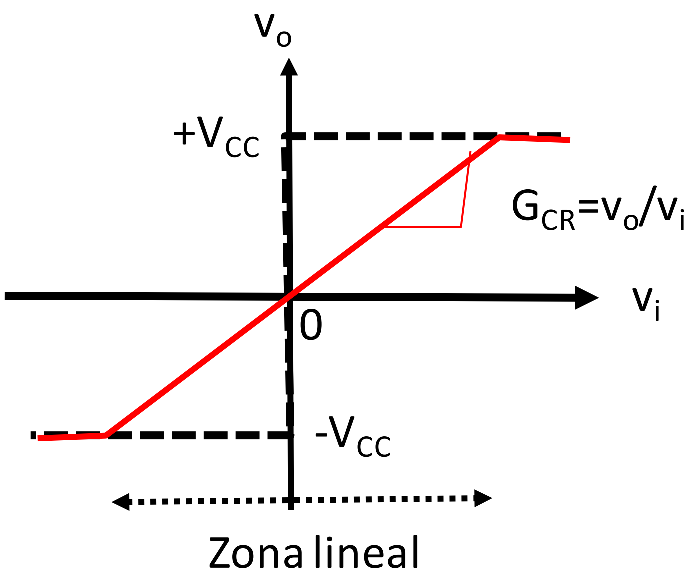
Amplificador operacional ideal: aplicaciones

Lineales

AO con realimentación negativa

Ejemplo:





$$\left.\begin{array}{l} G_{CR}=\dfrac{v_o}{v_i}=\dfrac{A}{1+A\cdot\beta} \\ A\cdot\beta>>1 \end{array}\right\}\Rightarrow \frac{v_o}{v_i}\cong\frac{1}{\beta}=\frac{v_o}{v_r}\Rightarrow v_\varepsilon\cong 0\Rightarrow v_+=v_-$$

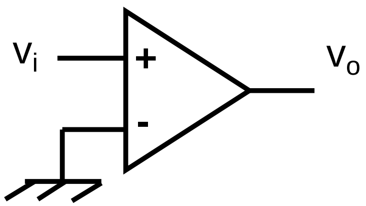
Amplificador operacional ideal: aplicaciones

No Lineales

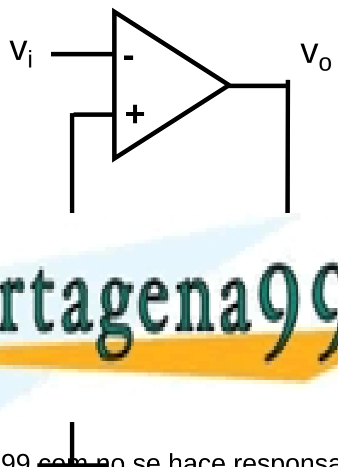
Ej: Comparador

- AO sin realimentar
- AO con realimentación positiva

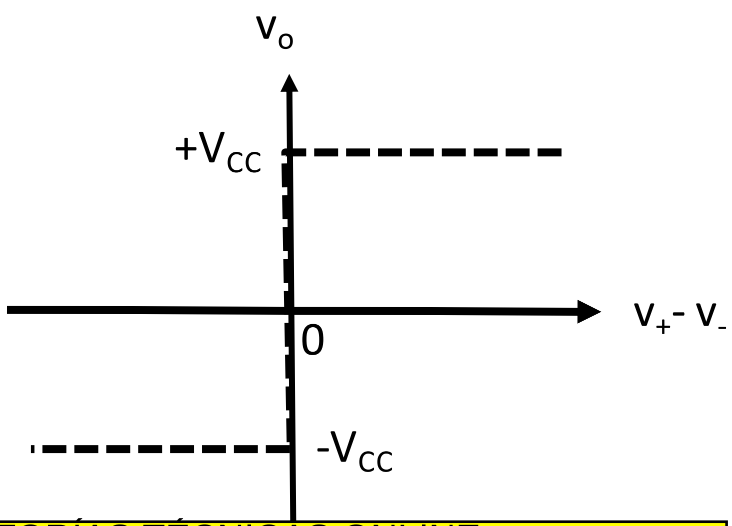
Ejemplo1:



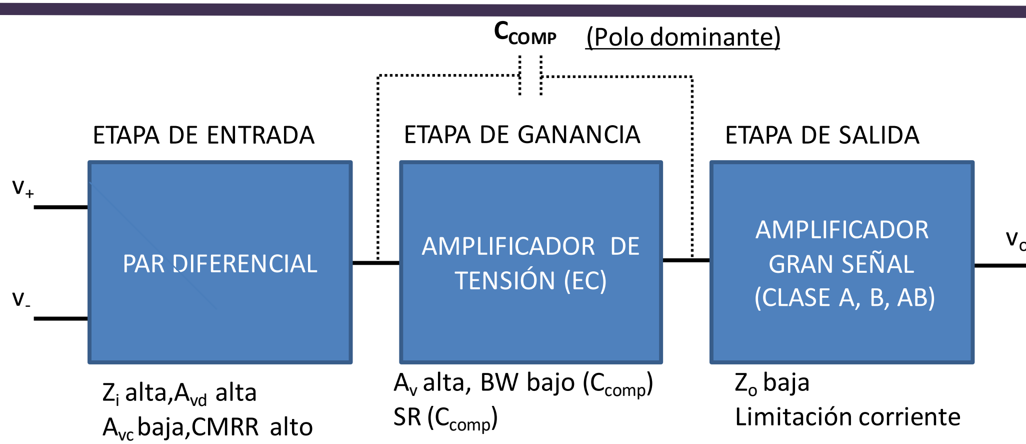
Ejemplo2:



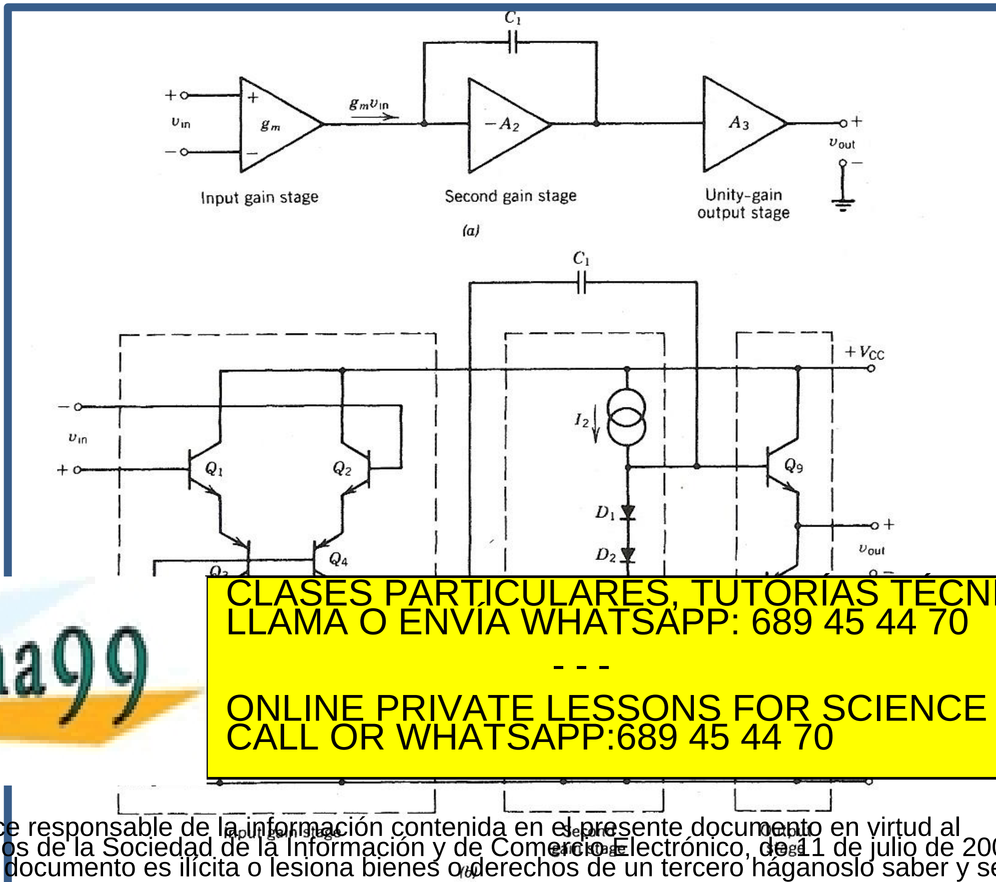
$$v_o \cong \begin{cases} +V_{CC} & v_+ > v_- \\ -V_{CC} & v_+ < v_- \end{cases}$$

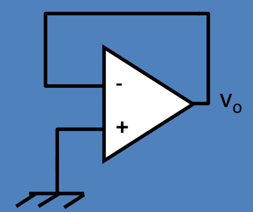
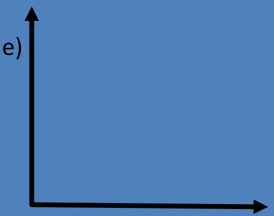
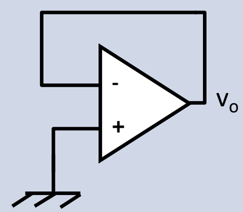
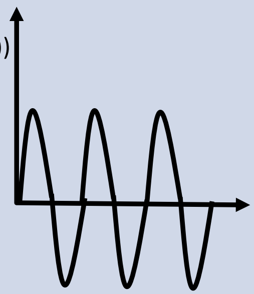
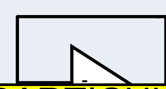
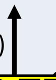


ETAPAS DE UN AMPLIFICADOR OPERACIONAL REAL



Esquema interno simplificado



CON COMPENSACIÓN INTERNA (Polo dominante en etapa de ganancia)	**-BW bajo** **- Estabilidad** **-741, TL081,** **-LM324**		
SIN COMPENSACIÓN INTERNA	-BW ALTO - Inestabilidad -LM301		
			

AMPLIFICADOR OPERACIONAL REAL: ERRORES DE CONTINUA

ERRORES DE CONTINUA (V_{io}, I_B, I_{io})

Par diferencial etapa de entrada (Q_1, Q_2):

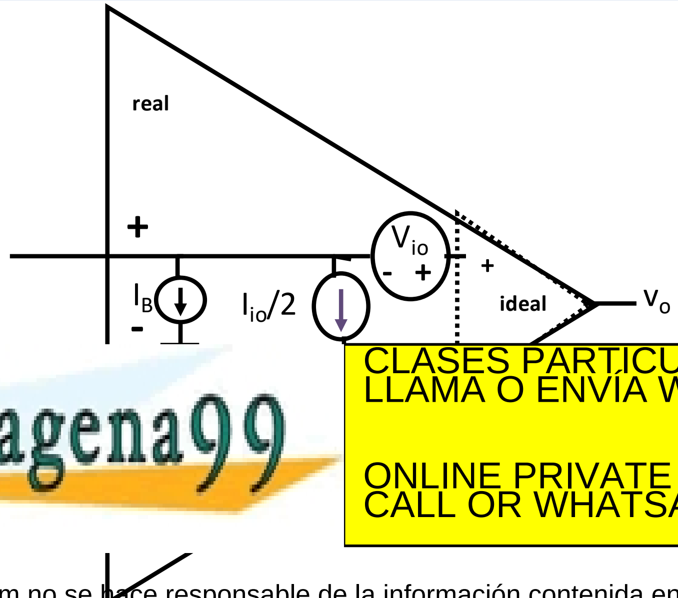
- TENSIÓN DE OFFSET DE ENTRADA (V_{io})

$$\left.\begin{matrix} V_{BEQ_1} \neq V_{BEQ_2} \\ V_{EQ_1} = V_{EQ_2} \end{matrix}\right\} V_{BQ_1} \neq V_{BQ_2} \Rightarrow (V_+ - V_-)_{DC} = V_{io}(mV)$$

- CORRIENTE DE POLARIZACIÓN DE ENTRADA (I_B) Y CORRIENTE DE OFFSET (I_{io})

$$\left.\begin{matrix} I_{-DC} \neq 0(I_{BaseQ_1}) \\ I_{+DC} \neq 0(I_{BaseQ_2}) \end{matrix}\right\} I_{BIAS} = I_B(nA, pA)$$

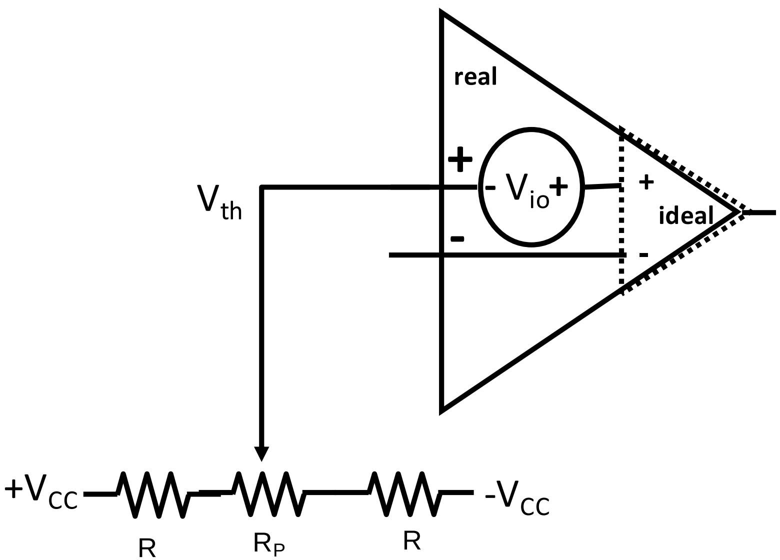
$$+ \quad Q_1 \neq Q_2 \Rightarrow I_{+DC} - I_{-DC} = I_{OFFSET} = I_{io}\,(nA, pA)$$



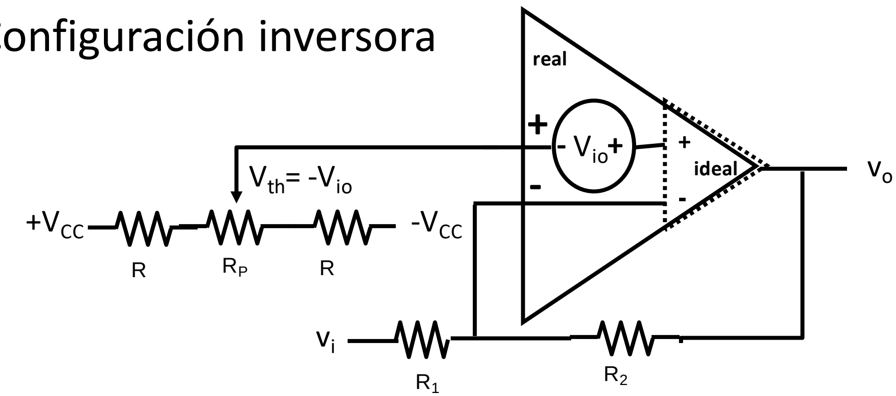
$$v_{oreal} = v_o\big|_{Vio} + v_o\big|_{I_B} + v_o\big|_{I_{io}}$$

TENSIÓN DE OFFSET DE ENTRADA (V_{io})

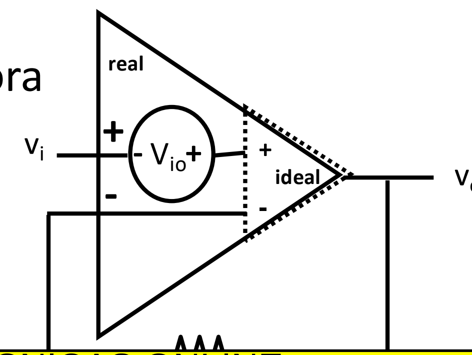
COMPENSACIÓN EXTERNA : Eliminación del efecto de V_{io} a la salida del operacional



Configuración inversora



Configuración no inversora



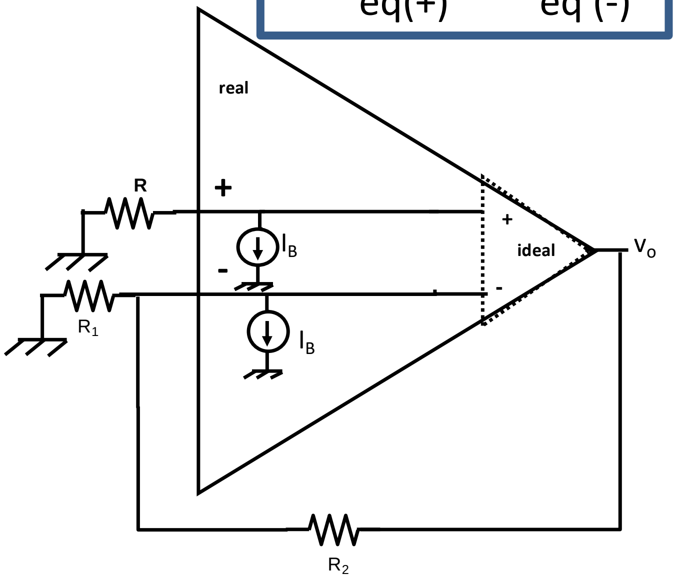
tener $V_{th} = \pm V_{io}$

CORRIENTES DE POLARIZACIÓN DE ENTRADA (I_B) Y CORRIENTE DE OFFSET DE ENTRADA (I_{io})

COMPENSACIÓN:

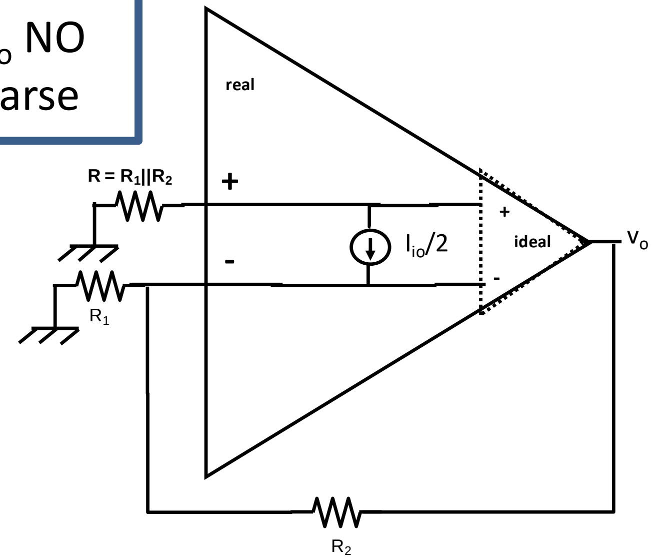
Eliminación del efecto de I_B a la salida del operacional

$R_{eq(+)} = R_{eq\,(-)}$



Disminución del efecto de I_{io} a la salida del operacional

El efecto de I_{io} NO puede eliminarse



$$\left.\begin{array}{l} v_+ = -R\dfrac{I_{io}}{2} \\ \dfrac{v_o - v_-}{\ldots} \quad I_{io} \quad v_- \end{array}\right\} \Rightarrow \frac{v_o}{R_2} - \frac{I_{io}}{2}\cdot\left(\frac{R}{R_2} + \frac{R}{R_1} + 1\right) = 0$$

$R_1 \qquad R_1 + R_2$

ERRORES DE CONTINUA (V_{io}, I_B, I_{io})

LM741

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \le 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \le 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \le T_A \le T_{AMAX}$										
	$R_S \le 50\Omega$			4.0							mV
	$R_S \le 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	$T_A = 25°C$, $V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			0.210			1.5			0.8	μA

TL081

Symbol	Parameter	Conditions	TL081C			Units
			Min	Typ	Max	
V_{OS}	Input Offset Voltage	$R_S = 10\ k\Omega$, $T_A = 25°C$ Over Temperature		5	15 20	mV mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	$R_S = 10\ k\Omega$		10		μV/°C
I_{OS}	Input Offset Current	$T_j = 25°C$, (Notes 3, 4) $T_j \le 70°C$		25	100 4	pA nA
I_B	Input Bias Current	$T_j = 25°C$, (Notes 3, 4) $T_j \le 70°C$		50	200 8	pA nA

LM301
(C = 30pF)

Symbol	Parameter	LM101A - LM201A			LM301A			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input Offset Voltage ($R_S \le 10k\Omega$) $T_{amb} = +25°C$		0.7	2		2	7.5	mV
[illegible]	Input Offset Current Drift $25°C \le T_{amb} \le T_{max.}$ $T_{min} \le T_{amb} \le T_{max}$		10 20	100 200		10 20	300 600	pA/°C

AMPLIFICADOR OPERACIONAL REAL: RESISTENCIAS DE ENTRADA Y SALIDA, GANANCIA

R_i, R_o, A_{vd}, CMRR

LM741

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Resistance	$T_A = 25°C$, $V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \le T_A \le T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Large Signal Voltage Gain	$T_A = 25°C$, $R_L \ge 2\ k\Omega$										
	$V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \le T_A \le T_{AMAX}$, $R_L \ge 2\ k\Omega$,										
	$V_S = \pm 20V$, $V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V$, $V_O = \pm 2V$	10									V/mV
Common-Mode Rejection Ratio	$T_{AMIN} \le T_A \le T_{AMAX}$										
	$R_S \le 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \le 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
r_O Output resistance	$V_O = 0$, See Note 5								75		Ω

TL081

Symbol	Parameter	Conditions	TL081C			Units
			Min	Typ	Max	
R_{IN}	Input Resistance	$T_j = 25°C$		10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	$V_S = \pm 15V$, $T_A = 25°C$, $V_O = \pm 10V$, $R_L = 2\ k\Omega$	25	100		V/mV
		Over Temperature	15			V/mV
CMRR	Common-Mode Rejection Ratio	$R_S \le 10\ k\Omega$	70	100		dB

LM301

Symbol	Parameter	LM101A - LM201A			LM301A			Unit
		Min	Typ	Max	Min	Typ	Max	
Z_i	Input Impedance *	1.5	4		1.5	4		MΩ
R_o	Output Resistance *		75			75		Ω

R_i, R_o, A_{vd}, CMRR

Common-Mode Rejection Ratio

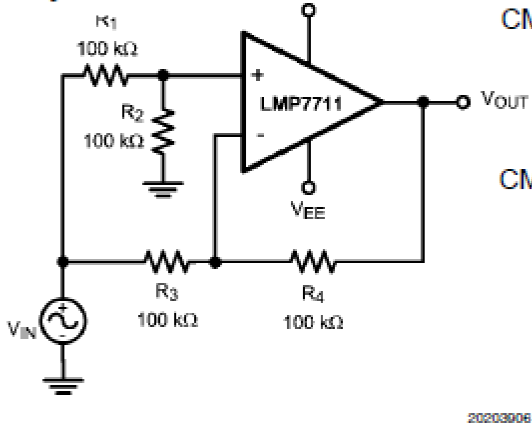


FIGURE 6. CMRR TEST CIRCUIT

$CMRR = \Delta V_{COM}/\Delta V_{OS}$.

$CMRR = A_{DIF}/A_{COM}$.

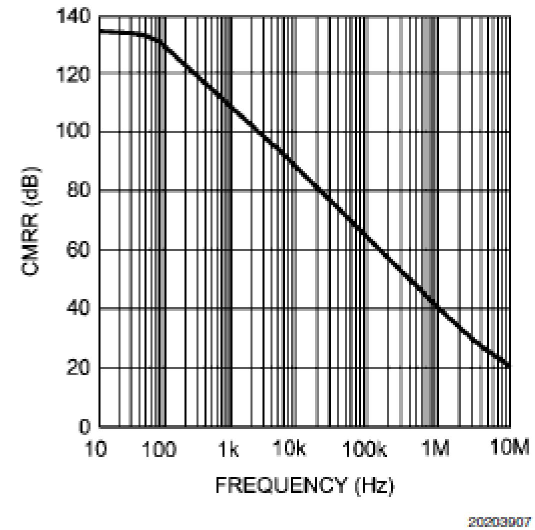
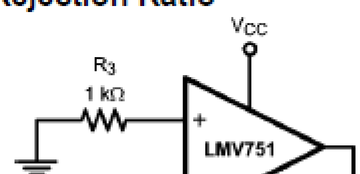
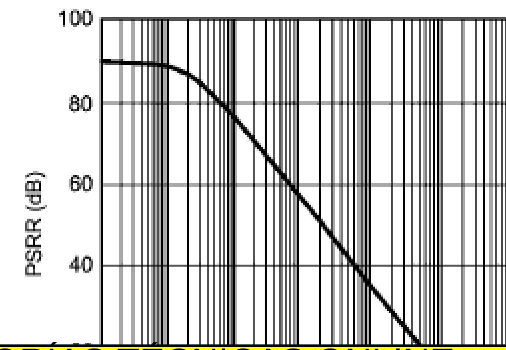


FIGURE 7. SIMULATED CMRR RESPONSE vs. FREQUENCY

Supply Voltage Rejection Ratio





20203908

FIGURE 9. PSRR TEST CIRCUIT

FIGURE 10. SIMULATED PSRR RESPONSE vs. FREQUENCY

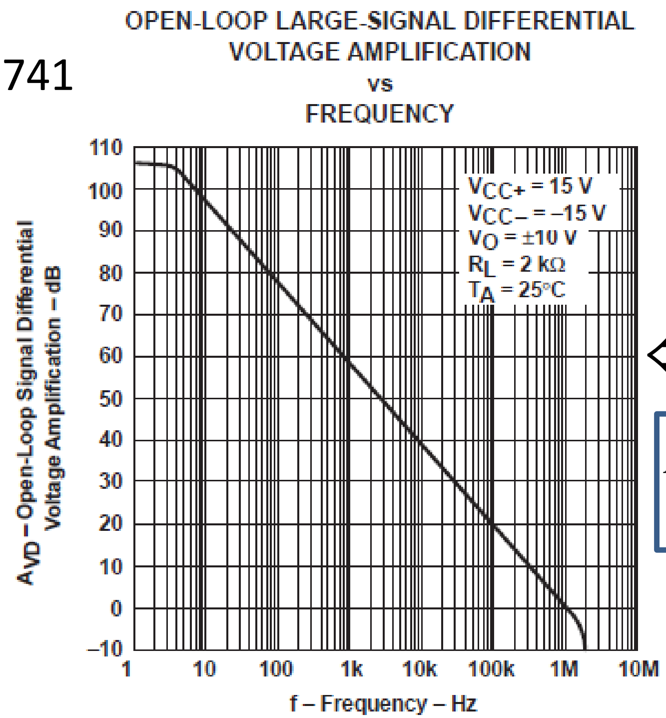
AMPLIFICADOR OPERACIONAL REAL: PRODUCTO GANANCIA x ANCHO DE BANDA

Producto GxBW

SIN REALIMENTAR

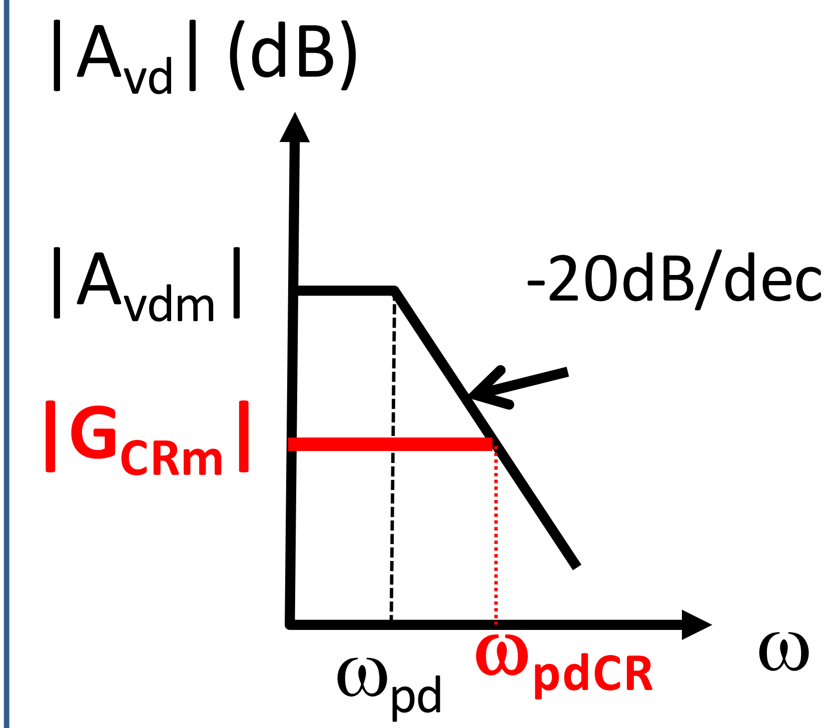
GxBW = cte= 1MHz (741)

Ej: 741



⟺ Sistema de primer orden (1 solo polo)

$$A(j\omega) = \frac{A_{vdm}}{1 + j\,\omega/\omega_{pd}}$$



CON REALIMENTACIÓN NEGATIVA

AMPLIFICADOR OPERACIONAL REAL: SLEW RATE

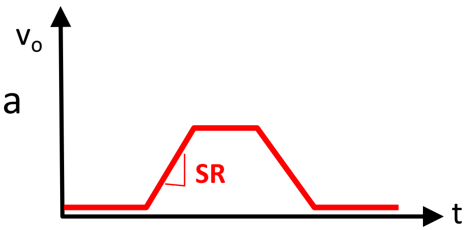
Slew Rate (SR)

- Operación AO "Gran Señal"
- Máxima velocidad de respuesta

$$SR\left(V/\mu s\right) = \left.\frac{dv_o}{dt}\right|_{máx}$$

EFECTO

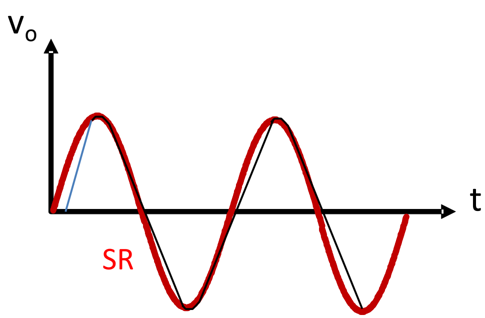
- v_i cuadrada



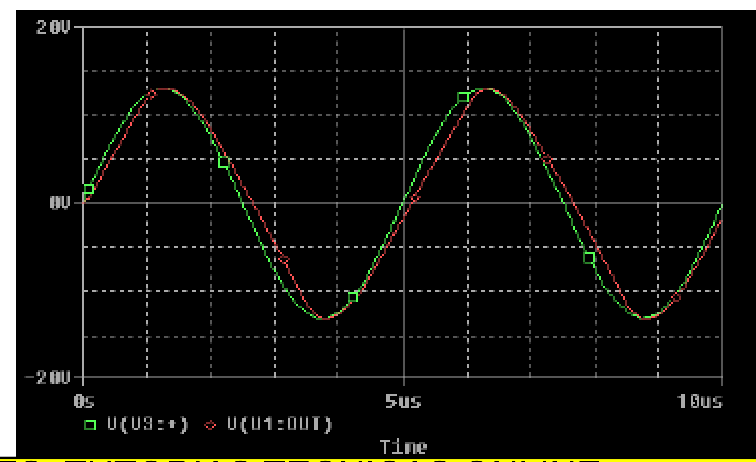
- v_i no cuadrada (ej. Sinusoidal)

$$si \quad \left.\frac{dv_o}{dt}\right|_{máx} < SR$$

$$si \quad \left.\frac{dv_o}{dt}\right|_{máx} > SR$$



Simulación en PSpice



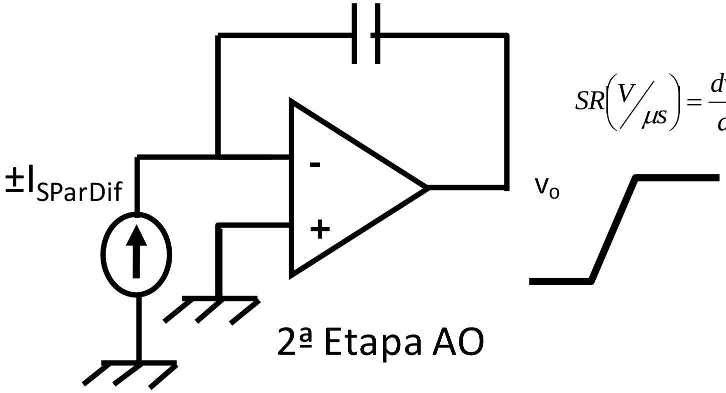
Slew Rate (SR)

- Operación AO "Gran Señal"
- Máxima velocidad de respuesta

$$SR\left(\frac{V}{\mu s}\right) = \left.\frac{dv_o}{dt}\right|_{máx}$$

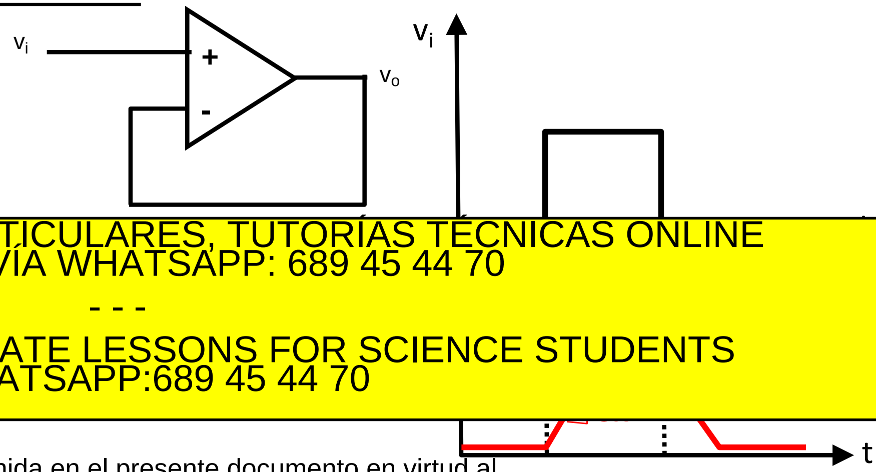
ORIGEN

Si $v_{iAO} >> V_T \Rightarrow$ Q_1 o Q_2 ParDif OFF



$$SR\left(\frac{V}{\mu s}\right) = \left.\frac{dv_o}{dt}\right|_{máx} = \pm\frac{I_{SParDif}}{C_1}$$

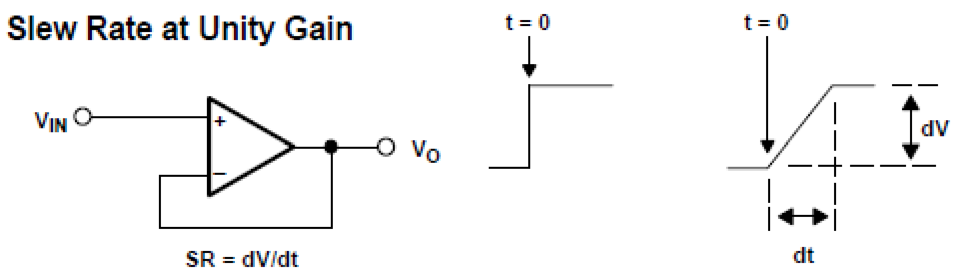
MEDIDA

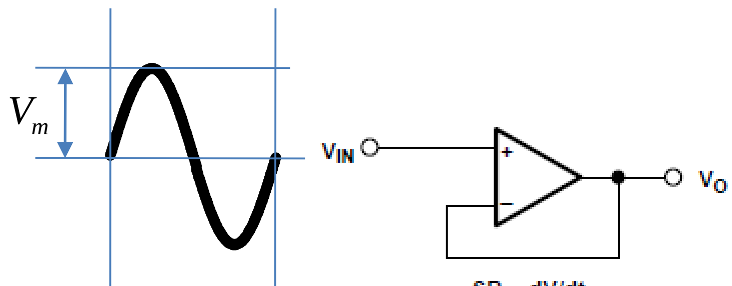


Slew Rate (SR)

- Operación AO “Gran Señal”
- Máxima velocidad de respuesta

$$SR\left(V/\mu s\right) = \left.\frac{dv_o}{dt}\right|_{máx}$$





$$f_{s(\max)} = \frac{}{2\pi \cdot V_m}$$