

TEMA 5: AMPLIFICADOR OPERACIONAL Y CIRCUITOS DE APLICACIÓN

Cartagena99

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- El amplificador operacional real
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 - Características a frecuencias medias (R_i , A_{vd} , R_o , CMRR)
 - Producto Ganancia x Ancho de Banda (GxBW)
 - Slew Rate (SR)

The logo for Cartagena99 features the text 'Cartagena99' in a stylized, green, serif font. The '99' is significantly larger and more prominent than the 'Cartagena' part. The text is set against a light blue and orange gradient background that resembles a stylized wave or a banner.

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EL AMPLIFICADOR OPERACIONAL IDEAL

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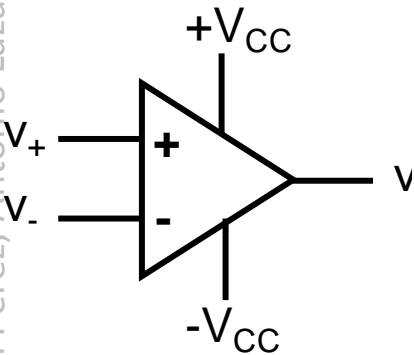
The logo for Cartagena99 features the text "Cartagena99" in a stylized, green, serif font. The text is set against a light blue background that tapers to the right, and a horizontal orange bar is positioned below the text.

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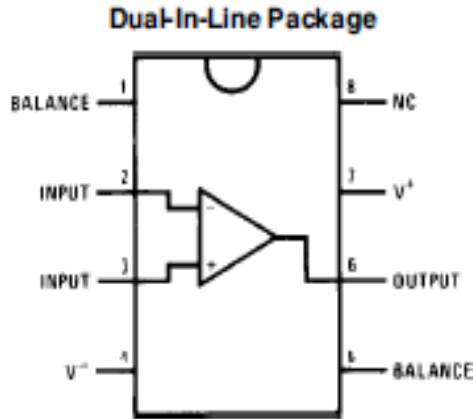
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AO: Amplificador de tensión integrado con entrada diferencial

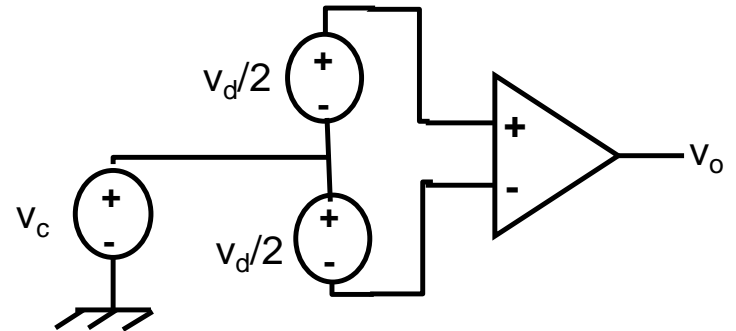
Símbolo



Encapsulado (DIP8)



Ganancia:
Modo común y modo diferencial



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



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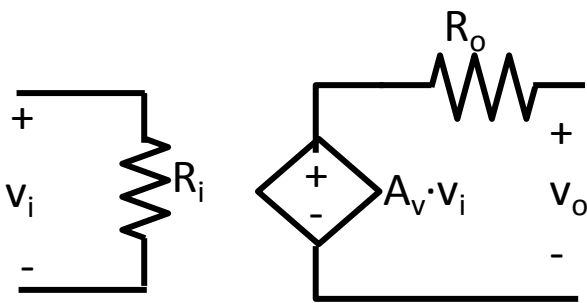
Amplificador operacional ideal

Respuesta a frecuencias medias

Respuesta en frecuencia

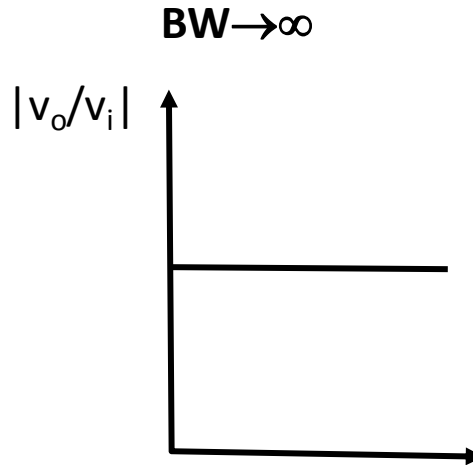
Velocidad de respuesta

Amplificador de tensión



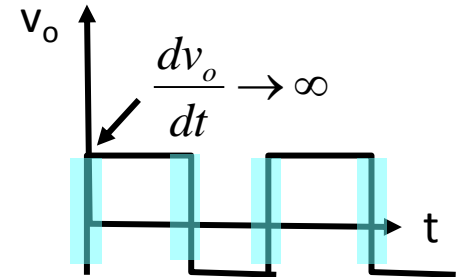
AO IDEAL

Ro = 0



$\angle v_o/v_i$

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



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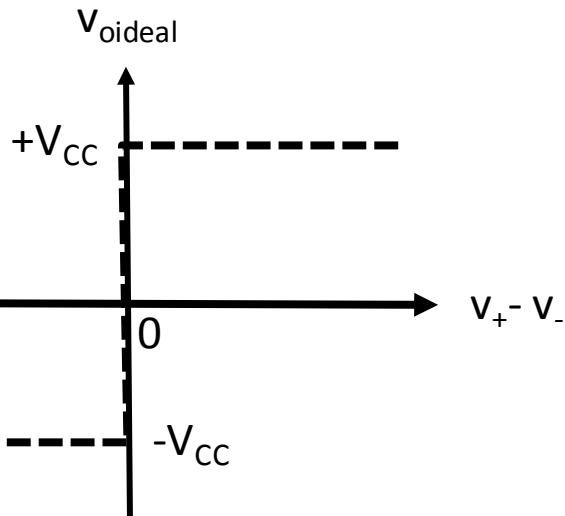
$$A_{VC} = \infty$$

$$GMR = 20 \log(A_{VC}/A_{VCL}) \rightarrow \infty$$

Amplificador operacional ideal

Función de transferencia

Resumen Características



Parámetro	AO ideal	AO real
Ri	∞ $(\Rightarrow i_+ = i_- = 0)$	0.1-5M Ω (par BJT) >10 ¹⁰ (par FET)
Ro	0	20-200 Ω
Avd	∞	10 ⁵ -10 ⁶ V/V
CMRR	∞	80-120dB
BW	∞	1-10MHz (BW ganancia unidad)
$(dv_o/dt)_{max}$	∞	1V/ μ s-30V/ μ s
$(V_o - V_i)_{DC}$	0	$V_o \approx 1.5mV$ (BJT)

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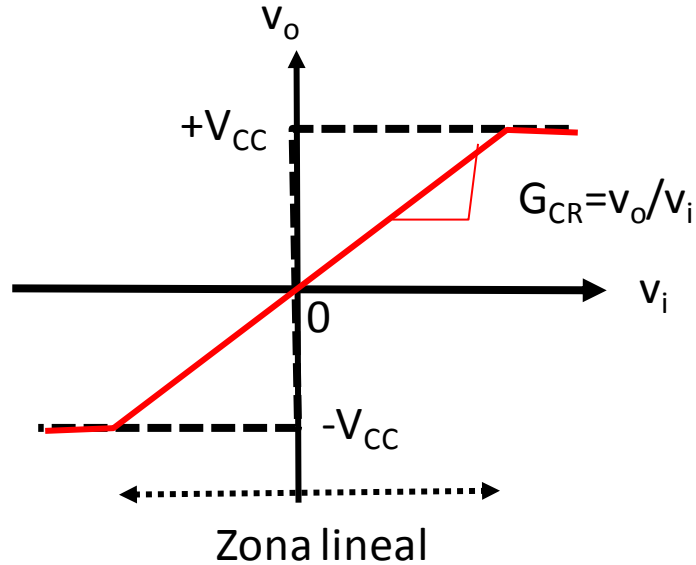
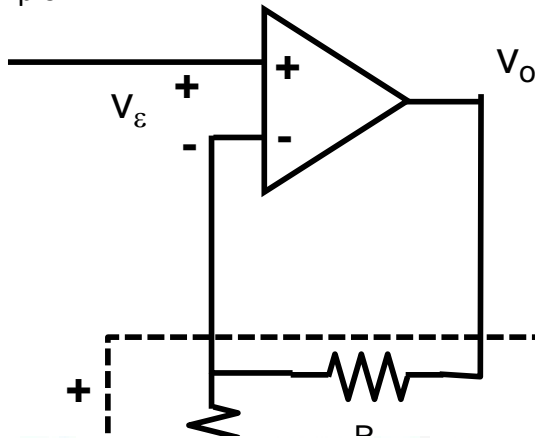
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Amplificador operacional ideal: aplicaciones

Lineales

AO con realimentación negativa

Ejemplo:



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

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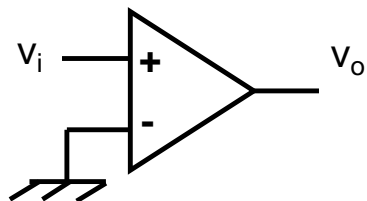
Amplificador operacional ideal: aplicaciones

No Lineales

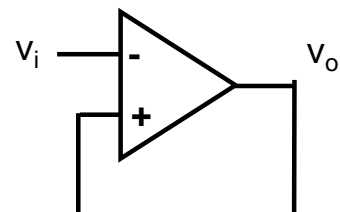
Ej: Comparador

- AO sin realimentar
- AO con realimentación positiva

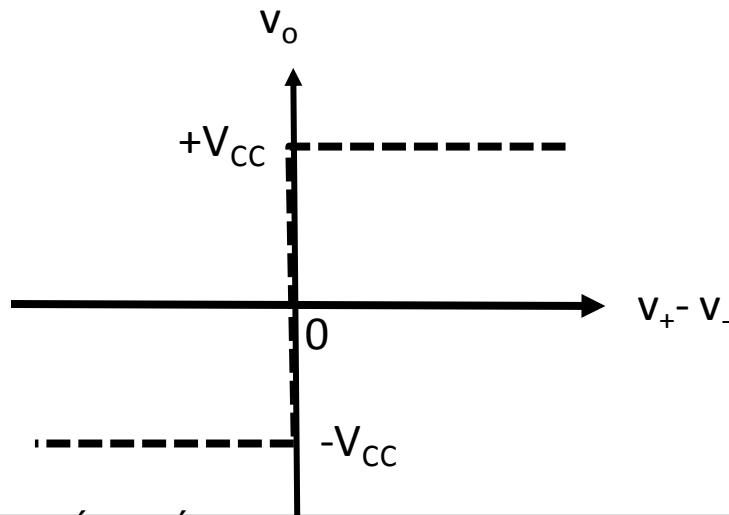
Ejemplo1:



Ejemplo2:



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



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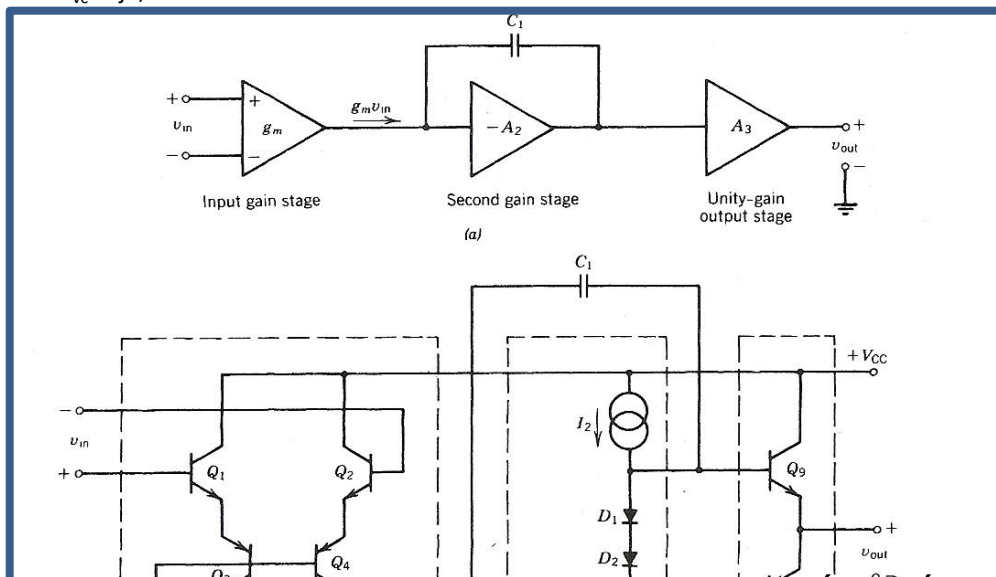
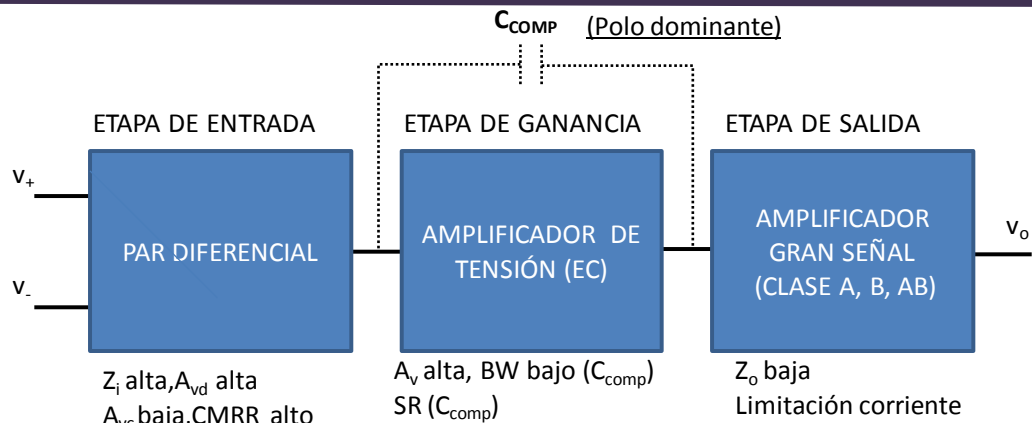
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ETAPAS DE UN AMPLIFICADOR OPERACIONAL REAL

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Esquema interno simplificado

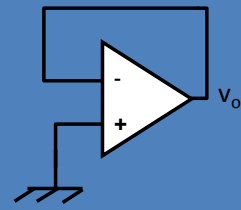
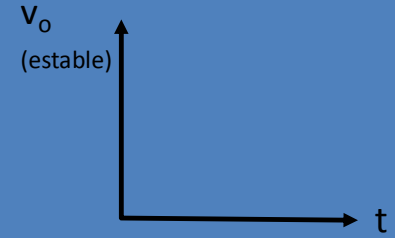
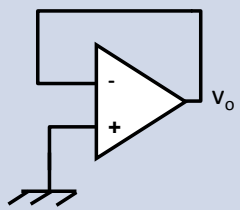
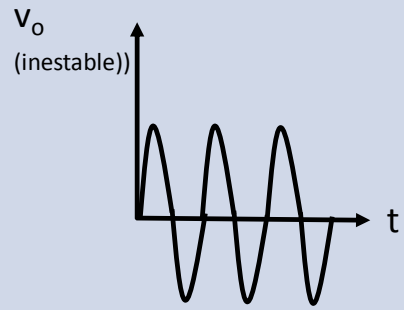
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<p>CON COMPENSACIÓN INTERNA (Polo dominante en etapa de ganancia)</p>	<p>-BW bajo - Estabilidad</p> <p>-741, TL081</p>		
<p>SIN COMPENSACIÓN INTERNA</p>	<p>-BW ALTO - Inestabilidad</p> <p>-LM301</p>		

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AMPLIFICADOR OPERACIONAL REAL: ERRORES DE CONTINUA

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

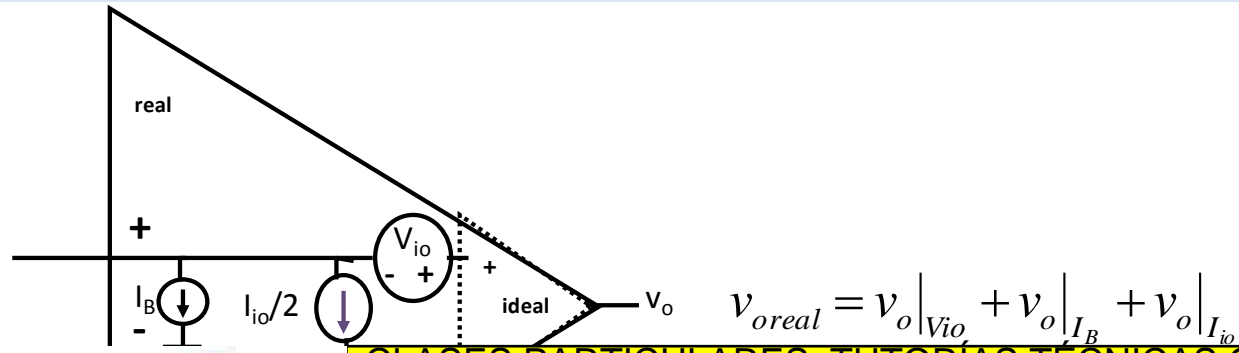
Par diferencial etapa de entrada (Q_1, Q_2):

- 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})

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

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



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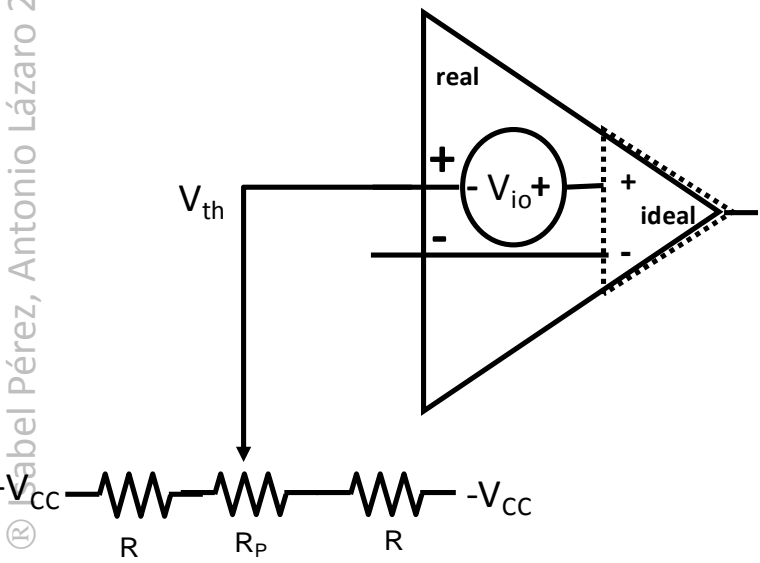
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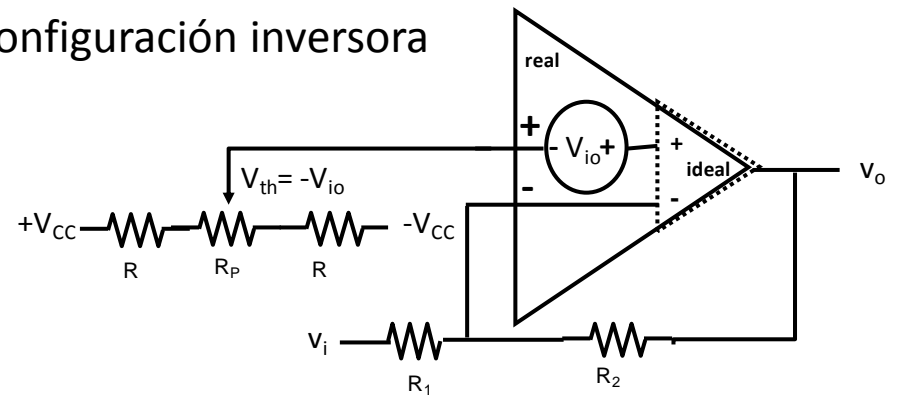
TENSIÓN DE OFFSET DE ENTRADA (V_{io})

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

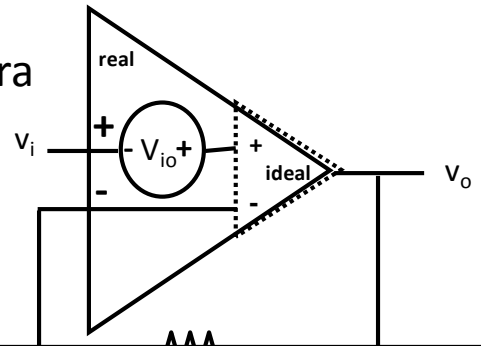
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Configuración inversora



Configuración no inversora



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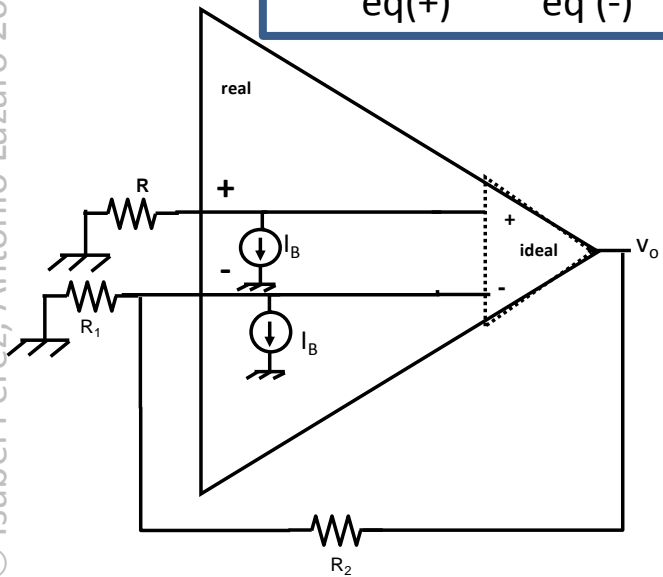
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CORRIENTES DE POLARIZACIÓN DE ENTRADA (I_B) Y CORRIENTE DE OFFSET DE ENTRADA (I_{io})

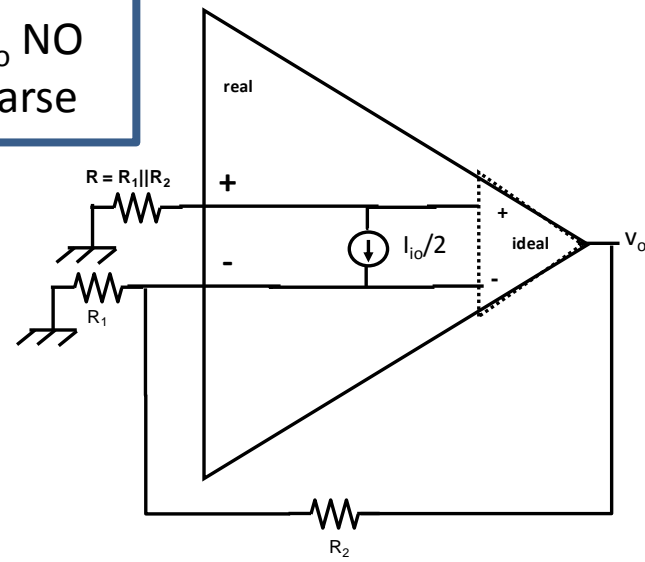
COMPENSACIÓN:
 Eliminación del efecto de I_B a la salida del operacional

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



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

El efecto de I_{io} NO puede eliminarse



$$v_+ = -R \frac{I_{io}}{2}$$

$$v_o - v_- = \frac{I_{io}}{2} \left(\frac{R}{R_2} + \frac{R}{R_1} + 1 \right) = 0$$

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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	$T_A = 25^\circ\text{C}$					1.0	5.0		2.0	6.0	mV
	$R_B \leq 10\text{ k}\Omega$		0.8	3.0							mV
	$R_B \leq 50\Omega$										
Average Input Offset Voltage Drift	$T_{AMIN} \leq T_A \leq T_{AMAX}$			4.0							mV
	$R_B \leq 50\Omega$						6.0			7.5	mV
	$R_B \leq 10\text{ k}\Omega$										$\mu\text{V}/^\circ\text{C}$
Average Input Offset Voltage Drift			15								$\mu\text{V}/^\circ\text{C}$
Input Offset Voltage Adjustment Range	$T_A = 25^\circ\text{C}, V_B = \pm 20\text{V}$	± 10				± 15			± 15		mV
Input Offset Current	$T_A = 25^\circ\text{C}$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							$\text{nA}/^\circ\text{C}$
Input Bias Current	$T_A = 25^\circ\text{C}$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA

TL081

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

LM301

($I_C = 30\text{ nA}$)

Symbol	Parameter	LM101A - LM201A			LM301A			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input Offset Voltage ($R_S \leq 10\text{ k}\Omega$) $T_{amb} = +25^\circ\text{C}$		0.7	2		2	7.5	mV
	Input Offset Current Drift $25^\circ\text{C} \leq T_{amb} \leq T_{max}$		10	100		10	300	$\text{pA}/^\circ\text{C}$

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AMPLIFICADOR OPERACIONAL REAL: RESISTENCIAS DE ENTRADA Y SALIDA, GANANCIA

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$R_i, R_o, A_{vd}, CMRR$

LM741

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Resistance	$T_A = 25^\circ\text{C}, V_S = \pm 20\text{V}$	1.0	6.0		0.3	2.0		0.3	2.0		M Ω
	$T_{AMIN} \leq T_A \leq T_{AMAX}, V_S = \pm 20\text{V}$	0.5									M Ω
Large Signal Voltage Gain	$T_A = 25^\circ\text{C}, R_L \geq 2\text{ k}\Omega, V_S = \pm 20\text{V}, V_O = \pm 15\text{V}$	50									V/mV
	$V_S = \pm 15\text{V}, V_O = \pm 10\text{V}$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}, R_L \geq 2\text{ k}\Omega, V_S = \pm 20\text{V}, V_O = \pm 15\text{V}$	32									V/mV
	$V_S = \pm 15\text{V}, V_O = \pm 10\text{V}$				25			15			V/mV
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}, R_S \leq 10\text{ k}\Omega, V_{CM} = \pm 12\text{V}$				70	90		70	90		dB
	$R_S \leq 50\Omega, V_{CM} = \pm 12\text{V}$	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	$T_J = 25^\circ\text{C}$		10 ¹²		Ω
A_{VOL}	Large Signal Voltage Gain	$V_S = \pm 15\text{V}, T_A = 25^\circ\text{C}, V_O = \pm 10\text{V}, R_L = 2\text{ k}\Omega$	25	100		V/mV
		Over Temperature	15	--		V/mV
CMRR	Common-Mode Rejection Ratio	$R_S \leq 10\text{ k}\Omega$	70	100		dB

LM301

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

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R_i , R_o , A_{vd} , CMRR

Common-Mode Rejection Ratio

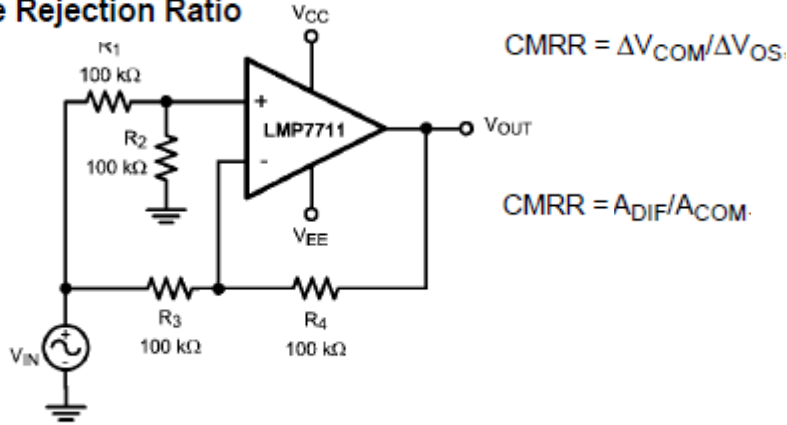


FIGURE 6. CMRR TEST CIRCUIT

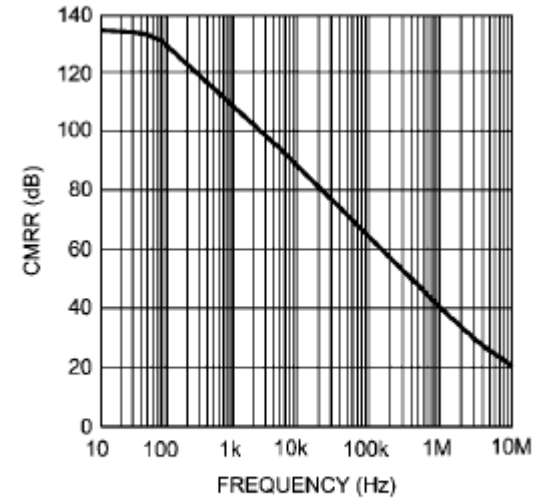


FIGURE 7. SIMULATED CMRR RESPONSE vs. FREQUENCY

Supply Voltage Rejection Ratio

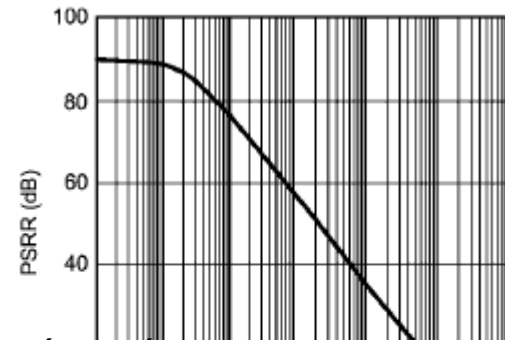
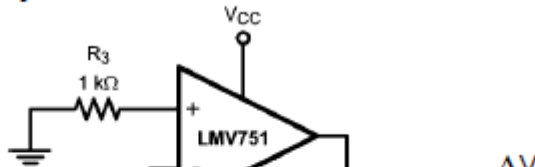


FIGURE 10. SIMULATED PSRR RESPONSE vs. FREQUENCY

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AMPLIFICADOR OPERACIONAL REAL: PRODUCTO

GANANCIA x ANCHO DE BANDA

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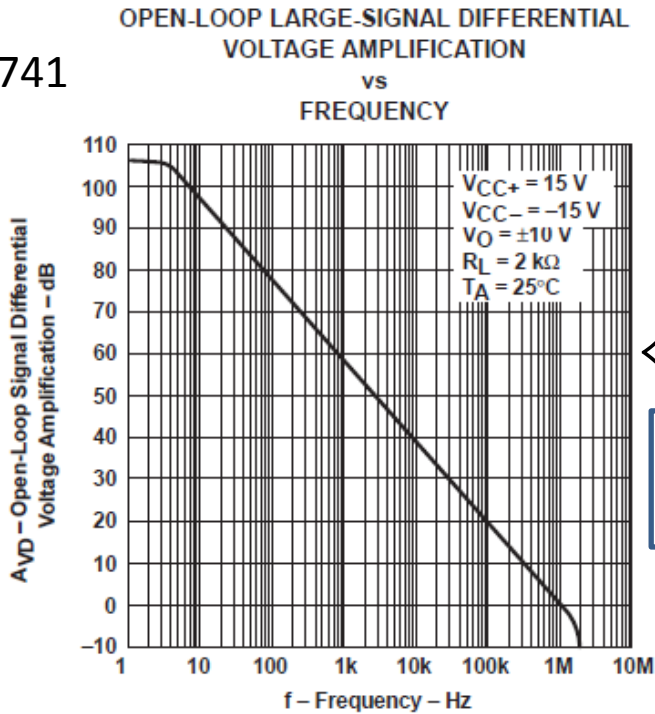


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Producto GxBW
SIN REALIMENTAR

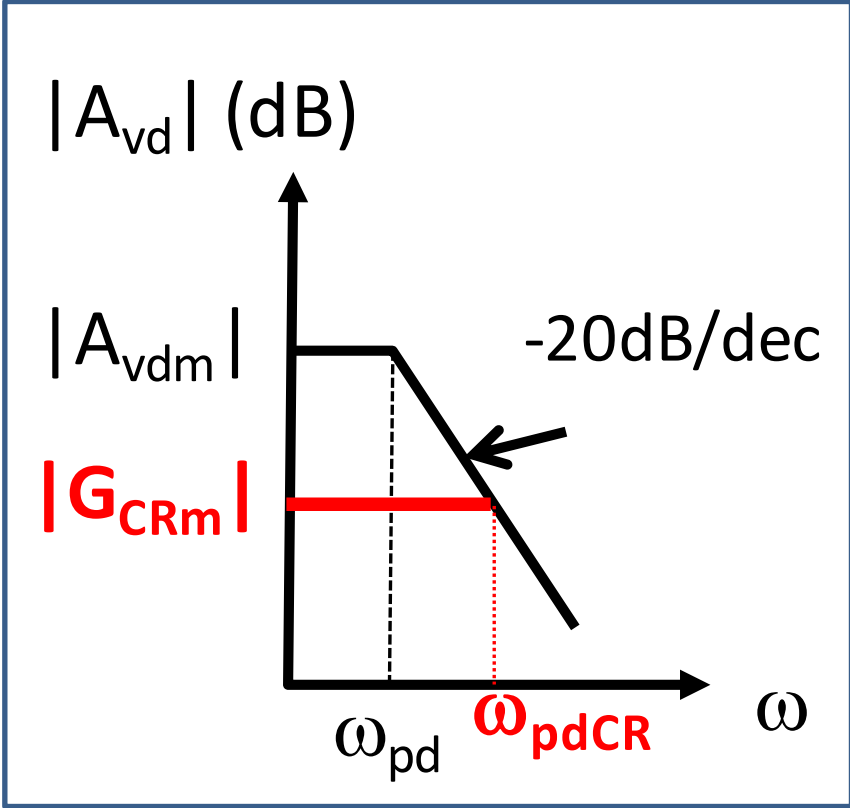
$GxBW = cte = 1\text{MHz (741)}$

Ej: 741



Sistema de primer orden (1 solo polo)

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



CON REALIMENTACIÓN NEGATIVA



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AMPLIFICADOR OPERACIONAL REAL: SLEW RATE

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Slew Rate (SR)

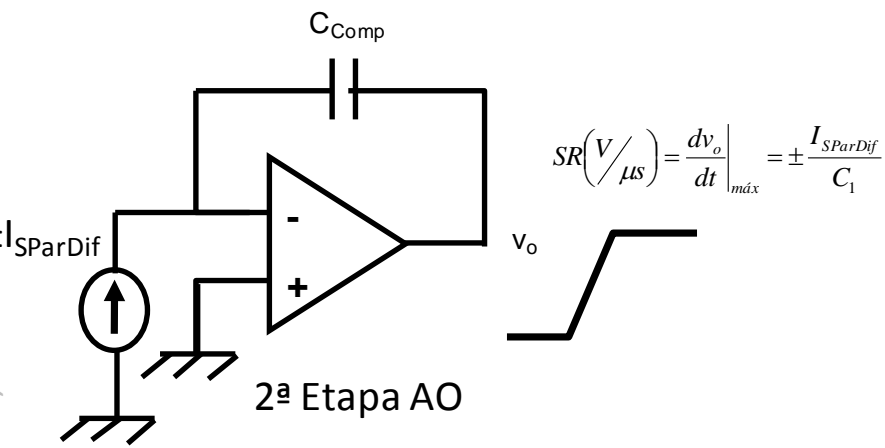
$$SR \left(\frac{V}{\mu s} \right) = \left. \frac{dv_o}{dt} \right|_{m\acute{a}x}$$

• Operación AO "Gran Señal"

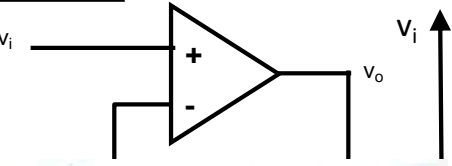
• Máxima velocidad de respuesta

ORIGEN

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

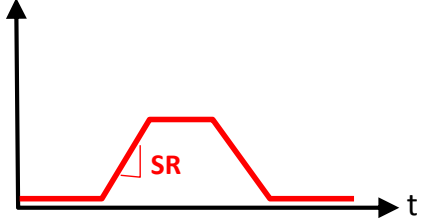


MEDIDA



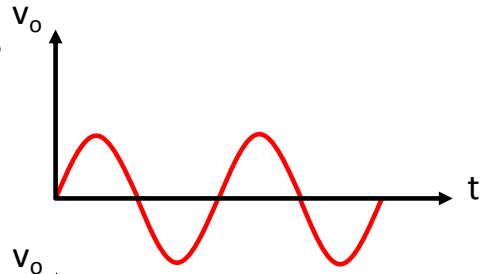
EFFECTO

• v_i cuadrada

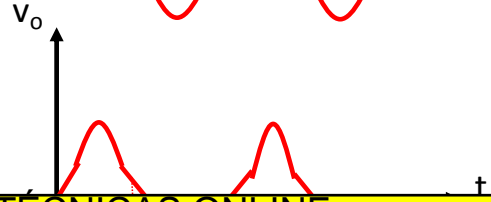


• v_i no cuadrada (ej. Sinusoidal)

si $\left. \frac{dv_o}{dt} \right|_{m\acute{a}x} < SR$



si $\left. \frac{dv_o}{dt} \right|_{m\acute{a}x} > SR$



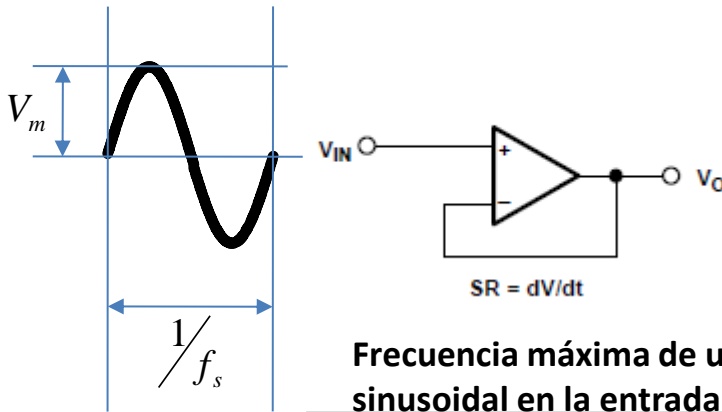
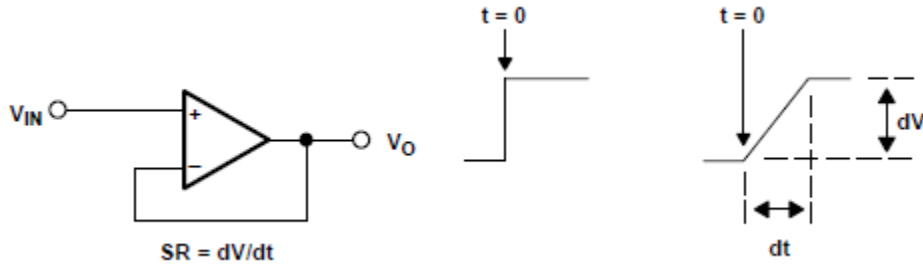
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Slew Rate at Unity Gain



Frecuencia máxima de una onda sinusoidal en la entrada

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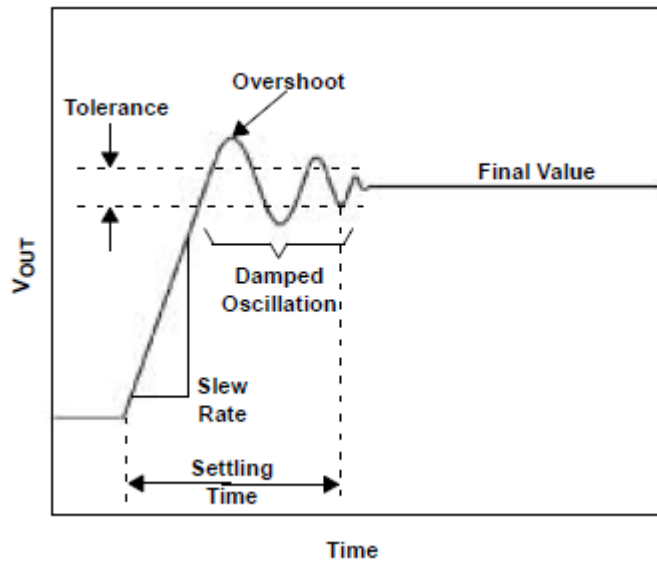
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Cartagena99

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Settling Time



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