

Analog Electronics

Unit 6

Real Operational Amplifier

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6.1 Introduction

Definition:

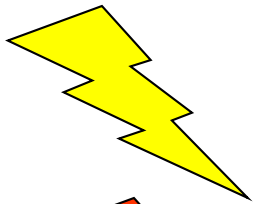
Voltage amplifier with the following real features:



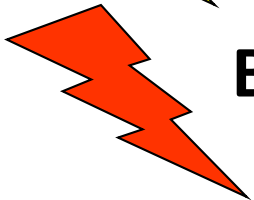
Very high voltage gain ($A = 10^5 \sim 10^{10}$)



**Very high input impedance ($1 \text{ M}\Omega \sim 1 \text{ G}\Omega$).
Differential input.**



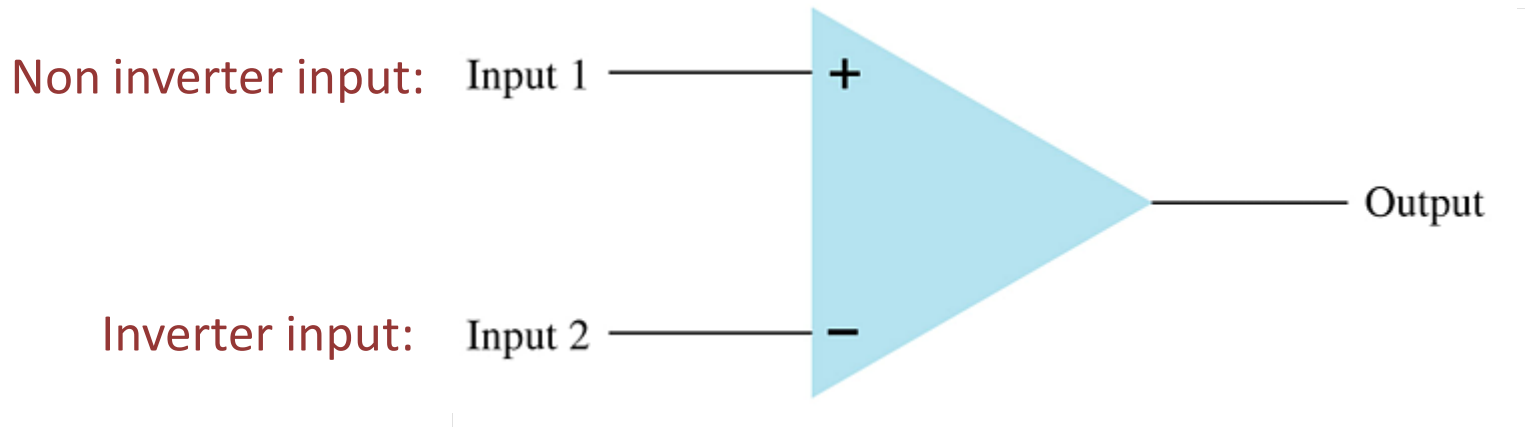
Very low output impedance ($5 \Omega \sim 1 \text{ k}\Omega$)



Bandwidth $0 \text{ Hz} \dots 20 \text{ kHz}$ (aprox).

6.1 Introduction

Symbology:



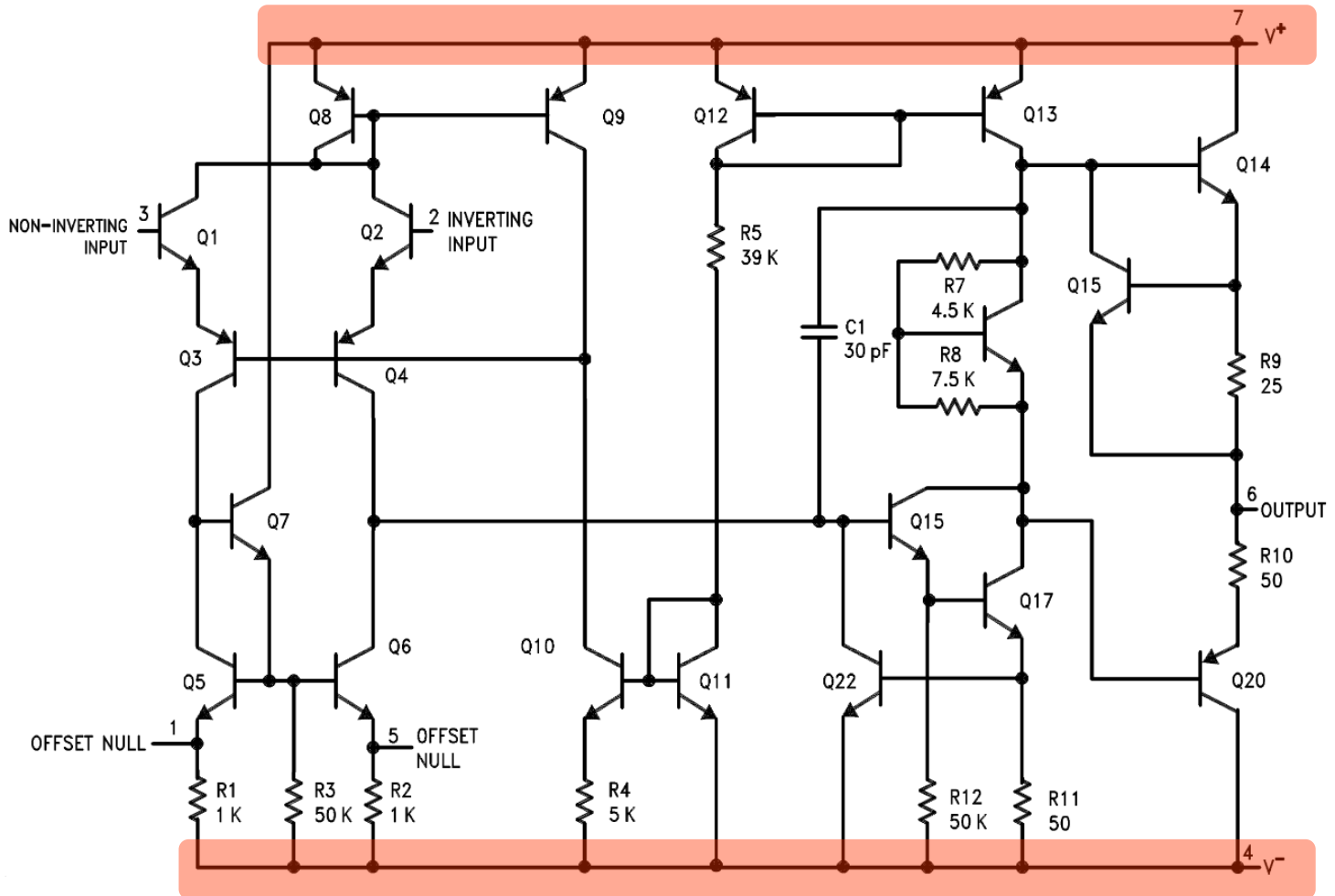
Transfer function:

$$V_O = A_{OL} \cdot (V_+ - V_-)$$

Electrical Characteristics, LM741C

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Large signal voltage gain	$V_S = \pm 15 \text{ V}, V_O = \pm 10 \text{ V}, R_L \geq 2 \text{ k}\Omega$	$T_A = 25^\circ\text{C}$	20	200		V/mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$	15			
Output voltage swing	$V_S = \pm 15 \text{ V}$	$R_L \geq 10 \text{ k}\Omega$	± 12	± 14		V
		$R_L \geq 2 \text{ k}\Omega$	± 10	± 13		

6.1 Introduction



Rail

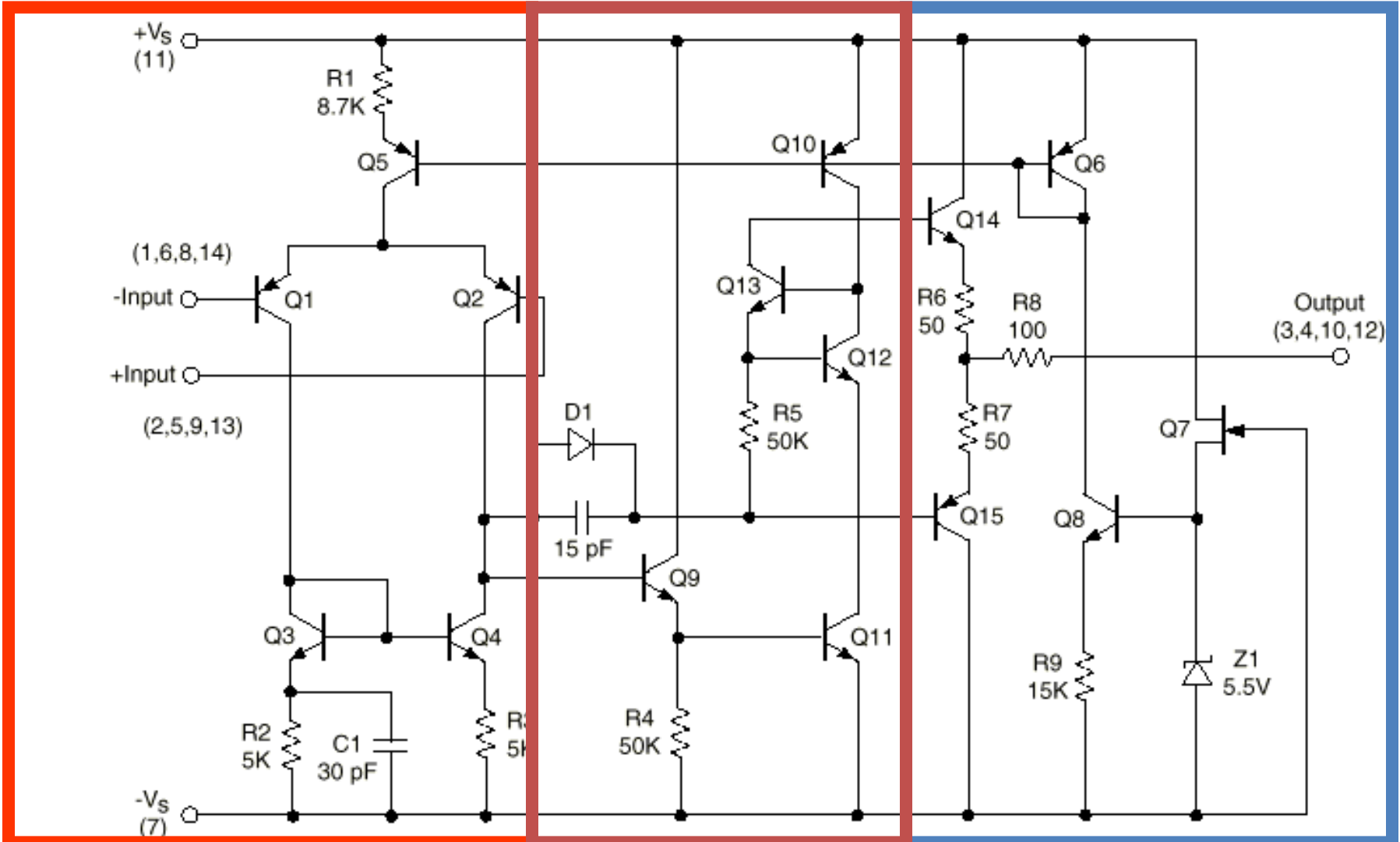
Rail

6.1 Introduction

Initial differential stage

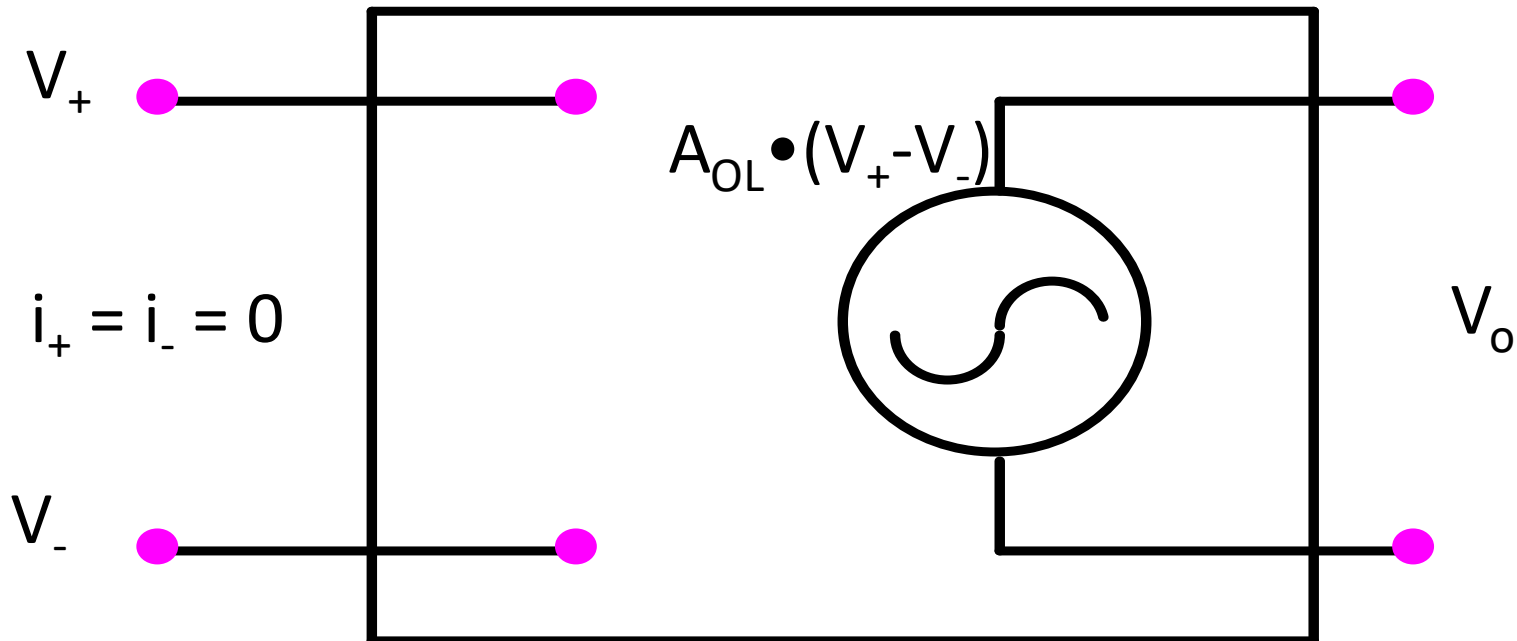
Intermediate amplification stages

Final power stage



6.1 Introduction

Cuadripole ideal model of the OA:

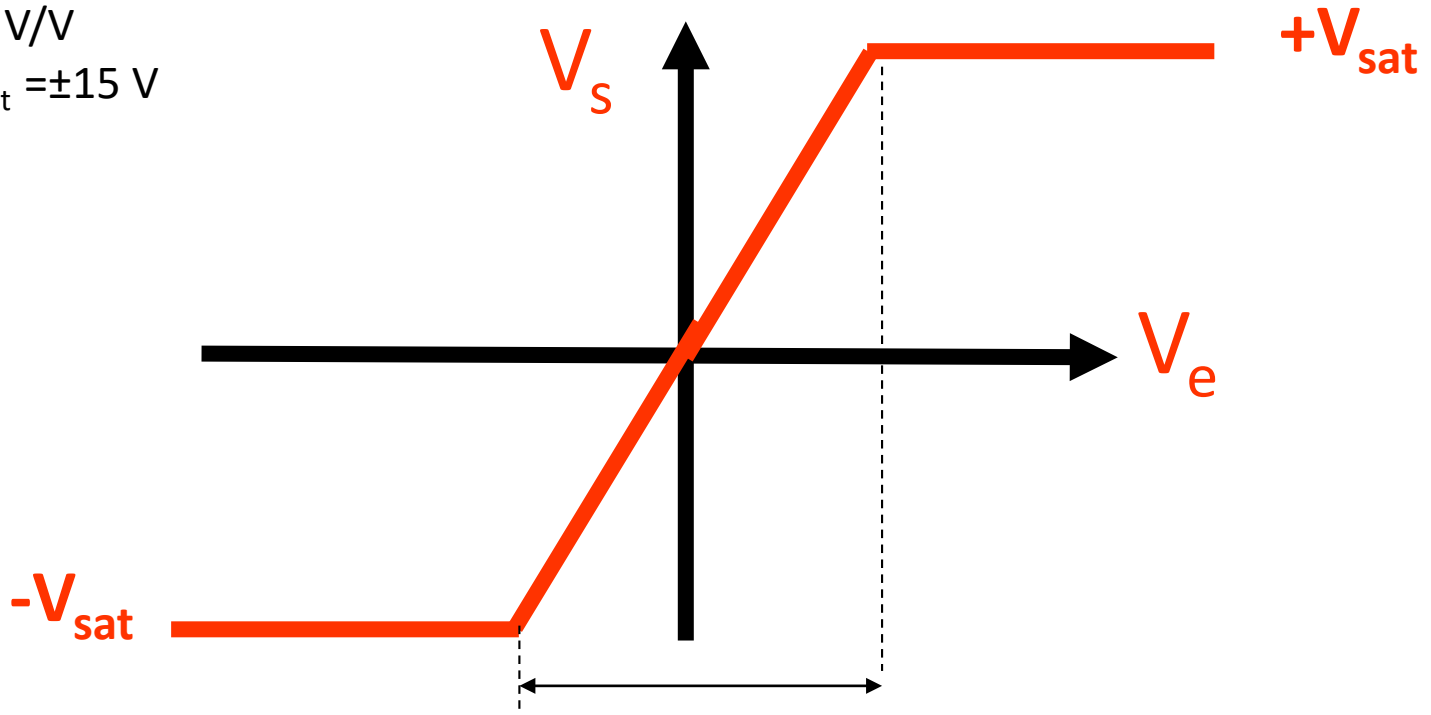


6.1 Introduction

Real OA

$$A=10^6 \text{ V/V}$$

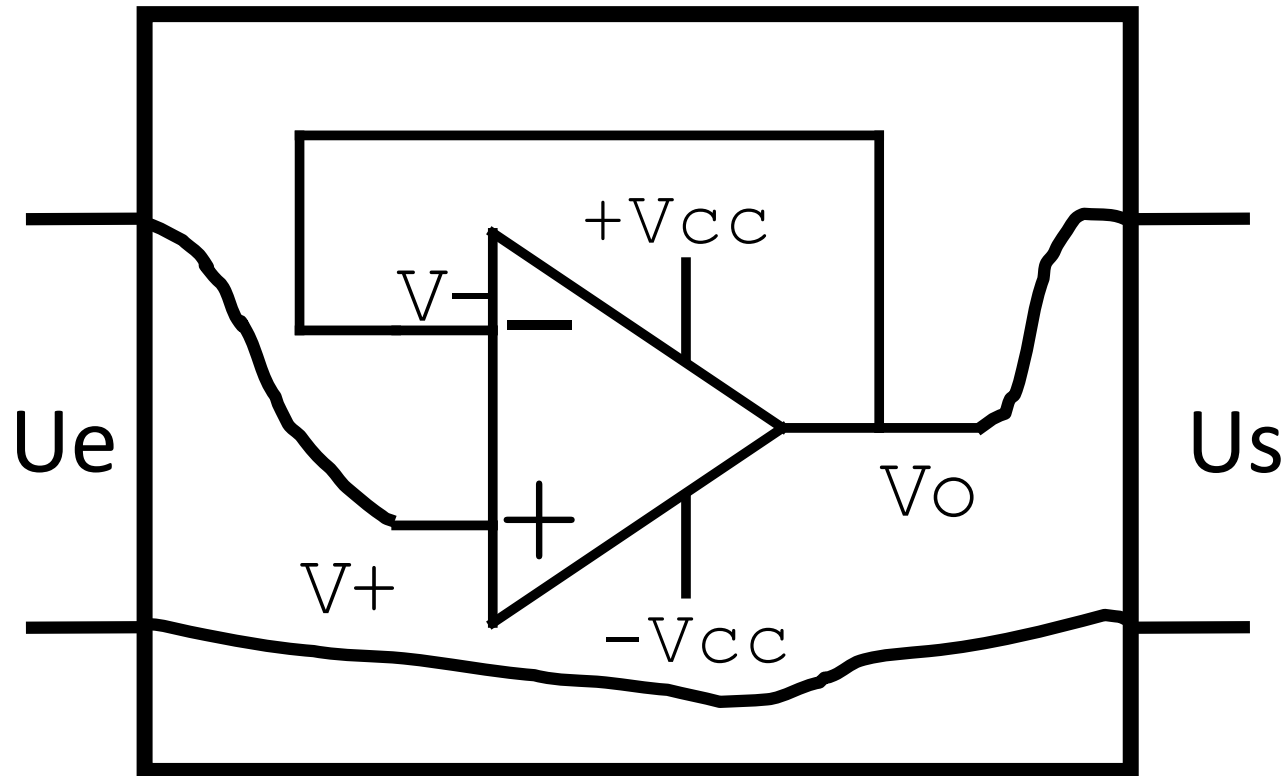
$$V_{cc}=V_{sat}=\pm 15 \text{ V}$$



- R** Linear input range?
 ¿Saturation?
 ¿Variability of the gain,
 Predictable output?

6.1 Introduction

Negative Feedback of the OA



¿Fdt?

$V_{CC} = \pm 15 \text{ V}$

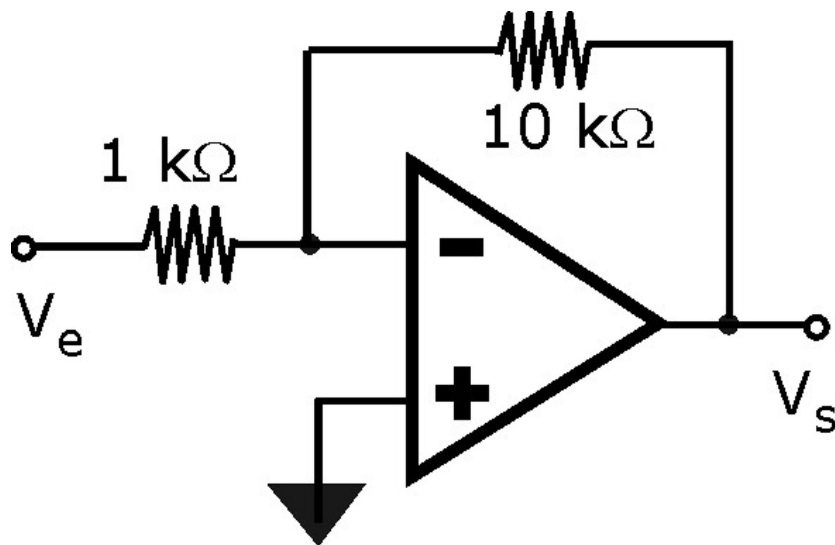
6.1 Introduction

Advantages of negative feedback:

- The gain is predictable and depends on the external components (resistors).

Ex: -10 V/V (20 dB)

- The gain is smaller → The input linear range increases



Ex: $\pm 14\text{V}/10 = \pm 1.4 \text{ V}$

6.1 Introduction

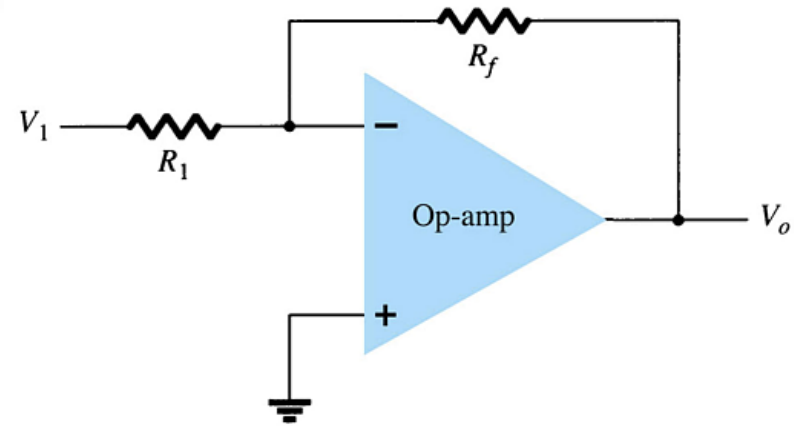
Procedure to analyze circuits with negative feedback of OA:

1. We know that: $V_+ \approx V_-$; $i_+ = i_- \approx 0$; $i_o???$
2. Analysis:
 - Computation of known voltages (Voltage divider or Millman...)
 - Currents definition and 1st Kirchoff 's law.
3. Calculation of:
 - $G = V_o / V_i \Rightarrow V_o = f(V_i)$
 - $Z_i \Rightarrow V_i = f(I_i)$

6.1 Introduction

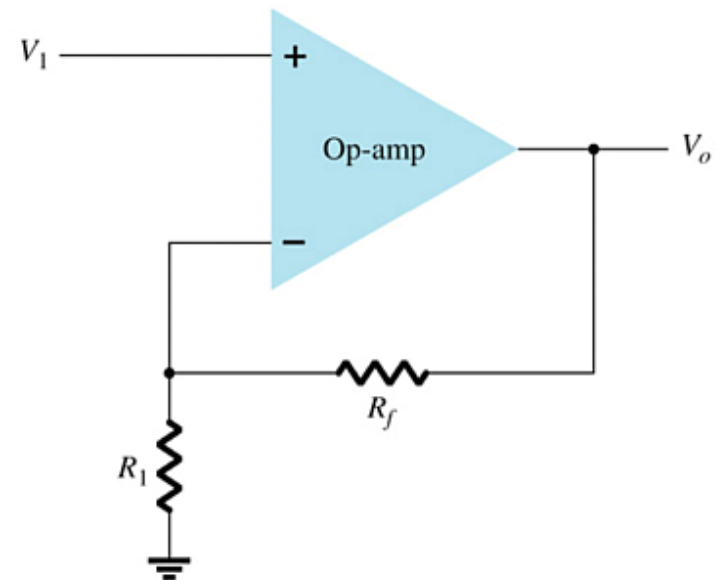
Inverter amplifier:

$$G = \frac{V_o}{V_i} = -\frac{R_f}{R_1}$$



Noninverting Amplifier:

$$G = 1 + \frac{R_f}{R_1}$$



6.1 Introduction

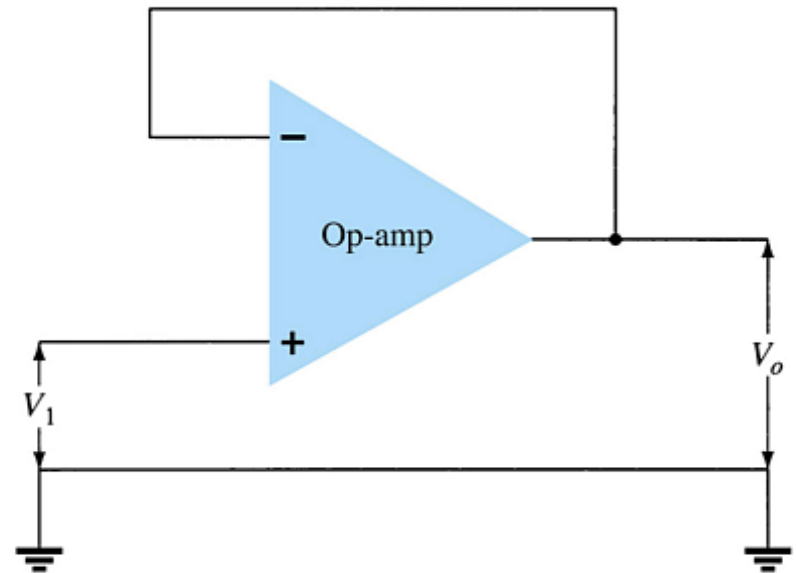
Unity Follower:

$$V_o = V_1$$

Any amplifier with no gain or loss is called a **unity gain amplifier**.

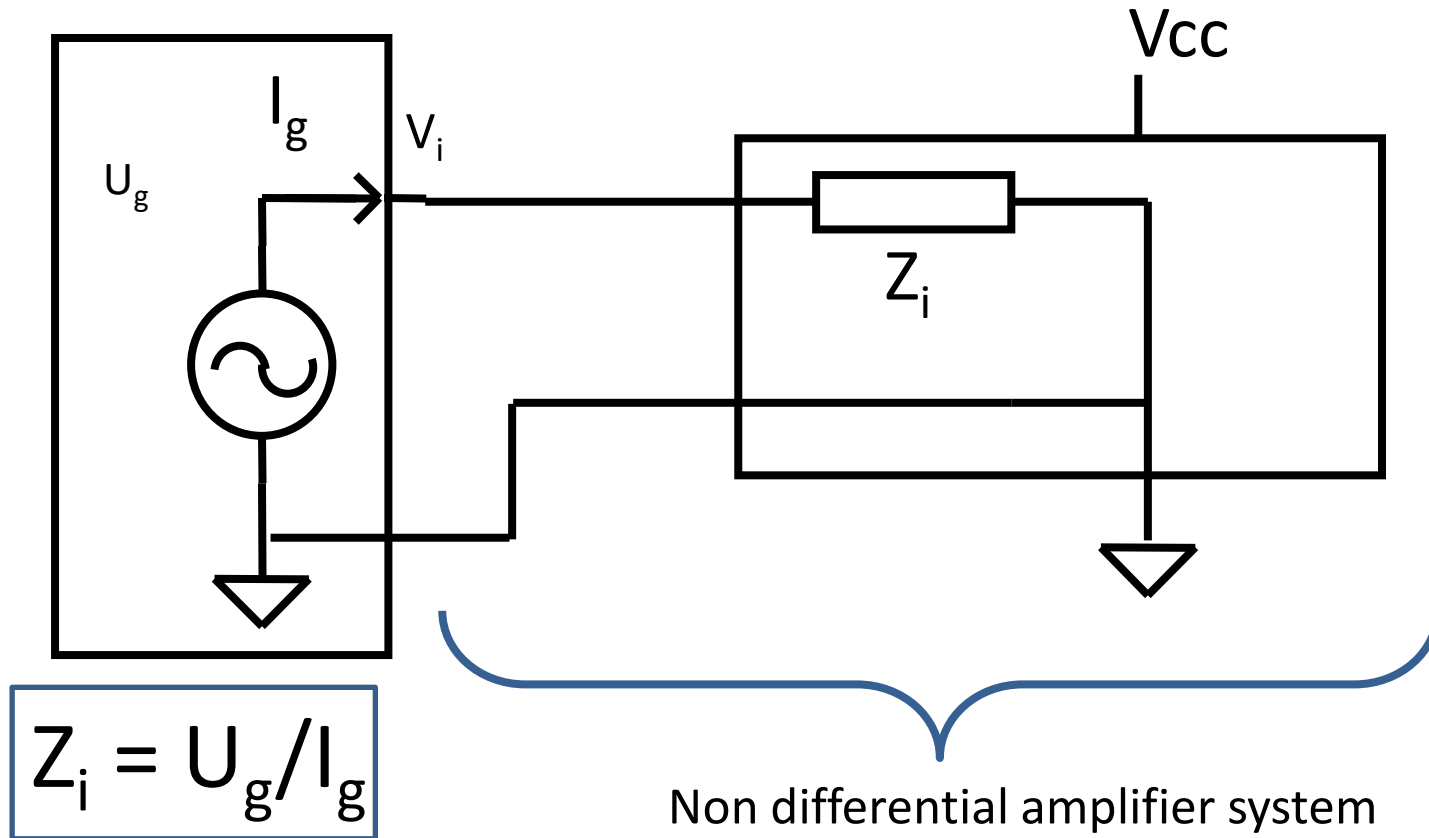
The advantages of using a unity gain amplifier:

- Very high input impedance
- Very low output impedance



6.1 Introduction

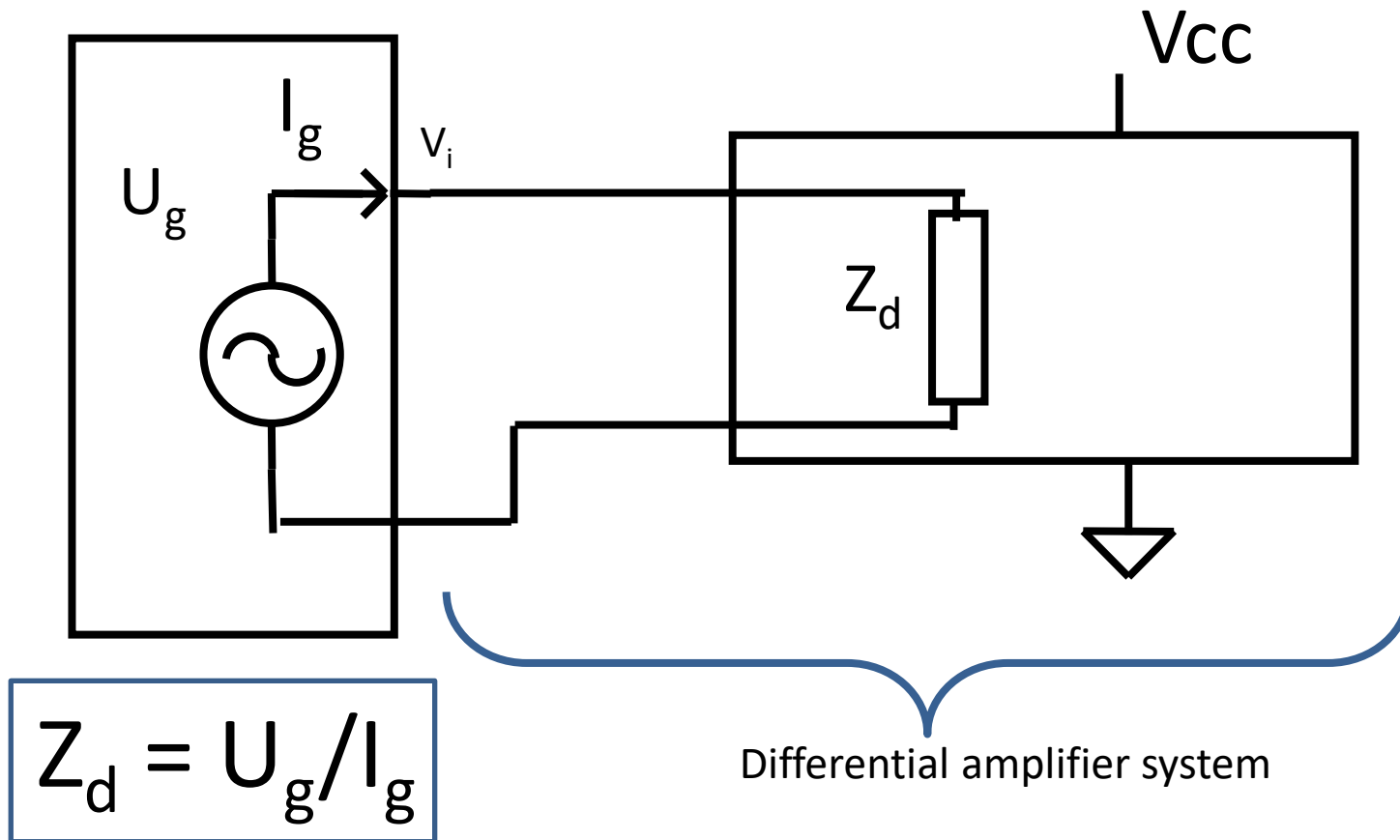
Calculation of Z_i (NON differential amplifiers)



Non differential amplifier system

6.1 Introduction

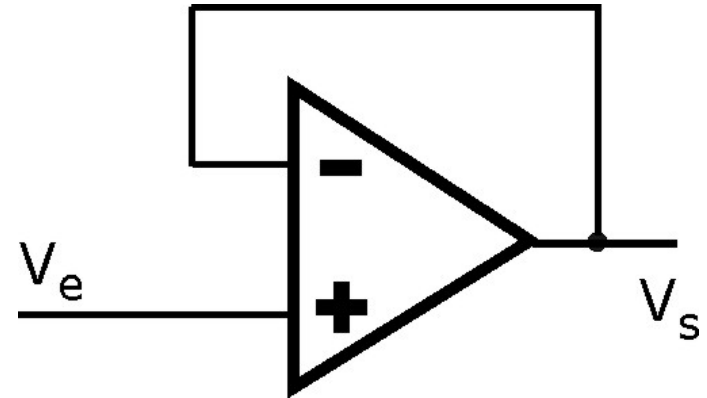
Calculation of Z_d (differential amplifiers)



6.1 Introduction

Effect of negative feedback on input impedance

$$Z_e \approx R_{e-AO} \cdot A_{OL}$$

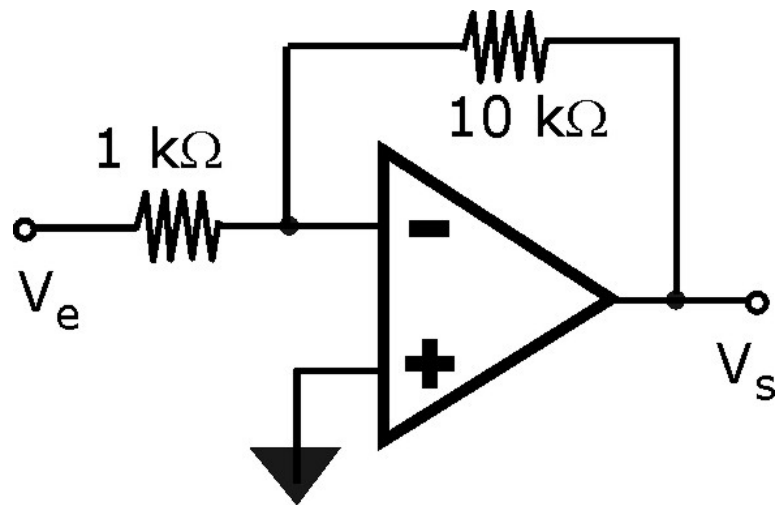


Electrical Characteristics, LM741C⁽¹⁾

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input resistance	$T_A = 25^\circ\text{C}$, $V_S = \pm 20\text{ V}$	0.3	2		M Ω
Input voltage range	$T_A = 25^\circ\text{C}$	± 12	± 13		V
Large signal voltage gain	$V_S = \pm 15\text{ V}$, $V_O = \pm 10\text{ V}$, $R_L \geq 2\text{ k}\Omega$	$T_A = 25^\circ\text{C}$	20	200	V/mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$	15		

6.1 Introduction

Effect of negative feedback on input impedance (Z_o)



$$Z_o \approx \frac{R_{O-AO}}{A_{OL}} \approx 0$$

OP27 $V_S = \pm 15\text{ V}$, $T_A = 25^\circ\text{C}$, unless otherwise noted.

Parameter	Symbol	Test Conditions	OP27A/OP27E			OP27G			Unit
			Min	Typ	Max	Min	Typ	Max	
LARGE SIGNAL VOLTAGE GAIN	A_{vo}	$R_L \geq 2\text{ k}\Omega, V_o = \pm 10\text{ V}$	1000	1800		700	1500		V/mV
		$R_L \geq 600\ \Omega, V_o = \pm 10\text{ V}$	800	1500		600	1500		V/mV
OPEN-LOOP OUTPUT RESISTANCE	R_o	$V_o = 0, I_o = 0$		70			70		Ω

6.2 Offset error

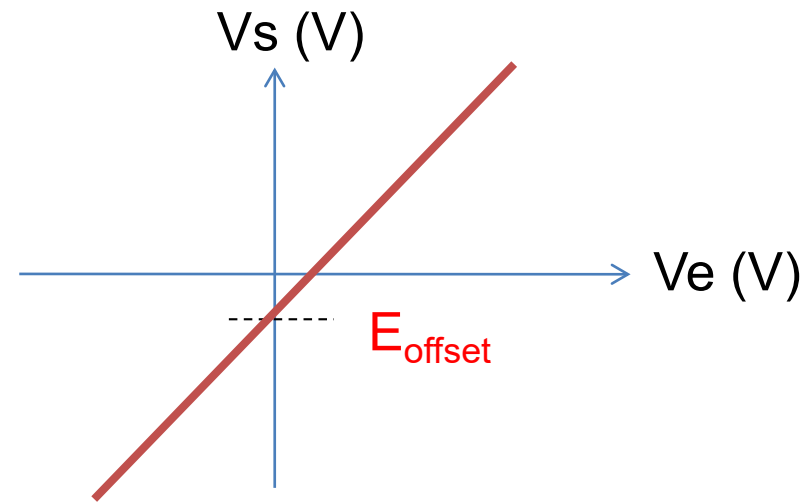
DC Offset Parameters

Even when the input voltage is zero, there can be an output **offset**. The following can cause this offset:

- Input offset voltage
- Input offset current
- Input bias current

6.2 Offset error

It is the output value when the input is null (E_{offset})



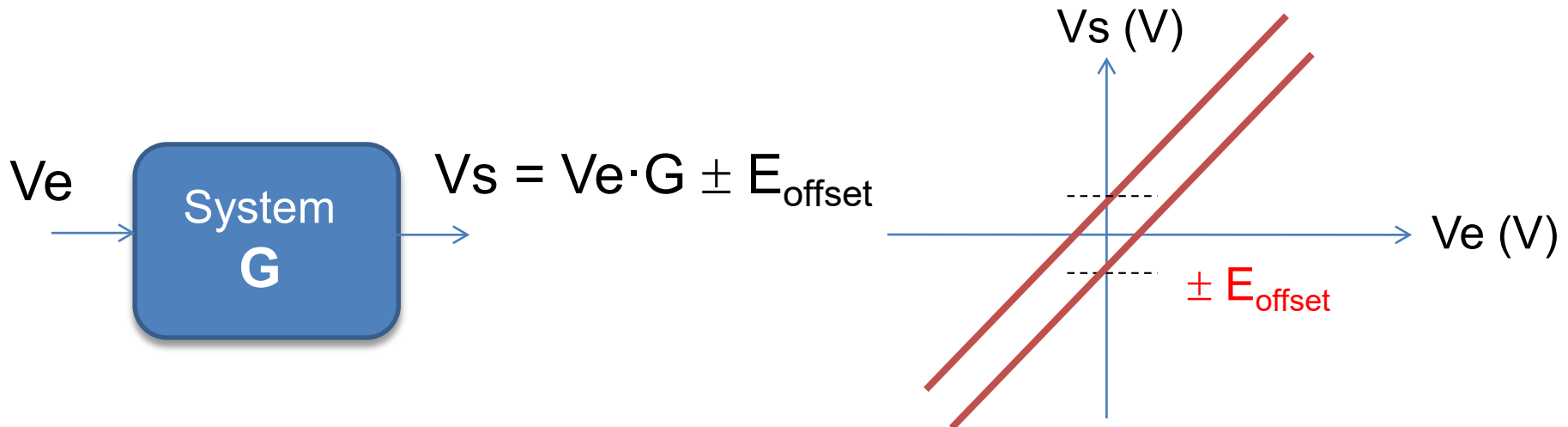
In systems with Oas, E_{offset} depends on 2 parameters of the OA:

- 1) V_{IO} , V_{OS} , *input offset voltage*)
- 2) Polarizing currents at the input (I_{IB} , *input bias current*; I_{IO} , *input offset current*)

6.2 Offset error

The offset error measured in a particular system is a specific value (with sign), ex: +50 mV, –80 mV

On the contrary, if it is not measured but estimated from the OA features, the value is given by a range

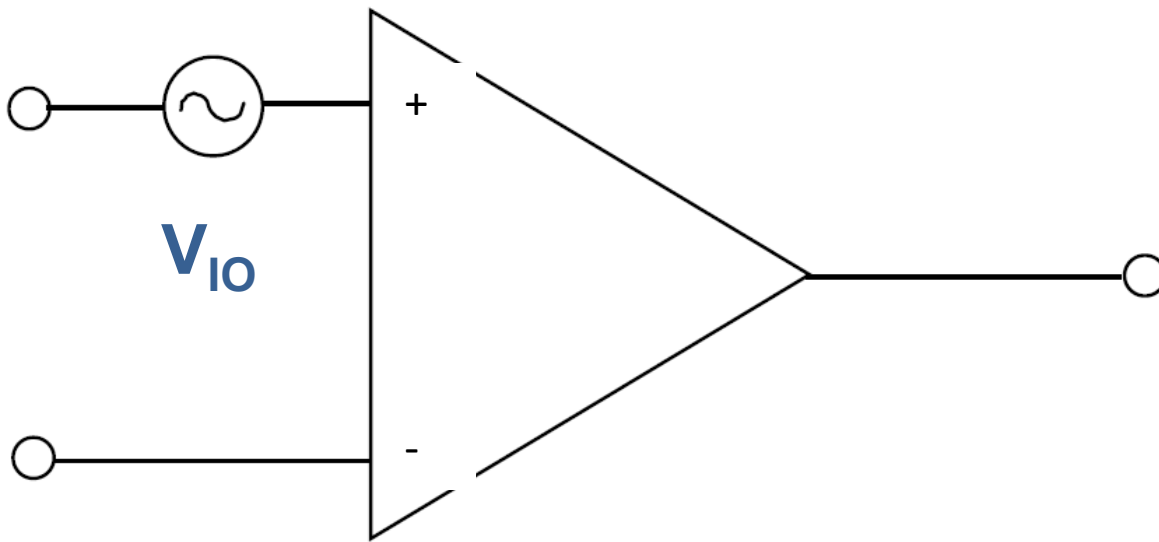


6.2 Offset error

Input Offset Voltage (V_{IO} , V_{OS})

Small voltage that has to be applied at the input of the OA to achieve an output of 0V.

It can be **modelled** as a voltage source in series with the inverter or non-inverter input.



6.2 Offset error

Input Offset Voltage (V_{IO} , V_{OS})

Chopper Stabilized Op Amps:	<1 μ V
General Purpose Precision Op Amps:	50-500 μ V
Best Bipolar Op Amps:	10-25 μ V
Best JFET Input Op Amps:	100-1,000 μ V
High Speed Op Amps:	100-2,000 μ V
Untrimmed CMOS Op Amps:	5,000-50,000 μ V
DigiTrim™ CMOS Op Amps:	<100 μ V-1,000 μ V

Low offset
($V_{IO} < 500\mu\text{V}$)

Find in the datasheets the **typical** value for V_{IO} of the following OAs:

741A (bipolar general purpose)

TL081C (JFET general purpose)

OP27A (bipolar precision)

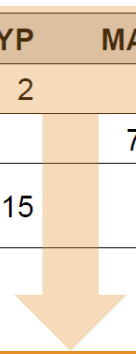
LT1055 (JFET precision)

6.2 Offset error

Input Offset Voltage (V_{IO} , V_{OS})

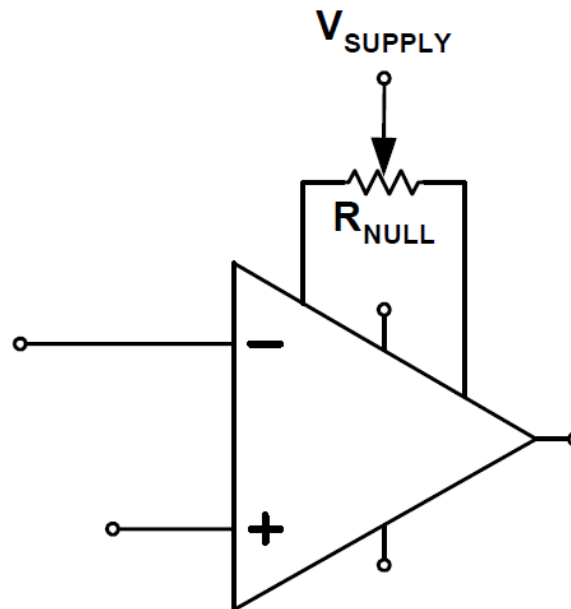
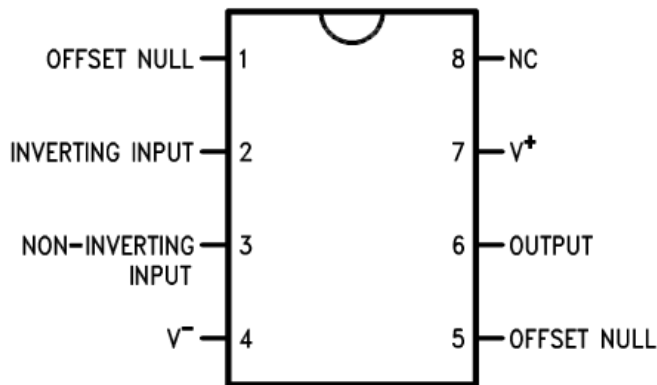
Electrical Characteristics, LM741C⁽¹⁾

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 10 \text{ k}\Omega$	$T_A = 25^\circ\text{C}$		2	6	mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			7.5	mV
Input offset voltage adjustment range	$T_A = 25^\circ\text{C}, V_S = \pm 20 \text{ V}$			± 15		mV



Dispersion

Only for a Temperature



6.2 Offset error

Input Offset Voltage (V_{IO} , V_{OS})

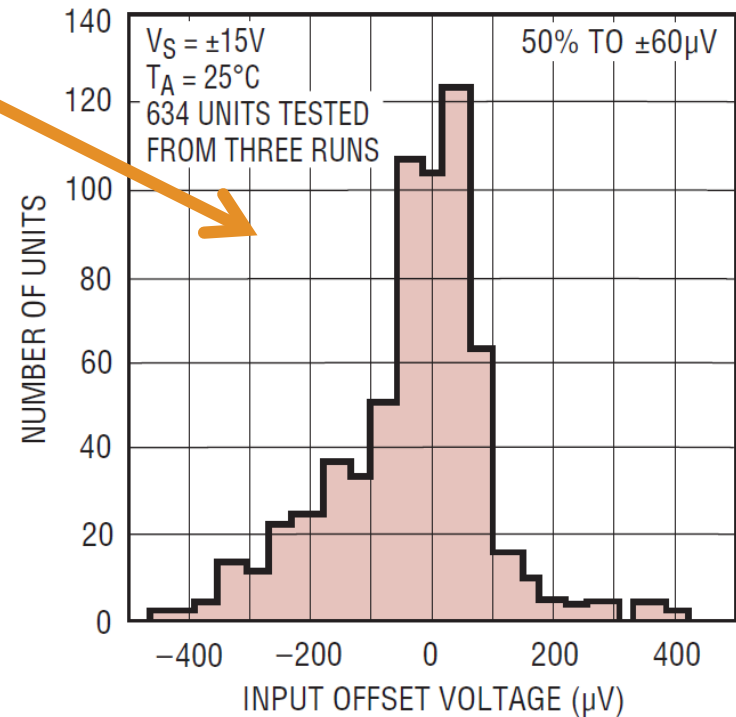


FEATURES

- *Guaranteed* Offset Voltage: 150 μ V Max
-55 $^{\circ}$ C to 125 $^{\circ}$ C: 500 μ V Max

Dispersion

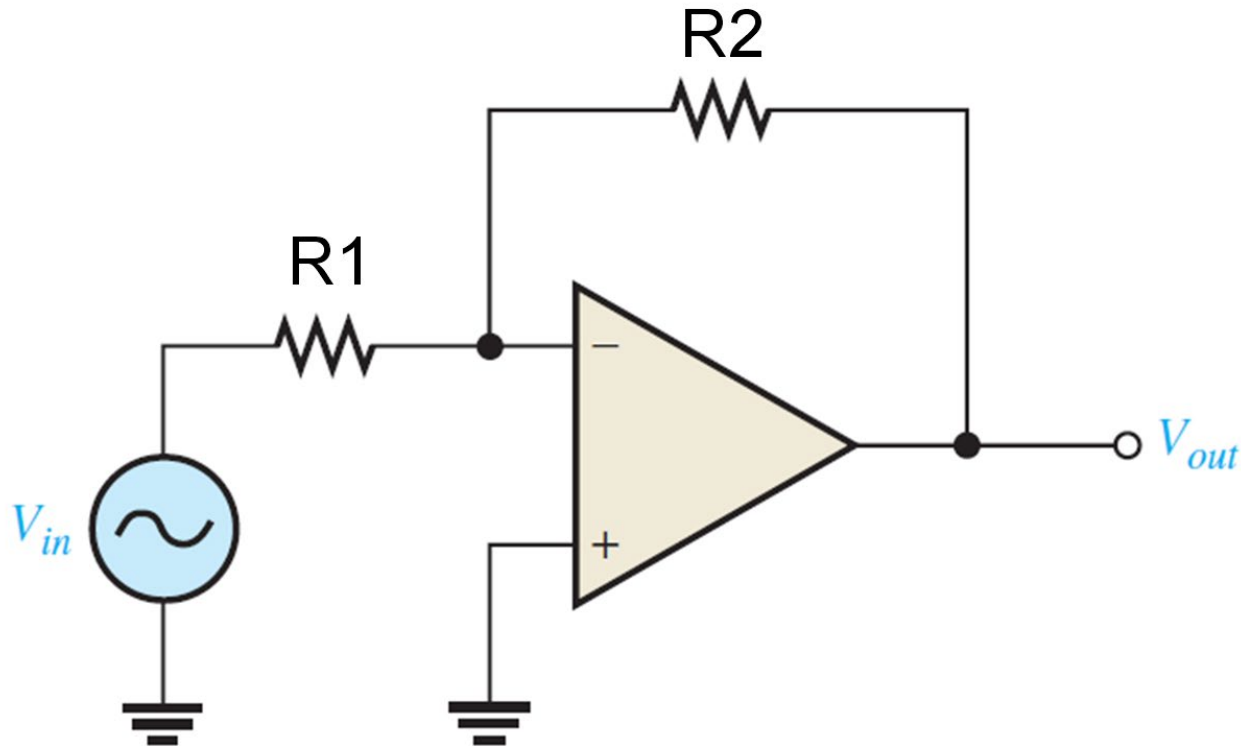
Distribution of Input Offset Voltage (H Package)



6.2 Offset error

Impact of V_{IO} on the output

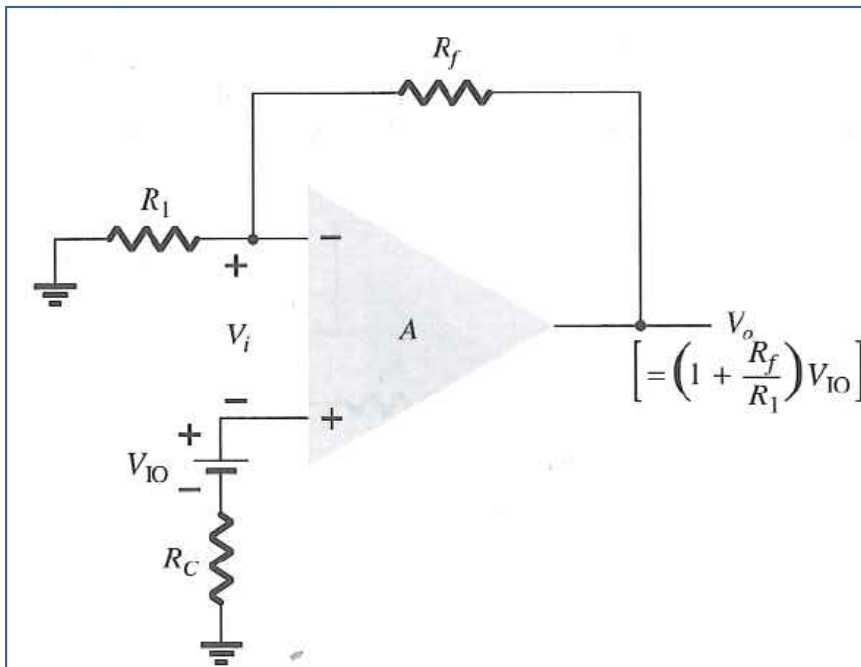
Estimate the **maximum** offset error at the output of the circuit (at 25°C).
The OA is a 741C with a supply voltage of $\pm 15\text{ V}$ ($R2=10\text{ k}\Omega$, $R1=1\text{ k}\Omega$)



6.2 Offset error

Impact of V_{IO} on the output

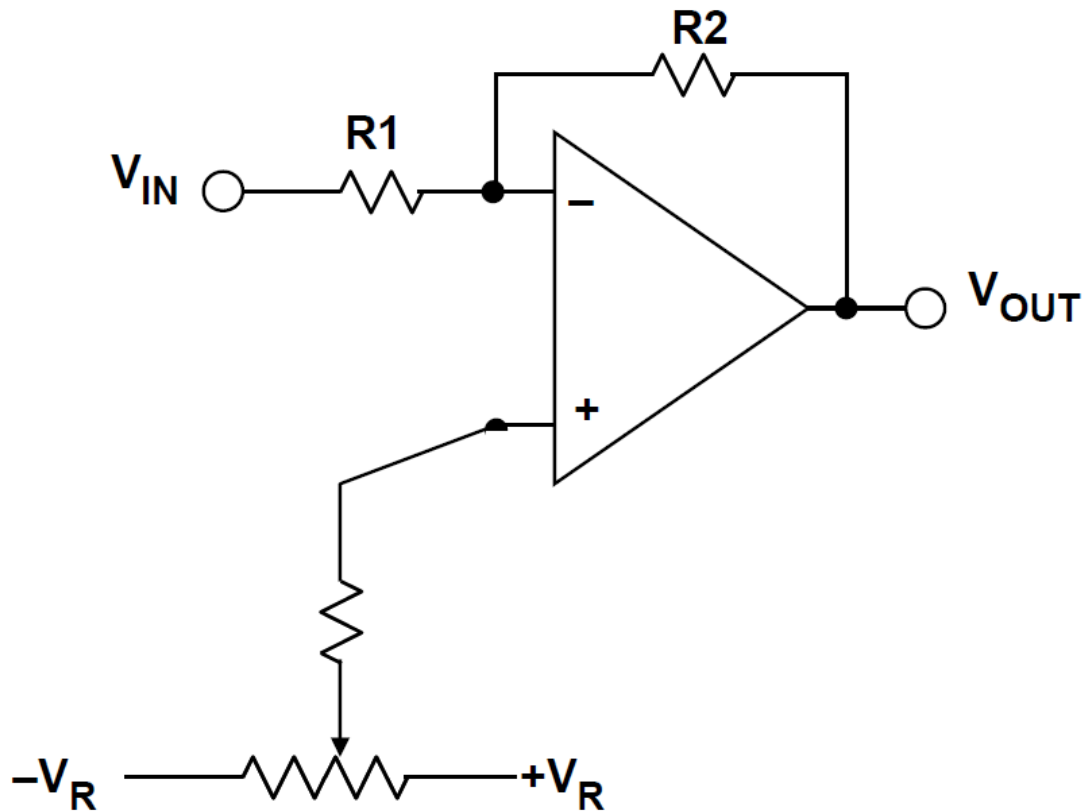
The effect of this input offset voltage on the output can be calculated with:



$$V_{o(\text{offset})} = V_{IO} \frac{R_1 + R_f}{R_1}$$

6.2 Offset error

Correction of the error due to V_{IO}



Find the minimum value of V_R to compensate the error due to V_{IO} (at 25°C) in the circuit if the OA is a TL081C supplied at $\pm 15\text{ V}$ ($R2=10\text{ k}\Omega$, $R1=1\text{ k}\Omega$)

Design the circuit with a potentiometer $P=100\ \Omega$ and the supply voltage for V_R $\pm 15\text{ V}$

6.2 Offset error

Temperature drift of the offset voltage (TCV_{IO} , α_{VIO})

Electrical Characteristics, LM741C⁽¹⁾

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 10 \text{ k}\Omega$	$T_A = 25^\circ\text{C}$		2	6	mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			7.5	mV
Input offset voltage adjustment range	$T_A = 25^\circ\text{C}, V_S = \pm 20 \text{ V}$			± 15		mV

Temperature

		MIN	MAX	UNIT
T_A	Ambient temperature			$^\circ\text{C}$
	TL08xM	-55	125	
	TL08xQ	-40	125	
	TL08xI	-40	85	
	TL08xC	0	70	

C (Commercial)

I (Industrial)

M (Military)

6.2 Offset error

Temperature drift of the offset voltage (TCV_{IO} , α_{VIO})

$V_S = \pm 15\text{ V}$, $-55^\circ\text{C} \leq T_A \leq 125^\circ\text{C}$, unless otherwise noted.

Parameter	Symbol	OP27A			Unit
		Min	Typ	Max	
INPUT OFFSET VOLTAGE ¹	V_{OS}		30	60	μV
AVERAGE INPUT OFFSET DRIFT	TCV_{OS}^2 TCV_{OSn}^3		0.2	0.6	$\mu\text{V}/^\circ\text{C}$

$V_S = \pm 15\text{ V}$, $T_A = 25^\circ\text{C}$, unless otherwise noted.

Parameter	Symbol	OP27A/OP27E			μV
		Min	Typ	Max	
INPUT OFFSET VOLTAGE ¹	V_{OS}		10	25	

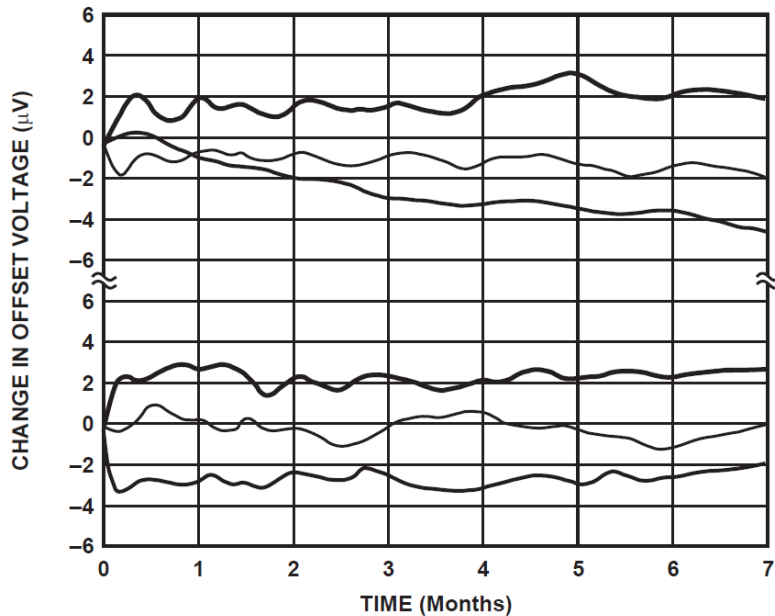
*Estimate the **typical** offset error at the output of an inverter amplifier based on an OP27A ($G = -50\text{ V/V}$) for a temperature range of 0 and 50°C*

6.2 Offset error

Temporal drift of the offset voltage

$V_S = \pm 15\text{ V}$, $T_A = 25^\circ\text{C}$, unless otherwise noted.

Parameter	Symbol	OP27A/OP27E			OP27G			Unit
		Min	Typ	Max	Min	Typ	Max	
INPUT OFFSET VOLTAGE ¹	V_{OS}		10	25		30	100	μV
LONG-TERM V_{OS} STABILITY ^{2, 3}	V_{OS}/Time		0.2	1.0		0.4	2.0	$\mu\text{V}/\text{Mo}$



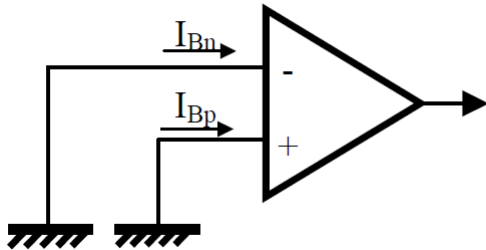
Estimate the typical variation of the offset error at the output of a non-inverter amplifier based on a OP27A ($G=100\text{ V/V}$) in 12 months

Figure 14. Long-Term Offset Voltage Drift of Six Representative Units

6.2 Offset error

Bias current (I_{IB})

The Bias current (I_B) is the average current of the input currents in the OA (polarizing currents)



$$I_{IB} = \frac{|I_{IB}^- + I_{IB}^+|}{2}$$

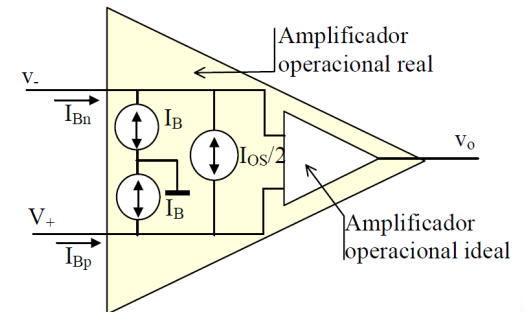
Offset currents in the input (I_{IO})

It is the difference of the polarizing currents in the input terminals of the OA

$$I_{IO} = |I_{IB}^+ - I_{IB}^-|$$

$$I_{IB}^+ = I_{IB} + \frac{I_{IO}}{2}$$

$$I_{IB}^- = I_{IB} - \frac{I_{IO}}{2}$$

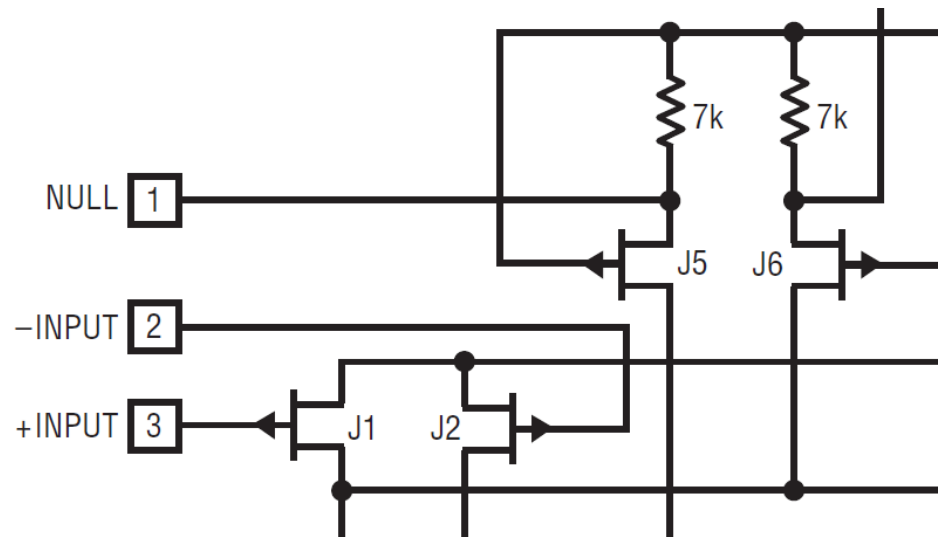
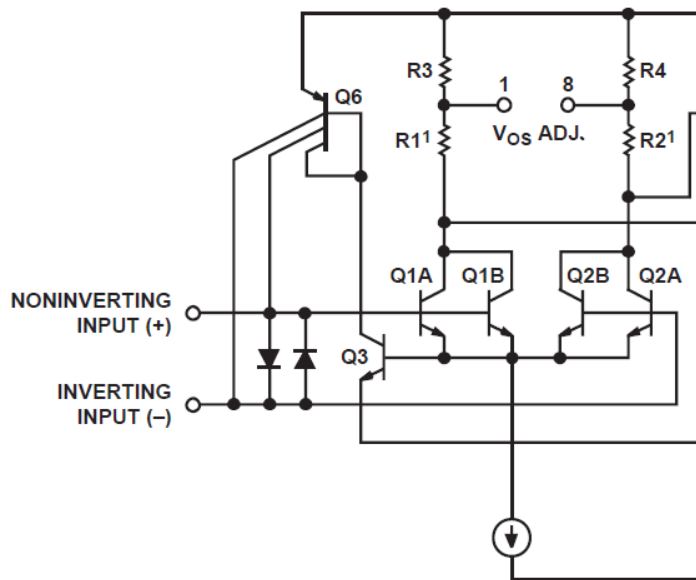


6.2 Offset error

I_{IB} , *input bias current*; I_{IO} , *input offset current*

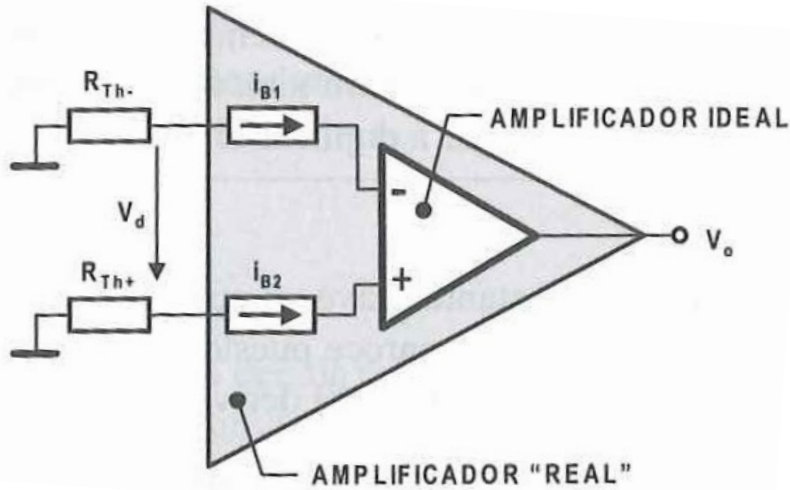
Compare the **typical** values of I_{IB} and I_{IO} of the following OAs

Bipolar	JFET
741C	TL081C
OP27A	LT1055



6.2 Offset error

Output Offset Voltage Due to Input Polarizing Currents

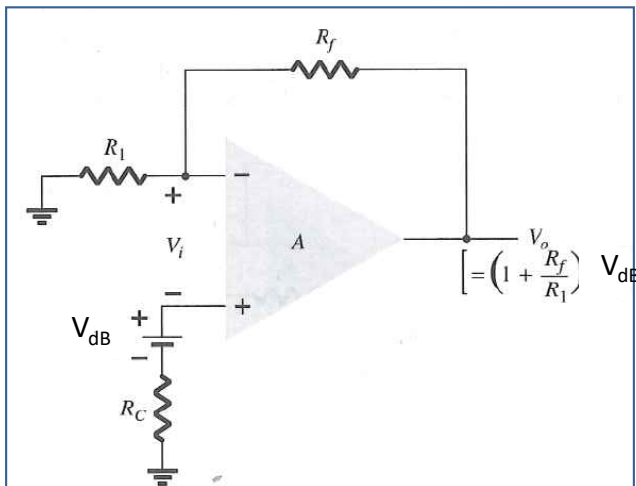


$$V_d = R_{Th-} I_{B1} - R_{Th+} I_{B2}$$

$$I_{B2} = I_B + \frac{I_{IO}}{2} \quad I_{B1} = I_B - \frac{I_{IO}}{2}$$

$$V_d = R_{Th-} \left(I_B - \frac{I_{IO}}{2} \right) - R_{Th+} \left(I_B + \frac{I_{IO}}{2} \right)$$

$$V_d = I_B \left| R_{Th-} - R_{Th+} \right| + I_{IO} (R_{Th+} + R_{Th-}) / 2$$



$$V_{o(\text{offset})} = V_{dB} \frac{R_1 + R_f}{R_1}$$

6.2 Offset error

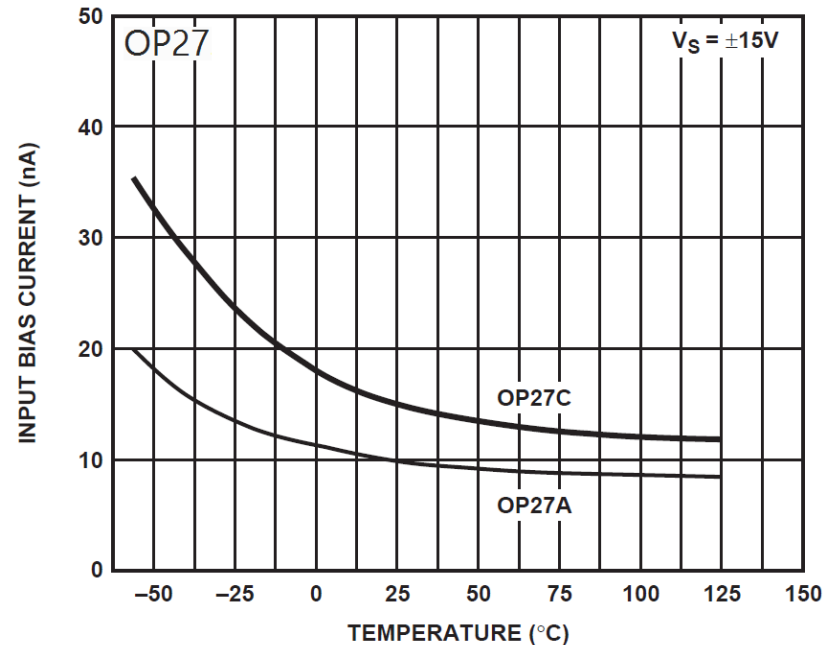
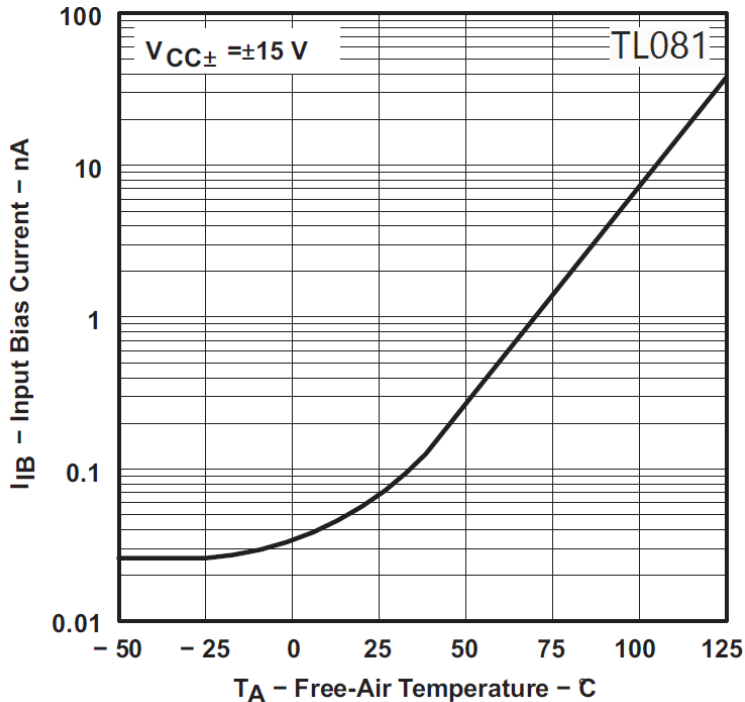
The bias and offset currents depend on temperature. The drift with temperature should be taken into account when the operation happens at elevated temperatures. The data of these drifts are given in the data sheets.

Deriva térmica de I_B :

$$\Delta I_B / \Delta T \text{ (pA/}^\circ\text{C)}$$

Deriva térmica de I_{OS} :

$$\Delta I_{OS} / \Delta T \text{ (pA/}^\circ\text{C)}$$



6.2 Offset error

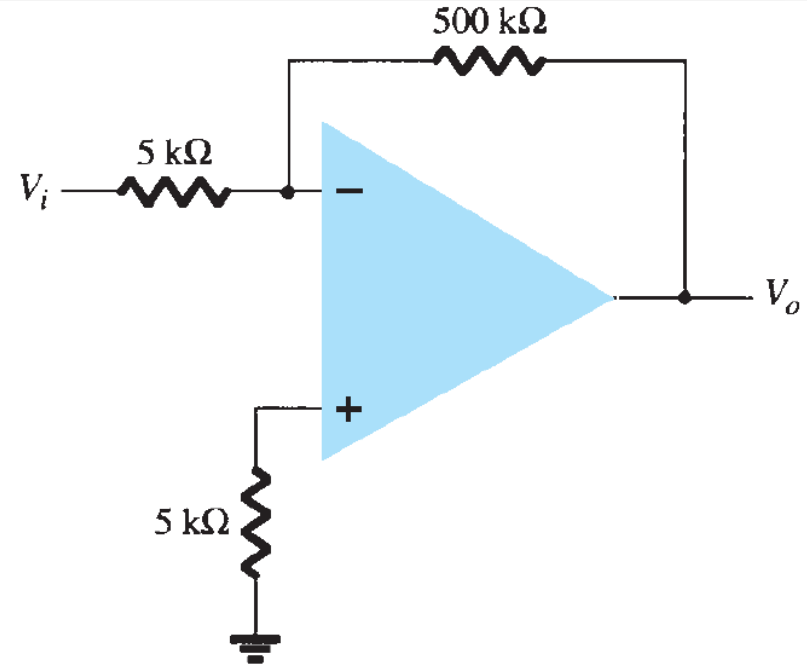
Total Offset Due to V_{IO} and I_{IO} and I_B

Op-amps may have an output offset voltage due to both factors V_{IO} and Polarizing currents. The total output offset voltage will be the sum of the effects of both:

$$V_o(\text{offset}) = V_o(\text{offset due to } V_{IO}) + V_o(\text{offset due to } I_B \text{ and } I_{IO})$$

6.2 Offset error

Estimate the total $V_{o(\text{offset})}$ due to the polarizing currents at the input of OA (741C), and due to the input offset voltage (V_{IO}) of the OA. Assume $T=25^\circ\text{C}$.



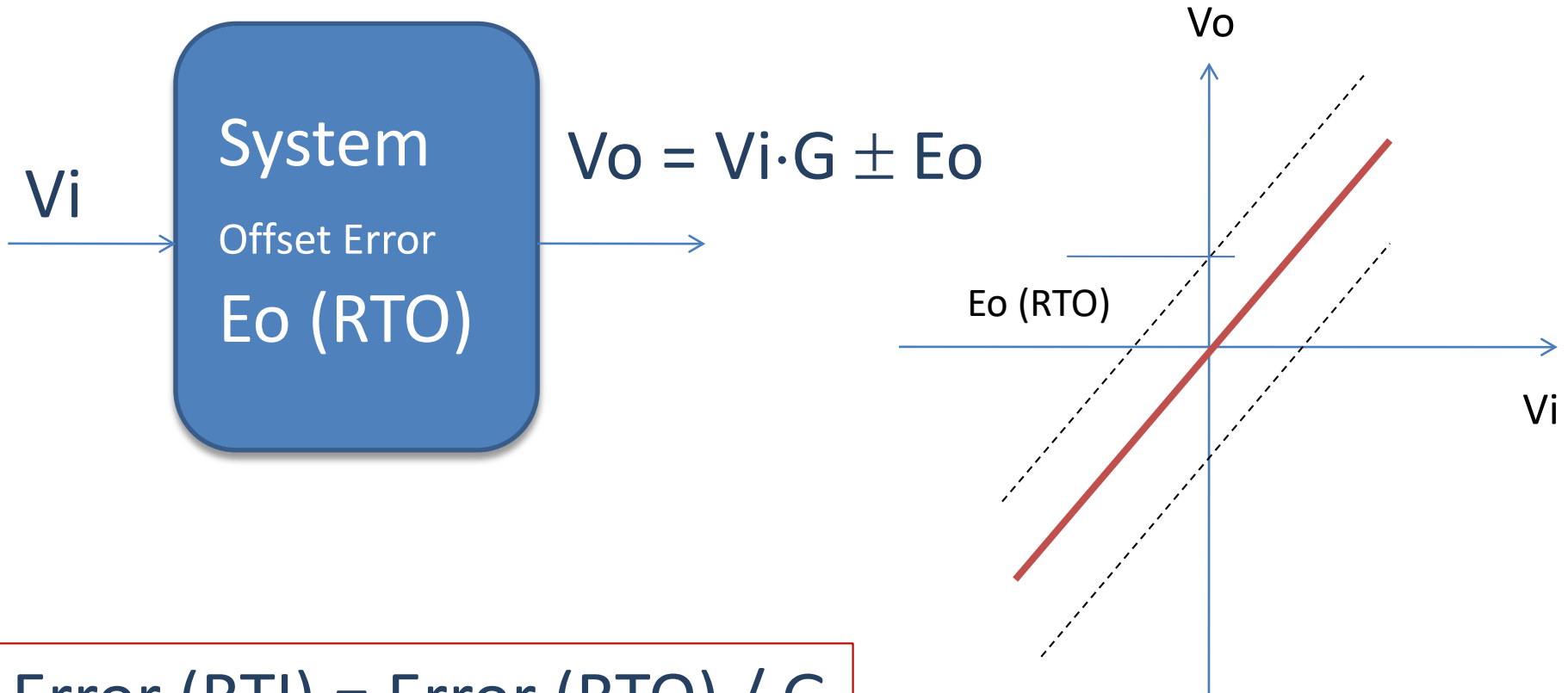
Electrical Characteristics, LM741C⁽¹⁾

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 10 \text{ k}\Omega$	$T_A = 25^\circ\text{C}$		2	6	mV
		$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$			7.5	mV
Input offset voltage adjustment range	$T_A = 25^\circ\text{C}, V_S = \pm 20 \text{ V}$			± 15		mV
Input offset current	$T_A = 25^\circ\text{C}$			20	200	nA
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$				300	
Input bias current	$T_A = 25^\circ\text{C}$			80	500	nA
	$T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}}$				0.8	μA

6.2 Offset error

Systematic Errors

Offset error (additive, absolute error)

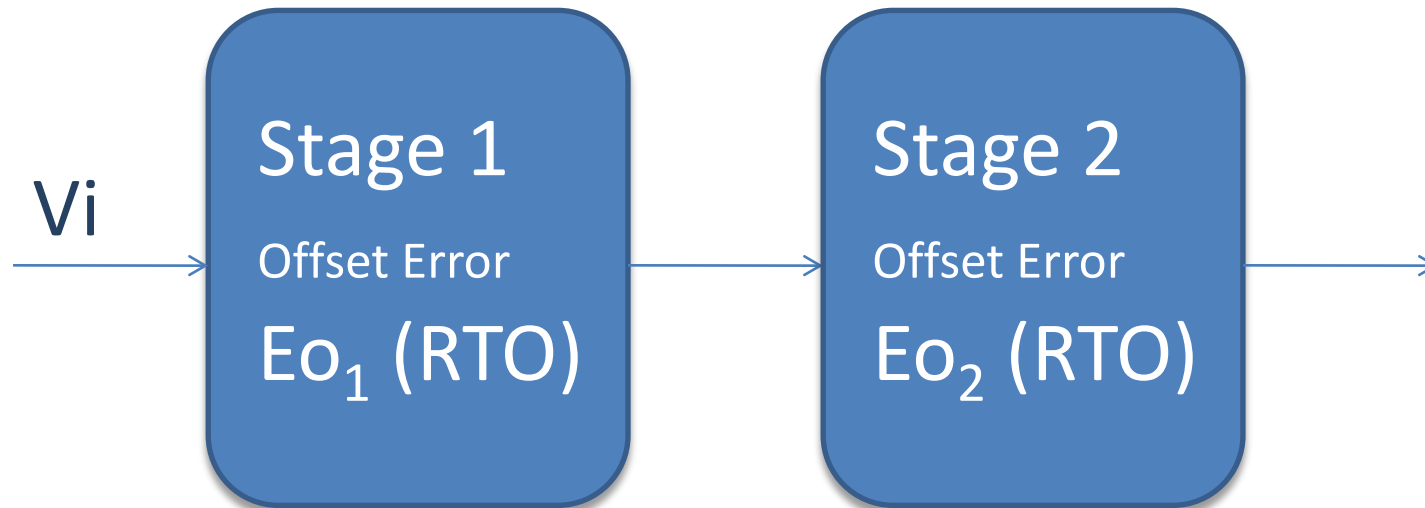


$$\text{Error (RTI)} = \text{Error (RTO)} / G$$

6.2 Offset error

Systematic Errors

Offset error in multistage systems

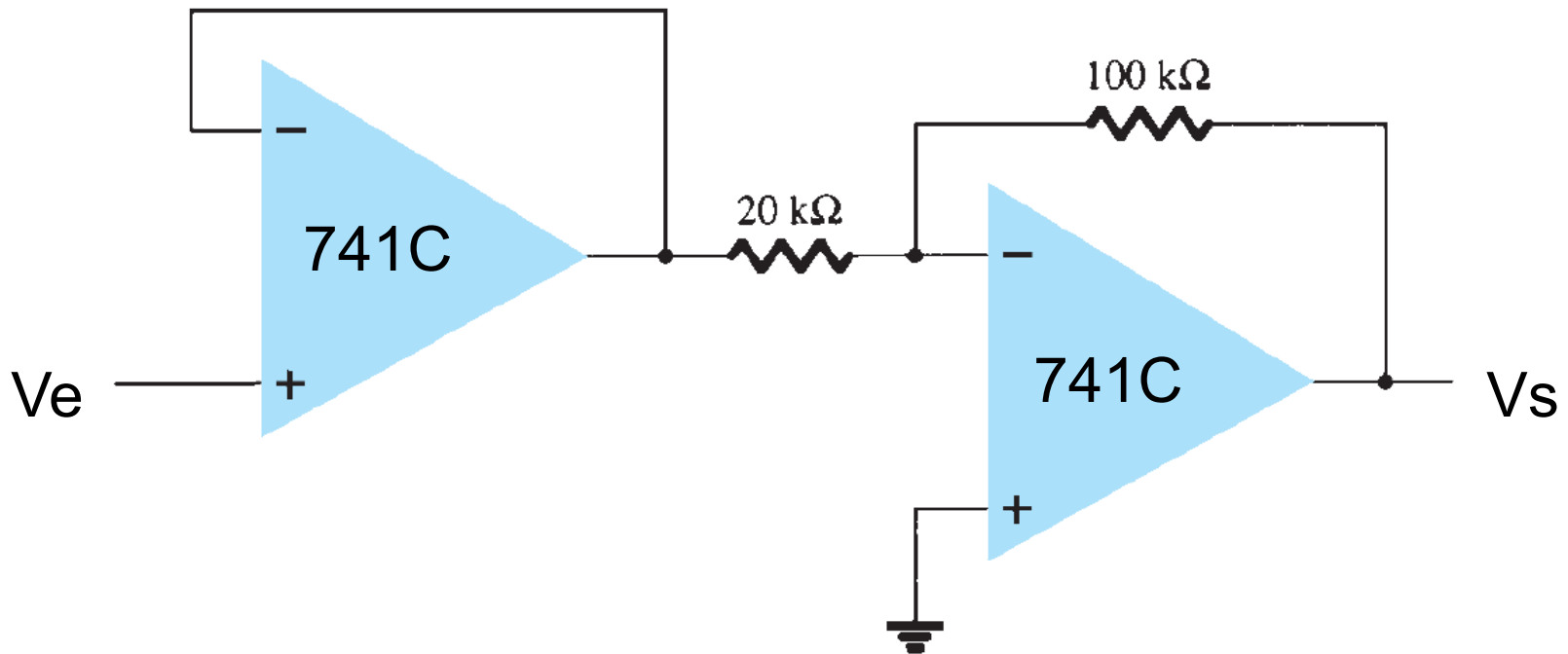


$$\text{Offset Error (RTO)} = \pm[|E_{o_1}| |G_2| + |E_{o_2}|]$$

$$\text{Offset Error (RTI)} = \pm[E_{o_1}/G_1 + E_{o_2}/(G_2 G_1)]$$

6.2 Offset error

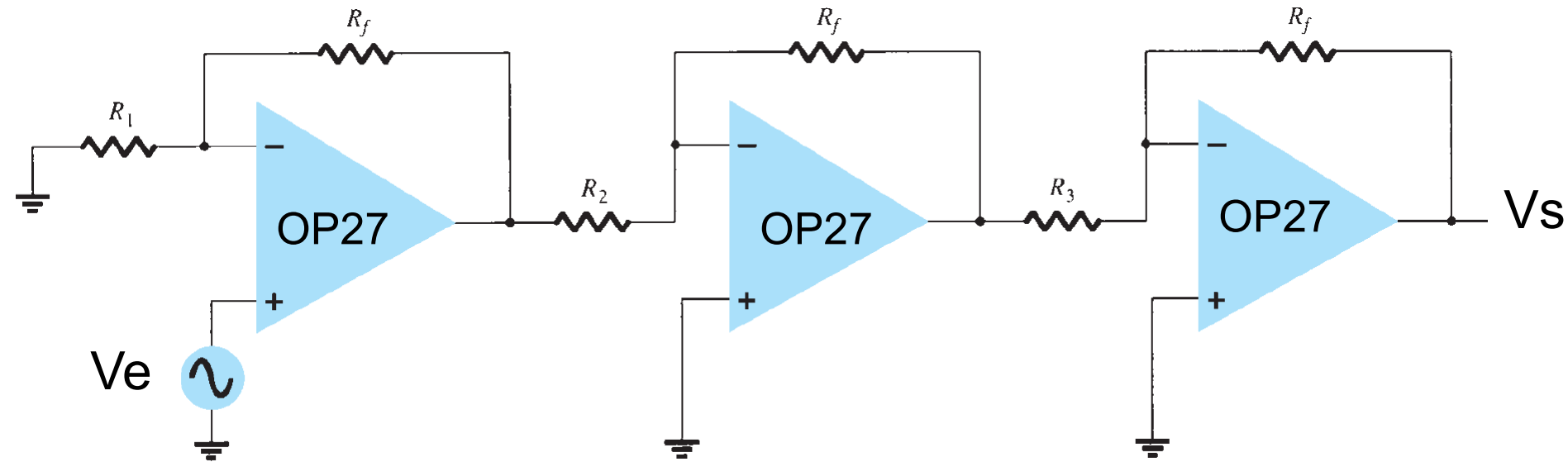
Estimate the $V_{o(\text{offset})}$ due to the offset voltage of the OAs and due to their polarizing currents at the input (Temperature is 25°C)



6.2 Offset error

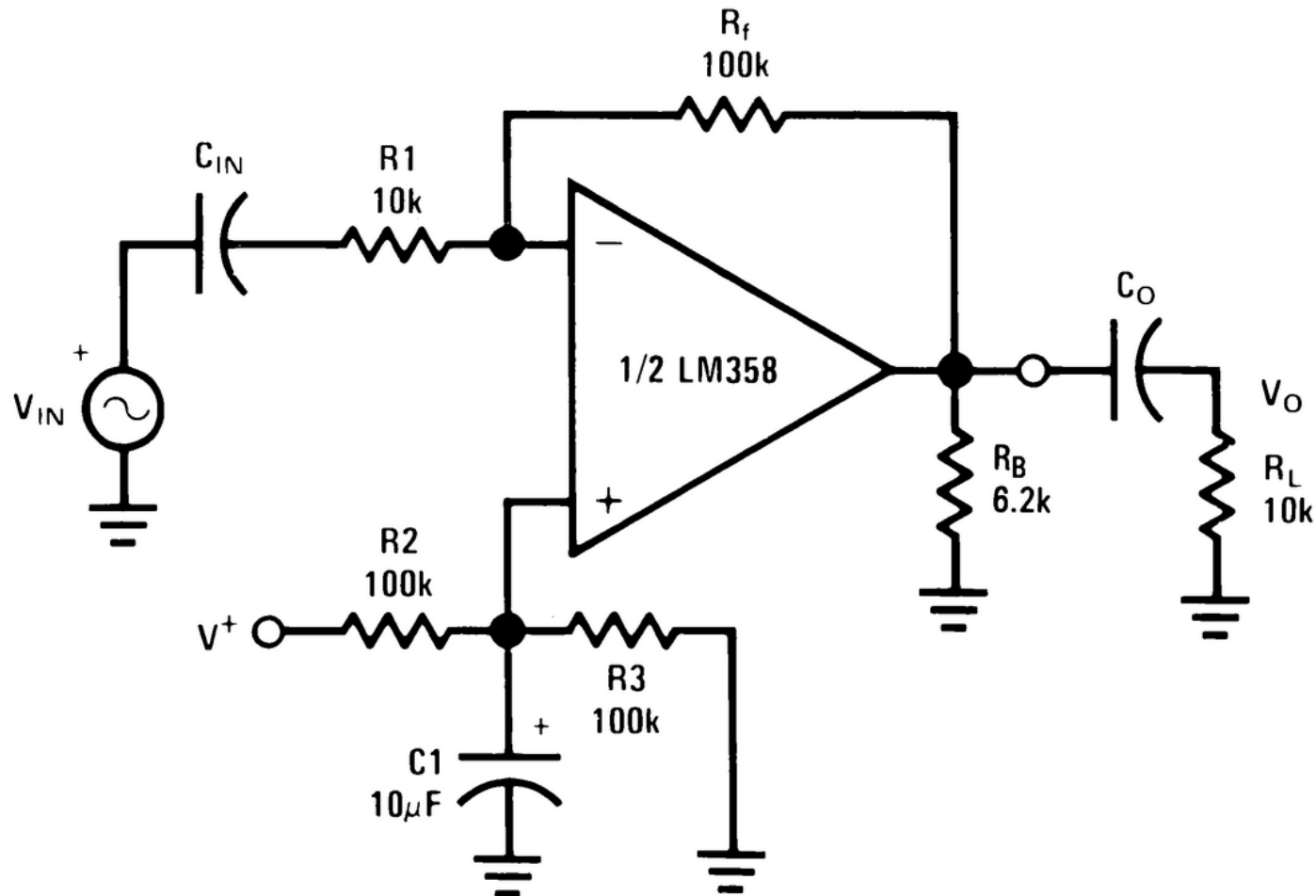
Estimate the $V_{o(\text{offset})}$ due to the offset voltage of the OAs and due to their polarizing currents at the input (Temperature is 25°C)

$R_f=10\text{ k}\Omega$, $R_1=1\text{ k}\Omega$, $R_2=2\text{ k}\Omega$, $R_3=5\text{ k}\Omega$



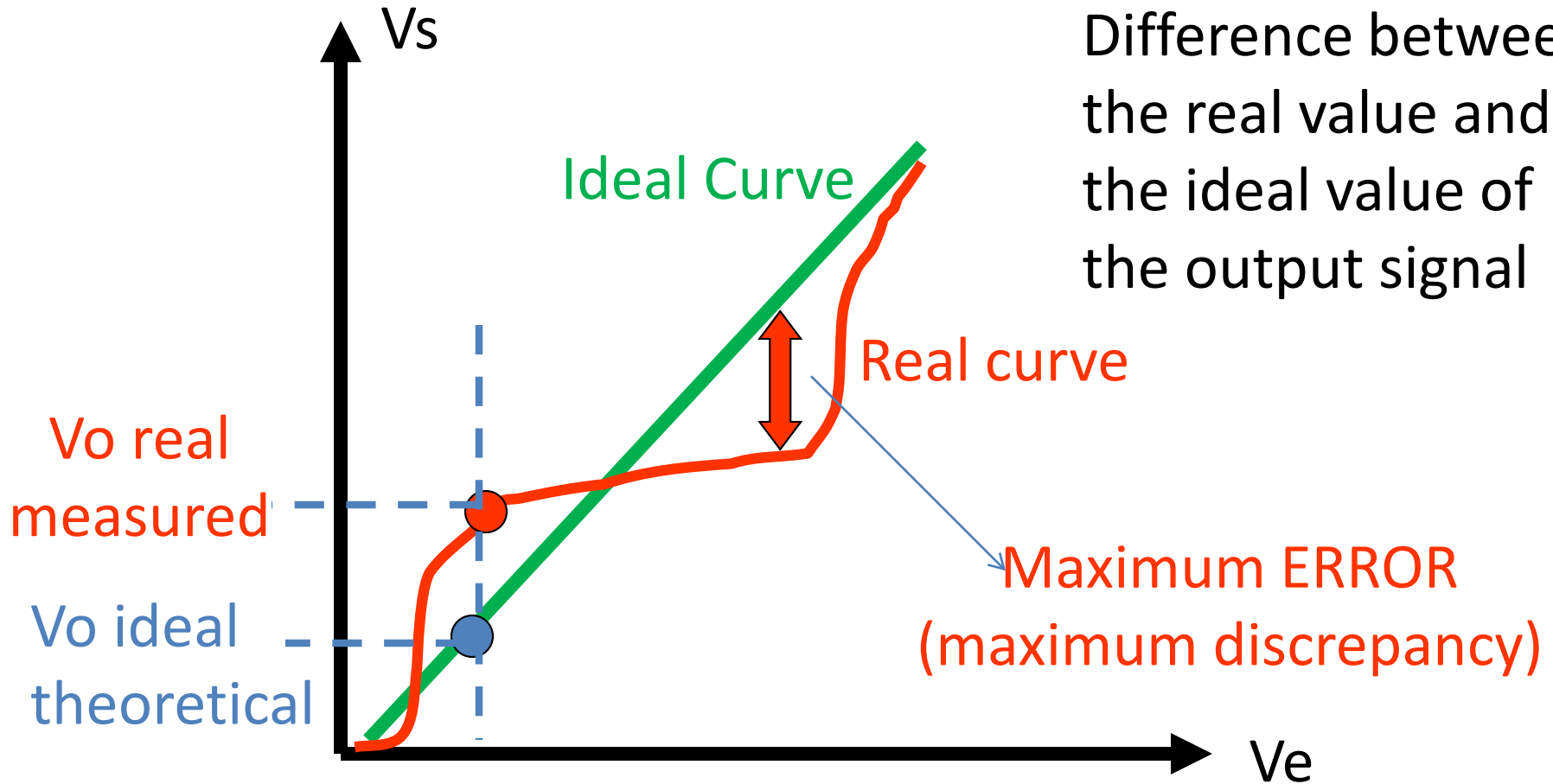
6.2 Offset error

Estimate the $V_{o(\text{offset})}$ due to the offset voltage of the OA (LM358) and due to its polarizing currents at the input (Temperature is 25°C)



6.2 Offset error

Accuracy



ACCURACY:

Difference between the real value and the ideal value of the output signal

6.2 Offset error

Errors Formulation:

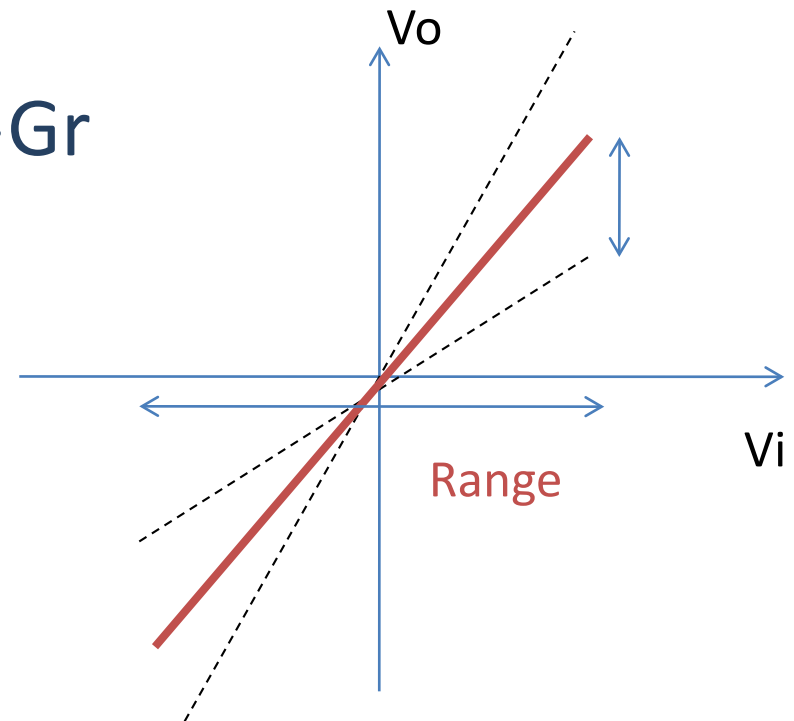
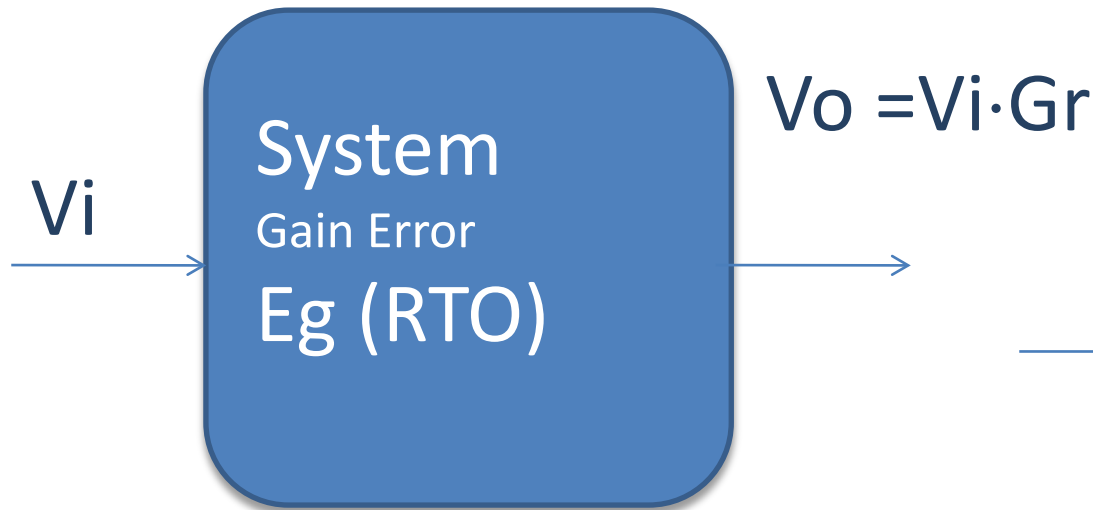
$$\text{ABSOLUTE ERROR} = \\ | \text{Real value} - \text{ideal value} |$$

$$\text{RELATIVE ERROR}(\%) = \\ \left| \frac{\text{Real value} - \text{ideal value}}{\text{ideal value}} \right| 100$$

6.3 Gain error

Systematic Errors

Gain error (multiplicative, relative error)



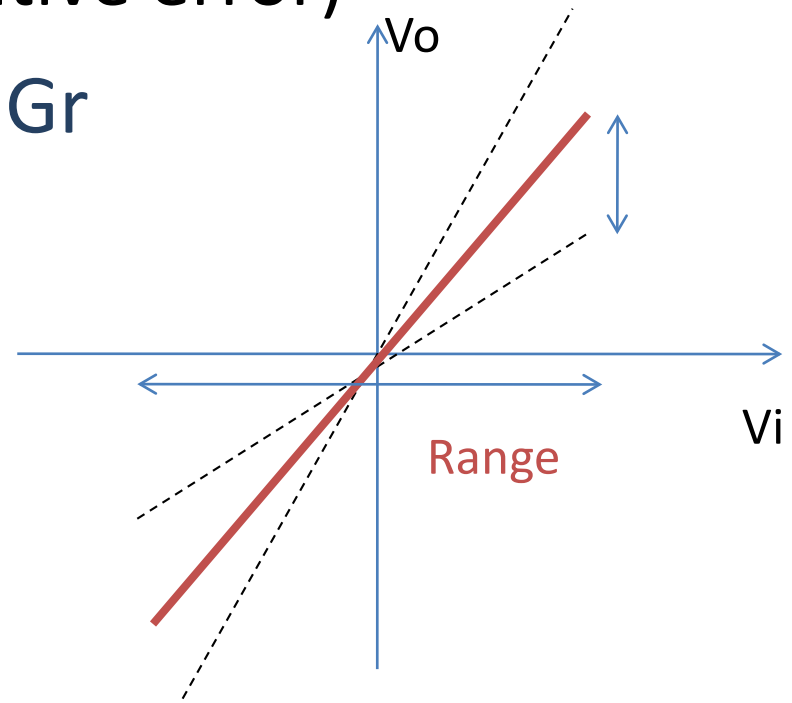
- The relative error is constant in all the range.
Regardless of V_i

$$E_{g(rel)} = \left| \frac{V_i G_i - V_i G_r}{V_i G_i} \right| 100 = \left| \frac{G_i - G_r}{G_i} \right| 100$$

6.3 Gain error

Systematic Errors

Gain error (multiplicative, relative error)



- The absolute error is maximum in the range limits

$$E_{g(abs)} = |V_i G_i - V_i G_r|$$

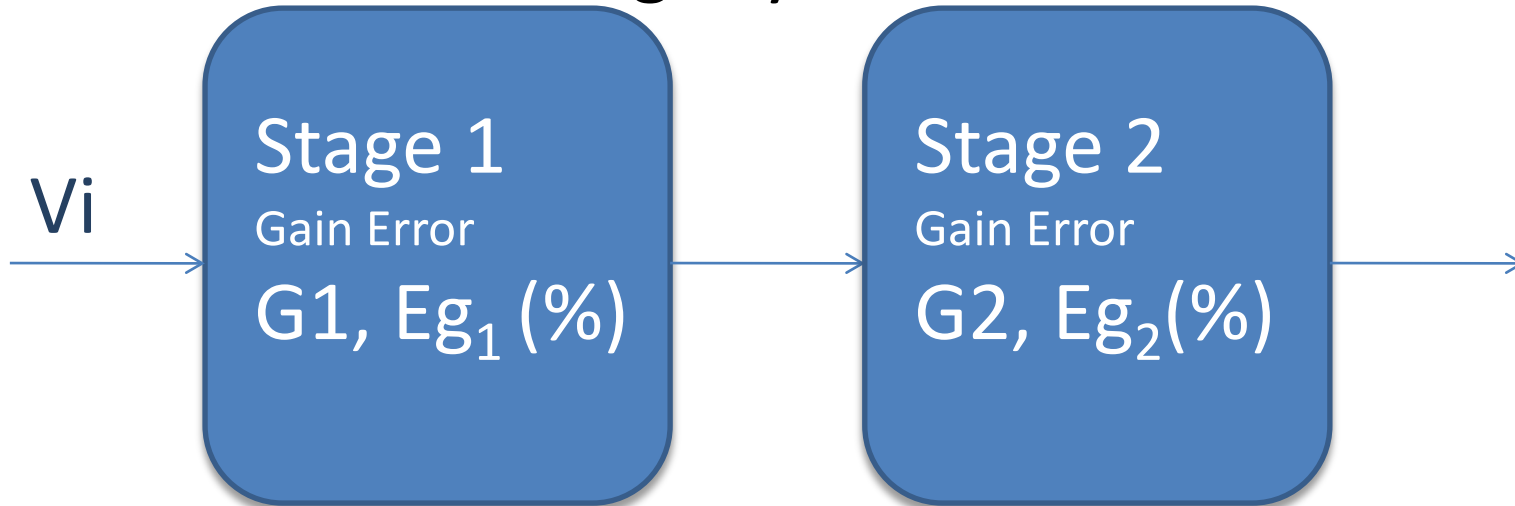
$$E_{g(rel)} = \left| \frac{V_i G_i - V_i G_r}{V_i G_i} \right| 100$$

$$E_{g(abs)} = \frac{E_{g(rel)}}{100} V_i G_i$$

6.3 Gain error

Systematic Errors

Gain error in multistage systems

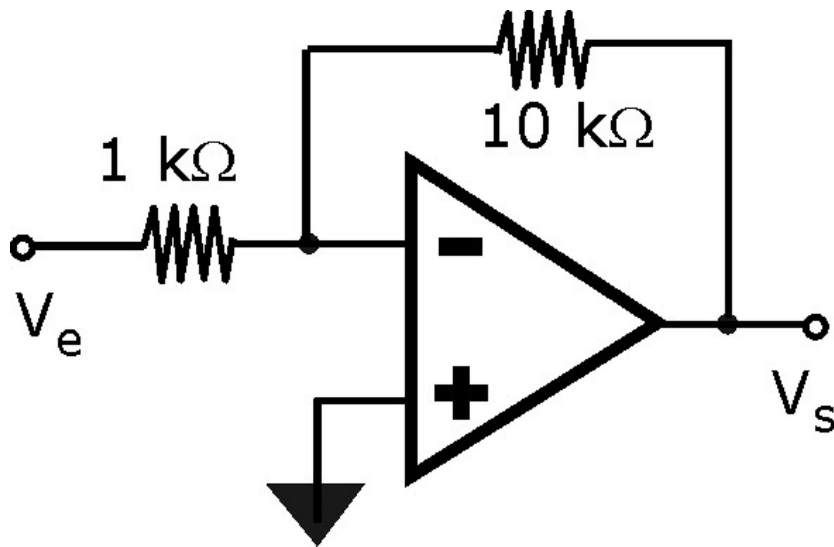


$$E_{g(rel)} = \left| \frac{V_i G_{1i} G_{2i} - V_i G_{1r} G_{2r}}{V_i G_{1i} G_{2i}} \right| 100 = \left| \frac{G_{Ti} - G_{Tr}}{G_{Ti}} \right| 100$$

$$E_{g(abs)} = \frac{E_{g(rel)}}{100} V_i G_{Ti}$$

6.3 Gain error

Impact of the gain error on design

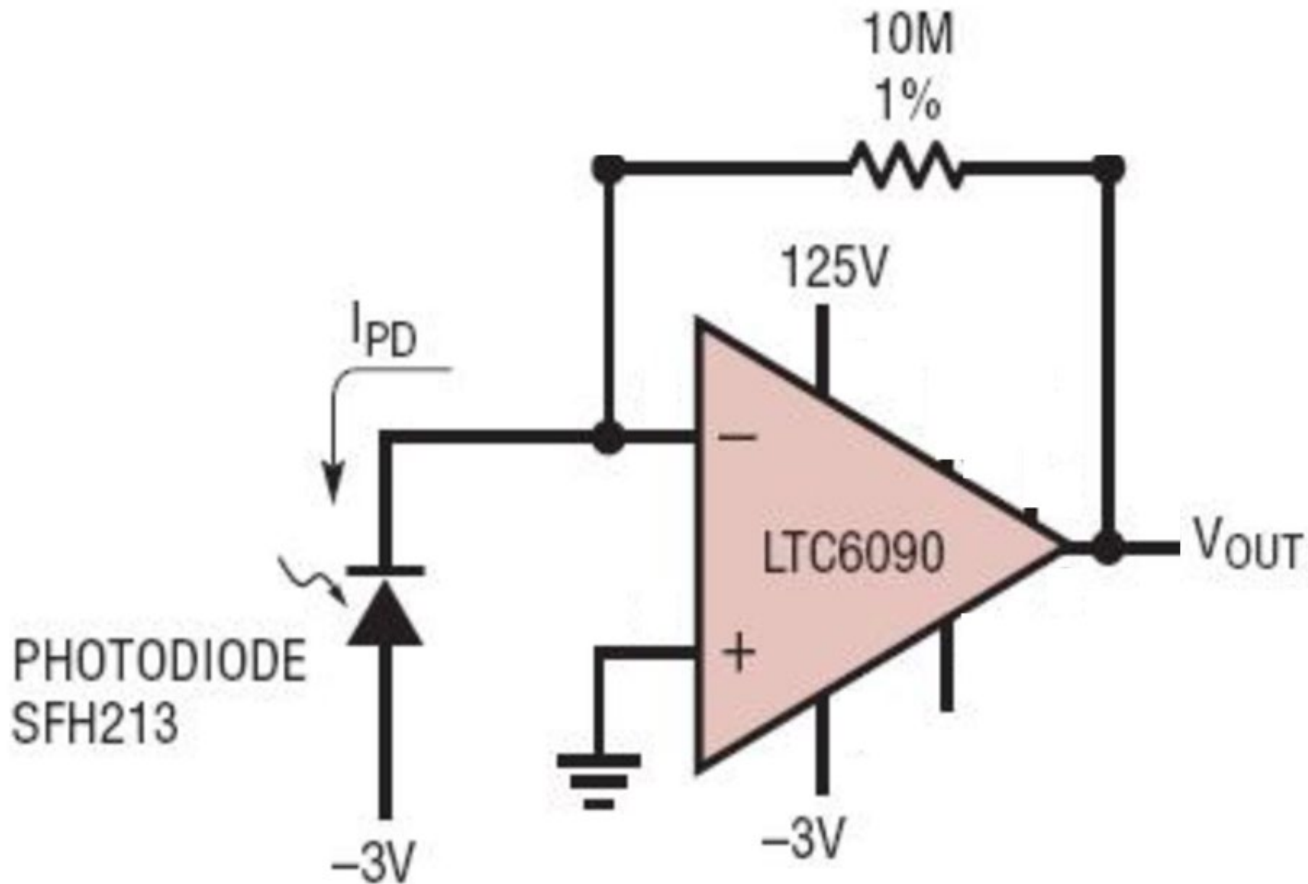


Estimate the gain error of the amplifier if the resistors have a tolerance of 5%

6.3 Gain error

Impact of the gain error on design

Estimate the gain error of the current to voltage converter



P11.

(1/2)

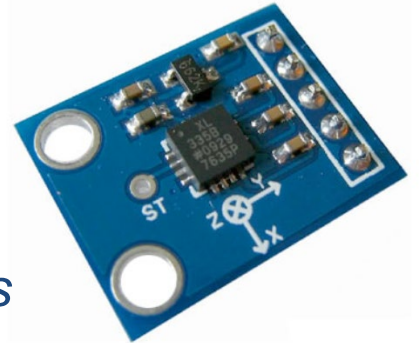
El registro de las vibraciones es de gran importancia no sólo para aplicaciones en sismología, sino por ejemplo para monitorizar las incidencias en un envío de mensajería.

Para poder registrar vibraciones se puede hacer uso de un acelerómetro.

Se necesita montar un sistema para registrar vibraciones usando un acelerómetro

(rango ± 0.5 G salida ± 2 mV). Para convertir la señal del sensor en una señal de ± 2 V,

se decide conectar en cascada dos módulos amplificadores



	Módulo 1	Módulo 2
Tensión de offset (RTO)	6 mV	5 mV
Ganancia de tensión ideal	100 (40 dB)	10 (20 dB)
Ganancia de tensión real	40 ± 0.02 dB	20 ± 0.018 dB
Ruido máximo a la salida (pp)	15 μ V	10 μ V
Máxima corriente a la salida	500 mA	700 mA
Capacidad a la salida	2 nF	1 nF
Tensión de alimentación (simétrica)	± 15 V	± 15 V
Corriente consumida	1.5 A	1.8 A
Ancho de banda (pequeña señal)	10 kHz	15 kHz

Una vez conectados en serie, se desea valorar cuál será la exactitud del sistema completo, así como otras características de funcionamiento.

- 1) Calcular la ganancia (sensibilidad) del acelerómetro.*
- 2) Calcular la exactitud del circuito completo de amplificación expresada como unidades de aceleración. Calcular el valor exacto del error para el caso de no aceleración (0 G) y para el fondo de escala.*
- 3) Representar la función de transferencia ideal del sistema amplificador completo.*

6.4 Dynamic Specifications of the OA

Frequency Parameters

An OA is a wide-bandwidth amplifier. The following affect the bandwidth of the OA:

- Gain Band width product
- Slew rate

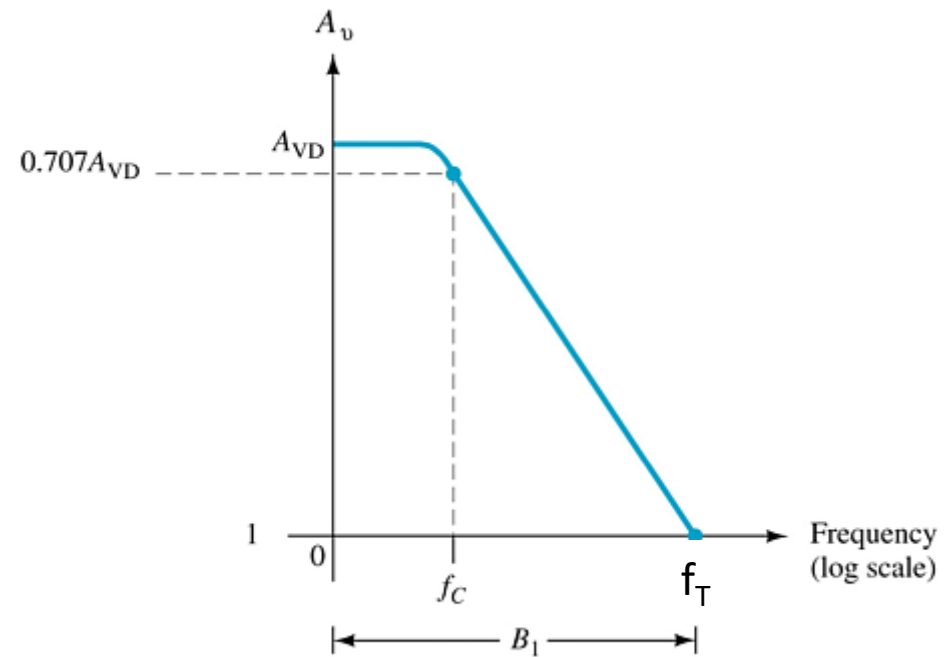
6.4 Dynamic Specifications of the OA. GBP

Gain Bandwidth Product

The OA's high frequency response is limited by internal circuitry. The plot shown is for an open loop gain (A_{OL} or A_{VD}). This means that the OA is operating at the highest possible gain with no feedback resistor.

In the open loop, the OA has a narrow bandwidth. The bandwidth widens in closed-loop operation, but then the gain is lower.

$$\text{GPB} = G_{sys} \times BW_{sys} = 1 \times f_T$$



6.4 Dynamic Specifications of the OA. GBP

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High cut off frequency: Effect of the GBP

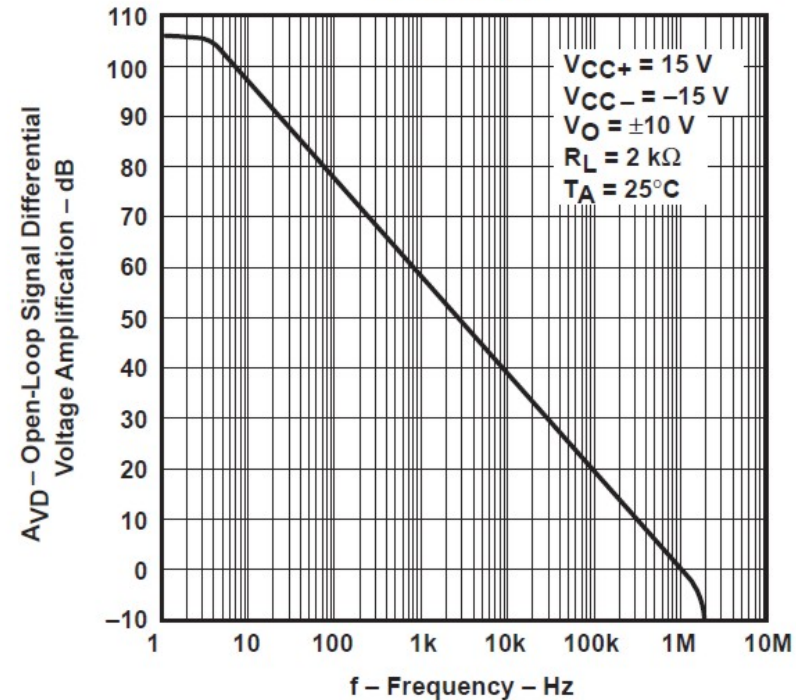
$G \times BW = f_T$ is provided in the OA data sheet.

It is equivalent to the frequency where $A_{VD} = 0$ dB

$$f_{\text{max-GxBW}} = G \times BW / G_{\text{system}}$$

- AO741 → 1 MHz TL081 → 4 MHz

OPEN-LOOP LARGE-SIGNAL DIFFERENTIAL
VOLTAGE AMPLIFICATION
vs
FREQUENCY

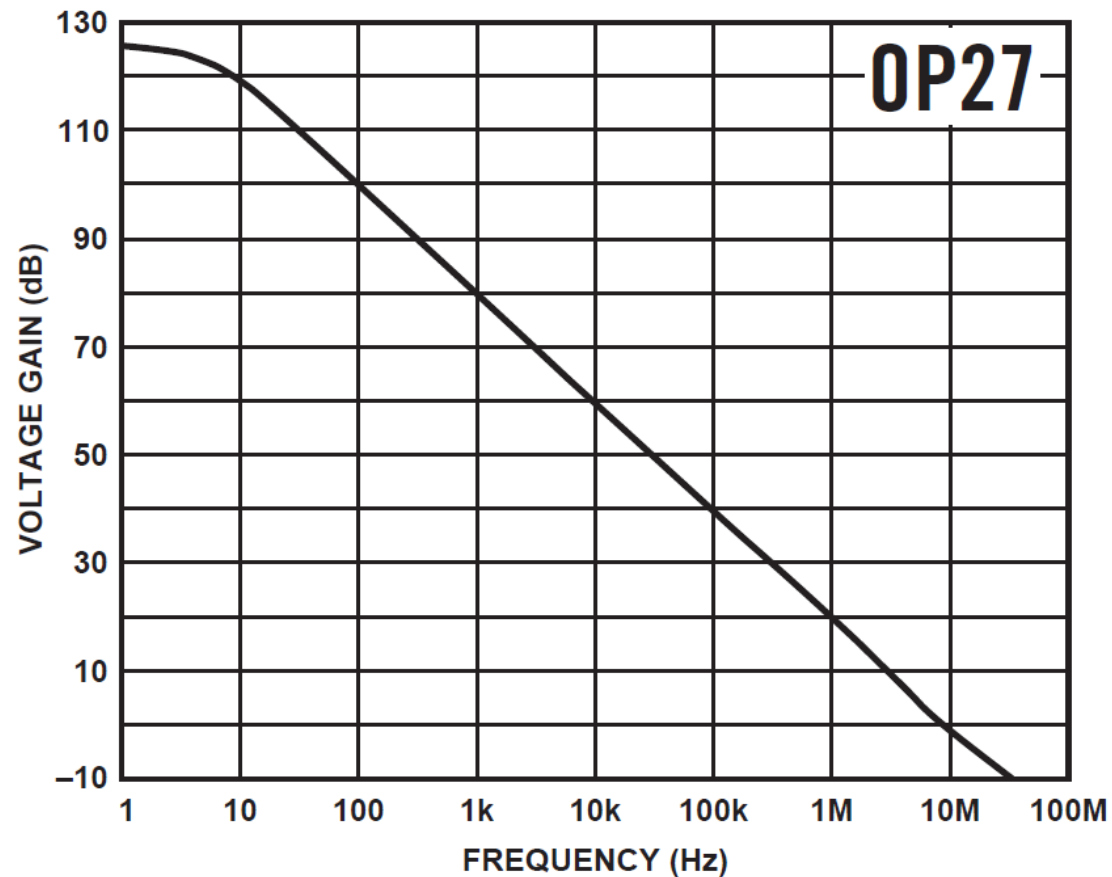


6.4 Dynamic Specifications of the OA. GBP

Product G • BW del OP27

Ex: for a follower circuit
based on OP27 (G=1)
BW_{sis} ?

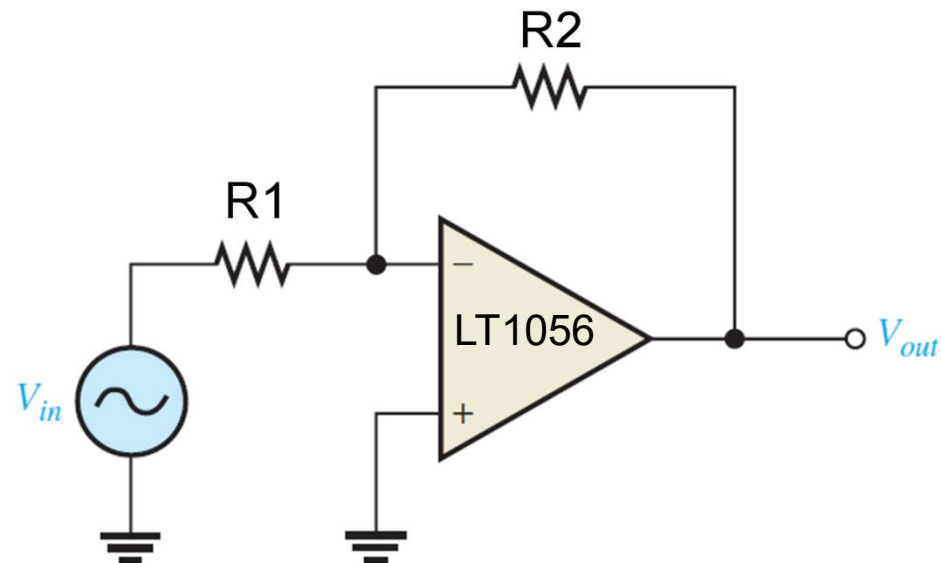
$$\text{GBP} = G_{\text{sys}} * \text{BW}_{\text{sys}} = f_T$$



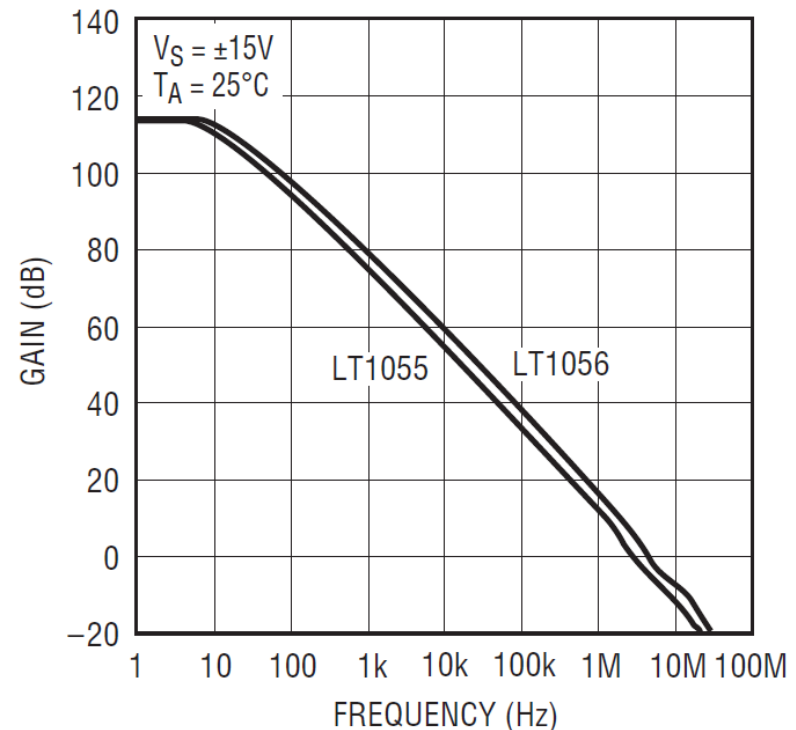
6.4 Dynamic Specifications of the OA. GBP

The **bandwidth of a system** based on an OA with negative feedback is the ratio between the GBW of the OA and the modulus of the gain of the system.

Calculate the bandwidth of a system based on an inverter amplifier based on an OA LT1055AM ($R_1=1\text{ k}\Omega$, $R_2 = 50\text{ k}\Omega$)

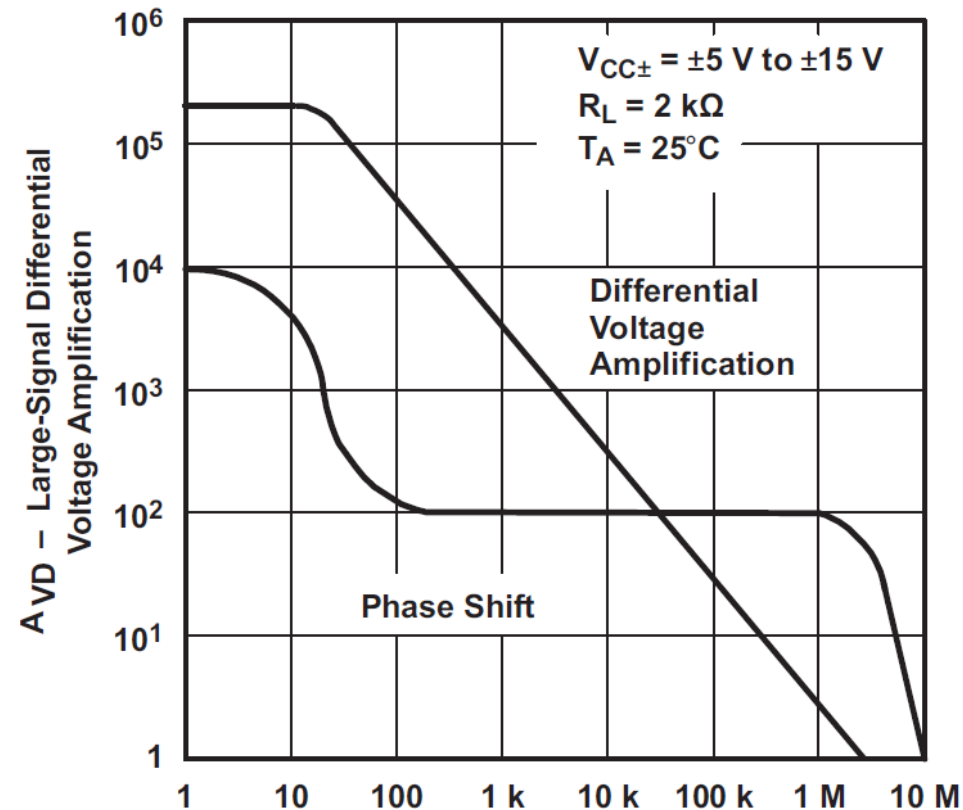
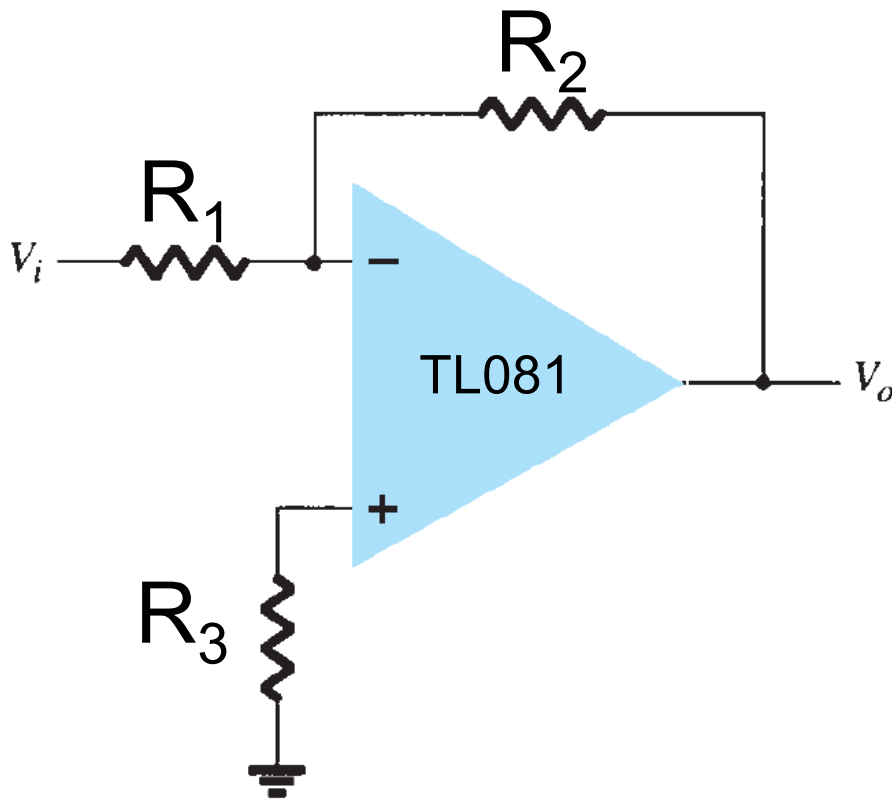


$$f_{\max-GBW} = \frac{GBW_{OA}}{G_{syst}}$$



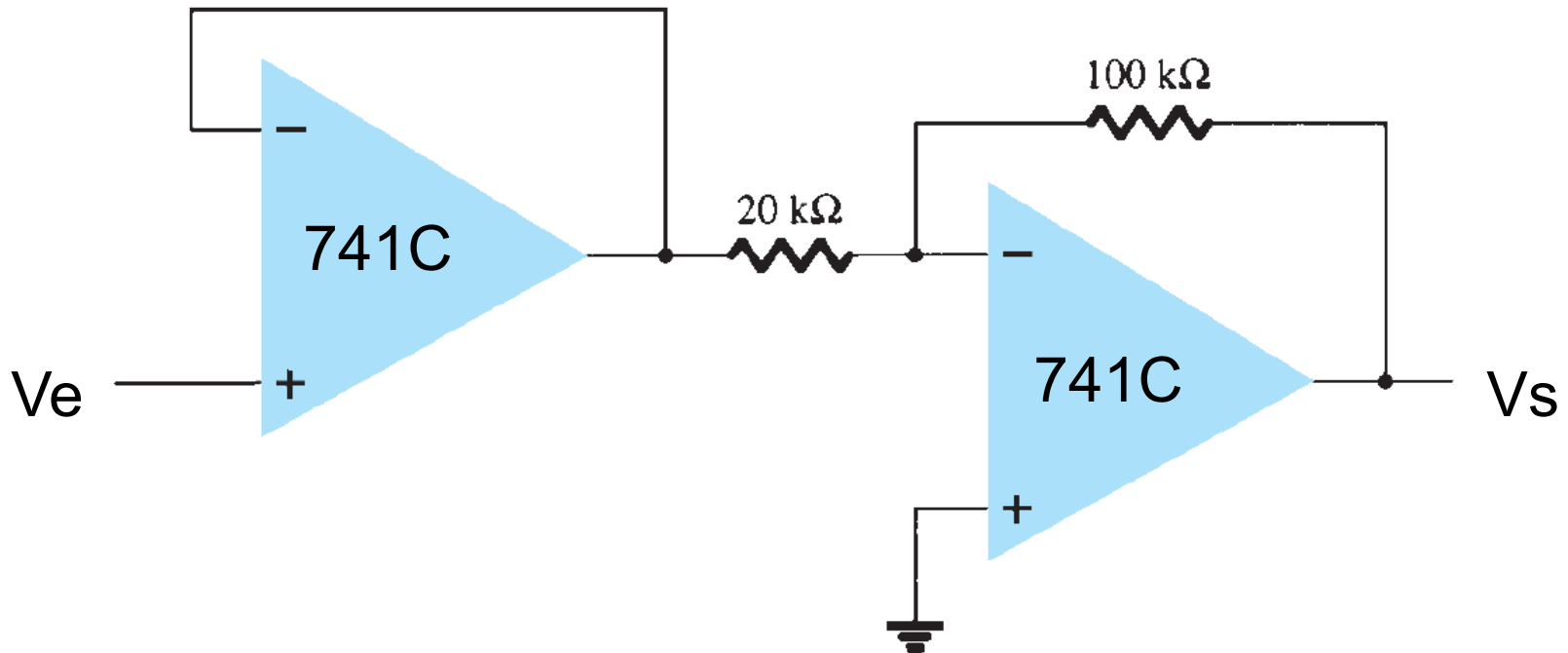
6.4 Dynamic Specifications of the OA. GBP

Calculate the maximum value of R_2 so that the amplifier has a minimum BW of 300 kHz ($R_1=1\text{ k}\Omega$, $R_3 = 1\text{ k}\Omega$)



6.4 Dynamic Specifications of the OA. GBP

Calculate the bandwidth and represent the bode diagram of the amplifier based on 2 stages



6.4 Dynamic Specifications of the OA. SR

High cut off frequency: Effect of the Slew rate

Maximum variation rate with respect to the time of the output signal of the system:

$$SR = \left| \frac{dV_o}{dT} \right|_{\max} \quad (V/\mu s)$$

Caused by:

- Maximum output current
- Load capacitances $SR = I_{\max} / C_{\text{load}}$

TL081, TL081A, TL081B, TL082, TL082A
TL082B, TL084, TL084A, TL084B

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	$V_I = 10\text{ V}, R_L = 2\text{ k}\Omega, C_L = 100\text{ pF}$, See Figure 19	8 ⁽¹⁾	13		V/ μ s
		$V_I = 10\text{ V}, R_L = 2\text{ k}\Omega, C_L = 100\text{ pF}$, $T_A = -55^\circ\text{C}$ to 125°C , See Figure 19	5 ⁽¹⁾			

LT1055/LT1056

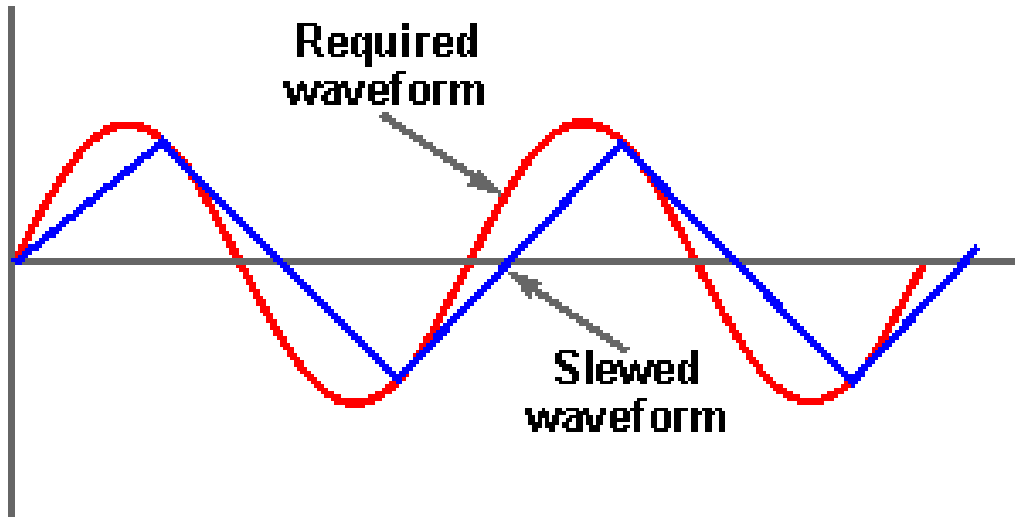
ELECTRICAL CHARACTERISTICS $T_A = 25^\circ\text{C}$. $V_S = \pm 15\text{V}$, $V_{CM} = 0\text{V}$ unless otherwise noted.t

SYMBOL	PARAMETER	CONDITIONS	LT1055AM/LT1056AM LT1055AC/LT1056AC			LT1055M/LT1056M LT1055CH/LT1056CH LT1055CN8/LT1056CN8			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	
SR	Slew Rate	LT1055	10	13		7.5	12		V/ μ s
			12	16		9.0	14		V/ μ s
GBW	Gain Bandwidth Product	f = 1MHz	5.0			4.5			MHz
			6.5			5.5			MHz

6.4 Dynamic Specifications of the OA. SR

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High cut off frequency: Effect of the Slew rate



Maximum frequency of a sinusoidal wave that the OA can provide without distortion

$$f_{\max\text{-SR}} = \text{SR} / (\pi \cdot \text{Max excursion of output signal})$$

$$f_{\max\text{-SR}} = \frac{\text{SR}}{2\pi A} \quad \text{A is the peak amplitude of the output signal}$$

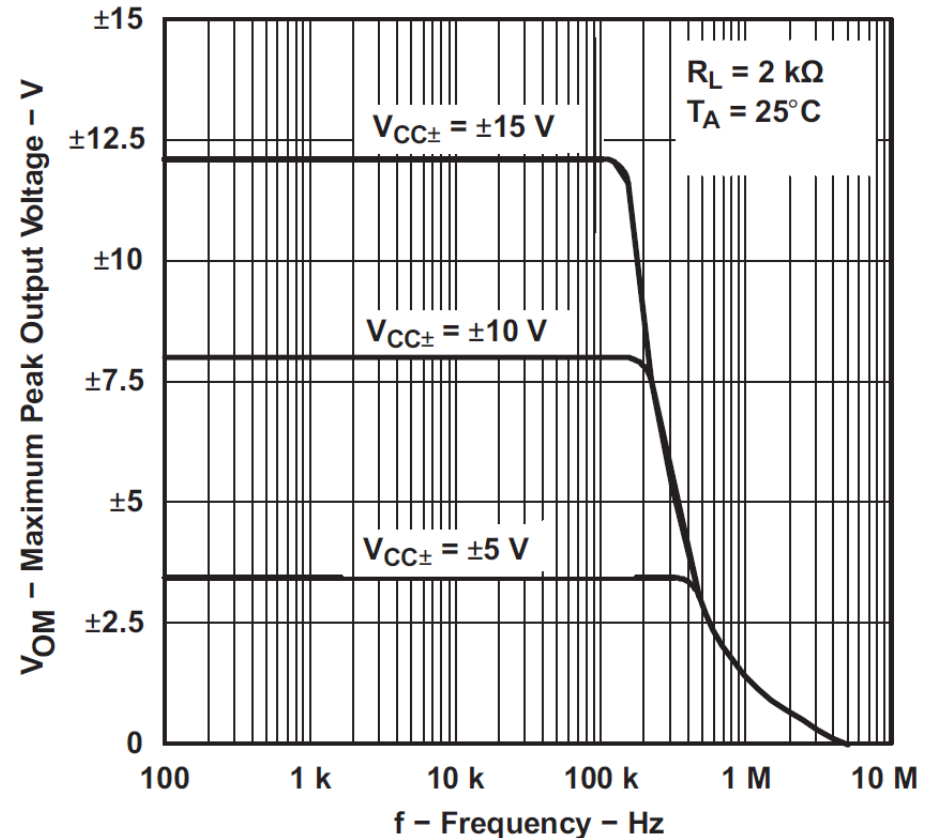
6.4 Dynamic Specifications of the OA

Impact of the Slew Rate (SR) on the system BW

The value of $f_{\text{max-SR}}$ does NOT depend on the gain of the system, but on the maximum excursion of the output signal of the OA

Calculate the bandwidth due to the SR of the TL081 if the excursion of the output signal is $\pm 15\text{ V}$

Repeat the calculation for excursions of $\pm 10\text{ V}$ and $\pm 5\text{ V}$



6.4 Dynamic Specifications of the OA

The GBP (GBW) parameter of the OA allows the estimation of the bandwidth of the system for small signal (small amplitudes of the output signal)

$$f_{\text{max-GBW}} = \frac{\text{GBW}_{\text{AO}}}{G_{\text{systema}}}$$

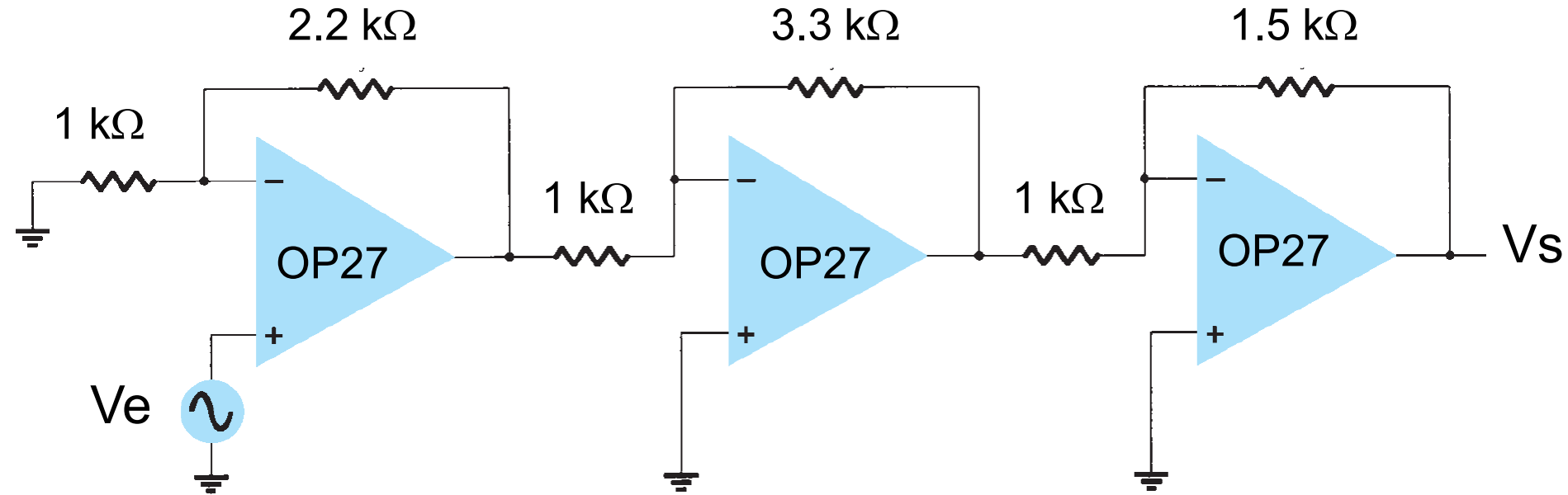
... Where as the SR of the OA allows the estimation of the bandwidth of the system for big signals (big amplitudes of the output signal)

$$f_{\text{max-SR}} = \frac{\text{SR}}{2\pi A}$$

The BW of the system will be the most restrictive (the smallest one) of both estimations.

6.4 Dynamic Specifications of the OA

Estimate the maximum processing frequency of the system based on 3 OAs OP27A if the input voltage varies between ± 300 mV



6.4 Dynamic Specifications of the OA

High cut off frequency: Concomittant effect in OA based systems

$$BW = f_{cs} - f_{ci}$$

$$f_{cs} = \text{minimum} \{f_{\text{max-SR}}, f_{\text{max-GxBW}}, f_{\text{max-RC}}\}$$

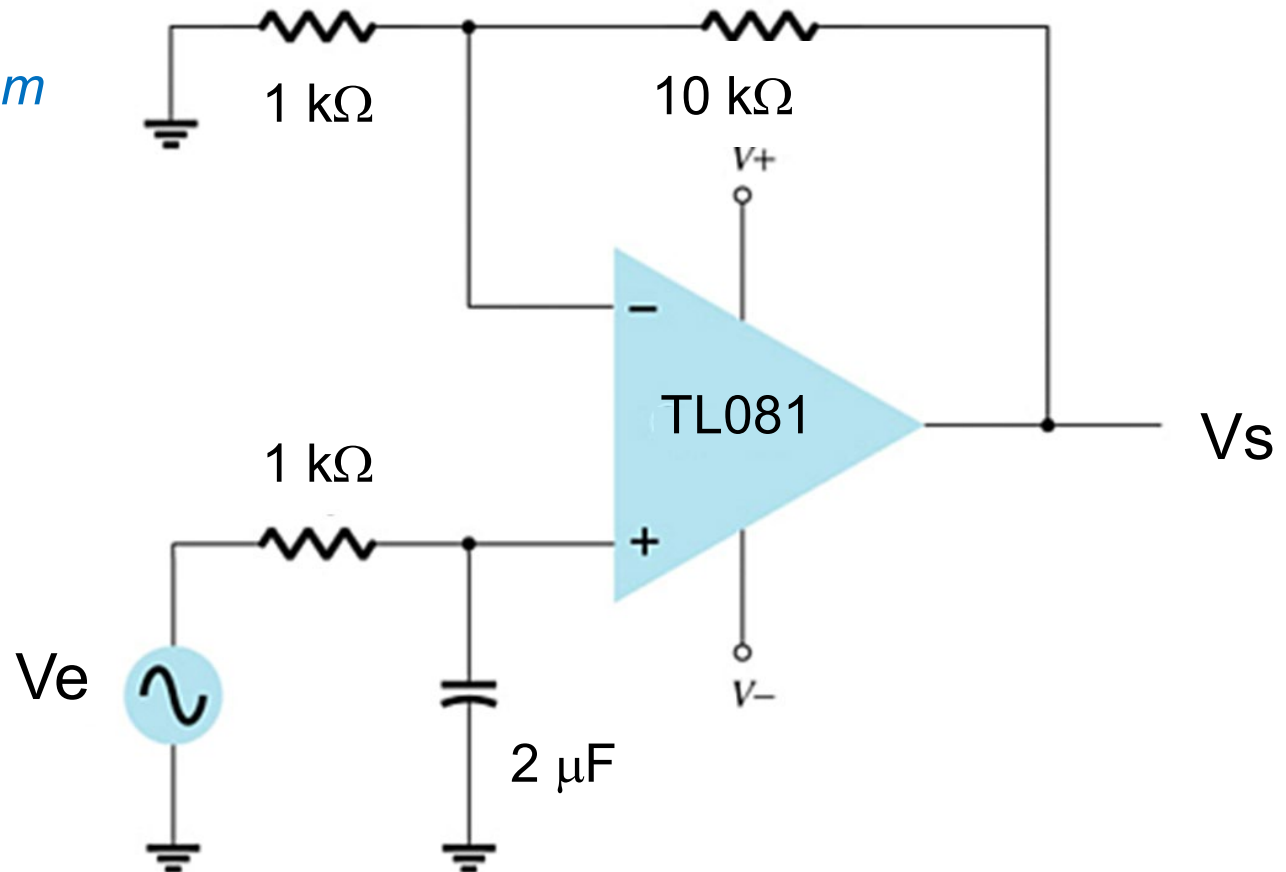
$$f_{ci} = \text{maximum} \{f_{\text{ci-RC}}\}$$

Capacitors present in the system can introduce high cut-off frequencies ($f_{\text{max-RC}}$)

6.4 Dynamic Specifications of the OA

Estimate the minimum and the maximum processing frequency of the system based on an OA TL081 if the input voltage varies between ± 500 mV

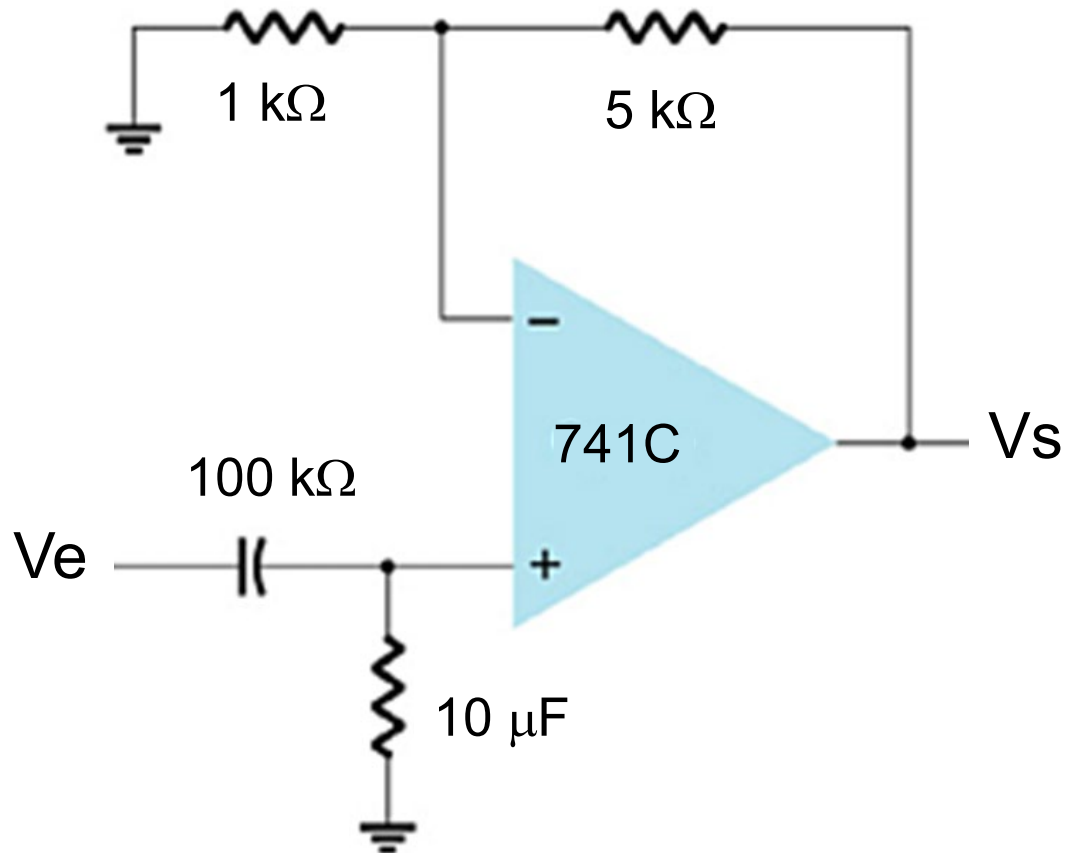
Represent the Bode diagram of the system



6.4 Dynamic Specifications of the OA

Estimate the minimum and the maximum processing frequency of the system based on an OA 741C (supplied with $\pm 15\text{ V}$) if the input voltage varies between $\pm 2\text{ V}$

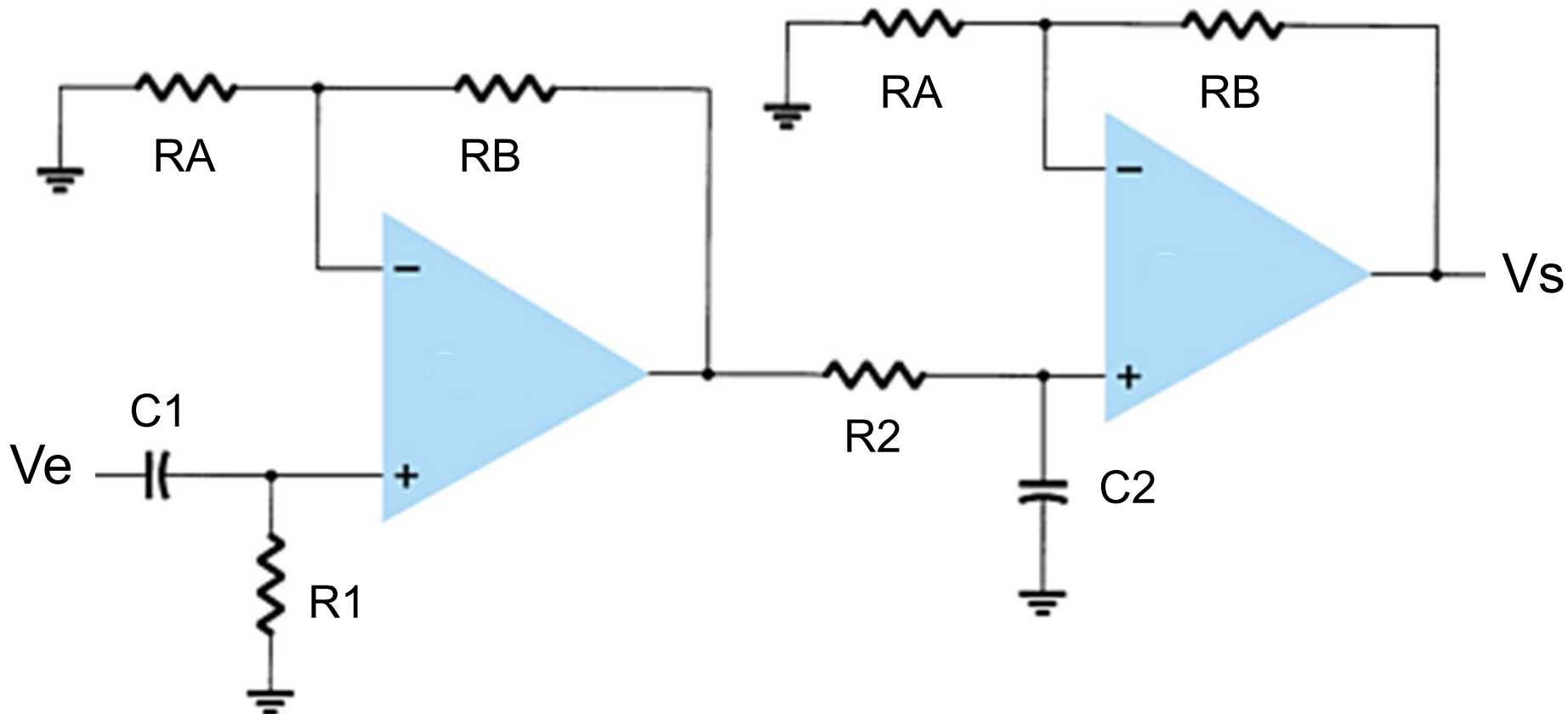
Represent the Bode diagram of the system



6.4 Dynamic Specifications of the OA

Design the values of R_1 , R_2 , C_1 , C_2 , R_B and R_A to achieve a gain of 12 dB and a bandwidth of 20 Hz – 20 kHz

Check whether this bandwidth is possible using OAs OP27 (supplied with ± 15 V) and V_e varies between ± 2 V



6.4 Dynamic Specifications of the OA

Calculate the bandwidth and represent the Bode Diagram (amplitude).

The OA is LT1055AM. Input voltage $\pm 2,5$ V.

Estimate the $V_{o(\text{offset})}$ due to the offset voltage of the OA.

What is the effect of the polarizing currents of the OA on the offset error at the output of the OA?

