

**Laboratório 1**  
**Amplificadores**  
**Básicos com Amp Op**

# Recordação

**Amplificador Inversor**

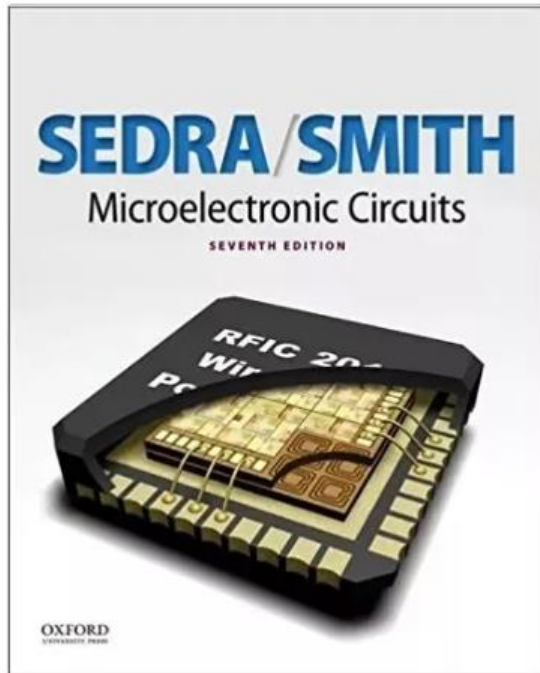
**Amplificador Não -Inversor**

**Seguidor de Tensão (Buffer)**

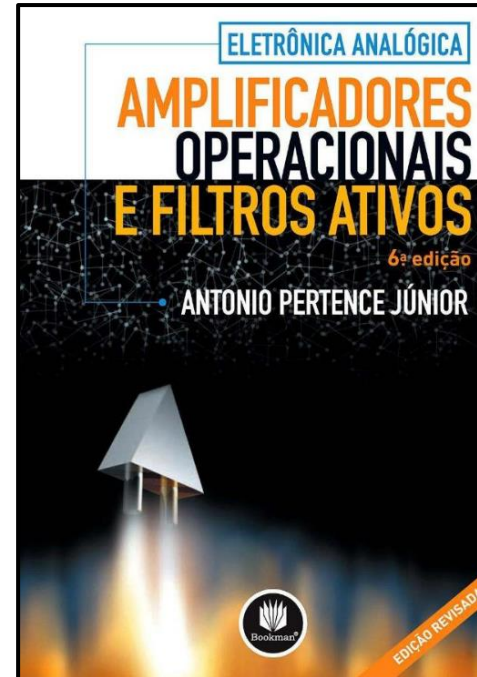
**A Single Op-Amp Difference Amplifier**

**Three Op-Amp Difference Amplifier  
(Instrumentation Amplifier)**

## Referências Bibliográficas

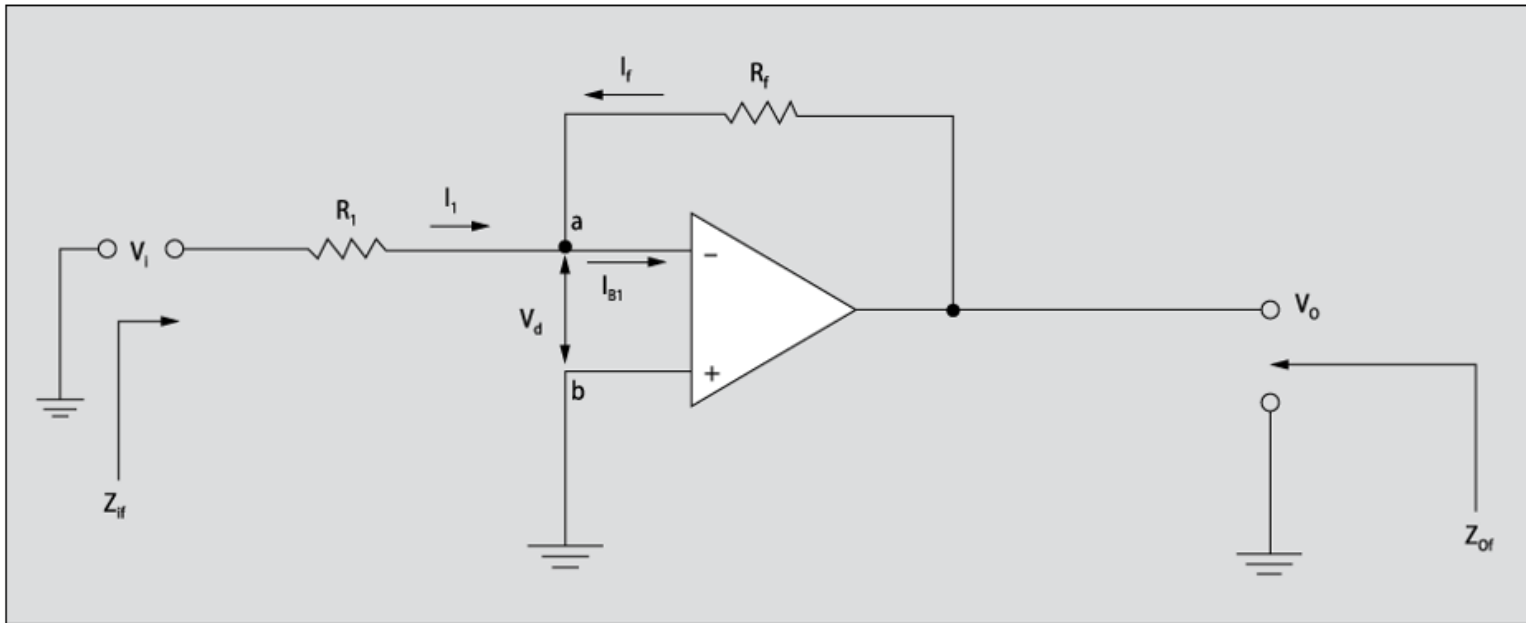


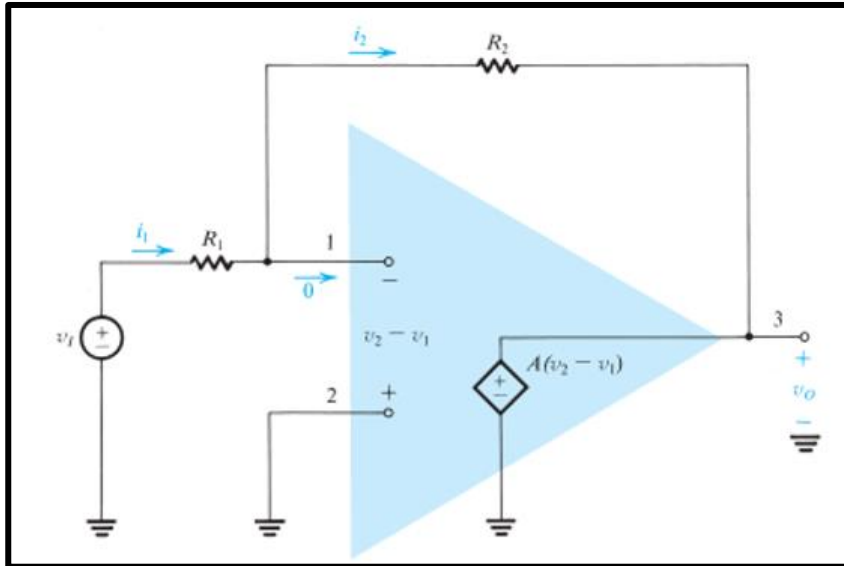
Oxford University Press  
2015, 7th Edition



Bookman  
2003, 6ª edição

# Amplificador Inversor





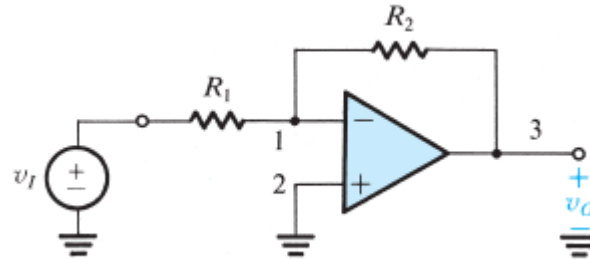
$$i_1 = \frac{v_I - v_1}{R_1} = \frac{v_I - 0}{R_1} = \frac{v_I}{R_1}$$

Where will this current go? It cannot go into the op amp, since the ideal op amp has an infinite input impedance and hence draws zero current. **It follows that  $i_1$  will have to flow through  $R_2$  to the low-impedance terminal 3.**

$$v_O = v_1 - i_1 R_2 = 0 - \frac{v_I}{R_1} R_2$$

$$\rightarrow \boxed{G = \frac{v_O}{v_I} = -\frac{R_2}{R_1}}$$

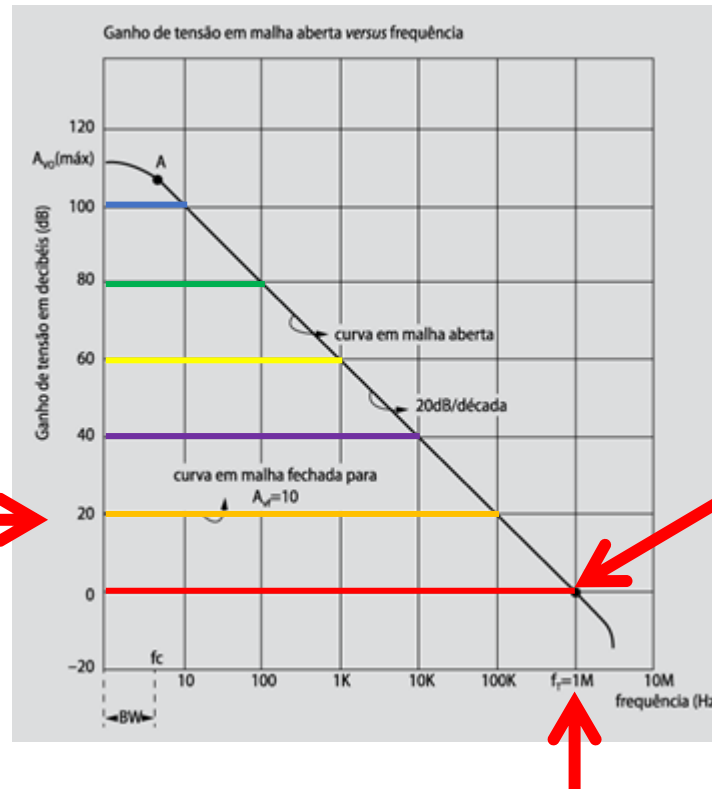
# Resposta em Frequência



$$PGL = A_{vf} \times BW = f_T$$

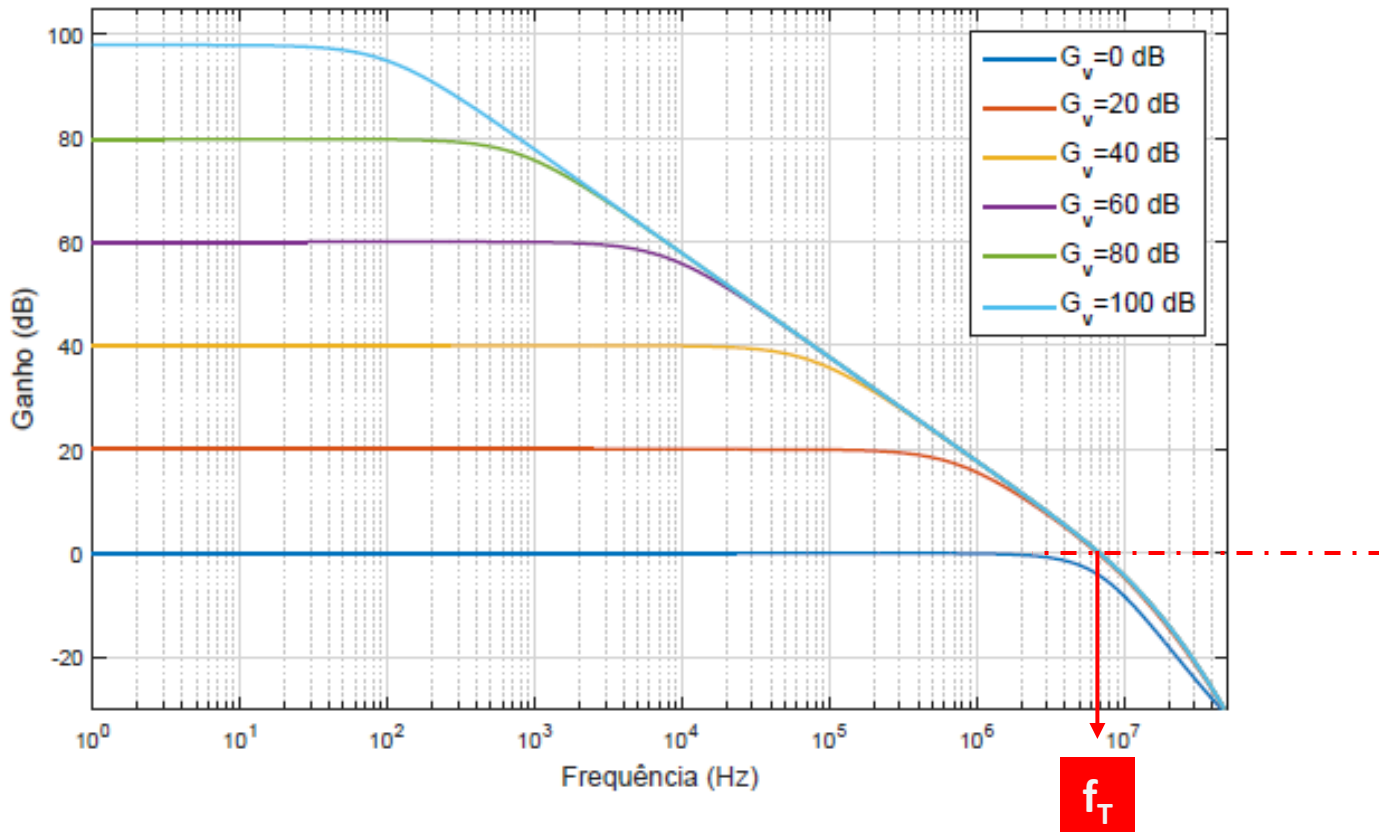
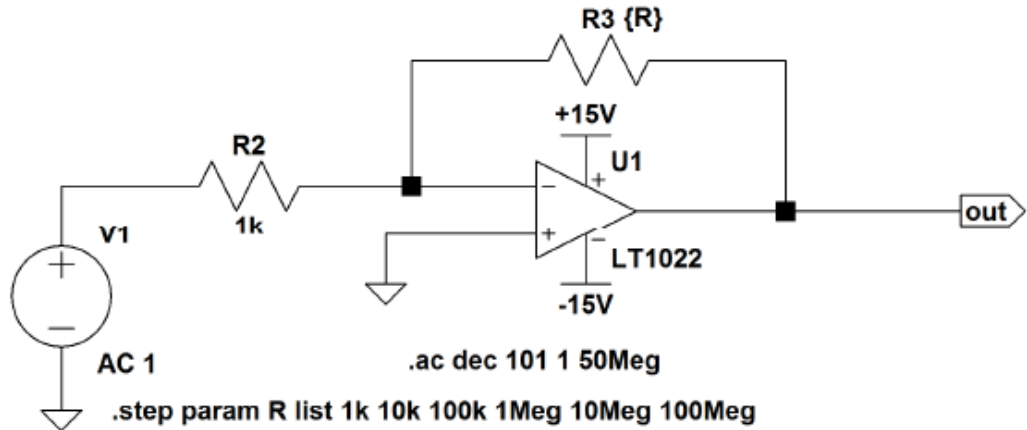
$$A_{vf} = 10(20\text{dB})$$

$$BW = \frac{1\text{MHz}}{10} = 100\text{KHz}$$

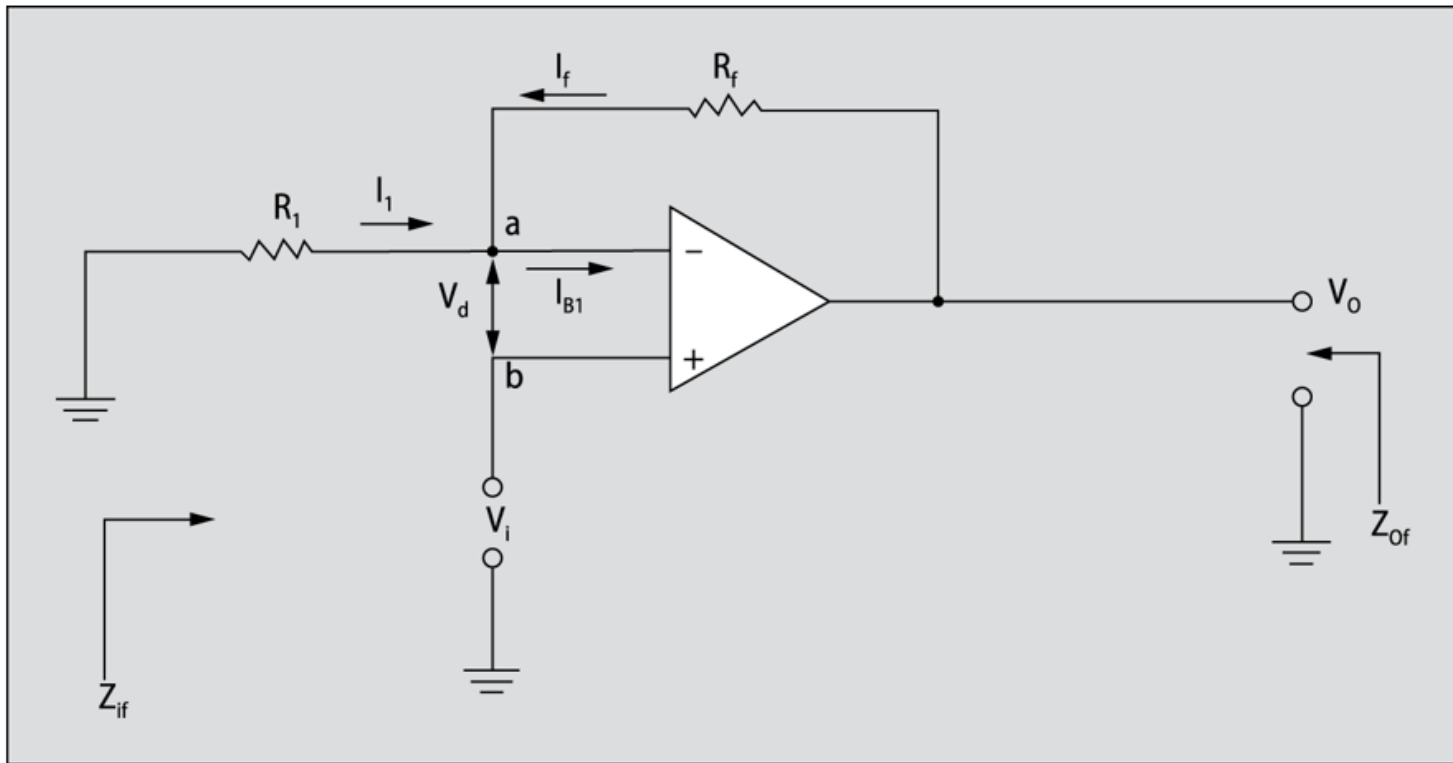


LM741 |  $f_T = 1\text{MHz}$   
 LF351 |  $f_T = 4\text{MHz}$

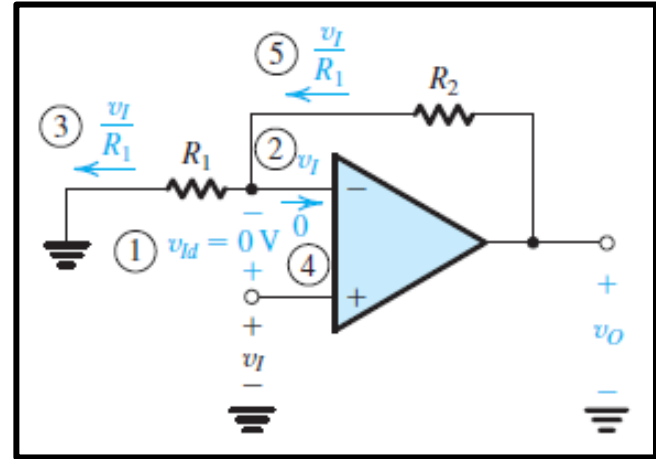
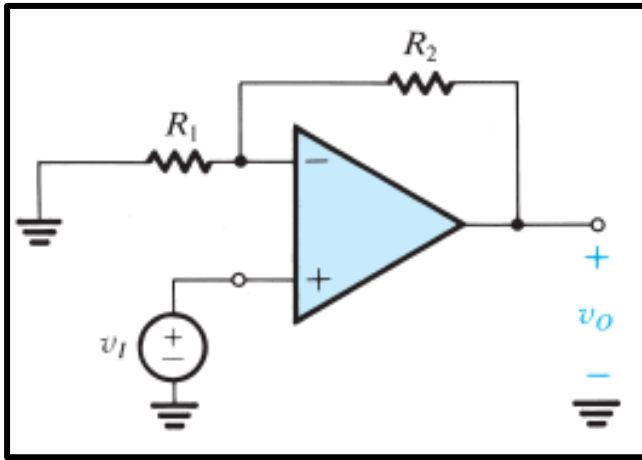
# Resposta em Frequência em Simulação (LTSPice )



# Amplificador Não-Inversor







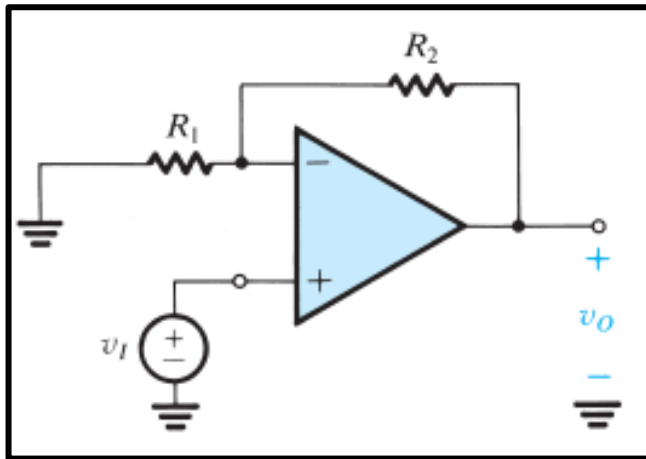
$$v_{Id} = \frac{v_o}{A} = 0$$

$$v_o = v_I + \left(\frac{v_I}{R_1}\right) R_2$$

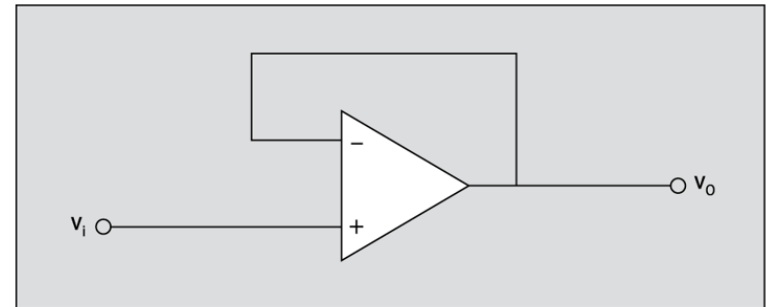


$$G = \frac{v_o}{v_I} = 1 + \frac{R_2}{R_1}$$

# Seguidor de Tensão (Buffer)



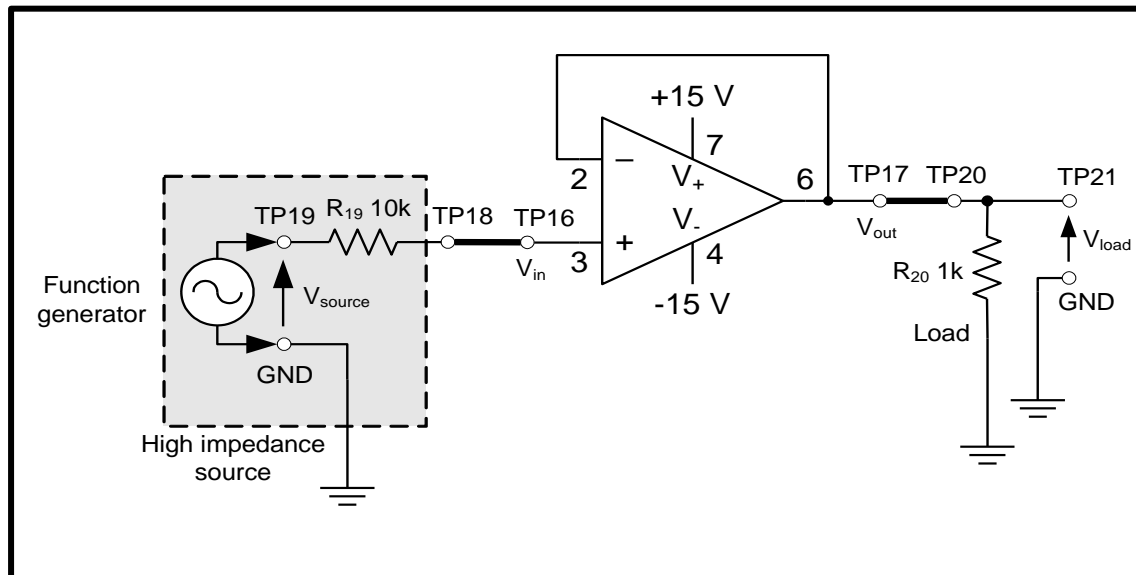
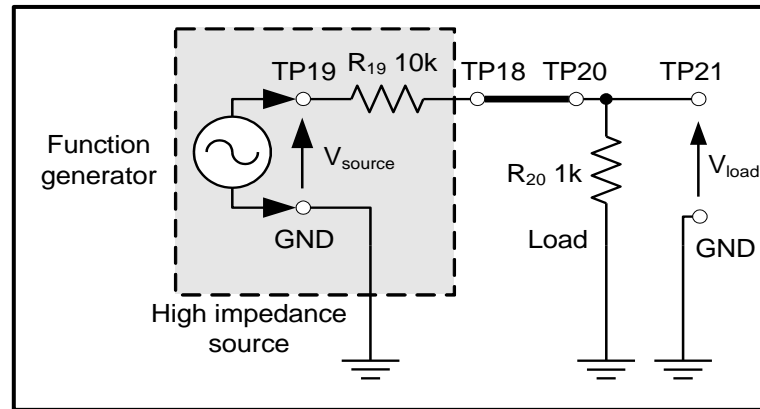
$$G = \frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$



$$A_{vf} = \frac{v_o}{v_i} = 1$$

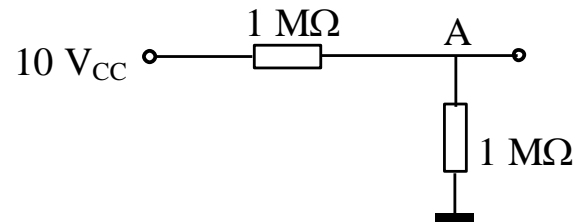
## Exemplo 1

# Loading Effect Op Amp Buffer



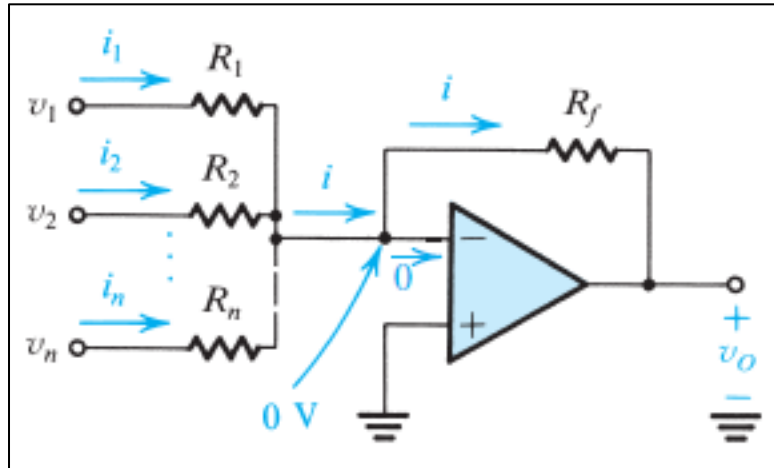
## Exemplo 2

- Implemente o circuito abaixo em um protoboard. Meça a tensão  $V_A$  utilizando um voltímetro analógico.



- Repita a medida anterior utilizando um circuito isolador entre o ponto A e o voltímetro analógico.

# Amplificador Somador Inversor



$$i_1 = \frac{v_1}{R_1}$$

$$i_2 = \frac{v_2}{R_2}$$

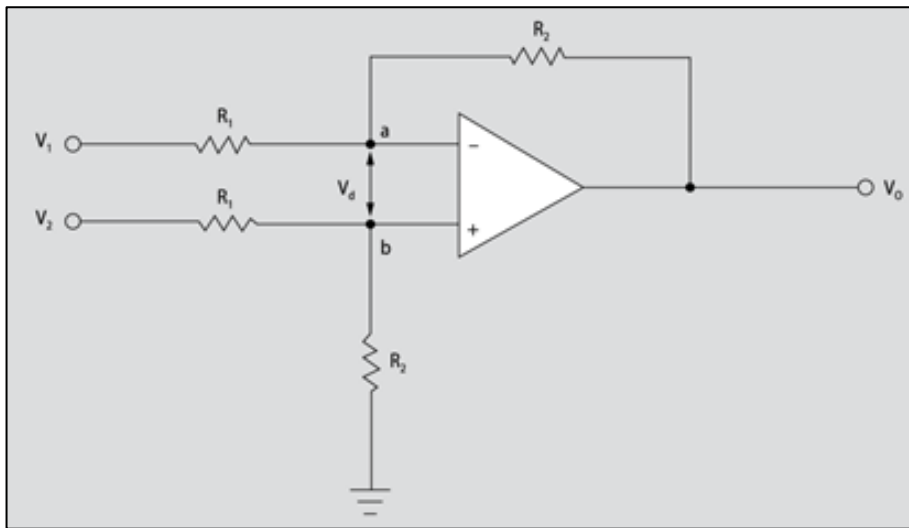
$$\dots i_n = \frac{v_n}{R_n}$$

$$\left. \begin{aligned} i &= i_1 + i_2 + \dots + i_n \\ v_o &= 0 - iR_f \end{aligned} \right\}$$



$$v_o = - \left( \frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \dots + \frac{R_f}{R_n} v_n \right)$$

# A Single Op-Amp Difference Amplifier



■ Nó a:

$$\frac{v_1 - v_a}{R_1} + \frac{v_o - v_a}{R_2} = 0$$

■ Nó b:

$$\frac{v_2 - v_b}{R_1} - \frac{v_b}{R_2} = 0$$

$$V_a = V_b \text{ (terra virtual)}$$



$$\frac{v_1 - \left(\frac{R_2}{R_1 + R_2}\right) \cdot v_2}{R_1} + \frac{v_o - \left(\frac{R_2}{R_1 + R_2}\right) \cdot v_2}{R_2} = 0$$



$$v_o = \frac{R_2}{R_1} (v_2 - v_1)$$

1

Although ideally the difference amplifier will amplify only the differential input signal  $v_{Id}$  and reject completely the common-mode input signal  $v_{Icm}$ , practical circuits will have an output voltage  $v_o$  given by

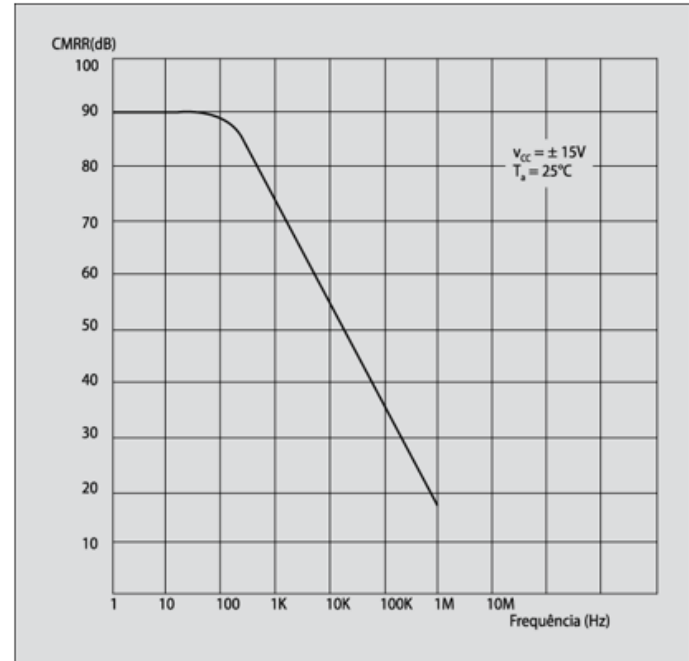
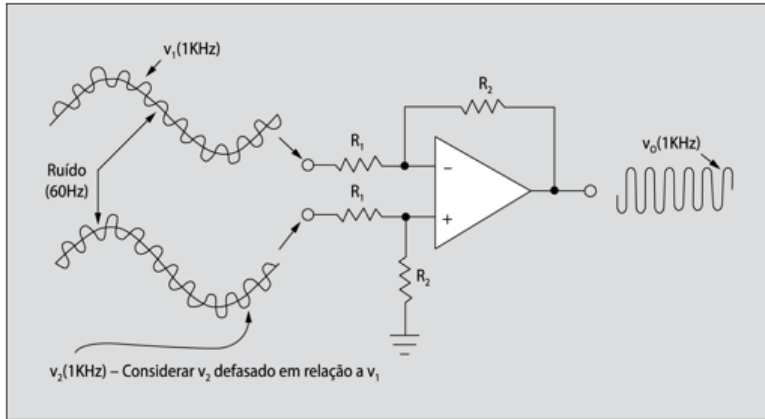
$$v_o = A_d v_{Id} + A_{cm} v_{Icm}$$

2

Where  $A_d$  denotes the amplifier differential gain and  $A_{cm}$  denotes its common-mode gain (ideally zero). The efficacy of a differential amplifier is measured by the degree of its rejection of common-mode signals in preference to differential signals. This is usually quantified by a measure known as the **common-mode rejection ratio (CMRR)**, defined as:

$$CMRR = 20 \log \frac{|A_d|}{|A_{cm}|}$$

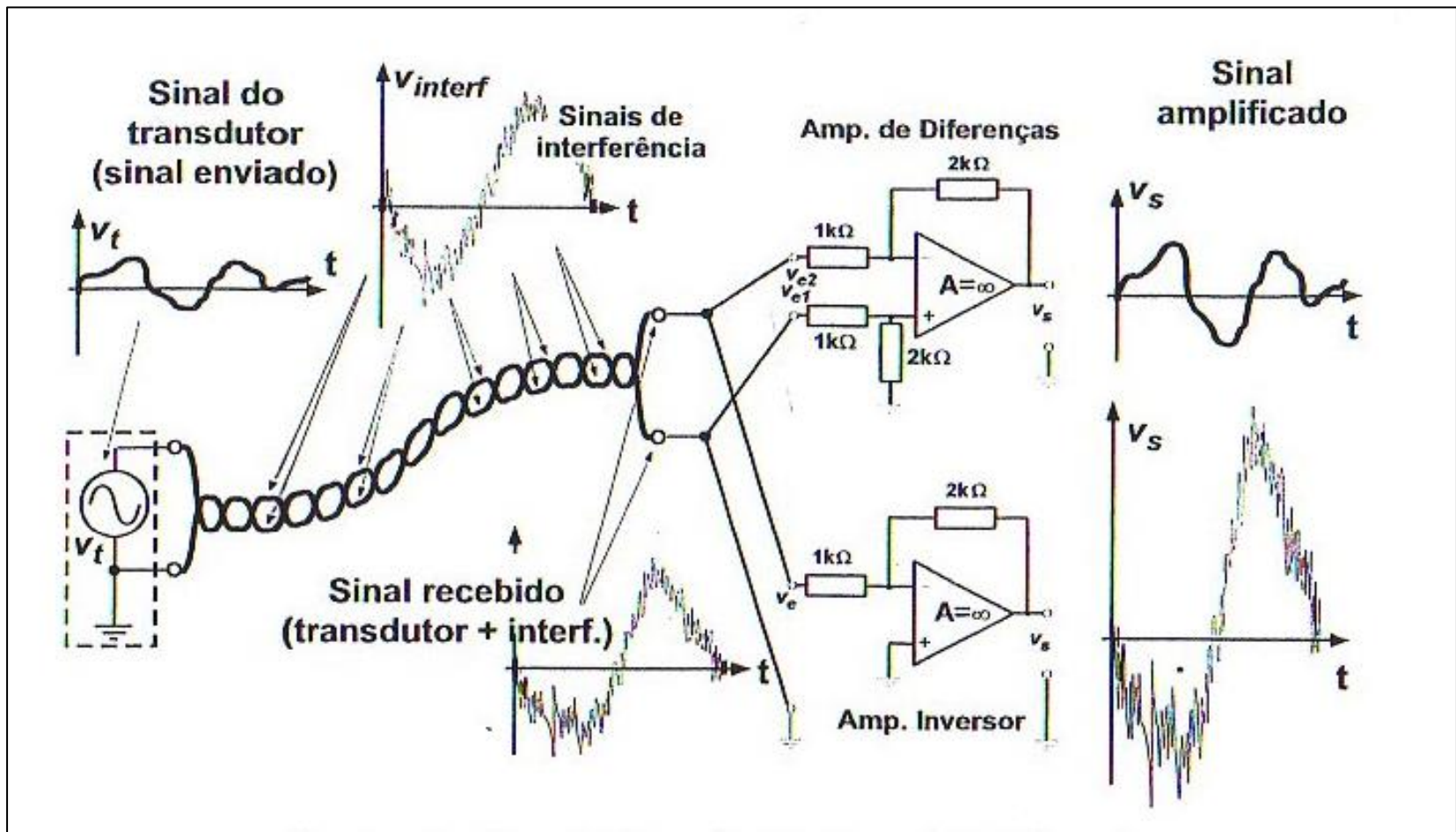
# CMRR



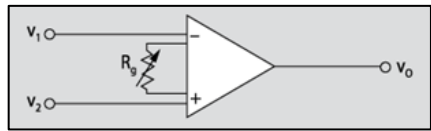
$$\text{CMRR} = 20 \log \frac{|A_d|}{|A_{cm}|}$$



# Aplicação: Uso em instrumentação

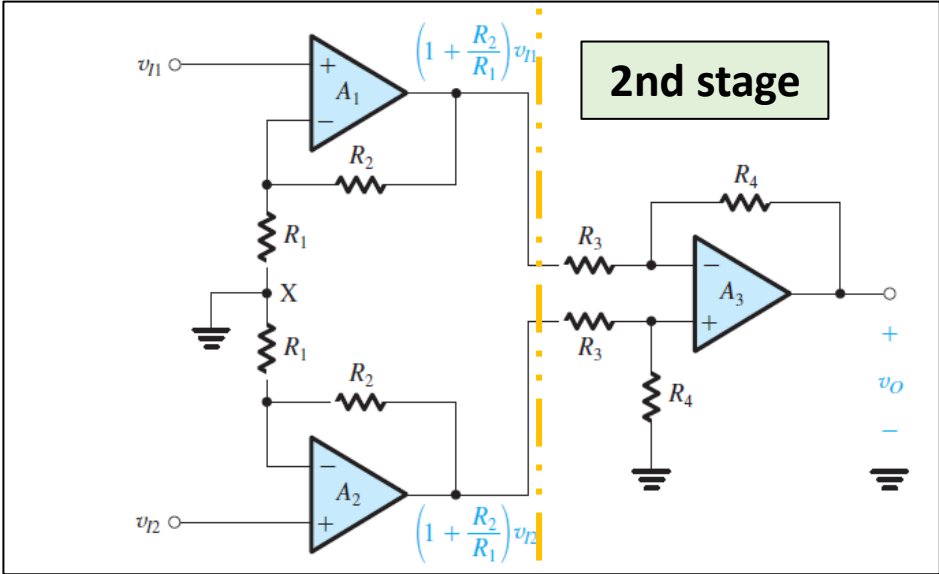


# **Three Op-Amp Difference Amplifier (Instrumentation Amplifier)**



**Simbolo**

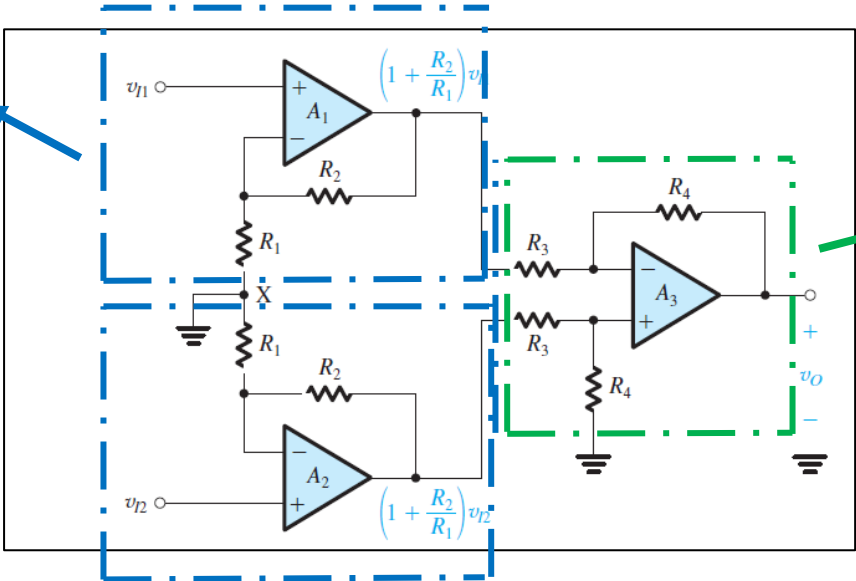
**1st stage**



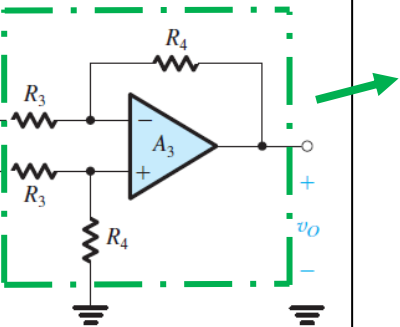
**2nd stage**

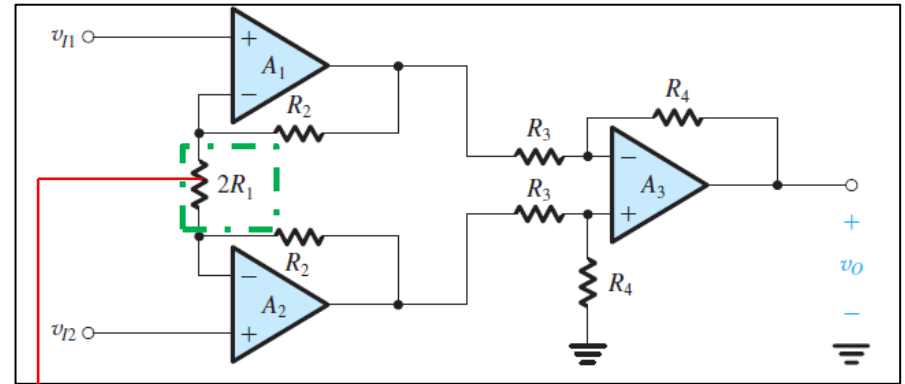
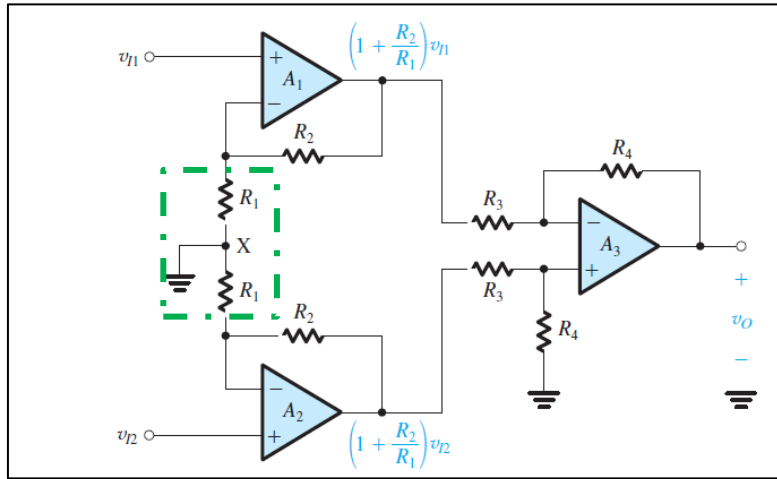


**Noninverting Amplifiers**



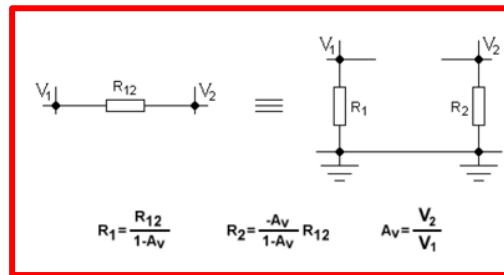
**Single Op Amp Difference Amplifier**



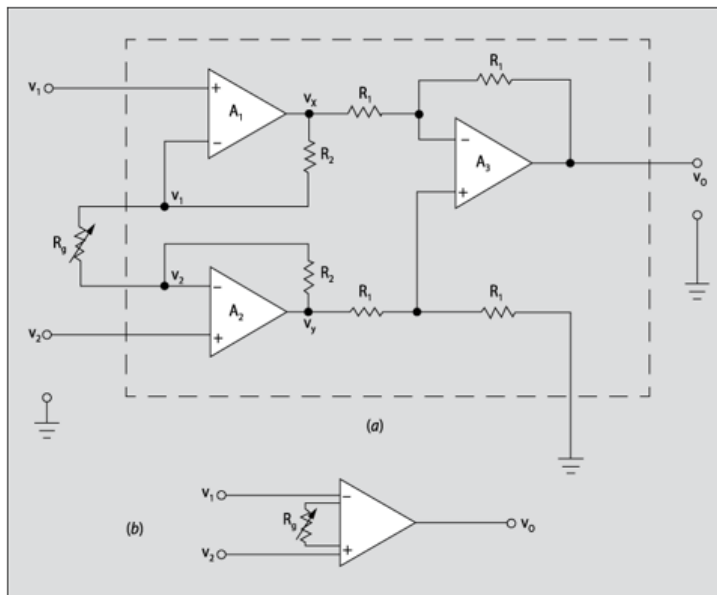


The circuit with the connection between node X and ground removed and the two resistors  $R_1$  and  $R_1$  lumped together. **This simple wiring change dramatically improves performance !**

**Teorema de Miller**



- Resistência de entrada muito alta
- Resistência de saída menor que a dos amp ops comuns
- CMRR superior superior à 100 dB
- Ganho de tensão em malha aberta muito superior ao dos amp ops comuns
- Tensão de offset muito baixa
- Drift térmico extremamente baixo



LH36 (National)

$R_i = 300 \text{ M}\Omega$

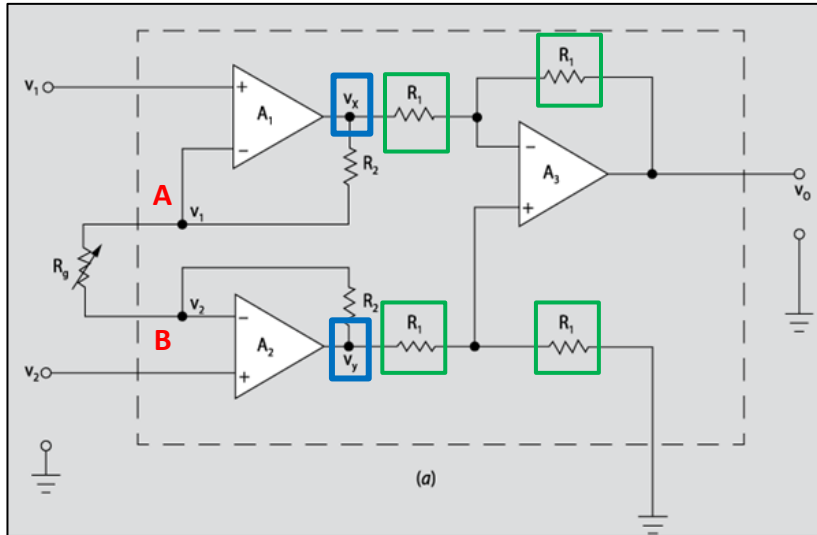
$R_o = 0,5\Omega$

CMRR = 100 dB

$V_i$  (offset) = 0,5 mV

Drift relativamente alto =  $10\mu\text{V}/^\circ\text{C}$

Se  $R_3 = R_4$ :



**A** 
$$\frac{v_x - v_1}{R_2} + \frac{v_2 - v_1}{R_g} = 0$$



$$v_x = \frac{v_1 \cdot R_g + v_1 \cdot R_2 - v_2 \cdot R_2}{R_g}$$

1

**B** 
$$\frac{v_y - v_2}{R_2} + \frac{v_1 - v_2}{R_g} = 0$$



$$v_y = \frac{v_2 \cdot R_2 + v_2 \cdot R_g - v_1 \cdot R_2}{R_g}$$

2

O estágio seguinte é um amplificador diferencial :

$$v_o = (v_y - v_x)$$

3

Das equações (1), (2) e (3), resulta :

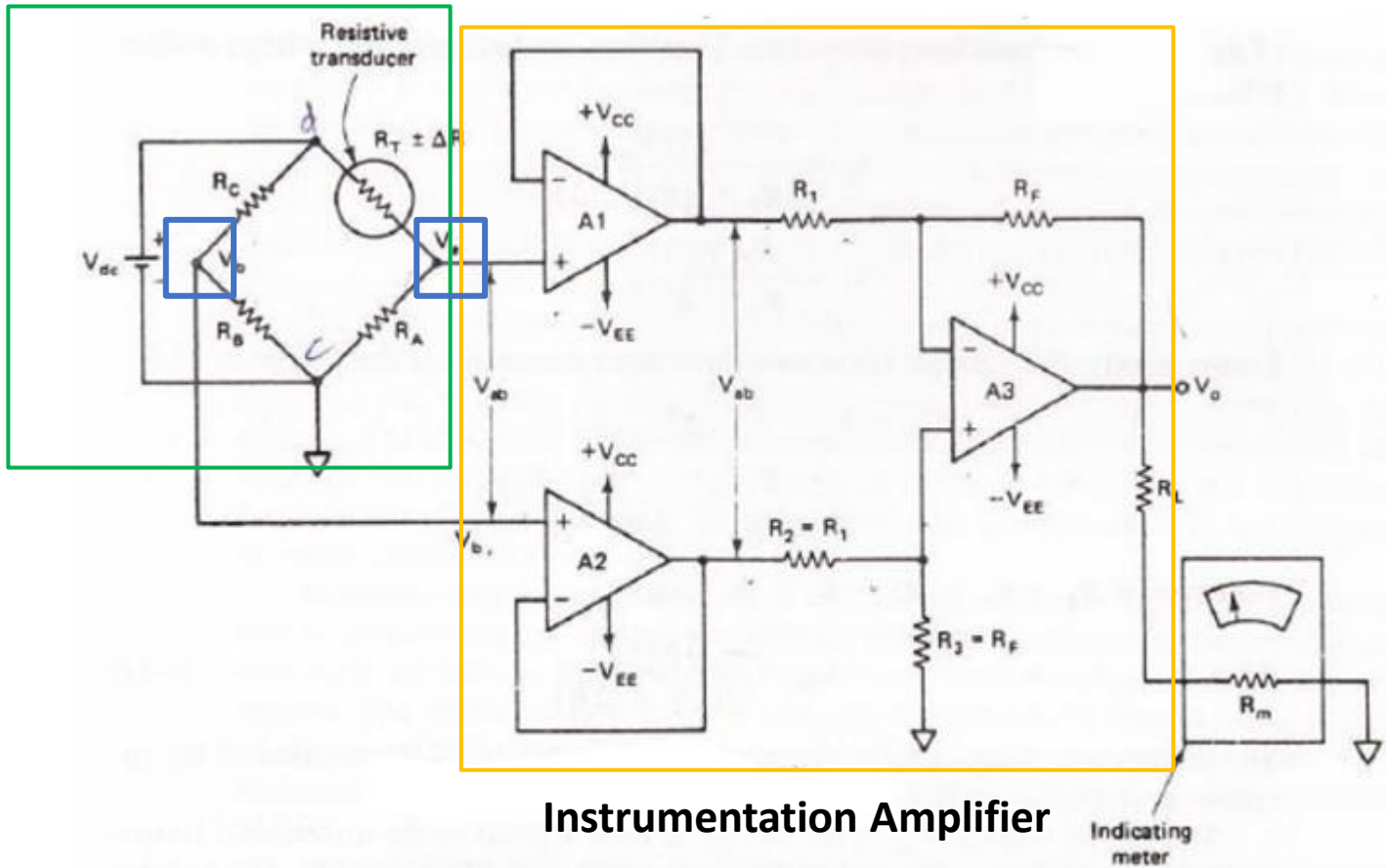
$$v_o = \left(1 + \frac{2R_2}{R_g}\right) (v_2 - v_1)$$

# Application of Instrumentation Amplifier

Temperature indicator

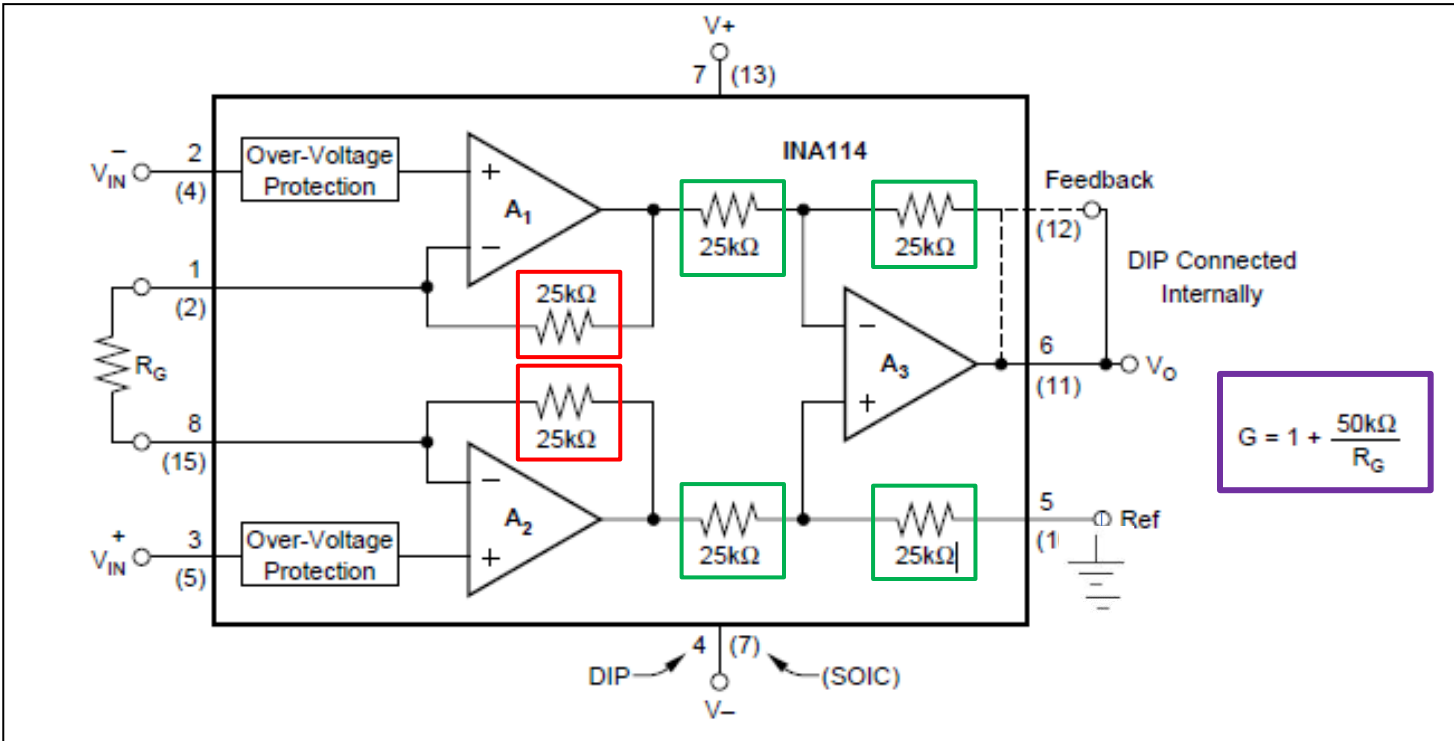
Temperature controller

Light-intensity meter



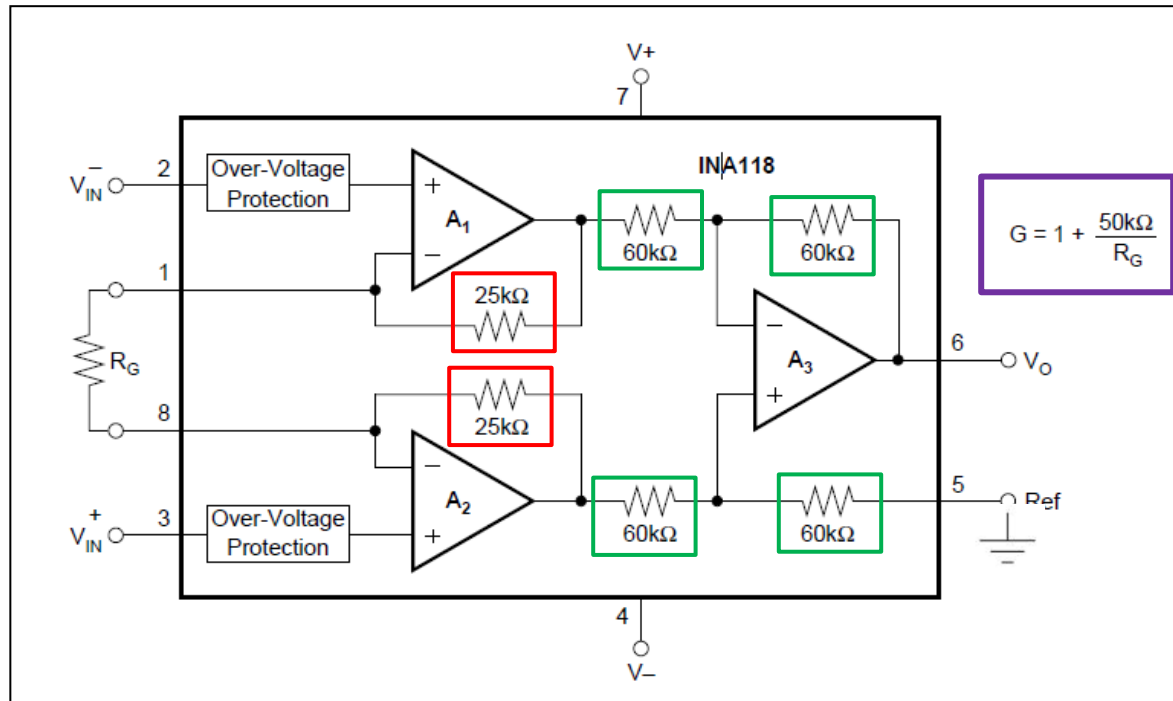
# Amplificadores de Instrumentação Integrados

## INA114

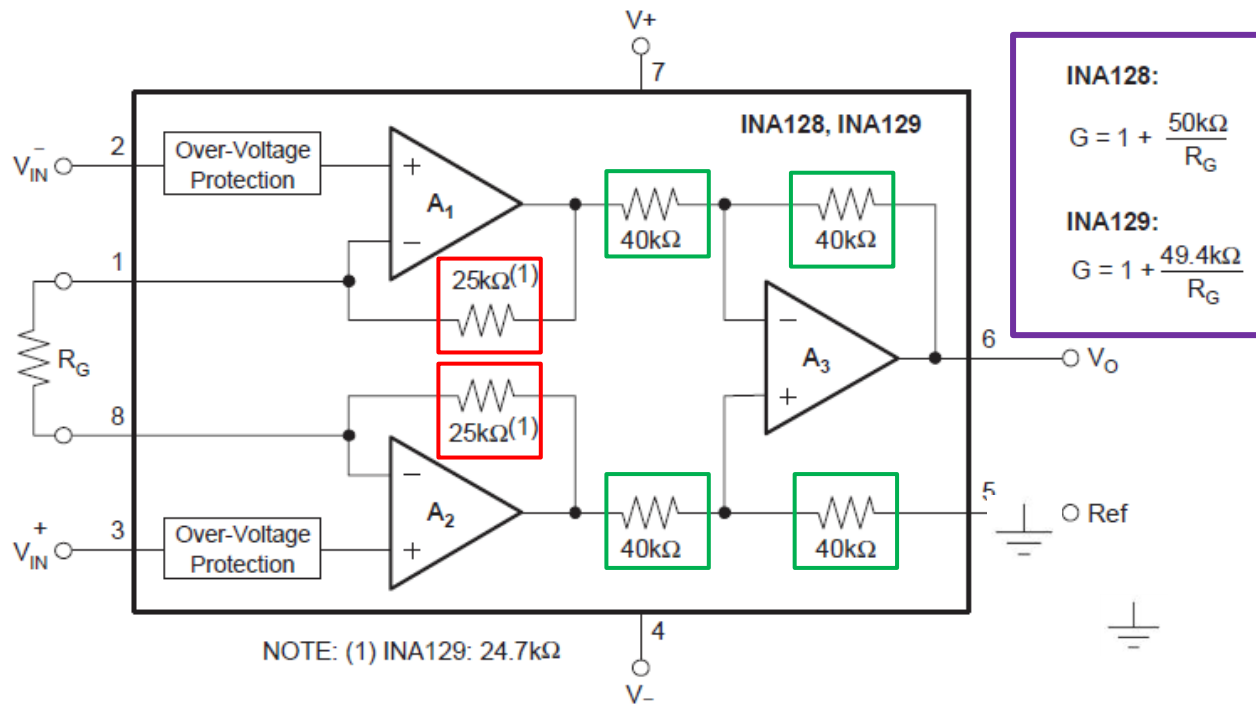




# INA118



# INA128 e INA129



$$v_o = A_d v_d + A_c v_c$$

$$v_d = v_1 - v_2$$

$$v_c = \frac{v_1 + v_2}{2}$$

$A_d$  - differential gain

$A_c$  - common mode gain

1 If  $v_c = 0$

$$A_d = \frac{v_o}{v_d}$$

$$\rightarrow v_1 = -v_2$$

$$v_d = v_1 - v_2 = 2v_1$$

$$A_d = \left| \frac{v_o}{2v_1} \right|$$

$$\text{If } v_1 = 0,5V$$

$$\rightarrow A_d = |v_{od}|$$

2 if  $v_d = 0$

$$A_c = \frac{v_o}{v_c}$$

$$\rightarrow v_1 = v_2$$

$$v_c = v_2$$

$$A_c = \left| \frac{v_o}{v_1} \right|$$

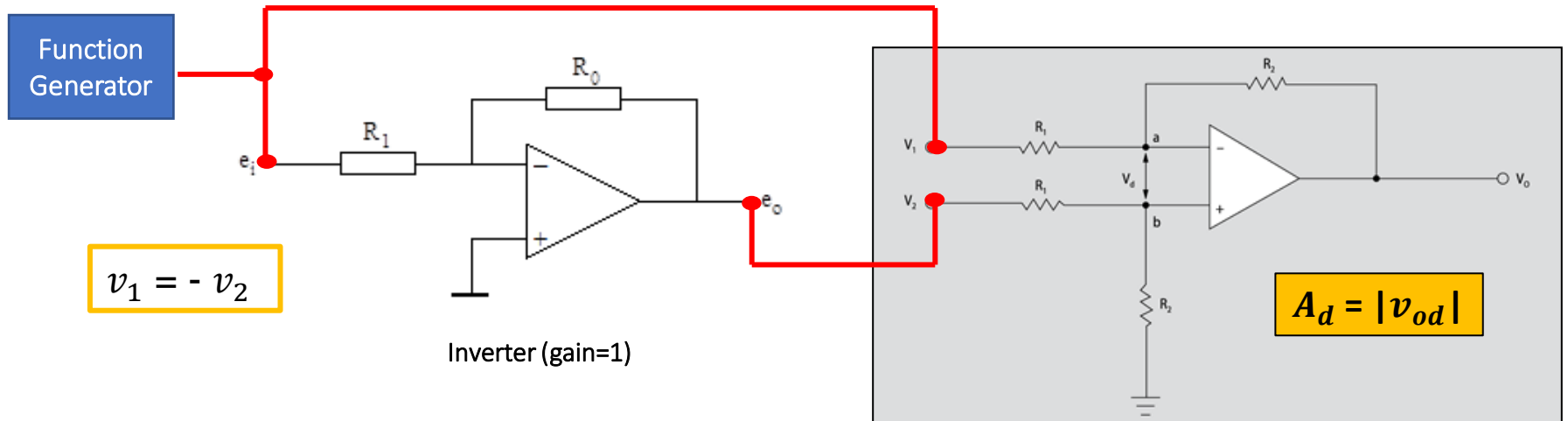
$$\text{If } v_1 = 1V$$

$$\rightarrow A_c = |v_{oc}|$$

$$\rightarrow \text{CMRR} = \left| \frac{A_d}{A_c} \right|$$

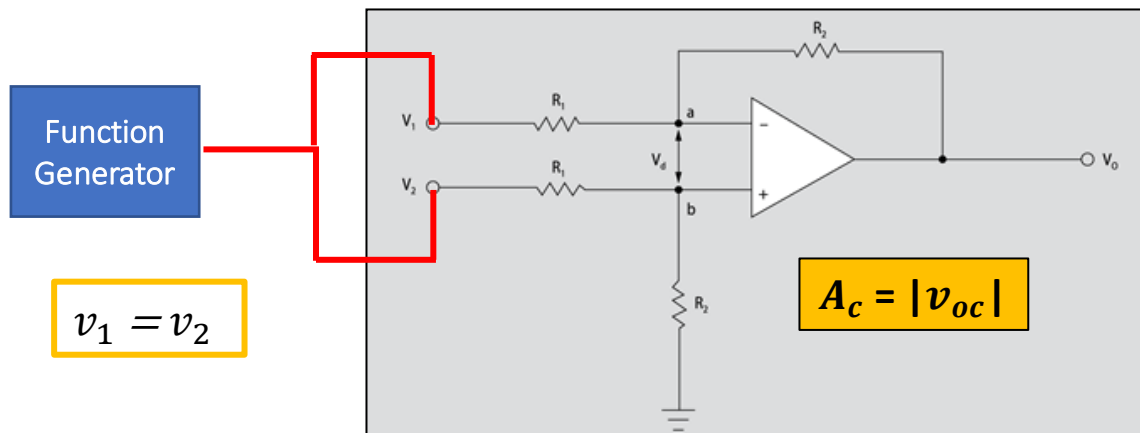
## $A_d$ Measurement

3  $A_d$  measurement using  $|v_1^{\max}| = |v_2^{\max}| = 0,5V$ .



## $A_c$ Measurement

4  $A_c$  measurement using  $v_1^{\max} = v_2^{\max} = 1V$ .

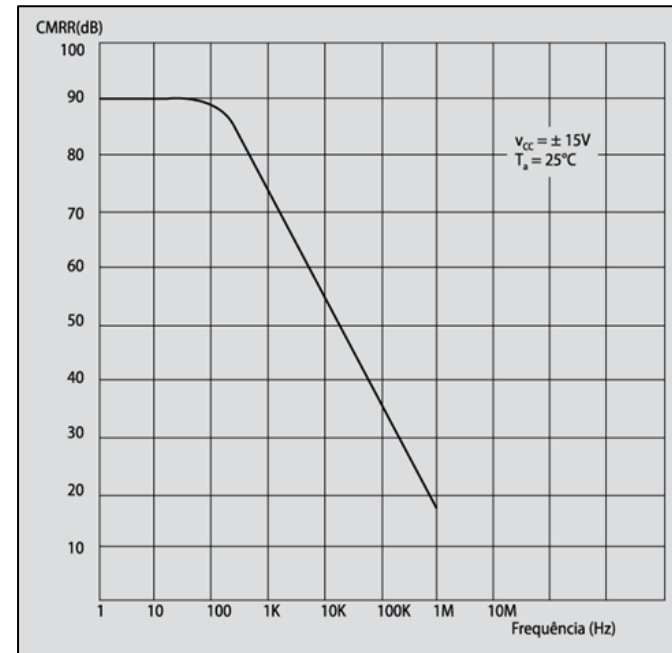


$$CMRR = \left| \frac{A_d}{A_c} \right|$$

## CMRR measurement is made in different frequencies !

$$\text{CMRR} = \left| \frac{A_d}{A_c} \right|$$

| f (Hz) | $A_d =  v_{od} $ | $A_c =  v_{oc} $ | $\text{CMRR} = \frac{ A_d }{ A_c }$ |
|--------|------------------|------------------|-------------------------------------|
| 60     |                  |                  |                                     |
| 1K     |                  |                  |                                     |
| 5K     |                  |                  |                                     |
| 7K     |                  |                  |                                     |
| 10K    |                  |                  |                                     |



Typical CMRR Curve

# Roteiro Experimental

## SEL393- Laboratório de Instrumentação Eletrônica I

### Laboratório 1 – Amplificadores Básicos com Op Amp

O objetivo do laboratório 1 é a familiarização com o **“Kit educacional ME3000 – Módulo 2”** da Dream Catcher e a comparação de desempenho de amplificadores diferenciais básicos e de instrumentação.

#### Kits Educacionais

Utilize o roteiro experimental **“ME3000 - Lab 5 - Practical Op Amp Circuits - v1.32”** e o **“Kit educacional ME3000 – Módulo 2”** e implemente um amplificador inversor, um amplificador somador, um amplificador não inversor, um amplificador diferencial básico e um circuito buffer.

## Simulação em LTSpice

### Resposta em Frequência

A fig. 1 mostra a resposta em frequência do op amp 741 em função do ganho da malha de realimentação.

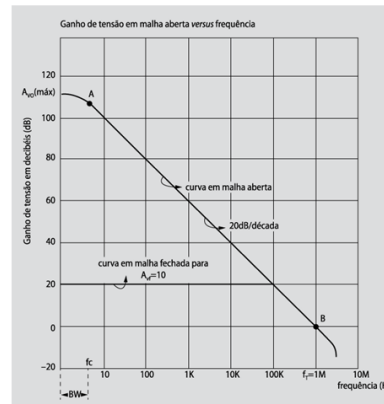


Fig. 1 – Resposta em Frequência do op amp 741

1.1) Simule um amplificador inversor utilizando os op amps 741, 351 e 318, LM158, LT1022 e TL081. Determine a frequência de transição ( $f_T$ ) desses op amps gerando um gráfico semelhante ao mostrado na Fig. 1. Compare os valores da frequência de transição ( $f_T$ ) com os valores de datasheet destes op amps.

### Amplificadores Diferenciais

1.2) Compare o desempenho de amplificadores diferenciais básicos com ganho de 20 dB implementados com os op amps 741 e 351.

1.3) Compare o desempenho de um amplificador diferencial básico (ganho de 20 dB) implementado com o op amp 741 com um amplificador diferencial de instrumentação (ganho de 20 dB) implementado com o INA114.

1.4) Compare o desempenho de amplificadores diferenciais de instrumentação (ganho de 20 dB) implementados com o INA114 e INA118.



# **Kits Educacionais**

# **ME3000 – Analog Electronic Courseware**

# ME3000 Analog Electronics Courseware

*Out-of-Box Teaching Solution for Analog Electronics*

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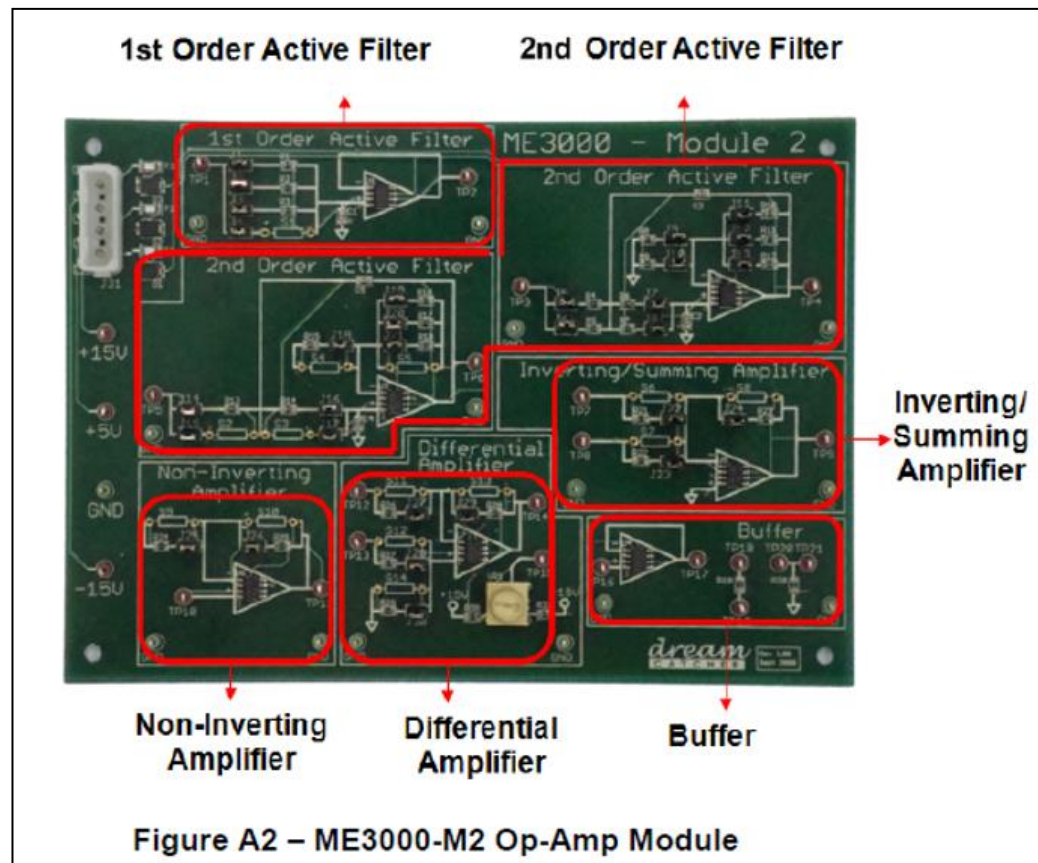
## Quick Start Guide

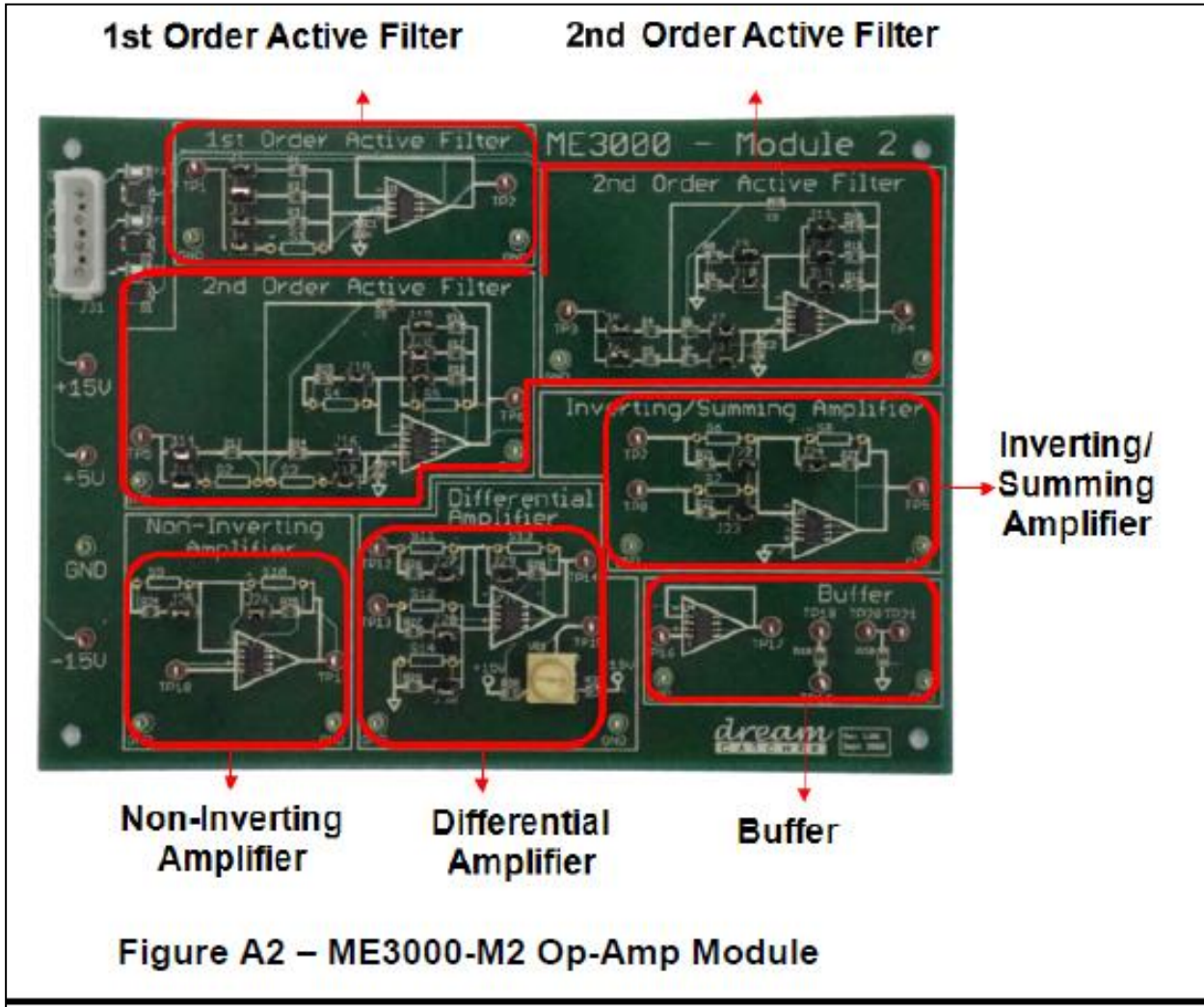
revision 1.31  
Printed on 20 September 2012



### Op-Amp Module (Module 2)

- 1st Order Active Filter
- 2nd Order Active Filter
- Buffer
- Inverting/Summing Amplifier
- Non-Inverting Amplifier
- Differential Amplifier





Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly **+15V** and **-15V**, respectively. Set both current limits to 0.5 A. Turn on the power supply.

Figure A2 – ME3000-M2 Op-Amp Module

### 3.3 Lab Sheets

| No | Lab Sheet                   | Objective   | Duration |
|----|-----------------------------|---|----------|
| 1  | Diode Characteristics       | To understand the characteristics of diodes   | 3 Hours  |
| 2  | Rectifier Circuits          | To understand the basic operations of rectifier circuits  | 3 Hours  |
| 3  | BJT Characteristics         | To understand the characteristics of a bipolar junction transistor (BJT)  | 3 Hours  |
| 4  | DC Biasing                  | To demonstrate the effects of DC biasing on the AC operation of a common-emitter amplifier                                | 3 Hours  |
| 5  | Practical Op-Amp Circuits   | To understand the typical configurations of operational amplifier circuits and their characteristics                      | 3 Hours  |
| 6  | RF Class A Tuned Amplifiers | To demonstrate the practical issues in designing an RF tuned amplifier and perform AC measurements on a Class A amplifier | 3 Hours  |
| 7  | 555 Multivibrator Circuits  | To understand the basic operations of a 555 Timer IC and design astable and monostable multivibrators using 555 timers    | 3 Hours  |
| 8  | Active Filters              | To understand the working principles of active filters and design an active low pass filter                               | 3 Hours  |



## ME3000 Analog Electronics

### Lab 5

## Practical Op-Amp Circuits

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#### Objective

- i) To understand typical operational amplifier circuits and their characteristics

#### Equipment Required

- i) ME3000-M2 Analog Electronics Training Kit
- ii) Digital Multimeter, [recommendation](#): Agilent 34405A or U2741A
- iii) 50 MHz Oscilloscope or equivalent, [recommendation](#): Agilent DSO1002A 60 MHz or U2701A
- iv) 10 MHz Function Generator or equivalent, [recommendation](#): Agilent 33220A or U2761A
- v) Dual Output (+/- 12V, 0.5A) DC Power Supply, [recommendation](#): Agilent E3631A

#### Accessories Required

- i) 1 x 4-way power supply cable
- ii) 1 x BNC(m)-to-grabber clips coaxial cable
- iii) 6 x jumper cables terminated with grabber clips at both ends
- iv) 1 x antistatic wrist strap

#### Caution:

*An electrostatic discharge generated by a person or an object coming in contact with electrical components may damage or destroy the training kit. To avoid the risk of electrostatic discharge, please wear the antistatic wrist strap and observe the handling precautions and recommendations contained in the EN100015-1 standard. Do not connect or disconnect the device while it is being energized.*

## 1. Introduction

An operational amplifier (op-amp) is an integrated circuit capable of amplifying the voltage difference between its two input terminals. As shown in Figure 1, a [general purpose](#) op-amp has two input terminals which are the *non-inverting (+)* and *inverting (-)* inputs, a single output terminal, and two voltage supply terminals ( $V_+$  and  $V_-$ ). Most of the op-amps require dual power supplies ( $\pm 5$  Vdc,  $\pm 15$  Vdc, and so forth), but some op-amps (such as LM3900) may be powered from a single supply.

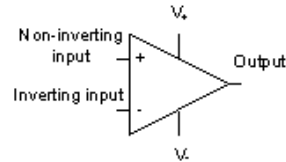


Figure 1 – Op-Amp Circuit Symbol

The simplest form of an op-amp comes in an 8-pin IC package, such as the commonly used 741. The connection diagram for the 741 op-amp is depicted in Figure 2.

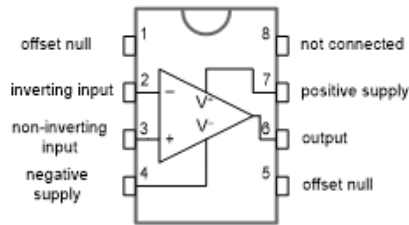


Figure 2 – 741 Op-Amp Connection Diagram

An op-amp has the following three important characteristics:

- High open-loop gain
- High input impedance
- Low output impedance

Different configurations of a negative feedback network are used to reduce voltage gain of op-amps to produce practical and linear circuits. In the following experiments, five typical op-amp configurations are introduced, namely the inverting amplifier, summing amplifier, non-inverting amplifier, differential amplifier, and buffer.



## 2. Inverting Amplifier

1. Locate the Inverting/Summing Amplifier section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Inverting/Summing Amplifier section.
3. Insert jumpers J22 and J24 to construct an inverting amplifier circuit shown in Figure 3.

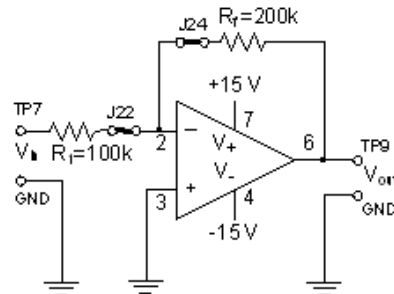


Figure 3 – Inverting Amplifier Schematic Diagram

4. With  $V_{in(p-p)} = 1.0\text{ V}$ , predict  $V_{out(p-p)}$  using the following equation:

$$V_{out} = -\frac{R_f}{R_1} V_{in} \quad , \text{ negative (-) sign indicates a } 180^\circ \text{ phase shift}$$

5. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP7 ( $V_{in}$ ). Connect the CH2 probe of the oscilloscope to TP9 ( $V_{out}$ ). Connect the instrument references to the GND terminals.
6. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly +15 V and -15 V, respectively. Set both current limits to 0.5 A. Turn on the power supply. Refer to Appendix for details.
7. Apply a 1.0 V peak-to-peak sine wave of 1 kHz to input  $V_{in}$  of the inverting amplifier.
8. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
9. Use the multimeter to measure  $V_{out(p-p)}$  (this measured value should be close to the predicted value) and record the phase shift of  $V_{out}$  with respect to  $V_{in}$  ( $\phi$ ). Calculate the ratio of  $V_{out(p-p)}/V_{in(p-p)}$ .
10. Turn off the power supply and disconnect all the cables from the Inverting/Summing Amplifier section.

### 3. Summing Amplifier

1. The Inverting Amplifier section on the ME3000-M2 training kit can be modified into a Summing Amplifier.
2. Insert jumper J23 to construct a two-input summing amplifier circuit shown in Figure 4.

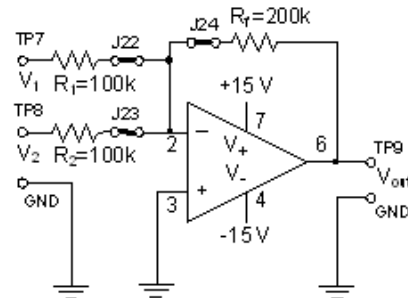


Figure 4 – Two-Input Summing Amplifier Schematic Diagram

3. With  $V_2 = 2\text{ V}$ , predict  $V_{out}$  when  $V_1 = -1\text{ V}$ ,  $0\text{ V}$ , and  $+1\text{ V}$  using following equation:

$$V_{out} = -\frac{R_f}{R_1}(V_1 + V_2)$$

4. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP7 ( $V_1$ ). Connect the CH2 probe of the oscilloscope to TP9 ( $V_{out}$ ). Connect the instrument references to the GND terminals.
5. Connect TP15 ( $-7.5\text{ V} \sim +7.5\text{ V}$  adjustable DC voltage source) to TP8 ( $V_2$ ) using the jumper cable.
6. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly  $+15\text{ V}$  and  $-15\text{ V}$ , respectively. Set both current limits to  $0.5\text{ A}$ . Turn on the power supply.
7. Adjust the potentiometer  $VR_1$  to obtain  $V_2 = 1.0\text{ V}$ . Use the multimeter to measure  $V_2$ .
8. Apply a  $2.0\text{ V}$  peak-to-peak sine wave of  $1\text{ kHz}$  to input  $V_1$  of the summing amplifier.
9. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
10. Measure  $V_{out}$  when  $V_1 = -1\text{ V}$ ,  $0\text{ V}$ , and  $+1\text{ V}$ .
11. Slowly adjust  $V_2$  by turning  $VR_1$ . Observe how  $V_{out}$  changes when  $V_2$  is varied between  $0\text{ V}$  and  $5\text{ V}$ . Comment on your observation.
12. Turn off the power supply and disconnect all the cables from the Inverting/Summing Amplifier section.

#### 4. Non-Inverting Amplifier

1. Locate the Non-Inverting Amplifier section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Non-inverting Amplifier section.
3. Insert jumpers J25 and J26 to construct a non-inverting amplifier circuit shown in Figure 5.

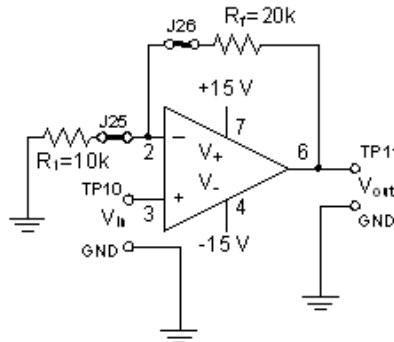


Figure 5 – Non-Inverting Amplifier Schematic Diagram

4. With  $V_{in(pp)} = 1.0\text{ V}$ , predict  $V_{out(pp)}$  using the following equation:

$$V_{out} = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

5. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP10 ( $V_{in}$ ). Connect the CH2 probe of the oscilloscope to TP11 ( $V_{out}$ ). Connect the instrument references to the GND terminals.
6. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly +15 V and -15 V, respectively. Set both current limits to 0.5 A. Turn on the power supply.
7. Apply a 1.0 V peak-to-peak sine wave of 1 kHz to input  $V_{in}$  of the inverting amplifier.
8. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
9. Measure  $V_{out(pp)}$  (this measured value should be close to the predicted value) and record the phase shift of  $V_{out}$  with respect to  $V_{in}$  ( $\phi$ ). Calculate the ratio of  $V_{out(pp)}/V_{in(pp)}$ .
10. Turn off the power supply and disconnect all the cables from the Non-inverting Amplifier section.

## 5. Buffer Circuit

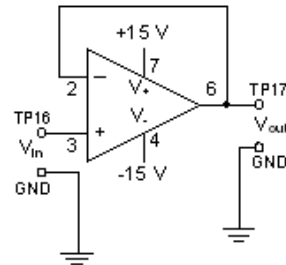


Figure 4 – Buffer Schematic Diagram

1. Locate the Buffer Circuit section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Buffer Circuit section.
3. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP16 ( $V_{in}$ ). Connect the CH2 probe of the oscilloscope to TP17 ( $V_{out}$ ). Connect the instrument references to the GND terminals.
4. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly +15 V and -15 V, respectively. Set both current limits to 0.5 A. Turn on the power supply.
5. Apply a 1.0 V peak-to-peak sine wave of 1 kHz to input  $V_{in}$ . Measure  $V_{out(PP)}$  and record the phase shift of  $V_{out}$  with respect to  $V_{in}$  ( $\phi$ ). Calculate the ratio of  $V_{out(PP)}/V_{in(PP)}$ . Sketch the  $V_{in}$  and  $V_{out}$  waveforms.
6. The next experiment tests the buffer ability to reduce loading effect.
7. Disconnect the function generator and oscilloscope from TP16 and TP17.
8. Connect the function generator output and CH1 of the oscilloscope to TP19. The function generator forms a high impedance source with R19 at TP18.
9. Connect TP18 to TP20 using the jumper cable. This connects the high impedance source to the load circuit (R20), as shown in Figure 5.

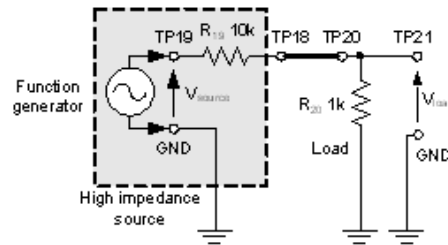


Figure 5 – Setup to Study the Loading Effect

10. Connect CH2 of the oscilloscope to TP21.
11. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the  $V_{source}$  and  $V_{out}$  waveforms.
12. Measure  $V_{out(oc)}$ .
13. Disconnect TP18 from TP20.
14. Connect TP18 to TP16 ( $V_{in}$  of the buffer) and TP20 to TP17 ( $V_{out}$  of the buffer), as shown in Figure 6.
15. Using the oscilloscope, observe and sketch the  $V_{source}$  and  $V_{out}$  waveforms.

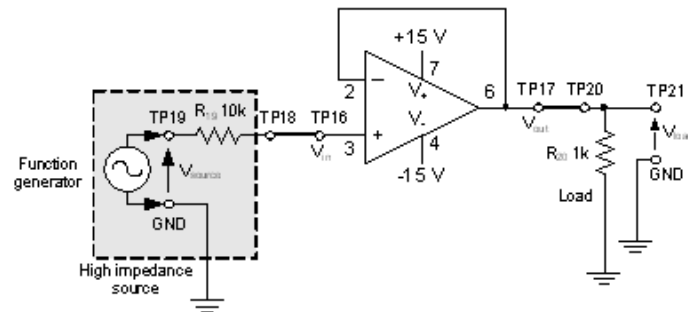
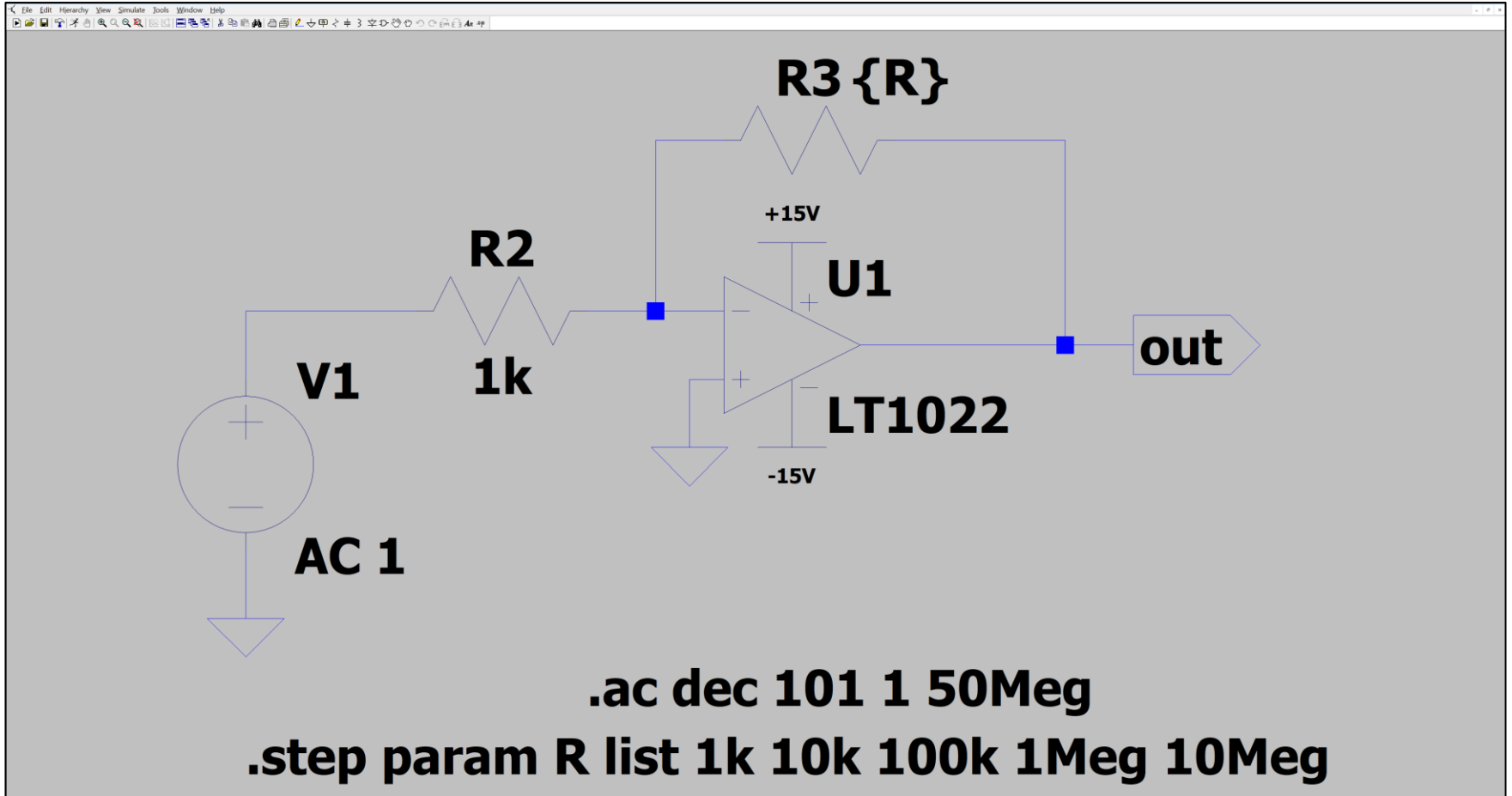


Figure 6 – Buffer Connections to Minimize the Loading Effect

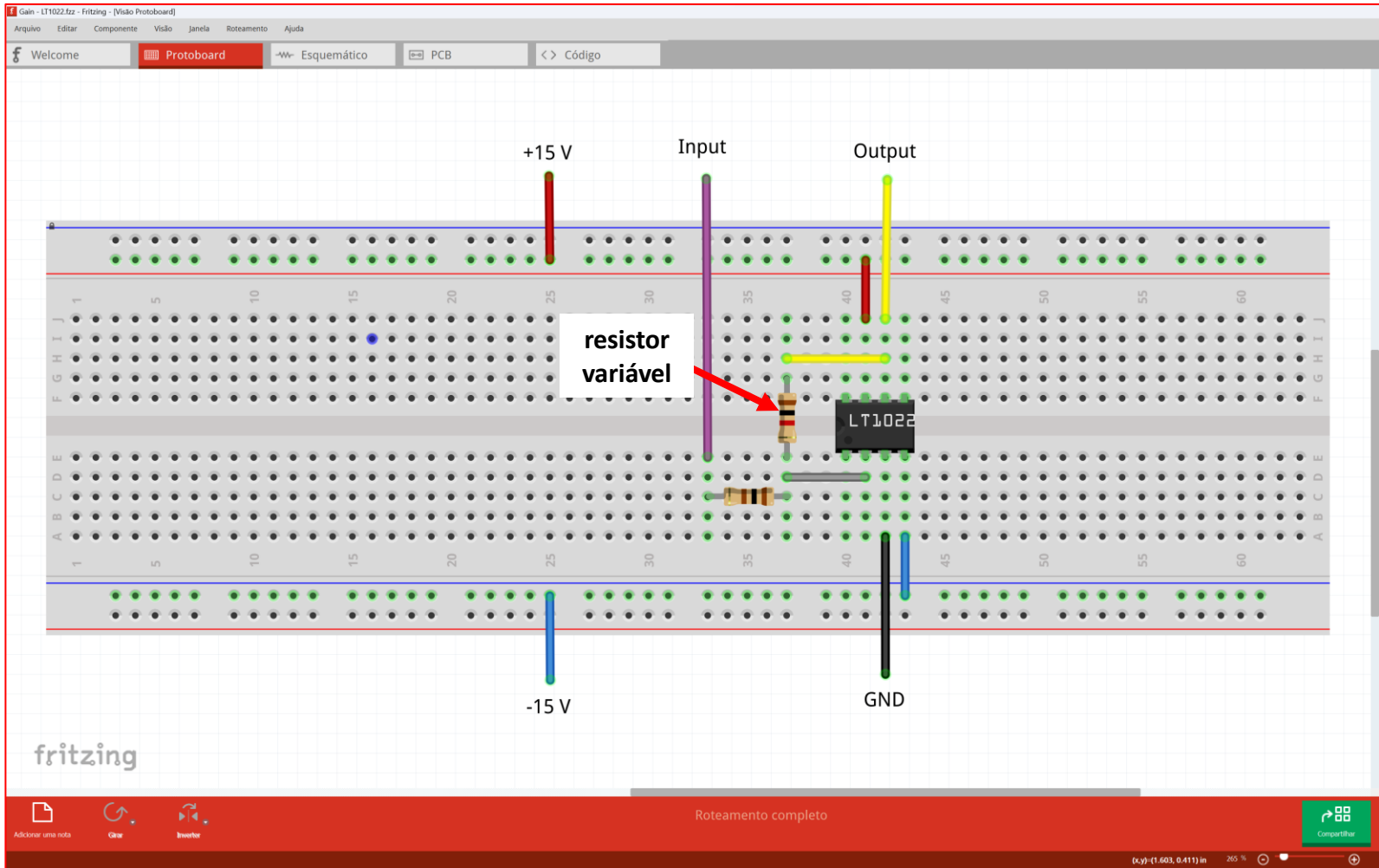
16. Measure  $V_{out(oc)}$ . Comment on your observation.
17. Turn off the power supply and disconnect all the cables from the Buffer Circuit section.

# Simulação em LTSPice

# Medida da Resposta em Frequência



# Ganho x Frequência (Fritzing – LT1022)



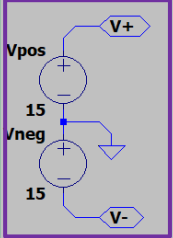
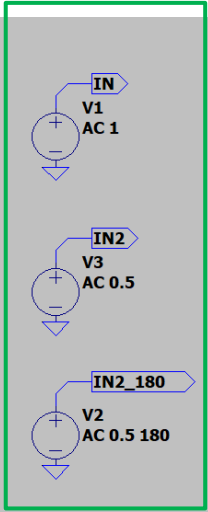
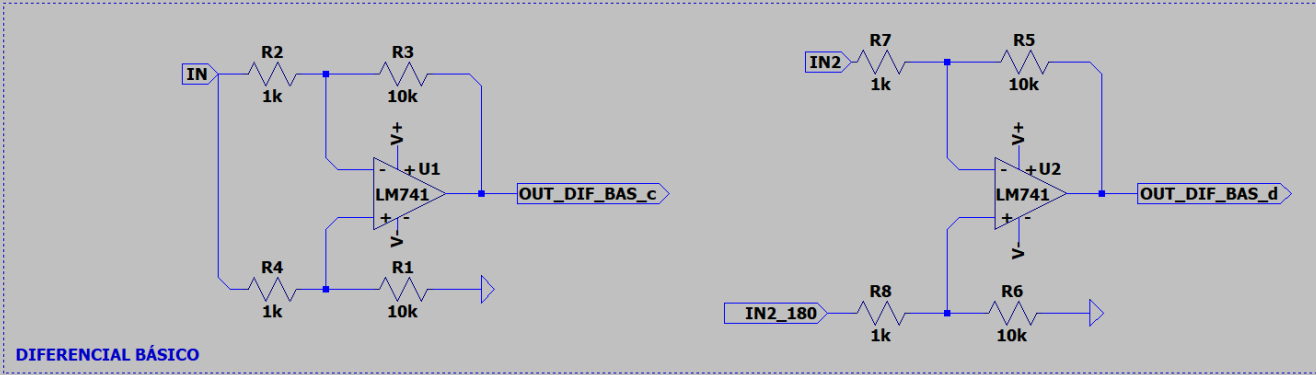


**Single Op Amp  
Difference Amplifier  
Medida da CMRR  
(LM741)**

Sinais de Entrada

Alimentação Simétrica do Amp Op

Medida  $A_c$



;DADOS DE SIMULAÇÃO  
.ac dec 1001 10 1meg

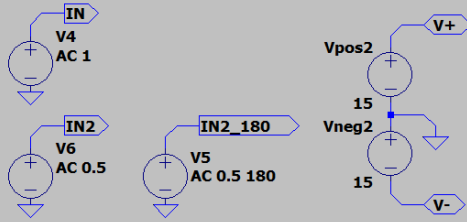
Sinais que devem ser observados:  
=> CMRR do Amp. Diferencial Básico  
 $V(OUT\_DIF\_BAS\_d)/V(OUT\_DIF\_BAS\_c)$

Medida  $A_d$

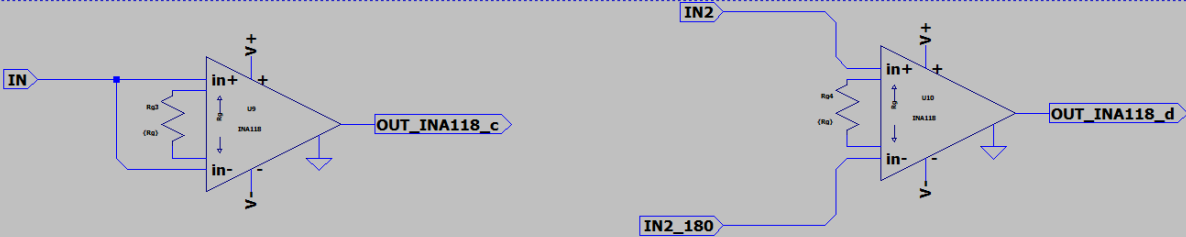
$$CMRR = \left| \frac{A_d}{A_c} \right|$$

# **Instrumentation Amplifier**

**Medida da CMRR  
(INA118)**



$$CMRR = \left| \frac{A_d}{A_c} \right|$$



;DADOS DE SIMULAÇÃO  
.ac dec 1001 10 1meg  
.param Rg=50k/9

Sinais que devem ser observados:  
=> CMRR do Amp. de Instrumentação INA118  
V(OUT\_INA118\_d)/V(OUT\_INA118\_c)

AMPLIFICADOR DE INSTRUMENTAÇÃO INA118

Medida  $A_{cm}$

Medida  $A_d$

# CMRR (Fritzing – INA118)

