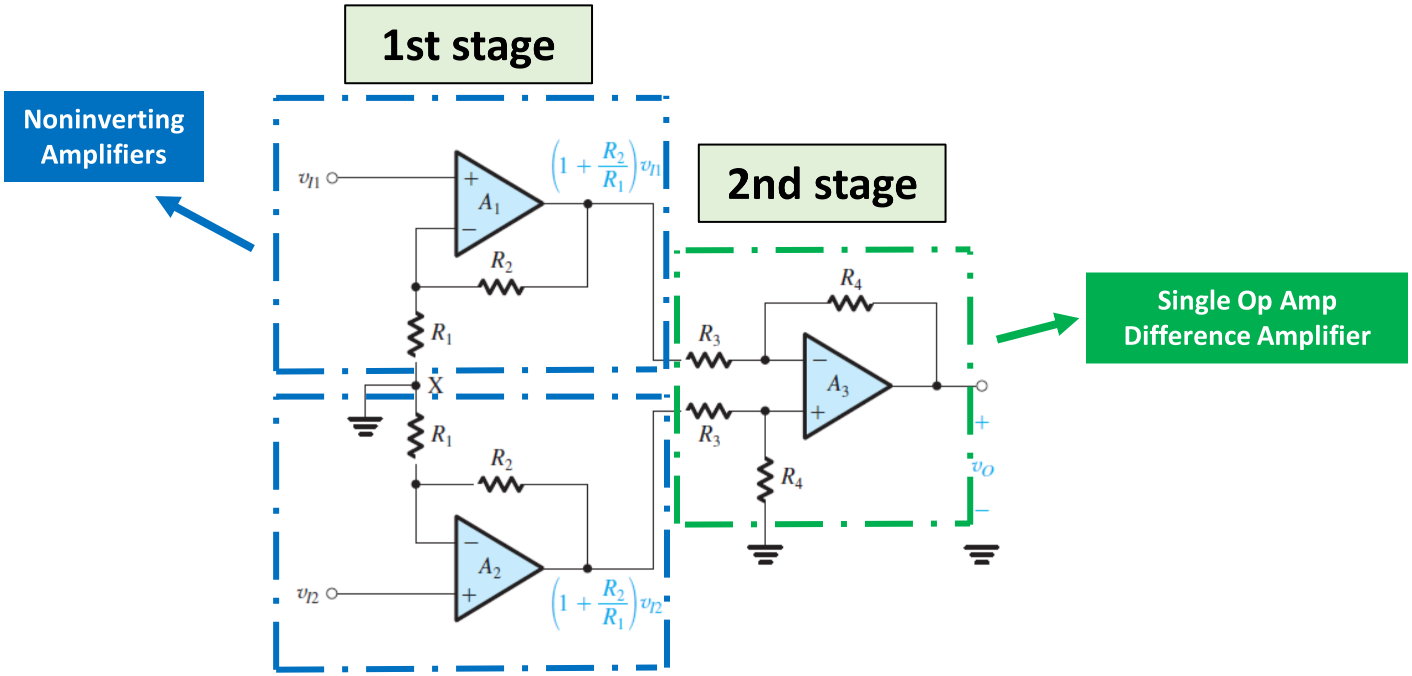
Instrumentation Amplifier

(Three Op Amp Difference Amplifier)

Topology 1



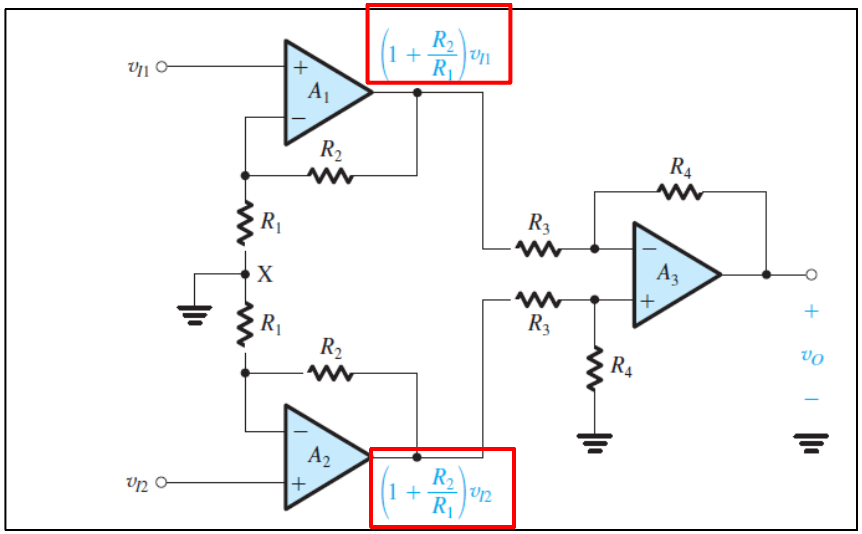
1 It consists of two stages in cascade:

The **first stage** is formed by op amps ***A*₁** and ***A*₂** and their associated resistors.

The **second stage** is the difference amplifier formed by op amp ***A*₃** and its four associated resistors.

Observe that each of A_1 and A_2 is connected in the noninverting configuration and thus realizes a gain of $(1+R_2/R_1)$.

It follows that each of v_{I1} and v_{I2} is amplified by this factor, and the resulting amplified signals appear at the outputs of A_1 and A_2, respectively.



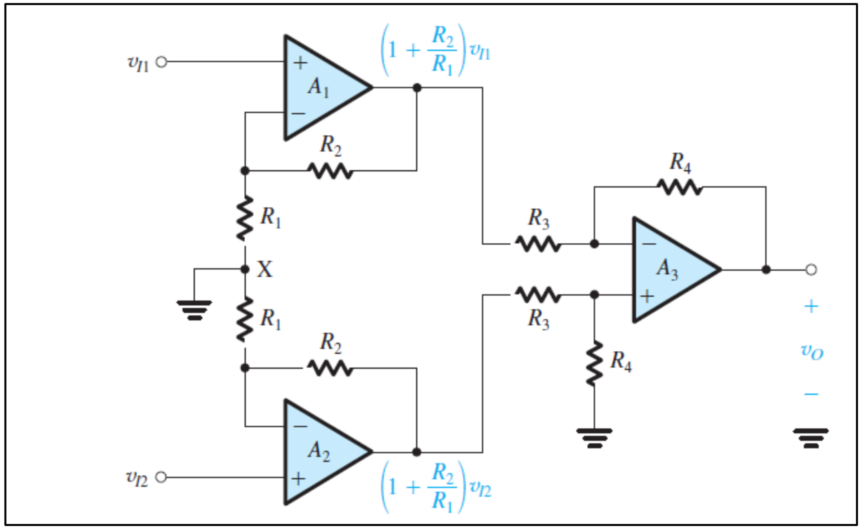
2 The difference amplifier in the second stage operates as follows:

$$v_o = \frac{R_4}{R_3}\,(v_{Id}) \;\rightarrow\; v_o = \frac{R_4}{R_3}\left(\overbrace{1+\frac{R_2}{R_1}}^{A_2}v_{I2} - \overbrace{1+\frac{R_2}{R_1}}^{A_1}v_{I1}\right)$$

$$\rightarrow\; \boxed{v_o = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)(v_{I2}-v_{I1})}$$

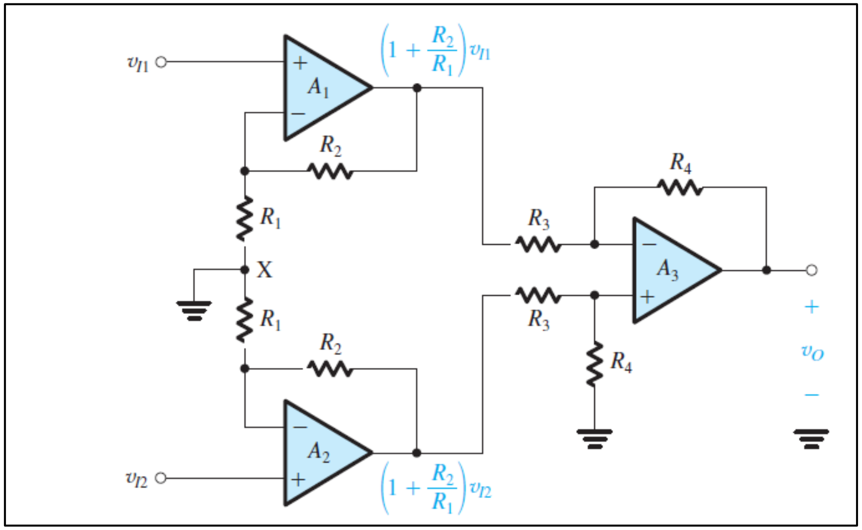
Advantage and Disadvantages

Advantage



The circuit above has the advantage of very **high (ideally infinite) input resistance** and high differential gain.

Disadvantages

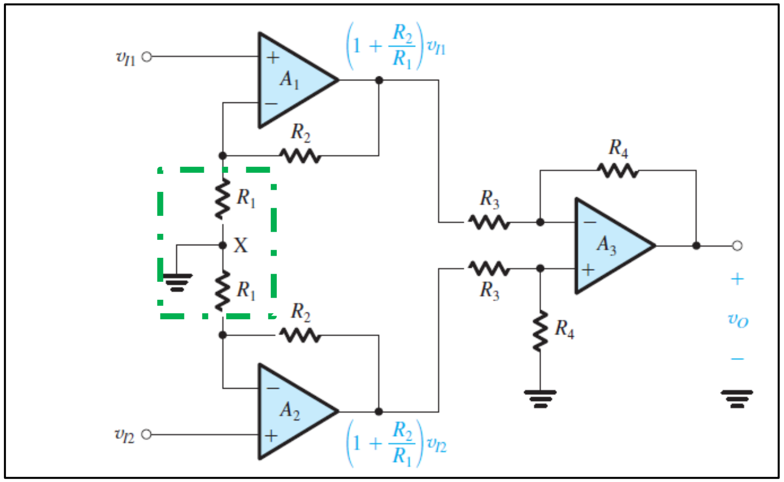


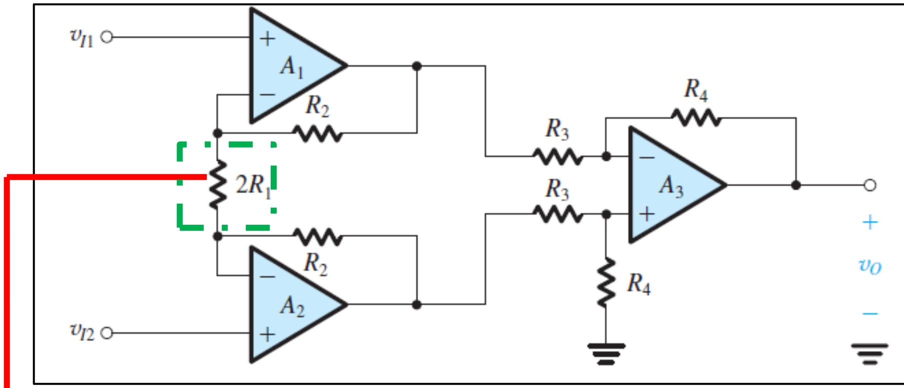
$$v_o = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)(v_{I2}-v_{I1})$$

1. **The two amplifier channels in the first stage have to be perfectly matched**.

2. To vary the differential gain A_d, two resistors have to be varied simultaneously, say the two resistors labeled R_1. **At each gain setting the two resistors have to be perfectly matched** which is a difficult task.

Topology 2

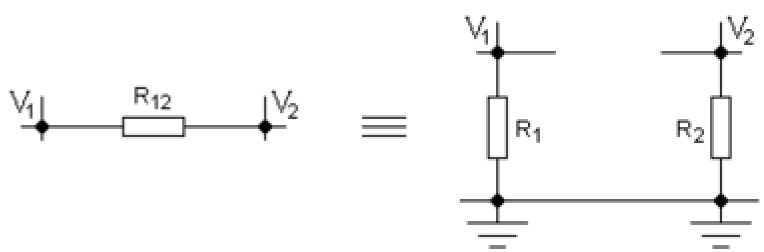




The circuit with the connection between node X and ground removed and the two resistors R_1 lumped together.

This simple wiring change dramatically improves performance !

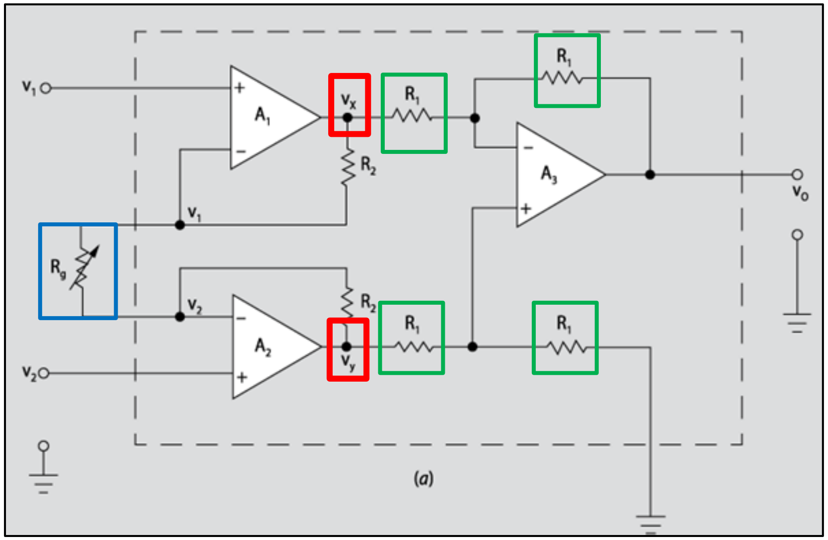
Miller's Theorem



$$R_1 = \frac{R_{12}}{1 - A_V} \qquad R_2 = \frac{-A_V}{1 - A_V} R_{12} \qquad A_V = \frac{V_2}{V_1}$$

Gain Calculation

$R_3 = R_4$ and $R_g = 2R_1$



Nó X

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

$$v_x = \frac{v_1 \cdot R_g + v_1 \cdot R_2 - v_2 \cdot R_2}{R_g} \quad (1)$$

Nó Y

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

$$v_y = \frac{v_2 \cdot R_2 + v_2 \cdot R_g - v_1 \cdot R_2}{R_g} \quad (2)$$

$$v_o = \left(v_y - v_x\right) \quad (3)$$

(Differential Amplifier | G=1)

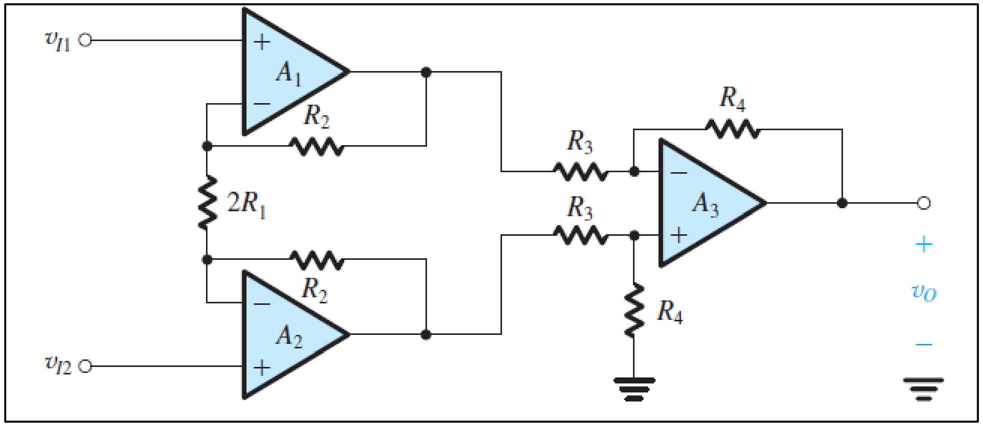
(1) and (2) and (3):

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

Calculation of A_d and A_{cm}

$R_3 = R_4$ and $R_g = 2R_1$

1



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

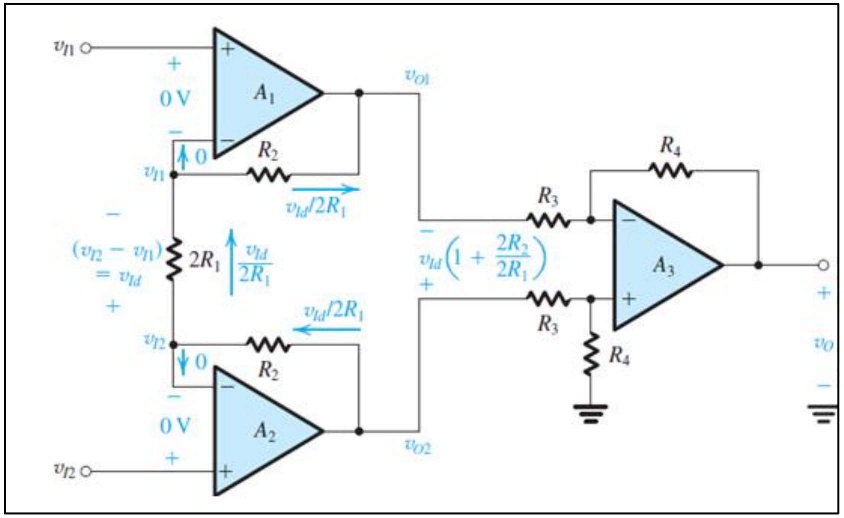
$$v_o = A_d v_{Id} + A_{cm} v_{Icm}$$

$$A_d = \left(1 + \frac{2R_2}{R_g}\right)$$

2 The common-mode gain will be zero because of $R_3 = R_4$.

$$A_{cm} = 0$$

Advantages



$$v_O = \frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right)v_{Id}$$

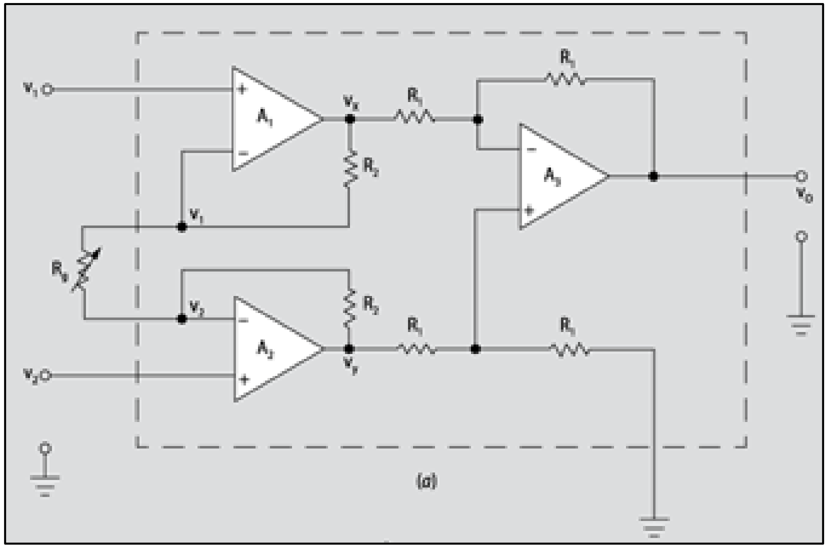
1 We observe from the gain expression that the it can be varied by changing only one resistor ($2R_1$).

2 **Consider next what happens when the two input terminals are connected together to a common mode input voltage v_{Icm}:**

An equal voltage appears at the negative input terminals of A_1 and A_2, causing the current through $2R_1$ to be zero. Thus there will be no current flowing in the R_2 resistors, and the voltages at the output terminals of A_1 and A_2 will be equal to the input (v_{Icm}). Thus the first stage no longer amplifies v_{Icm}. It simply propagates v_{Icm} to its two output terminals, where there are a zero common-mode output by A_3.

This is an excellent differential amplifier circuit and is widely employed as an instrumentation amplifier !
It is the input amplifier used in a variety of electronic instruments !

Integrated Instrumentation Amplifier



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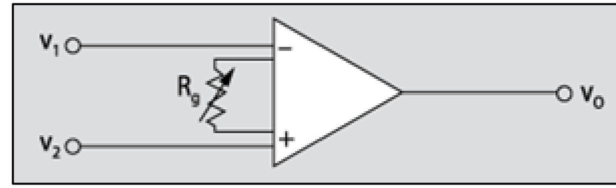


Input resistance very high.

Output resistance smaller than usual op amps.

CMRR higher than 100 dB.

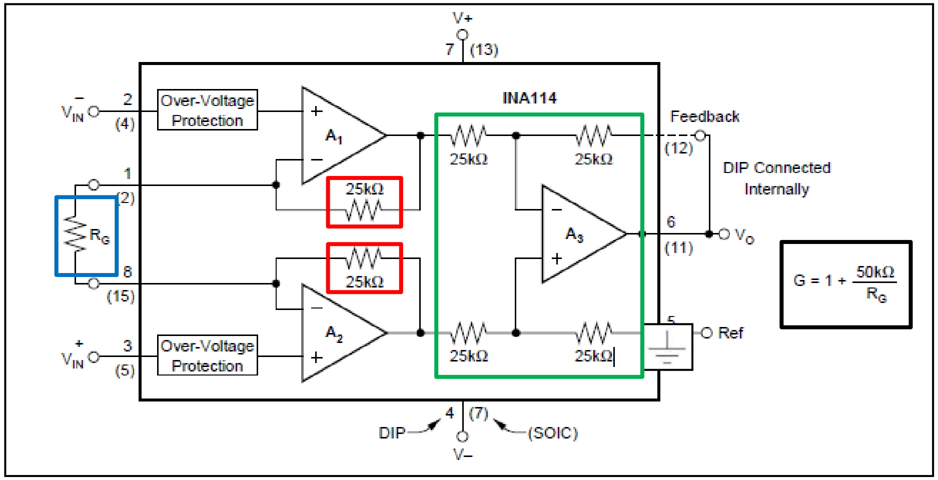
Open loop gain higher than usaul op amps.

Offset voltage low.

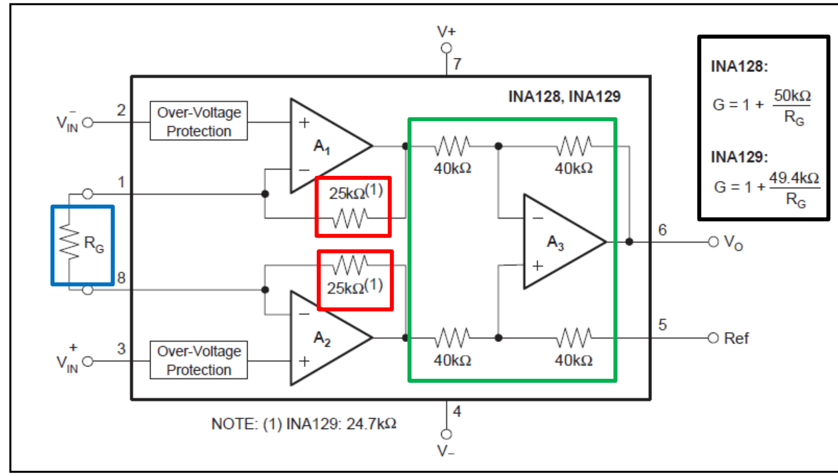
Thermal drift very low.

Example: LH36 (National)
R_i = 300 MΩ
R_o = 0,5Ω
CMRR = 100 dB

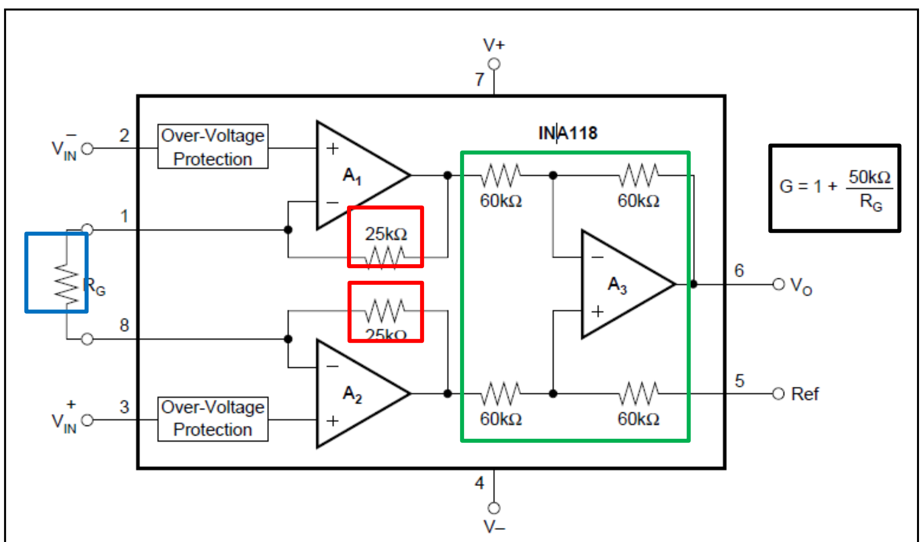
INA114 (tecnologia BJT)



INA128 - INA129 (tecnologia BJT)



INA118 (tecnologia BJT)

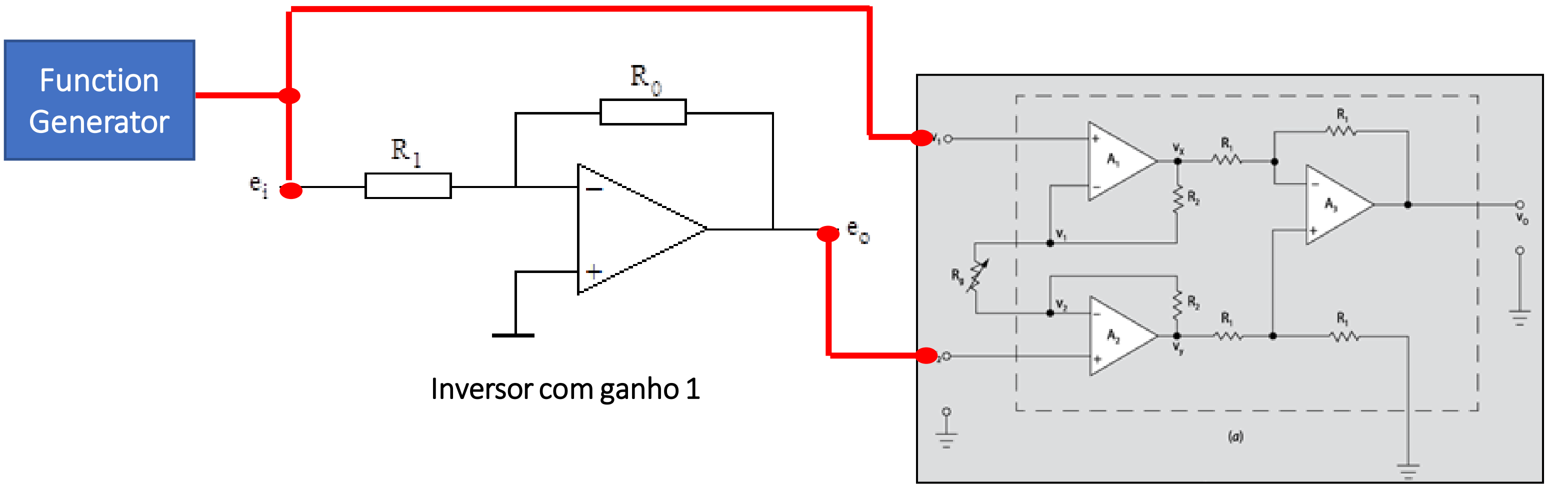


$$G = \frac{v_o}{(v_+^{in} - v_-^{in})}\left(1 + \frac{2R_2}{R_g}\right)$$

CMRR Measurement

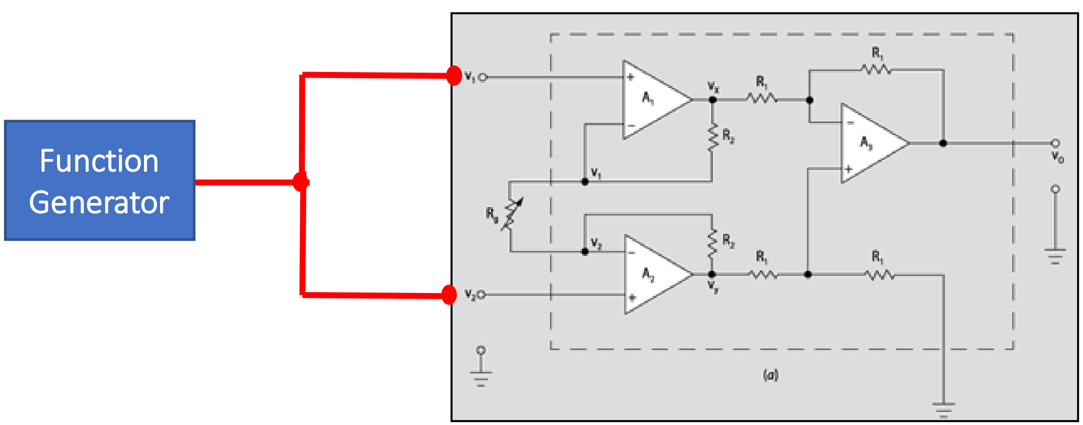
A_d Measurement

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



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

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

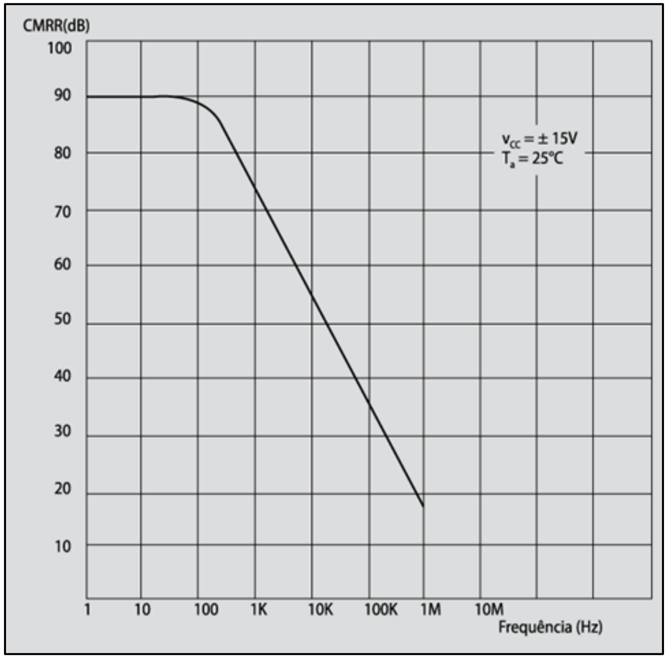


$$A_c = |v_{oc}|$$

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

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

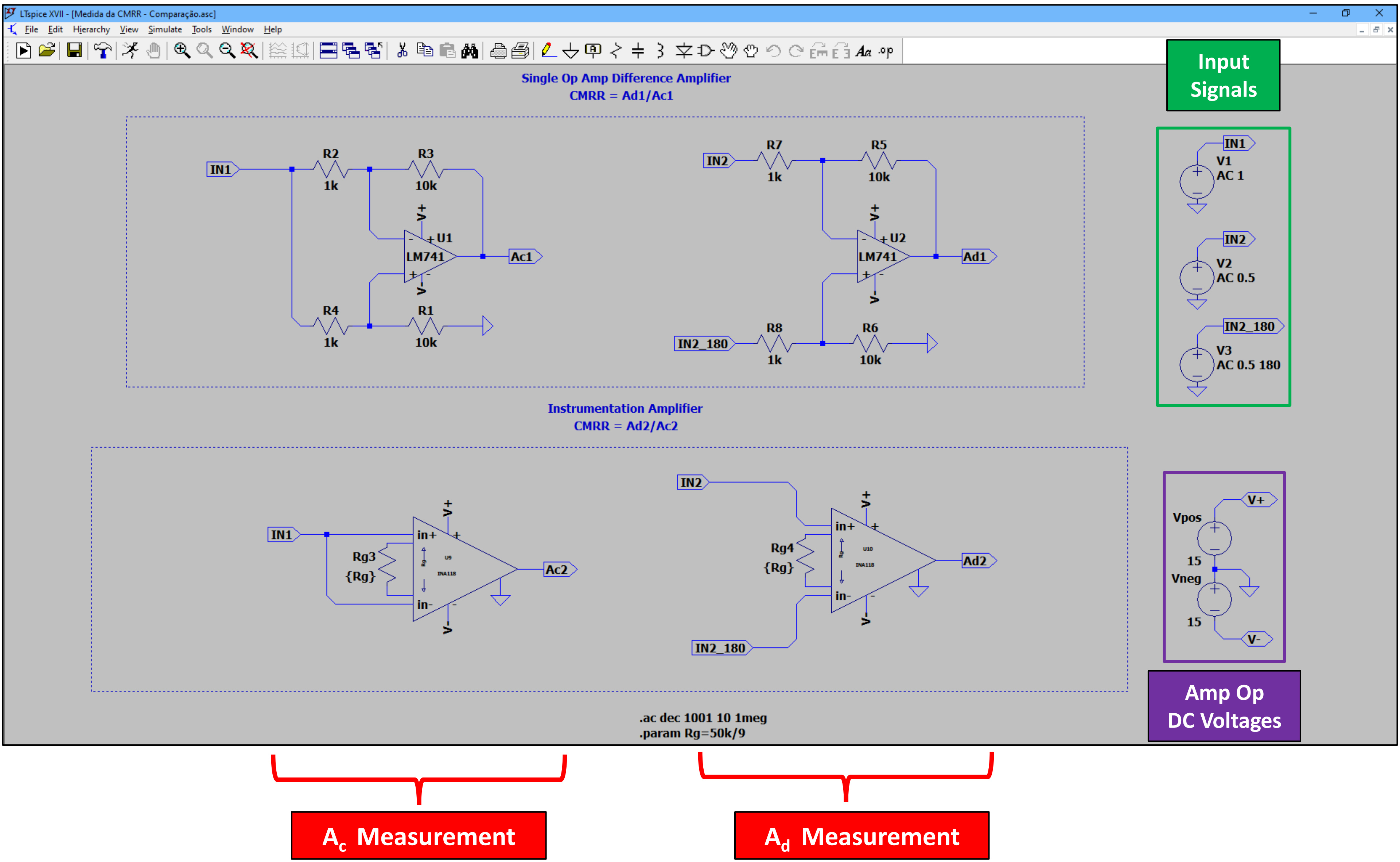
f (Hz)	$A_d = \lvert v_{od} \rvert$	$A_c = \lvert v_{oc} \rvert$	$\mathrm{CMRR} = \frac{\lvert A_d \rvert}{\lvert A_c \rvert}$
60			
1K			
5K			
7K			
10K			



Typical CMRR Curve

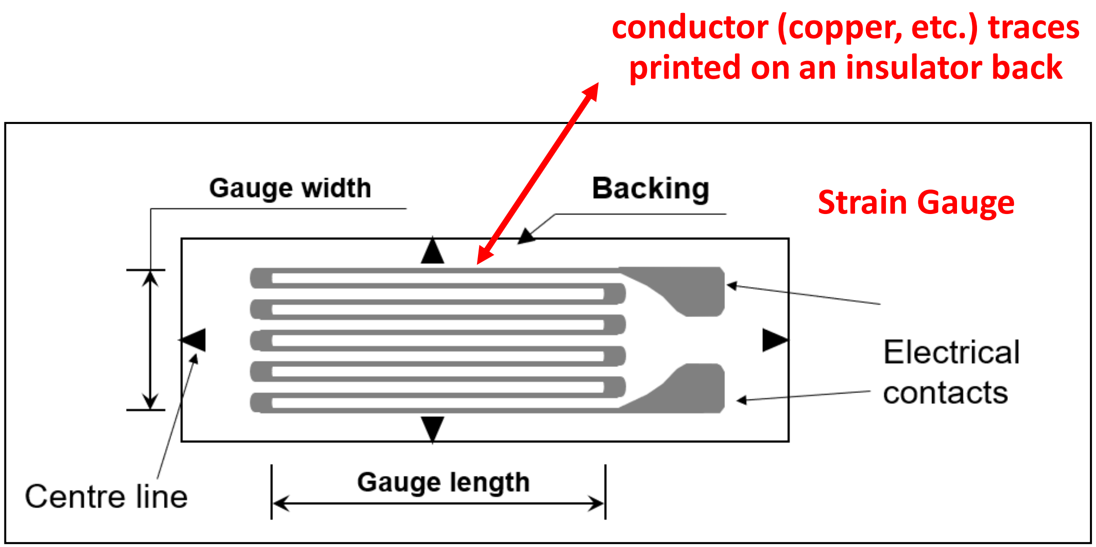
CMRR Measurement in the LTSPice

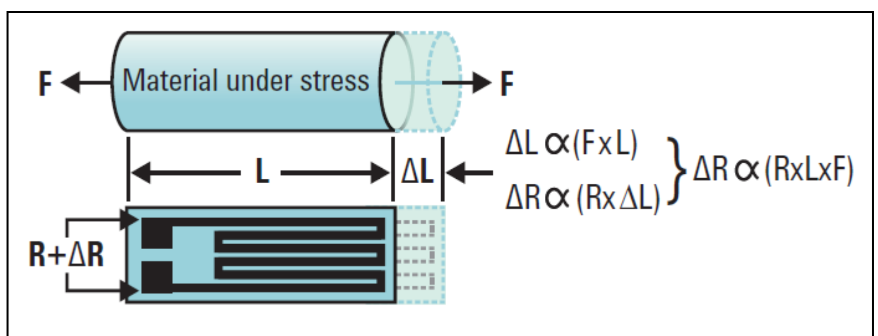
$$\text{CMRR} = \left|\frac{A_d}{A_c}\right|$$



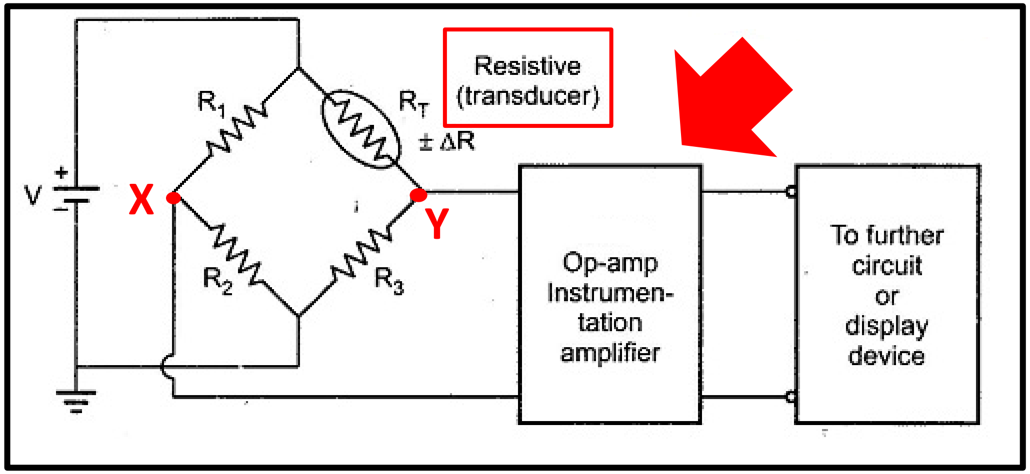
Application

In many industrial applications it is necessary to measure various physical quantities such as temperature, light, humidity, water flow etc. These are measured by transducers. The output of transducer is required to be amplified for which instrumentation amplifier is used. The figure shows a practical instrumentation amplifier with a transducer bridge.





Stress (F), strain (ΔL) and strain gauge response (ΔR)



$$V_X = V_Y \rightarrow R_T R_2 = R_1 R_3$$

(Equilíbrio)

Temperature Meter

The circuit of the instrumentation amplifier can be used as a temperature indicator if **the transducer in the bridge circuit is a thermistor** and the output meter is calibrated in degrees Celsius or Fahrenheit. The bridge can be balanced at a desired reference condition, for instance 25′C. As the temperature varies from its reference value, the resistance of the thermistor changes and the bridge becomes unbalanced. This unbalanced bridge in turn produces the meter movement. The meter can be calibrated to read a desired temperature range by selecting an appropriate gain for the differential instrumentation amplifier. In figure the metal movement is dependent on the amount of imbalance in the bridge that is, the change ΔR in the value of the thermistor resistance.

Temperature Controller

A simple and inexpensive temperature control circuit may be constructed by using a **thermistor in the bridge circuit** and by replacing a meter with a relay in the circuit of instrumentation amplifier. The output of the differential instrumentation amplifier drives a relay that controls the current in the heat-generating circuit. A properly designed circuit should energize a relay when the temperature of the thermistor drops below a desired value, causing the heat unit to turn on.

Light-intensity Meter

The circuit in the figure can be used as a light-intensity meter if a **transducer is a photocell**. The bridge can be balanced for darkness conditions. Therefore, when exposed to light the bridge will be unbalanced and cause the meter to deflect. The meter can be calibrated in terms of lux to measure the change in light intensity.

The light-intensity meter using an instrumentation bridge amplifier is more accurate and stable than single-input inverting or non-inverting configurations because the common-mode (noise) voltages are effectively rejected by the differential configuration.