SENSOR_LAB_1

Sensor_lab EE3901

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Design and Analysis of an Instrumentation Amplifier (INA)

Introduction:

Instrumentation amplifiers (INAs) are designed to amplify small differential signals while rejecting common-mode signal/noise. They are commonly employed in sensor signal conditioning, biomedical instrumentation, and industrial measurement systems where accurate, high common-mode rejection ratio (CMRR), and low-noise signal amplification are essential. The most popular INA configuration utilizes three operational amplifiers, providing high input impedance, precise gain control, and excellent common-mode rejection ratio (CMRR).

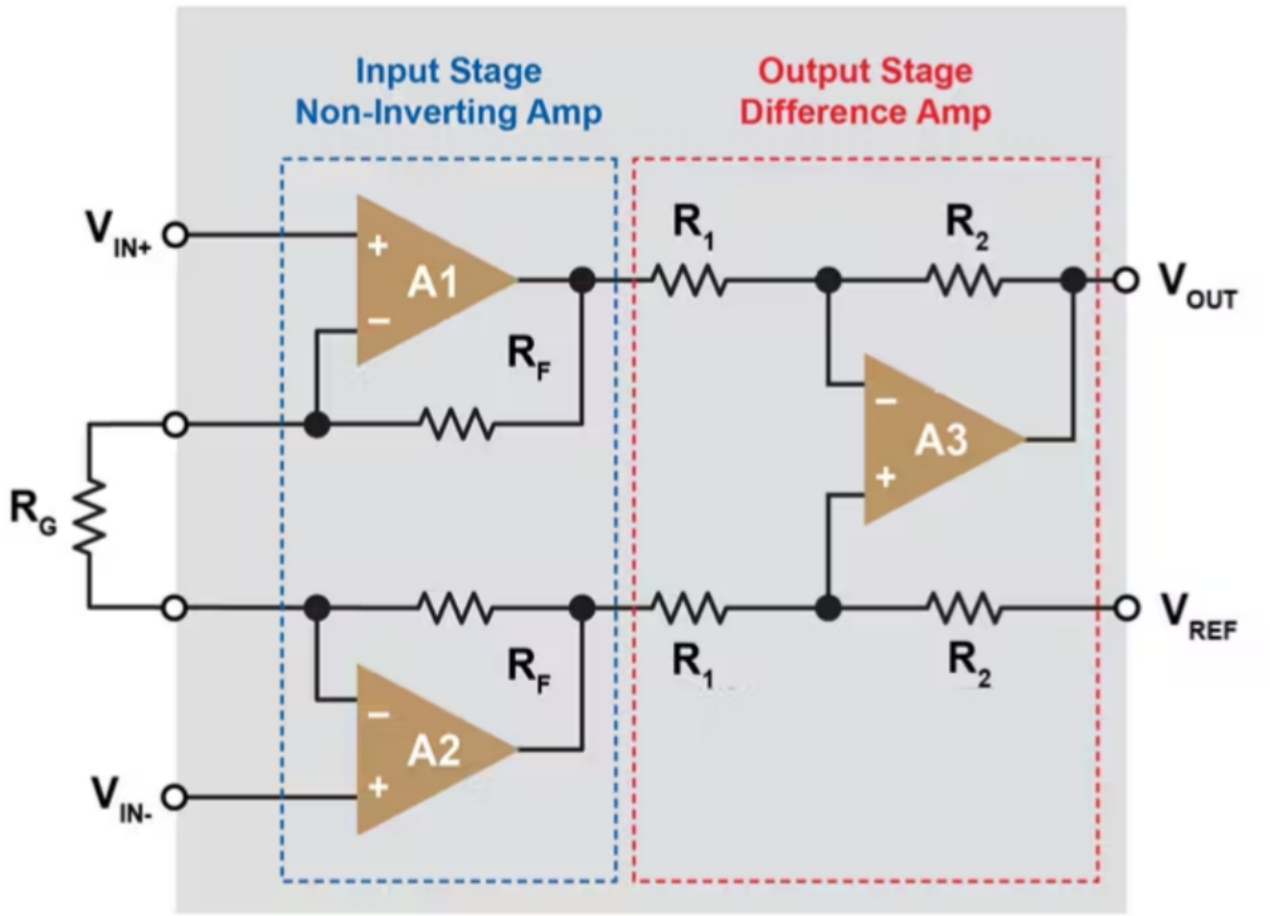


Fig. 1. Instrumentation amplifier circuit[ref.]. Set $R_F = R_1 = R_2 = R$. A1 to A3 are opamps.

Components used:

→ MCP6004 IC - 1

→ ADALM1000 Kit - 1

→ 10 kΩ resistors - 7

→ Potentiometer - 2

→ Digital multimeter - 1

→ Wires - [Red, Black, Yellow]

Circuit design and Calculations

* Difference input $(V_d) = V_1 - V_2$

* CMRR $(V_o) = G(V_1 - V_2)$

  where, CMRR, $\rho = \dfrac{A_d}{A_c}$

  A_d → difference mode gain

  A_c → common mode gain

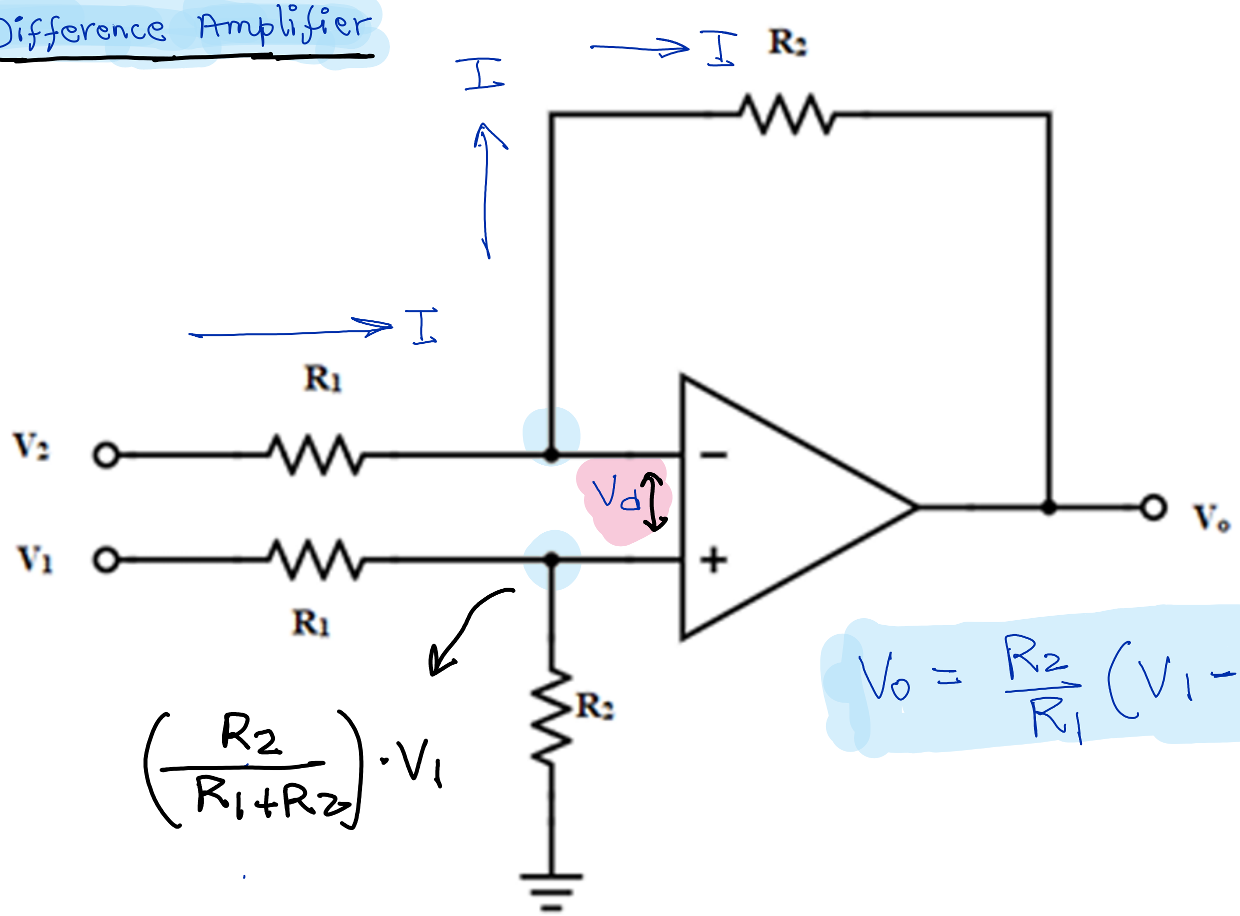
CMRR is the ability of the amplifier to reject common mode signals.

* Common Mode Input $(V_c) = \dfrac{V_1 + V_2}{2}$

Also,
- $\rho_{ideal} = \infty$
- $\rho_{dB} = 20 \log_{10}\left(\dfrac{A_d}{A_c}\right)$
- $V_o = A_d V_d + A_c V_c$

Difference Amplifier

Fig-2

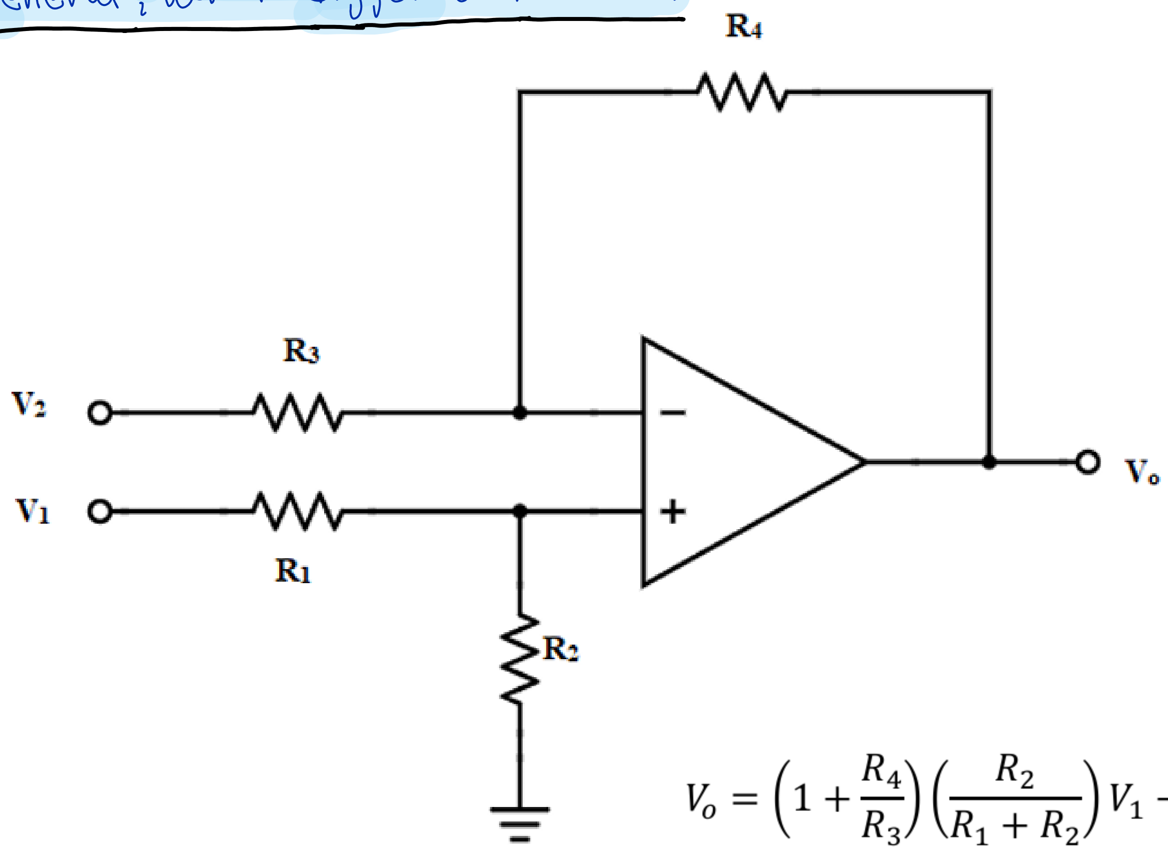


$$\left(\frac{R_2}{R_1+R_2}\right)\cdot V_1$$

$$V_o = \frac{R_2}{R_1}\left(V_1 - V_2\right)$$

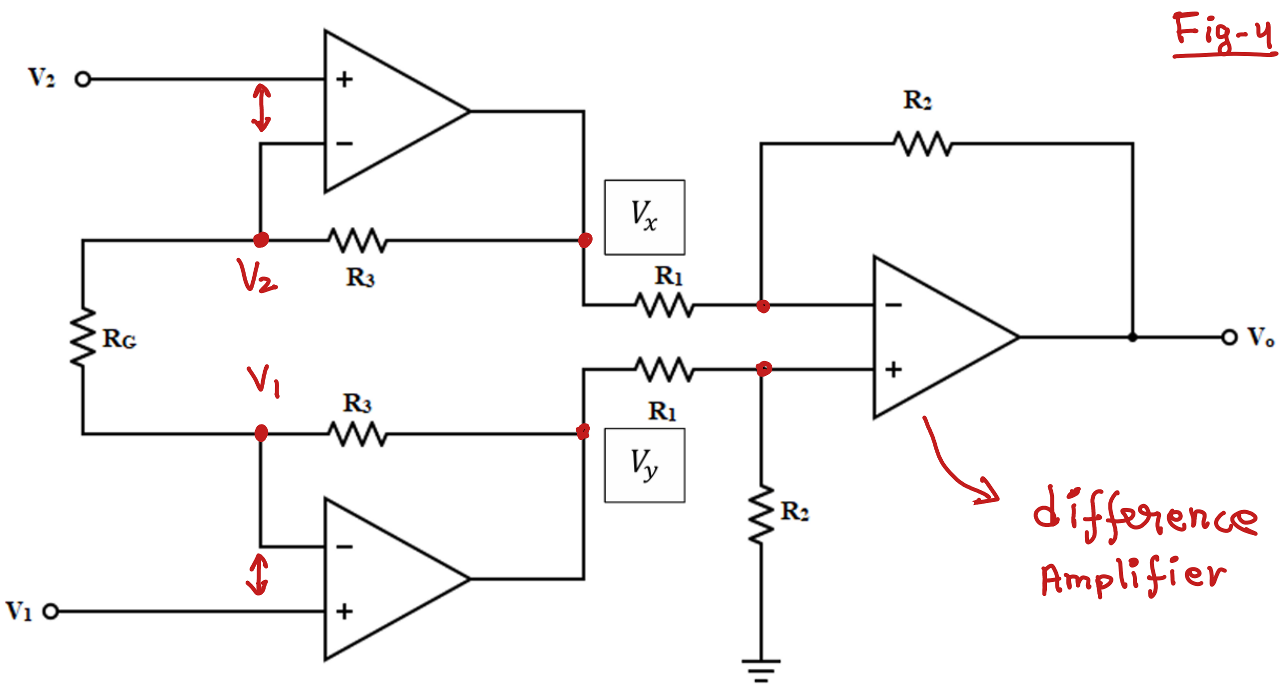
In general, with different R values

Fig-3



$$V_o = \left(1+\frac{R_4}{R_3}\right)\left(\frac{R_2}{R_1+R_2}\right)V_1 - \frac{R_4}{R_3}V_2$$

Instrumentation Amplifier (INA)



$$V_x = \left(1 + \frac{R_3}{R_G}\right)V_2 - \frac{R_3}{R_G}V_1 \quad ; \quad V_y = \left(1 + \frac{R_3}{R_G}\right)V_1 - \frac{R_3}{R_G}V_2 \quad ; \quad V_o = \frac{R_2}{R_1}\left(V_y - V_x\right)$$

$$V_o = \frac{R_2}{R_1}\left[\left(1 + \frac{R_3}{R_G}\right)V_1 - \frac{R_3}{R_G}V_2 - \left(1 + \frac{R_3}{R_G}\right)V_2 + \frac{R_3}{R_G}V_1\right]$$

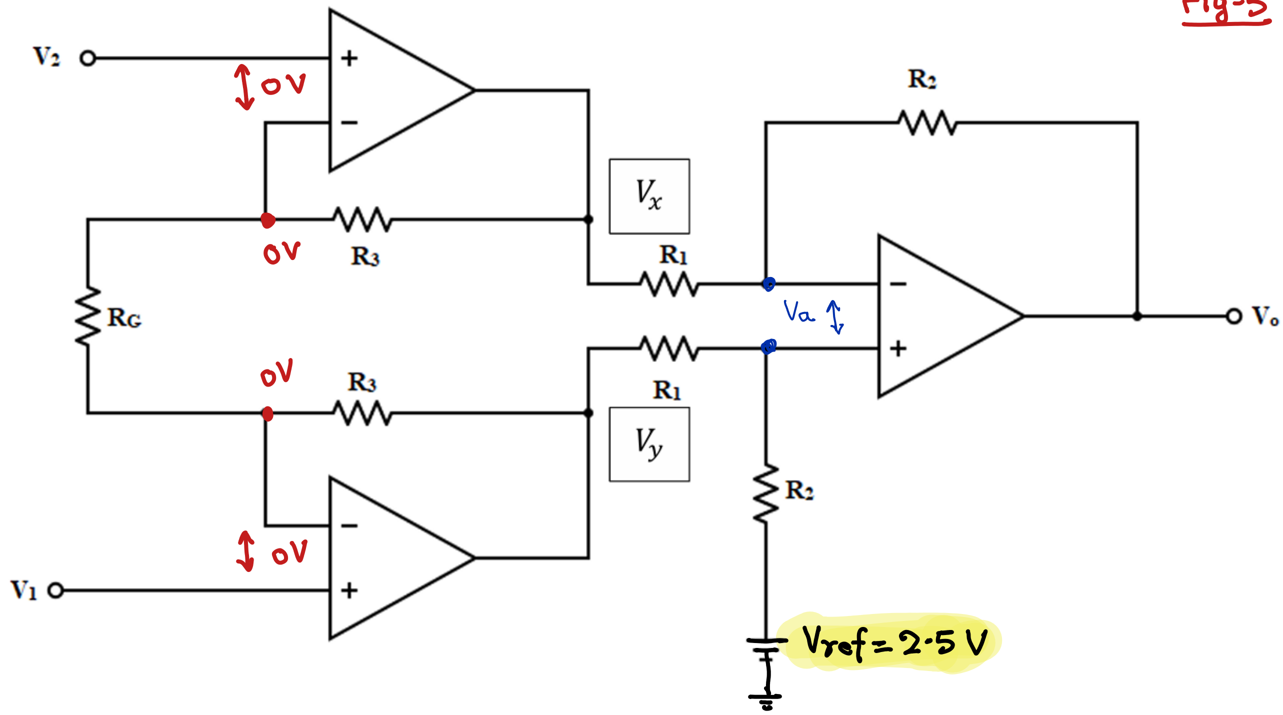
$$V_o = \frac{R_2}{R_1}\left[\left(1 + \frac{2R_3}{R_G}\right)V_1 - \left(1 + \frac{2R_3}{R_G}\right)V_2\right] \Rightarrow V_o = \frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_G}\right)[V_1 - V_2]$$

It is given that, $R_1 = R_2 = R_3 = R = 10\,k\Omega$, So,

$$V_o = \left(1 + \frac{2R}{R_G}\right)[V_1 - V_2] \Rightarrow \underbrace{\frac{V_o}{V_1 - V_2}}_{A_d = 3} = 1 + \frac{2 \times 10k}{R_G} \Rightarrow R_G = \frac{20k}{2} = 10k$$

Expression when $V_1 = V_2 = 0\,V$ and $V_{ref} = 2.5\,V$

Fig-5



Since $V_o = \frac{R_2}{R_1}(V_y - V_x)$, and by symmetry $V_x = V_y$

Also, adding the effect of Vref, by eqns forming –

$$\Rightarrow \frac{V_y - V_a}{R} = \frac{V_a - 2.5}{R} \qquad \Rightarrow \frac{V_x - V_a}{R} = \frac{V_a - V_o}{R}$$

$$\Rightarrow V_y = 2V_a - 2.5 \qquad \Rightarrow V_x = 2V_a - V_o$$

Comparing, both above equations, $\boxed{V_o = 2.5V}$

If $V_{REF} \neq 0\,V$ and $R_1 = R_2 = R_F = R$

$$V_o = \left(1 + \frac{2R}{R_G}\right)V_d + \left(1 + \frac{R}{R}\right)\frac{1}{2}V_{Ref}$$

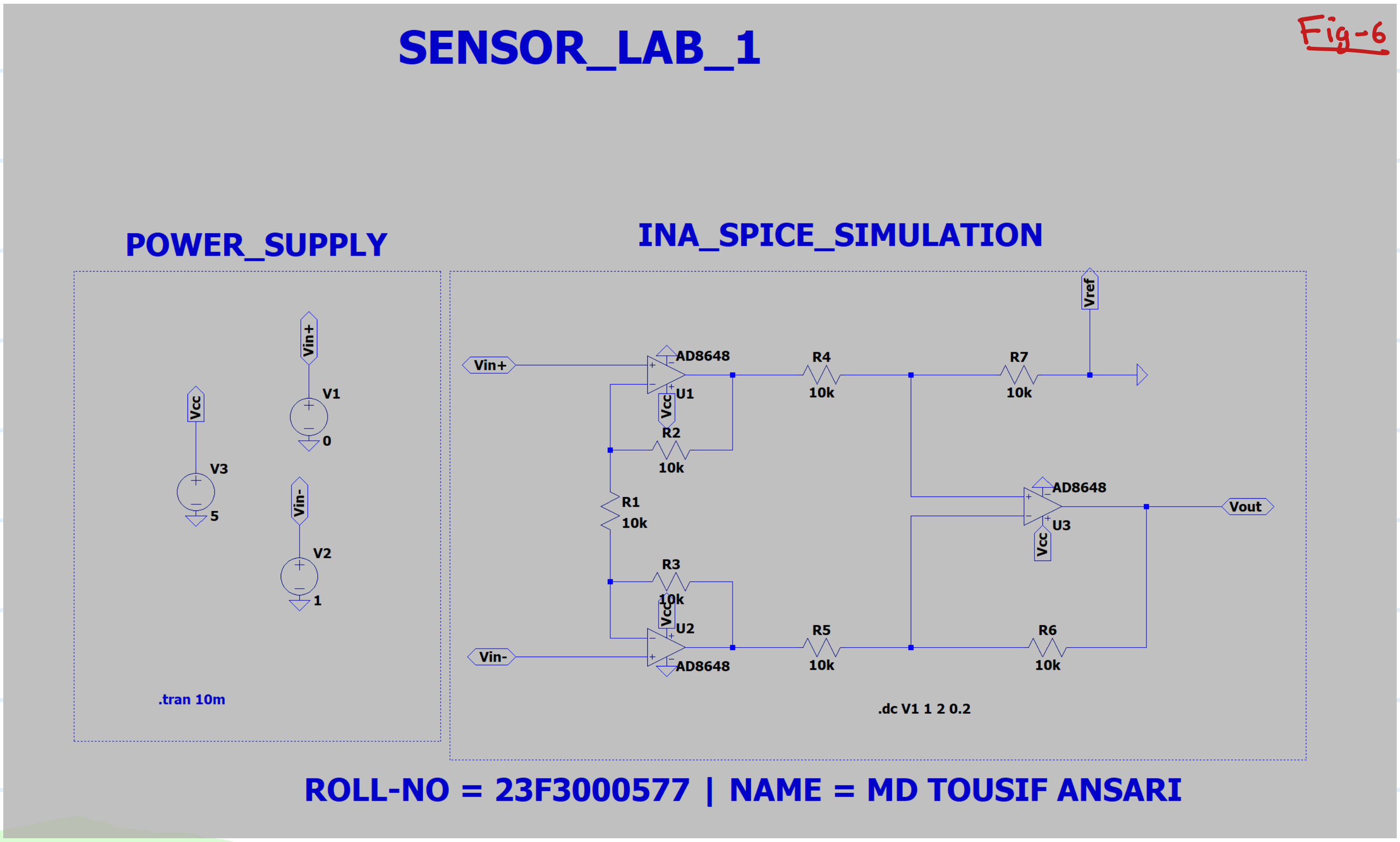
$$V_o = \left(1 + \frac{2R}{R_G}\right)V_d + V_{Ref}$$

→ Also using these equation when $V_{ref} \neq 0$

$V_1 = V_2 = 0$; $V_d = (V_1 - V_2)$, So, $\boxed{V_o = V_{ref}}$

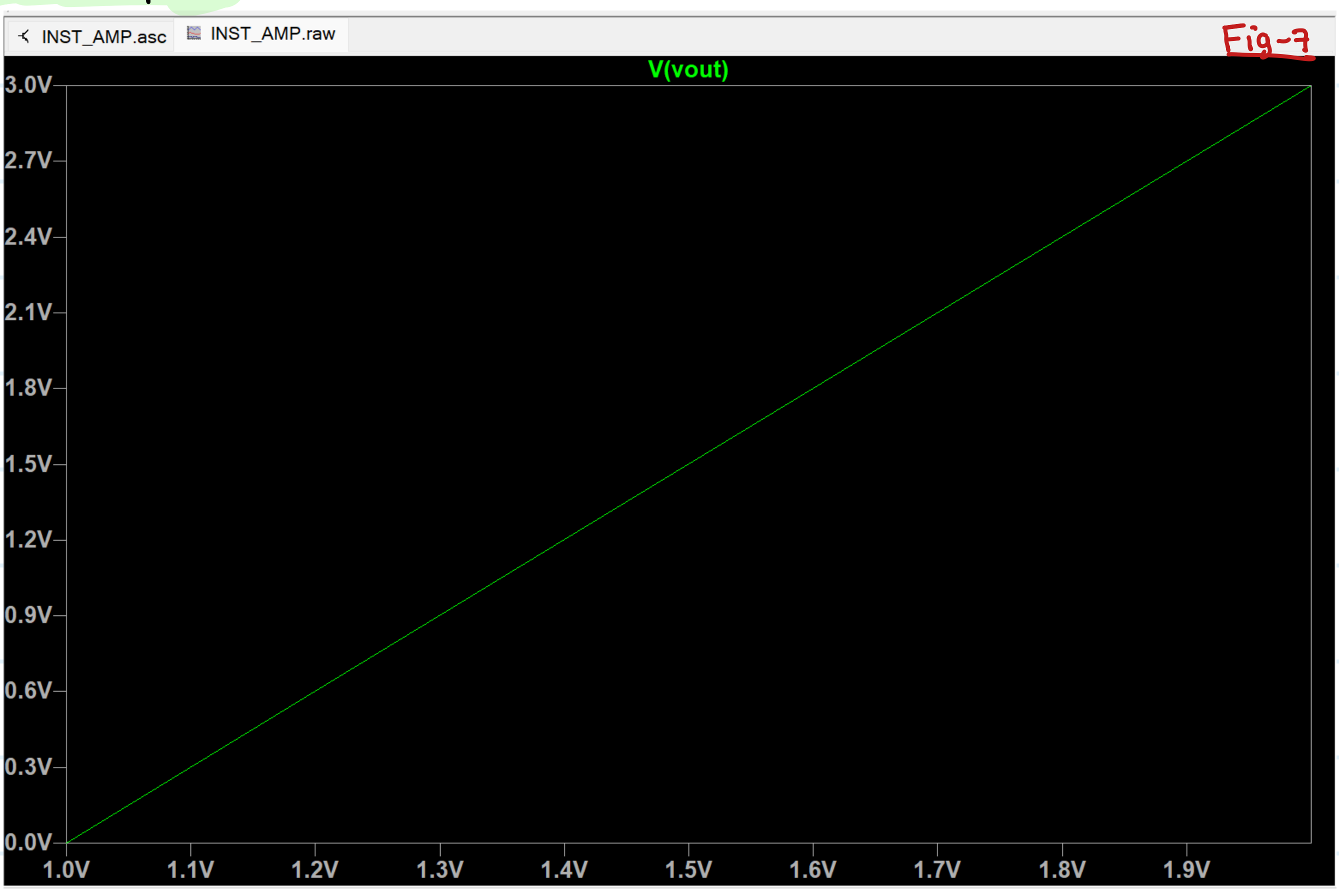
Simulation screenshots and associated voltage waveforms

Fig-6



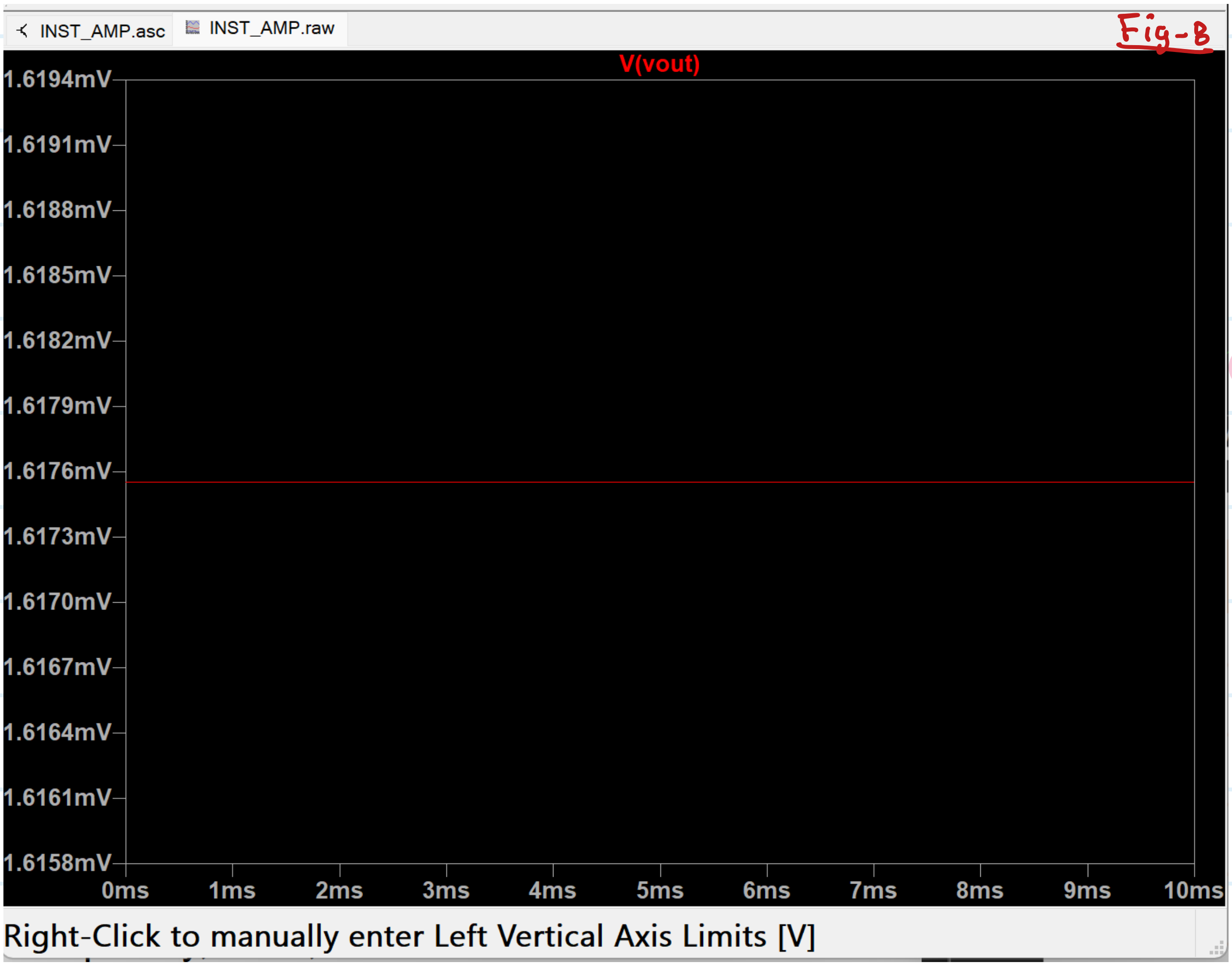
Output

Fig-7



Output when $V_{in+} = V_{IN-} = 1.5\ V$ {Simulation}

Fig-8



$V_{out} = 1.6\ mV$

* Common mode Gain :

$$A_{cm} = V_{out} / V_{cm}$$

$$A_{cm} = 1.6\ mV / 1.5\ V$$

$$A_{cm} = 0.0010667$$

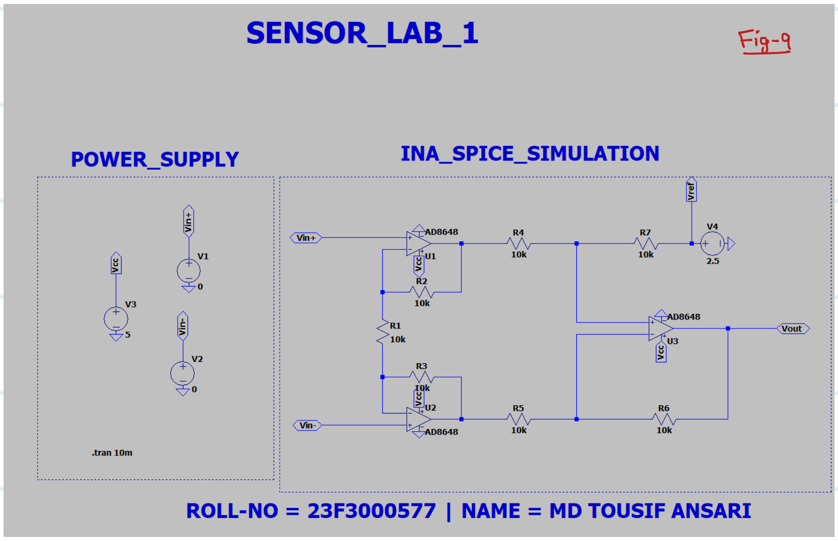
* CMRR

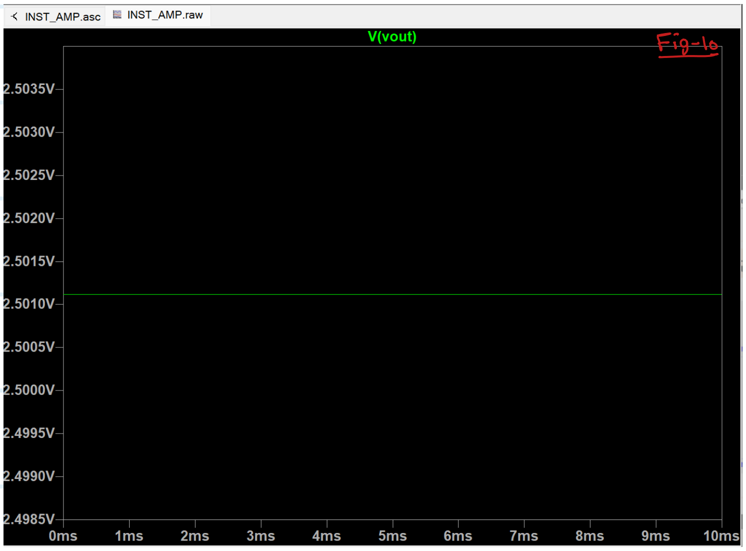
$$CMRR = A_d / A_{cm}$$

$$CMRR = 3 / 0.0010667$$

$$CMRR = 2812.5$$

Circuit Simulation $\{V_{in+} = V_{in-} = 0 \; , \; V_{ref} = 2.5V\}$





$$V_{out} = 2.5 \text{ V}$$

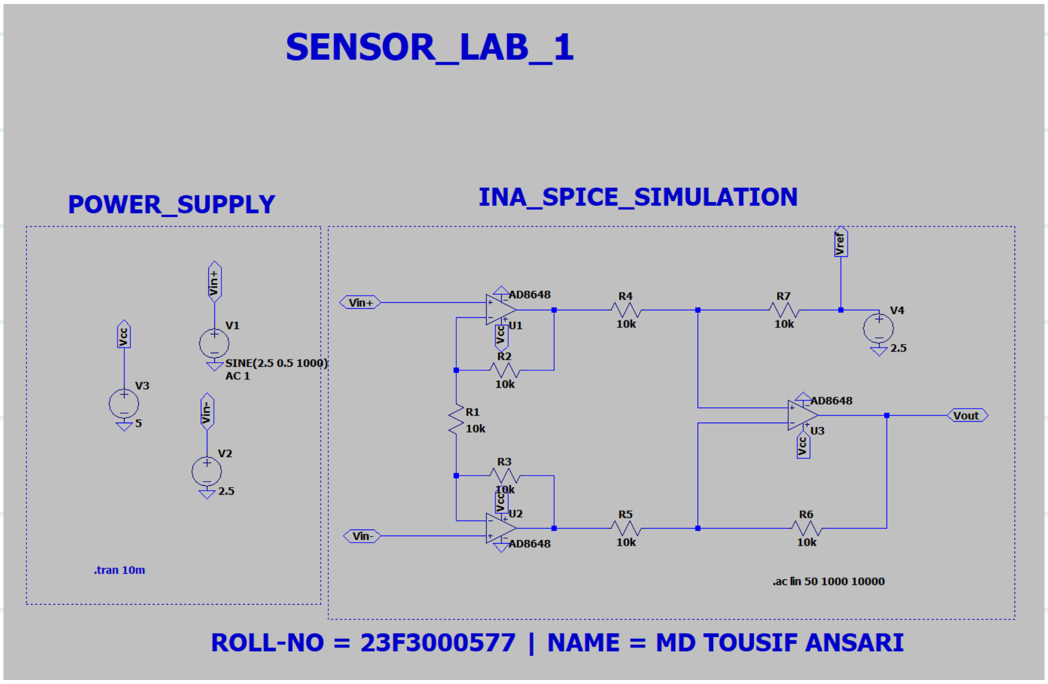
Frequency Analysis

→ To do so, we set , $V_d = 0.5 \sin(2\pi f t)$ and varying frequency. [1 KHz - 10 KHz]

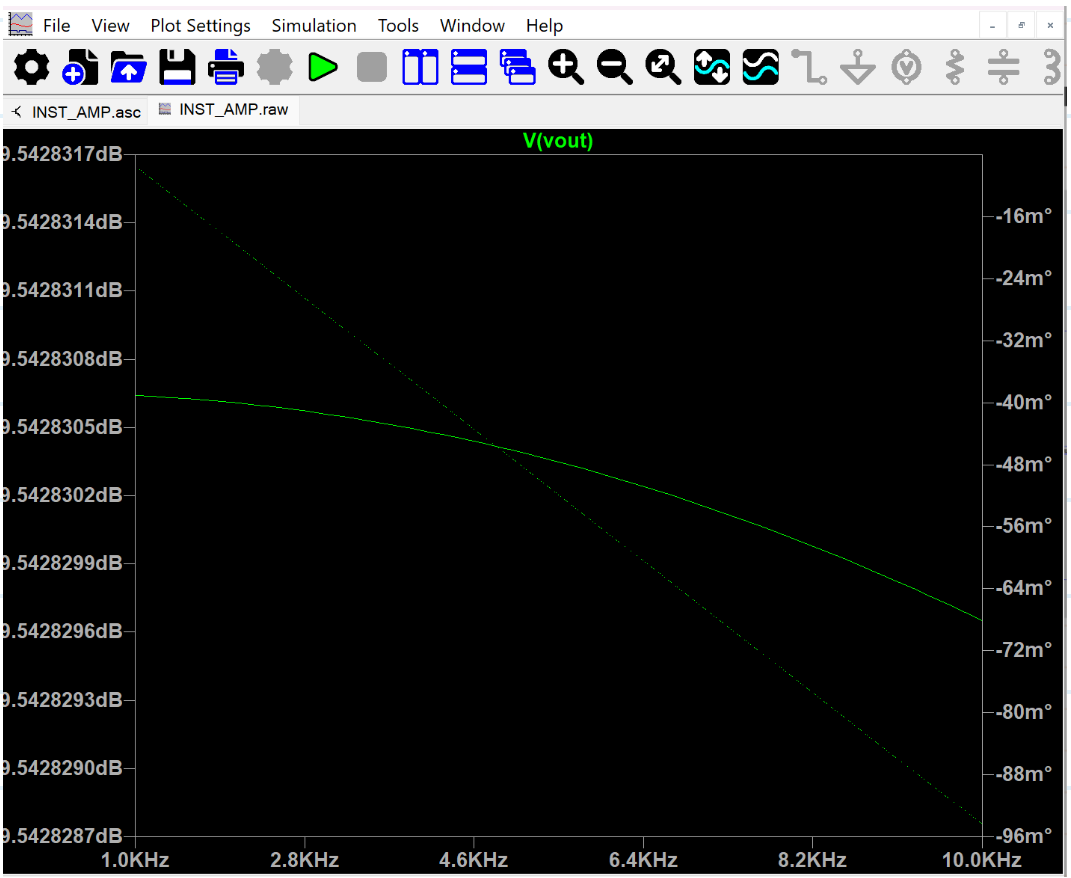
→ Diffrential Gain Can be calculated using,

$$\boxed{A_d = \frac{V_{out}}{V_d}}$$

Simulation



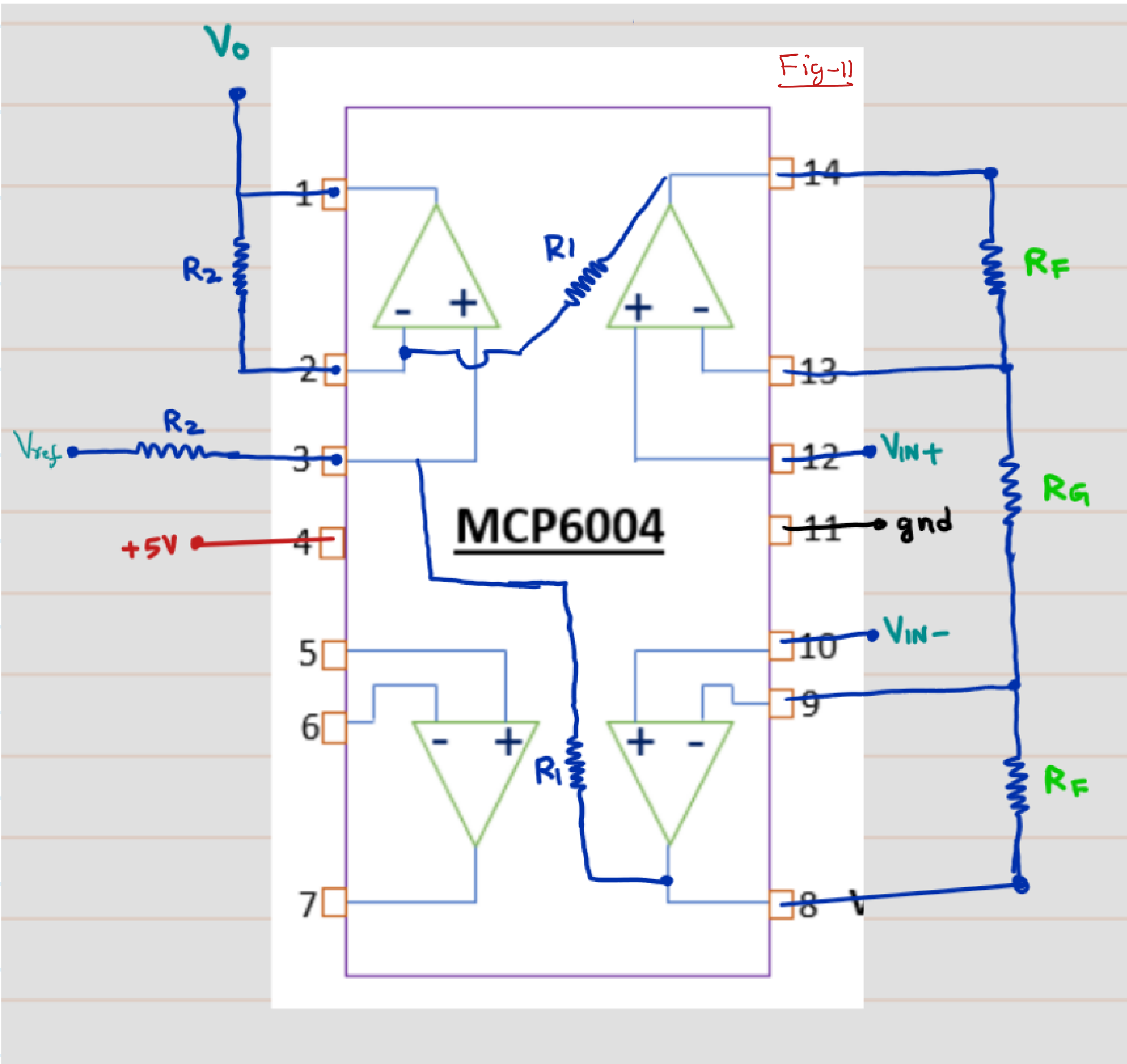
- Frequency response Simulation



→ Gain Remains Constant as we change frequency.

Photographs of the experimental setup, including the breadboard with the assembled circuit.

- Pin Diagram



INA Pin Diagram

All R are 10 kΩ [V_{in+} = 1V ; V_{in-} = {1-2}V {0.2} varying ; V_{ref} = 0V]

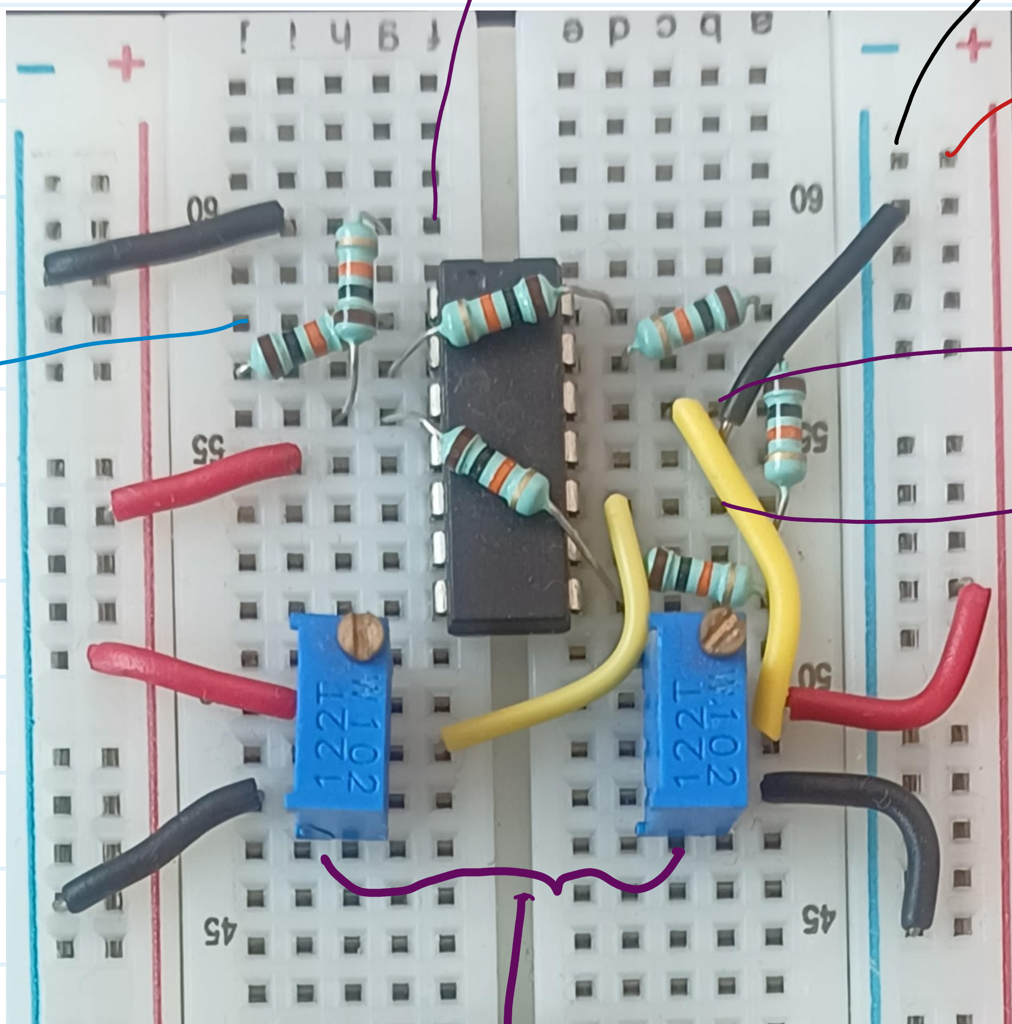
Breadboard View

All 10 kΩ Resistors are used.

Vref

gnd

+5 V



output (V_o)

V_{in} + (fixed)

V_{in} – (variying)

Fig-12

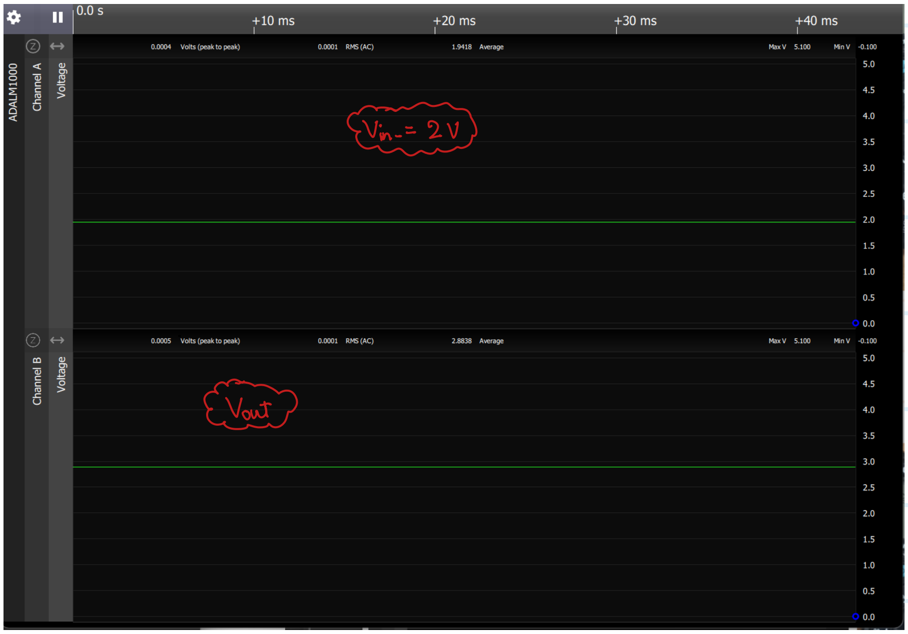
Potentiometer (10k)

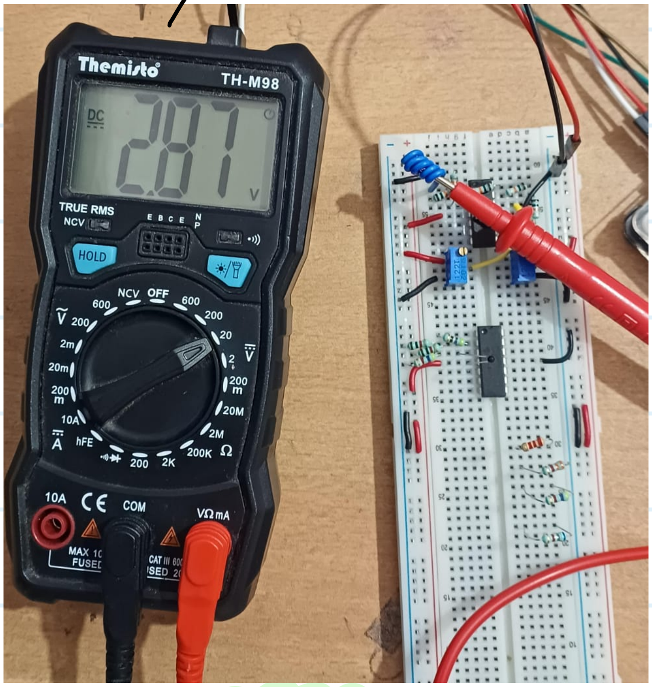
For variying voltage from [1 → 2 V]

Output $[V_{in+} = 1V, V_{in-} = \{1 \rightarrow 2\}V, V_{ref} = 0V]$

★ $V_{in+} = 1V$; $V_{in-} = 2V$

due to real world condⁿ.

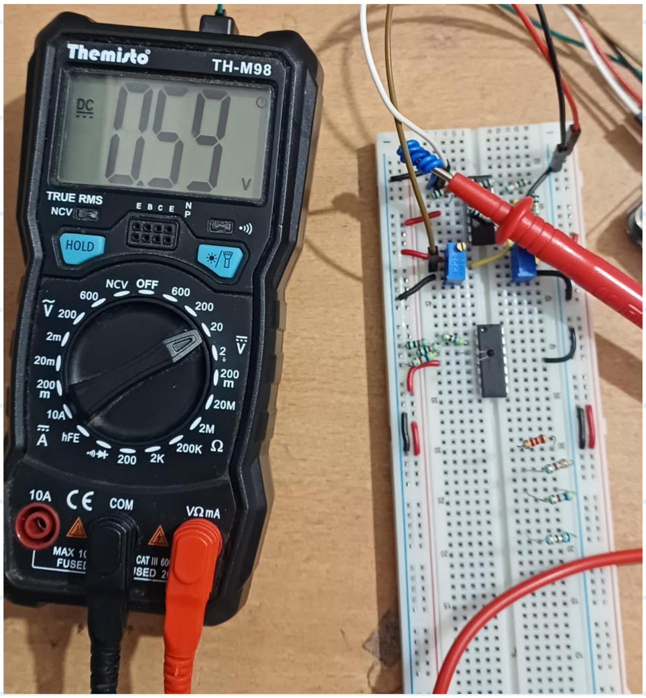




Adalm1000 output

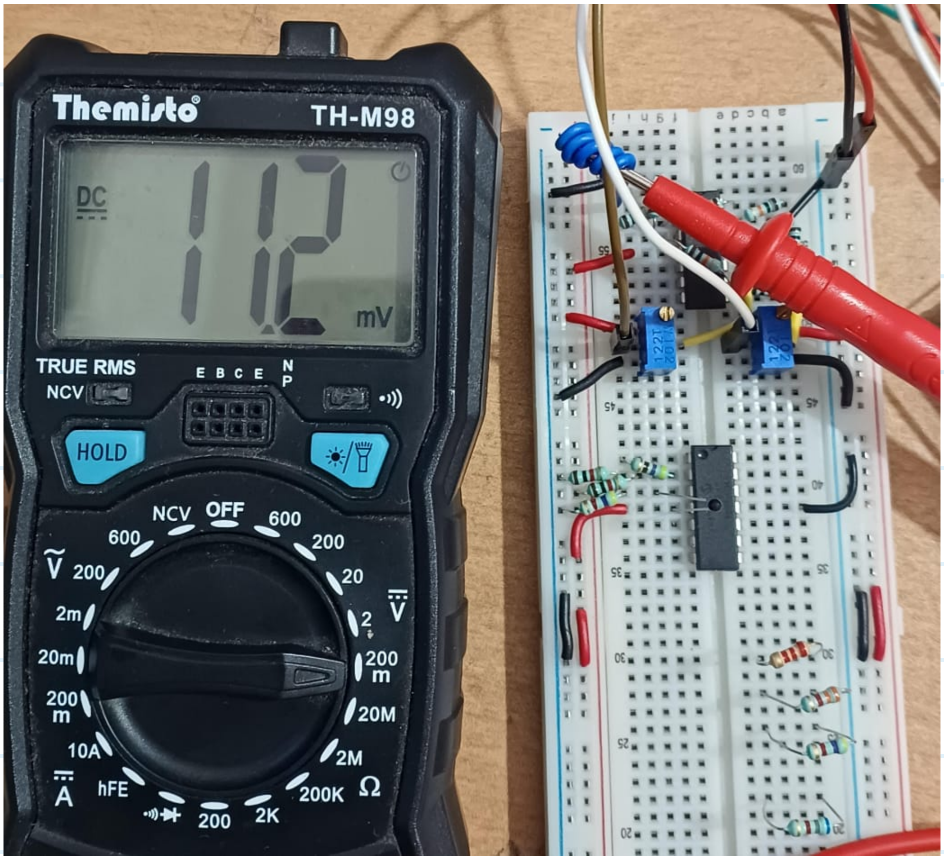
multimeter

★ $V_{in+} = 1V$; $V_{in-} = 1.2V$



Output [$V_{in+} = V_{in-} = 1.5\,V$, $V_{ref} = 0\,V$]

we notice it is a little bit above zero



* In multimeter we get Vout as 11.2 mV whereas in simulation we got 1.6 mV

Frequency Response Output

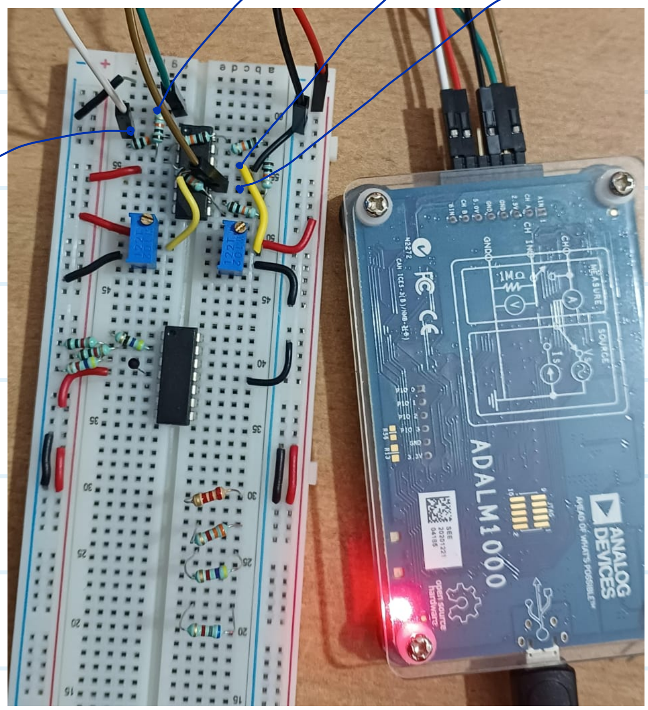
Bread Board Setup

2.5 V

2.5 V

$0.5 \sin(2\pi f t)$

output

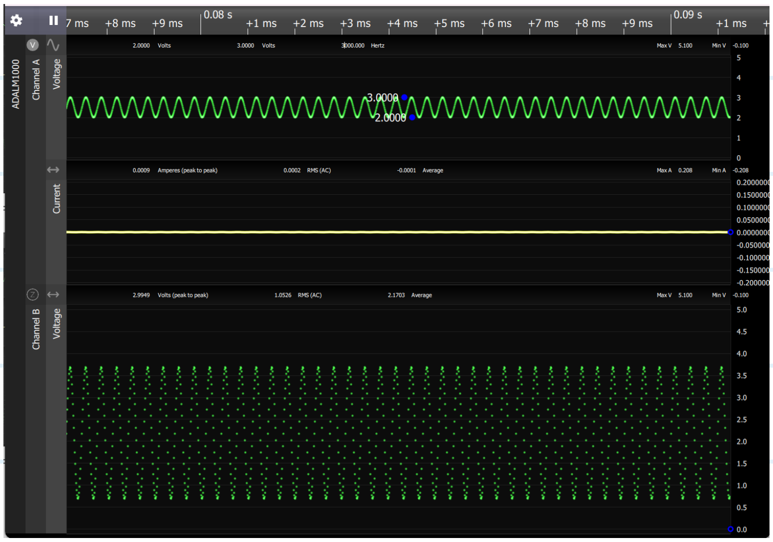


Adalm1000 [Output]

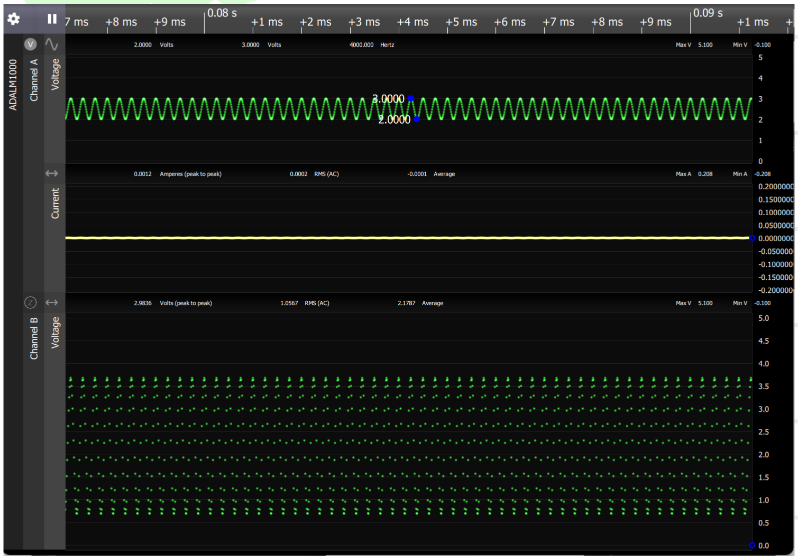
★ Frequency = 1000 Hz

★ Frequency = 2000 Hz

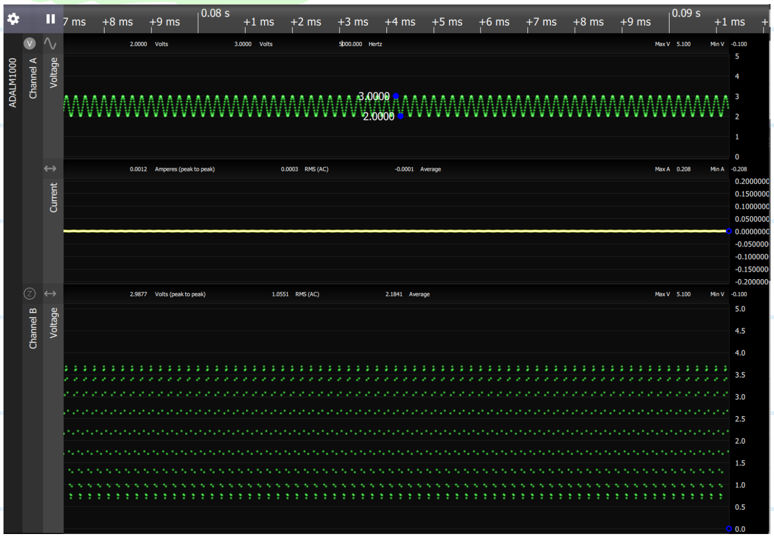
★ Frequency = 3000 Hz



★ Frequency = 4000 Hz

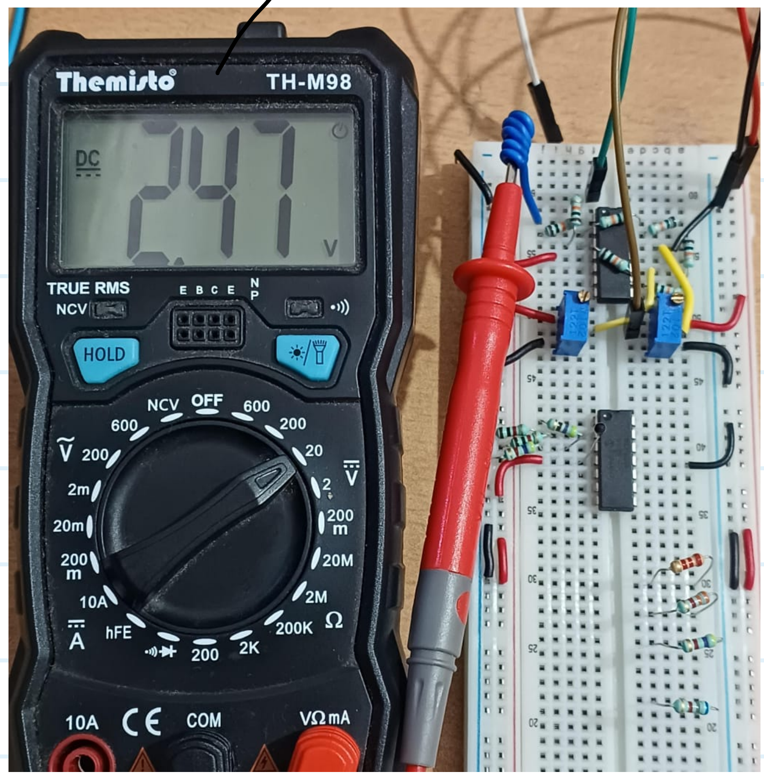


★ Frequency = 5000 Hz



Output [$V_{in+} = V_{in-} = 0V$; $V_{ref} = 2.5V$]

Multimeter output
$V_o = 2.47V$



Deviation between Calculated values i.e $V_o = 2.5V$ and Actual value $V_o = 2.47V$.