

Instrumentation Amplifier Lab Report

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Subject: Sensors lab EE3901

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Objective :

To make and understand behaviour of an instrumentation amplifier

Components :

- Opamp : MCP6004
- Resistors : 10 Kohm
- Trim pot : 1 Kohm

Derivation of Instrumentation Amplifier Output

The given circuit is a three-op-amp instrumentation amplifier consisting of:

1. Input Stage (Two Non-Inverting Amplifiers - A1 and A2).
2. Output Stage (A Difference Amplifier - A3).

We are given the conditions: - $R_F = R_1 = R_2 = R$ - $V_{REF} = 0$

Step 1: Input Stage Gain

The output voltages of amplifiers A1 and A2 are:

$$\text{let, } V_d = V_{in+} - V_{in-}$$

$$V_{A1} = V_{in+} + \frac{R}{R_G} V_d \quad (1)$$

$$V_{A2} = V_{in-} - \frac{R}{R_G} V_d \quad (2)$$

Step 2: Difference Amplifier Stage

The outputs of A1 and A2 are inputs to the difference amplifier A3. The gain of a standard difference amplifier (for $R_1 = R_2$) is:

$$V_{out} = \left(\frac{R_2}{R_1} \right) (V_{A1} - V_{A2}) \quad (3)$$

Since $R_1 = R_2 = R$, the gain simplifies to 1:

$$V_{out} = V_{A1} - V_{A2} \quad (4)$$

Substituting the values from Step 1:

$$V_{out} = V_{in+} + \frac{R}{R_g} V_d - (V_{in-} - \frac{R}{R_g} V_d) \quad (5)$$

$$V_{\text{out}} = (V_{IN+} - V_{IN-}) + \frac{2R}{R_g} V_d \quad (6)$$

$$V_{\text{out}} = V_d \left(1 + \frac{2R}{2Rg} \right) \quad (7)$$

Final Result

$$V_{\text{out}} = \left(1 + \frac{2R}{R_G} \right) (V_{IN+} - V_{IN-}) \quad (8)$$

Thus, the instrumentation amplifier provides a differential gain of:

$$G = 1 + \frac{2R}{R_G} \quad (9)$$

Multiplying this gain by the differential input voltage ($V_{IN+} - V_{IN-}$) gives the final output.

Simulation (LTSpice)

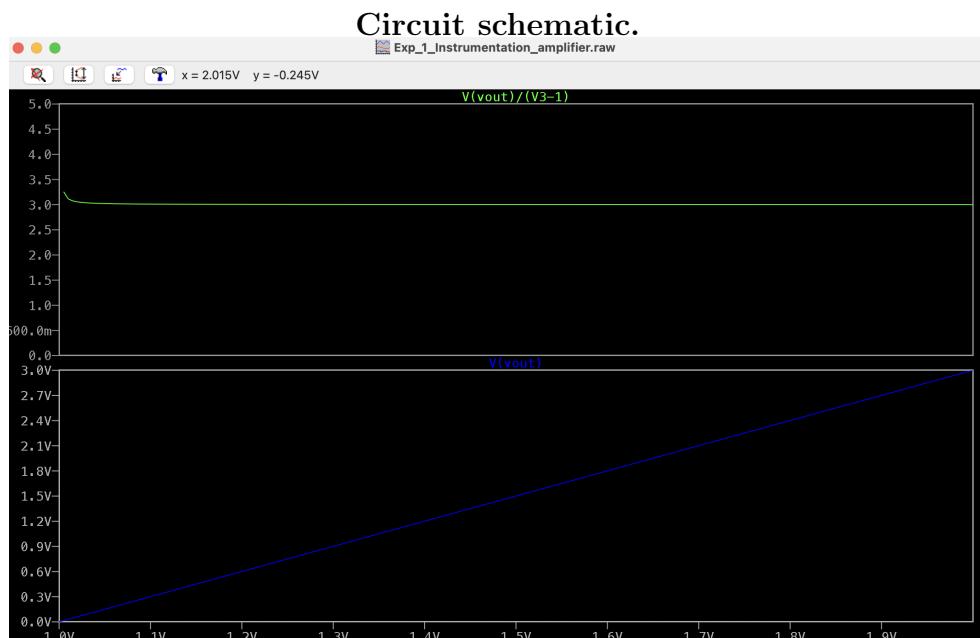
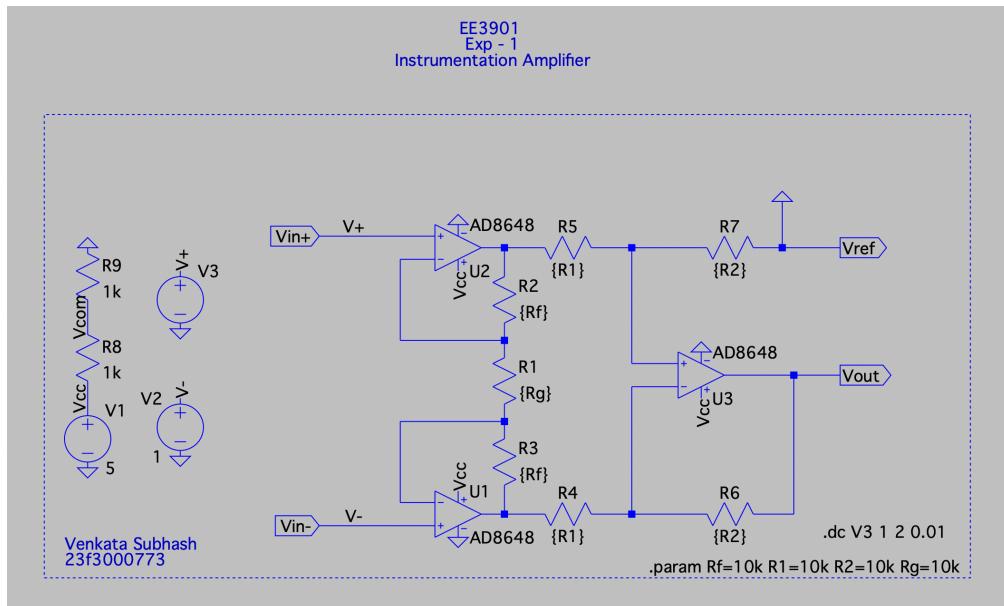
As Differential gain for our Instrumentation amplifier is

$$A_d = \left(1 + \frac{2R}{R_g} \right) \quad (10)$$

We will adjust R_g to get the desired A_d .

1. With differential gain 3

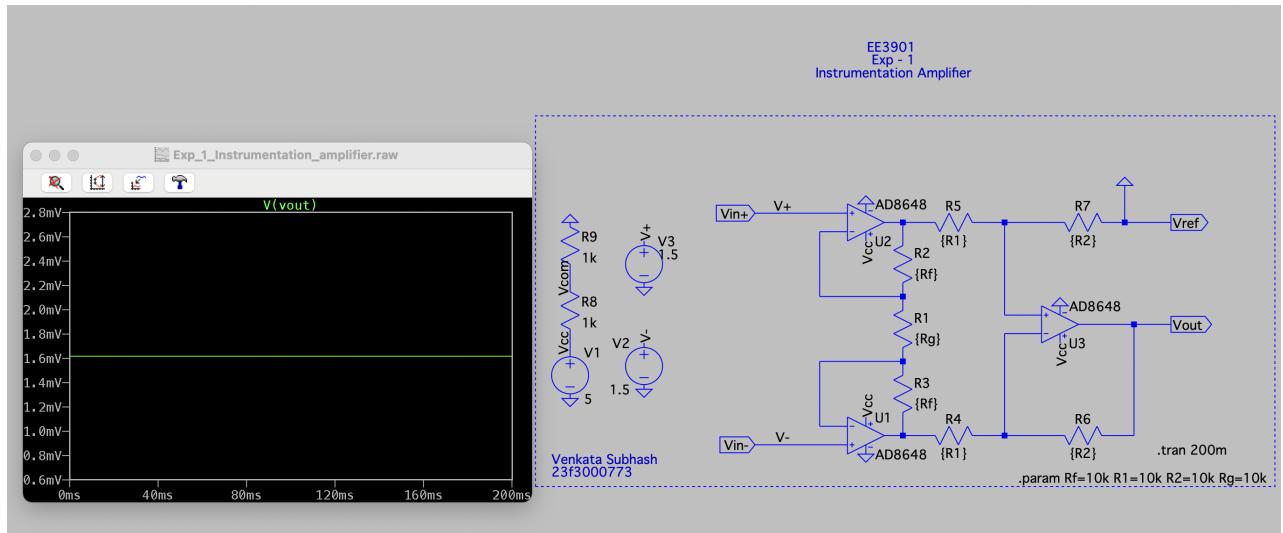
Let's set our R as 10 Kohms and R_g as 10 Kohms to get A_d as 3.



Characteristics when DC Sweeping V_{in+} from 1V to 2V when $V_{in-} = 1V$

Top (Green plot) : A_d vs V_{in+}
bottom (Blue plot) : V_{out} vs V_{in+}

2. Calculating CMRR when $V_{in+} = V_{in-} = 1.5$



$$V_{out} = 1.6 \text{ mV} \text{ when } V_{in+} = V_{in-} = 1.5 \text{ .}$$

1. Common-mode Gain

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

$$A_{cm} = 1.6\text{mv}/1.5\text{v}$$

$$A_{cm} = 0.0010667$$

2. CMRR

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

$$\text{CMRR} = 3/0.0010667$$

$$\text{CMRR} = 2812.5$$

3. Frequency Response Analysis

To analyze the frequency dependence of the amplifier's differential gain, we set a fixed differential input voltage:

$$V_d = 0.5 \sin(2\pi ft) \text{ V} \quad (11)$$

The frequency f was varied from 1 kHz to 10 kHz. The corresponding output voltage was recorded, and the differential gain A_d was calculated using:

$$A_d = \frac{V_{\text{out}}}{V_d} \quad (12)$$

A plot of **gain vs. frequency** is provided in Figure 1 to illustrate the amplifier's frequency response.

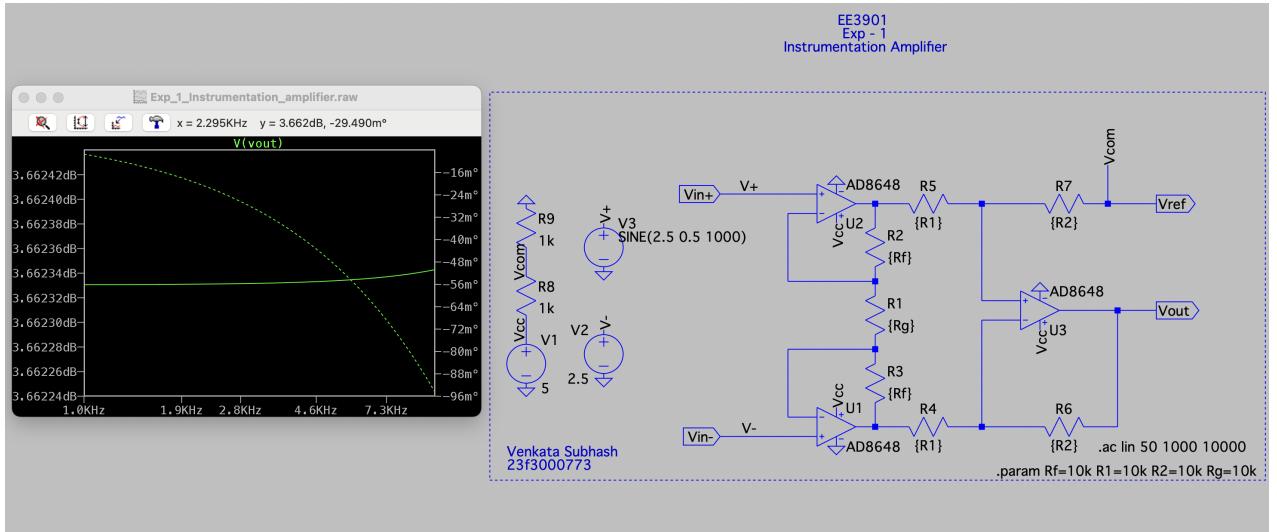
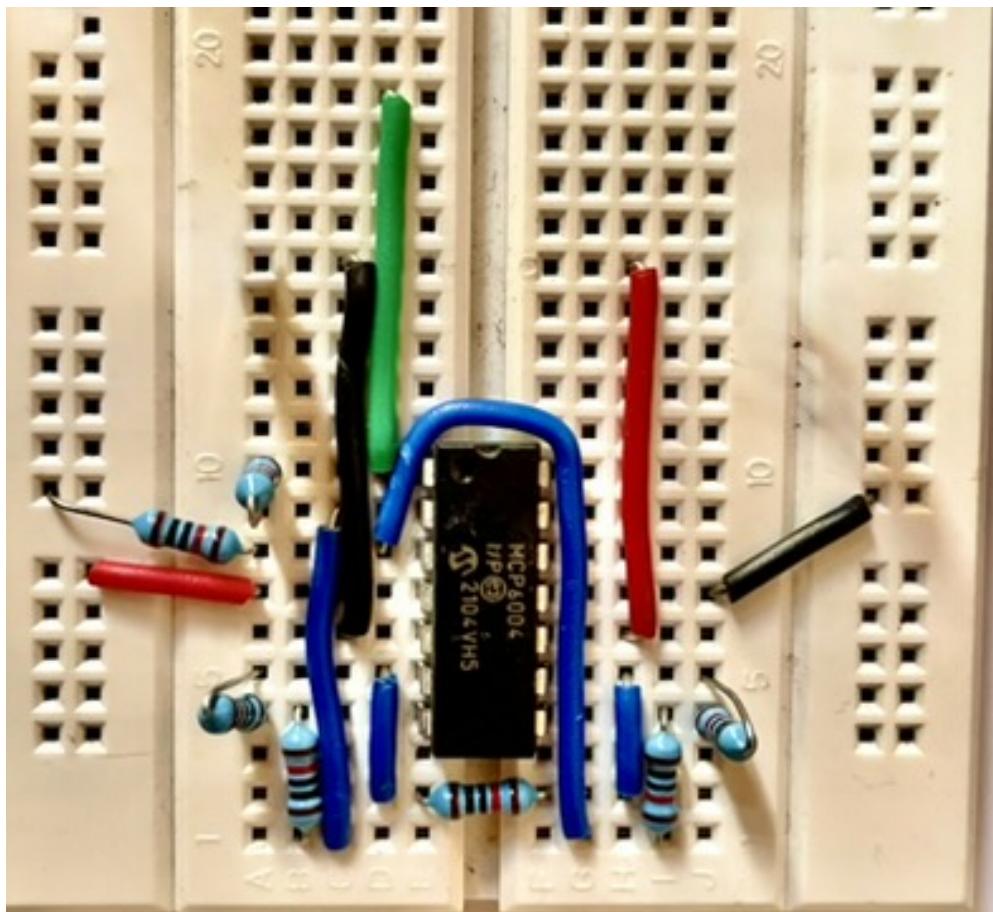


Figure 1: Plot of Gain vs. Frequency

From the results, we observe that gain remains almost constant with the change in frequency.

Circuit implementation on breadboard

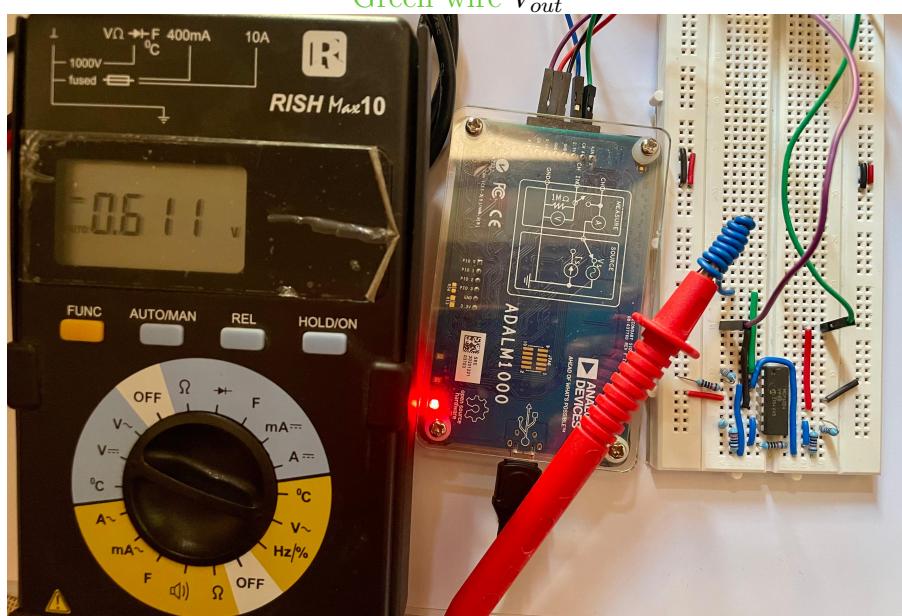


Circuit on Breadboard

Red wire V_{in+}

Black wire V_{in-}

Green wire V_{out}



1. DC Characteristics

1. $V_d = 3$

Set $R_g = 10 \text{ kOhms}$
 $V_{in-} = 1\text{v}$ (fixed value)
 V_{in+} increasing in steps of 0.2v from 1v to 2v.

V_d (V)	V_{out} (V)	A_d (V)
0	0.013	-
0.2	0.611	3.055
0.4	1.210	3.025
0.6	1.808	3.013
0.8	2.404	3.005
1.0	2.971	2.971

Table 1: Measured Input and Output Voltages with Calculated V_d

2. $V_d = 20$

Set $R_g = 1.05 \text{ kohms}$
 $V_{in-} = 2.5 \text{ v}$ (fixed value)
 V_{in+} increasing in steps of 50 mv from 2.5 v to 2.7 v.

V_d (V)	V_{out} (V)	A_d (V)
0	0.01	-
0.05	1.041	20.82
0.1	2.078	20.78
0.15	3.118	20.79
0.2	4.15	20.75

Table 2: Measured Input and Output Voltages with Calculated V_d

My observation :

While obtaining the DC characteristics for $A_d = 20$ by sweeping the voltage from 1V to 1.2V, I observed abnormal behavior in the circuit. However, when the sweep was started from 2.5V, the circuit functioned as expected.

2. Calculating CMRR when $V_{in+} = V_{in-} = 1.5\text{v}$

- When $A_d = 3$.



- When $A_d = 20$.



Common mode gain:

$$V_{out} = 0.014 \text{ V}$$

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

$$A_{cm} = 14 \text{ mV}/1.5 \text{ V}$$

$$A_{cm} = 0.00934$$

CMRR :

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

$$\text{CMRR} = 3/0.00934$$

$$\text{CMRR} = 321.199$$

Common mode gain:

$$V_{out} = 0.0403 \text{ V}$$

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

$$A_{cm} = 40.3 \text{ mV}/1.5 \text{ V}$$

$$A_{cm} = 0.026867$$

CMRR :

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

$$\text{CMRR} = 20/0.026867$$

$$\text{CMRR} = 744.416$$

3. Frequency Response Analysis

To analyze the frequency dependence of the amplifier's differential gain, we set a fixed differential input voltage:

$$V_d = 0.5 \sin(2\pi ft) \text{ V} \quad (13)$$

where,

$$V_{in-} = 2.5 \text{ V}$$

$$V_{in+} = 0.5 \sin(2\pi ft) + 2.5 \text{ V}$$

The frequency f was varied from 1 kHz to the 5 kHz (maximum supported by ADALM 1000). The corresponding output voltage was recorded, and the differential gain A_d was calculated using:

$$A_d = \frac{V_{out}}{V_d} \quad (14)$$

The recorded data is presented in Table 3.

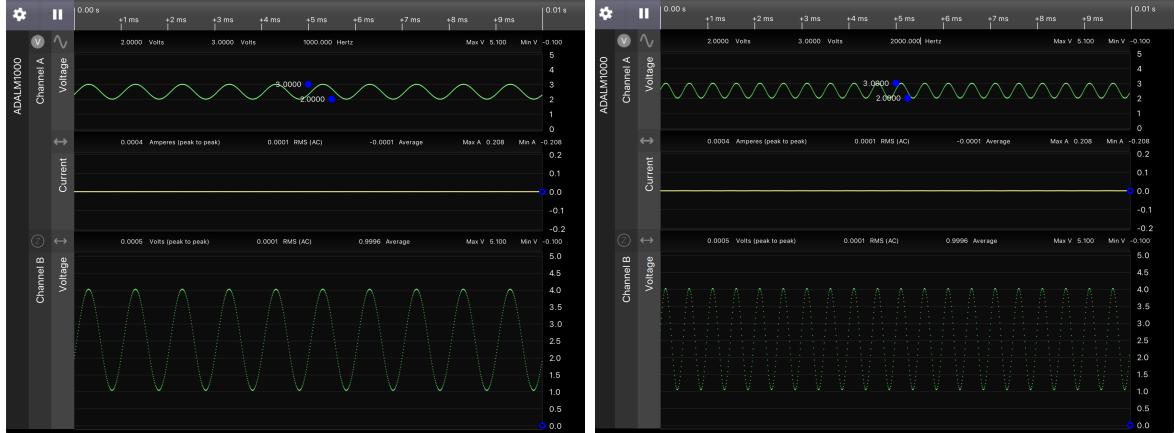
Frequency (kHz)	V_{out} (V) (Peak to peak)	A_d
1000	3	3
2000	3	3
3000	3	3
4000	3	3
5000	3	3

Table 3: Measured Output Voltage and Gain at Different Frequencies

Attaching some snapshots of the Pixel pulse software for the reference

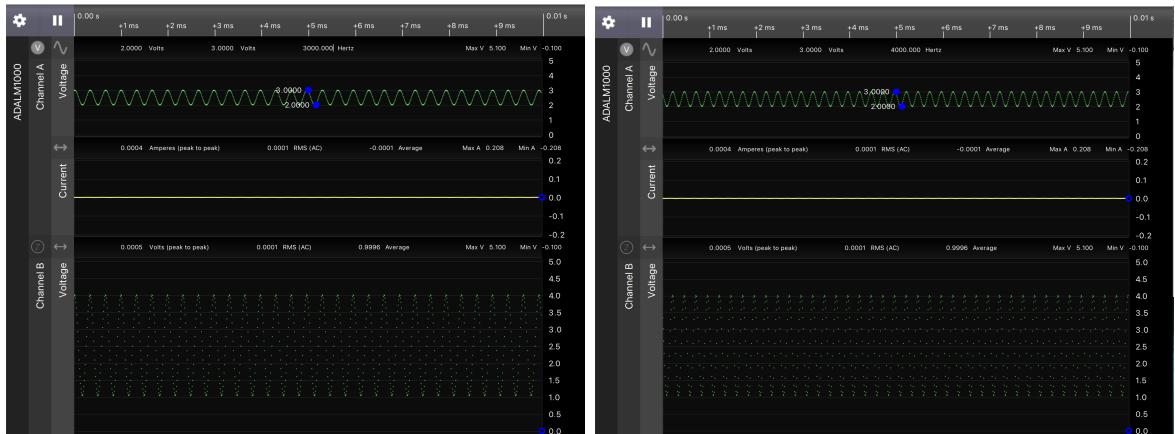
$$\begin{aligned} \text{Here } V_{in-} &= V_{ref} = 2.5 \text{ V} \\ V_{in+} &= 0.5 \sin(2\pi ft) + 2.5 \text{ V} \end{aligned}$$

From the results, we observe that gain remains almost constant with the change in frequency.



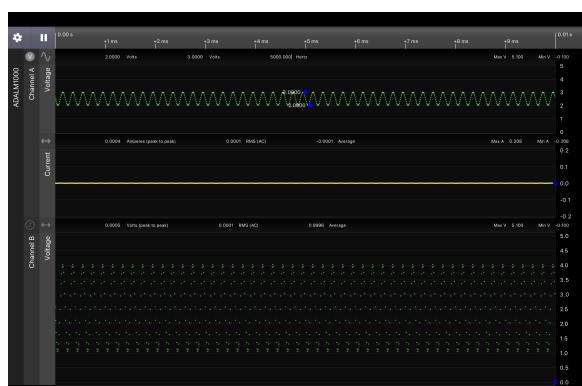
$F = 1000 \text{ Hz}$

$F = 2000 \text{ Hz}$



$F = 3000 \text{ Hz}$

$F = 4000 \text{ Hz}$



$F = 5000 \text{ Hz}$

Figure 2: Waveform outputs at different frequencies

Output Voltage Calculation for Given Inputs

The general equation for the output voltage of an instrumentation amplifier is:

$$V_{\text{out}} = \left(1 + \frac{2R}{R_G}\right) (V_{IN+} - V_{IN-}) + V_{\text{REF}} \quad (15)$$

Substituting Given Values

Given that:

$$V_{IN+} = 0, \quad V_{IN-} = 0, \quad V_{\text{REF}} = 2.5V$$

The differential input voltage is:

$$V_d = V_{IN+} - V_{IN-} = 0 - 0 = 0 \quad (16)$$

Substituting this into the equation:

$$V_{\text{out}} = \left(1 + \frac{2R}{R_G}\right) (0) + V_{\text{REF}} \quad (17)$$

$$V_{\text{out}} = V_{\text{REF}} \quad (18)$$

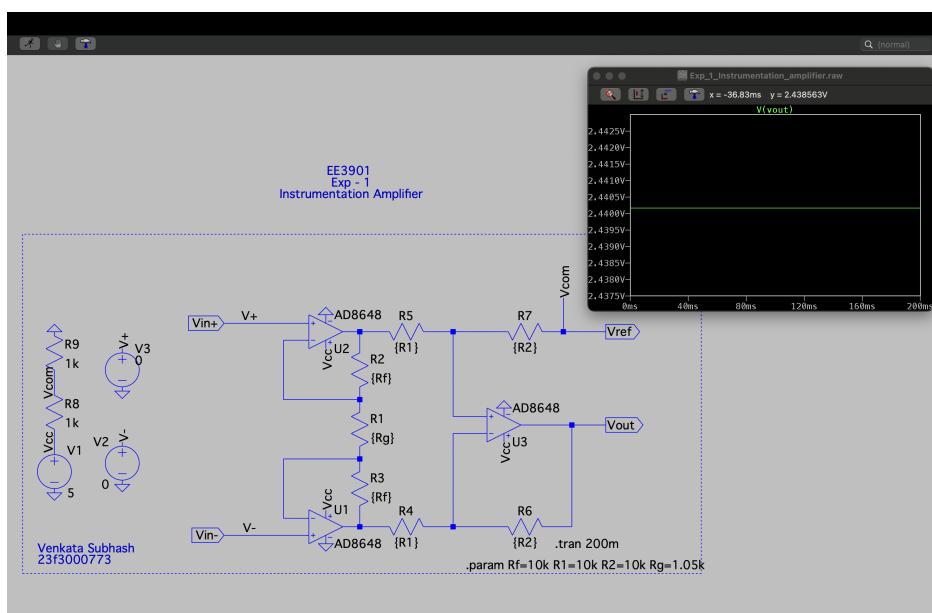
Final Output Voltage

$$V_{\text{out}} = 2.5V \quad (19)$$

Verification via Simulation and Experimentation

To confirm this result:

- Simulation:



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

- Experiment:



$$V_{out} = 2.435 \text{ V}$$

Observation: There is a slight deviation between the calculated value, i.e. $V_{out} = 2.5$ V and the actual value, i.e. $V_{out} = 2.435$ V which may be due to error in the measurement devices, stray capacitance.