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: - $R_F = R_1 = R_2 = R$ - $V_{\mathrm{REF}} = 0$

Step 1: Input Stage Gain

The output voltages of amplifiers A1 and A2 are:

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

$$V_{A1} = \ V_{in+} + \frac{R}{R_G} V_d \tag{1}$$

$$V_{A2} = \ V_{in-} - \frac{R}{R_G} V_d \tag{2}$$

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:

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

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

$$V_{\text{out}} = V_{A1} - V_{A2} \tag{4}$$

Substituting the values from Step 1:

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

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

$$V_{out} = V_d \ (1 + \frac{2R}{2Rg}) \tag{7}$$

Final Result

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

Thus, the instrumentation amplifier provides a differential gain of:

$$G = 1 + \frac{2R}{R_G} \tag{9}$$

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

Simulation (LTSpice)

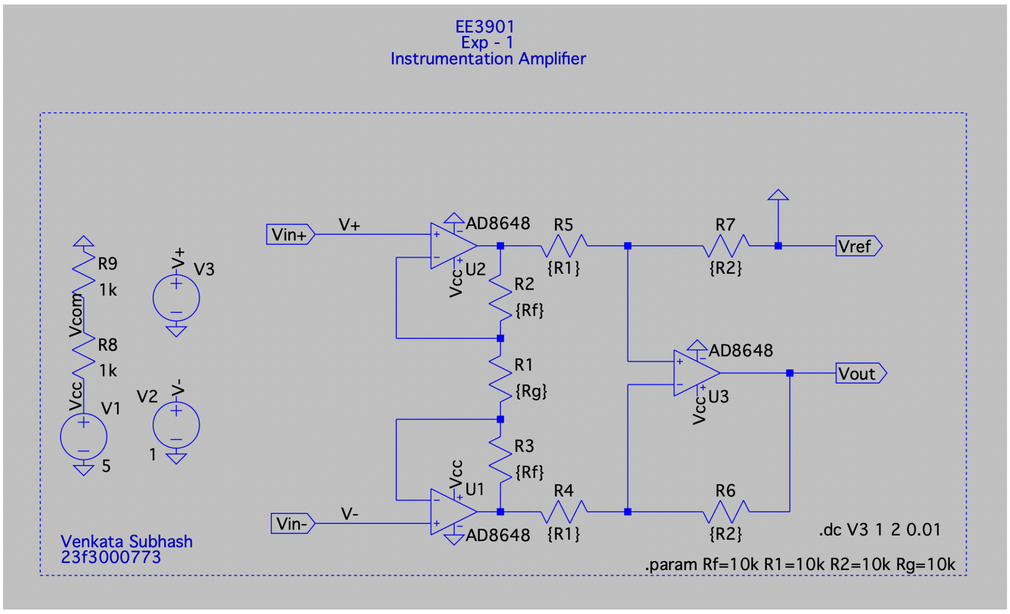
As Differential gain for our Instrumentation amplifier is

$$A_{\mathrm{d}} = \left(1 + \frac{2R}{R_G}\right) \tag{10}$$

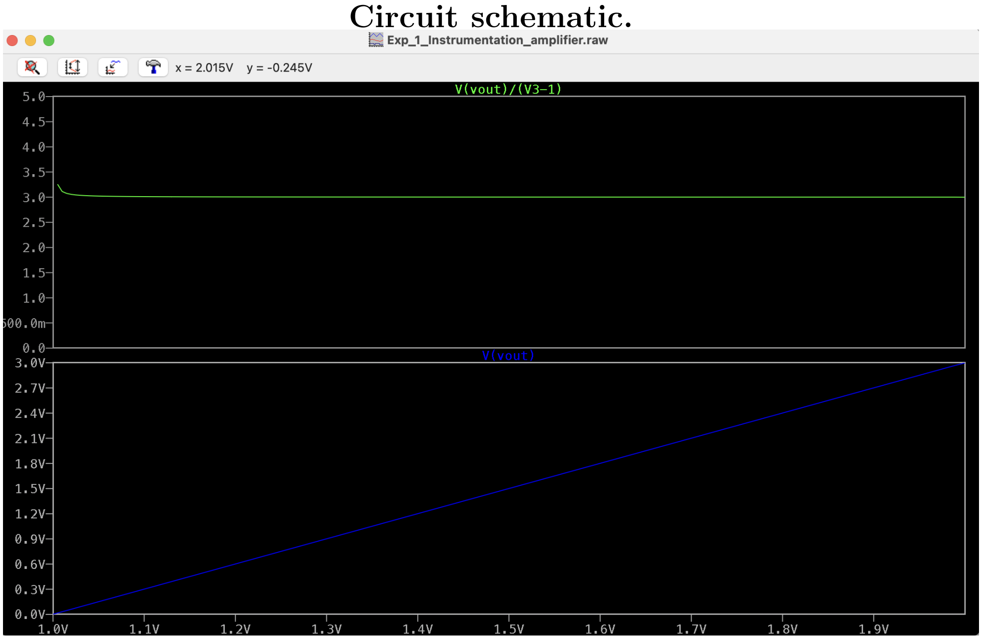
We will adjust R_g to get the desired A_d.

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.



Circuit schematic.

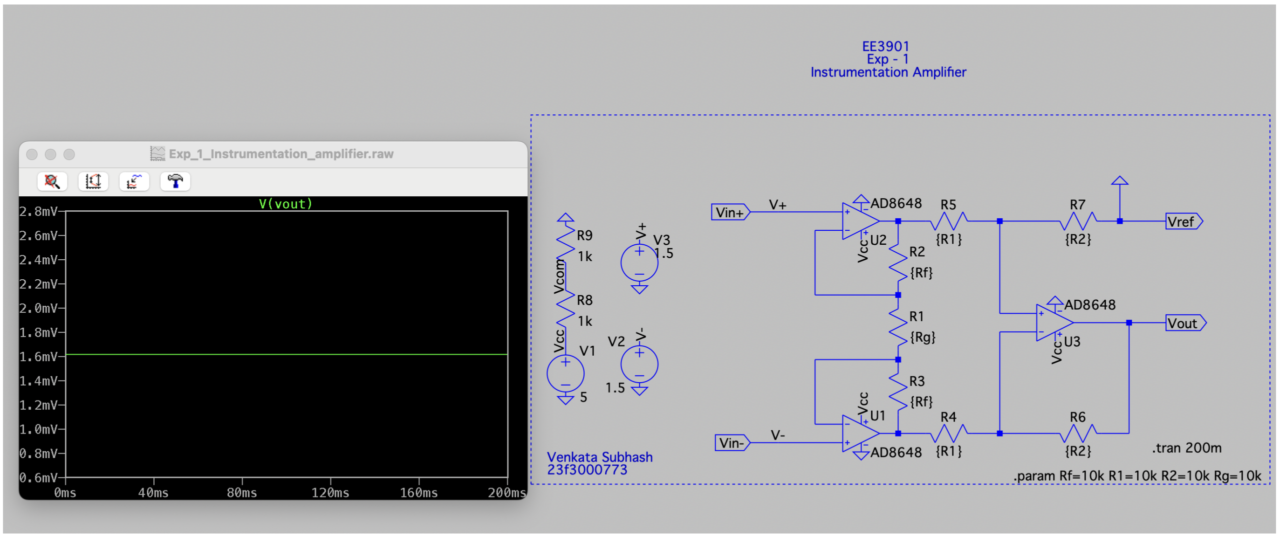


Charecteristics when DC Sweeping $V_{\text{in}+}$ form 1v to 2v when $V_{\text{in-}} = 1$v

Top (Green plot) : A_d vs $V_{\text{in}+}$

bottom (Blue plot) : V_out vs $V_{\text{in}+}$

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



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

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:

$$V_d = 0.5 \sin(2\pi f t) \text{ V} \tag{11}$$

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:

$$A_d = \frac{V_{\text{out}}}{V_d} \tag{12}$$

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

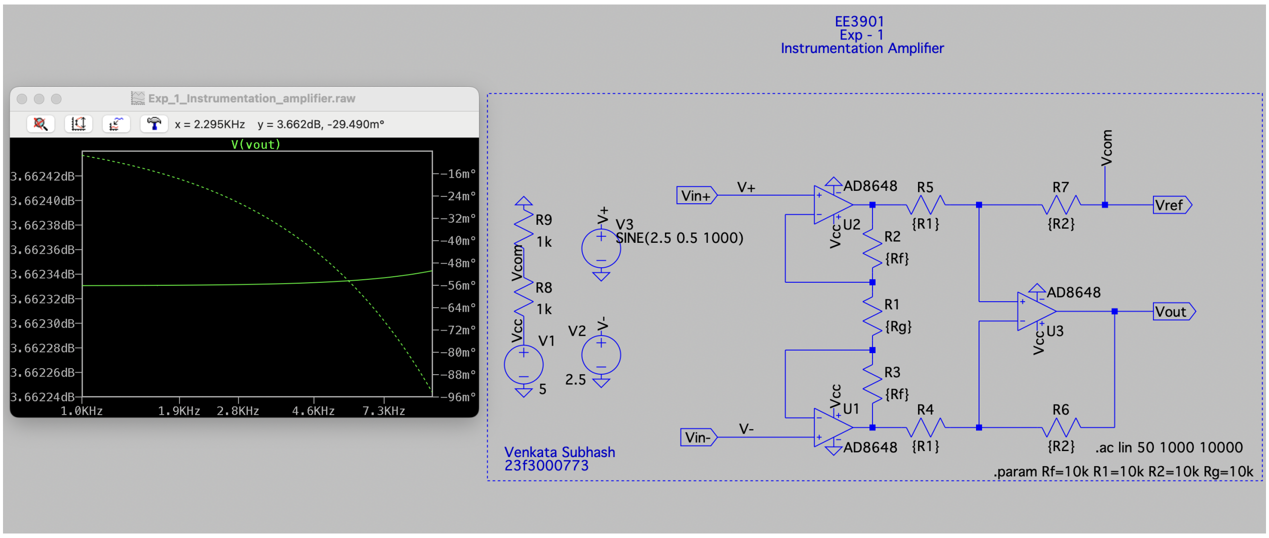
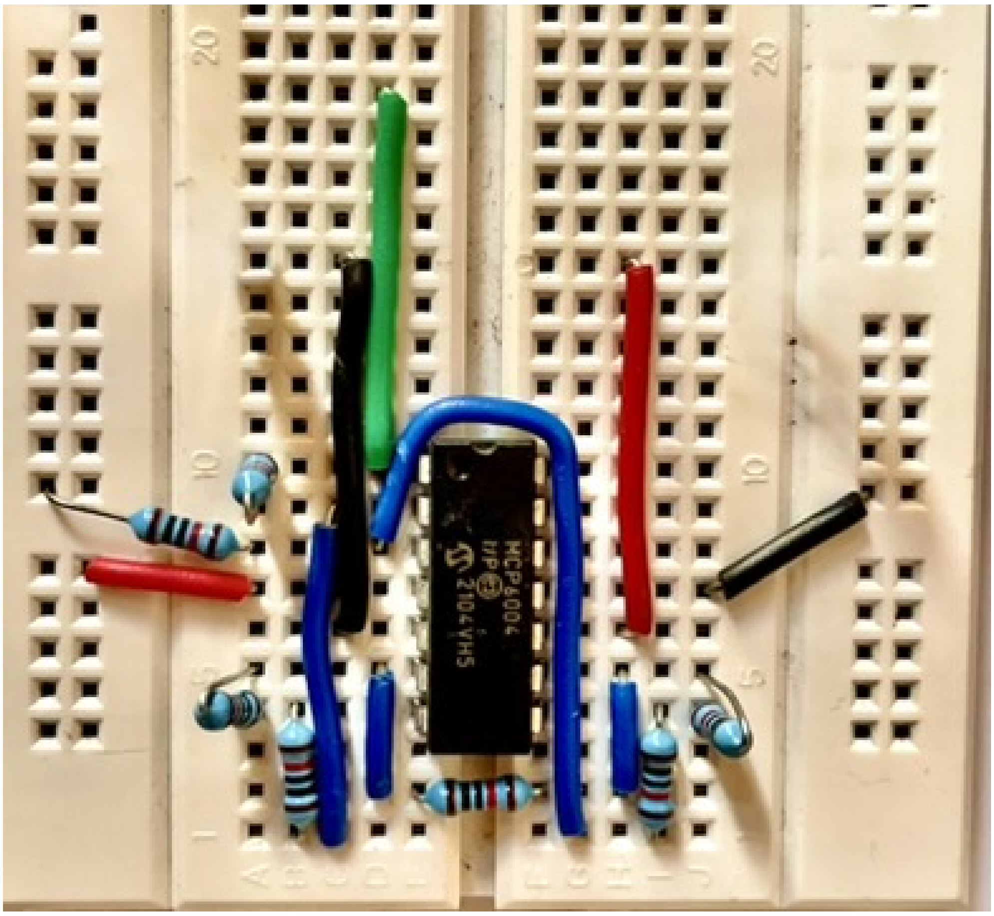


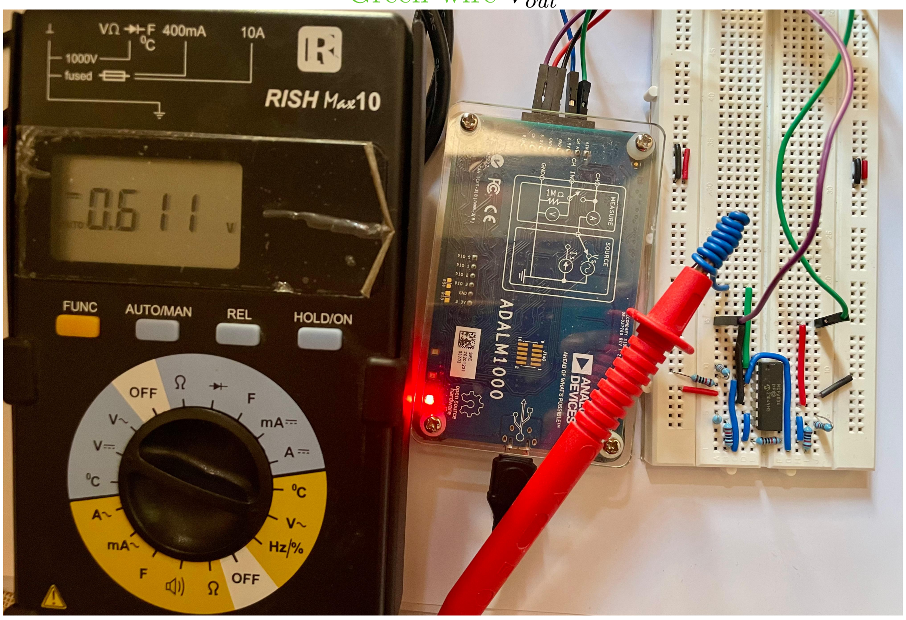
Figure 1: Plot of Gain vs. Frequency

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 Charecteristics

1. V_d = **3**

Set $R_g = 10$ **kOhms**

$V_{in-} = 1$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 $R_g = 1.05$ **kohms**

$V_{in-} = 2.5$ 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 $V_{in+} = V_{in-} = 1.5$v

1. When $A_d = 3$.

Common mode gain:

$V_{out} = 0.014$ V
$A_{cm} = V_{out}/V_{cm}$
$A_{cm} = 14$ mV1.5 V
$A_{cm} = 0.00934$

CMRR :

CMRR $= A_d/A_{cm}$
CMRR $= 3/0.00934$
CMRR $= 321.199$

2. When $A_d = 20$.

Common mode gain:

$V_{out} = 0.0403$ V
$A_{cm} = V_{out}/V_{cm}$
$A_{cm} = 40.3$ mV1.5 V
$A_{cm} = 0.026899$

CMRR :

CMRR $= A_d/A_{cm}$
CMRR $= 3/0.026899$
CMRR $= 111.66$

3. Frequency Response Analysis

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

$$V_d = 0.5 \sin(2\pi f t) \text{ V} \tag{13}$$

where,

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

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

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:

$$A_d = \frac{V_{\text{out}}}{V_d} \tag{14}$$

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

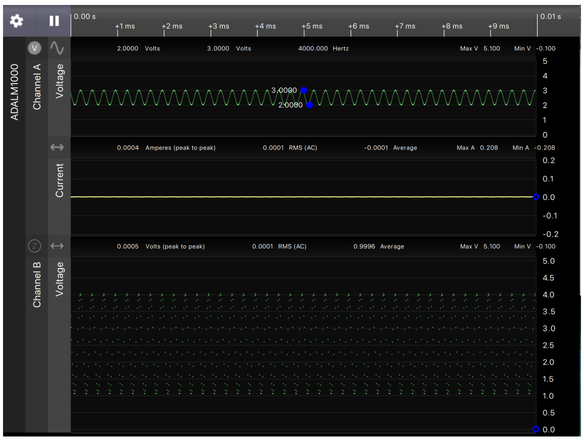
Here $V_{in-} = V_{ref} = 2.5$ V
$V_{\text{in}+} = 0.5 \sin(2\pi f t) + 2.5$ V

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

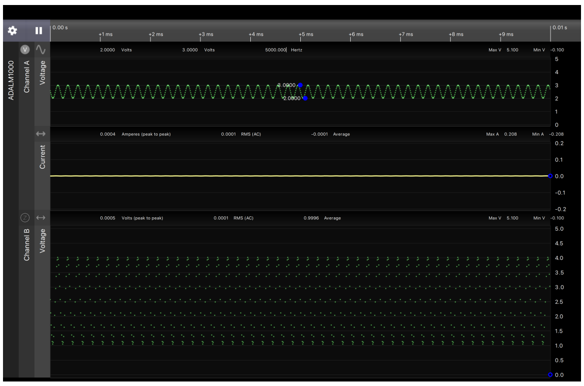
F = 1000 Hz

F = 2000 Hz

F = 3000 Hz



F = 4000 Hz



F = 5000 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:

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

Substituting Given Values

Given that:

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

The differential input voltage is:

$$V_d = V_{IN+} - V_{IN-} = 0 - 0 = 0 \tag{16}$$

Substituting this into the equation:

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

$$V_{\text{out}} = V_{\text{REF}} \tag{18}$$

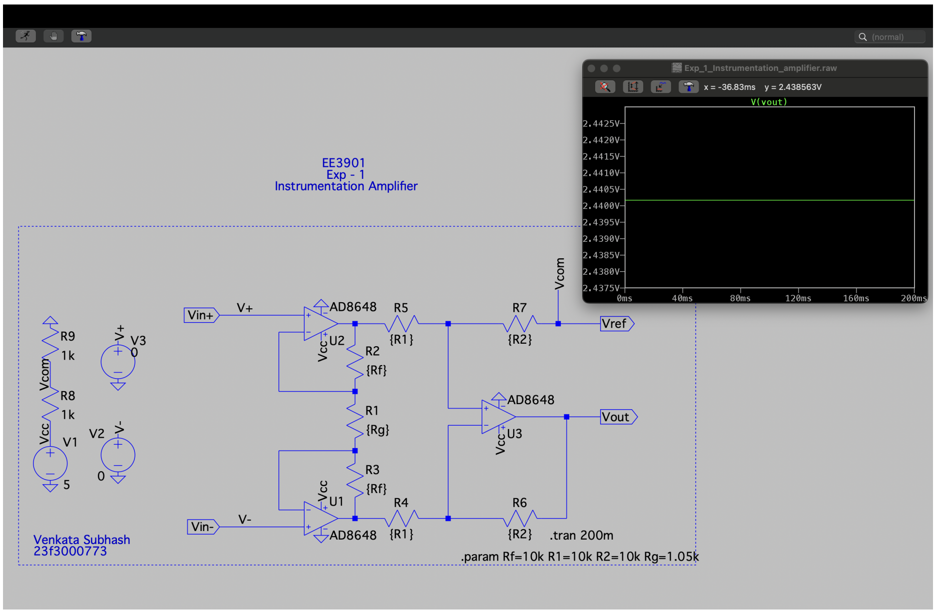
Final Output Voltage

$$V_{\text{out}} = 2.5V \tag{19}$$

Verification via Simulation and Experimentation

To confirm this result:

- **Simulation:**



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

- **Experiment:**

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

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.