Laboratory Report

Experiment 2: Analog Signal Conditioning

Programme: Mechatronics Engineering
Mechatronics Control and Automation Lab (MCTA 3104)
Section 2
Semester 1 2024/2025
Lecturer: Dr. Muhammad Afif Bin Husman
Prepared By: Syeda Samia (2123536) & Nur Ayu Naziera Binti Rosli (2119202) & Shareen Arawie Bin Hisham (2116943)
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Objectives

- To design and construct an inverting amplifier and a Wheatstone bridge with a differential amplifier.
- To simulate the circuits using Multisim and compare the results with experimental data.
- To analyse and comment on the similarities and discrepancies between experimental and simulated results.

Introduction

In modern mechatronics systems, analog signal conditioning is an essential step to ensure that signals from sensors or other components are appropriately processed for further analysis and control. This experiment focuses on designing, constructing, and analyzing two critical circuits: inverting and non-inverting amplifiers using operational amplifiers (op-amps) and a Wheatstone bridge integrated with a differential amplifier. These setups are fundamental in conditioning weak analog signals and enhancing their precision. The objectives of this lab are to understand the practical implementation of analog circuits, evaluate their performance, and compare experimental results with simulations performed in Multisim. This approach provides hands-on experience with theoretical principles and assesses the consistency between simulation and real-world behaviour. Additionally, factors like gain accuracy and the op-amp saturation, and are analyzed, which are pivotal for optimizing signal integrity in various engineering applications.

Equipment

- Multimeter
- Oscilloscope
- Function generator
- Digital multimeter
- ±15V DC power supply
- 741 Op-amp
- 78 kΩ resistor
- 49.4 kΩ resistor
- 15.7 kΩ resistor
- 31.4 kΩ resistor
- Jumper wires

Setup

Task 1: Inverting Amplifier

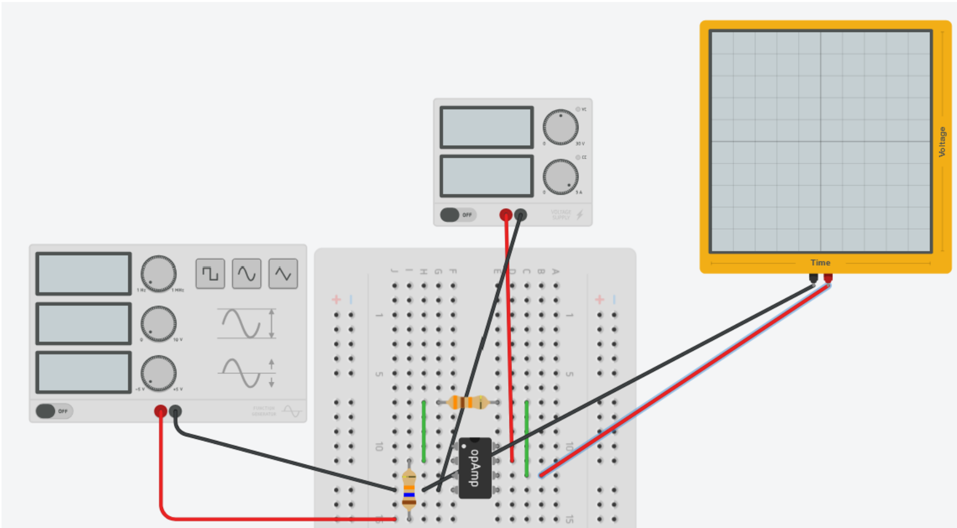


Figure 1: Inverting amplifier.

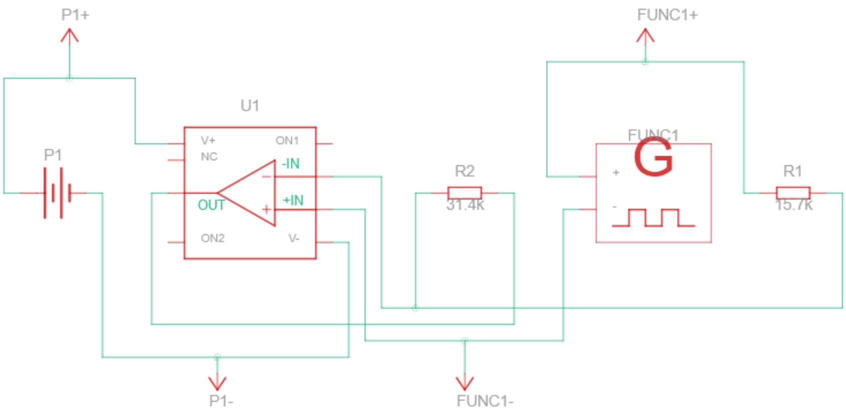


Figure 2: circuit diagram of an inverting amplifier.

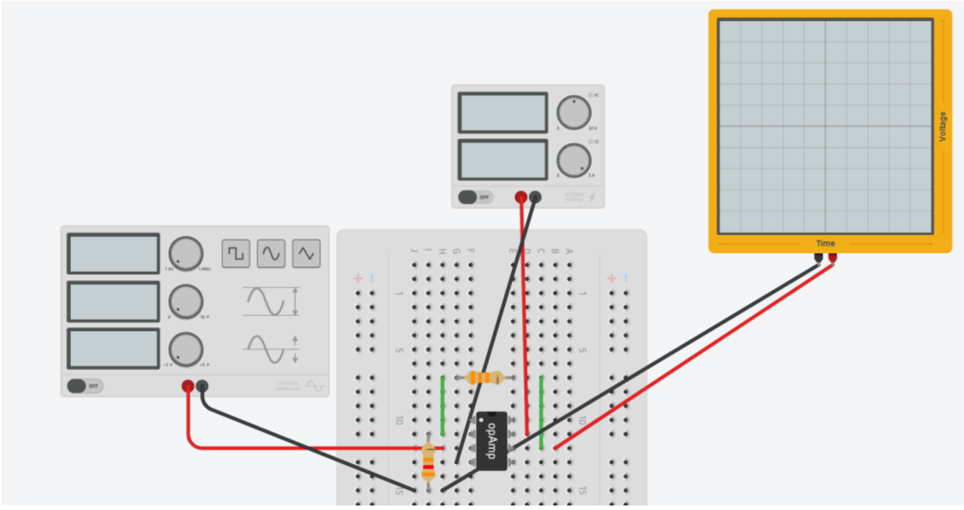


Figure 3: Non-inverting amplifier.

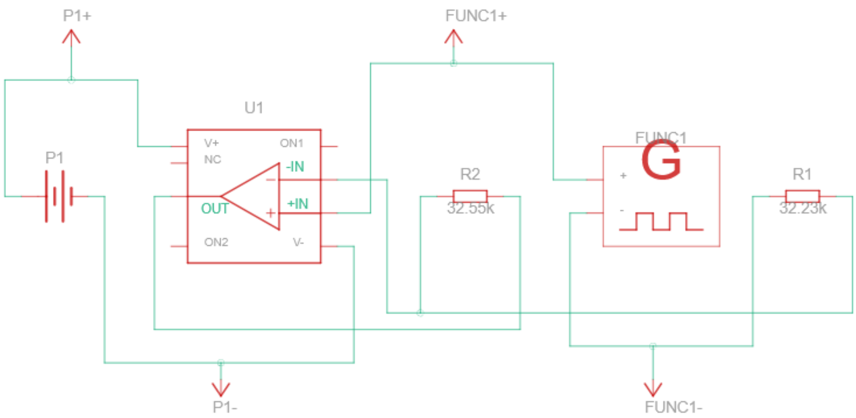


Figure 4: circuit diagram of a non-inverting amplifier.

Task 2: Wheatstone Bridge with Differential Amplifier

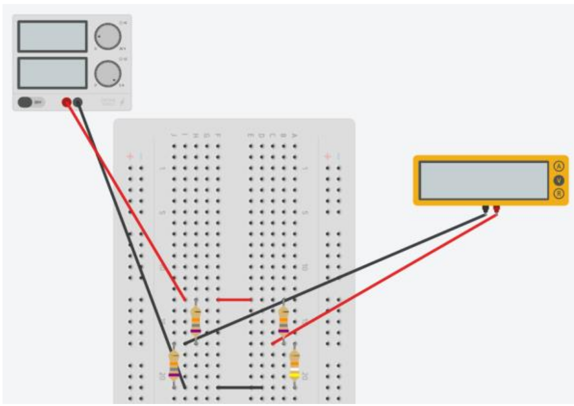


Figure 5: Setup of the Wheatstone bridge circuit.

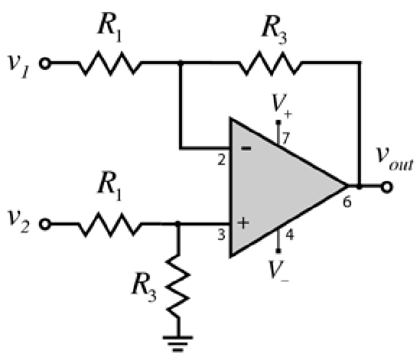


Figure 6: Differential amplifier.

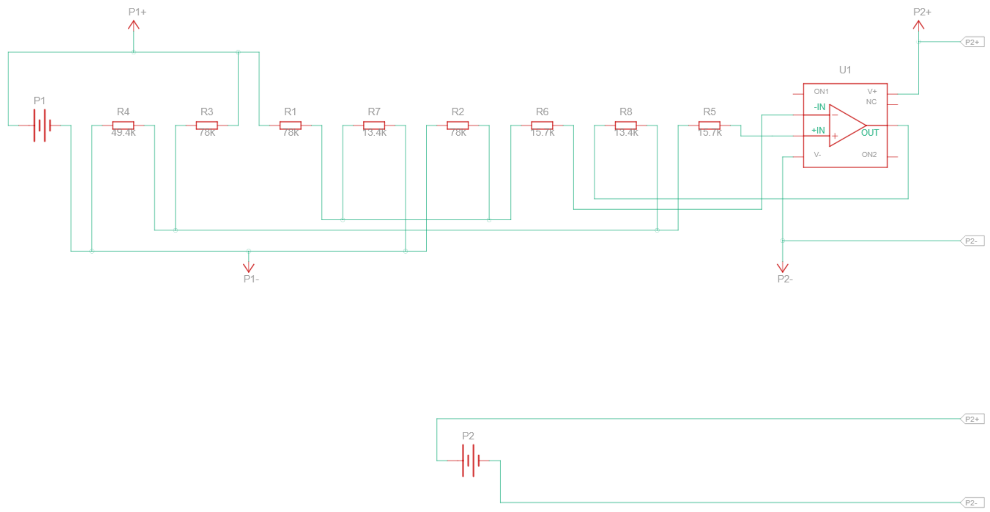


Figure 7: circuit of Wheatstone bridge connected a differential amplifier.

Experimental Procedure

Task 1: Inverting Amplifier

1. Design an op-amp inverting amplifier circuit with a gain of 2.
2. Construct the circuit using the appropriate components on a breadboard or simulation software.
3. Record the input and output waveforms using an oscilloscope.
4. Simulate the inverting amplifier circuit in Multisim.
5. Compare the waveforms obtained from the physical circuit and the Multisim simulation.
6. Comment on whether the experimental results match the simulation results and discuss any discrepancies.

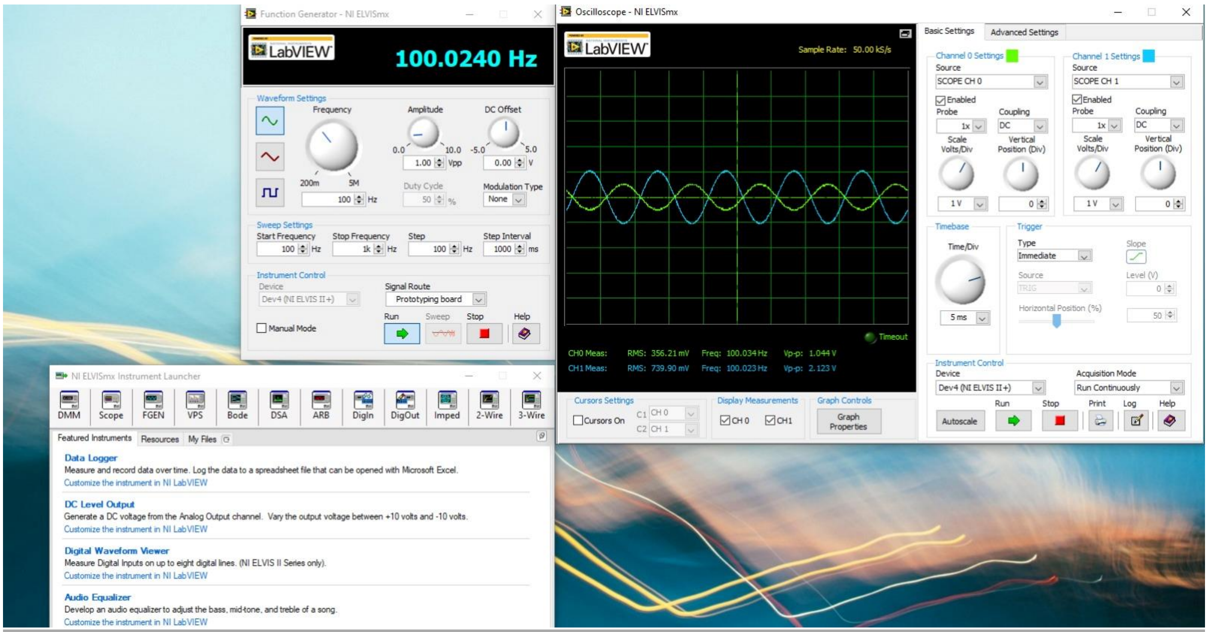
Task 2: Wheatstone Bridge with Differential Amplifier

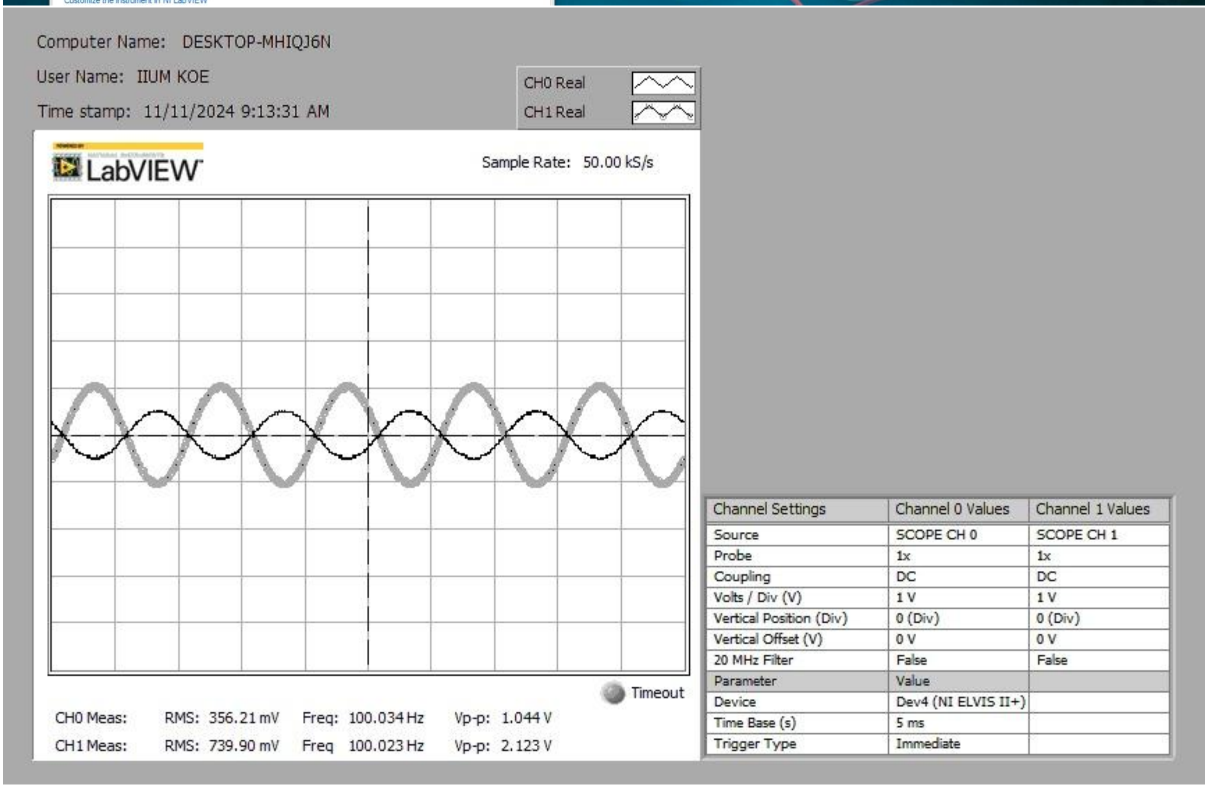
1. Design a standard Wheatstone bridge circuit.
2. Set the bridge to a balanced condition and verify it with theoretical calculations.
3. Add a differential amplifier to amplify the output of the Wheatstone bridge, ensuring a gain of 2 and taking into account potential op-amp saturation.
4. Determine the Common Mode Rejection Ratio (CMRR) of the instrumentation amplifier.
5. Simulate the Wheatstone bridge and differential amplifier circuits in Multisim.
6. Compare the experimental results with the simulated data and comment on any observations.

Results

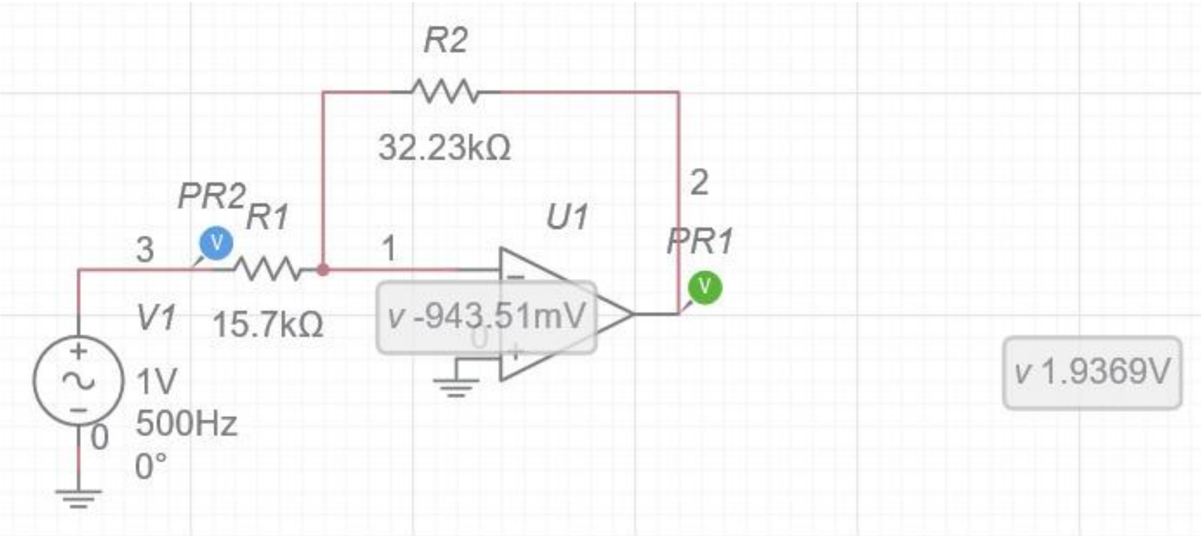
Task 1: Inverting Amplifier and non- inverting amplifier

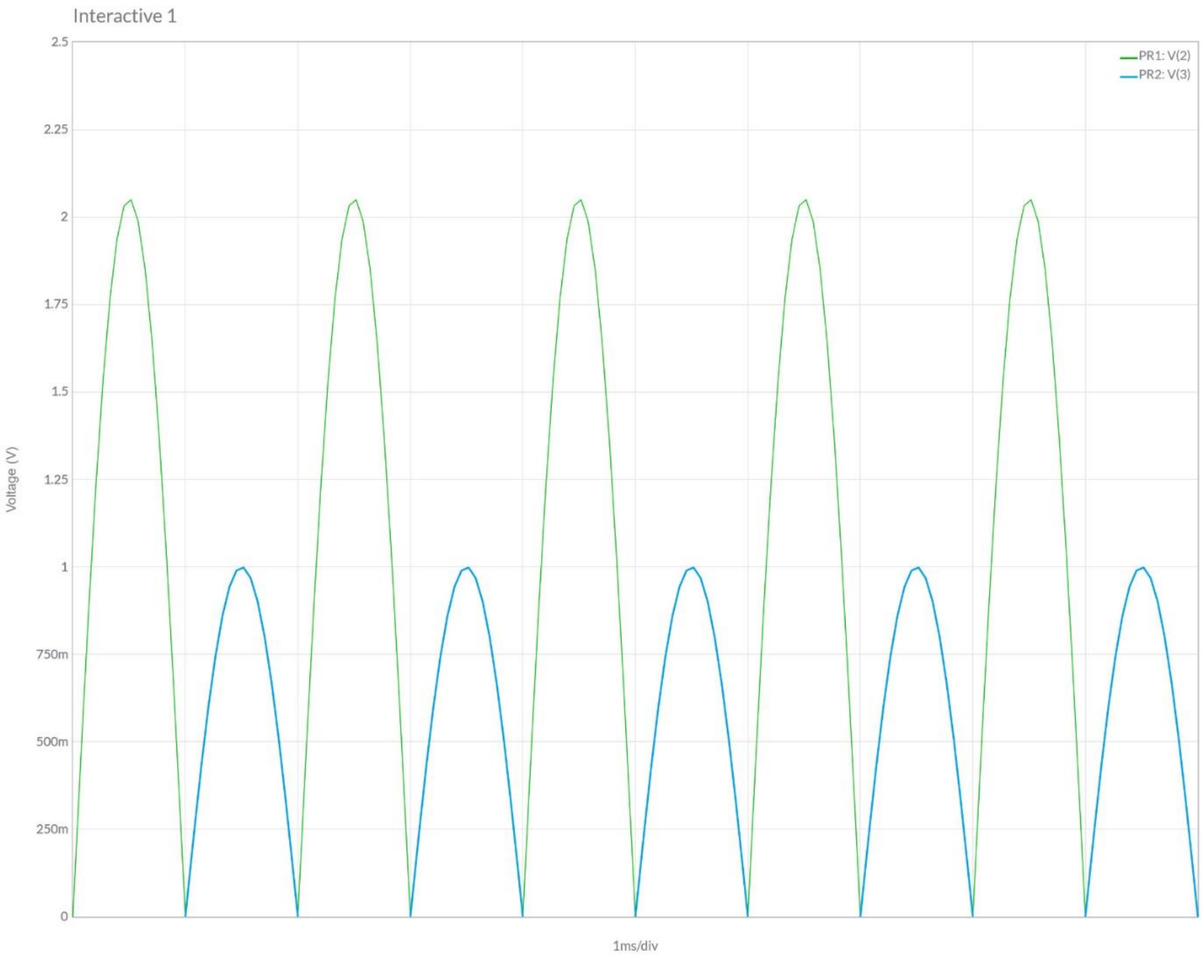
i. Inverting amplifier
   - Using elves



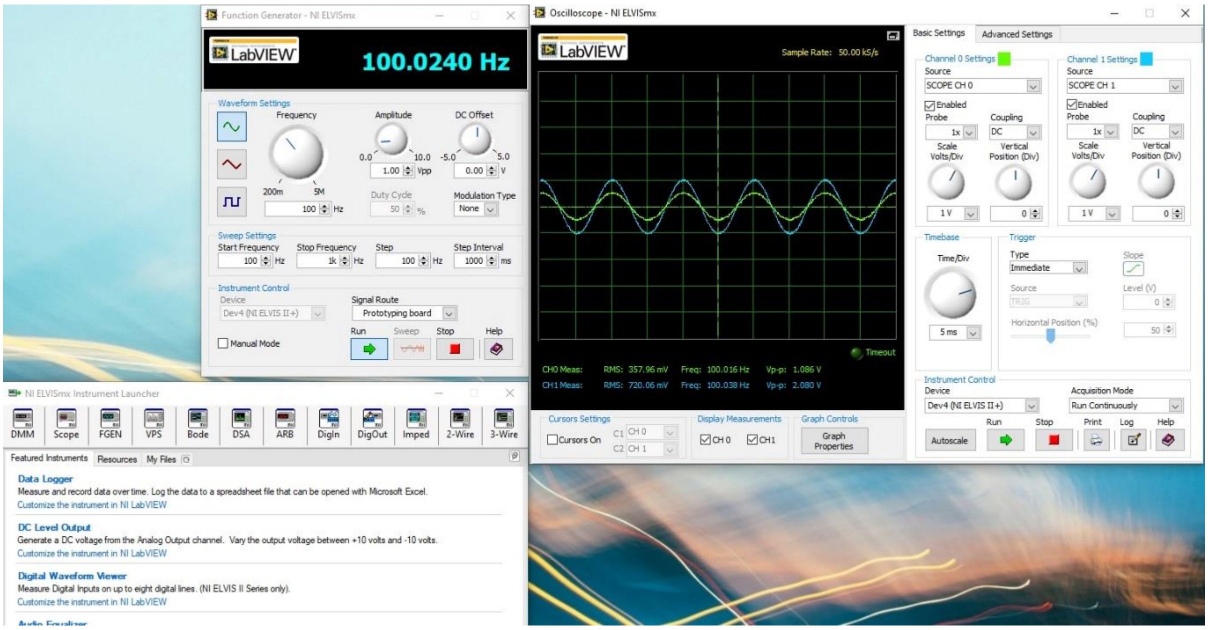


– Using Multism

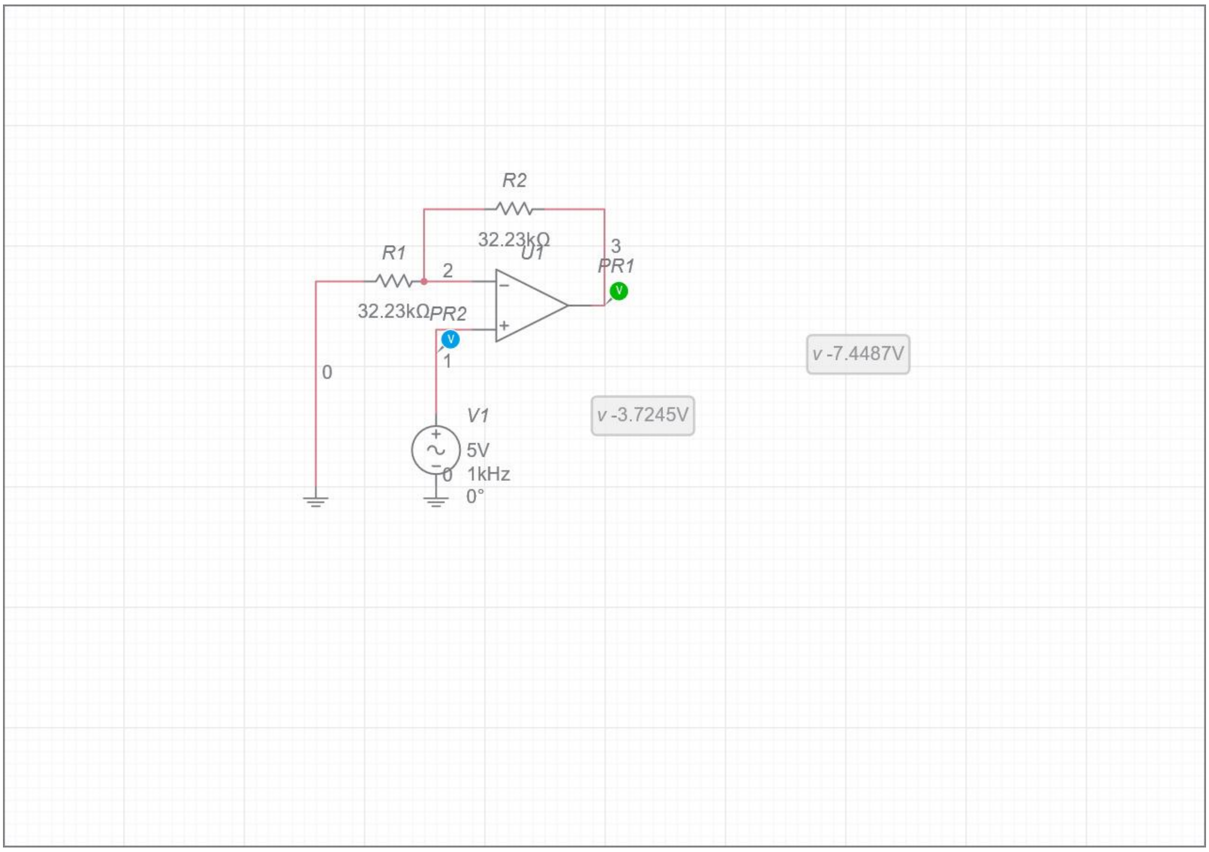




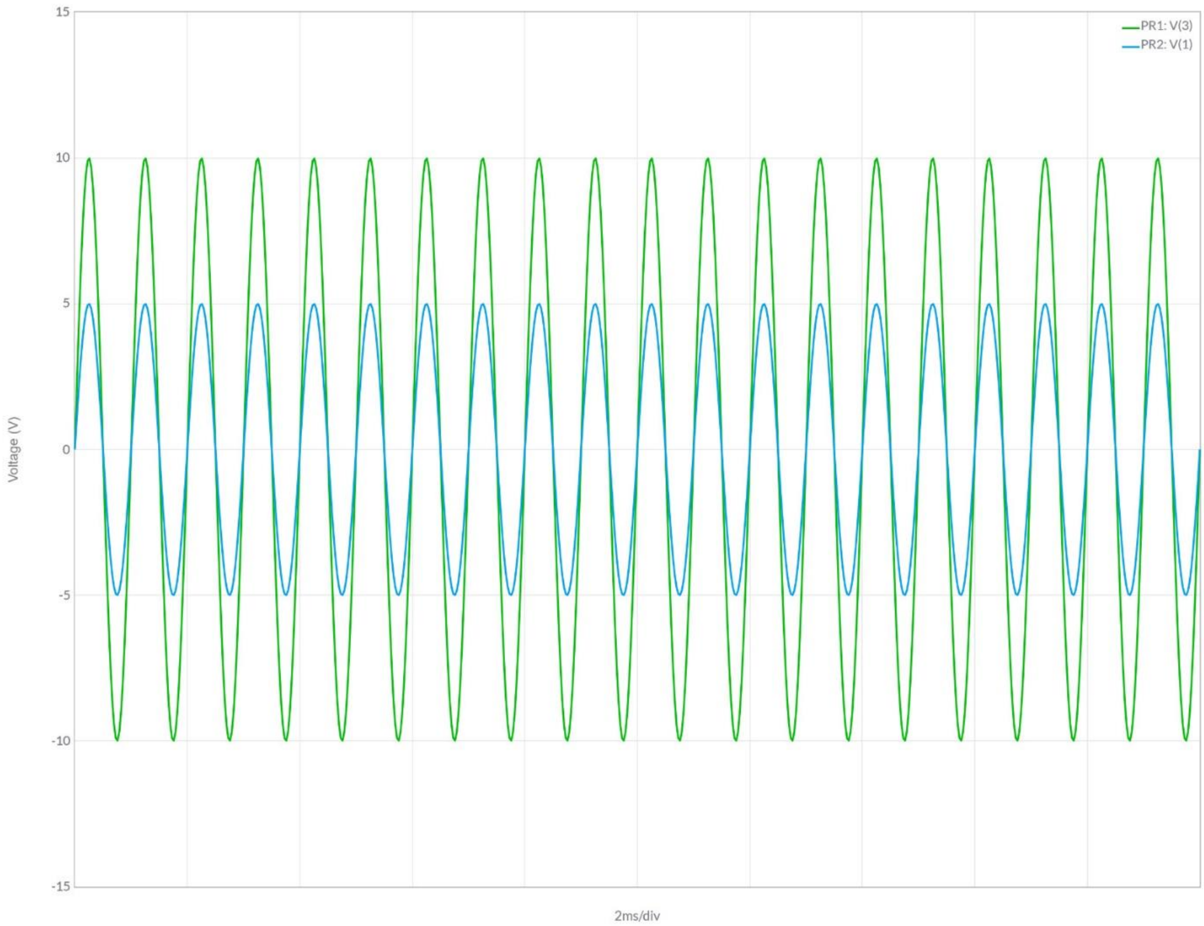
ii. Non – inverting amplifier
  - Using elves



– Using Multism



Interactive 1



Task 2: Wheatstone Bridge with Differential Amplifier

i. Design and construct a standard Wheatstone Bridge Circuit.
ii. Set the Wheatstone bridge in balanced condition. Verify with theoretical values.
iii. Add a differential amplifier to amplify the output of the Wheatstone Bridge with a gain of 2. Take into consideration the possible effects of op-amp saturation.

Wheatstone Bridge type	V_{out} (V)	V_{out} (V) with a differential amplifier of gain 2
Standard	0.66	1.7
Balanced	0	0.022

iv. Simulate the circuits in part i,ii and iii using Multisim.

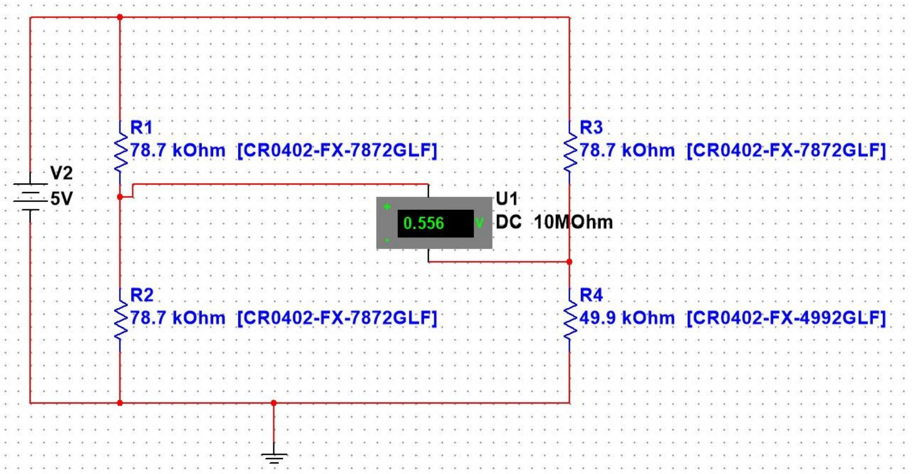


Figure 8: Multisim simulation of a standard Wheatstone Bridge circuit.

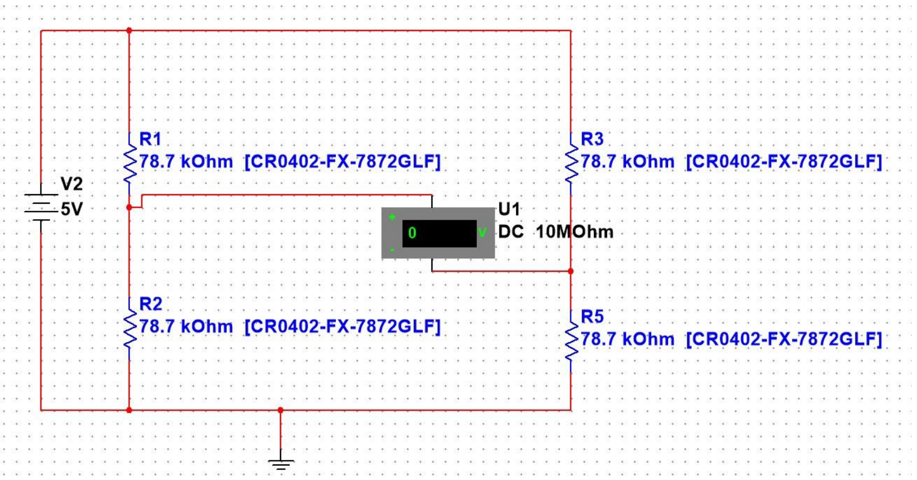


Figure 9: Multisim simulation of a balanced Wheatstone Bridge circuit.

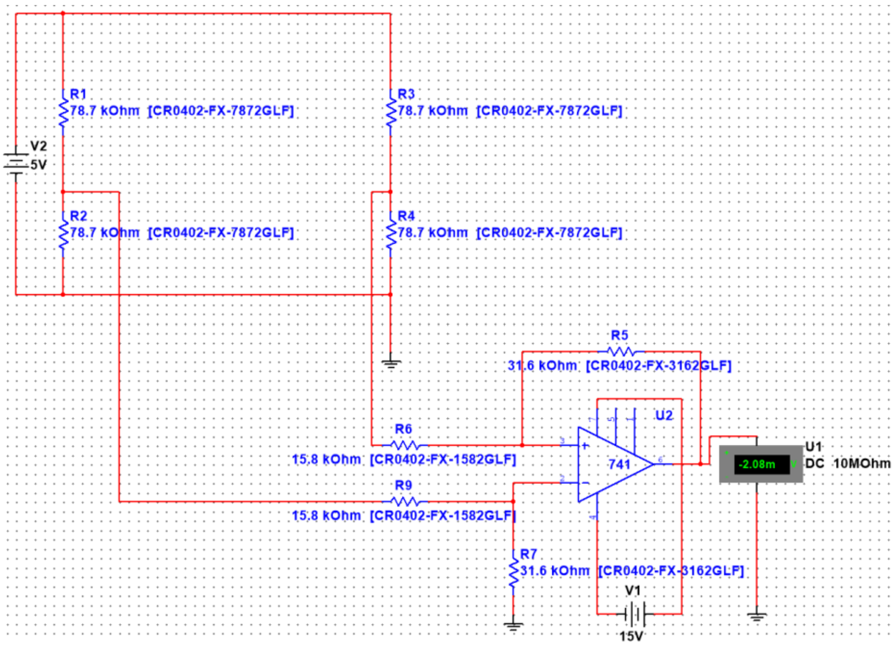


Figure 10: Multisim simulation of a balanced Wheatstone Bridge circuit with a deferential amplifier.

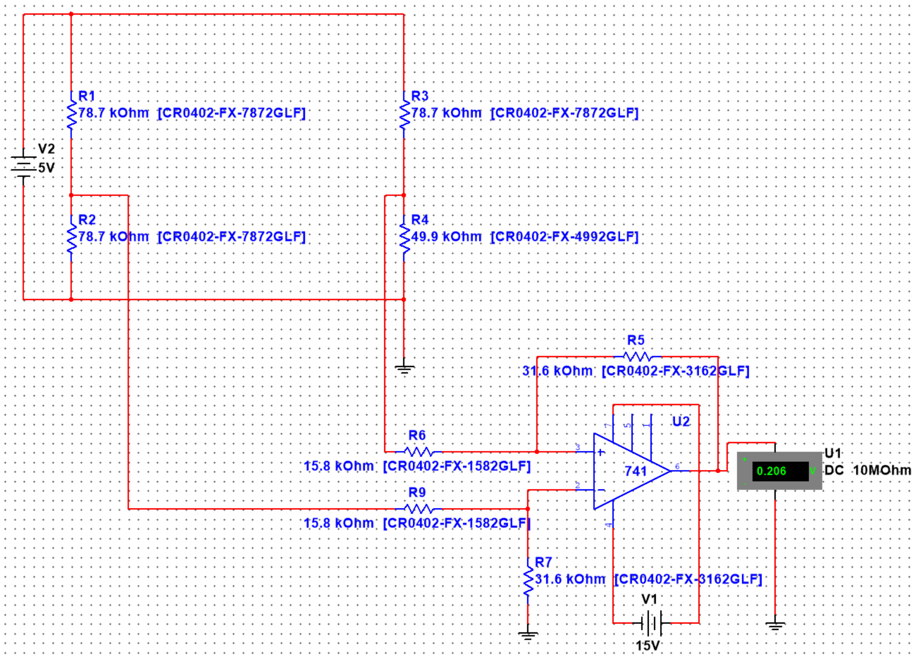


Figure 11: Multisim simulation of a standard Wheatstone Bridge circuit with a deferential amplifier.

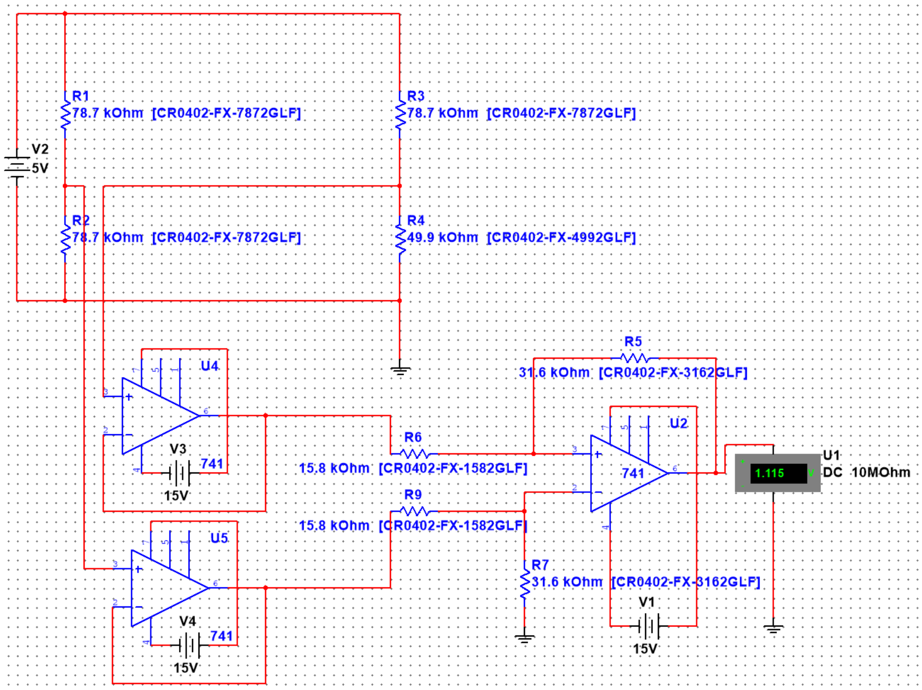


Figure 12: Multisim simulation of a standard Wheatstone Bridge circuit with a deferential amplifier and a buffer.

Discussions

Task 1: Inverting Amplifier

The inverting amplifier successfully achieved a gain of approximately -2, aligning with the theoretical formula G = - $\frac{Rf}{Rin}$. The output waveform inverted the phase of the input signal, as expected. However, slight deviations in gain may have occurred due to resistor tolerances, op-amp input offset voltage, or imperfections in the breadboard connections. The Multisim simulation closely matched the experimental results, affirming the accuracy of the circuit design. Minor differences observed between the two could be attributed to the idealized nature of simulations, which do not fully account for real-world op-amp limitations like finite bandwidth or slew rate.

Similarly, the non-inverting amplifier demonstrated a gain of G = 1 + $\frac{Rf}{Rin}$= 2, preserving the phase of the input signal as expected. The experimental waveform closely followed theoretical predictions, with slight discrepancies likely caused by power supply limitations or component inaccuracies. The Multisim simulations for the non-inverting amplifier were consistent with both theoretical and experimental results, showcasing the simulation's reliability in modeling such configurations. Real-world factors like parasitic capacitances and non-ideal op-amp behaviour contributed to minor differences between simulation and physical implementation.

In general, the experimental waveforms for both configurations were stable and aligned well with theoretical expectations, confirming the effectiveness of the circuit designs. The comparison between simulation and experimentation revealed the importance of accounting for non-idealities in practical circuits. Challenges such as resistor tolerances and op-amp limitations highlighted areas for improvement, such as using precision components. Overall, this task effectively demonstrated the operation of inverting and non-inverting amplifiers while validating theoretical and simulation models against experimental outcomes.

Task 2: Wheatstone Bridge with Differential Amplifier

In the lab, after adding a differential amplifier to the standard Wheatstone bridge, the output voltage increased from 0.66 V to 1.7 V. In theory the changed voltage should be double the original voltage since the amplifier has a gain of 2 meaning that the Wheatstone bridge's voltage should equal to 1.32 V. To measure the **percent error**, we use the formula below:

$$\delta = \left|\frac{v_A - v_E}{v_E}\right| \cdot 100\%$$

$\delta = percent\ error$

$v_A = actual\ value\ observed$

$v_E = expected\ value$

The error percentage for the output voltage of the standard Wheatstone bridge with a differential amplifier is $\delta = \left|\frac{1.7-1.32}{1.32}\right| \cdot 100\% = 28.78\%$. This error could be the result of many things including human error, random error, systematic error, the precision of the tool or the instrument used for measuring or environmental error such as wind, humidity, or temperature.

As for the balanced Wheatstone bridge, the output voltage before adding a differential amplifier was 0 V and after it became 0.022 V. A few reasons to why the circuit produces a measurable voltage after adding the amplifier is:

- Small mismatches in resistance or external factors like temperature can cause a tiny difference between the midpoints, and since a differential amplifier is designed to amplify, it amplifies the small difference making it detectable.
- An input offset voltage is a small inherent voltage difference between the inputs in a real-word differential amplifier. This offset voltage could be amplified and thus appears as an output.
- Differential amplifiers draw small input bias currents through their input terminals. These currents can interact with the resistances in the bridge and create a voltage difference, which is then amplified.

After simulating the experiment in Multisim, we can see a slight difference in the theoretical and practical values, to get a better look at the values side by side they were all combined in one table.

Wheatstone Bridge type	V_{out}(V)	V_{out}(V) with a differential amplifier	V_{out} (V) in Multisim	V_{out}(V) with a differential amplifier in Multisim	V_{out}(V) with a differential amplifier and amplifier in Multisim
Standard	0.66	1.7	0.556	0.206	1.115
Balanced	0	0.022	0	0.00208	NA

The percent error of the output voltage of the standard Wheatstone bridge is $\delta = \left|\frac{0.66-0.556}{0.556}\right| \cdot 100\% = 18.7\%$. This can be the result of environmental factors like humidity and temperature and/or human errors. Furthermore, when trying to get the output voltage of the Wheatstone bridge with a differential amplifier in Multisim, we got 0.206 V which is far from the expected value and that is because the two circuit have different impedances causing the second circuit to excessively load the first circuit. To solve this issue, we added a buffer between the two circuits thus allowing the output voltage to be 1.115 V. Since the output voltage of Wheatstone bridge in the simulation is 0.556 V its voltage after adding the differential amplifier should be 1.112 V. The percent error for this output voltage is $\delta = \left|\frac{1.115-1.112}{1.112}\right| \cdot 100\% = 0.27\%$. This tiny error can be due to the input offset value that the differential amplifier has. This voltage is added to the differential signal and amplified, resulting in a larger-than-expected output voltage.

The simulation is better at producing accurate output voltages, which is why the output voltage of the Wheatstone bridge circuit with a differential amplifier in Multisim is much lower than the one done in the laboratory. Lesser factors would affect a circuit in a simulation opposite to what happens in real-life experiments. However, that doesn't mean that the simulation is perfect either, as seen the output voltage is 0.00208 V and this could be because of the input offset value that we mentioned for the standard Wheatstone bridge done in Multisim.

Conclusion

The experiment successfully demonstrated the design, construction, and analysis of an inverting amplifier and a Wheatstone bridge with a differential amplifier. For the inverting amplifier, the experimental results closely aligned with theoretical predictions, achieving the expected gain of -2. Minor discrepancies were attributed to real-world factors such as resistor tolerances and op-amp limitations. Similarly, the Wheatstone bridge with a differential amplifier displayed an expected gain of 2, though deviations in experimental results highlighted factors like op-amp input offset voltage, environmental conditions, and measurement errors.

The use of Multisim simulations provided an invaluable tool for comparing theoretical and experimental results, showcasing its reliability in ideal circuit modelling while underscoring the impact of non-dualities in practical implementations. The addition of a buffer to address impedance mismatches in the Wheatstone bridge circuit further improved simulation accuracy, achieving minimal error rates.

References

Understanding Buffer Amplifier Operating Principle, Advantages and Applications. (n.d.). Components101. https://components101.com/articles/understanding-buffer-amplifier-operating-principle-advantages-and-applications

Harris, M. (2020, September 15). *An Introduction to Wheatstone Bridges*. Altium. https://resources.altium.com/p/wheatstone-bridges

Appendices

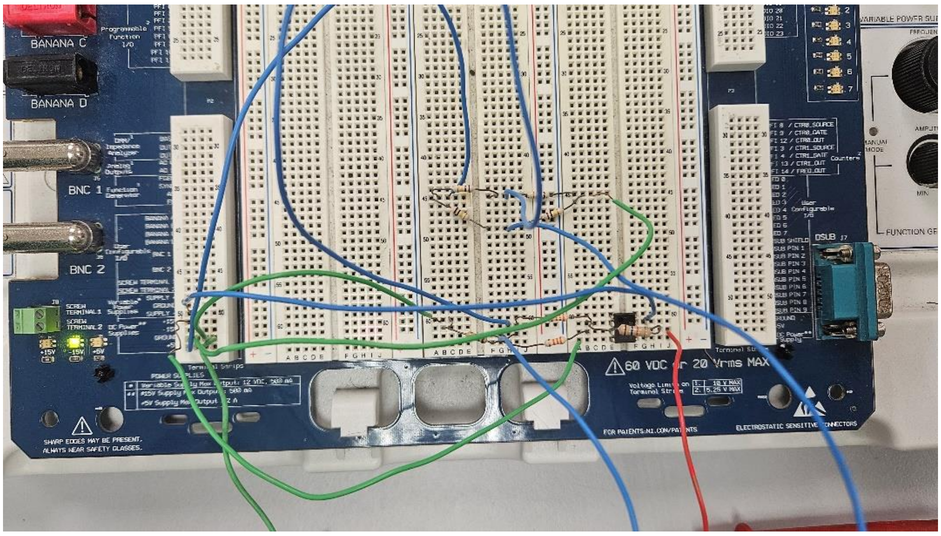


Figure 13: Balanced Wheatstone bridge with a differential amplifier.

Figure 14: Output voltage of a balanced Wheatstone bridge with a differential amplifier.

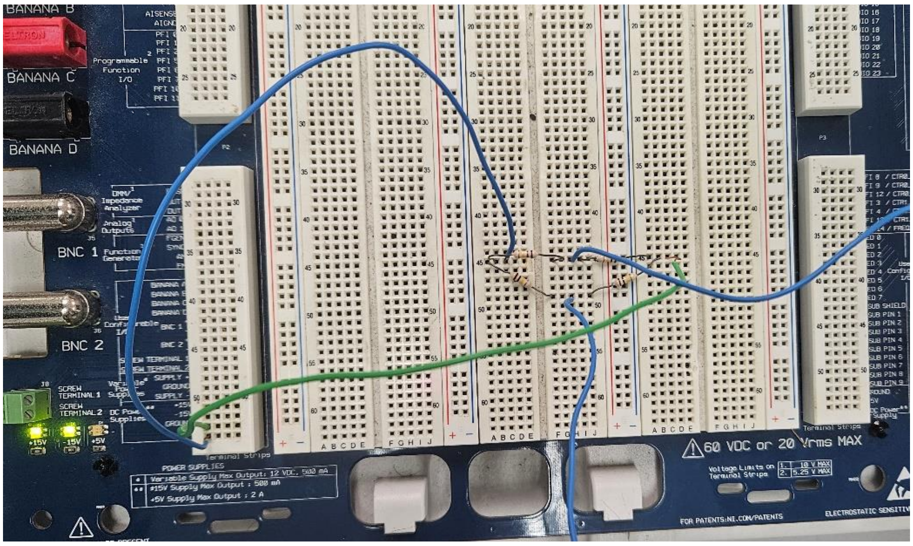


Figure 15: A balanced Wheatstone bridge circuit.

Figure 16:Output voltage of a balanced Wheatstone bridge circuit.

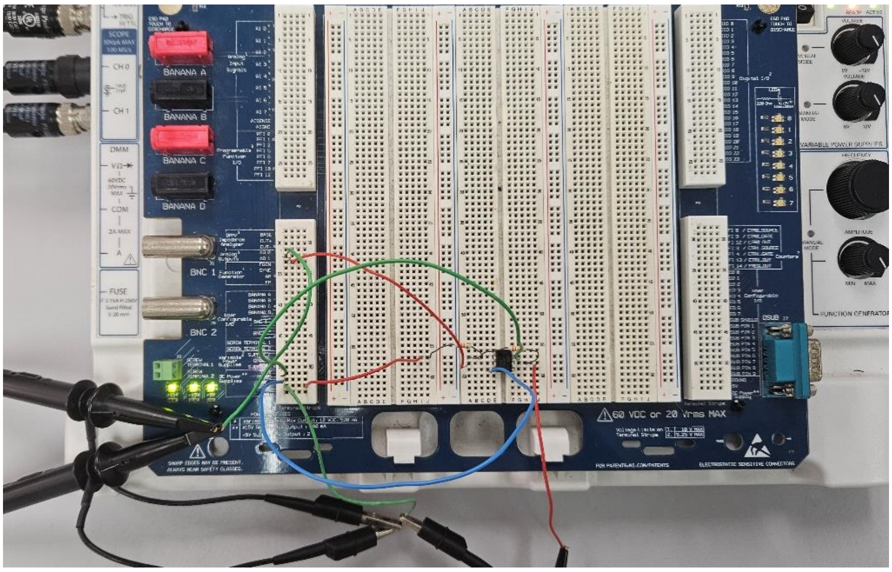


Figure 17: Inverting amplifier circuit.