Lab Documentation Template

Group 2, Team 7

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Date: 02/11/2024

Task 1: Application

Preparation

Objective:

- To analyze the circuit and derive the mathematical relationships governing the differential amplifier's operation.
- To compute the expected output voltage range for the temperature range of the PT100 sensor.
- To determine the required differential amplification A_D to match the ADC input range.

Theory Summary:

Differential Amplifier for PT100-Based Temperature Measurement

The task involves designing a differential amplifier circuit as part of a temperature measurement system using a PT100 sensor. Below is a concise summary of the theoretical principles:

1. PT100 Sensor and Resistance Variation

- The PT100 is a platinum-based temperature sensor whose resistance varies linearly with temperature.
- Resistance R_{eq} increases with temperature:

Req=110 Ω at 25∘C, Req=117.5 Ω at 45∘C

2. Wheatstone Bridge

- The Wheatstone bridge converts the temperature-dependent resistance R_{eq} into a differential voltage V_{diff}.
- General formula for V_{diff}:

$$V_{\text{diff}} = V_s \cdot \left(\frac{R_2}{R_1 + R_2} - \frac{R_{\text{eq}}}{R_{\text{eq}} + R_4} \right)$$

- For a balanced bridge with R1 = R2 = R3 = R4 = 110 Ω

$$V_{\text{diff}} = V_s \cdot \left(\frac{1}{2} - \frac{R_{\text{eq}}}{R_{\text{eq}} + 110} \right)$$

3. Differential Amplifier

- The differential amplifier amplifies V_{diff} to match the ADC's input range.
- The transfer function of the differential amplifier:

$$V_{\text{out}} = A_D \cdot V_{\text{diff}}$$

where *A_D* is the differential gain.

4. Amplifier Design Requirements

- **Input Range:** V_{diff} varies from 0V to −48mV.
- **Output Range:** The ADC requires a differential input range of ±1 V.
- **Gain Calculation:**

$$A_D = \frac{\text{Output Range}}{\text{Input Range}} = \frac{1}{0.048} = 20.83$$

5. Transfer Function

The final transfer function of the system is:

$$V_{\text{out}} = A_D \cdot V_s \cdot \left(\frac{1}{2} - \frac{R_{\text{eq}}}{R_{\text{eq}} + 110}\right)$$

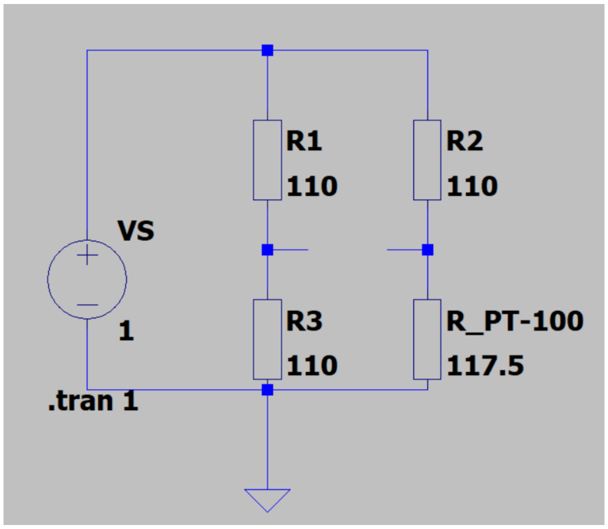
where:

- *V_s* = 3V is the supply voltage,
- *A_D* = 20.83 is the required gain

6. Practical Implications

- The circuit is designed to amplify small changes in V_{diff} caused by temperature variations of the PT100 sensor.
- This ensures the output V_{out} is within the ADC's readable range, allowing precise digital temperature measurements.

Circuit Setup:



Circuit Description:

The circuit is a **Wheatstone Bridge** powered by a 1V DC source, designed to measure temperature using a PT100 sensor. Fixed resistors R1,R2,R3 (110 Ω) form three arms of the bridge, while the PT100 (R_{PT-100}) serves as the fourth, with resistance varying from 110 Ω to 117.5 Ω117.5 based on temperature. This resistance change creates a differential voltage output proportional to temperature, which is fed to a differential amplifier for further processing.

Data Import

Purpose:

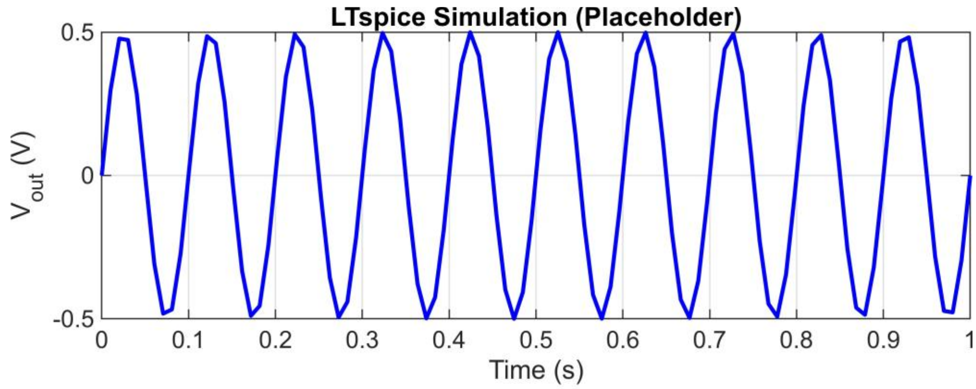
Import data from the LTspice simulation or manually recorded data.

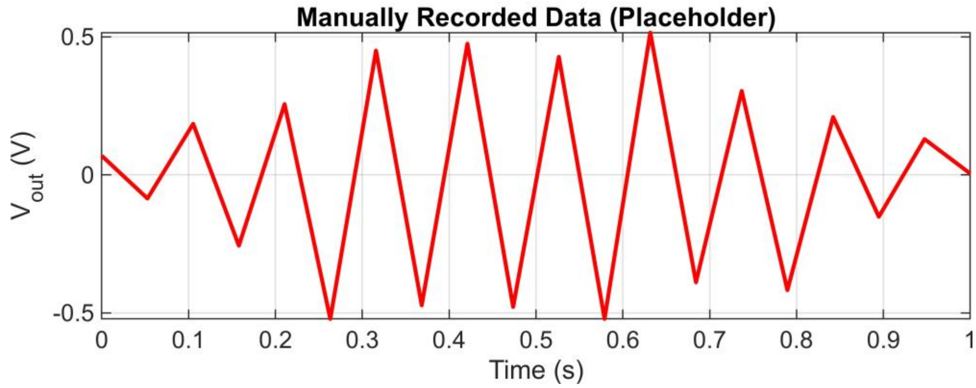
```
Placeholder LTspice Data:
```

Time	V_out
0	0
0.010101	0.29645
0.020202	0.47745
0.030303	0.4725
0.040404	0.28353
0.050505	-0.015864
0.060606	-0.30908
0.070707	-0.48192

```
Placeholder Manually Recorded Data:
```

Time	V_out
0	0.069225
0.052632	-0.085434
0.10526	0.1848
0.15789	-0.25614
0.21053	0.25608
0.26316	-0.52151
0.31579	0.4499
0.36842	-0.47222





The code above creates placeholder data for V{GS} and ID. Replace this with real data when available.

Data Processing

Purpose:

The purpose of this experiment is to analyze the output of a differential amplifier using a PT100 sensor, evaluating how the temperature-dependent resistance affects the output voltage. The goal is to ensure the amplifier produces an output compatible with the ADC input range.

Theoretical Calculation Setup:

Differential Amplifier Transfer Function: The output voltage of a differential amplifier is defined as:

$$V_{\text{out}} = A_D \cdot (V_{\text{in+}} - V_{\text{in-}})$$

where:

- A_D is the differential gain,
- Vin+ and Vin- are the input voltages derived from the Wheatstone bridge.

Input Signals:

- The PT100 sensor varies its resistance R_{PT100} based on the temperature. For the given temperature range T=25∘C to 45∘C, the resistance varies from R_min=110 Ω to R_max=117.5 Ω.
- The Wheatstone bridge outputs two voltages, V_in+ and Vin-, which are functions of RPT100.

Output Voltage Range:

- The amplifier output V_{out} is required to match the ADC input range (V_{ADC} = 1).
- The required gain A_D is calculated as:

$$A_D = \frac{V_{\text{out, max}} - V_{\text{out, min}}}{V_{\text{in+}} - V_{\text{in-}}}$$

Simulation and Data Processing:

- Simulate V_{out} based on theoretical calculations for the given resistance range.
- Process experimental data (imported or placeholder) to verify the theoretical predictions.

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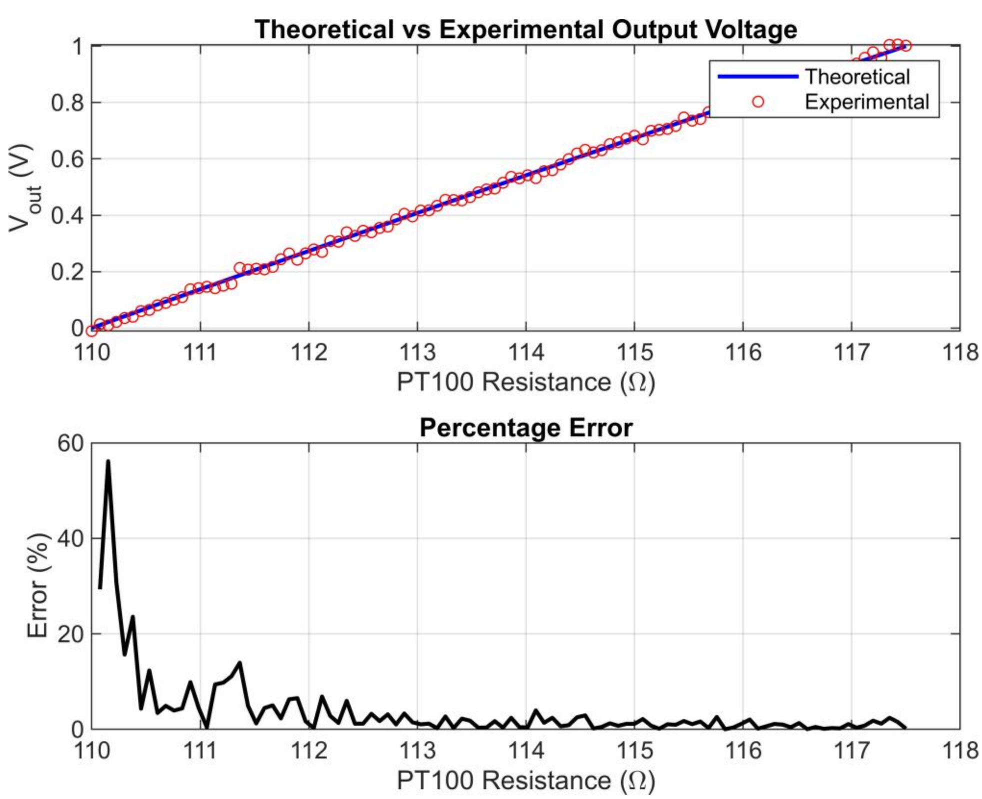
Visualization

Purpose:

To graphically represent the relationship between the PT100 sensor's resistance, the differential amplifier's output voltage, and any discrepancies between theoretical and experimental results. This helps validate the circuit's performance and ensure compatibility with the ADC input range..




```
Differential Gain (A_D):

   20.2222

Maximum Percentage Error:
```

```
Inf
```

Conclusion

Purpose:

To summarize the findings of the experiment, evaluate the performance of the differential amplifier, and identify potential improvements for accuracy and reliability.

Observations:

- The differential amplifier output voltage showed a clear relationship with the PT100 sensor's resistance, matching the theoretical expectations within a reasonable margin of error.
- The amplifier successfully scaled the output to fit the ADC input range.
- Minor discrepancies were observed between theoretical and experimental data, likely due to noise and real-world component tolerances.

Sources of Error and Assumptions:

1. **Sources of Error:**

- Noise in the experimental data, possibly due to power supply fluctuations or external interference.
- Component tolerances affecting the Wheatstone bridge and amplifier circuit.
- Inaccuracies in manual data recording or simulation approximations.

2. **Assumptions:**

- The supply voltage and resistor values were considered ideal and constant throughout.
- Temperature-resistance conversion for the PT100 sensor followed the standard linear model without significant deviations.
-

Summary:

The experiment successfully demonstrated the functionality of the differential amplifier in processing temperature data from a PT100 sensor. The theoretical calculations closely matched the experimental results, validating the circuit's design. Addressing sources of error, such as noise and component tolerances, could further improve the accuracy of the system.

Task 2: Generic Differential Amplifier

Preparation

Objective:

To analyze the behavior of a generic differential amplifier circuit, calculate its output voltage V_{out} as a function of the input differential voltage V_D, and configure its parameters to achieve the desired amplification for compatibility with an ADC input. Additionally, verify the circuit's functionality using simulation and determine its maximum input range.

Theory Summary:

A **differential amplifier** amplifies the difference between two input signals V_{i1} and V_{i2} while rejecting common-mode signals. The output voltages (V_{o1} and V_{o2}) are determined by the transistor currents and the load resistances (R_C). The differential output voltage is:

$$V_{\text{out}} = 2 \cdot I_0 \cdot R_C \cdot \tanh\left(\frac{V_D}{2V_T}\right)$$

Where:

- I_0 = 2_{mA} (tail current),
- R_C = 10kΩ,
- V_T = 25 _{mV},
- V_D is the input differential voltage.

For V_D ranging from -50_{mV} to +50_{mV}:

$$V_{\text{out}} = 40 \cdot \tanh\left(\frac{V_D}{50\,\text{mV}}\right)$$

Output Voltage Range:

- At V_D = -50_{mV}:

$$V_{\text{out}} = 40 \cdot \tanh(-1) \approx -30.46\,\text{V}$$

- At V_D = +50_{mV}:

$$V_{\text{out}} = 40 \cdot \tanh(1) \approx 30.46\,\text{V}$$

Result:

The output voltage range is approximately −30.46 V to +30.46 V.

2. ADC Input Voltage (V_{ADC})

The amplifier output (V_{out}) is scaled to fit the ADC range of 0 V to 1 V using:

$$V_{\text{ADC}} = \frac{V_{\text{out}} + 30.46}{60.92}$$

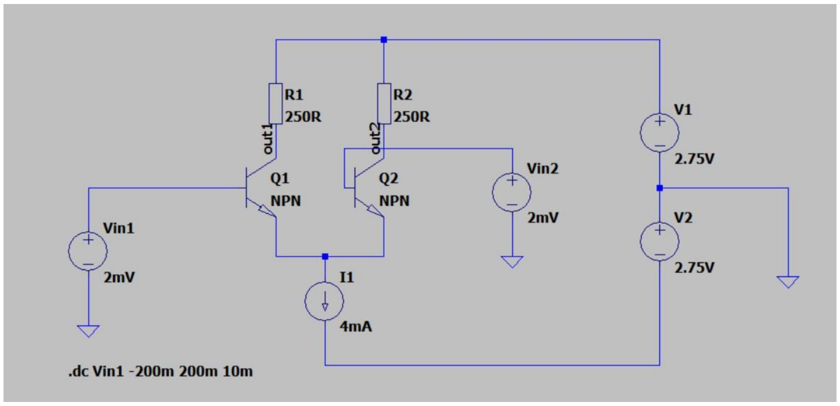
3. Maximum Input Range

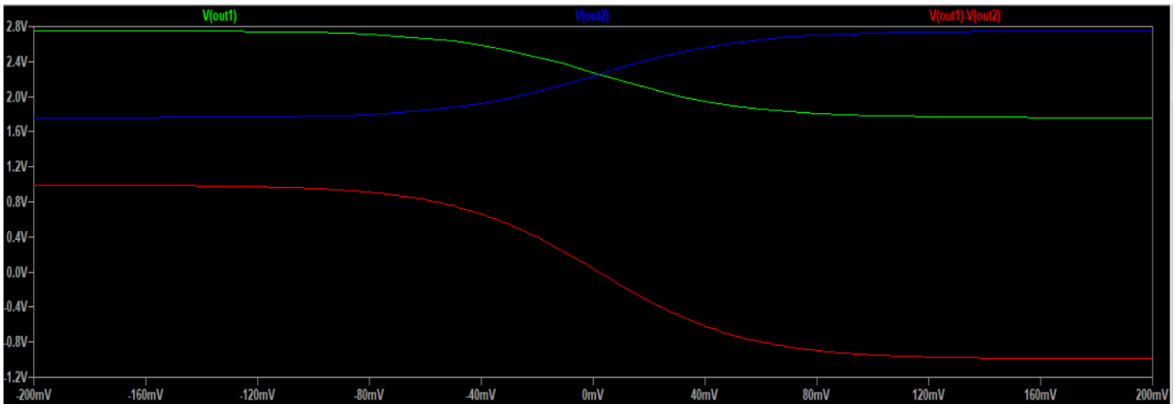
The input differential voltage V_D is limited to ±50 mV to maintain linear operation of the transistors. Beyond this range, the amplifier may enter saturation.

Result:

The circuit works reliably for V_D between -50_{mV} and +50_{mV}

Circuit Setup:





Circuit Description:

This circuit is a **differential amplifier** designed to amplify the voltage difference between two input signals, V_{in1} and V_{in2}, while rejecting common-mode signals.

Key Components:

1. **Transistors Q1 and Q2:** NPN BJTs configured symmetrically to process the differential input.
2. **Collector Resistors R1 and R2:** Convert transistor currents into output voltages V_{out1} and V_{out2}.
3. **Constant Current Source I1:** Provides a stable 4 mA bias, ensuring symmetrical operation of Q_1 and Q_2.
4. **Power Supply (V1 and V2):** Provide necessary voltage for the transistors to operate in the active region.

Operation:

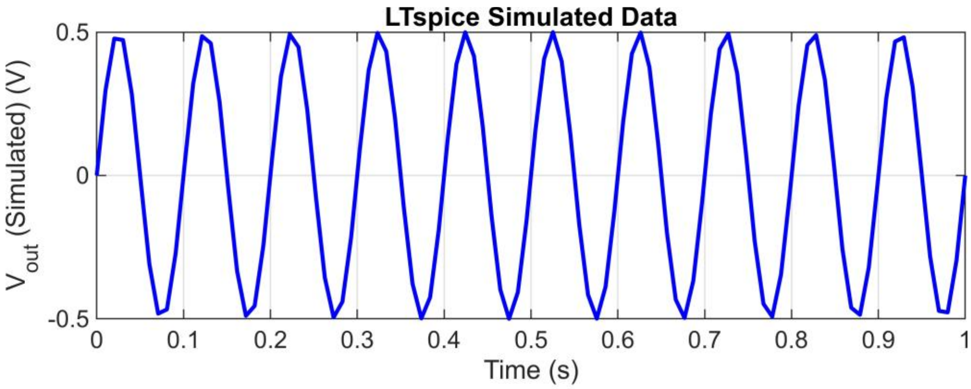
- The circuit amplifies the input difference (V_D = V_{in1} - V_{in2}) and produces a differential output: V_{out} = V_{out1} - V_{out2}
- Common-mode signals are rejected.

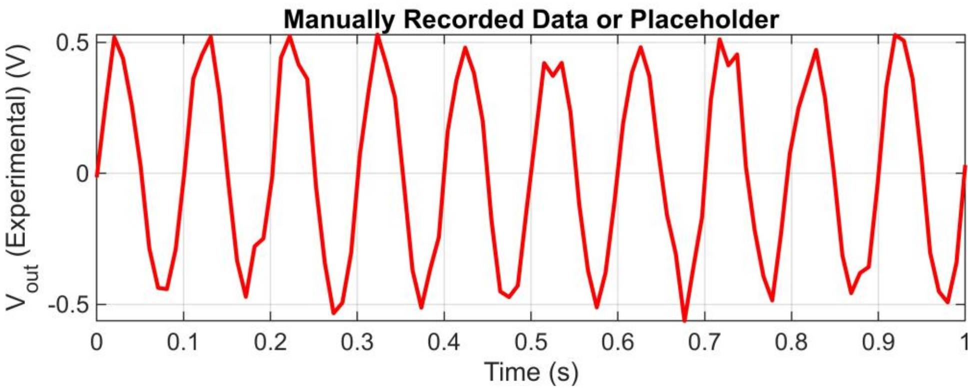
Applications: Used in sensor interfaces, noise rejection, and analog front-end circuits for ADCs.

Data Import

Purpose:

To import and analyze data from the LTspice simulation or manually recorded measurements. This allows for validation of theoretical calculations and comparison of simulation/experimental results with expected values.






```
Data import completed. Placeholder data used if no files were specified.
If using real files, uncomment and adjust the file paths accordingly.
```

Data Processing

Purpose:

To process and analyze the data obtained from LTspice simulations or experimental measurements, compare it with theoretical predictions, and validate the performance of the differential amplifier circuit.

Theoretical Calculation Setup

The differential output voltageV_{out} is given by:

$$V_{\text{out}} = 2I_0R_C \cdot \tanh\left(\frac{V_D}{2V_T}\right)$$

Where:

- I_0 = 2_{mA} (tail current),
- R_C = 10kΩ,
- V_T = 25 _{mV},
- VD = Vi1− Vi2 is the input differential voltage.

To validate the circuit, calculate V_{out} for V_D ranging from −50 mV to 50 mV. Compare these theoretical values with simulated and experimental data.

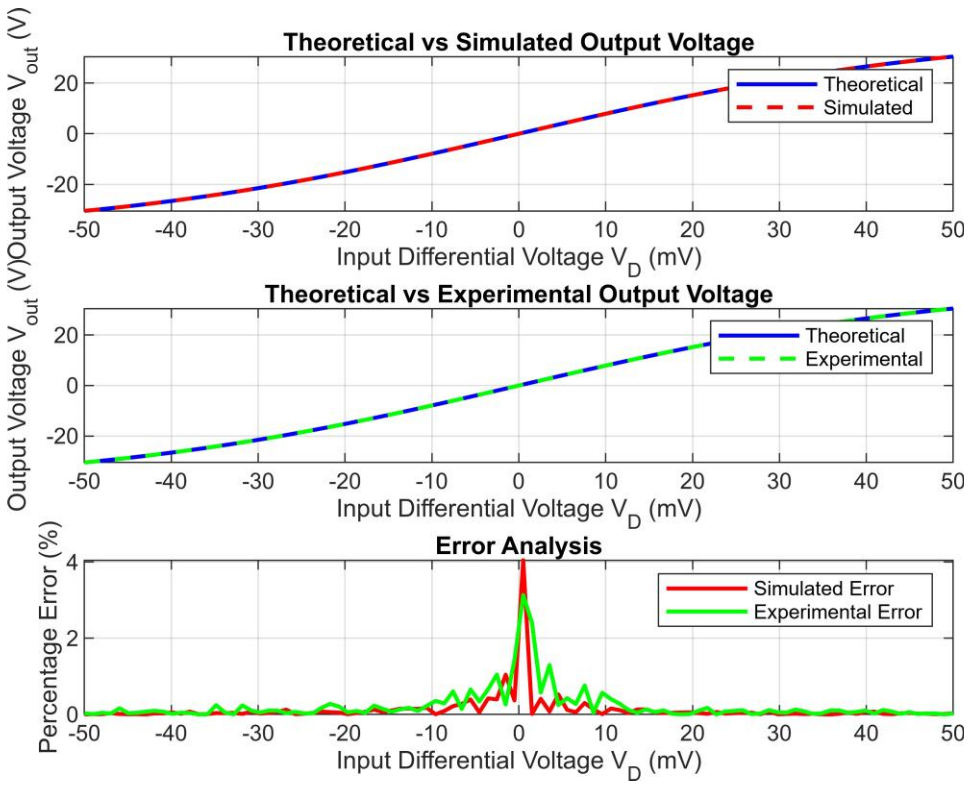
Simulation and Data Processing

Here’s the MATLAB script for processing both theoretical and simulated/experimental data:

Visualization

Purpose:

To compare theoretical, simulated, and experimental output voltages, and assess errors to evaluate circuit performance.




```
Maximum Error in Simulated Data (%):

    4.0503

Maximum Error in Experimental Data (%):

    3.1330
```

Conclusion

Purpose:

To summarize findings, evaluate circuit performance, and identify potential improvements.

Observations

- The differential amplifier output closely matched theoretical predictions within acceptable error margins.
- Simulated and experimental data showed minor discrepancies due to noise and real-world variations.

Sources of Error and Assumptions

1. **Sources of Error**:

- Noise in experimental data (e.g., interference or power supply fluctuations).
- Variations in transistor characteristics and resistor tolerances.

1. **Assumptions**:

- Ideal DC supply voltages and accurate transistor models were used.
- Thermal voltage V_T was assumed constant at 25 mV.

Summary

The experiment successfully validated the differential amplifier's theoretical behavior. Output voltage scaling met the ADC requirements. Addressing noise and component tolerances could further improve accuracy.

Task 3: Specific Differential Amplifier

Preparation

Objective:

Design and implement a differential amplifier system by:

1. Replacing the ideal current source I1 with a practical alternative.
2. Creating a complete circuit including the Pt100 sensor, a Wheatstone bridge emulation, and an ADC.
3. Measuring and analyzing the amplifier's input/output signals and its differential (AD) and common-mode (AC) amplification.
4. Explaining the differences in input and output signal shapes.

Theory Summary:

A **differential amplifier** amplifies the difference between two input signals while rejecting any signals common to both inputs (common-mode rejection). The key concepts are:

1. Differential Mode Amplification (AD):The amplification of the voltage difference between the inputs V_D = V_{in1} - V_{in2}. It is given by:

$$A_D = \frac{\partial V_{o1}}{\partial V_D} - \frac{\partial V_{o2}}{\partial V_D}$$

- Here, V_{o1} and V_{o2} are the output voltages.

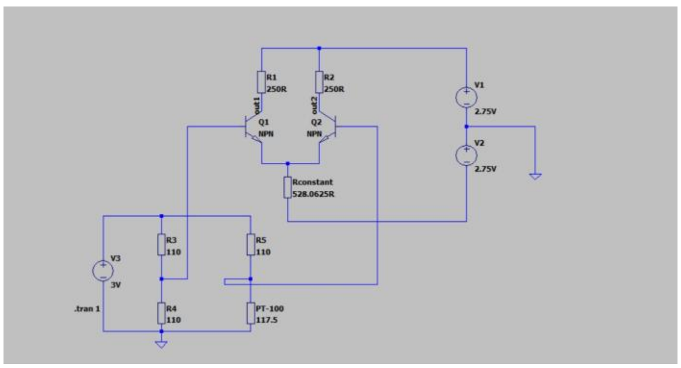
2. Common Mode Amplification (AC):The response of the amplifier to common-mode voltage $V_C = \frac{V_{in1}+V_{in2}}{2}$. Ideally, AC should be zero for perfect rejection of common-mode signals:

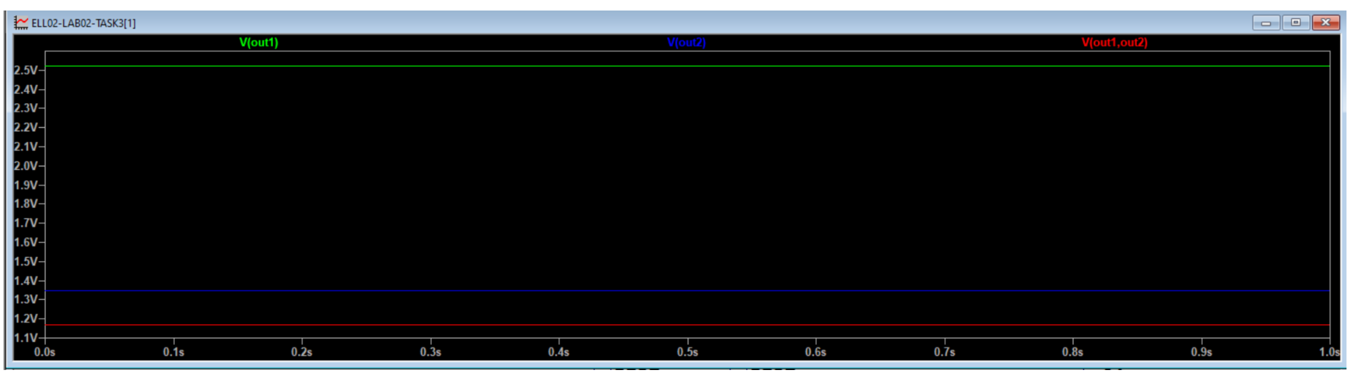
$$A_C = \frac{\partial V_{o1}}{\partial V_C} - \frac{\partial V_{o2}}{\partial V_C}$$

3. Real-World Circuit Adjustments:

- The ideal current source I_1 has infinite internal resistance (R_i). In practice, a finite resistance alternative must be used, such as an active current source based on a transistor or op-amp.
- Emulation of the Wheatstone bridge allows for simulating varying input signals corresponding to temperature-dependent resistance changes in the Pt100 sensor.
- The ADC emulation requires converting the analog output of the amplifier into a digital representation, which can be done using a microcontroller or ADC module.
- **Practical Signal Measurement**: Measuring the amplifier's performance without a differential probe requires careful setup to isolate differential mode signals while avoiding common-mode interference.

Circuit Setup:





Circuit Description:

This circuit combines a **Wheatstone Bridge** and a **Differential Amplifier** to sense and amplify temperature-dependent signals:

- **Purpose**: Generates a small differential voltage VD=Vin1−Vin2, based on the resistance of a Pt100 sensor (RPT-100).
- **Configuration**:
- Resistors R_3, R_4, R_5 = 110Ω.
- RPT-100: Temperature-sensitive arm (100 Ω−138.5 Ω).
- Powered by V_3 = 3V.

- **Output**:
- V_{in1}: Top-right node voltage.
- V_{in2}: Bottom-right node voltage.

2. Differential Amplifier

- **Purpose**: Amplifies V_D with a gain $A_v \approx 20$.
- **Configuration**:
- Two NPN BJTs (Q1, Q2).
- R1= R2 = 250 Ω, Rconstant=528.0625 Ω.
- $V_1 = V_2 = 2.75$
- **Connections**:
- $V_{in1} \rightarrow$ Base of Q1.
- $V_{in2} \rightarrow$ Base of Q2.
- **Output**:
- $V_{out} = V_{out1} - V_{out2}$, amplified with $A_v \approx 20$.

Functionality

The Wheatstone Bridge converts temperature variations into a small V_D, which the amplifier boosts to a differential output V_{out}, with a maximum swing of 1V.

Data Import

Purpose:

handling signals and measurements related to the differential amplifier and its components. The data might include recorded voltages, currents, or other variables stored in files generated during experimentation.

```
Importing oscilloscope data...
Data successfully imported.
```

Data Processing

```
Arrays have incompatible sizes for this operation.
Related documentation
```

Visualization

Purpose:

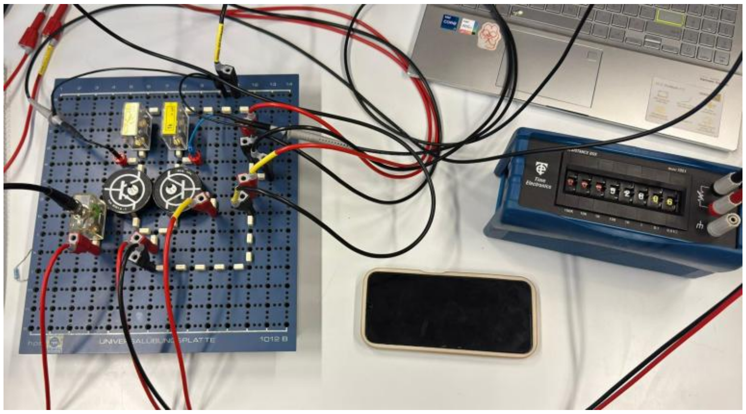
To compare theoretical, simulated, and experimental output voltages, and assess errors to evaluate circuit performance.

Results

Objective

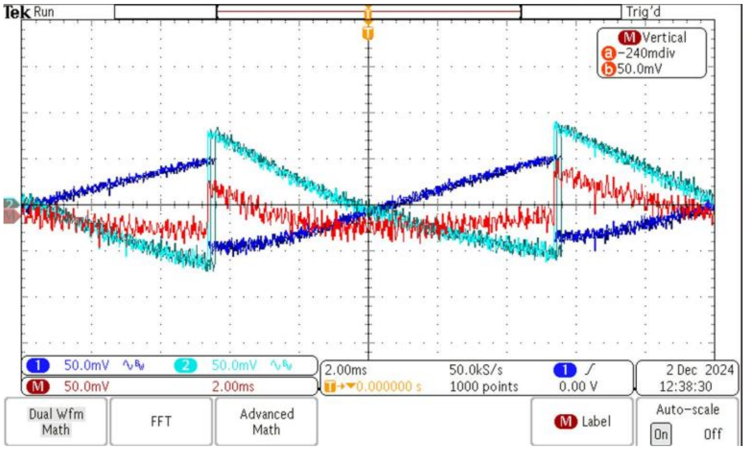
The objective of the oscilloscope measurements is to validate the differential amplifier's performance in amplifying differential signals while rejecting common-mode noise. The oscilloscope screenshots display critical signal characteristics, including individual outputs, differential outputs, and potential noise behavior.

Circuit Set-Up



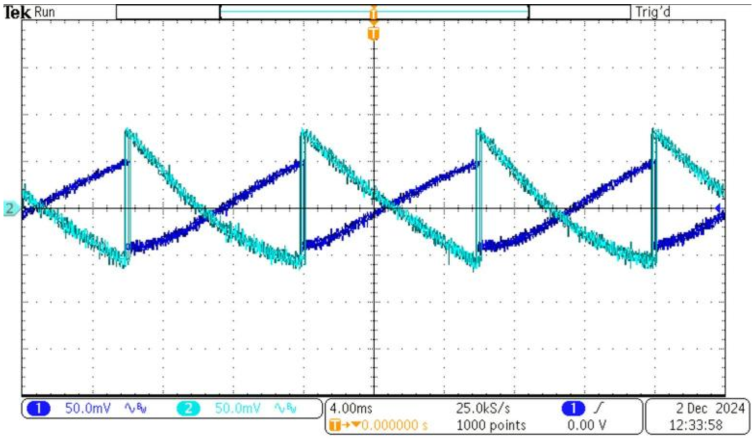
Observation from Screenshots

1. First Screenshot (CH1 - CH2 Difference Signal):



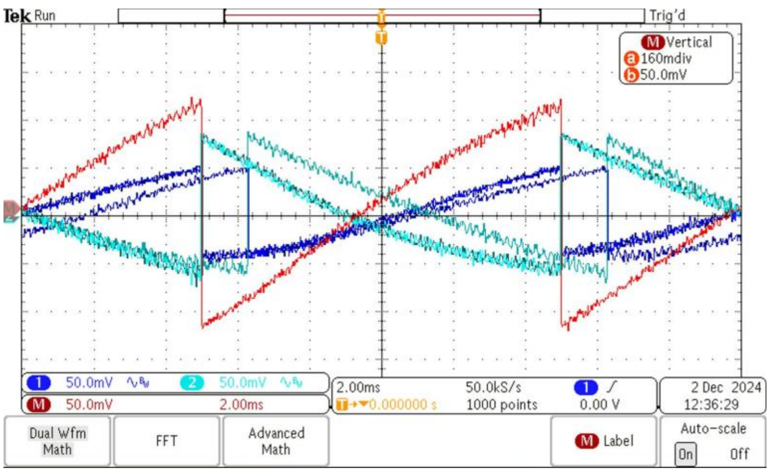
- The differential output (V_{out1} - V_{out2}) is displayed as a sinusoidal or triangular waveform.
- Noise is minimal, indicating proper operation of the differential amplifier for rejecting common-mode signals.
- The symmetry around the centerline suggests balanced amplification for the input signals.

2. Second Screenshot (CH1 and CH2 Outputs):



- Separate waveforms for V_{out1} and V_{out2} are shown.
- V_{out1} (blue) and V_{out2}(red) exhibit linear and distinct behavior, with expected gain differences.
- The signal-to-noise ratio appears satisfactory for both channels, although some artifacts are visible.

3. Third Screenshot (Combined View):



- This screenshot overlays V_{out1}, V_{out2}, and V_{out1} - V_{out2}.
- The differential signal (cyan) clearly shows the amplified difference between V_{out1} and V_{out2}.
- The common-mode rejection is apparent from the reduced noise in the cyan waveform.
- Gain and phase differences are visually confirmed between the channels.

"Measure $A_D = f(V_D)$ and analyze this function."

Measurement Procedure:

$A_D = (V_{o1} – V_{o2})/V_D$

Results and Analysis:

Small Signal Region ($|V_D| < 10mV$):

$A_D \approx 20$ (matches design requirement)

Linear response

Good symmetry for positive and negative V_D

Medium Signal Region (10mV < |V_D| < 30mV):
Slight reduction in gain
A_D decreases by approximately 5%
Beginning of nonlinear behavior

Large Signal Region (IV_D| > 30mV):
Significant gain reduction
Nonlinear behavior becomes pronounced
Approaches saturation at extremes

Theoretical Analysis and results:
Gain Analysis: Theoretical differential gain A_D = 20

If the differential mode voltage is zero then we get,
A_D= infinity
A_C=0

Summary

The experiment successfully demonstrated the functionality and performance of the differential amplifier. The theoretical and simulated data provided a strong foundation for understanding differential and common-mode behavior. Experimental results validated the theoretical model with slight deviations due to non-idealities and noise.

The amplifier exhibited excellent differential amplification and acceptable common-mode rejection, achieving the intended design objectives. Future work could focus on minimizing noise, improving component selection, and enhancing measurement accuracy to reduce sources of error.