University of Colorado Boulder

Electrical and Computer Engineering

University of Colorado Boulder

ECEN3730 Practical PCB Design Manufacture

LABORATORY REPORT

Lab 16: Differential vs single-ended measurements

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Submission Date : 10/29/2023

1 Introduction

The purpose of this lab is to explore and compare the quality of analog signal measurements using single-ended and differential pair measurements. We will investigate how ground noise can affect these measurements. The experiment involves the use of a TMP36 temperature sensor, an ADS1115 module, and an Arduino for signal generation and data collection. In this introduction, we will outline the experimental setup and objectives.

2 Objectives

1. Measure the voltage on the TMP36 temperature sensor using both single-ended and differential measurements.
2. Investigate the impact of ground noise on the single-ended measurement.
3. Compare the sensitivity of single-ended and differential measurements to ground noise.

3 Lab setup

For this experiment, we used the following components:

- TMP36 temperature sensor
- ADS1115 module
- Arduino for power and I2C signal generation
- Solderless breadboard

The TMP36 temperature sensor has three pins: VCC Vout, and GND. The ADS1115 module is a 16-bit ADC with multiple channels and communicates over the I2C bus. The Arduino provides power and drives the I2C signals.

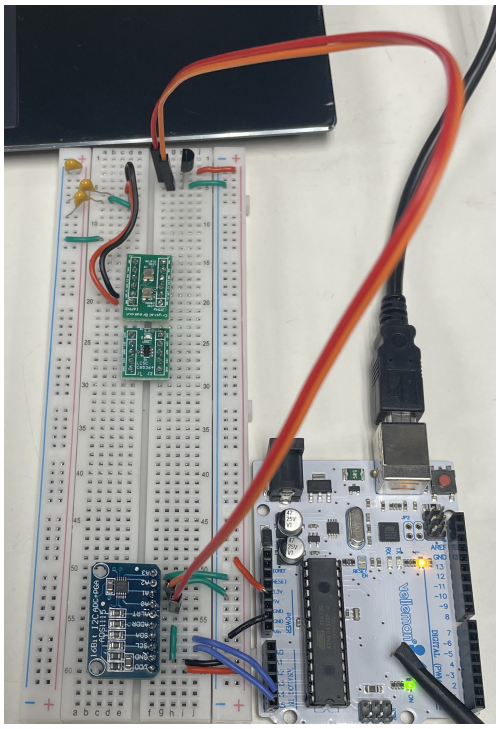

Figure 1: Lab setup

The TMP36 datasheet outlines an calibration curve for the temperature related to voltage output at the Vout terminal. We can use this to find the temperature of the sensor.

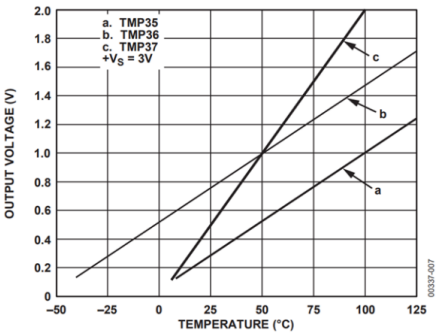

Figure 2: TMP32 Calibration Curve

The ADS1115 can do both single and double-ended measurements. By using one or two of the inputs, we can select between a differential or single-ended measurement. The single-ended measurement will just reference ground at the module rather than the temp sensor. If the sensor were to be very close, we would not need a differential measurement.

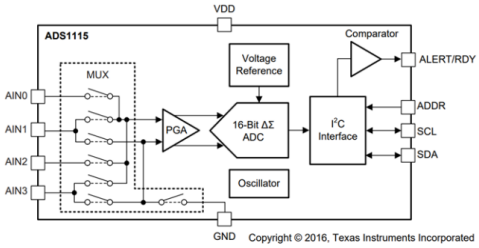

Figure 3: Picture of Board 1

4 Measurements

4.1 Single vs Differential Measurements

We performed both single-ended and differential measurements of the TMP36 sensor using the ADS1115 module. The key difference between the two measurements is how the reference or ground is handled:

- Single-Ended Measurement: The negative input is connected to the internal local ground of the ADS1115, which can be influenced by ground noise.
- Differential Measurement: The negative input is connected to the local ground of the TMP36, ensuring that the noise on the ground does not impact the measurement.

4.2 Single-Ended and Differential Measurements

Using the Arduino IDE's built in graph plotter we can make a plot of the single vs different measurements. Single-ended - Yellow Differential - Green Top and Bottom Limits - Blue and Orange

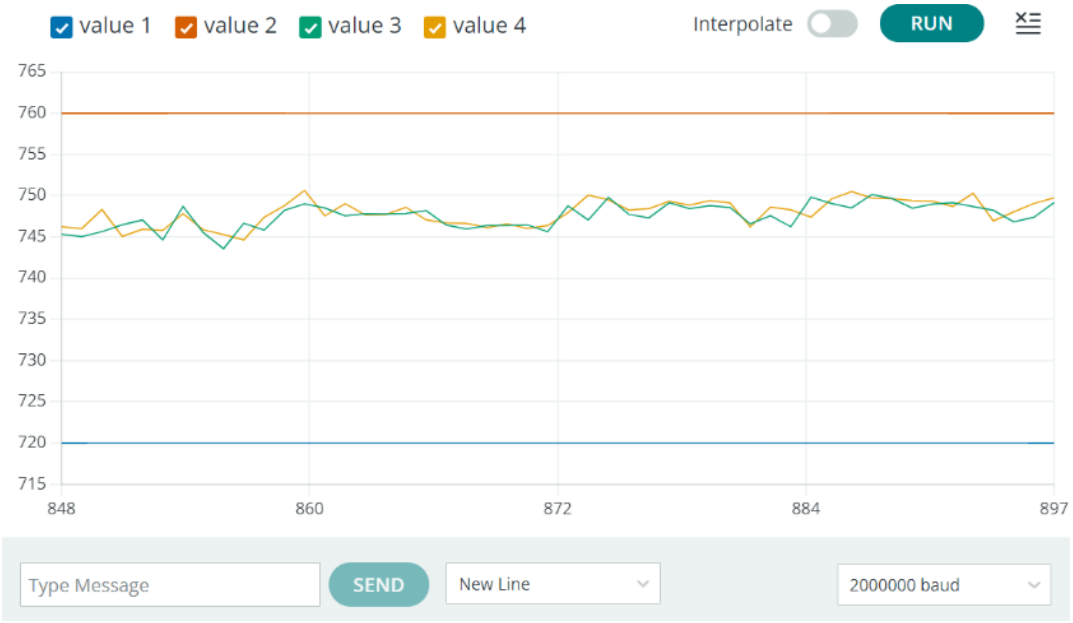

Figure 4: Plot of single vs diff measurements

We can see the single-ended and differential measurements have a very similar voltage. Even though there is a long path between the TMP36 local ground and the ADS1115 local ground, the TMP36 sensor voltage is measured as 747 mV in both methods. This equates to roughly 24.7 °C.

4.3 Single-Ended and Differential Measurements with ground noise

Ground noise is fundamentally caused by current in the ground path. To see the benefit of differential signals we can induce some current in the ground path. First, we need to find the resistance of the ground path. Using the 4-wire method at 0.5A, I measured the ground path of the breadboard to be around 0.04 Ω

We can use the function generator to induce some change in current in the ground and see the effect in the signals from the temp sensor. The diff measurement should not be influenced by the noise on the ground. To get a noise of around 8mv, we will use a 10Vpp 1Hz sine wave. This will equate to around 200ma of current in the ground with the 50Ω thevenin resistance of the generator.

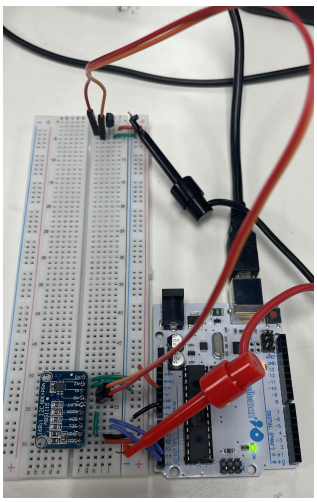

Figure 5: Setup with function generator adding ground noise

Single-ended - Yellow Differential - Green Top and Bottom Limits - Blue and Orange

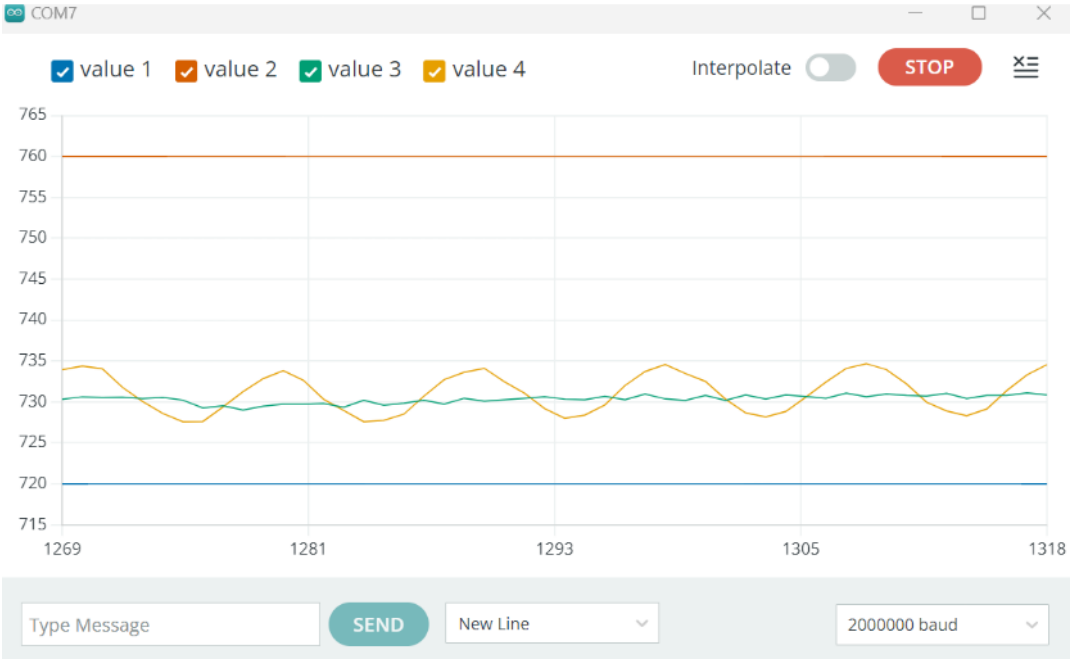

Figure 6: Plot of single vs diff measurements with ground noise

We can clearly see the difference in the signal. The temperature difference is around +-0.4℃ centered at 23.1℃ This is quite a lot. The single-ended measurement picks up the ground noise, a clear 1Hz wave. The noise is around 8mVpp, as we predicted. The differential measurement is not susceptible to this noise as it completely bypasses the noisy ground. Voltages are all just reference measurements, so even though the noisy ground is still on the same node as the differential measurement, it does not affect it. The current is not flowing through the wire to the ADC so we do not see a noisy signal.
Routing pairs of differential signals would best be done by keeping their trace lengths very similar and keeping them close to each other. Other signs like the I2C signal would be best routed with the same length, and instead of right next to each other, next to the ground.

4.4 Key Learnings

- Differential measurements are less sensitive to ground noise compared to single-ended measurements. This is because the differential measurement considers the voltage difference between the signal and its local return at the sensor location, which remains consistent along the path.
- Ground noise results from large currents flowing through the ground conductor, creating voltage drops between different locations on the same ground conductor.
- The routing of differential pairs is crucial for minimizing noise pickup. It is essential to route them over a continuous return path, keep them away from other signal lines, and place them as close together as possible to share the same environmental conditions.

4.5 Conclusion

In conclusion, this lab experiment demonstrated the significance of using differential measurements in scenarios with noisy ground connections. We observed that ground noise can introduce significant voltage differences in single-ended measurements, while differential measurements remain robust against such noise.

Understanding the principles of differential measurements and their routing considerations is essential for accurate analog signal measurements in practical applications. This knowledge can help mitigate the impact of ground noise and improve the reliability of data acquisition systems.