University of Colorado - Boulder

ECEN 5730
Practical PCB Design Manufacture — Fall 2024

Lab 16 Report - Differential vs Single-Ended Measurement

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Introduction

In this lab, we explored the difference between differential and single-ended measurements of an analog signal, particularly focusing on how noise on the power rail affects the accuracy of each method. The experiment used an ADS1115 module and a TMP36 temperature sensor connected on opposite sides of a breadboard to simulate noisy conditions. By comparing the performance of these two measurement types, we aimed to determine under what conditions a differential measurement is more reliable.

Setup

The lab setup consisted of an ADS1115 module configured to measure both differential and single-ended signals from a TMP36 temperature sensor. The TMP36 was placed at one end of the breadboard, while the ADS1115 was at the other. This configuration allowed us to introduce noise into the ground return path and observe its effects.

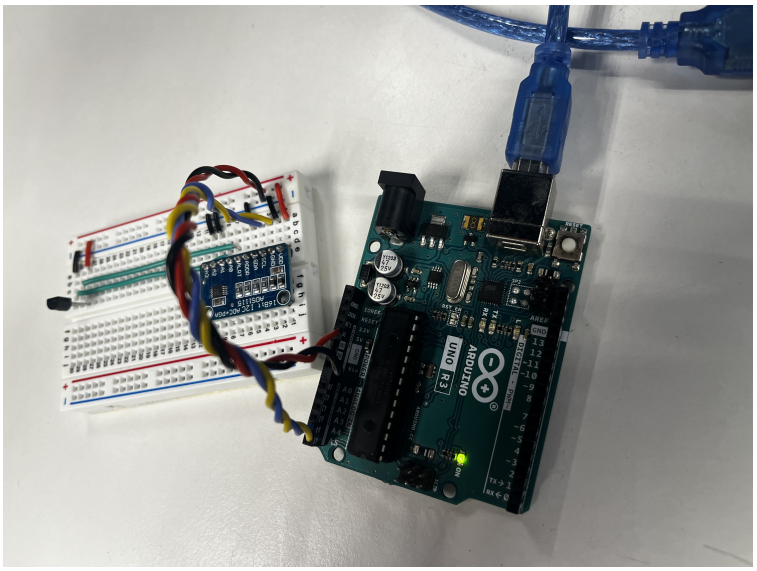

Figure 1: Circuit Setup

In this setup, the TMP36 provided the voltage source, and the ADS1115 performed both single-ended and differential measurements of the sensor output.

Results

Signal Comparison without Noise

Without injecting noise into the power rail, the single-ended and differential signals tracked closely, with only a minor offset. The red trace in the figure below shows the single-ended measurement, which is offset by approximately 1 mV compared to the blue trace representing the differential measurement. This indicates that, under ideal conditions, single-ended measurements can be nearly as accurate as differential measurements.

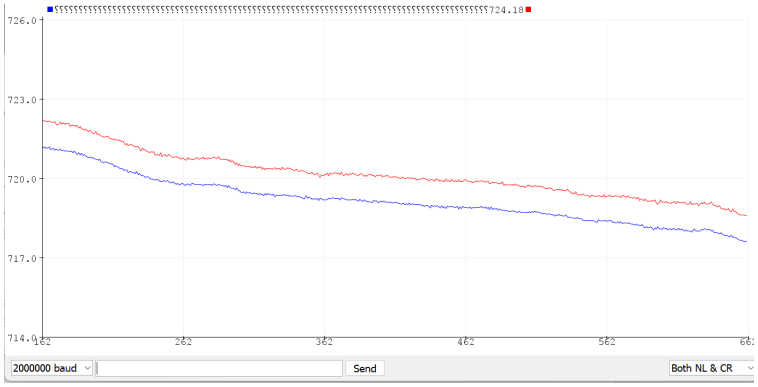

Figure 2: Signal Comparison Without Noise

Signal Comparison with Noise

When a 50Hz sine wave was injected into the power rail to simulate noise, the single-ended signal was significantly affected, while the differential signal remained stable. This demonstrates that differential measurements are more resilient to power rail noise, as the differential method effectively cancels out common-mode noise.

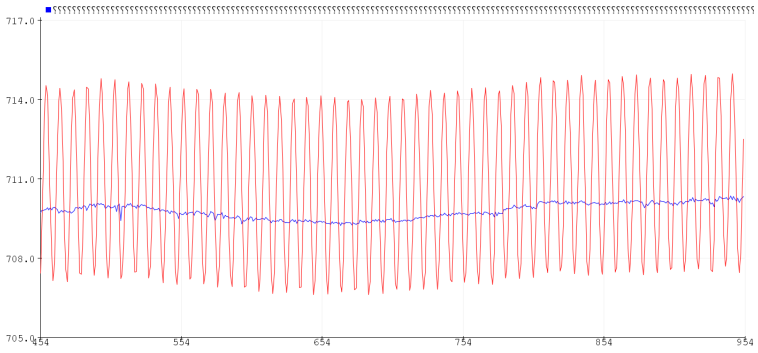

Figure 3: Signal Comparison with Noise

Discussion

From the results, we see a clear distinction between single-ended and differential measurements. The differential measurement is more accurate in the presence of noise, as it effectively rejects the noise introduced into the ground return path. However, single-ended measurements are still useful when noise levels are low, as they can produce accurate results with a simpler wiring setup.

Question Responses

1. **With no current in the ground connection between the TMP36 and ADS1115, what was the temperature read by the TMP36?** The temperature read by the TMP36 with no current in the ground connection was approximately 20°C, corresponding to a voltage output of 0.7V.

2. **With no current in the ground return path, what was the voltage difference between the differential measurement and the single-ended measurement of the TMP36?** The voltage difference between the differential and single-ended measurements was approximately 1 mV, indicating a minor offset between the two methods.

3. **What was the current from the function generator in your ground return between the TMP36 and ADS1115 in your setup?** The current from the function generator in the ground return was measured at 200 mA peak-to-peak.

4. **What is the voltage difference you measured between the single-ended and differential measurements when there was current flowing through the ground path?** When current was flowing through the ground path, the voltage difference between the single-ended and differential measurements was approximately 8 mV, with the single-ended measurement being more affected by the noise.

5. **How would you recommend routing the differential pair from the sensor to the ADS1115 for the lowest noise pickup?** To achieve the lowest noise pickup, I would recommend routing the differential pair as close together as possible and over a continuous ground plane. This routing minimizes noise pickup by ensuring both signal lines experience the same environmental noise, which can then be rejected by the differential measurement.

Conclusion

This lab demonstrated the importance of differential measurements in rejecting noise from the power rail, especially in circuits where ground noise is significant. While single-ended measurements can be effective in low-noise environments, differential measurements provide greater reliability in noisy conditions, making them the preferred method for precision analog sensing in high-noise environments. However, the complexity of adding extra wires or PCB traces may sometimes make single-ended measurements more practical, depending on the specific application and noise levels.