Design Guide: TIDA-060042

Series Resistance Temperature Detector (RTD) Sensing Reference Design

Description

This reference design demonstrates a fully space graded ratiometric temperature sensing circuit using ADS1282EVM-PDK. This circuit measures temperature at up to 10 different locations without any use of buffers. The majority of space applications require temperature measurement in multiple sub-systems that will benefit from this multi-location circuit.

Resources

TIDA-060042	Design Folder
ADS1282-SP	Product Folder
LMP7704-SP	Product Folder
TPS7A4501-SP	Product Folder

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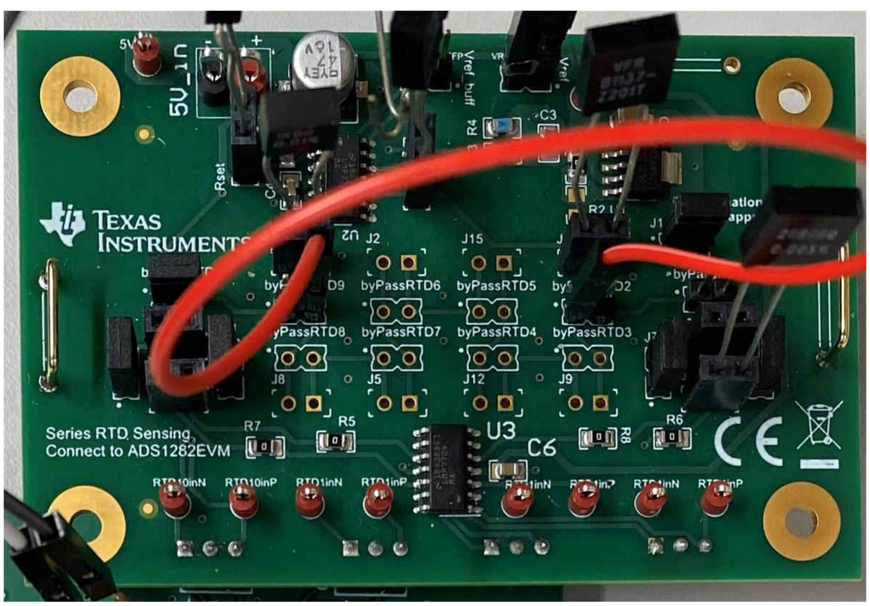
Features

- Measure temperature at up to 10 different locations
- Ratiometric temperature sensing
- 99.93% accuracy
- No use of buffer
- Small size and low cost

Applications

- Satellite electrical power system (EPS)
- Radar imaging payload
- Communications payload
- Command and data handling (C&DH)



1 System Description

This reference design demonstrates a temperature sensing system that can measure temperature at 10 different locations. The system consists of TIDA-060042 and ADS1282EVM-PDK. TIDA-060042 is a *Resistance Temperature Detector* (RTD) board that connects 10 RTDs in a series. Shown in Figure 2-1, each of the RTD outputs a differential signal proportional to its resistance, and is captured by ADS1282EVM-PDK for temperature calculation. Due to the large input impedance of ADS1282-SP, the accuracy of the measurement is greater than 99.93% without calibration or using any buffers. Compare to traditional space temperature measurement circuits, this circuit is not only more flexible and accurate, but also has smaller size and lower cost for reducing use of buffers.

2 System Overview

Table 2-1 details the system specifications of TIDA-060042, the RTD board, which is designed to connect to ADS1282EVM-PDK for temperature measurement.

Table 2-1. TIDA-060042 System Specification

	Net name	Description	Value	Unit	Error [%]
Power Supply	5V_in	RTD board power supply	5	V	N/A
Input	Rref	Sets the Vref for ADS1282EVM	4.76 for I_{RTD} [1] ≈ 0.5 mA	kOhm	0.05%
			2.18 for I_{RTD} ≈ 1 mA		
			1.1 for I_{RTD} ≈ 1.5 mA		
	Rset	Sets the current at all RTDs and Rref	1.5k for I_{RTD} ≈ 0.5 mA	Ohm	0.05%
			750 for I_{RTD} ≈ 1 mA		
			500 for I_{RTD} ≈ 1.5 mA		
	RTD1 to RTD10	10 RTDs located at different locations	0 to 135	Ohm	0.05%
Output	ADCin1	Voltage across RTD1	0 to Vref[2]/(2*gain[3])	V	0.1%
	ADCin2	Voltage across RTD2	0 to Vref/(2*gain)	V	0.1%

2.1 Block Diagram

This reference design uses equivalent commercial components on the PCB instead of the full space grade ICs for electrical performance evaluation. Compare to space grade IC, commercial devices have similar electrical characteristics but is not radiation tolerant. In addition, ADS1282-SP is not placed on TIDA-060042. Instead, TIDA-060042 is designed to connect to ADS1282EVM-PDK for temperature measurement. Figure 2-1 illustrates the recommended comprehensive block diagram, and Figure 2-2 illustrates how TIDA-060042, the RTD board, is connects to ADS1282EVM-PDK for temperature measurement.

1 Current of all RTDs, Rset, and Rref as shown in Figure 2-1

2 Vref is the voltage across Rref in Figure 2-1

3 ADS1282-SP programable gain amplifier (PGA) gain, which could be set to 1, 2, 4, 8, 16, 32, and 64

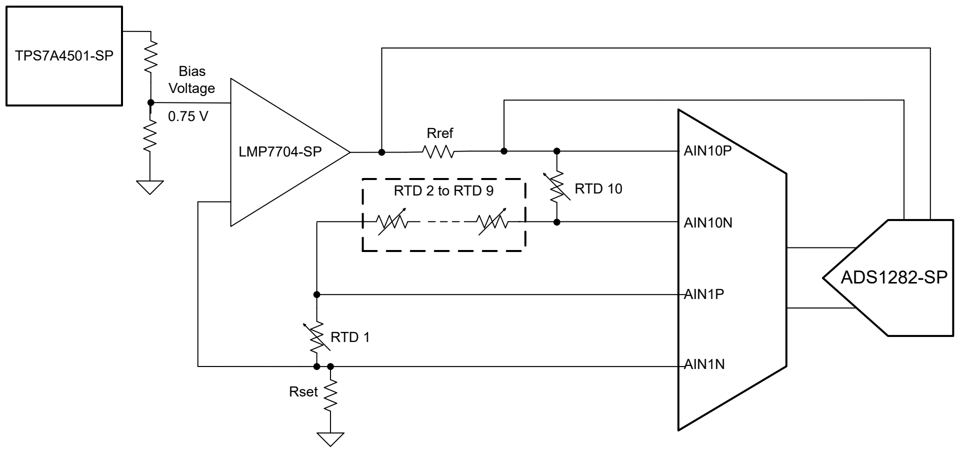


Figure 2-1. Temperature Sensing Application Block Diagram

LMP7704-SP, a rail-to-rail input and output op-amp, supplies a fixed current to each of the RTDs as well as to Rset and Rref. The value of Rset will set the current drawn by the series resistances, thus to adjust the current, Rset needs to be modified. The bias voltage is set to 0.75 V. Voltage across Rref is the ADS1282-SP reference voltage for setting the ADC Full Scale Range (FSR). Compared to Figure 2-1, Figure 2-2 has the mux removed. Only RTD1 and RTD10 are connected to ADS1282EVM-PDK for evaluating the effect of common mode voltage (Vcm) on the measured result.

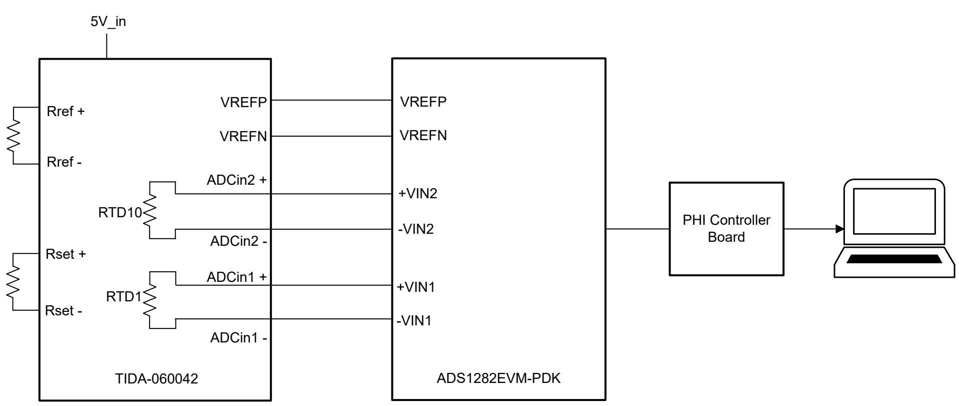


Figure 2-2. Connection Between TIDA-060042 and ADS1282EVM-PDK

2.2 Design Considerations

As Figure 2-2 illustrates, TIDA-060042 is designed to connect to ADS1282EVM-PDK to monitor voltage across RTD1 and RTD10. TIDA-060042 can measure the RTD voltages in two different ways: with or without buffers. Buffers are provided as an option but the main focus in this reference design is to evaluate ADS1282-SP without using any buffers. The following sections describe the formulas to calculate Rset, Rref, and the internal ADC gain, as well as simulations showing the effect of analog multiplexer connecting between TIDA-060042 and ADS1282EVM-PDK.

2.2.1 Rset, Rref, and Gain Calculation

ADS1282-SP input ranges from 0.7 V above AVSS and 1.25 V below AVDD. With AVDD set to 5 V, ADS1282EVM-PDK accepts inputs from 0.7 V to 3.75 V. In TIDA-060042, the Bias Voltage in Figure 2-1 is set to 0.75V. Based on the desired RTD current (I_{RTD}), Rset is calculated with Equation 1.

$$\text{Rset} = \frac{0.75\ \text{V}}{I_{RTD}} \tag{1}$$

Using the maximum RTD resistance, in this design is 135 Ω, Rref and Gain are calculated with the two formulas (Equation 2 and Equation 3).

$$R_{ref} > 135\ \Omega\ \times 2 \times \text{Gain} \tag{2}$$

$$R_{ref} < \frac{5\ \text{V}}{I_{RTD}} - R_{set} - 135\ \Omega \times 10 \tag{3}$$

Once Rset, Rref, and gain are confirmed, the percentage of positive ADC FSR used by each RTD is calculated with Equation 4. For highest performance, Rref is preferred to be as small as possible to maximize the use of positive FSR.

$$\%\ \text{positive FSR used} = \frac{135\ \Omega \times 2 \times \text{Gain}}{R_{ref}} \times 100\% \tag{4}$$

2.2.2 Analog Multiplexer Effect

Analog multiplexer (Mux) is not implemented in the design hardware, but the Mux is considered through simulation.

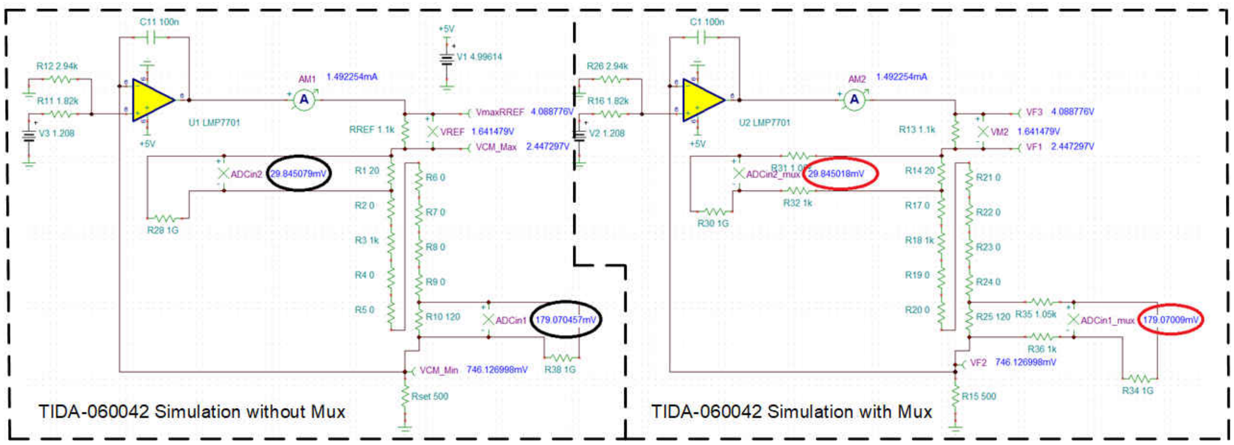


Figure 2-3. Analog Multiplexer Effect Simulation

Table 2-2. Analog Multiplexer Effect Simulation Results

	Without Mux	With mux	% difference
ADCin1 [mV]	179.070457	179.07009	0.0002%
ADCin2 [mV]	29.845079	29.845018	0.0002%

As shown in Figure 2-3 and Table 2-2, the RTD board is simulated with and without mux, and their schematic are shown on the right and left side of the figure, along with simulation result circled in red and black. To simulate a mux, a resistor to represent the MUX on-resistance is added and set to 1 kΩ allowing 50 Ω difference between each channel. Since ADS1282-SP has one GΩ differential input impedance with PGA chopping enabled, there are only about 0.0002% difference between the two circuits output. Compare this error with the error causing by the RTD itself, the error from mux is negligible and does not affect the overall performance.

2.3 Highlighted Products

The following sections describe the highlighted products used in this design.

2.3.1 ADS1282-SP

The ADS1282-SP is an extremely high-performance, single-chip analog-to-digital converter (ADC) with an integrated, low-noise programmable gain amplifier (PGA) and two-channel input multiplexer (mux). The ADS1282-SP is suitable for the demanding needs of energy exploration and seismic monitoring environments.

2.3.2 LMP7704-SP

The LMP7704-SP is a precision amplifier with low input bias, low offset voltage, 2.5-MHz gain bandwidth product, and a wide supply voltage. The device is radiation hardened and operates in the military temperature range of −55°C to +125°C. The high DC precision of this amplifier, specifically the low offset voltage of ±60 μV and ultra-low input bias of ±500 fA, make this device an excellent choice for interfacing with precision sensors with high output impedance. This amplifier can be configured for transducer, bridge, strain gauge, and trans-impedance amplification.

2.3.3 TPS7A4501-SP

The TPS7A4501-SP is a low-dropout (LDO) regulator optimized for fast-transient response. The 5962-1222402VHA can supply 750 mA of output current with a dropout voltage of 300 mV. The 5962R1222403VXC can supply 1.5 A of output current with a dropout voltage of 320 mV. Quiescent current is well controlled; it does not rise in dropout, as with many other regulators. In addition to fast transient response, the TPS7A4501-SP regulator has very-low output noise, which makes it better for sensitive RF supply applications.

Radiation reports for all the listed TI devices in Table 2-3 are found on their TI.com product folder.

Table 2-3. Radiation Qualification

PART NUMBER	TOTAL IONIZATION DOSAGE (kRAD)	Single Event Latch-Up Immune (MeV-cm2/mg)
ADS1282-SP	50	50 at 125℃, 60 at 80℃
LMP7704-SP	100	85
TPS7A4501-SP	100	86

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

The following three pieces of hardware needed to evaluate the accuracy of the series RTDs temperature sensing system:

- TIDA-060042: the RTD board that connects 10 RTDs in series and outputs differential RTD voltages as well as the reference voltage. Figure 3-1 shows the schematic of TIDA-060042.

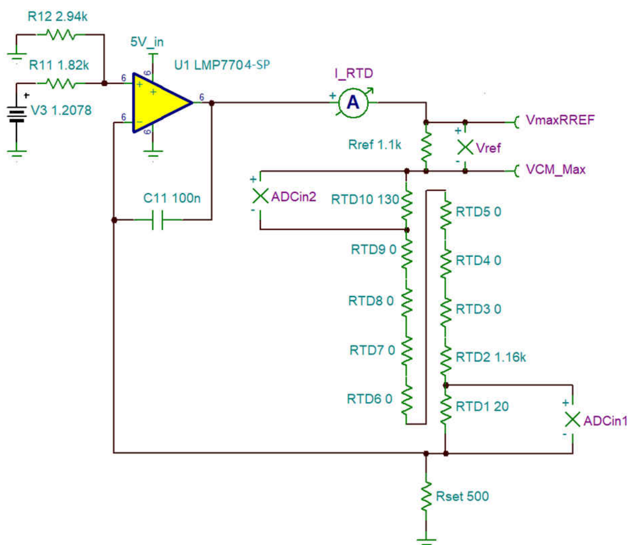


Figure 3-1. TIDA-060042 Schematic

- ADS1282EVM-PDK: the ADS1282-SP evaluation module. Modification is needed on the evaluation module such that Analog Front End (AFE) is bypass and Vref is directly provided by TIDA-060042.
- PHI Controller board: this board comes with ADS1282EVM-PDK. The board provides a convenient communication interface to ADS1282EVM-PDK over a USB 2.0 (or higher) for power delivery as well as digital input and output

Figure 3-2 shows an image with all three pieces of hardware connected.

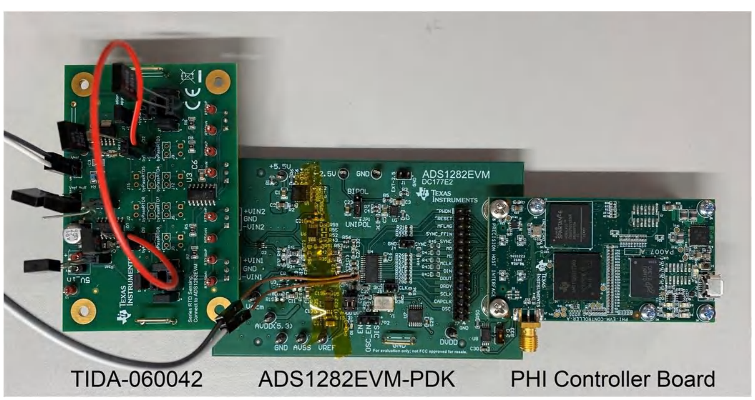


Figure 3-2. Hardware Setup

3.2 Software Requirements

The ADS1282EVM-PDK graphical user interface (GUI) is needed to evaluate TIDA-060042. This GUI software includes graphical tools for data capture, histogram analysis, spectral analysis, and linearity analysis. This GUI also has a provision for exporting data to a text file for post-processing. Refer to the ADS1282EVM-PDK user guide for more information.

3.3 Test Setup

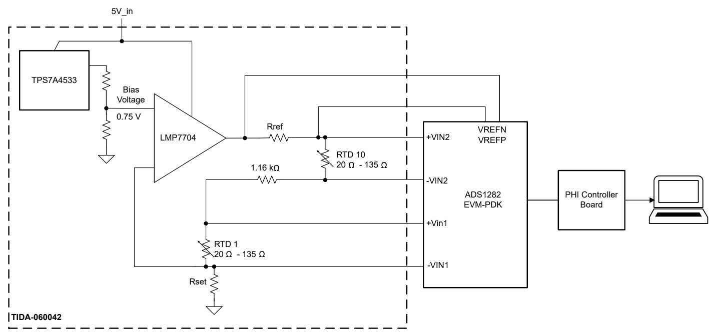


Figure 3-3. Lab Setup to Simulate Temperature Measurement

Figure 3-3 illustrates the block diagram of the lab setup for simulating temperature measurement. The purpose of this setup is to record RTD1 and RTD10's differential voltages. These two RTDs have the highest (High Vcm) and lowest (Low Vcm) common mode voltages, respectively. All RTDs are connected in series and current is biased by Rset. During data collection, Rset is set to three different values thus three sets of data are collected.

Following equations in Section 2.2.2, with I_{RTD} set to 0.497 mA, 0.995 mA, and 1.49 mA, the Rset, Rref, Gain, and % positive FSR are calculated and illustrates in Table 3-1.

Table 3-1. Test Setup with Different I_{RTD}

	Setup 1	Setup 2	Setup 3
I_{RTD} [mA]	0.497	0.995	1.49
Rset [Ω]	4.5k	750	500
Rref [Ω]	4.76k	2.18k	1.1k
Gain	16	8	4
% positive FSR used	90.8%	99.1%	98.2%

Figure 3-4 illustrates how (circled in red) to modify PGA gain, configure mux, and read the returned codes on GUI.

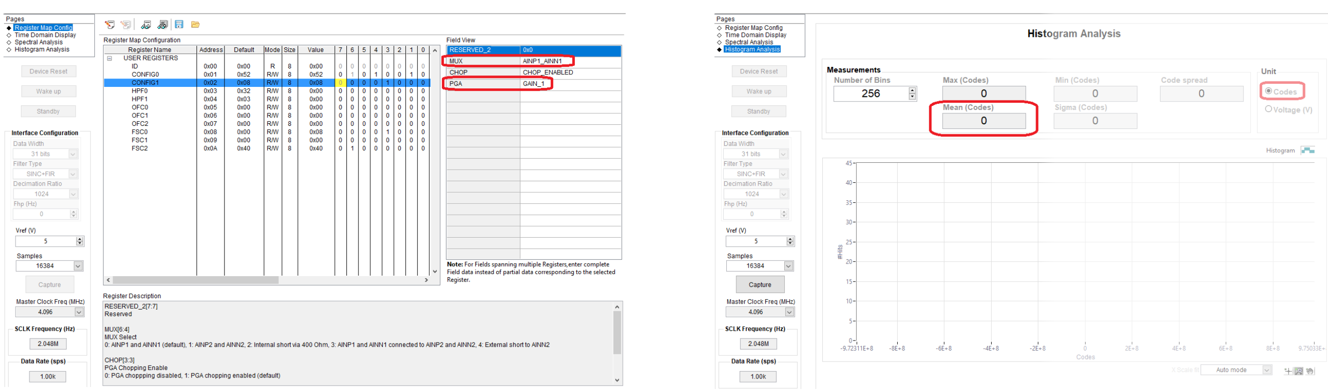


Figure 3-4. ADS1282EVM-PDK GUI Setting

The ADS1282EVM-PDK GUI returns values with 2 formats, codes and voltage. The codes is a 31 bits data and is used to calculate RTD resistance with the following equation, and the calculated value is compared with the actual resistor value for error analysis.

$$\text{RTD Resistance} = \frac{\text{Codes}}{\text{Gain} \times 2^{31}} \times \text{Rref} \tag{5}$$

3.4 Test Results

Figure 3-5 to Figure 3-7 illustrates the RTD resistance measurement percent error. Through out all three sets of collected data, the common mode voltage (Vcm) have a small effect on the result. All captured data shown in Figure 3-7 have percent error less than 0.07% error. Therefore, it is recommended to bias the RTD current at around 1.5 mA for the best performance.

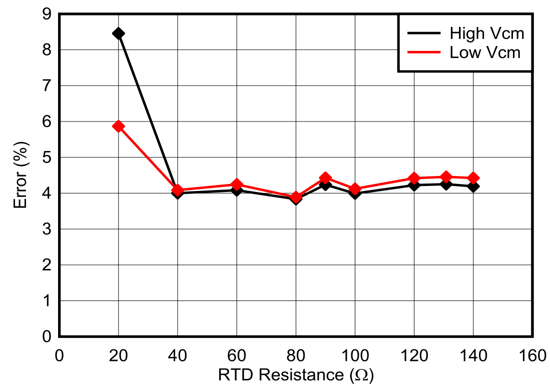


Figure 3-5. Temperature Measurement Accuracy with I_{RTD} = 0.5 mA

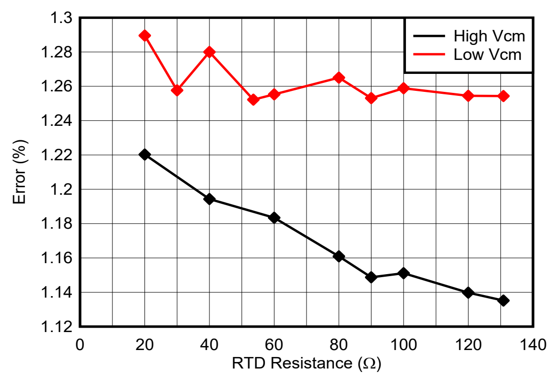


Figure 3-6. Temperature Measurement Accuracy with I_{RTD} = 1 mA

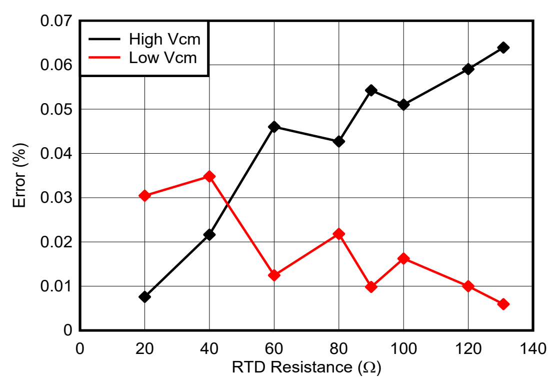


Figure 3-7. Temperature Measurement Accuracy with I_{RTD} = 1.5 mA

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-060042.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-060042.

4.2 Documentation Support

1. Texas Instruments, *ADS1282-SP High-resolution analog-to-digital converter (ADC)* data sheet
2. Texas Instruments, *ADS1282EVM-PDK ADS1282 performance demonstration kit* data sheet

4.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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5 About the Author

Jiajun Guan is a system engineer at Texas Instruments, where he is responsible for developing system designs for the Aerospace and Defense sector. Jiajun has been with TI since 2021. Jiajun earned his Electrical Engineering Bachelor and Masters degrees from California Polytechnic State University.