Thermocouple Temperature Measurements Using Isolated Amplifiers

Introduction

The most common thermocouple in use today is the *Type K*. A Type-K thermocouple is inexpensive, accurate, and works reliably in harsh environments. Type-K thermocouples can measure temperatures ranging from –200°C to +1250°C and have a Seebeck coefficient of S = 41 µV/K at room temperature.

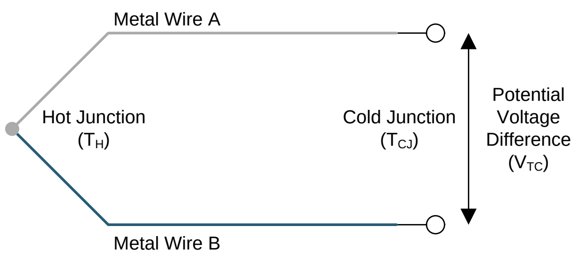

Figure 1. Basic Thermocouple Operation

The magnitude of the thermoelectric voltage (V_{TC}) developed between the two ends of the thermocouple, as shown in Figure 1, is proportional to the gradient in temperature across the two dissimilar metals as given by Equation 1.

$$V_{TC} = S \times (T_H - T_{CJ}) \quad (1)$$

To effectively measure the small thermoelectric voltage developed across the thermocouple (V_{TC}), traditional applications employ a gain stage ahead of an analog-to-digital converter (ADC), or they use an ADC that integrates a programmable gain amplifier (PGA) stage such as the ADS1220 shown in Figure 2.

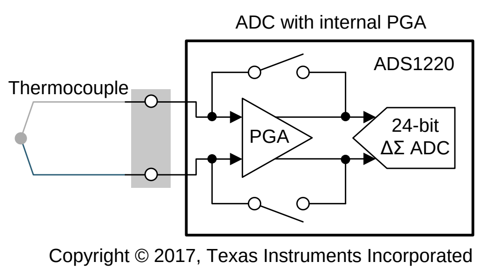

Figure 2. ADS1220 With Internal PGA

When thermocouples are used in industrial environments where ground potential differences can be hundreds of volts, the thermocouple and signal conditioning circuitry are often galvanically isolated. One common method of isolating the circuit shown in Figure 2 is to use a digital isolator between the outputs of the ADC and its host processor or microcontroller as shown in Figure 3.

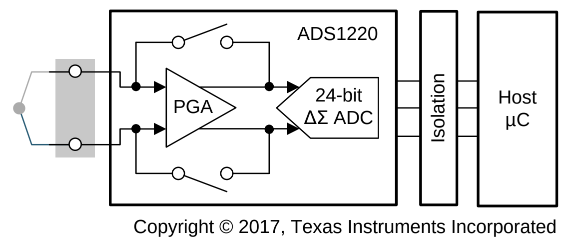

Figure 3. ADC With Isolated Digital Interface

Analog Isolation Approach

An alternative method to isolating the thermocouple is to use an isolation amplifier in combination with a gain stage for the thermocouple. The AMC1301 is an isolation amplifier with a differential input voltage range of ±250 mV. The highest measurement resolution is achieved when the V_{TC} of the thermocouple is matched to the input range of the AMC1301.

Figure 4 shows a simplified block diagram of the PGA in the ADS1220 where the gain is calculated as in Equation 2.

$$\text{Gain} = 1 + 2\left(\frac{R_F}{R_G}\right) \quad (2)$$

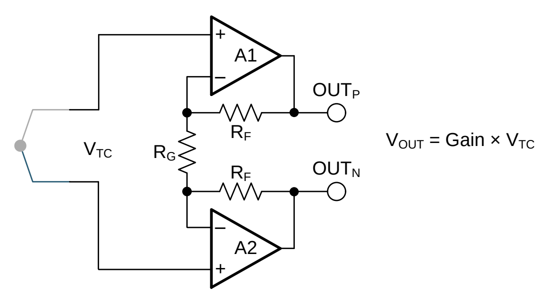

Figure 4. ADS1220 PGA Implementation

A similar fully differential input and output gain stage can be adapted for use with the differential input of the AMC1301.

To calculate the maximum gain that can be used with this gain stage, the maximum thermocouple voltage needs to be calculated. The largest thermoelectric voltage is produced when the hot junction is at its highest and the cold junction at its lowest temperature. The AMC1301 can operate down to T_A = –40°C, which sets the low limit for the cold junction temperature. Using a cold junction temperature of T_{CJ} = 0°C, the maximum thermocouple voltage will be V_{TC} = 50.644 mV when the temperature at the hot junction reaches T_H = 1250°C. At T_H = –40°C and T_{CJ} = 0°C, the output voltage of a K-Type thermocouple is V_{TC} = –1.527 mV. When the thermocouple hot junction is at T_H = 1250ºC and the cold junction is at T_{CJ} = –40ºC, the voltage difference will be V_{TC} = 50.644 mV – (–1.527 mV) = 52.171 mV. Setting the gain of the gain stage to 4.8 matches the maximum thermoelectric voltage to the maximum 250 mV linear input range of the AMC1301.

The TLV6002 is a dual amplifier for cost-constrained applications with 1-MHz input bandwidth and low quiescent current that includes internal RF and EMI filters making it an ideal candidate for use in the gain stage. Two biasing resistors are added to the circuit to set the thermocouple common-mode voltage to mid supply for the TLV6002 amplifier gain stage. Note that the biasing current will flow through the thermocouple. To minimize self-heating of the thermocouple, values in the range of 1 MΩ to 50 MΩ are commonly used for this purpose. The final circuit is shown in Figure 5.

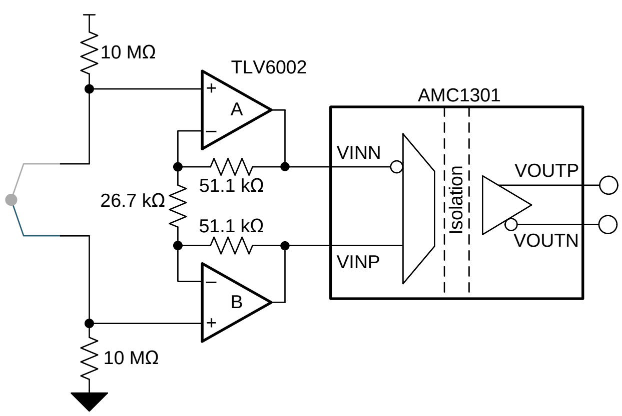

Figure 5. Gain Stage with AMC1301

Following Equation 2, setting R_F = 51.1 kΩ and R_G = 26.7 kΩ yields a gain of 4.8 for the circuit.

The AMC1301 provides a fully differential output with a fixed gain of 8.2 and a common-mode output voltage of 1.44 V. At the two temperature measurement extremes, the AMC1301 will output differential voltages of 2.05 V (T_H = 1250°C, T_{CJ} = –40°C) and –449.6 mV (T_H = –40°C, T_{CJ} = 125°C), respectively, with the common-mode voltage centered around 1.44 V. If a single-ended output is desired, an additional amplifier stage can be introduced to convert the differential output of the AMC1301 to a single-ended signal.

Cold Junction Compensation

To accurately measure the hot junction temperature of the thermocouple, the terminal end or cold junction temperature must be known. This cold junction compensation (CJC) can be done in a variety of ways. The easiest approach for this isolated measurement application is to use a local temperature measurement device such as the TMP275. This temperature sensor operates from a 2.5-V to 5.5-V supply and features an I^2C output with an accuracy of ±0.5°C in the –20°C to +100°C temperature range. The CJC algorithm is implemented inside the system controller by first measuring V_{TC} and then the cold junction temperature as determined by the TMP275. The cold junction temperature is converted to voltage by lookup table and summed with V_{TC}. The result is then converted back to temperature again by lookup table.

Conclusion

Isolation of thermocouples is quite common in many industrial applications. Traditional methods of isolating the thermocouple employ digital or optical methods which increase design complexity. Using the AMC1301, it is possible to maintain a fully differential isolated analog temperature measurement with minimal power consumption.

Table 1. Device Information

Device	Description
AMC1301	Precision, ±250 mV Input, 3 µs Delay, Reinforced Isolated Amplifier
TLV6002	Dual 1-MHz, Low-Power Operational Amplifier for Cost-Sensitive Systems
TMP275	±0.5°C Temperature Sensor with I2C/SM Bus Interface in Industry Standard LM75 Form Factor & Pinout

Table 2. Adjacent Tech Notes

SBAA233	*Reducing System Cost, Size and Power Consumption in Isolated Data Acquisition Systems using ADS122U04* TI TechNote
SBAA229	*Interfacing a Differential-Output (Isolated) Amplifier to a Single-Ended Input ADC* TI TechNote

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