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 \( S = 41 \mu V/K \) at room temperature.

![Figure 1. Basic Thermocouple Operation](image)

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](image)

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. ADS1220 PGA Implementation](image)

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 $T_A = -40^\circ C$, which sets the low limit for the cold junction temperature. Using a cold junction temperature of $T_{CJ} = 0^\circ C$, the maximum thermocouple voltage will be $V_{TC} = 50.644 \, \text{mV}$ when the temperature at the hot junction reaches $T_H = 1250^\circ C$. At $T_H = -40^\circ C$ and $T_{CJ} = 0^\circ C$, the output voltage of a K-Type thermocouple is $V_{TC} = -1.527 \, \text{mV}$. 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.

Following Equation 2, setting $R_F = 51.1 \, \text{k} \Omega$ and $R_G = 26.7 \, \text{k} \Omega$ 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 ($T_H = 1250^\circ C$, $T_{CJ} = -40^\circ C$) and $-449.6 \, \text{mV}$ ($T_H = -40^\circ C$, $T_{CJ} = 125^\circ C$), 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 I²C 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

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

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 |
IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI') technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, “TI Resources”) are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI’s provision of TI Resources does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT. AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include, without limitation, TI’s standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated