Low-Cost, Noise-Immune, Isolated Thermocouple Signal Processor

ABSTRACT

This application report describes a low-cost, thermocouple-based, temperature measurement system featuring high-noise immunity and electrical isolation between the analog and digital circuits. Unlike conventional designs employing analog cold junction compensation, in this design the thermocouple is connected directly to the differential inputs of a INA326 instrumentation amplifier. This configuration takes advantage of the high (>90 dB) CMRR (common mode rejection ratio) of the instrumentation amplifier.

A thermocouple is a simple device, consisting of two wires of dissimilar metallic composition connected at...
one point. The point at which the wires connect forms a junction. A small voltage is produced that is proportional to the difference in temperature between the shorted and the open ends of the thermocouple leads. Typically this voltage, commonly called the Seebeck Coefficient, ranges from 30 µV to 60 µV per °C, depending on the metals used. For a K-type thermocouple, these metals are nickel/chromium and nickel, and the Seebeck Coefficient is approximately 39.4 µV per °C.

Because the voltage produced by the thermocouple is proportional to the difference in temperature between its leads, it is necessary to accurately know the temperature of the connector where the thermocouple attaches to the measurement system. In this design, a platinum RTD (resistance temperature detector) is used to make this measurement.

The PT100 RTD is connected to a separate instrumentation amplifier (U2), set to the same gain as the instrumentation amplifier connected to the thermocouple (U1). The PT100 has a resistance of 100 Ω at 0°C. Its resistance is a linear function of temperature, with a coefficient of 0.385% per °C. Voltage Vtc is therefore a function of temperature and the current through the RTD. The value of resistor R1 (20 kΩ) is chosen such that the temperature coefficient of voltage Vpt matches that of a K-type thermocouple (39.4 µV per °C). The value of resistor R2 is set equal to that of R1 and the value of R3 is set to 100 Ω, so that Vtc is 0 at 100°C.

The Reference input on U1 provides an easy way to sum Vpt (the temperature-dependent voltage from the platinum RTD) and Vtc (the temperature-dependent voltage from the thermocouple).

\[
\begin{align*}
\text{tp} & = \text{probe (junction) temperature in °C} \\
\text{ta} & = \text{ambient (card) temperature °C} \\
\text{Vtc} & = \text{thermocouple generated voltage in mV} \\
V(\text{PT100}) & = 10.19 + 0.0395 \times \text{ta (millivolts)} \\
Vtc & = 0.0395 \times (\text{tp} - \text{ta}) \\
Vpt & = 100 \times (V(\text{PT100}) - 10.19) + 2048 = 2048 + 3.95 \times \text{ta millivolts} \\
\text{ADCVIN} & = 100 \times \text{Vtc} + \text{Vpt} = 2048 + 3.95 \times (\text{tp} - \text{ta}) + 3.95 \times \text{ta} = 2048 + 3.95 \times \text{ta (millivolts)}
\end{align*}
\]

The ADS1244 is a 24-bit A/D converter with an effective resolution of 20 bits (7.8 µV, as connected). The DCR10505 is an isolated DC-to-DC converter with an internal voltage regulator, and supplies the 5 volts to the analog circuits. Two digital signals (Data Out and Clock) connect the ADS1244 to the MSP430F122 ultralow power microcontroller. The ISO721Ms provide ground isolation between the analog and digital grounds. Note that electrical isolation is maintained between analog ground (circuits to the left of the blue dashed line in the figure) and digital ground (circuits to the right of the blue dashed line).
Figure 1. Example Card
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information 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.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplifiers</td>
<td>Audio</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Automotive</td>
</tr>
<tr>
<td>DSP</td>
<td>Broadband</td>
</tr>
<tr>
<td>Interface</td>
<td>Digital Control</td>
</tr>
<tr>
<td>Logic</td>
<td>Military</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Optical Networking</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Security</td>
</tr>
<tr>
<td>Low Power Wireless</td>
<td>Telephony</td>
</tr>
<tr>
<td></td>
<td>Video &amp; Imaging</td>
</tr>
<tr>
<td></td>
<td>Wireless</td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments  
Post Office Box 655303 Dallas, Texas 75265

Copyright © 2007, Texas Instruments Incorporated