BURR - BROWN®
APPLICATION BULLETIN
Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111
Telex: 066-6491 • FAX (520) 889-1510 • Product Info: (800) 548-6132 • Internet: www.burr-brown.com/ • FAXLine: (800) 548-6133

GIVING ΔΣ CONVERTERS A LITTLE GAIN BOOST WITH A FRONT END ANALOG GAIN STAGE

By Bonnie Baker

Sensing small signals is a challenge in process control environments where the sensors used to capture temperature, pressure, and other environmental information produce low level signals. These signals can easily be masked by the ambient noise in the physical vicinity of the measurement, placing tough requirements on the electronics in the remainder of the signal path. If a high level of accuracy is required in these data acquisition systems, the effective signal full-scale range must be decreased making the signal-to-noise ratio (SNR) higher. Several techniques, in the digital domain as well as analog domain, can be used to improve the signal-to-noise ratio of the sensing system. An example of a circuit that can easily implement digital and analog techniques to improve the signal to noise ratio is shown in Figure 1. In this circuit an instrumentation amplifier is used at the front end of the analog signal path. This analog gain stage directly changes the effective full scale range of the overall system. Following the instrumentation amplifier, a delta-sigma converter is utilized because of its internal analog gain and digital filtering capability. When the delta-sigma converter is properly configure, analog gain and digital filtering are optimized to further improve the SNR. The finishing touches of the signal conditioning is performed by the µController, where software gain or bit shifting is used.

This application bulletin discusses the design trade-offs in the implementation of an analog gain stage prior to the delta-sigma converter. For this example an instrumentation amplifier, such as the INA128 is used. The INA128 is chosen because the inputs to the device are differential providing good common-mode rejection over frequency and it can be used in a single supply environment. The value of additional gain prior to the A/D converter will be shown in a temperature sensing application circuit. For more information concerning software gain, refer to Application Bulletin AB-106. For a detailed discussion concerning the issues of implementing the programmable gain amplifier and digital filter of the delta sigma converter, refer to Application Bulletin AB-108.

Sensing devices, such as thermocouples, RTDs and strain gages respond to physical or mechanical occurrences that are measured and manipulated in the process control environment. The sensitivity of these devices vary and are dependent on their construction. For example, the thermocouple (Figure 2a) is used to sense large temperature changes in the ranges of 0°C to 1700°C. The thermocouple is constructed with two dissimilar metals that are connected together. A voltage is created as a result of the temperature

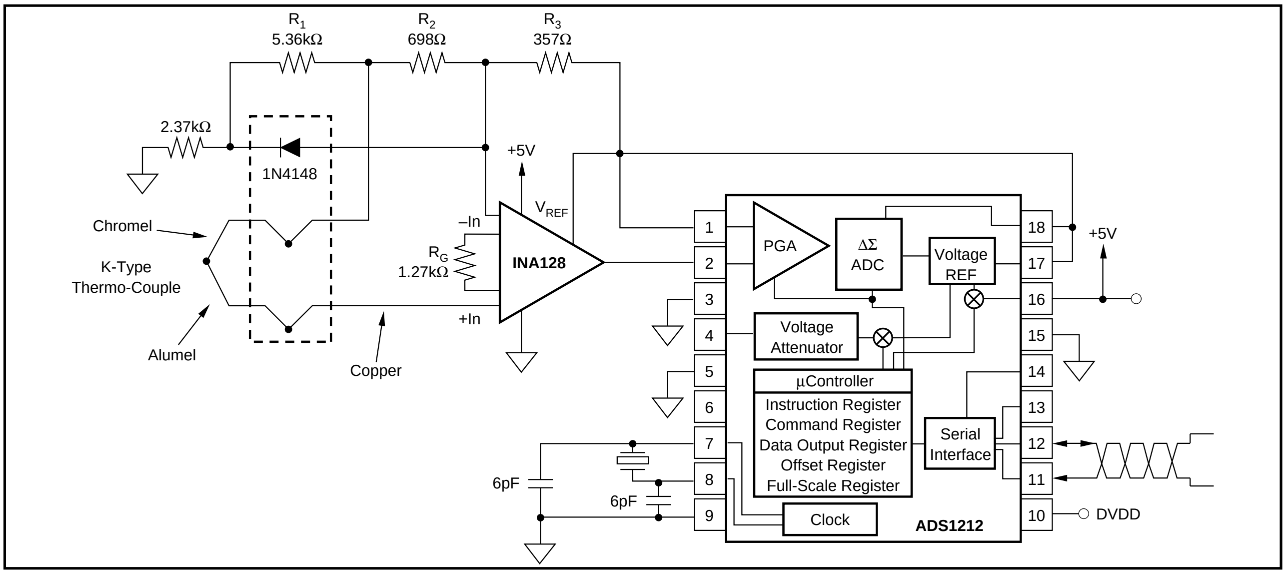

FIGURE 1. This Circuit Implements a High Accuracy Thermocouple Interface with Cold Junction Compensation. The ΔΣ A/D converter, ADS1212, is used to achieve high accuracy for this circuit in the 19- to 20-bit range. The INA128 is used to match the output range of the thermocouple to the input full-scale range of the data conversion system.

Printed in U.S.A. January, 1997

difference from one end of the metals to the other. The sensitivity of four different thermocouples is shown in the table below:

ISA TYPE	METALS USED FOR WIRE	TEMPERATURE COEFFICIENT (µV/°C at 0°C)
E	Chromel/Constantan	58.5
J	Iron/Constantan	50.2
K	Chromel/Alumel	39.4
T	Copper/Constantan	38.0

TABLE I. Temperature Coefficients of Various Thermocouple Types.

Thermocouples are low impedance, voltage output devices and require a temperature reference or compensation point. These devices do not require voltage or current excitation, which is a plus, however, their sensitivity is very low. For example, the K-Type thermocouple has approximately a 40µV/°C sensitivity to changes in temperature and will change approximately 50mV for a temperature range of 0°C to 1250°C.

Another device used for sensing temperature is the RTD. These devices are available in a variety of metallic materials; platinum being the most reliable. Although the temperature range of the RTD is smaller than that of the thermocouple (see Figure 2b) it is very accurate, stable, and repeatable over time. The platinum RTD's sensitivity is 0.00385Ω/Ω/°C. This translates to a 300Ω to 400Ω delta covering the full temperature range of the device. RTDs require an excitation current that is used to convert the resistance of the device to voltage. The current source that is used to excite the RTD can be used as a front end gain element. Caution should be exercised with this current source because errors can be generated as a result of self heating of the RTD. With a platinum RTD, an excitation of 2.5mA will generate a full scale delta voltage across the RTD of 750mV to 1000mV.

As a final example of a typical sensing device, the strain gage is used (Figure 2c). Typically these devices require current excitation. These bridges can have a single, double or four active element construction. Each resistive element is nominally equal to the other three. Typical magnitudes of the resistance of the four elements in the bridge can vary from 300Ω to 10kΩ. If the designer stays within the bounds of the mechanical stress restrictions of these devices, the full scale output ranges can vary between 10mV to 100mV.

Of the sensors discussed, the thermocouple and strain gage present the most challenging issues in digitizing the signal due to the extremely low ranges at their outputs. A circuit designed to sense the voltage changes of a thermocouple is shown in Figure 1.

The single supply temperature sensing system shown in Figure 1 uses a K-Type thermocouple to sense the change in temperature. The temperature range of a K-Type thermocouple is typically 0°C to 1250°C, having a sensitivity of 39.4µV/°C at 0°C. For a full-scale temperature swing, the delta output voltage of the thermocouple would be ~50mV. The 2.5V voltage reference of the ΔΣ A/D converter, ADS1212, is used to bias the diode as well as set the common-mode voltage of the inputs and output stage reference of the instrumentation amplifier. The Common-Mode Voltage of the INA128 vs the desired Output Swing is shown in Figure 3. Keeping in mind that the thermocouple can only produce positive voltages, the optimal full-scale INA128 output swing of 2.25V to 4.25V is achievable with the common-mode of the thermal couple inputs biased to 2.25V (implemented with R_3). This is done to insure the INA128 is configured for the widest output swing possible in this single supply circuit. The output swing restrictions of the INA128 dictate the gain of the instrumentation amplifier be 40V/V. The 1N4148 diode (–2mV/°C) is positioned on the isothermal block along with wire junctions of Alumel/Copper (135.9µV/°C at 0°C) and Chromel/Copper (96.5µV/°C at 0°C) to offset the undesirable temperature effects of these junctions. A voltage divider across the diode

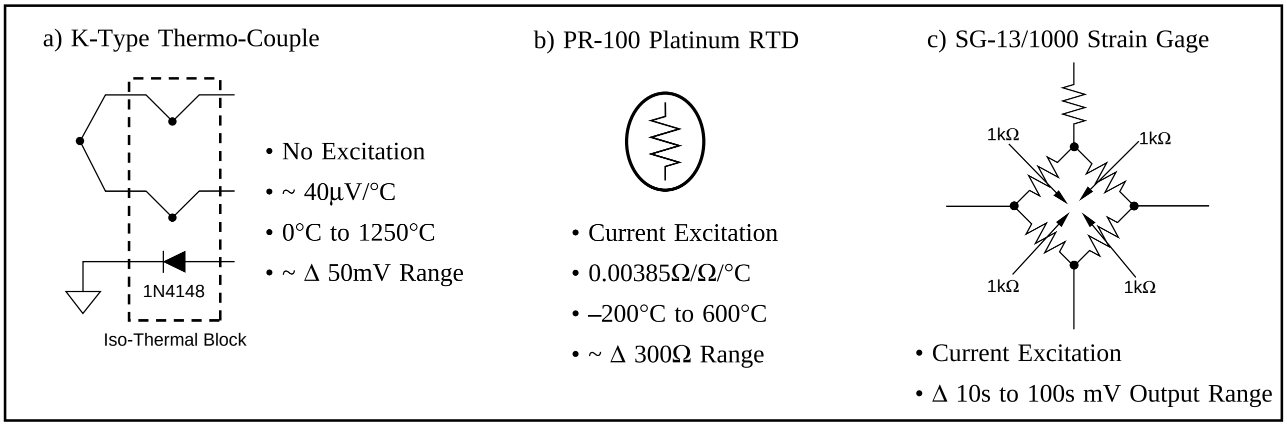

FIGURE 2. Sensing Devices, such as Thermocouples, RTDs and Strain Gages, produce small signals and often reside in noisy environments. The output voltages and resistances of these devices require careful front end signal conditioning.

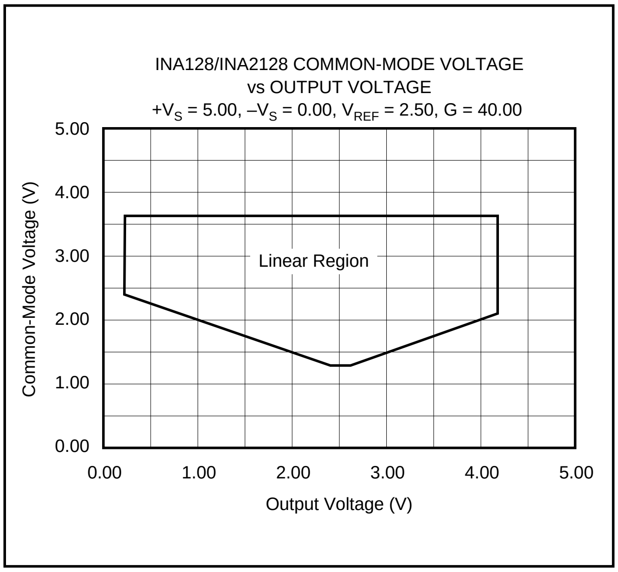

FIGURE 3. Typical Performance of the INA128 Instrumentation Amplifier.

(R_1 and R_2) is used to subtract the errors generated by the two junctions, Alumel/Copper and Chromel/Copper. An added benefit to this approach of using the ΔΣ converter reference is a reduction of errors due to the fact that the entire system is based on the same reference and reduction of system cost.

The ΔΣ converter, ADS1212, has the ability enhance the accuracy of the signal conversion by means of the PGA gain (at the input) and digital filter stages in the device. In the event that the optimum combination of the two internal stages of the A/D converter cannot provide the required system LSB size, other methods, like the input gain stage using the INA128 can be used. For example, an optimum configuration for the ADS1212 with a data rate of 10Hz, would be a Turbo (oversampling rate) setting of 4 and PGA gain setting of 4. Refer to AB-108 for details concerning optimization and noise analysis of the PGA gain and Turbo Mode settings of the ADS1212. For a 10Hz data rate and zero input, the effective output rms noise level of the ADS1212 would be ~6µVrms. In a system where the thermocouple is connected directly to the ΔΣ converter's inputs, one LSB for a K-Type thermocouple, which has a Δ50mV output range for a temperature delta of 1250°C, would equal ~6.094m°C. The effective resolution for this system would be 21.3 bits-rms. However, the thermocouple output range of 50mV (max) would never achieve the full-scale input range of the ΔΣ converter of 2V.

With the INA128 configured for a gain of 40, the output noise of the instrumentation amplifier would be calculated as:

$$\begin{aligned}\mathrm{INA}_{\mathrm{OUTPUT\ NOISE}} &= \mathrm{NOISE}_{\mathrm{at\ 10HZ}} \bullet \sqrt{10} \bullet \mathrm{GAIN}_{\mathrm{INA}} \\ &= 10\mathrm{nV}/\sqrt{\mathrm{Hz}} \bullet 3.1623 \bullet 40 \\ &= 1.265\mu\mathrm{Vrms}\end{aligned}$$

The effective LSB at the thermocouple would be ~40.7nVrms. This is calculated with the following formula:

$$\mathrm{SYSTEM\ NOISE}_{\mathrm{RTO}} = \sqrt{\left(\mathrm{INA}_{\mathrm{OUTPUT\ NOISE}}\right)^2 \bullet \mathrm{GAIN}_{\mathrm{PGA}} + \left(\mathrm{ADC}_{\mathrm{NOISE}}\right)^2}$$

$$\mathrm{EFFECTIVE\ SYSTEM\ LSB}_{\mathrm{RTI}} = \mathrm{SYSTEM\ NOISE}_{\mathrm{RTO}} / \left(\mathrm{GAIN}_{\mathrm{INA}} \bullet \mathrm{GAIN}_{\mathrm{PGA}}\right)$$

In the system where the INA128 is placed in the signal path, one LSB for a K-Type thermocouple would equal ~1.03m°C. Note that this is almost a 40X improvement over the system with the ΔΣ converter alone. The effective resolution of this entire system would then be ~20.2 bits-rms but the thermocouple output range would closely match the INA128's full-scale input range.