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Devices Connected/Referenced	
AD7793	3-Channel, Low Noise, Low Power, 24-Bit Σ-Δ ADC with On-Chip In-Amp and Reference
ADuC832	Precision Analog Microcontroller

Complete Thermocouple Measurement System Using the AD7793 24-Bit Sigma-Delta ADC

EVALUATION AND DESIGN SUPPORT

Design and Integration Files

Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

The circuit, shown in Figure 1, is a complete thermocouple system based on the AD7793 24-bit sigma-delta ADC. The AD7793 is a low power, low noise, complete analog front end for high precision measurement applications. The device includes a PGA, internal reference, internal clock, and excitation currents, thereby greatly simplifying the thermocouple system design. The system noise is approximately 0.02°C peak-to-peak.

The AD7793 consumes only 500 µA maximum, making it suitable for any low power application, such as smart transmitters where the complete transmitter must consume less than 4 mA. The AD7793 also has a power down option. In this mode, the complete ADC along with its auxiliary functions are powered down so that the part consumes 1 µA maximum.

Since the AD7793 provides an integrated solution for thermocouple design, it interfaces directly to the thermocouple. For the cold junction compensation, a thermistor along with a precision resistor is used. These are the only external components required for the cold junction measurement other than some simple R-C filters for EMC considerations.

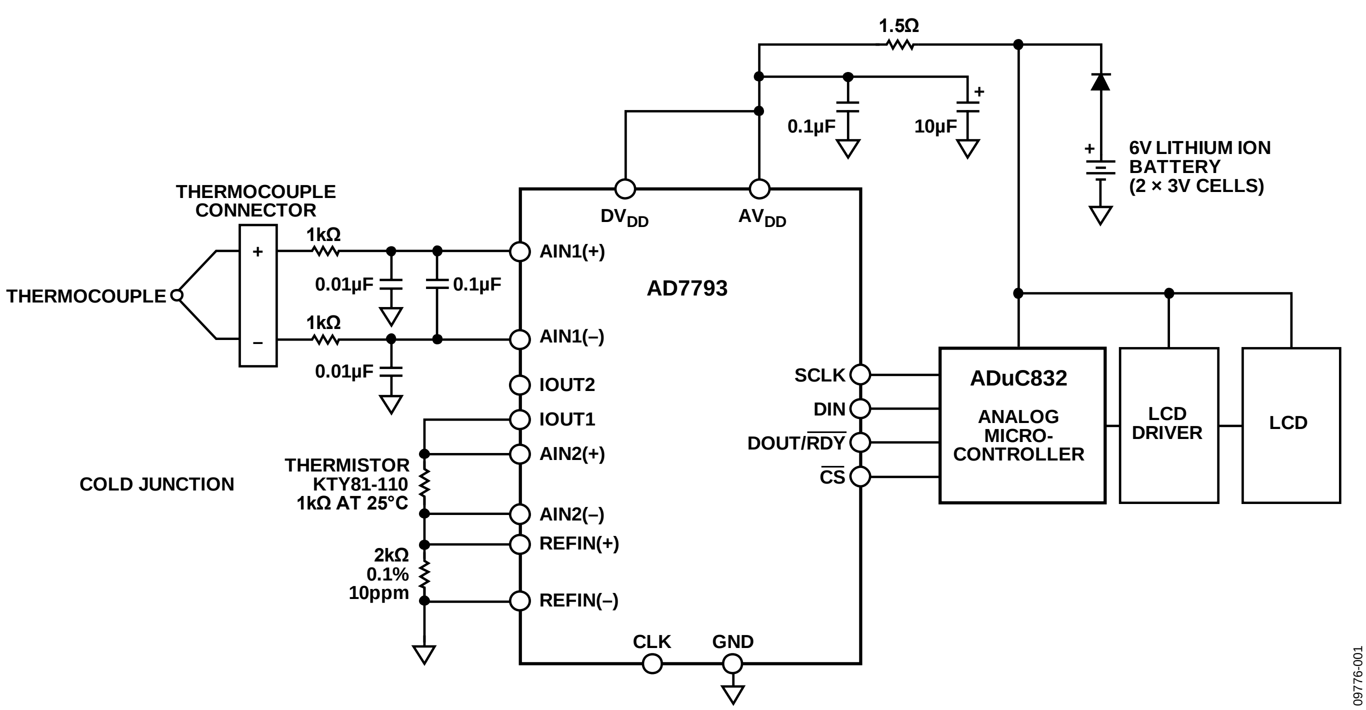

Figure 1. Thermocouple Measurement System with Cold Junction Compensation (Simplified Schematic: All Connections and Decoupling Not Shown)

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CIRCUIT DESCRIPTION

A type "T" thermocouple is used in the circuit. This thermocouple (made from copper and constantan) measures temperature from −200°C to +400°C. It generates a typical temperature dependent voltage of 40 µV/°C.

A thermocouple does not have a linear transfer function. For a temperature range of 0°C to +60°C , the response is quite linear. However, for wider temperature ranges, a linearization routine is required.

The circuit tested does not include linearization. Therefore, the useful measurement range of the circuit is from 0°C to +60°C. For this temperature range, the thermocouple generates a voltage from 0 mV to 2.4 mV. The internal 1.17 V reference is used for the thermocouple conversions. So, the AD7793 is configured for a gain of 128.

Since the AD7793 operates from a single power supply, the signal generated by the thermocouple must be biased above ground so that it is within the acceptable range of the ADC. For a gain of 128, the absolute voltage on the analog inputs must be between GND + 300 mV and AVDD – 1.1 V.

The bias voltage generator onboard the AD7793 biases the thermocouple signal so that it has a common-mode voltage of AVDD/2. This ensures that the input voltage limits are met with significant margin.

The thermistor has a value of 1 kΩ at +25°C. The typical resistance at 0°C is 815 Ω and 1040 Ω at +30°C. Assuming a linear transfer function between 0°C and 30°C , the relationship between cold junction temperature and thermistor resistance R is

$$\textit{Cold Junction Temperature} = 30 \times (R - 815)/(1040 - 815)$$

The 1 mA excitation current on the AD7793 is used to supply the thermistor and the 2 kΩ precision resistor. The reference voltage is generated using this external precision 2 kΩ resistor. This architecture gives a ratiometric configuration—the excitation current is used to supply the thermistor and to generate the reference voltage. Therefore, any deviation in the value of the excitation current does not alter the accuracy of the system.

The AD7793 operates at a gain of 1 when sampling the thermistor channel. For a maximum cold junction of +30°C, the maximum voltage generated across the thermistor is 1 mA × 1040 Ω = 1.04 V.

The precision resistor is chosen so that the maximum voltage generated across the thermistor multiplied by the PGA gain is less than or equal to the voltage generated across the precision resistor.

For a conversion value of ADC_CODE, the corresponding thermistor resistance R equals

$$R = (ADC\_CODE - \text{0x800000}) \times 2000/2^{23}$$

One other consideration is the output compliance of the IOUT1 pin of the AD7793. When the 1 mA excitation current is used, the output compliance equals AVDD – 1.1 V. From the previous calculations, this specification is met since the maximum voltage at IOUT1 equals the voltage across the precision resistor plus the voltage across the thermistor, which equals 2 V + 1.04 V = 3.04 V.

The AD7793 is configured to operate with an output data rate of 16.7 Hz. For every ten conversions read from the thermocouple, one conversion is read from the thermistor. The resultant temperature equals

$$\textit{Temperature} = \textit{Thermocouple Temperature} + \textit{Cold Junction Temperature}$$

The conversions from the AD7793 are processed by the ADuC832 analog microcontroller, and the resultant temperature is displayed on the LCD display.

The thermocouple design is operated from 6 V (2 × 3 V Lithium Ion) batteries. A diode reduces the 6 V to a level suitable for the AD7793 and the ADuC832 analog microcontroller. An RC filter is placed between the ADuC832 power supply and the AD7793 power supply so that the power supply digital noise to the AD7793 is minimized.

Figure 2 shows the relationship between voltage generated across the thermocouple and temperature for a T-type thermocouple. The circled area is the region from 0°C to +60°C where the transfer function is approximately linear.

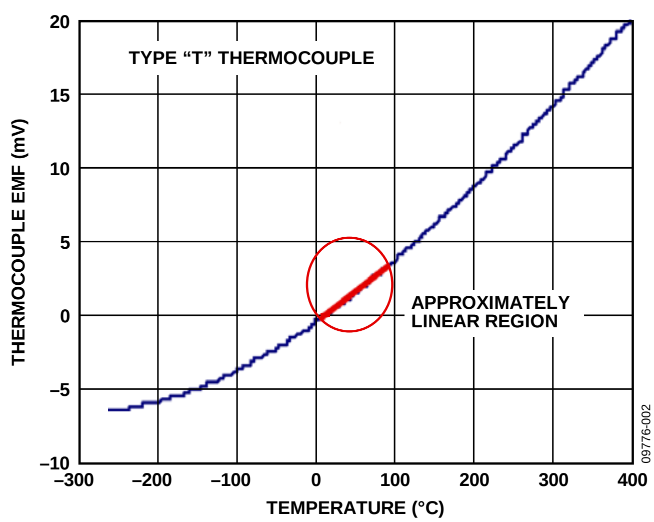

Figure 2. Thermocouple EMF vs Temperature

When the system is at room temperature, the thermistor should indicate the value of the ambient temperature. The thermocouple indicates the relative temperature with respect to the cold junction temperature, i.e., the temperature difference between the cold junction (thermistor) and the thermocouple. Therefore, at room temperature, the thermocouple should indicate 0°C .

If the thermocouple is placed in an ice bucket, the thermistor continues to measure the ambient (cold junction) temperature. The thermocouple should indicate the negative of the thermistor value so that the overall temperature equals zero.

Finally, for an output data rate of 16.7 Hz and a gain of 128, the rms noise of the AD7793 equals 0.088 μV. The peak-to-peak noise is

$$6.6 \times \mathit{RMS\ Noise} = 6.6 \times 0.088\ \mu\text{V} = 0.581\ \mu\text{V}$$

If the thermocouple has a sensitivity of precisely 40 μV/°C, the thermocouple should measure the temperature to a resolution of

$$0.581\ \mu\text{V} \div 40\ \mu\text{V} = 0.014°\text{C}$$

Figure 3 shows the actual test board. The system was evaluated by measuring the thermistor temperature, the thermocouple temperature, and the resolution at room temperature and when the thermocouple was placed in an ice bucket. The results are shown in Table 1.

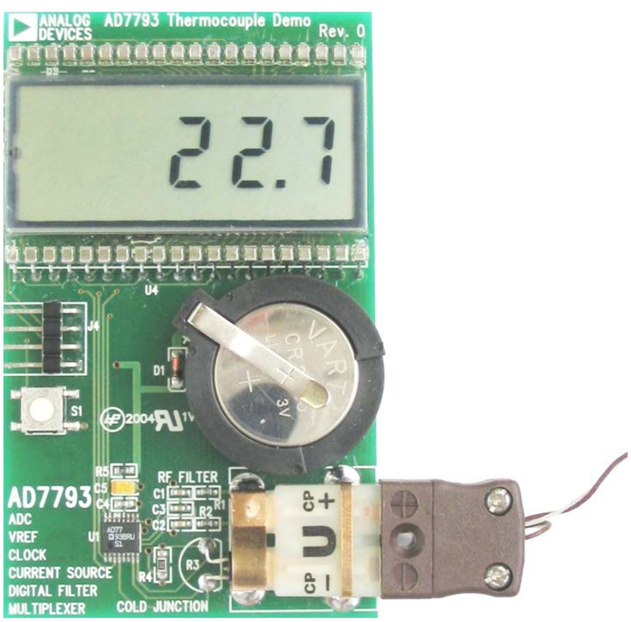

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Figure 3. Thermocouple System Using the AD7793

Table 1. Test Results for Thermocouple System

	0°C	**Ambient Temperature (20°C)**
Thermocouple Reading (°C)	−20	0
Thermistor Reading (°C)	20.3	20.3
Resultant Reading (°C)	0.3	20.3
Peak-to-Peak Noise (°C)	0.02	0.02

From Table 1, the thermocouple is reporting the correct value, while the thermistor has a 0.3°C error. This is the accuracy of the system when linearization is not included. Including linearization for the thermocouple and the thermistor would improve the accuracy of the system, and it would also allow the system to measure a wider range of temperatures.

If the difference between the minimum and maximum temperature readings is measured for every 10 readings, the peak-to-peak noise in terms of temperature is 0.02°C. Therefore, the actual peak-to-peak resolution is very close to the expected value.

COMMON VARIATIONS

The AD7793 is a low noise, low power ADC. Other suitable ADCs are the AD7792 and AD7785. Both parts have the same feature set as the AD7793. However, the AD7792 is a 16-bit ADC while the AD7785 is a 20-bit ADC.

CIRCUIT EVALUATION AND TEST

Test data was taken using the board shown in Figure 3. Complete documentation for the system can be found in the CN-0206 Design Support package at www.analog.com/CN0206-DesignSupport.

LEARN MORE

CN-0206 Design Support Package: www.analog.com/CN0206-DesignSupport

Kester, Walt. 1999. *Sensor Signal Conditioning*. Section 7. Analog Devices.

MT-004 Tutorial, *The Good, the Bad, and the Ugly Aspects of ADC Input Noise—Is No Noise Good Noise?* Analog Devices.

MT-022 Tutorial, *ADC Architectures III: Sigma-Delta ADC Basics,* Analog Devices.

MT-023 Tutorial, *ADC Architectures IV: Sigma-Delta ADC Advanced Concepts and Applications*, Analog Devices.

MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND"*, Analog Devices.

MT-101 Tutorial, *Decoupling Techniques*, Analog Devices.

Data Sheets and Evaluation Boards

AD7793 Data Sheet

AD7793 Evaluation Board

ADuC832 Data Sheet

ADuC832 Evaluation System

REVISION HISTORY

10/11—Revision 0: Initial Version

CN09776-0-10/11(0)