AN867

Temperature Sensing With A Programmable Gain Amplifier

Author: Bonnie C. Baker
Microchip Technology Inc.

INTRODUCTION

Although it is simple to measure temperature in a stand-alone system without the help of Microchip's Programmable Gain Amplifiers (PGA), a variety of problems can be eliminated by implementing temperature-sensing capability in multiplexed applications with a PGA. One of the main advantages is that you can eliminate a second signal path to the microcontroller and still maintain the accuracy of your sensing system. In particular, the multiplexed PGAs you can use are the MCP6S22 (two-channel), MCP6S26 (six-channel), and MCP6S28 (eight-channel).

The most common sensors for temperature measurements are the Thermistor, Silicon Temperature Sensor, RTD and Thermocouple. Microchip's PGAs are best suited to interface to the Thermistor or Silicon Temperature Sensor.

In this application note we will discuss the implementation of temperature measurement systems from sensor to the PICmicro® microcontroller using a NTC Thermistor, Silicon Temperature sensor, PGA, anti-aliasing filter, A/D converter and microcontroller.

INTERFACING THE PGA TO THERMISTORS

The most appropriate configuration when using a NTC thermistor with Microchip's PGA is in the resistance-versus-temperature mode. The resistance of an NTC thermistor has a negative, non-linear temperature coefficient response. The resistance-versus-temperature response of a 10 kΩ, NTC thermistor is shown in Figure 1.

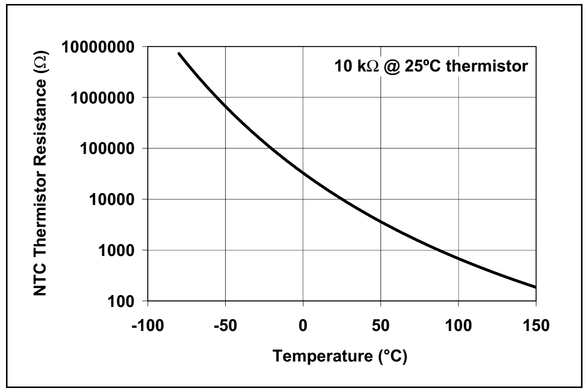

FIGURE 1: *The NTC thermistor has a non-linear resistance response over temperature with a negative temperature coefficient.*

It is obvious in this example that this type of response is inefficient in a linear system. Typically, analog integrated circuits are linear in nature, as are Microchip's PGA devices. A first-level linearization of the thermistor output can be implemented with the circuits in Figure 2. This type of circuit will perform precision temperature measurement over, approximately, a 50°C temperature range. In this figure, the thermistor is placed in series with a standard resistor (R_{SER}, 1%, metal film) and a voltage source.

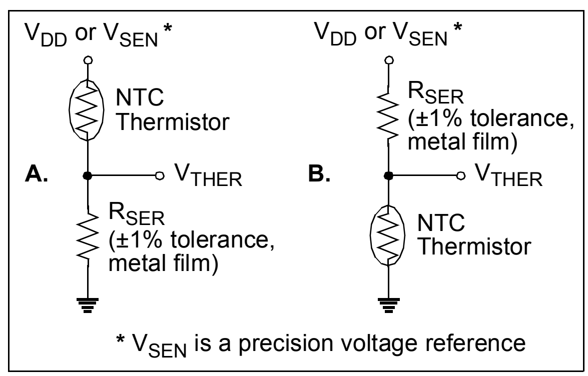

FIGURE 2: *The NTC thermistor can be linearized over a 50°C range with a voltage source and series resistance. Figure 2A has a positive temperature coefficient, while Figure 2B has a negative temperature coefficient at V_{THER}.*

The value of R_{SER} is equal to the value of the thermistor at the median temperature of the 50°C window you are trying to measure. For instance, if a 10 kΩ NTC thermistor is selected, this specification implies that the thermistor will be 10 kΩ at 25°C. If the measurement window is between 0°C and 50°C, the standard resistor (R_{SER}) should be 10 kΩ. The response of V_{THER} in Figure 2, Diagram A is shown in Figure 3.

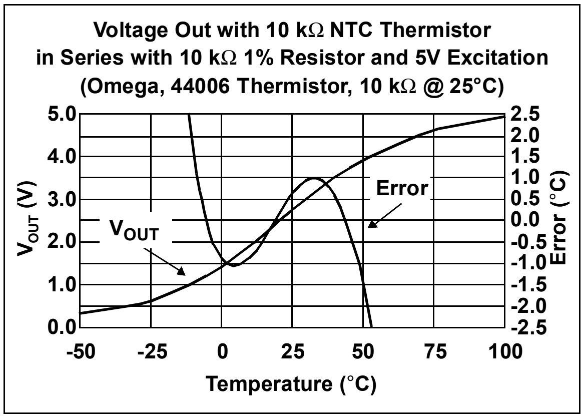

FIGURE 3: *The NTC thermistor has a non-linear resistance response over temperature.*

A circuit that shows the interface between thermistor and one of Microchip's PGAs is shown in Figure 4. In this circuit, the output of the thermistor circuit (V_{THER}) is connected directly to one input of the PGA.

The configuration for the thermistor circuit in this figure has a positive temperature coefficient. When a look-up table is utilized in the controller, this particular circuit is designed to test temperature from 0°C to 50°C with 10-bit linear performance. The voltage at CH0 of the PGA is centered around 2.5V. The voltage swing of the thermistor circuits is from 1.5V (of 0°C sensing) to 4.0V (for 50°C sensing). In this configuration, the PGA gain should be 1V/V and the reference voltage (V_{REF}) should be 0V or ground.

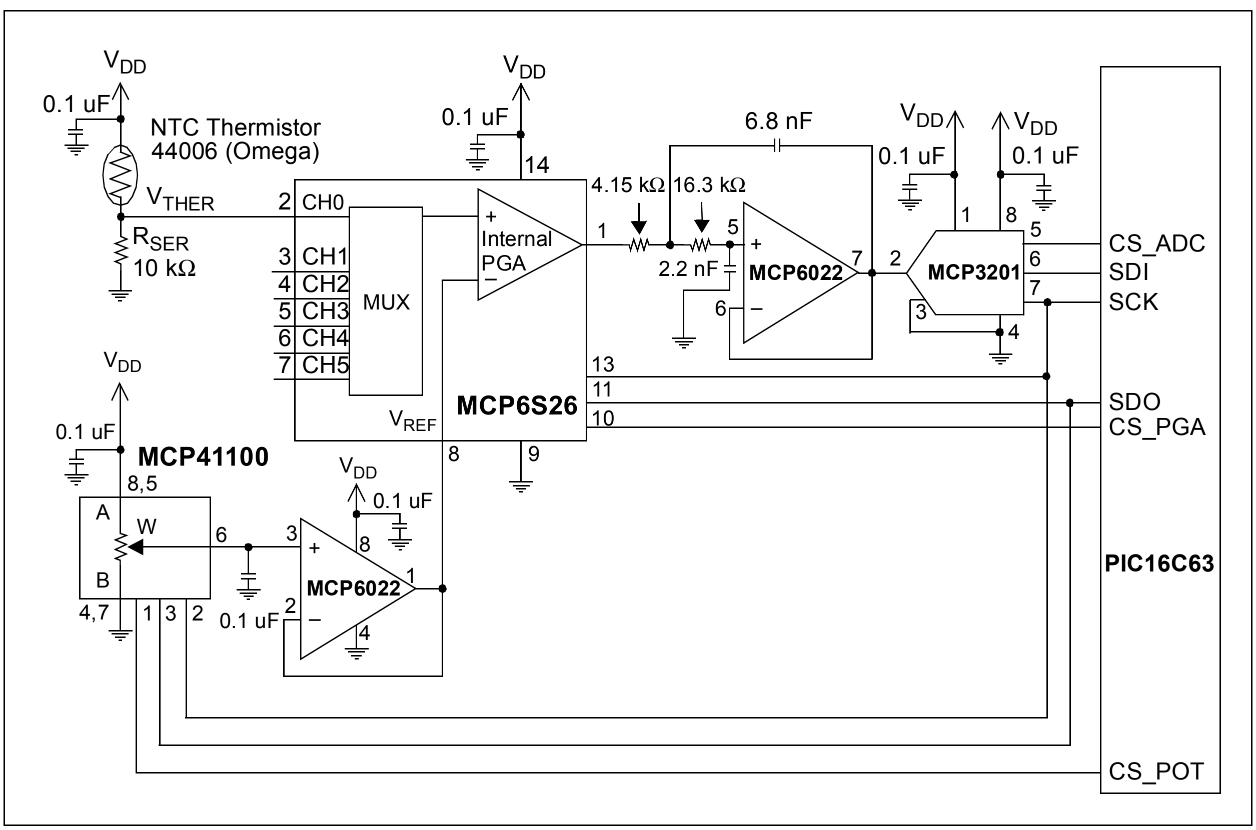

FIGURE 4: *The linearized thermistor is connected directly to the MCP6S26, a six channel PGA.*

INTERFACING THE PGA TO A SILICON TEMPERATURE SENSOR

The Silicon Temperature Sensor is an alternative that can be interfaced with Microchip's PGAs. Silicon Temperature Sensors are available with various output structures, such as voltage out, digital out or logic out (which indicate temperature thresholds). Microchip's voltage output Silicon Temperature sensors are used when driving the input of a multiplexed PGA. The voltage out Silicon Temperature Sensors from Microchip are the TC1046, TC1047 and TC1047A.

Although all of these sensors can be interfaced with the MCP6S26, the TC1047A is used in the example shown in Figure 5. The output range of the TC1047A, and, consequently, the programming of V_{REF} and gain of the MCP6S26, is dependent on your measurement needs. Table 1 gives some example temperature ranges. Refer to the TC1047A data sheet (DS21498) for more information concerning your temperature measurement requirements.

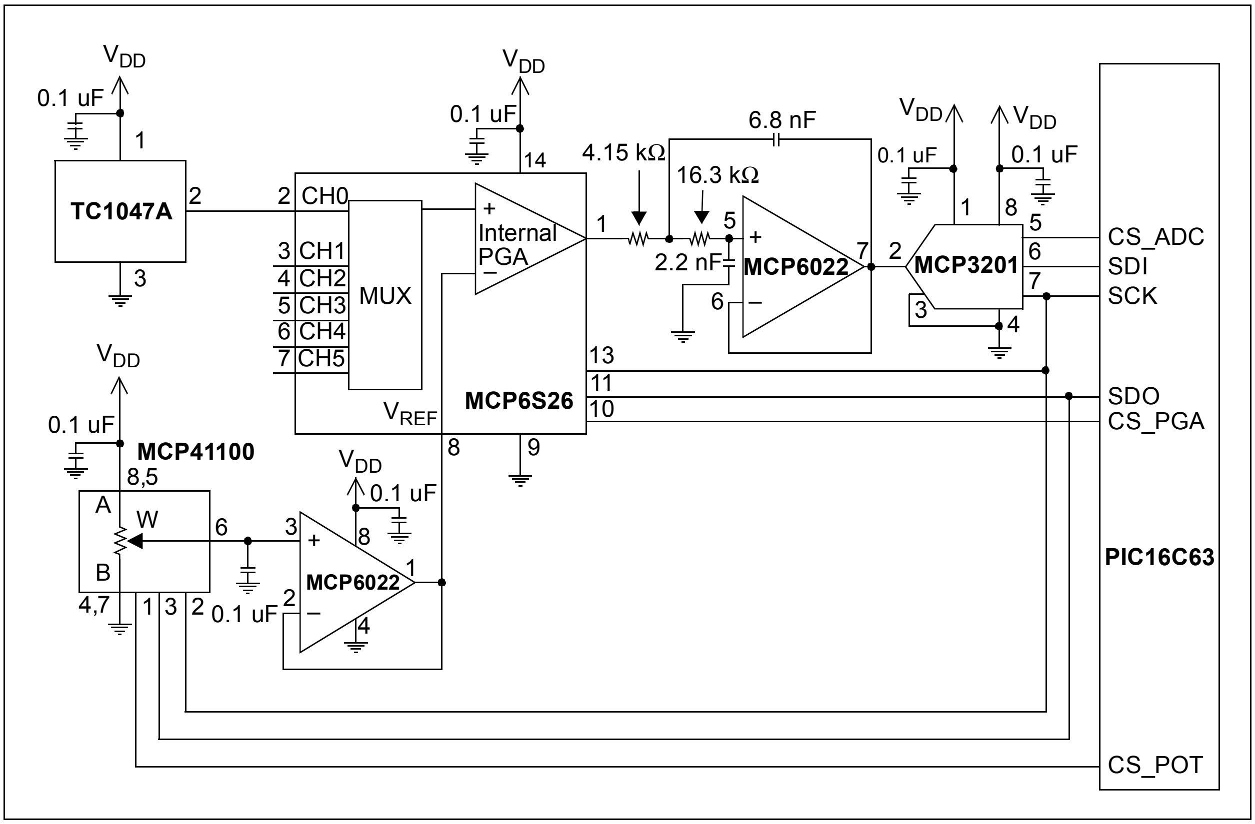

FIGURE 5: TC1047A Silicon Temperature Sensor from Microchip is interfaced with the 6-channel MCP6S26 PGA. The voltage reference on pin 8 of the MCP6S26 should be equal to 0V or ground. If a higher, smaller range of the output of the temperature sensor is targeted, the reference circuitry using the MCP41100 and MCP6022 could be used.

TABLE 1: GIVEN A TEMPERATURE MEASUREMENT RANGE, THE KNOWN OUTPUT OF THE TC1047A IS USED IN THE CALCULATION TO OPTIMIZE THE MCP6S26 PGA.

Temperature Measurement Range (°C, typ)	TC1047A Minimum Output (V, typ)	TC1047A Maximum Output (V, typ)	PGA Gain (V/V)	PGA V_{REF} (V)
-30 to +125	0.2	1.75	2	0
-30 to +85	0.2	1.35	2	0
0 to +70	0.5	1.2	5	0.5
70 to +100	1.2	1.5	10	1.25

Selection of PGA Gain

The maximum gain is easily calculated. Take the magnitude of the difference of the input and multiply by the various PGA gain options (1, 2, 4, 5, 8, 10 or 32). Choose the largest output while still being less than V_{DD} - 600 mV (so that the PGA output remains in its linear region).

PGA Reference Voltage

The input range of the reference voltage pin is V_{SS} to V_{DD} of the PGA. In the circuit of Figure 5, V_{SS} = Ground and V_{DD} = 5V. The transfer function of the PGA is equal to:

EQUATION

$$V_{OUT} = GV_{IN} - (G-1)V_{REF}$$

With this ideal formula, the actual restrictions of the output of the PGA should be taken into consideration. Generally speaking, the output swing of the PGA is less that 25 mV from the rail, as specified in the MCP6S2X PGA data sheet (DS21117). However, to obtain good linear performance, the output should be kept within 300 mV from the supply rails. This is specified in the conditions of the “DC gain error” and “DC output nonlinearity”.

Consequently, beyond the absolute voltage limitations on the PGA voltage reference pin, the voltage output swing capability further limits the selection of the voltage at pin 8. The formulas that can be used to calculate these values are:

EQUATION

$$V_{IN}(min) \geq (V_{OUT}(min) + (G-1)V_{REF})/G$$

$$V_{IN}(max) \leq (V_{OUT}(max) + (G-1)V_{REF})/G$$

where:

V_{IN} = input voltage to the PGA.

V_{OUT}(min) = minimum output voltage of PGA = V_{SS} + 0.3V.

V_{OUT}(max) = maximum output voltage of PGA = V_{DD} - 0.3V.

G = gain of the PGA.

V_{REF} = Voltage applied to the PGA’s V_{REF} pin.

It should be noted that the voltage reference to the PGA can be set using a voltage reference device. A variable voltage reference may be required because of the various requirements on other channels of the PGA. If a variable voltage reference is required, the circuit in Figure 4 and Figure 5 can be used.

DIGITIZING THE SIGNAL FOR THE MICROCONTROLLER

In Figure 4 and Figure 5, the signal path takes the temperature voltage from the output of the PGA, through an anti-aliasing filter, into an A/D converter and then to the PICmicro® microcontroller for further processing.

At the output of the PGA, an anti-aliasing filter is inserted. This is done prior to the A/D conversion in order to reduce noise. The anti-aliasing filter can be designed with a gain of one or higher, depending on the circuit requirements. Again, the MCP6022 operational amplifier is used to match the frequency response of the PGA. Microchip’s FilterLAB® software can be used to easily design this filter’s frequency cut-off and gain. The anti-aliasing filter in this circuit is a Sallen-Key (non-inverting configuration) with a cut-off frequency of 10 Hz. This frequency is low enough to remove most of the noise in this, essentially, DC measurement.

Generally speaking, the corner frequency should be selected to pass all of the input signals to the multiplexer in your specific design. For more information concerning the design of anti-aliasing filters, refer to Microchip Technology’s AN699, “Anti-Aliasing, Analog Filters for Data Acquisition Systems” (DS00699).

Finally, the signal at the output of the filter is connected to the input of a 12-bit A/D converter (MCP3201). In this circuit, if noise is kept under control, it is possible to obtain 12-bit accuracy from the converter. Noise is kept under control by using an anti-aliasing filter (as shown in Figure 4 and Figure 5), appropriate bypass capacitors, short traces, linear supplies and a solid ground plane. The entire system is manipulated on the same SPI™ bus for the PGA, digital potentiometer and A/D converter with no digital feed through from the converter during conversion.

PERFORMANCE DATA

This data was taken using one MCP6S26 and one Omega™ Thermistor (44006) and one TC1047A temperature sensor from Microchip. V_{DD} was equal to 5V and V_{SS} equal to ground. The data is reported reliably, but does not represent a statistical sample of the performance of all devices in the product family.

Thermistor Response

The 44006 thermistor from Omega is a 10 kΩ @ 25°C device with 0.2°C resistance tolerance at room temperature. The series resistor (R_{SER}) was 10 kΩ, making this temperature-sensing network linear ±1°C over a 50°C range; 0°C to 50°C. Using 5V for V_{DD}, the linear range of this network over-temperature is 1.17V (0°C) to 3.7V (50°C).The reference voltage applied to the MCP6S26 was ground, with the PGA gain set to 1. The reference voltage applied to the 12-bit A/D converter (MCP3201) was 5V and the 2nd order anti-aliasing filter frequency was 10 Hz.

The data taken from this configuration is in Table 2.

TABLE 2: FROM THE CIRCUIT DIAGRAM OF FIGURE 4, THE RESULTS OF TESTING WITH THE 10 kΩ @ 25°C, 44006 THERMISTOR FROM OMEGA.

Temp. (°C)	Output Voltage MCP6S26 PGA	Digital Output MCP3201 12-bit Converter	Expected PGA Output
0	1.20	984	1.17
5	1.45	1189	1.41
10	1.68	1377	1.67
15	1.96	1607	1.94
20	2.22	1820	2.22
25	2.49	2041	2.5
30	2.77	2270	2.77
35	3.03	2484	3.02
40	3.27	2680	3.26
45	3.47	2844	3.48
50	3.66	3000	3.68

CONCLUSION

The MCP6S2X family of PGAs have one-channel, two-channel, six and eight-channel devices in the product offering. Changing from channel-to-channel may entail a gain and reference voltage change. This could require three 16-bit communications to occur between the PGA and digital potentiometer. With a clock rate of 10 MHz on the SPI interface, this would require approximately 3.4 µs. Additionally, the PGA amplifier would need to settle. Refer to the MCP6S2X PGA data sheet (DS21117) for the settling-time versus gain specification.

This precision PGA device from Microchip not only offers excellent offset voltage performance, but the configurations in these temperature-sensing circuits are easily designed without the headaches of stability that the stand-alone amplifier circuits present to the designer. Stability with these programmable gain amplifiers have been built-in by Microchip engineers.

REFERENCES

AN865, “Sensing Light with a Programmable Gain Amplifier”, Bonnie C. Baker, Microchip Technology Inc.

AN251, “Bridge Sensing with the MCP6S2X PGAs”, Bonnie C. Baker, Microchip Technology Inc.

AN699, “Anti-Aliasing, Analog Filters for Data Acquisition Systems”, Bonnie C. Baker, Microchip Technology Inc.

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2355 West Chandler Blvd.
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2355 West Chandler Blvd.
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Tel: 480-792-7966 Fax: 480-792-4338

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

Australia
Microchip Technology Australia Pty Ltd
Marketing Support Division
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401-2402, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou
Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Hong Kong SAR
Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

China - Shanghai
Microchip Technology Consulting (Shanghai) Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen
Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office
Rm. 1812, 18/F, Building A, United Plaza
No. 5022 Binhe Road, Futian District
Shenzhen 518033, China
Tel: 86-755-82901380 Fax: 86-755-8295-1393

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Rm. B505A, Fullhope Plaza,
No. 12 Hong Kong Central Rd.
Qingdao 266071, China
Tel: 86-532-5027355 Fax: 86-532-5027205

India
Microchip Technology Inc.
India Liaison Office
Marketing Support Division
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
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Singapore
Microchip Technology Singapore Pte Ltd.
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#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Microchip Technology (Barbados) Inc.,
Taiwan Branch
11F-3, No. 207
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Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy
Microchip Technology SRL
Via Quasimodo, 12
20025 Legnano (MI)
Milan, Italy
Tel: 39-0331-742611 Fax: 39-0331-466781

United Kingdom
Microchip Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44-118-921-5869 Fax: 44-118-921-5820

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