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.](image)

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 (RSER, 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}.](image)
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 $V_{\text{VITHER}}$ in Figure 2, Diagram A is shown in Figure 3.

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 ($V_{\text{VITHER}}$) 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 ($V_{\text{VREF}}$) should be 0V or ground.

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

**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.

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

© 2003 Microchip Technology Inc.
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 \( V_{DD} - 600 \text{ mV} \) (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, \( V_{SS} = \text{Ground} \) and \( V_{DD} = 5\text{V} \). The transfer function of the PGA is equal to:

\[
V_{OUT} = G(V_{IN} - (G - 1)V_{REF})
\]

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 than 25 mV from the rail, as specified in the MCP6022 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 non-linearity”.

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:

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

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

where:

- \( V_{IN} \) = input voltage to the PGA.
- \( V_{OUT\text{ (min)}} \) = minimum output voltage of PGA = \( V_{SS} + 0.3\text{V} \).
- \( V_{OUT\text{ (max)}} \) = maximum output voltage of PGA = \( V_{DD} - 0.3\text{V} \).
- \( G \) = gain of the PGA.
- \( V_{REF} \) = Voltage applied to the PGA’s VREF 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.

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

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

AN251, “Bridge Sensing with the MCP6S2X PGAs”, Bonnie C. Baker, Microchip Technology Inc.
Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip’s Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip’s products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, KEELoo, MPLAB, PIC, PICmicro, PICSTART, PRO MATE and PowerSmart are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, microIoD, MXDEV, MXLAB, PICMASTER, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Accuron, Application Maestro, dsPICDEM, dsPICDEM.net, ECONOMONITOR, FanSense, FlexROM, fuzzyLAB, In-Circuit Serial Programming, ICSP, ICEPIC, microPort, Migratable Memory, MPASM, MPLIB, MPLINK, MPSIM, PICC, PICKit, PICDEM, PICDEM.net, PowerCal, PowerInfo, PowerMate, PowerTool, rILAB, rIPIC, Select Mode, SmartSensor, SmartShunt, SmartTel and Total Endurance are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

Serialized Quick Turn Programming (SQTP) is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2003, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

Printed on recycled paper.
WORLDWIDE SALES AND SERVICE

AMERICAS
Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Atlanta
3780 Manned Road, Suite 130
Alpharetta, GA 30022
Tel: 770-640-0034 Fax: 770-640-0307

Boston
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Chicago
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Detroit
Tri-Attra Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, IN 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

Phoenix
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
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 - Shenzhen
Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office
Unit 915
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shin Yokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471-6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
No7-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Microchip Technology (Barbados) Inc.,
Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Austria
Microchip Technology Austria GmbH
Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399 Fax: 43-7242-2244-393

Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Lautrup høj 1-3
Ballerpark DK-2750 Denmark
Tel: 45-4420-9895 Fax: 45-4420-9910

France
Microchip Technology SARL
Parc d’Activité du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - 1er Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Microchip Technology GmbH
Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-89-627-144-0 Fax: 49-89-627-144-44

Italy
Microchip Technology SRL
Via Quasimodo, 12
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

United Kingdom
Microchip Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG4 5TU
Tel: 44-118-921-5869 Fax: 44-118-921-5820

05/30/03