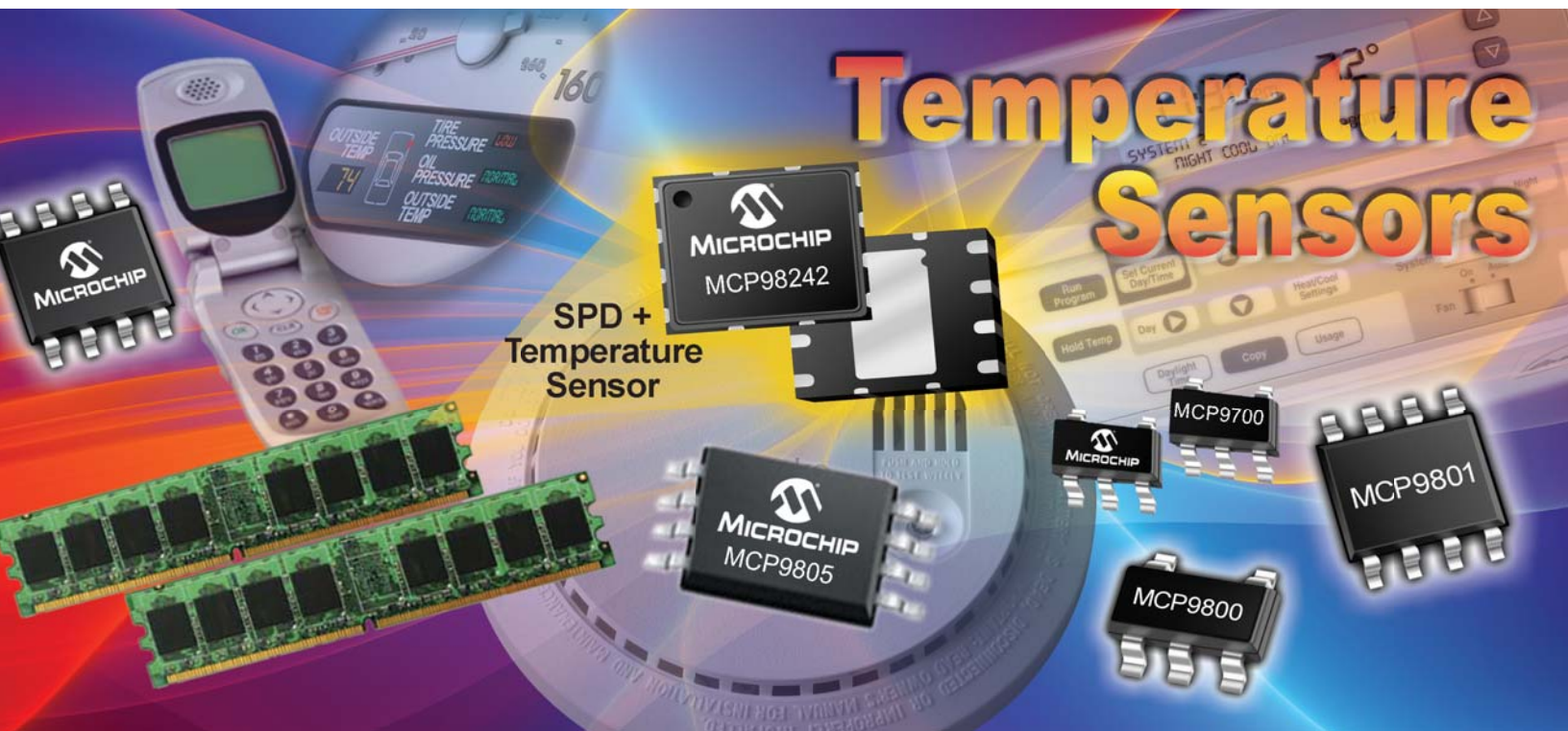# MICROCHIP

Temperature Sensor Design Guide

Temperature Measurement Solutions for Silicon IC Temperature Sensor, Thermocouple, RTD and Thermistor-Based Applications

Design ideas in this guide use the following devices. A complete device list and corresponding data sheets for these products can be found at www.microchip.com.

| Voltage Output Temperature Sensors	Logic Output Temperature Sensors		Serial Output Temperature Sensors		Comparators and Operational Amplifiers		PGA
MCP9700	TC620	TC6501	MCP9800	TC72	TC913A	MCP6544	MCP6S21
MCP9701	TC621	TC6502	MCP9801	TC74	TC7650	MCP6001	MCP6S22
MCP9700A	TC622	TC6503	MCP9802	TC77	TC7652	MCP6021	MCP6S24
MCP9701A	TC623	TC6504	MCP9803	TCN75	MCP616	MCP6231	MCP6S28
TC1046	TC624		MCP9805	TCN75A	MCP6541	MCP6271	
TC1047A			MCP98242		MCP6542	MCP6281	
					MCP6543	MCP6291	

www.microchip.com/analog

TEMPERATURE SENSORS – OVERVIEW

In many systems, temperature control is fundamental. There are a number of passive and active temperature sensors that can be used to measure system temperature, including: thermocouple, resistive temperature detector, thermistor and silicon temperature sensors. These sensors provide temperature feedback to the system controller to make decisions such as, over-temperature shutdown, turn-on/off cooling fan, temperature compensation or general purpose temperature monitor.

Microchip offers a broad portfolio of thermal management products, including Logic Output, Voltage Output and Serial Output Temperature Sensors. These products allow the system designer to implement the device that best meets their application requirements. Key features include high accuracy, low power, extended temperature range and small packages.

In addition, Microchip's linear products can be used to support Thermocouple, RTD and Thermistor applications.

Common Methods of Interfacing a Sensor
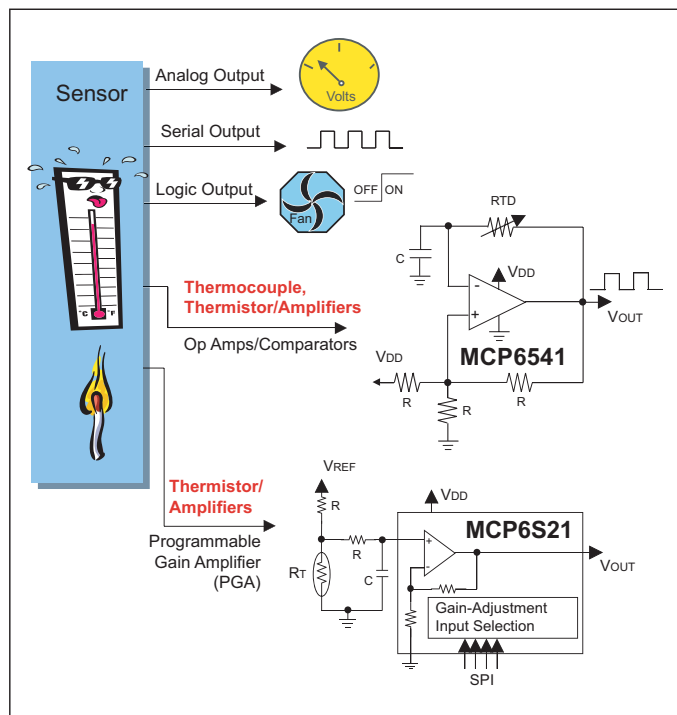
Temperature Measurement Applications

- Computing:
  - CPU overtemperature protection
  - Fan control
- Cellular/PCS:
  - Power amplifier temperature compensation
  - Thermal sensing of display for contrast control
- Power Supply Embedded Systems:
  - Overtemperature shutdown
  - Battery management

Silicon Output Temperature Sensors

Logic Output Temperature Sensors:

Logic output temperature sensor families offer excellent temperature accuracy (±1°C, typical), with a very low operating current of less than 600 µA. These devices can replace mechanical switches in a variety of sensing and control applications.

Voltage Output Temperature Sensors:

Voltage output temperature sensors develop an output voltage proportional to temperature, with a typical temperature coefficient of 6.25 mV/°C, 10 mV/°C and 19.5 mV/°C respectively. These temperature-to-voltage converters can sense a -40°C to +125°C temperature range and feature an offset voltage that allows reading negative temperatures without requiring a negative supply voltage. The extremely low operating current minimizes self-heating and maximizes battery life.

Serial Output Temperature Sensors:

Serial (digital) output temperature sensors offer excellent temperature accuracy (±0.5°C, typical) with a very low operating current of 250 µA (typical). Communication with these devices is accomplished via an industry standard SMBus, I^{2}C™ or SPI compatible interface protocol. These devices feature fast temperature conversion rate, with temperature resolution for the entire family ranging from 0.0625°C to 0.5°C.

Thermocouples

Thermocouples are usually selected because of their wide temperature range (as low as -270°C to as high as 1750°C), ruggedness and price; however, they are highly non-linear and often require significant linearization algorithms. In addition, the voltage output of this temperature sensing element is relatively low when compared to devices that can convert voltage signals to a digital representation. Consequently, analog gain stages are required in the circuit.

Resistive Temperature Detectors (RTDs)

RTDs are able to sense temperatures with extreme accuracy, have consistent and repeatable performance and low drift error (-200°C to +850°C). For precision, these sensors also require a linearization look-up table in the microcontroller due to sensor non-linearities.

Thermistors

Thermistors (-100°C to +150°C) are normally used for overtemperature shutdown purposes. Although not as accurate as some of the other temperature sensor solutions, thermistors are inexpensive and come in small packages. They are also non-linear and require a temperature compensation look-up table.

LOGIC OUTPUT TEMPERATURE SENSORS

Logic output sensors typically function as a thermostat, notifying the system that a minimum or maximum temperature limit has been reached. Sometimes referred to as a temperature switch, these devices can be used to turn-on either a fan or warning light when high or low temperature conditions are detected. Since the output is typically not latched, the switch will turn off when the temperature falls below or rises above the temperature set point. Note that it is necessary to have hysteresis so the switch does not "chatter" when crossing the temperature set point.

Most logic output temperature sensors are available in either a **Hot** (for temperature-increasing applications) or **Cold** (for temperature-decreasing applications) option. The hot and cold options ensure that the hysteresis is in the appropriate position, either below or above the temperature set point.

Logic Output Temperature Sensor Key Features:
- Logic-Level Output
- Notifies System When Temperature is Above (or Below) a Preset Value
- Factory and User-programmable Temperature Settings
- Available in a Variety of Output Configurations

Logic Output Temperature Sensor Applications:
- Fan Controllers
- Power Supplies
- Motor Drives
- RF Power Amplifiers

TC6501/2/3/4 Key Features:
- Factory-programmed Temperature Set Points
- No External Components Required
- Small SOT-23 Packages

TC620/1 Key Features:
- Dual Trip Point Temperature Sensor
- Wide Voltage Supply Range: +4.5V to +18V
- User-programmable Trip Point and Hysteresis

TC623 Key Features:
- Dual Trip Point Temperature Sensor
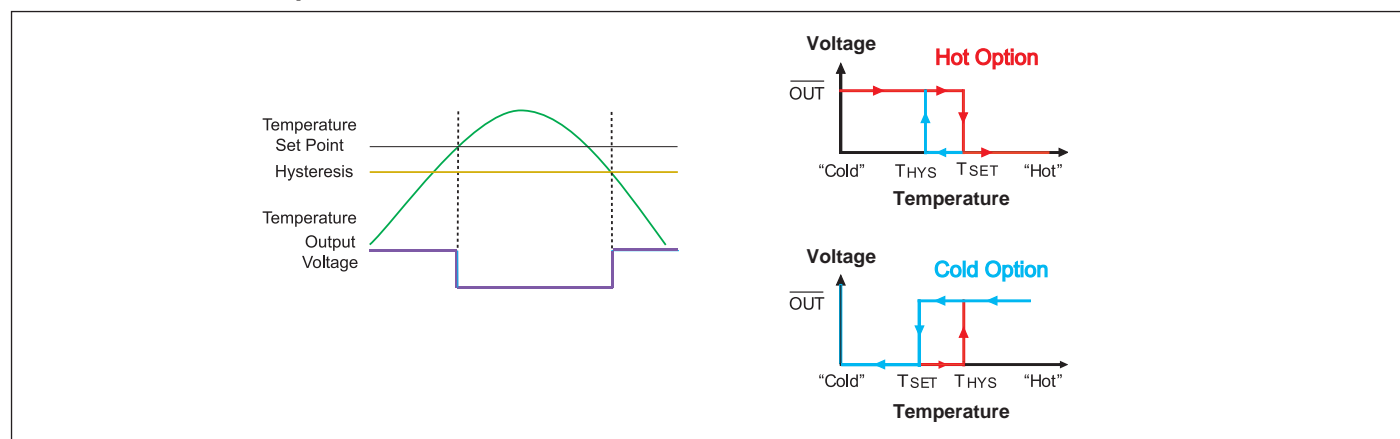- User-programmable Trip Point and Hysteresis

TC622/4 Key Features:
- Low-Cost Single Trip Point Temperature Sensor
- Temperature Set Point Easily Programs with a Single External Resistor
- TO-220 Package for Direct Mounting to Heatsink

Logic Output Temperature Sensors Used as Temperature Switches
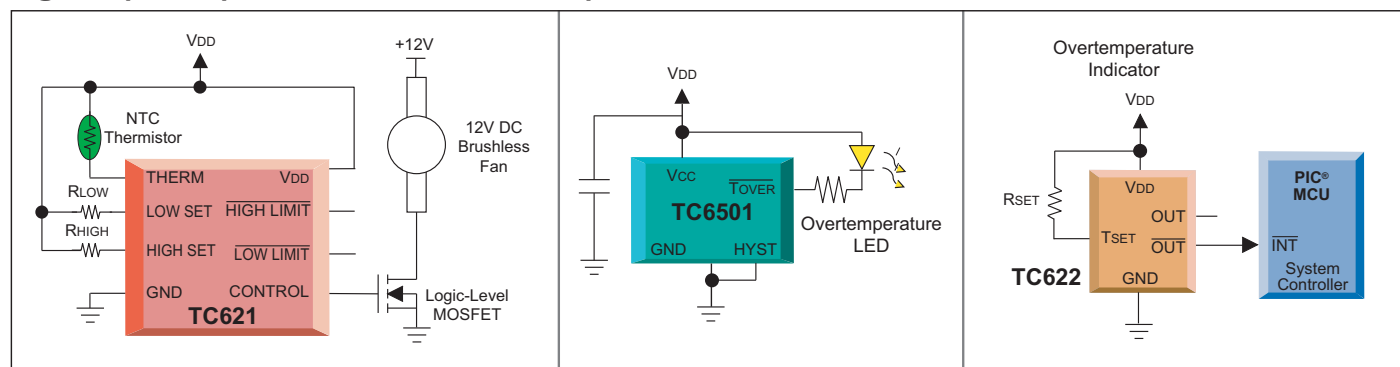
TC6501 Hot and Cold Options

Temperature Sensor Design Guide

VOLTAGE OUTPUT TEMPERATURE SENSORS

A Voltage Output Temperature Sensor provides an analog output signal of varying voltage on a single pin. The output voltage has a factory set slope (e.g., 10 mV/°C) and correlates to the ambient temperature of the device. The device output is typically connected to a stand-alone or integrated ADC (Analog-to-Digital Converter).

The circuit shown below can be used to measure the LCD panel's temperature at multiple locations. The operational amplifier functions as an averaging circuit to provide a composite voltage output that can be used to adjust the LCD contrast.

Voltage Output Temperature Sensor Key Features:

- Easy System Integration
- Reduces PCB Space
- Low Current Consumption
- Minimizes Design Time

Voltage Output Temperature Sensor Typical Applications:

- Cellular Phones
- Temperature Measurement/Instrumentation
- Consumer Electronics

TC1046 Key Features:

- Wide Temperature Measurement Range: -40°C to +125°C
- High Temperature Accuracy: ±0.5°C (typ.)
- Linear Temperature Slope: 6.25 mV/°C

TC1047A Key Features:

- Wide Temperature Measurement Range: -40°C to +125°C
- High Temperature Accuracy: ±0.5°C (typ.)
- Linear Temperature Slope: 10 mV/°C

MCP6021 (Op Amp) Key Features:

- Single-Supply: 2.5V to 5.5V
- Rail-to-Rail Input and Output
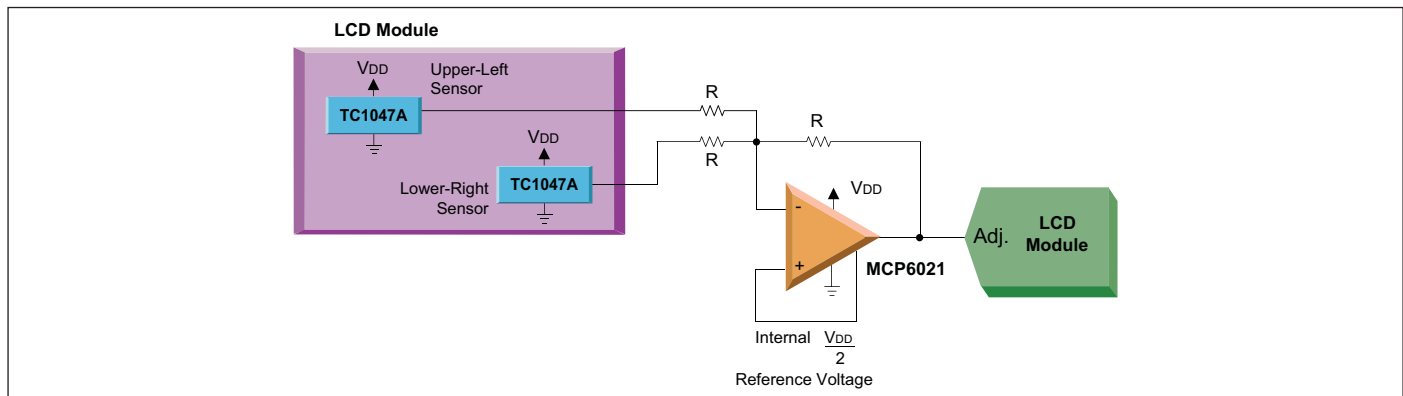- Unity-Gain Stable
- V_{DD}/2 Reference Output

MCP9700 Key Features:
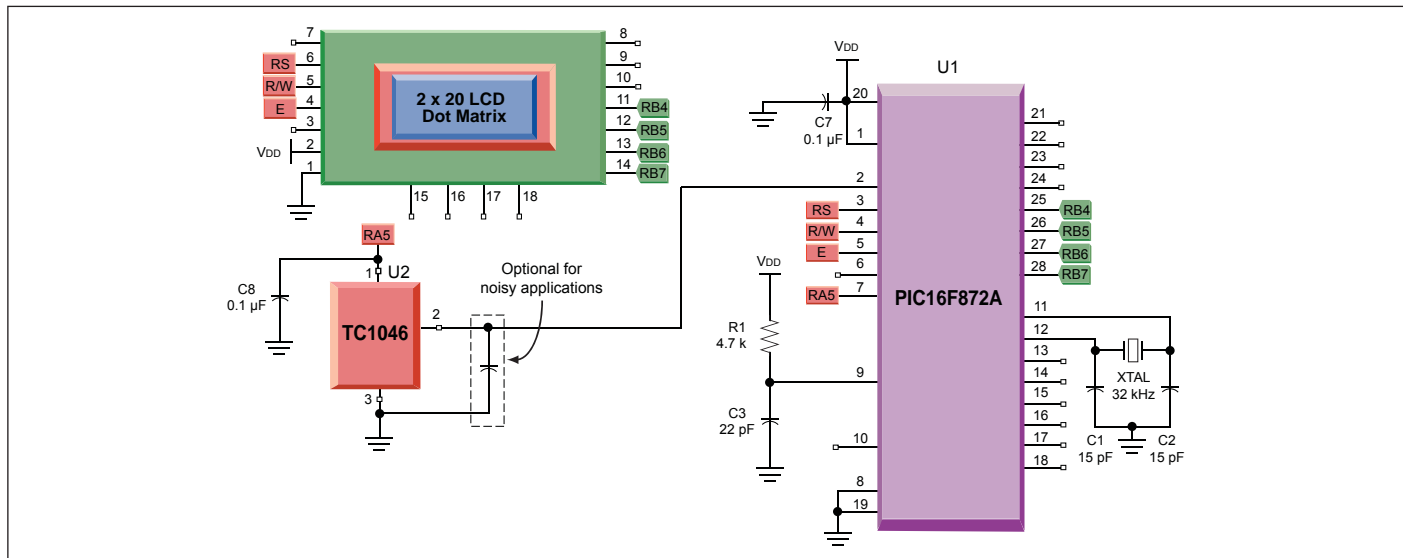
- Low Cost
- Temperature Accuracy: ±1°C (typ.)

MCP9700A Key Features:

- Low Cost
- Temperature Accuracy: ±1°C (typ.)

LCD Contrast Control

Using the TC1046 to Create a Simple Temperature Measurement System

4

VOLTAGE OUTPUT TEMPERATURE SENSORS

Linear Active Thermistors

The MCP9700/01 and MCP9700A/01A families of Linear Active Thermistor® Integrated Circuits (ICs) are analog temperature sensors that convert temperature to an analog voltage output.
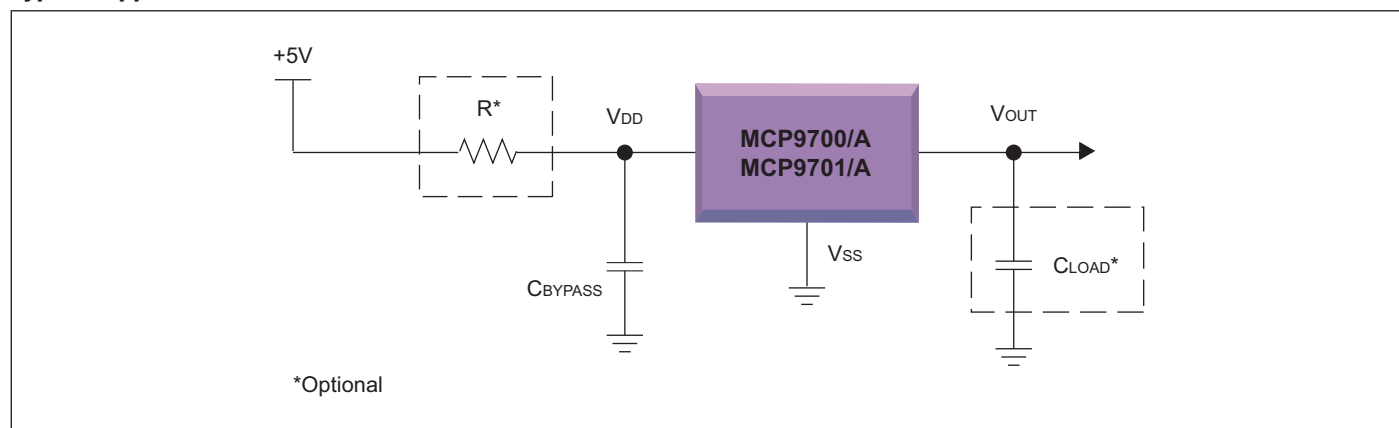
These sensors compete with a thermistor solution in price and performance. Unlike resistive sensors (such as thermistors), Linear Active Thermistor ICs do not require an additional signal-conditioning circuit. Therefore, the biasing circuit development overhead for thermistor solutions can be eliminated by implementing these low-cost devices. The voltage output pin (V$_{OUT}$) can be directly connected to the ADC input of a microcontroller.

The sensor output voltage is proportional to ambient temperature with temperature coefficient of 10 mV/°C and 19.5 mV/°C with output voltage at 0°C scaled to 500 mV and 400 mV, respectively. These coefficients are ideal for 8-bit Analog-to-Digital Converters referenced at 5V and 2.5V. The operating current is 6 µA (typ.) and they use a PCB space saving 5-pin SC-70/SOT-23 and 3-pin TO-92 packages.

MCP9700/01 Key Features:

- 5-pin SC-70 Package
- 3-pin TO-92 Package
- 5-pin SOT-23 Package
- Operating temperature range: -40°C to 125°C
- Temperature Coefficient: 10 mV/°C (MCP9700)
- Temperature Coefficient: 19.5 mV/°C (MCP9701)
- Low power: 6 µA (typ.)

MCP9700/01 and MCP9700A/01A Typical Applications:

- Entertainment Systems
- Home Appliance
- Battery Packs and Power Supplies for Portable Equipment
- General Purpose Temperature Monitoring

Sensor Application Tips

The MCP9700/01 and MCP9700A/01A ICs are designed to drive large capacitive loads. This capability makes the sensors immune to board parasitic capacitance, which allows the sensors to be remotely located and to drive long PCB trace or shielded cables to the ADC. In addition, adding capacitive load at V$_{OUT}$ helps the sensors transient response by reducing overshoots or undershoots. This provides a more stable temperature reading.

IC temperature sensors use analog circuitry to measure temperature. Unlike digital circuits, analog circuits are more susceptible to power-supply noise. It is recommended that a bypass capacitor C$_{BYPASS}$ of 0.1 µf to 1 µf be placed at close proximity to the V$_{DD}$ and V$_{SS}$ pins of the sensor. The capacitor provides protection against power-supply glitches by slowing fast transient noise. However, the effectiveness of the bypass capacitor depends upon the power-supply source resistance. Larger source resistance provides RC network with the C$_{BYPASS}$ and adds a corner frequency to filter out the power-supply noise. Adding a series resistor to the power-supply line is adequate to increase the source resistance.

Typical Application Circuit For a Thermistor Solution

VOLTAGE OUTPUT TEMPERATURE SENSORS

IC Sensor Compensation Technique

Typically, the accuracy of an IC temperature sensors is within ±1°C at room temperature and the accuracy error increases exponentially at hot and cold temperature extremes. The sensor error characteristic has a parabolic shape, which can be described using a second order equation. The equation can be used to compensate the sensor error to provide higher accuracy over the operating temperature range. This is done by evaluating the equation at the temperature of interest (sensor output in degree Celsius) and subtracting the result from the sensor output. The subtracted result in °C is the compensated sensor output.

For higher accuracy, the equation can be computed using a standard PIC microcontroller, such as PIC16FXXXX, PIC18FXXXX, PIC24FXXXX or dsPIC30FXXXX.

Compensated Sensor Output (°C) = Sensor Output (°C) – Sensor Error|$_{\text{Sensor Output (°C)}}$

A short look-up table can also be generated for low-level PIC microcontrollers such as PIC10FXX, PIC12FXXX, PIC14FXXX and PIC16FXXX. For additional information, see AN1001: *IC Temperature Sensor Accuracy Compensation with a PIC® Microcontroller.*

Typical Results

Equation 1, 2 and 3 show the 2nd order error equation of the tested parts for the MCP9800, MCP9700/A and MCP9701/A, respectively. Since these devices have functional differences, the operating temperature range and temperature error coefficients differ. The equations below describe the typical device temperature error characteristics.

Equation 1: MCP9800 2nd Order Equation

$$Error_{T\_2} = EC_2(125\,°C - T_A) \cdot (T_A - -55\,°C) + EC_1(T_A - -55\,°C) + Error_{-55}$$

Where:

EC_2 = 150 x 10^{-6}°C/°C^2
EC_1 = 7 x 10^{-3}°C/°C
$Error_{-55}$ = -1.5°C

Equation 2: MCP9700/A 2nd Order Equation

$$Error_{T\_2} = EC_2(125\,°C - T_A) \cdot (T_A - -40\,°C) + EC_1(T_A - -40\,°C) + Error_{-40}$$

Where:

EC_2 = 244 x 10^{-6}°C/°C^2
EC_1 = 2 x 10^{-12}°C/°C » 0°C/°C
$Error_{-40}$ = -2°C

Equation 3: MCP9701/A 2nd Order Equation

$$Error_{T\_2} = EC_2(125\,°C - T_A) \cdot (T_A - -515\,°C) + EC_1(T_A - -15\,°C) + Error_{-15}$$

Where:

EC_2 = 200 x 10^{-6}°C/°C^2
EC_1 = 1 x 10^{-3}°C/°C
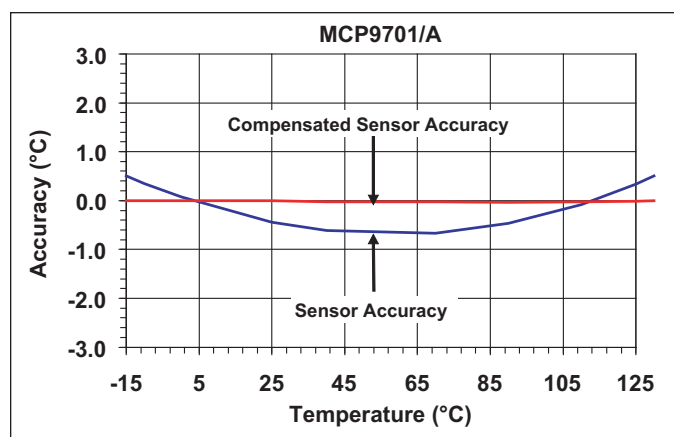$Error_{-15}$ = -1.5°C

Graph 1: MCP9800 2nd Order Equation
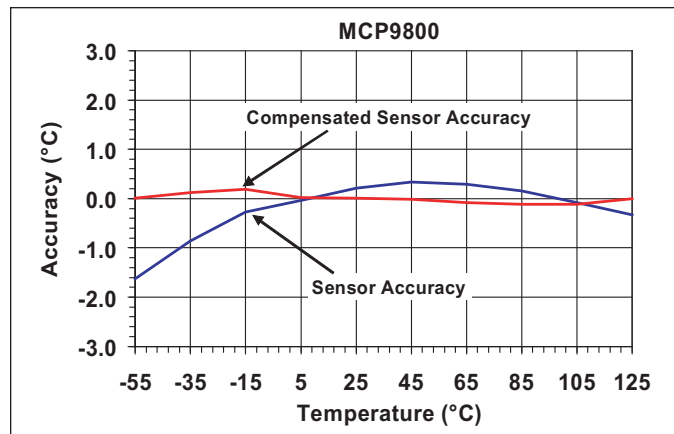
Graph 2: MCP9700/A 2nd Order Equation
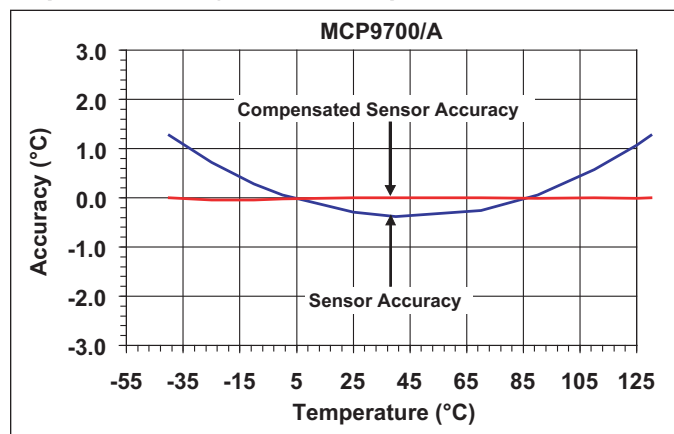
Graph 3: MCP9701/A 2nd Order Equation

SERIAL OUTPUT TEMPERATURE SENSORS

Typically, serial output temperature sensors use a two or three wire interface to the host controller and provide functions that are user programmable. Functions such as temperature alert output allow the user to configure the device as a stand-alone temperature monitoring system. The alert output can be used to notify the system controller to act upon the change in temperature. This feature eliminates the need for the system controller to monitor temperature continuously using the serial interface.

The figure below illustrates a multi-zone temperature measurement application. Communication with the MCP9801 is accomplished via a two-wire I2C™/SMbus compatible serial bus. This device can be set to notify the host controller when the ambient temperature exceeds a user-specified set point. The microcontroller can monitor the temperature of each sensor on the serial bus by either reading the temperature data register or functioning as a stand-alone thermostat. The temperature threshold trip point is programmed by writing to the set point register. The ALERT pin is an open-drain output that can be connected to the microcontroller's interrupt pin for overtemperature interrupt.

Serial Output Temperature Sensor Applications:
- Personal Computers
- Set-top Boxes
- Cellular Phones
- General Purpose Temperature Monitoring

MCP9800/1/2/3 Key Features:
- ±1°C (max.) Accuracy From -10°C to +85°C
- Supply Current: 200 µA (typ.)
- One Shot Temperature Measurement

TC72 Key Features:
- 10-Bit Temperature-to-Digital Converter
- Power-saving One-shot Temperature Measurement
- Low Power Consumption

TC74 Key Features:
- Simple 2-wire Serial Interface
- Digital Temperature-sensing in SOT-23-5 or TO-22-5 Packages
- Low Power Consumption

TC77 Key Features:
- 13-Bit Temperature-to-Digital Converter
- Low Power Consumption
- ±1°C (max.) Accuracy From +25°C to +65°C
- SPI Compatible Communications Interface

TCN75 Key Features:
- Industry Standard SMBus/I2C™ Interface
- Programmable Trip Point and Hysteresis
- Thermal Event Alarm Output Functions as Interrupt or Comparator/Thermostat Output

A Multi-zone Temperature Measurement System Using the Two-wire Serial Communication Port of the MCP9801

DIGITAL TEMPERATURE SENSOR

The MCP9805 digital temperature sensor is designed to meet the JEDEC standard JC42.4 for Mobile Platform Memory Module Thermal Sensor. This device provides an accuracy of ±1°C (max.) from a temperature range of +75°C to +95°C (active range) and ±2°C (max.) from +40°C to +125°C (monitor range) as defined in the JEDEC standard. In addition, this device has an integrated 256 byte EEPROM for SPD.

MCP9805 Key Features:

- Accuracy with 0.25°C/LSb Resolution:
  - ±1°C (max.) from +75°C to +95°C
  - ±2°C (max.) from +40°C to +125°C
  - ±3°C (max.) from -20°C to +125°C
- 256 byte EEPROM for SPD
- Operating Current: 200 µA (typ.)
- Shutdown Current: 0.1 µA (typ.)

MCP9805 Applications:

- Dual In-line Memory Module (DIMM)
- Personal Computers (PCs) and Servers
- Hard Disk Drives and Other PC Peripherals
- General Purpose Temperature Sensor

Register Structure Block Diagram

Typical Application

Register Structure Block Diagram

DIGITAL TEMPERATURE SENSOR

The MCP98242 digital temperature sensor is designed to meet the JEDEC standard JC42.4 for Mobile Platform Memory Module Thermal Sensor. This device provides an accuracy of ±1°C (max.) from a temperature range of +75°C to +95°C (active range) and ±2°C (max.) from +40°C to +125°C (monitor range) as defined in the JEDEC standard.

MCP98242 Key Features:

- Accuracy with 0.25°C/LSb Resolution:
  - ±1°C (max.) from +75°C to +95°C
  - ±2°C (max.) from +40°C to +125°C
  - ±3°C (max.) from -20°C to +125°C
- 256 byte EEPROM for SPD
- Shutdown Current: 0.1 μA (typ.)

MCP98242 Applications:

- Dual In-line Memory Module (DIMM)
- Personal Computers (PCs) and Servers
- Hard Disk Drives and Other PC Peripherals
- General Purpose Temperature Sensor

Typical Application
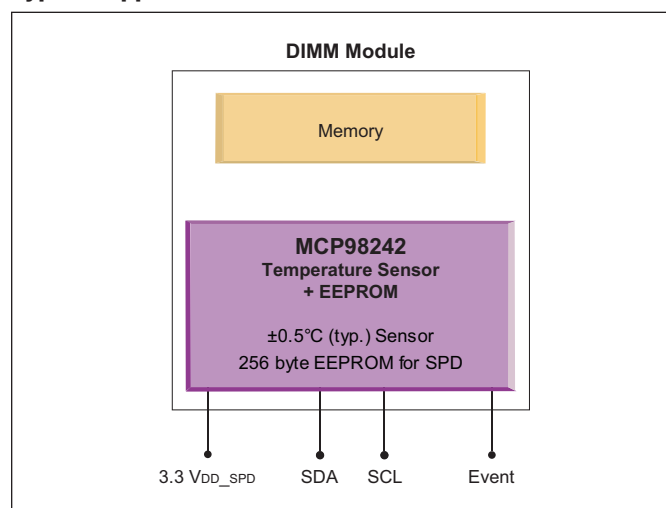
Register Structure Block Diagram
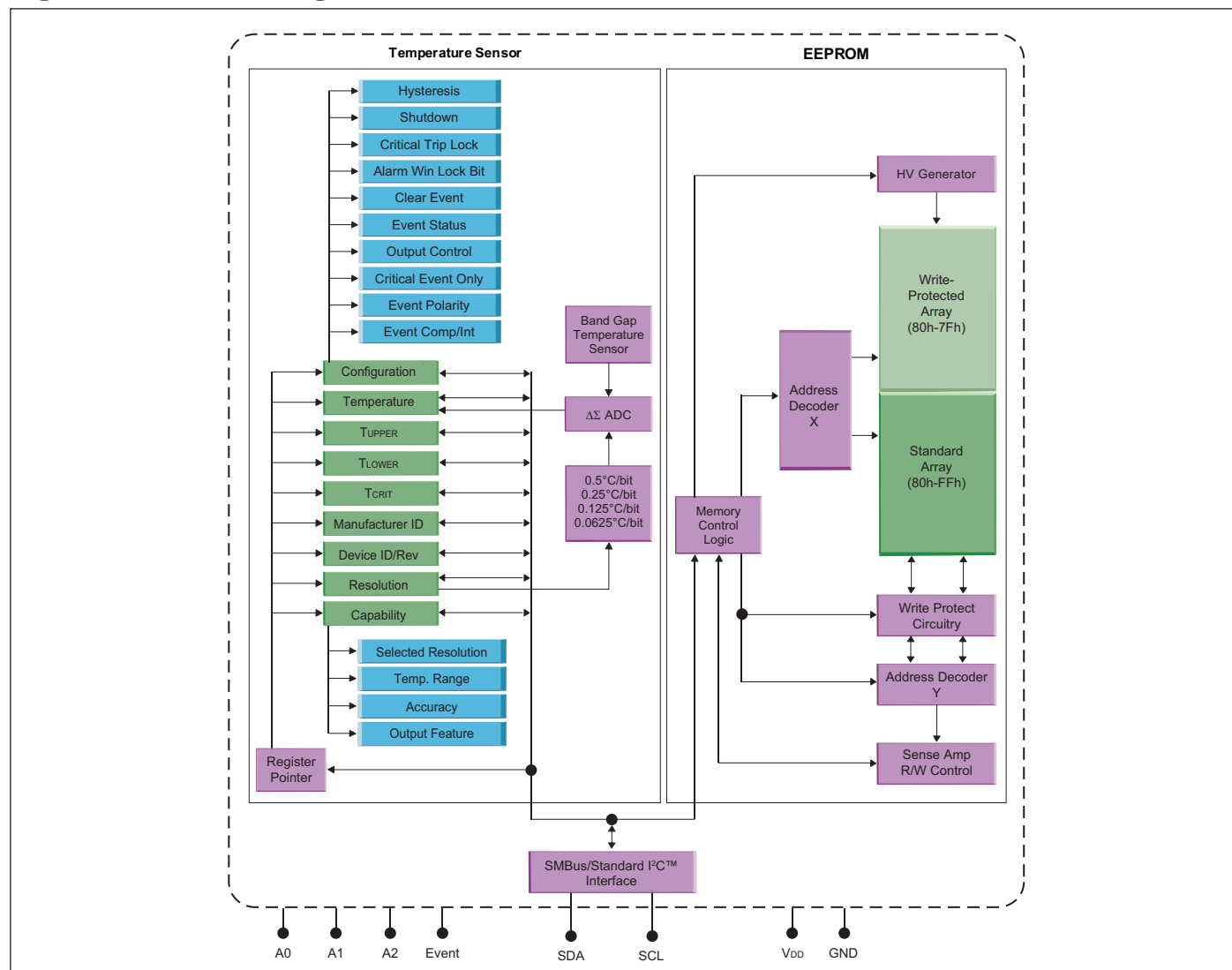
THERMOCOUPLES

Thermocouples

The thermocouple can quantify temperature as it relates to a reference temperature. This reference temperature is usually sensed using a Thermistor, RTD or Integrated Silicon Sensor. The wide temperature ranges of the thermocouple make it appropriate for many hostile sensing environments.

The thermocouple consists of two dissimilar metallic wires that are connected at two different junctions, one for temperature measurement and the other for reference. The temperature difference between the two junctions is determined by measuring the change in voltage across the dissimilar metals at the temperature measurement junction.

The Instrument Society of America (ISA) defines a number of commercially available thermocouple types in terms of performance. Type E, J, K and T are base-metal thermocouples and can be used to measure temperatures from about -200°C to 1000°C. Type S, R and B are noble-metal thermocouples and can be used to measure temperatures from about -50°C to 2000°C.

The circuit shown below can be used for remote thermocouple sensing applications. The thermocouple is connected to the circuitry via a shielded cable and EMI filters. The thermocouple is tied to a positive and negative supply via large resistors so that the circuit can detect a failed open-circuit thermocouple.

The TC913A auto-zeroed op amp is selected because of its low offset voltage of 15 µV (max.) and high Common Mode Rejection Ratio (CMRR) of 116 dB (typ.). Auto-zero and chopper amplifiers are good thermocouple amplifiers due to their low offset voltage and CMRR specifications.

The cold junction compensation circuit is implemented with the TC1047A silicon IC temperature sensor located on the PCB.

Thermocouple Key Features:

- Self-powered
- -270°C to 1750°C
- Remote Sensing
- Robust Sensor

Thermocouple Applications:

- Stoves
- Engines
- Thermopiles

Silicon Sensors for Cold Junction Compensation:

- TC1047A Analog Temperature Sensor
- MCP9800 12-bit Serial Output Temperature Sensor

Thermocouple Amplifier Circuit
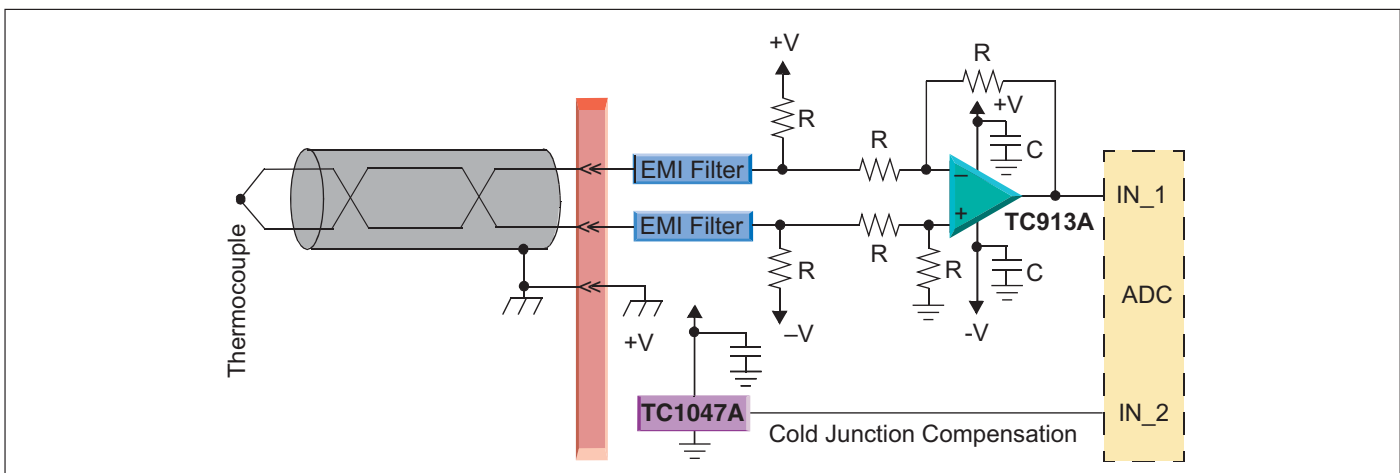
RESISTIVE TEMPERATURE DETECTORS (RTDs)

RTDs

RTDs (Resistive Temperature Detectors) serve as the standard for precision temperature measurements due to their excellent repeatability and stability characteristics. RTDs provide the designer with an absolute result that is fairly linear over temperature. The RTD's linear relationship between resistance and temperature simplifies the implementation of signal-conditioning circuitry.

Circuit A below is easy to modify for a desired temperature-to-frequency range. It requires either precision, low-drift components or a calibration step to achieve high accuracy. Circuit B utilizes pull-up and pull-down resistors to excite the RTD, employing the TC913A op amp to amplify the small voltage changes that correspond to temperature.

RTD Key Features:

- Extremely Accurate with Excellent Linearity
- Variety of Packages
- Wire-wound or Thin-film

RTD Applications:

- Industrial Instrumentation
- Hot Wire Anemometers
- Laboratory-quality Measurements

Recommended Products:

- TC913A/B – Auto-zero Op Amps
- TC7650/2 – Chopper-stabilized Op Amps
- MCP616/7/8/9 – Micropower Bi-CMOS Op Amps
- MCP6021/2/4 – 10 MHz Bandwidth Op Amps
- MCP6041/2/3/4 – 600 nA, Rail-to-Rail Input/Output Op Amps
- MCP6541/2/3/4 – Push-Pull Output Sub-Microamp Comparators
- MCP6S21/2/6/7 – Single-ended, Rail-to-Rail Input/Output Low-gain Programmable Gain Amplifiers (PGAs)

RTD Temperature Measurement Circuits
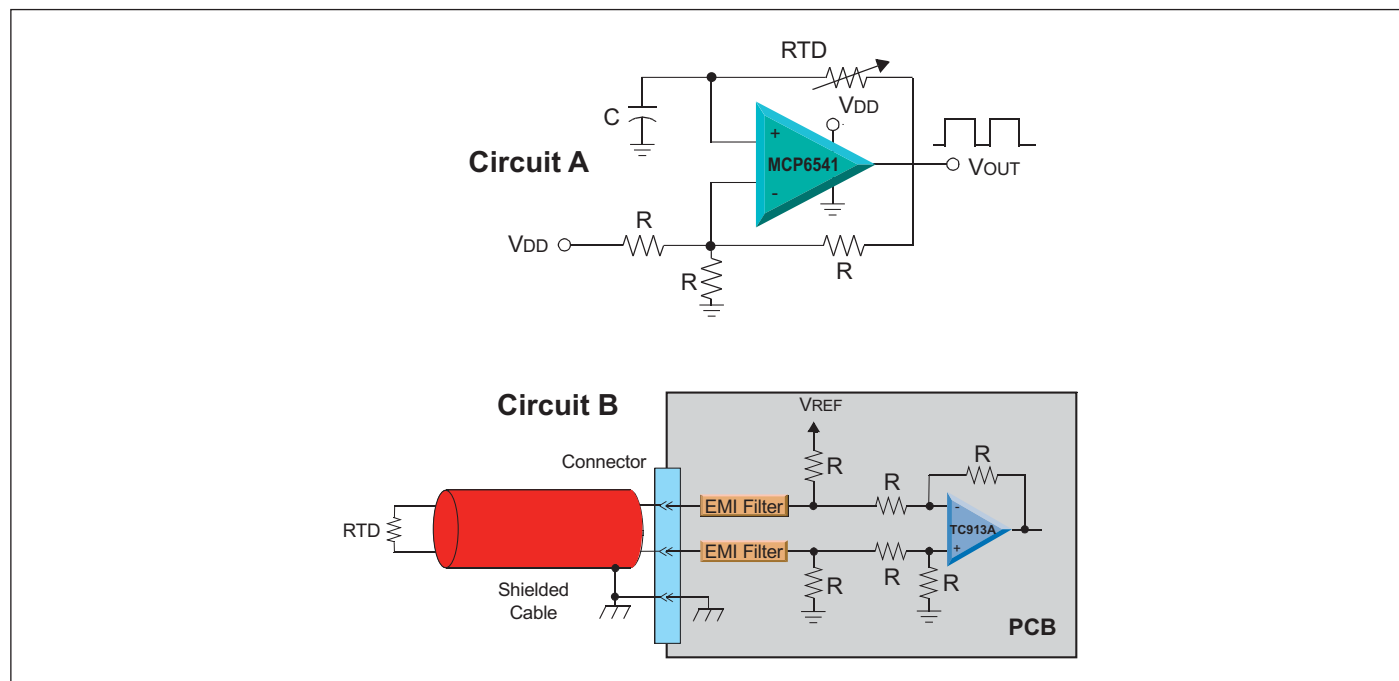
THERMISTORS (THERMALLY SENSITIVE RESISTORS)

Thermistors are built with semiconductor materials and can have either a positive (PTC) or negative (NTC) temperature coefficient. However, the NTC is typically used for temperature sensing.

Advantages of thermistors include a very high sensitivity to changes in temperature (having a thermal response of up to -100Ω/°C at 25°C), fast response time and low cost. The main drawback of thermistors is that the change in resistance with temperature is highly non-linear at temperatures below 0°C and greater than 70°C.

A conventional fixed gain thermistor amplifier circuit is shown below. A simple voltage divider is created with a reference resistor (R_1) and the thermistor (R_T). A constant voltage source is supplied (V_{REF}) with the output of the voltage divider (V_{TH}) directly correlating to temperature. The response is shown in the graph of temperature vs. output voltage to the right of the circuit. It is fairly linear in the range of 0-70°C, but the accuracy of the circuit is limited without adding additional circuitry.

The advantage of the PGA circuit (below) is illustrated by comparing the V_{OUT} slope plots of the conventional circuit with the PGA circuit. The V_{OUT} slope for the PGA circuit has a minimum value of 30 mV for temperatures greater than 35°C, which means that only a 9-bit ADC is required. In contrast, a voltage divider with a gain of 1 will require an 11-bit, or higher, ADC to provide an equivalent temperature resolution. The resolution of a thermistor circuit is important in applications such as overtemperature shutdown circuits.
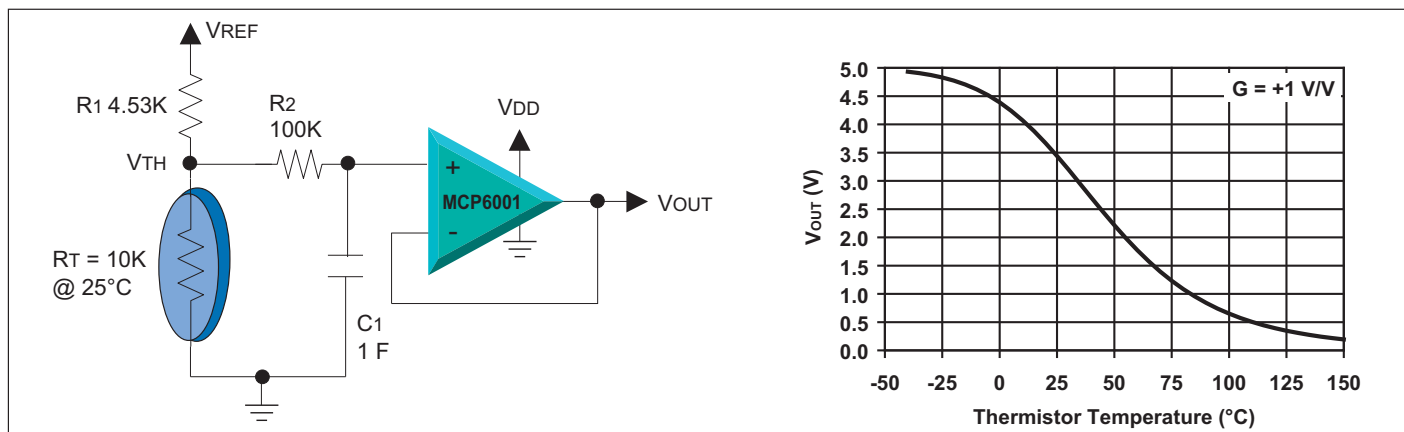
Thermistor Key Features:

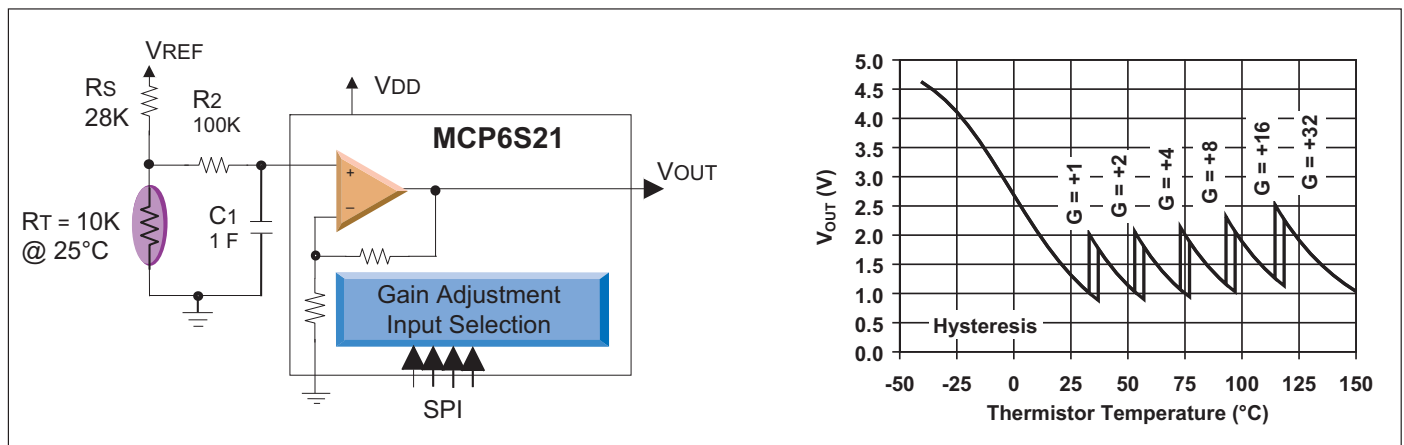- Inexpensive
- Two-wire Measurement
- Variety of Packages

Thermistor Applications:

- Battery Chargers
- Power Supplies
- Cold Junction Compensation

Conventional Fixed Gain Thermistor Amplifier

PGA Circuit Interfaced with a Thermistor

RELATED SUPPORT MATERIAL

The following Application Notes are available on the Microchip web site: **www.microchip.com.**

Application Notes

General Temperature Sensing

AN679: *Temperature Sensing Technologies*

The most popular temperature sensor technologies are discussed at a level of detail that will give the reader insight into the methods for determining which sensor is most appropriate for a particular application.

AN867: *Temperature-Sensing with a Programmable Gain Amplifier*

The implementation of temperature measurement systems from sensor to PIC® microcontroller using a NTC thermistor, silicon temperature sensor, anti-aliasing filter, A/D converter and microcontroller are discussed.

AN929: *Temperature Measurement Circuits for Embedded Applications*

Explores selection techniques for temperature sensor and conditioning circuits to maximize the measurement accuracy, while simplifying the interface to a microcontroller.

AN1001: *IC Temperature Sensor Accuracy Compensation with a PICmicro® Microcontroller*

The typical accuracy of analog and serial-output IC temperature sensors is within ±1°C, however, at hot or cold extremes, the accuracy decreases non-linearly. This application note is based on the analog output MCP9700/9701 and serial output MCP9800 temperature sensors. It derives an equation describing the sensor's typical non-linear characteristics, which can be used to compensate for the sensor's accuracy error over the specified operating temperature range.

Silicon IC Temperature Sensors

Analog Output

AN938: *Interfacing a TC1047A Analog Output Temperature Sensors to a PICmicro®* Microcontroller

Discusses system integration, firmware implementation and PCB layout techniques for using the TC1047A in an embedded system.

TB051: *Precision Temperature Measurement Technical Brief*

Provides a description for interfacing a TC1046 temperature sensor to a PIC16F872 microcontroller. A 2 x 20 dot matrix LCD is included in the design to provide additional functionality.

Logic Output

AN762: *Applications of the TC62X Solid-State Temperature Sensor*

Sensing temperature and comparing that temperature to preset limits is the basis for a variety of problems that designers face in system design and process control. This Application Note discusses the new generation of small, easy-to-use, temperature-sensing products provided by Microchip; namely, the TC62X product family.

AN773: *Application Circuits of the TC620/TC621 Solid-State Temperature Sensors*

Discusses the benefits of the TC620/TC621 solid-state temperature sensors.

Serial Output

AN871: *Solving Thermal Measurement Problems Using the TC72 and TC77 Digital Silicon Temperature Sensors*

Discusses the benefits of the TC72/TC77 temperature sensors by analyzing their internal circuitry, illustrating the principles these sensors employ to accurately measure temperature.

AN913: *Interfacing the TC77 Thermal Sensor to a PICmicro® Microcontroller*

Discusses system integration, firmware implementation and PCB layout techniques for using the TC77 in an embedded system.

AN940: *Interfacing the TC72 SPI Digital Temperature Sensor to a PICmicro® Microcontroller*

Techniques for integrating the TC72 into an embedded system are demonstrated using the PICkit™ Flash Starter Kit.

TB050: *Monitoring Multiple Temperature Nodes Using TC74 Thermal Sensors and a PIC16C505*

The PIC16C505 is a 14-pin MCU that can easily interface to the TC74. This Technical Brief illustrates the ease of interfacing these two products.

TB052: *Multi-Zone Temperature Monitoring with the TCN75 Thermal Sensor*

Presents an example of a simple, multi-zone thermal-monitoring system using the Hardware mode of the Master Synchronous Serial Port (MSSP) module of a PIC® microcontroller.

RELATED SUPPORT MATERIAL

Thermocouples

AN684: *Single-Supply Temperature Sensing with Thermocouples*

This Application Note focuses on circuit solutions that use thermocouples in their design. The signal-conditioning path for the thermocouple system is discussed, followed by complete application circuits.

RTDs

AN687: *Precision Temperature Sensing with RTD Circuits*

Focuses on circuit solutions that use platinum RTDs in their design.

AN895: *Oscillator Circuits for RTD Temperature Sensors*

Demonstrates how to design a temperature sensor oscillator circuit using Microchip's low-cost MCP6001 operational amplifier and the MCP6541 comparator.

Thermistors

AN685: *Thermistors in Single-Supply Temperature Sensing Systems*

Focuses on circuit solutions that use Negative Temperature Coefficient (NTC) thermistors in their design.

AN897: *Thermistor Temperature Sensing with MCP6S2X PGA*

Presents two circuits that employ a precise, Negative Temperature Coefficient (NTC) thermistor for temperature measurement.

Demonstration/Evaluation Kits

For additional information on these and other analog demonstration and evaluation kits, visit the Microchip web site at: www.microchip.com/analogtools

MCP9700 Temperature-to-Voltage Converter PICtail™ Demonstration Board
Part Number: MCP9700DM-PCTL

MCP9800 Temp Sensor PICtail™ Demonstration Board
Part Number: MCP9800DM-PCTL

MCP9800 Temperature Data Logger Demonstration Board
Part Number: MCP9800DM-DL

TC72 Digital Temperature Sensor PICtail™ Demonstration Board
Part Number: TC72DM-PICTL

TC74 Serial Digital Thermal Sensor Demonstration Board
Part Number: TC74DEMO

TC77 Thermal Sensor PICtail™ Demonstration Board
Part Number: TC77DM-PICTL

TC64X/64XB Fan Speed Controller Demonstration Board
Part Number: TC642DEMO

TC64X/64XB Fan Speed Controller Evaluation Board
Part Number: TC642EV

TC650 Fan Controller Demonstration Board
Part Number: TC650DEMO

TC652 Fan Controller Demonstration Board
Part Number: TC652DEMO

TC1047A Temperature-to-Voltage Converter PICtail™ Demonstration Board
Part Number: TC1047ADM-PICTL

SELECTED PRODUCT SPECIFICATIONS

See Microchip's Advanced Parts Selector (MAPS) software for complete product selection and specifications.

Serial Output Temperature Sensor Products

Device	Serial Communication	Accuracy @ 25°C (Typ./Max)	Temperature Range (°C)	VDD Min. (V)	VDD Max (V)	Iq Max. (µA)	Packages	Development Tools
MCP9800	I2C™	0.5/1	-40 to +125	2.7	5.5	400	SOT-23-5	MCP9800DM-DL MCP9800DM-PCTL
MCP9801	I2C™	0.5/1	-40 to +125	2.7	5.5	400	SOIC-8, MSOP-8	–
MCP9802	SMBus	0.5/1	-40 to +125	2.7	5.5	400	SOT-23-5	–
MCP9803	SMBus	0.5/1	-40 to +125	2.7	5.5	400	SOIC-8, MSOP-8	–
MCP9805	SMBus	2/3 (0.5/1 75°C-95°C)	-40 to +125	3.0	3.6	500	TSSOP-8, 2x3 DFN-8	–
MCP98242	SMBus	2/3 (0.5/1 75°C-95°C)	-40 to +125	3.0	3.6	500	TSSOP-8, 2x3 DFN-8	–
TC74	SMBus/I2C	0.5/2	-40 to +125	2.7	5.5	350	SOT-23-5, TO-220-5	TC74DEMO
TCN75	SMBus/I2C	0.5/2	-40 to +125	2.7	5.5	1000	SOIC-8, MSOP-8	–
TC72	4-Wire SPI	0.5/1	-40 to +125	2.65	5.5	400	MSOP-8, 2x3 DFN-8	TC72DM-PICTL
TC77	3-Wire SPI	0.5/1	-40 to +125	2.7	5.5	400	SOIC-8, SOT-23-5	TC77DM-PCTL

Analog (Voltage Output) Temperature Sensor Products

Device	Accuracy @ 25°C (Typ./Max)	Temperature Range (°C)	VDD Min. (V)	VDD Max. (V)	Iq Max. (µA)	Slope (mV/°C)	Offset Voltage (Output @ 0°C) (mV)	Packages	Development Tools
MCP9700	1/4	-40 to +125	2.3	5.5	12	10	500	SOT-23-5, SC-70-5, TO-92-3	MCP9700DM-PCTL
MCP9700A	1/2	-40 to +125	2.3	5.5	12	10	500	SC-70-5	MCP9700DM-PCTL
MCP9701	1/4	-40 to +125	3.1	5.5	12	19.5	400	SC-70-5, TO-92-3	–
MCP9701A	1/2	-40 to +125	3.1	5.5	12	19.5	400	SC-70-5	–
TC1046	0.5/2.0	-40 to +125	2.7	4.4	60	6.25	424	SOT-23-3	–
TC1047/A	0.5/2.0	-40 to +125	2.7	4.4	60	10	500	SOT-23-3	TC1047ADM-PCTL

Logic Output Temperature Sensor Products

Device	Accuracy @ 25°C (Typ./Max)	Temperature Range (°C)	Temperature Set Points	VDD Min. (V)	VDD Max (V)	Iq Max. (µA)	Packages	Development Tools
TC620	1/3	-40 to +125	User-selectable, set by external resistor	4.5	18	400	PDIP-8, SOIC8	–
TC621	1/3	-40 to +125	User-selectable, set by external resistor	4.5	18	400	PDIP-8, SOIC8	–
TC622	1/5	-40 to +125	User-selectable, set by external resistor	4.5	18	600	PDIP-8, SOIC-8, TO-220-5	–
TC623	1/3	-40 to +125	User-selectable, set by external resistor	2.7	4.5	250	PDIP-8, SOIC8	–
TC624	1/5	-40 to +125	User-selectable, set by external resistor	2.7	4.5	300	PDIP-8, SOIC8	–
TC6501	0.5/4	-40 to +125	Factory programmed thresholds	2.7	5.5	40	SOT-23-5	–
TC6502	0.5/4	-40 to +125	Factory programmed thresholds	2.7	5.5	40	SOT-23-5	–
TC6503	0.5/4	-40 to +125	Factory programmed thresholds	2.7	5.5	40	SOT-23-5	–
TC6504	0.5/4	-40 to +125	Factory programmed thresholds	2.7	5.5	40	SOT-23-5	–

SELECTED PRODUCT SPECIFICATIONS

Operational Amplifiers

Device	# per Package	GBWP (kHz)	Iq (Typ./Max) (µA)	Vos Max. (mV)	Temperature Range (°C)	Operating Voltage Range (V)	Packages	Development Tools
TC913A	2	1500	8500/1100	0.15	0 to +70	6.5 to 16	PDIP-8	
TC7650	1	2000	2000/3500	0.05	0 to +70	4.5 to 16	PDIP-8, PDIP-14	–
TC7652	1	400	1000/3000	0.05	0 to +70	5 to 16	PDIP-8, PDIP-14	–
MCP601	1, 2, 4	2800	230/325	2	-40 to +125	2.7 to 5.5	TSSOP-14, PDIP-8, SOIC-8, SOT-23-5	–
MCP616	1, 2, 4	190	19/25	0.15	-40 to +85	2.3 to 5.5	PDIP-8, SOIC-8, MSOP-8	–
MCP6001	1, 2, 4	1000	100/170	7	-40 to +125	1.8 to 5.5	SOT-23-5, SC-70-5	–
MCP6041	1, 2, 4	14	0.6/1	3	-40 to +125	1.4 to 5.5	TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5	–
MCP6141	1, 2, 4	100	0.6/1	3	-40 to +125	1.4 to 5.5	TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5	–
MCP6231	1, 2, 4	300	20/30	7	-40 to +125	1.8 to 5.5	TSSOP-14, PDIP-8, SOIC-8, SOT-23-5, SC-70-5	–
MCP6271	1, 2, 4	2000	120/240	3	-40 to +125	2.0 to 5.5	TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5	–
MCP6281	1, 2, 4	5000	450/570	3	-40 to +125	7.2 to 5.5	TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5	–
MCP6291	1, 2, 4	10,000	1000/1300	3	-40 to +125	2.4 to 5.5	TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5	–

Voltage Reference

Device	Vcc Range	Output Voltage (V)	Max Load Current (mA)	Initial Accuracy (%)	Temperature Coefficient (ppm/°C)	Max. Supply Current (µA @ 25°C)	Packages	Development Tools
MCP1525	2.7 to 5.5	2.5	±2	±1	50	100	TO-92-3, SOT-23B-3	–

Comparators

Device	# per Package	Typical Propagation Delay (µsec)	Vos Max (mV)	Operating Voltage (V)	Temperature Range (°C)	Packages	Development Tools
MCP6541	1	4	5	1.6 to 5.5	-40 to +85	PDIP-8, SOIC-8, MSOP-8, SOT-23-5	–
MCP6542	2	4	5	1.6 to 5.5	-40 to +85	PDIP-8, SOIC-8, MSOP-8	–
MCP6543	1	4	5	1.6 to 5.5	-40 to +85	PDIP-8, SOIC-8, MSOP-8	–
MCP6544	4	4	5	1.6 to 5.5	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	–

Programmable Gain Amplifiers (PGAs)

Device	Channels	-3 db BW (MHz)	Iq Typical (mA)	Vos (µV)	Operating Voltage (V)	Temperature Range (°C)	Packages	Development Tools
MCP6S21	1	2 to 12	1.1	275	2.5 to 5.5	-40 to +85	PDIP-8, SOIC-8, MSOP-8	–
MCP6S22	2	2 to 12	1.1	275	2.5 to 5.5	-40 to +85	PDIP-8, SOIC-8, MSOP-8	–
MCP6S26	6	2 to 12	1.1	275	2.5 to 5.5	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	–
MCP6S28	8	2 to 12	1.1	275	2.5 to 5.5	-40 to +85	PDIP-16, SOIC-16	–

Stand-Alone Analog and Interface Portfolio

Thermal Management
- Temperature Sensors
- Fan Speed Controllers/ Fan Fault Detectors

Power Management
- LDO & Switching Regulators
- Charge Pump DC/DC Converters
- Power MOSFET Drivers
- PWM Controllers
- System Supervisors
- Voltage Detectors
- Voltage References

Battery Management
- Li-Ion/Li-Polymer Battery Chargers
- Smart Battery Managers

Linear
- Op Amps
- Programmable Gain Amplifiers
- Comparators
- Linear Integrated Devices

Mixed-Signal
- A/D Converter Families
- Digital Potentiometers
- D/A Converters
- V/F and F/V Converters
- Energy Measurement ICs

Interface
- CAN Peripherals
- Infrared Peripherals
- LIN Transceiver
- Serial Peripherals
- Ethernet Controller

Analog and Interface Attributes

Robustness
- MOSFET Drivers lead the industry in latch-up immunity/stability

Low Power/Low Voltage
- Op Amp family with the lowest power for a given gain bandwidth
- 600 nA/1.4V/14 kHz bandwidth Op Amps
- 1.8V charge pumps and comparators
- Lowest power 12-bit ADC in a SOT-23 package

Integration
- One of the first to market with integrated LDO with Reset and Fan Controller with temperature sensor
- PGA integrates MUX, resistive ladder, gain switches, high-performance amplifier, SPI interface

Space Savings
- Resets and LDOs in SC70, A/D converters in a 5-lead SOT-23 package
- CAN and IrDA® Standard protocol stack embedded in an 18-pin package

Accuracy
- Low input offset voltages
- High gains

Innovation
- Low pin-count embedded IrDA Standard stack, FanSense™ technology
- Select Mode™ operation

For more information, visit the Microchip web site at: www.microchip.com

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