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
- MCP9700
- MCP9701
- TC1046
- TC1047A

Logic Output Temperature Sensors
- TC620
- TC621
- TC622
- TC623
- TC624

Serial Output Temperature Sensors
- MCP9800
- MCP9801
- MCP9802
- MCP9803
- MCP9805

Comparators and Operational Amplifiers
- TC913A
- TC7650
- TC7652
- MCP616
- MCP6541
- MCP6542
- MCP6543

PGA
- MCP6544
- MCP6001
- MCP6021
- MCP6231
- MCP6271
- MCP6281
- MCP6291
Temperature Sensor Design Guide

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

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, I2C™ 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.

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
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 temperature conditions are detected. Since the output is typically not latched, the switch will turn off when the temperature falls below the temperature setpoint. Note that it is necessary to have hysteresis so the switch does not “chatter” when crossing the temperature setpoint.

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

**Logic Output Temperature Sensors Used as Temperature Switches**

![Diagram of Logic Output Temperature Sensors Used as Temperature Switches]

**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
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

Using the TC1046 to Create a Simple Temperature Measurement System
Linear Active Thermistors

The MCP9700/01 Linear Active Thermistor™ Integrated Circuit (IC) is an analog temperature sensor that converts temperature to an analog voltage output.

This sensor competes with a thermistor solution in price and performance. Unlike resistive sensors (such as thermistors), the Linear Active Thermistor IC does not require an additional signal-conditioning circuit. Therefore, the biasing circuit development overhead for thermistor solutions can be eliminated by implementing this low-cost device. The voltage output pin (Vout) 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 use a PCB space saving 5-pin SC-70 package.

MCP9700/01 Key Features:

- 5-pin SC-70 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 Typical Applications:

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

Sensor Application Tips

The MCP9700/01 is designed to drive large capacitive loads. This capability makes the sensor immune to board parasitic capacitance, which allows the sensor to be remotely located and drive long PCB trace or shielded cables to the ADC. In addition, adding capacitive load at Vout helps the sensor 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 CBYPASS of 0.1 μf to 1 μf be placed at close proximity to the Vdd and Vss 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 CBYPASS 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
**Temperature Sensor Design Guide**

**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|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 PICmicro® Microcontroller.

**Typical Results**

Equation 1, 2 and 3 show the 2nd order error equation of the tested parts for the MCP9800, MCP9700 and MCP9701, 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**

\[
\text{Error}_{T,2} = EC_2(125°C - T_A) \cdot (T_A - -55°C) + EC_1(T_A - -55°C) + \text{Error}_{-55}
\]

Where:

- \(EC_2 = 150 \times 10^{-6}°C/°C^2\)
- \(EC_1 = 7 \times 10^{-3}°C/°C\)
- \(\text{Error}_{-55} = -1.5°C\)

**Equation 2: MCP9700 2nd Order Equation**

\[
\text{Error}_{T,2} = EC_2(125°C - T_A) \cdot (T_A - -40°C) + EC_1(T_A - -40°C) + \text{Error}_{-40}
\]

Where:

- \(EC_2 = 244 \times 10^{-6}°C/°C^2\)
- \(EC_1 = 2 \times 10^{-12}°C/°C \times 0°C/°C\)
- \(\text{Error}_{-40} = -2°C\)

**Equation 3: MCP9701 2nd Order Equation**

\[
\text{Error}_{T,2} = EC_2(125°C - T_A) \cdot (T_A - -515°C) + EC_1(T_A - -15°C) + \text{Error}_{-15}
\]

Where:

- \(EC_2 = 200 \times 10^{-6}°C/°C^2\)
- \(EC_1 = 1 \times 10^{-3}°C/°C\)
- \(\text{Error}_{-15} = -1.5°C\)
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
Temperature Sensor Design Guide

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.

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
- 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

Typical Performance Curves

Temperature Accuracy Histogram, TA = +95°C

Temperature Accuracy Histogram, TA = +75°C
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 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
**Temperature Sensor Design Guide**

### 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

![Circuit A Diagram]

![Circuit B Diagram]
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 $-100 \, \Omega/°C$ at 25°C), fast response time and low cost. The main drawback of thermistors is that the change in resistance with temperature is 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
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.
Temperature Sensor Design Guide

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
### Analog (Voltage Output) Temperature Sensor Products

<table>
<thead>
<tr>
<th>Device</th>
<th>Temperature Range (°C)</th>
<th>Voo Min. (V)</th>
<th>Voo Max. (V)</th>
<th>Iq Max. (μA)</th>
<th>Slope (mV/°C)</th>
<th>Offset Voltage (Output @ 0°C) (mV)</th>
<th>Packages</th>
<th>Development Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCP9700</td>
<td>-40 to +125</td>
<td>2.3</td>
<td>5.5</td>
<td>12</td>
<td>10</td>
<td>500</td>
<td>SOT23-5</td>
<td>MCP9700DM-PCTL</td>
</tr>
<tr>
<td>MCP9701</td>
<td>-40 to +125</td>
<td>3.1</td>
<td>5.5</td>
<td>12</td>
<td>19.5</td>
<td>400</td>
<td>SC-70-5</td>
<td>SC-70-5</td>
</tr>
<tr>
<td>TC1046</td>
<td>-40 to +125</td>
<td>2.7</td>
<td>4.4</td>
<td>60</td>
<td>6.25</td>
<td>424</td>
<td>SOT23-3</td>
<td>TC1047ADM-PCTL</td>
</tr>
<tr>
<td>TC1047/A</td>
<td>-40 to +125</td>
<td>2.7</td>
<td>4.4</td>
<td>60</td>
<td>10</td>
<td>500</td>
<td>SOT23-3</td>
<td>TC1047ADM-PCTL</td>
</tr>
</tbody>
</table>

### Logic Output Temperature Sensor Products

<table>
<thead>
<tr>
<th>Device</th>
<th>Temperature Range (°C)</th>
<th>Temperature Set Points</th>
<th>Voo Min. (V)</th>
<th>Voo Max. (V)</th>
<th>Iq Max. (μA)</th>
<th>Packages</th>
<th>Development Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>T620</td>
<td>-40 to +125</td>
<td>User-selectable, set by external resistor</td>
<td>4.5</td>
<td>18</td>
<td>400</td>
<td>PDP-8, SOIC-8</td>
<td></td>
</tr>
<tr>
<td>T621</td>
<td>-40 to +125</td>
<td>User-selectable, set by external resistor</td>
<td>4.5</td>
<td>18</td>
<td>400</td>
<td>PDP-8, SOIC-8</td>
<td></td>
</tr>
<tr>
<td>T622</td>
<td>-40 to +125</td>
<td>User-selectable, set by external resistor</td>
<td>4.5</td>
<td>18</td>
<td>600</td>
<td>PDP-8, SOIC-8, SOT-220-5</td>
<td></td>
</tr>
<tr>
<td>T623</td>
<td>-40 to +125</td>
<td>User-selectable, set by external resistor</td>
<td>2.7</td>
<td>4.5</td>
<td>250</td>
<td>PDP-8, SOIC-8</td>
<td></td>
</tr>
<tr>
<td>T624</td>
<td>-40 to +125</td>
<td>User-selectable, set by external resistor</td>
<td>2.7</td>
<td>4.5</td>
<td>300</td>
<td>PDP-8, SOIC-8</td>
<td></td>
</tr>
<tr>
<td>T6501</td>
<td>-40 to +125</td>
<td>Factory programmed thresholds</td>
<td>2.7</td>
<td>5.5</td>
<td>40</td>
<td>SOT23-3</td>
<td></td>
</tr>
<tr>
<td>T6502</td>
<td>-40 to +125</td>
<td>Factory programmed thresholds</td>
<td>2.7</td>
<td>5.5</td>
<td>40</td>
<td>SOT23-3</td>
<td></td>
</tr>
<tr>
<td>T6503</td>
<td>-40 to +125</td>
<td>Factory programmed thresholds</td>
<td>2.7</td>
<td>5.5</td>
<td>40</td>
<td>SOT23-3</td>
<td></td>
</tr>
<tr>
<td>T6504</td>
<td>-40 to +125</td>
<td>Factory programmed thresholds</td>
<td>2.7</td>
<td>5.5</td>
<td>40</td>
<td>SOT23-3</td>
<td></td>
</tr>
</tbody>
</table>
## Operational Amplifiers

<table>
<thead>
<tr>
<th>Device</th>
<th># per Package</th>
<th>GBWP (kHz)</th>
<th>$I_O$ (Typ./Max) ($μA$)</th>
<th>$V_{OS}$ Max. (mV)</th>
<th>Temperature Range (°C)</th>
<th>Operating Voltage Range (V)</th>
<th>Packages</th>
<th>Development Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>T913A</td>
<td>2</td>
<td>1500</td>
<td>8500/1100</td>
<td>0.15</td>
<td>0 to +70</td>
<td>6.5 to 16</td>
<td>PDIP-8</td>
<td></td>
</tr>
<tr>
<td>TC7650</td>
<td>1</td>
<td>2000</td>
<td>2000/3500</td>
<td>0.05</td>
<td>0 to +70</td>
<td>4.5 to 16</td>
<td>PDIP-8, PDIP-14</td>
<td></td>
</tr>
<tr>
<td>TC7652</td>
<td>1</td>
<td>400</td>
<td>1000/3000</td>
<td>0.05</td>
<td>0 to +70</td>
<td>5 to 16</td>
<td>PDIP-8, PDIP-14</td>
<td></td>
</tr>
<tr>
<td>MCP601</td>
<td>1, 2, 4</td>
<td>2800</td>
<td>230/325</td>
<td>2</td>
<td>-40 to +125</td>
<td>2.7 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, SOT-235</td>
<td></td>
</tr>
<tr>
<td>MCP616</td>
<td>1, 2, 4</td>
<td>190</td>
<td>19/25</td>
<td>0.15</td>
<td>-40 to +85</td>
<td>2.3 to 5.5</td>
<td>PDIP-8, SOIC-8, MSOP-8</td>
<td></td>
</tr>
<tr>
<td>MCP6001</td>
<td>1, 2, 4</td>
<td>1000</td>
<td>100/170</td>
<td>7</td>
<td>-40 to +125</td>
<td>1.8 to 5.5</td>
<td>SOT-23-5, SC-70-5</td>
<td></td>
</tr>
<tr>
<td>MCP6041</td>
<td>1, 2, 4</td>
<td>14</td>
<td>0.6/1</td>
<td>3</td>
<td>-40 to +125</td>
<td>1.4 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5</td>
<td></td>
</tr>
<tr>
<td>MCP6141</td>
<td>1, 2, 4</td>
<td>100</td>
<td>0.6/1</td>
<td>3</td>
<td>-40 to +125</td>
<td>1.4 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5</td>
<td></td>
</tr>
<tr>
<td>MCP6231</td>
<td>1, 2, 4</td>
<td>300</td>
<td>20/30</td>
<td>7</td>
<td>-40 to +125</td>
<td>1.8 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, SOT-23-5</td>
<td></td>
</tr>
<tr>
<td>MCP6271</td>
<td>1, 2, 4</td>
<td>2000</td>
<td>120/240</td>
<td>3</td>
<td>-40 to +125</td>
<td>2.0 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5</td>
<td></td>
</tr>
<tr>
<td>MCP6281</td>
<td>1, 2, 4</td>
<td>5000</td>
<td>450/570</td>
<td>3</td>
<td>-40 to +125</td>
<td>7.2 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5</td>
<td></td>
</tr>
<tr>
<td>MCP6291</td>
<td>1, 2, 4</td>
<td>10,000</td>
<td>1000/1300</td>
<td>3</td>
<td>-40 to +125</td>
<td>2.4 to 5.5</td>
<td>TSSOP-14, PDIP-8, SOIC-8, MSOP-8, SOT-23-5</td>
<td></td>
</tr>
</tbody>
</table>

## Voltage Reference

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

## Comparators

<table>
<thead>
<tr>
<th>Device</th>
<th># per Package</th>
<th>Typical Propagation Delay (μsec)</th>
<th>$I_O$ Typical (μA)</th>
<th>$V_{OS}$ (μV)</th>
<th>Operating Voltage (V)</th>
<th>Temperature Range (°C)</th>
<th>Packages</th>
<th>Development Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCP6541</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1.6 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-8, SOIC-8, MSOP-8, SOT-23-5</td>
<td></td>
</tr>
<tr>
<td>MCP6542</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1.6 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-8, SOIC-8, MSOP-8</td>
<td></td>
</tr>
<tr>
<td>MCP6543</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1.6 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-8, SOIC-8, MSOP-8</td>
<td></td>
</tr>
<tr>
<td>MCP6544</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1.6 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-14, SOIC-14, TSSOP-14</td>
<td></td>
</tr>
</tbody>
</table>

## Programmable Gain Amplifiers (PGAs)

<table>
<thead>
<tr>
<th>Device</th>
<th>Channels</th>
<th>-3 dB BW (MHz)</th>
<th>$I_O$ Typical (μA)</th>
<th>$V_{OS}$ (μV)</th>
<th>Operating Voltage (V)</th>
<th>Temperature Range (°C)</th>
<th>Packages</th>
<th>Development Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCP6S21</td>
<td>1</td>
<td>2 to 12</td>
<td>1.1</td>
<td>275</td>
<td>2.5 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-8, SOIC-8, MSOP-8</td>
<td></td>
</tr>
<tr>
<td>MCP6S22</td>
<td>2</td>
<td>2 to 12</td>
<td>1.1</td>
<td>275</td>
<td>2.5 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-8, SOIC-8, MSOP-8</td>
<td></td>
</tr>
<tr>
<td>MCP6S26</td>
<td>6</td>
<td>2 to 12</td>
<td>1.1</td>
<td>275</td>
<td>2.5 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-14, SOIC-14, TSSOP-14</td>
<td></td>
</tr>
<tr>
<td>MCP6S28</td>
<td>8</td>
<td>2 to 12</td>
<td>1.1</td>
<td>275</td>
<td>2.5 to 5.5</td>
<td>-40 to +85</td>
<td>PDIP-16, SOIC-16</td>
<td></td>
</tr>
</tbody>
</table>
## Analog and Interface Products

<table>
<thead>
<tr>
<th>Thermal Management</th>
<th>Power Management</th>
<th>Linear</th>
<th>Mixed-Signal</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Sensors</td>
<td>LDO &amp; Switching Regulators</td>
<td>Op Amps</td>
<td>A/D Converter Families</td>
<td>CAN Peripherals</td>
</tr>
<tr>
<td>Fan Speed Controllers/Fan Fault Detectors</td>
<td>Charge Pump DC/DC Converters</td>
<td>Programmable Gain Amplifiers</td>
<td>Digital Potentiometers</td>
<td>Infrared Peripherals</td>
</tr>
<tr>
<td></td>
<td>Power MOSFET Drivers</td>
<td>Comparators</td>
<td>D/A Converters</td>
<td>LIN Transceiver</td>
</tr>
<tr>
<td></td>
<td>PWM Controllers</td>
<td>Linear Integrated Devices</td>
<td>V/F and F/V Converters</td>
<td>Serial Peripherals</td>
</tr>
<tr>
<td></td>
<td>System Supervisors</td>
<td></td>
<td>Energy Measurement ICs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voltage Detectors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voltage References</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Battery Management</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-Ion/Li-Polymer Battery Chargers</td>
<td>Smart Battery Managers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 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

---

**Analog and Interface Products**

**Microchip Technology Inc.**

2355 W. Chandler Blvd. • Chandler, AZ 85224-6199

**Microcontrollers • Digital Signal Controllers • Analog • Serial EEPROMs**

Information subject to change. The Microchip name and logo, the Microchip logo, PIC and PICmicro are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. FanSense, Linear Active Thermistor, PICkit, PICtail and Select Mode are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks mentioned herein are property of their respective companies. © 2006, Microchip Technology Incorporated. All Rights Reserved, Printed in the U.S.A. 1/06