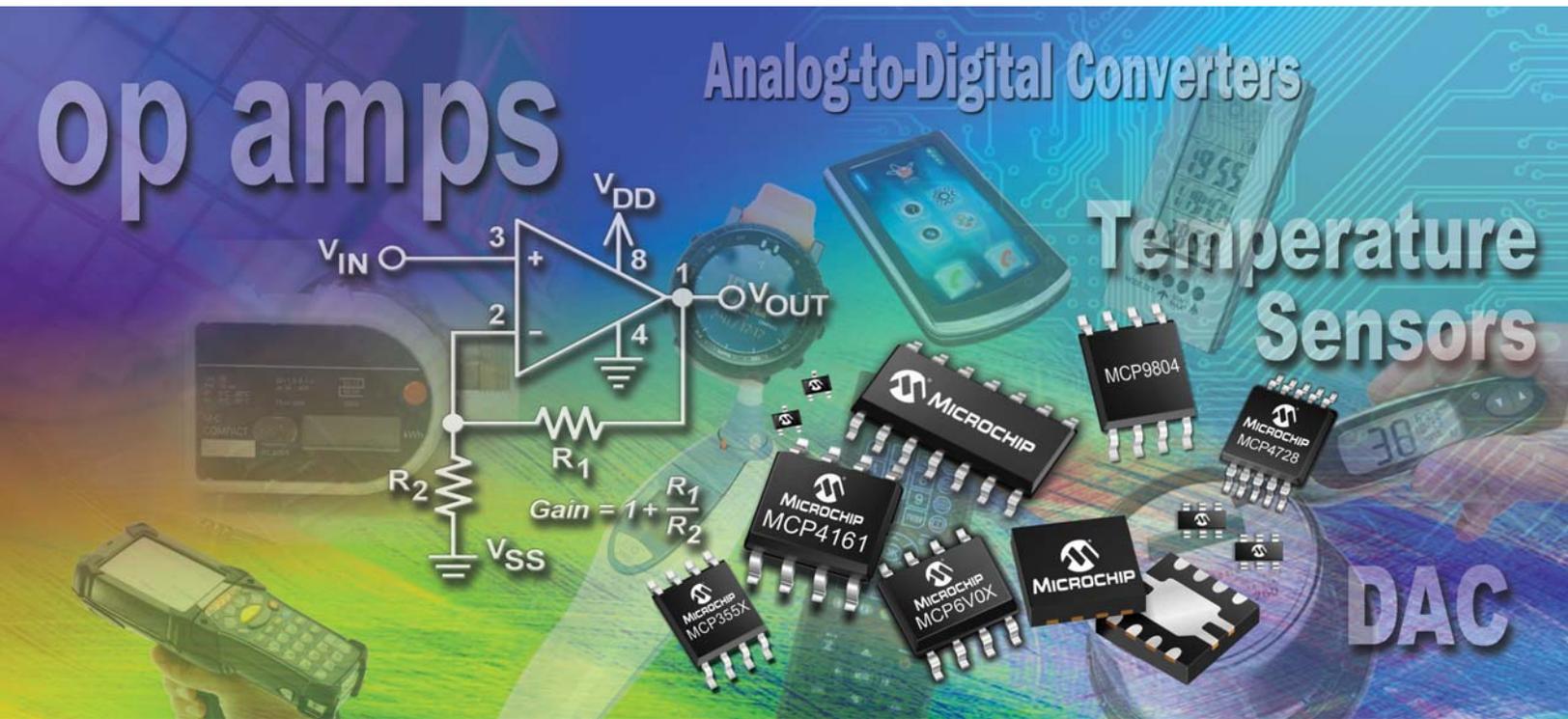




# SIGNAL CHAIN DESIGN GUIDE

## Devices For Use With Sensors



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/analog](http://www.microchip.com/analog).

### Operational Amplifiers

MCP6XX  
MCP6XXX  
MCP6V01/2/3  
MCP6V06/7/8

### Comparators

MCP654X  
MCP656X

### Analog-to-Digital Converters

MCP3421  
MCP3422/3/4  
MCP355X  
MCP3901

### Temperature Sensors

MCP9800  
MCP9804  
MCP9700/A  
MCP9701/A

### Voltage References

MCP1525  
MCP1541

### Digital Potentiometers

MCP40XX  
MCP40D1X  
MCP41XX  
MCP42XX  
MCP43XX  
MCP45XX  
MCP46XX  
MCP41XXX  
MCP42XXX

### Digital-to-Analog Converters

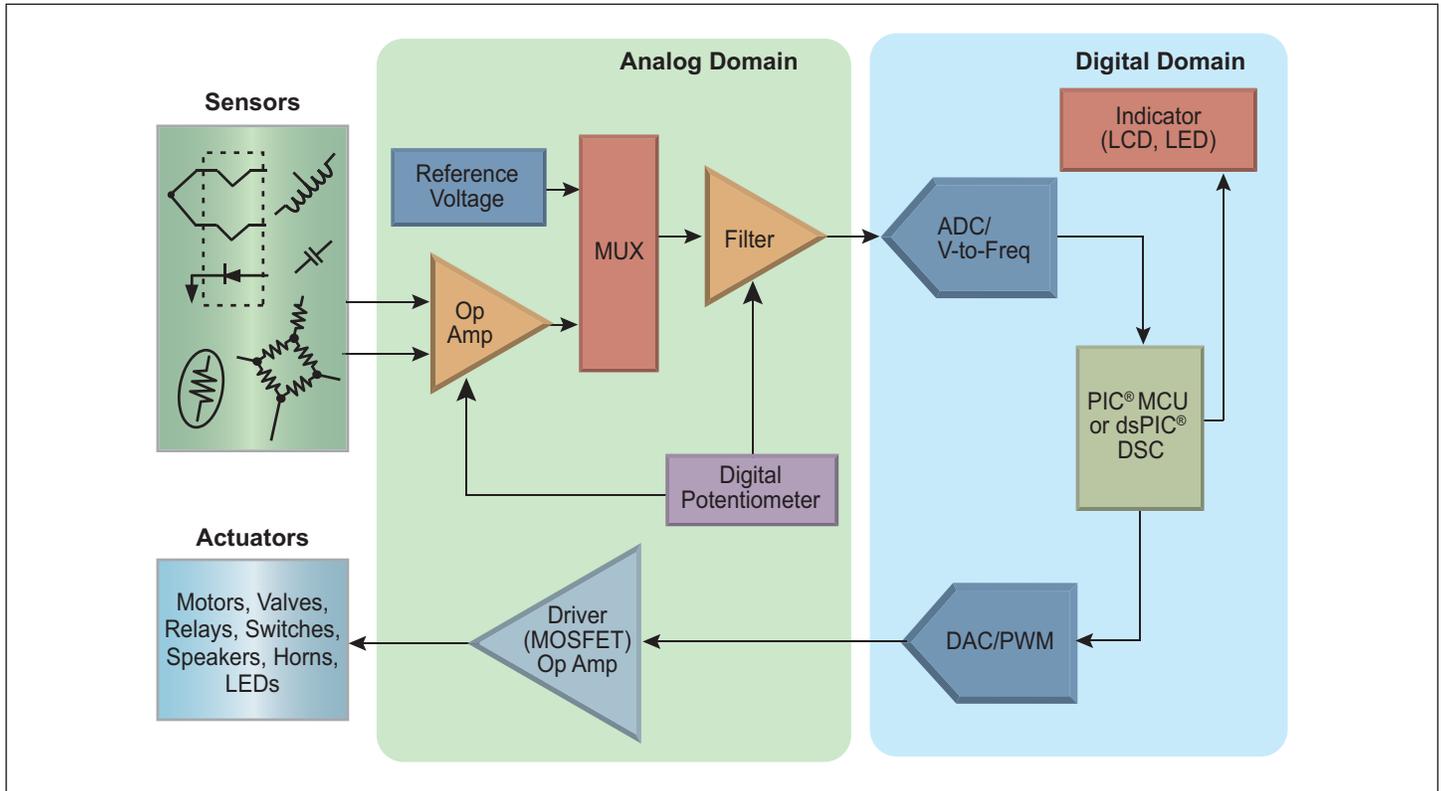
MCP4725  
MCP4728  
MCP482X  
MCP492X

# Signal Chain Overview

Typical sensor applications involve the monitoring of sensor parameters and controlling of actuators. The sensor signal chain, as shown below, consists of analog and digital domains. Typical sensors output very low amplitude analog signals. These weak analog signals are amplified and filtered, and converted to digital using op amps, an analog-to-digital or voltage-to-frequency converter, and is processed at the MCU. The analog sensor output typically needs proper signal conditioning before it gets converted to a digital signal.

The MCU controls the actuators and maintains the operation of the sensor signal conditioning circuits based on the condition of the signal detection. For the digital to analog feedback path, the digital to analog converter (DAC), digital potentiometer and Pulse-Width-Modulator (PWM) devices are most commonly used. The MOSFET driver is commonly used for the interface between the feedback circuit and actuators such as motors and valves. Microchip offers a large portfolio of devices for signal chain applications.

## Typical Sensor Signal Chain Control Loop



# Sensor Overview

Many system applications require the measurement of a physical or electrical condition, or the presence or absence of a known physical, electrical or chemical quantity. Analog sensors are typically used to indicate the magnitude or change in the environmental condition, by reacting to the condition and generating a change in an electrical property as a result.

Typical phenomena that are measured are:

- Electrical Signal and Properties
- Magnetic Signal and Properties
- Temperature
- Humidity
- Force, Weight, Torque and Pressure
- Motion and Vibration
- Flow
- Fluid Level and Volume
- Light and Infrared
- Chemistry/Gas

There are sensors that respond to these phenomena by producing the following electrical properties:

- Voltage
- Current
- Resistance
- Capacitance
- Charge

This electrical property is then conditioned by an analog circuit before being converted to a digital circuit. In this way, the environmental condition can be “measured” and the system can make decisions based on the result.

The table below provides an overview of typical phenomena, the type of sensor commonly used to measure the phenomena and electrical output of the sensor.

For additional information, please refer to Application Note AN990.

## Summary Of Common Physical Conditions and Related Sensor Types

Phenomena	Sensor	Electrical Output
<b>Magnetic</b>	Hall Effect	Voltage
	Magneto-Resistive	Resistance
<b>Temperature</b>	Thermocouple	Voltage
	RTD	Resistance
	Thermistor	Resistance
	IC	Voltage
	Infrared	Current
	Thermopile	Voltage
<b>Humidity</b>	Capacitive	Capacitance
	Infrared	Current
<b>Force, Weight, Torque, Pressure</b>	Strain Gauge	Resistance/Voltage
	Load Cell	Resistance
	Piezo-electric	Voltage or Charge
	Mechanical Transducer	Resistance, Voltage, Capacitance
<b>Motion and Vibration</b>	LVDT	AC Voltage
	Piezo-electric	Voltage or Charge
	Microphone	Voltage
	Ultrasonic	Voltage, Resistive, Current
	Accelerometer	Voltage
<b>Flow</b>	Magnetic Flowmeter	Voltage
	Mass Flowmeter	Resistance/Voltage
	Ultrasound/Doppler	Frequency
	Hot-wire Anemometer	Resistance
	Mechanical Transducer (turbine)	Voltage
<b>Fluid Level and Volume</b>	Ultrasound	Time Delay
	Mechanical Transducer	Resistance, Voltage
	Capacitor	Capacitance
	Switch	On/Off
	Thermal	Voltage
<b>Light</b>	Photodiode	Current
<b>Chemical</b>	pH Electrode	Voltage
	Solution Conductivity	Resistance/Current
	CO Sensor	Voltage or Charge
	Photodiode (turbidity, colorimeter)	Current

# Product Overviews

## Operational Amplifiers (Op Amps)

Microchip Technology offers a broad portfolio of op amp families built on advanced CMOS technology. These families are offered in single, dual and quad configurations, which are available in space saving packages.

These op amp families include devices with Quiescent Current ( $I_Q$ ) per amplifier between 0.6  $\mu$ A and 6 mA, with a Gain Bandwidth Product (GBWP) between 10 kHz and 60 MHz, respectively. The op amp with lowest supply voltage ( $V_{DD}$ ) operates between 1.4V and 6.0V, while the op amp with highest  $V_{DD}$  operates between 6.5V and 16.0V.

These op amp families fall into the following categories: General Purpose, Low Offset, Auto-zeroed, High Speed, Low Noise and mCal (self calibrating input offset voltage ( $V_{OS}$ )).

## Comparators

The **MCP6541** and **MCP6561** family of comparators provide ultra low power, 600 nA typical, and higher speed with 40 ns propagation delay, respectively. The **MCP6541** family low operating current is suitable for battery powered application and the output drive capability is ideal for alert buzzer driver applications. The **MCP6561** family with greater than 4 MHz toggle frequency is ideal for higher speed embedded system applications where sinusoidal output from sensors to square wave conversion is needed. The 47 ns typical propagation delay also makes this device ideal for microprocessor interface. Both families of comparators are available with single, dual and quad as well as with push-pull and open-drain output options (**MCP6546** and **MCP6566**).

## Programmable Gain Amplifier (PGA)

The **MCP6S21/2/6/8** and **MCP6S91/2/3** PGA families give the designer digital control over an amplifier using a serial interface (SPI bus). An input analog multiplexer with 1, 2, 6 or 8 inputs can be set to the desired input signal. The gain can be set to one of eight non-inverting gains: +1, 2, 4, 5, 8, 10, 16 and 32 V/V. In addition, a software shutdown mode offers significant power savings for portable embedded designs. This is all achieved in one simple integrated part that allows for considerably greater bandwidth, while maintaining a low supply current. Systems with multiple sensors are significantly simplified.

The **MCP6G01** family are analog Selectable Gain Amplifiers (SGA). The Gain Select input pin(s) set a gain of +1 V/V, +10 V/V and +50 V/V. The Chip Select pin on the **MCP6G03** puts it into shutdown to conserve power.

## Analog-to-Digital Converters (ADC)

Microchip offers a broad portfolio of high-precision Delta-Sigma, SAR and Dual Slope A/D Converters. The **MCP3550/1/3** Delta-Sigma ADCs offer up to 22-bit resolution with only 120  $\mu$ A typical current consumption in a small 8-pin MSOP package. The **MCP3421** is a single channel Delta-Sigma ADC and is available in a small 6-pin SOT-23 package. It includes a voltage reference and PGA. The user can select the conversion resolution up to 18 bits. The **MCP3422/3** and the **MCP3424** are two channel and four channel versions, respectively, of the **MCP3421** device. The **MCP300X** (10-bit), **MCP320X** (12-bit) and **MCP330X** (13-bit) SAR ADCs combine high performance and low power consumption in a small package, making them ideal for embedded control applications. The **TC5XX** Dual Slope ADC devices offer another alternative with up to 17-bits of conversion resolution.

The “Analog-to-Digital Converter Design Guide” (Microchip Document No. 21841) shows various application examples of the ADC devices.

Microchip also offers many high accuracy energy metering devices which are based on the Delta-Sigma ADC cores. The “Complete Utility Metering Solution Guide” (Microchip Document No: 24930) offers detailed solutions for metering applications.

## Voltage References

Microchip offers the **MCP15XX** family of low power and low dropout precision Voltage References. The family includes the **MCP1525** with an output voltage of 2.5V and the **MCP1541** with an output voltage of 4.096V. Microchip's voltage references are offered in SOT23-3 and TO-92 packages.

# Product Overviews

## Digital Potentiometers

Microchip's family of digital potentiometers offer a wide range of options. These devices support the 6-bit through 8-bit applications. Offering both volatile and non-volatile options, with digital interfaces from the simple Up/Down interface to the standard SPI and I<sup>2</sup>C™ interfaces. These devices are offered in small packages such as 6-lead SC70 and 8-lead DFN for the single potentiometer devices, 14-lead TSSOP and 16-lead QFN packages for the dual potentiometer devices, and 20-lead TSSOP and QFN packages for the quad potentiometer devices. Non-volatile devices offer a Wiperlock™ Technology feature, while volatile devices will operate down to 1.8V. Resistances are offered from 2.1 kΩ to 100 kΩ. Over 50 device configurations are currently available.

The “Digital Potentiometer Design Guide” (Microchip Document No. 22017), shows various application examples of the digital potentiometer devices.

## Digital-to-Analog Converters (DAC)

Microchip has a number of Digital-to-Analog Converters that range from high performance 12-bit devices to cost effective 8-bit devices.

The **MCP4725** is a single channel 12-bit DAC with non-volatile memory (EEPROM). The user can store DAC input code and configuration register bits into the EEPROM. This non-volatile memory feature enables the device to hold the DAC input code during power-off time allowing the DAC output to be available immediately after power-up. This feature is very useful when the DAC is used as a supporting device for other device operations in systems. The **MCP4725** is available in a tiny SOT23-6 package.

The **MCP4728** is a 12-bit DAC with four analog outputs. This device also has non-volatile memory (EEPROM) for each DAC channel. The user can select internal reference or V<sub>DD</sub> as reference individually for each channel. The **MCP4725** and **MCP4728** are available with I<sup>2</sup>C serial interface.

The **MCP4821/2** family of 12-bit DACs combines high performance with an internal reference voltage and SPI interface. The **MCP4921/2** family is similar and allows for an external reference. These DAC devices provide high accuracy and low noise, and are ideal for industrial applications where calibration or compensation of signals (such as temperature, pressure and humidity) is required. The **TC1320/1** family of DACs has 8- and 10-bit precision that uses the 2-wire SMBus/I<sup>2</sup>C serial interface protocol.

# Local Sensors

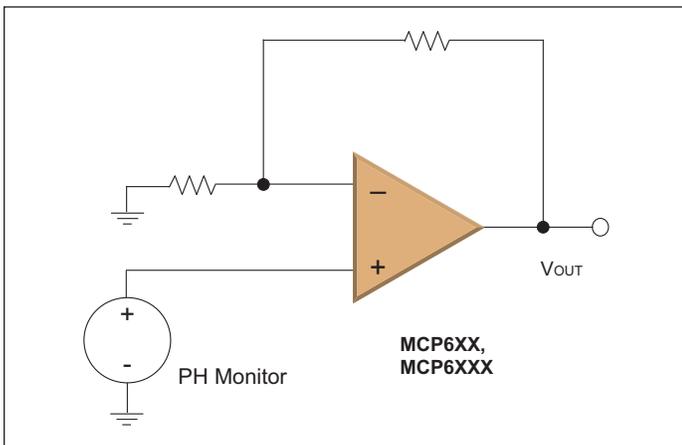
## Local Sensing

Local sensors are located relatively close to their signal conditioning circuits, and the noise environment is not severe; most of these sensors are single ended (not differential). Non-inverting amplifiers are a good choice for amplifying most of these sensors' output because they have high input impedance, and require a minimal amount of discrete components.

### Key Amplifier Features

- Low Cost
  - General Purpose Op Amps
- High Precision
  - Low Offset Op Amps
  - Auto-zeroed Op Amps
  - Low Noise Op Amps
- Rail-to-Rail Input/Output
  - Most Op Amp families
- High Input Impedance
  - Almost all Op Amp families
- Low Power and Portable Applications
  - Low Power Op Amps
- High Bandwidth and Slew Rate
  - High Speed Op Amps
- Load Drive
  - High Output Drive Op Amps

### Classic Gain Amplifier



## Sensors and Applications

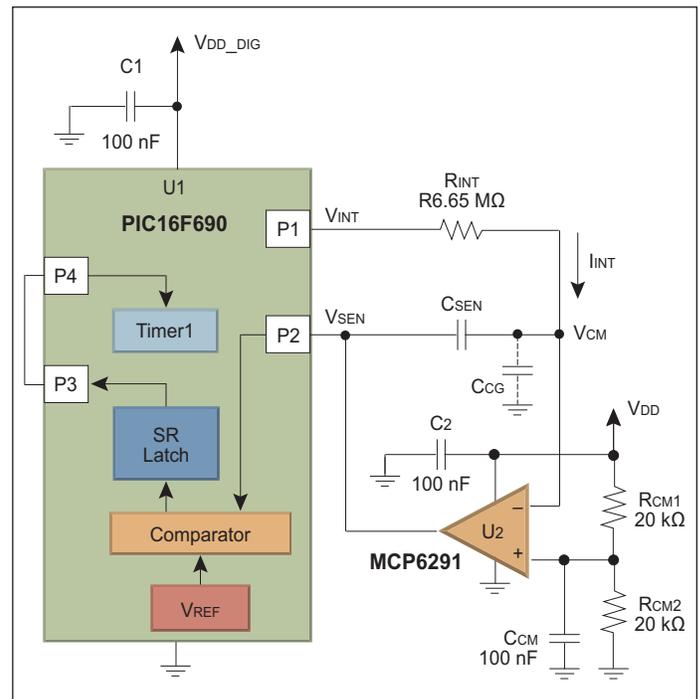
### Single Sensors

- Thermistors for battery chargers and power supply temperature protection
- Humidity Sensors for process control
- Pyroelectric infrared intrusion alarms, motion detection and garage door openers
- Smoke and fire sensors for home and office
- Charge amplifier for Piezoelectric Transducer detection
- Thermistor for battery chargers and home thermostats
- LVDT position and rotation sensors for industrial control
- Hall effect sensors for engine speed sensing and door openers
- Photoelectric infrared detector
- Photoelectric motion detectors, flame detectors, intrusion alarms

### Multiple Local Sensors

- Temperature measurement at multiple points on a Printed Circuit Board (PCB)
- Sensors that require temperature correction
- Weather measurements (temperature, pressure, humidity, light)

### Capacitive Humidity Sensor Circuit (PIC16F690DM-PCTLHS)



# Remote Sensors

## Remote Sensing

All sensors in a high noise environment should be considered as remote sensors. Also, sensors not located on the same PCB as the signal conditioning circuitry are remote. Remote sensing applications typically use a differential amplifier or an instrumentation amplifier.

### Key Amplifier Features

- Differential Input
- Large CMR
- Small Vos

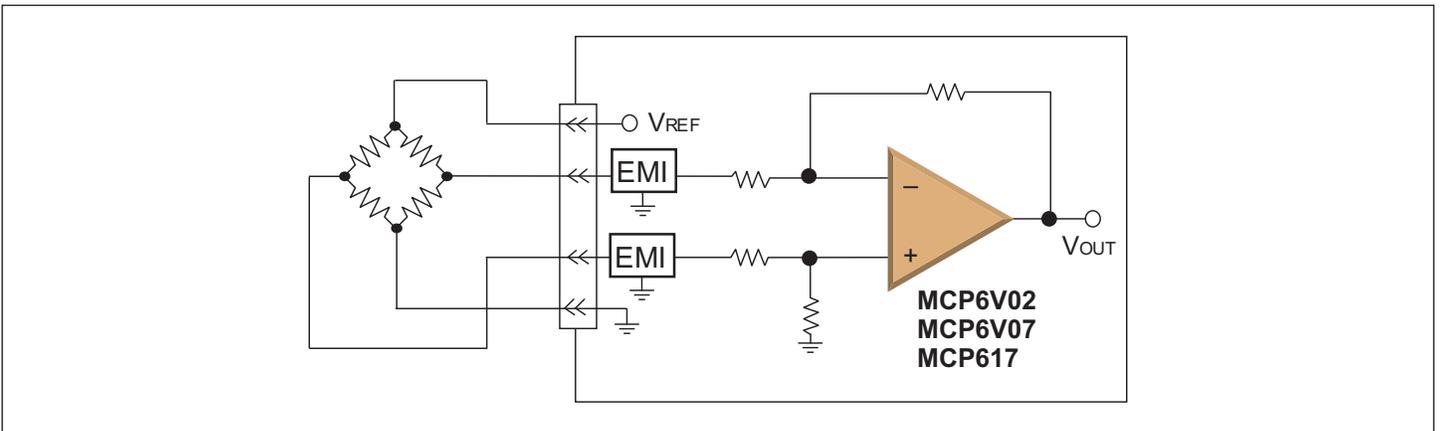
## Products

- High Precision
  - Low Offset Op Amps
  - Auto-zeroed Op Amps
  - Low Noise Op Amps

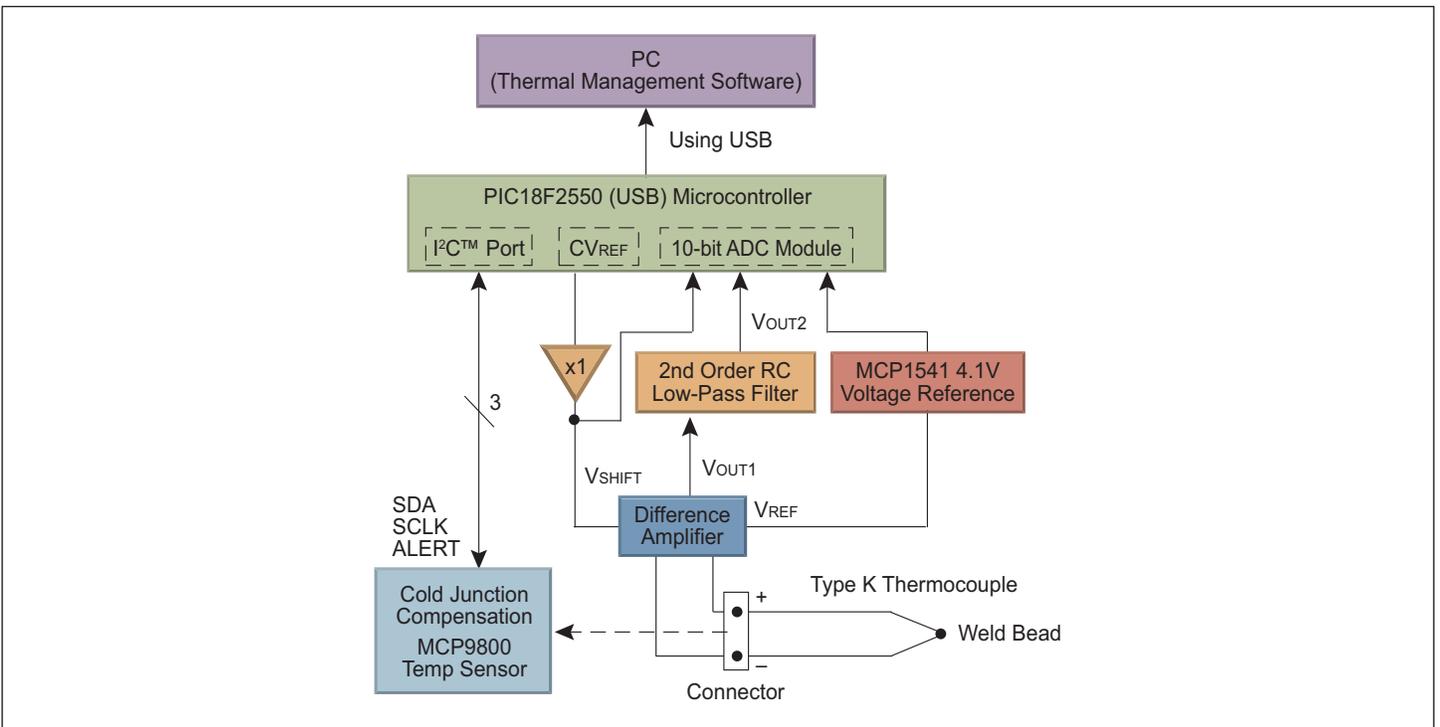
## Sensors and Applications

- High temperature sensors
  - Thermocouples for stoves, engines and process control
  - RTDs for ovens and process control
- Wheatstone Bridges
  - Pressure Sensors for automotive and industrial control
  - Strain gauges for engines
- Low side current monitors for motors and batteries

## Differential Amplifier



## MCP6V01 Thermocouple Auto-zeroed Reference Design (MCP6V01RD-TCPL)



# Oscillator Circuits For Sensors

## RC Operational Amplifier Oscillators For Sensor Applications

Op Amp or state-variable oscillators can be used to accurately measure resistive and capacitive sensors. Oscillators do not require an analog-to-digital converter and provide a sensor measurement whose conversion to digital has an accuracy limited only by the reference clock signal.

State-variable oscillators are often used in sensor conditioning applications because they have a reliable start-up and a low sensitivity to stray capacitance. Absolute quartz pressure sensors and humidity sensors are examples of capacitive sensors that can use the state-variable oscillator. Also, this circuit can be used with resistive sensors, such as RTDs, to provide temperature-to-frequency conversion.

The block diagram below shows a typical system level design, including the state-variable oscillator, PIC microcontroller and temperature sensor (used for temperature correction).

## Sensors and Applications

### Resistive Sensors

- RTDs
- Humidity
- Thermistors

### Capacitive Sensors

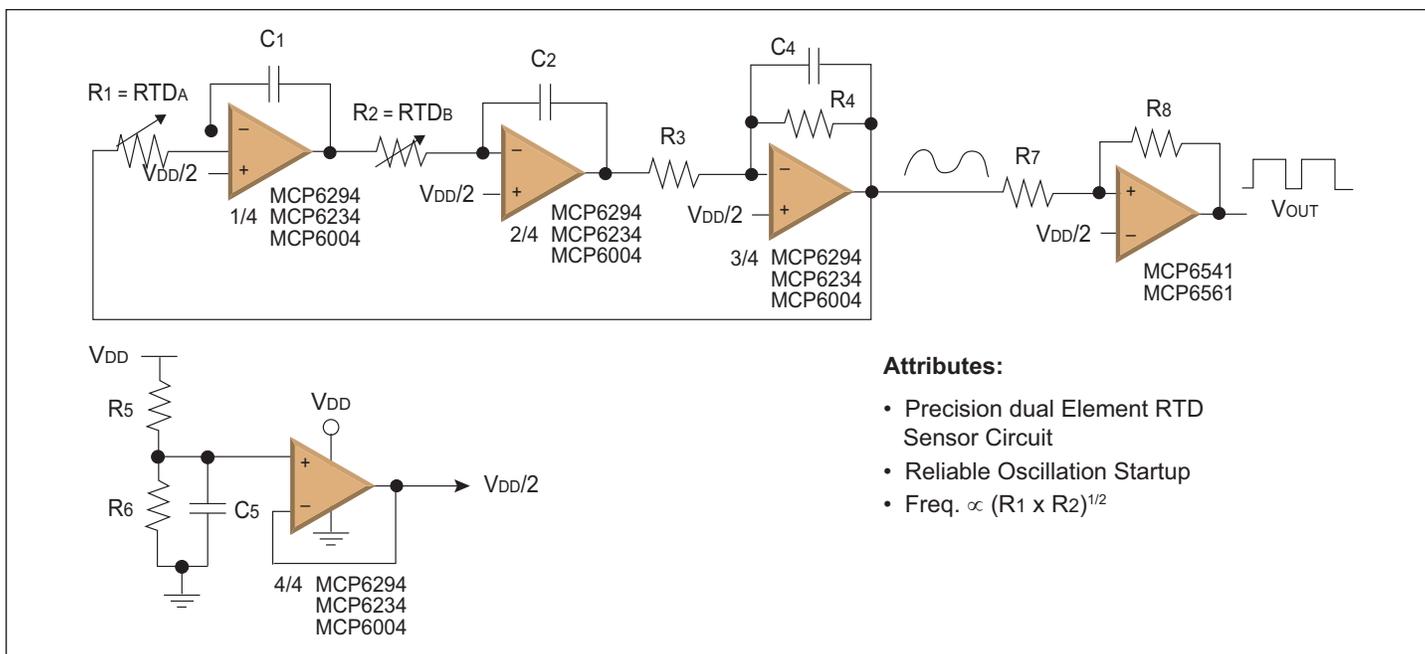
- Humidity
- Pressure
- Oil Level

### Related Application Notes:

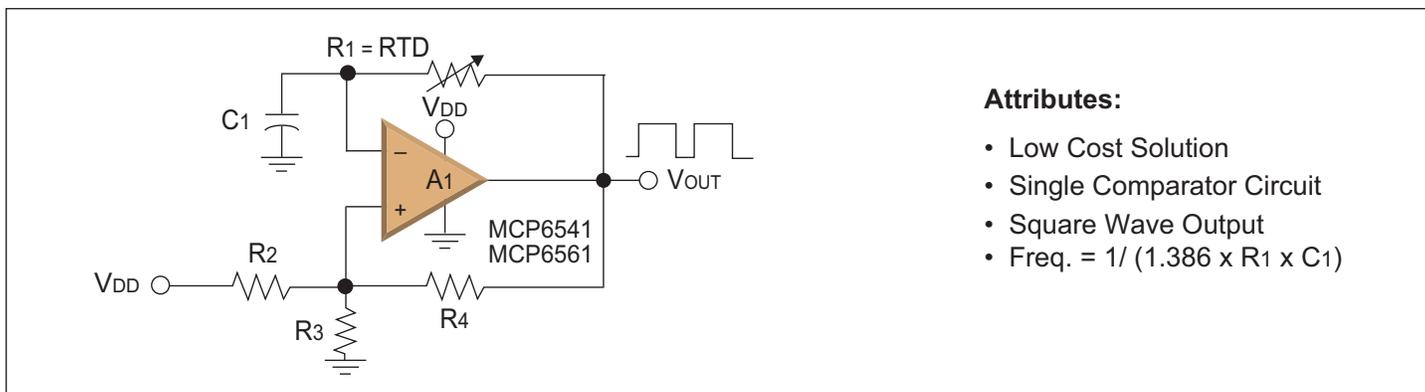
- AN895: Oscillator Circuits for RTD Temperature Sensors
- AN866: Designing Operational Amplifier Oscillator Circuits for Sensor Applications

Available on the Microchip web site at: [www.microchip.com](http://www.microchip.com)

## Oscillator Circuits for Sensors



## Oscillator Circuits for Sensors



# Wheatstone Bridge

## Bridge Sensor Circuit

Sensors for temperature, pressure, load or other physical excitation quantities are most often configured in a Wheatstone bridge configuration. The bridge can have anywhere from one to all four elements reacting to the physical excitation, and should be used in a ratiometric configuration when possible, with the system reference driving both the sensor and the ADC voltage reference. By using the same reference for both the sensor excitation and ADC, the variation in the reference can be cancelled out. Furthermore, the output voltage from the bridge sensor is proportional to the excitation voltage. Therefore, the ADC that is using the external reference is more popular than the ADC that is using internal reference, for the ratiometric configuration.

One example sensor from GE NovaSensor is an absolute pressure sensor, shown below, a four element varying bridge. This example uses the **MCP355X** family of delta sigma ADCs. When designing with the **MCP355X** family of 22-bit delta-sigma ADCs, the initial step should be to evaluate the sensor performance and then determine what

steps (if any) should be used to increase the overall system resolution when using the **MCP355X**. In many situations, the **MCP355X** devices can be used to directly digitize the sensor output, eliminating any need for external signal conditioning circuitry.

Using the absolute pressure sensor as our Wheatstone bridge example, the NPP-301 device has a typical full scale output of 60 mV when excited with a 3V battery. The pressure range for this device is 100 kPa. The **MCP3551** has a output noise specification of 2.5  $\mu\text{VRMS}$ .

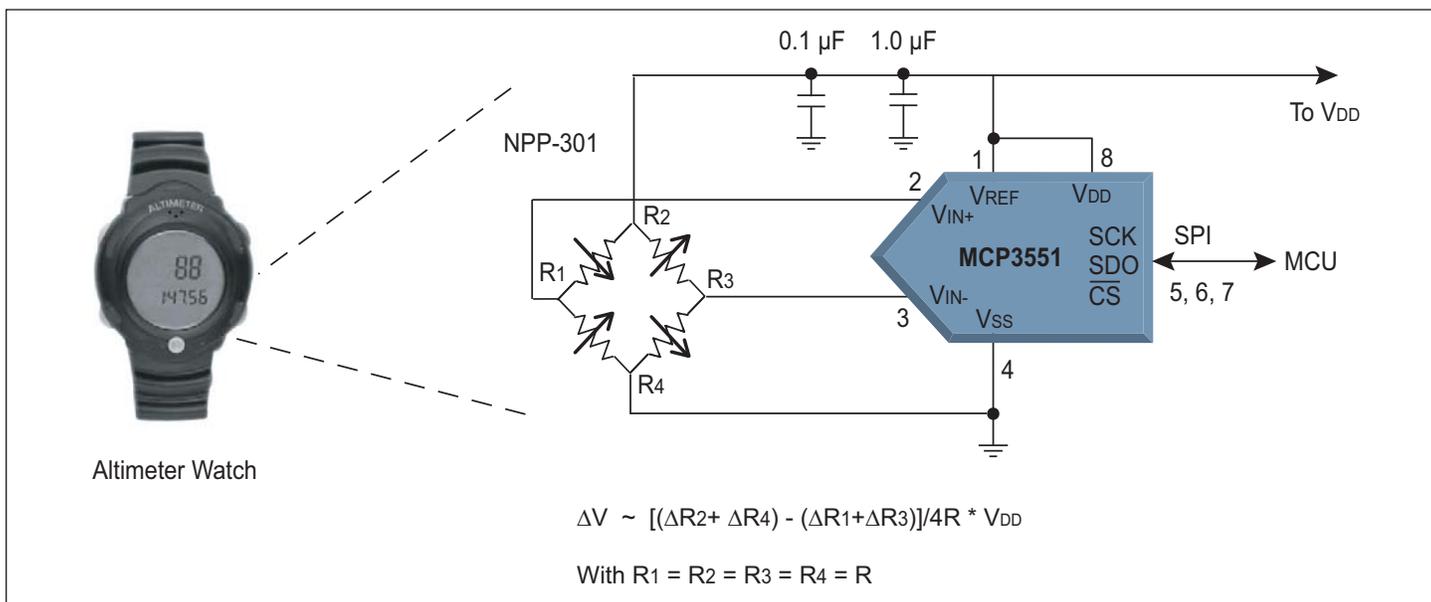
The following equation is a first order approximation of the relationship between pressure in pascals (P) and altitude (h), in meters.

$$\log(P) \approx 5 - \frac{h}{15500}$$

Using 60 mV as the full scale range and 2.5  $\mu\text{V}$  as the resolution, the resulting resolution from direct digitization in meters is 0.64 meters or approximately 2 feet.

It should be noted that this is only used as an example for discussion; temperature effects and the error from a first order approximation must be included in final system design.

## Example of Wheatstone Bridge Sensor Configuration with High Resolution Delta-Sigma ADC



# Delta-Sigma ADCs

## Voltage and Current Measurement Using Delta-Sigma ADCs

The **MCP342X** family devices are easy-to-use high precision delta sigma ADC devices from Microchip. These devices have an internal reference (2.048V) with a user programmable PGA (x1, x2, x4, x8). The ADC resolution is programmable as 12-bit, 14-bit, 16-bit or 18-bit by the user.

This ADC family offers single, dual and four differential input channels. Because of its simplicity and low price, this device family can be used for various applications from simple voltage and current measurement to high precision temperature measurement.

## MCP3422 Analog-to-Digital Converter (ADC) Feature Summary

Bit Resolution	18 bits (User can select 18-, 16-, 14- or 12-bit options)
Number of Differential Input Channels	2
Internal Programmable Gain Amplifier	x1, x2, x4 or x8 (user option)
INL Error (Typical)	10 PPM of full scale range
Offset Error (Typical)	15 $\mu$ V
Internal Reference Voltage	2.048V
Output Noise (Typical)	1.5 $\mu$ Vrms
Gain Error (Typical)	0.05% of full scale range
Interface	I <sup>2</sup> C™

## Voltage Measurement Using MCP3421 Device

(a) If  $V_{REF} < V_{BAT}$

(b) If  $V_{REF} > V_{BAT}$

$$V_{IN} = \left( \frac{R_2}{R_1 + R_2} \right) \cdot (V_{BAT})$$

$$V_{Measured} = \text{ADC Output Codes} \cdot \text{LSB} \cdot \frac{(R_1 + R_2)}{R_2} \cdot \frac{1}{PGA}$$

$$\text{LSB} = \frac{\text{Reference Voltage}}{2^{N-1}}$$

$$\text{LSB of 18-bit ADC} = \frac{\text{Reference Voltage}}{2^{N-1}} = \frac{2.048V}{2^{17}} = 15.625 \mu\text{V}$$

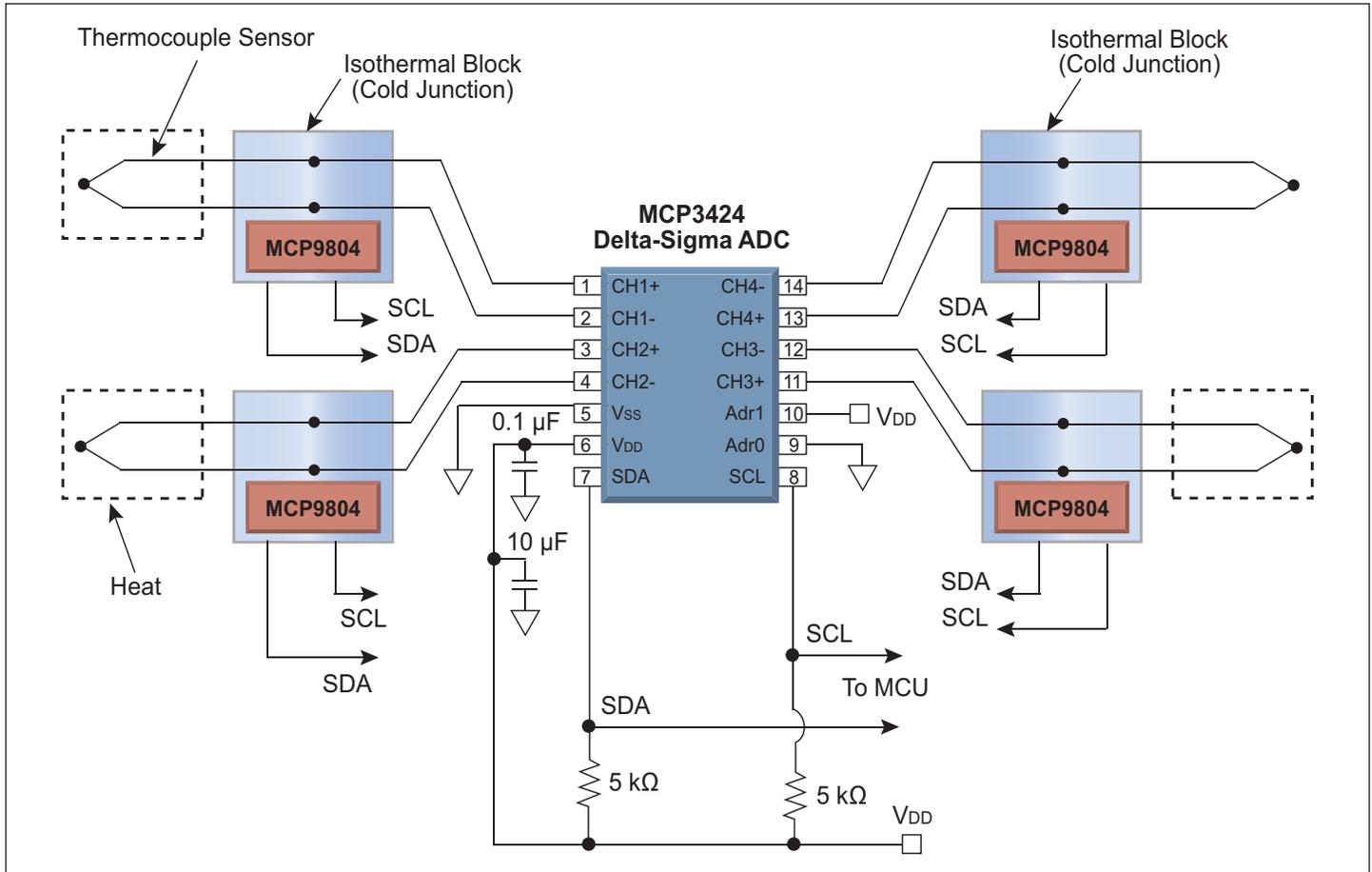
## Current Measurement Using MCP3421 Device

Current = (Measured Voltage)/(Known Resistance Value of Current Sensor)  
 Direction of current is determined by sign bit (MSB bit) of the ADC output code.

## Wireless Temperature Monitoring Solution

# Delta-Sigma ADCs

## Temperature Measurements Using 4 Channel ADC (MCP3424) See Thermocouple Reference Design (TMPSNSRD-TCPL1)



# Thermistor and RTD Solutions

## Thermistor Solutions

Typically, thermistors require an external resistor for biasing. In addition, the inherent non-linearity of a thermistor is improved by biasing the thermistor in a resistive ladder circuit to linearize the temperature-to-voltage conversion. Typically, the thermistor voltage is directly connected to an ADC to digitize the voltage measurement. The measured voltage is converted to temperature using a lookup table. However, at hot and cold temperature extremes the non-linearity of this approach is much greater with reduced change in voltage, which results in lower accuracy. This requires higher resolution and a more costly ADC.

The solution is to use Microchip's Linear Active Thermistors, the **MCP9700** and **MCP9701**. These are low-cost voltage output temperature sensors that replace almost any Thermistor application solutions. Unlike resistive type sensors such as Thermistors, the signal conditioning and noise immunity circuit development overhead can be avoided by using the low-cost Linear Active Thermistors. These sensors output voltage is proportional to ambient temperature with temperature coefficient of 10 mV/°C and 19.5 mV/°C. Unlike thermistors, these devices do not require additional computation for temperature measurement. The factory set coefficients provide linear interface to measure ambient temperatures (refer to AN1001 for sensor optimization).

### MCP9700 and MCP9701 Key Features

- SC70, T092 packages
- Operating temperature range: -40°C to +150°C
- Temperature Coefficient: 10 mV/°C (**MCP9700**)
- Temperature Coefficient: 19.5 mV/°C (**MCP9701**)
- Low power: 6 µA (typ.)

### Applications

- Refrigeration equipment
- Power supply over temperature protection
- General purpose temperature monitoring

## RTD Solution

Resistive Temperature Detectors (RTDs) are highly accurate and repeatable temperature sensing elements. When using these sensors a robust instrumentation circuit is required and it is typically used in high performance thermal management applications such as medical instrumentation. This solution uses a high performance Delta-Sigma Analog-to-Digital converter, and two resistors to measure RTD resistance ratiometrically. A ±0.1°C accuracy and ±0.01°C measurement resolution can be achieved across the RTD temperature range of -200°C to +800°C with a single point calibration.

This solution uses a common reference voltage to bias the RTD and the ADC which provides a ratio-metric relation between the ADC resolution and the RTD temperature resolution. Only one biasing resistor, RA, is needed to set the measurement resolution ratio (shown in equation below).

### RTD Resistance

$$R_{RTD} = R_A \left( \frac{Code}{2^n - 1 - Code} \right)$$

Where:

Code = ADC output code

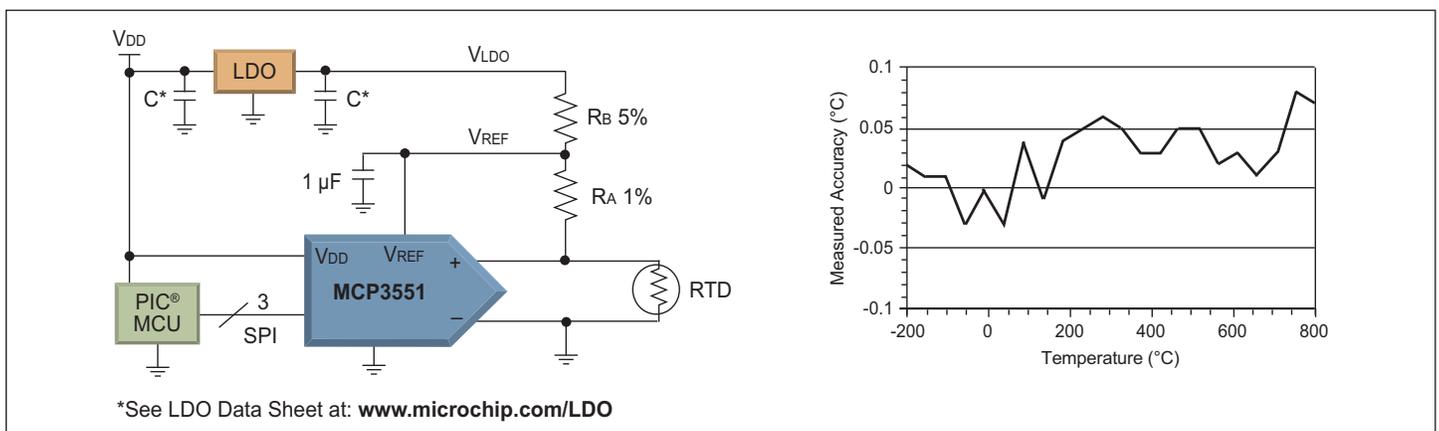
RA = Biasing resistor

n = ADC number of bits  
(22 bits with sign, MCP3551)

For instance, a 2V ADC reference voltage (VREF) results in a 1 µV/LSb (Least Significant Bit) resolution. Setting RA = RB = 6.8 kΩ provides 111.6 µV/°C temperature coefficient (PT100 RTD with 0.385Ω/°C temperature coefficient). This provides 0.008°C/LSb temperature measurement resolution for the entire range of 20Ω to 320Ω or -200°C to +800°C. A single point calibration with a 0.1% 100Ω resistor provides ±0.1°C accuracy as shown in the figure below.

This approach provides a plug-and-play solution with minimum adjustment. However, the system accuracy depends on several factors such as the RTD type, biasing circuit tolerance and stability, error due to power dissipation or self-heat, and RTD non-linear characteristics.

## RTD Instrumentation Circuit Block Diagram and Output Performance (see Application Note AN1154)



# Programmable Gain Using Digital Potentiometers

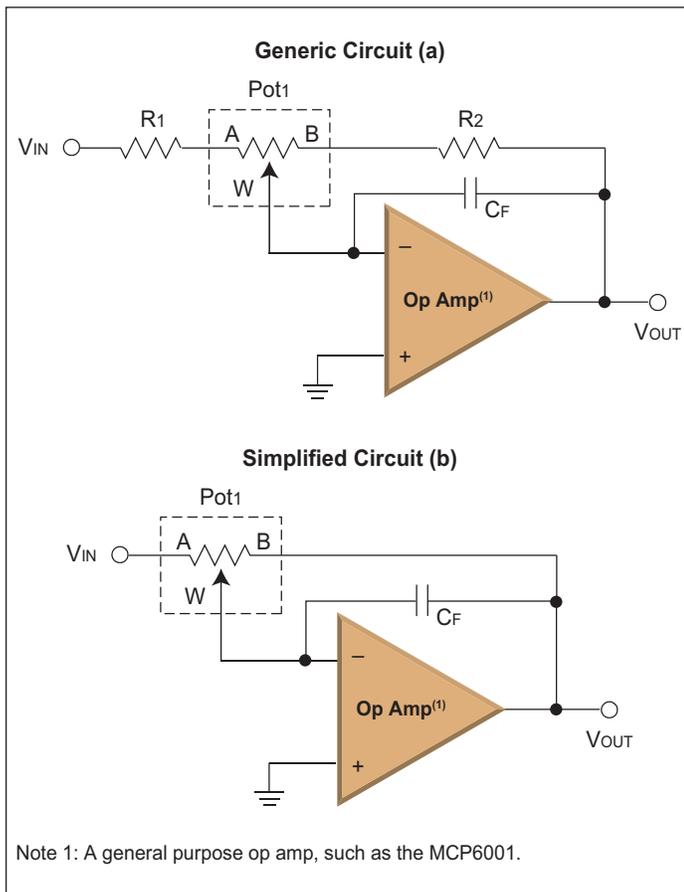
## Programmable Amplifier Gain Using a Digital Potentiometer

Many sensors require their signal to be amplified before being converted to a digital representation. This signal gain may be done with an operational amplifier. Since all sensors will have some variation in their operational characteristics, it may be desirable to calibrate the gain of the operational amplifier to ensure an optimal output voltage range.

The figure below shows two inverting amplifier with programmable gain circuits. The generic circuit (a) where R1, R2, and Pot1 can be used to tune the gain of the inverting amplifier, and the simplified circuit (b) which removes resistors R1 and R2 and just uses the digital potentiometers RAW and RBW ratio to control the gain.

The simplified circuit reduces the cost and board area but there are trade-offs (for the same resistance and resolution). Using the R1 and R2 resistors allows the range of the gain to be limited and therefore each digital potentiometer step is a fine adjust within that range. While in the simplified circuit, the range is not limited and therefore each digital potentiometer step causes a larger variation in the gain. The feedback capacitor (CF) is used for circuit stability.

### Inverting Amplifier with Programmable Gain Circuits



Equation 1-1 shows how to calculate the gain for the simplified circuit (Figure 1-1b). The gain is the ratio of the digital potentiometers wiper position on the RAB resistor ladder. As the wiper moves away from the midscale value, the gain will either become greater than one (as wiper moves towards Terminal A), or less than one (as wiper moves towards Terminal B).

The device's wiper resistance (RW) is ignored for first order calculations. This is due to it being in series with the op amp input resistance and the op amp input impedance is very large.

### Circuit Gain Equation

$$V_{OUT} = - \frac{R_{BW}}{R_{AW}} \times V_{IN}$$

$$R_{BW} = \frac{R_{AB}}{\# \text{ of Resistors}} \times \text{Wiper Code}$$

$$R_{AW} = \frac{\# \text{ of Resistors} - \text{Wiper Code}}{\# \text{ of Resistors}} \times R_{AB}$$

# Programmable Gain Using Digital Potentiometers

The table below shows a comparison of the gain between the circuits (a and b) in Figure 1-1 when using the same Digital Potentiometer (10 kΩ, 7-bit). What you also see is that when  $R_1 = R_2 = 10\text{ k}\Omega$ , the circuit's gain range is between 1 and 3. While when the simplified circuit is used (effectively having  $R_1 = R_2 = 0\Omega$ ) the circuit's gain range is between  $\sim 0$  and  $>127$ . Therefore the capability for finer calibration of the circuit is capable with the generic circuit, albeit with a narrower range.

Some devices have an even number of step resistors ( $R_s$ ) in the  $R_{AB}$  string, while others have an odd number. In the simplified circuit, devices with an even number of  $R_s$  resistors have a mid-scale wiper value that is unity gain.

For devices with an odd number of  $R_s$  resistors have a mid-scale wiper value that is near unity gain. The MCP4261 is an example of a device that has an even number of  $R_s$  resistors in the  $R_{AB}$  string, while the MCP4011 is an example of a device that has an odd number of  $R_s$  resistors in the  $R_{AB}$  string.

For devices with an odd number of  $R_s$  resistors in the  $R_{AB}$  string to be able to have an exact unity gain, the device would need to be used in the generic circuit configuration (Figure 1-1), and the components would need to be selected so  $R_1 + R_{AW}$  could equal  $R_2 + R_{BW}$ .

## Amplifier Gain vs. Wiper Code and $R_w$

# of Taps	# of Resistors	Wiper Code	10 kΩ Gain		Comment
			Simplified Circuit <sup>(1)</sup>	Generic Circuit <sup>(1, 2)</sup>	
129	128	0	0.0	1.000000	Zero Scale
		1	0.007874	1.007843	
		2	0.015873	1.015748	
		3	0.024000	1.023715	
		4	0.032258	1.031746	
		⋮	⋮	⋮	⋮
		⋮	⋮	⋮	⋮
		62	0.939394	1.639175	
		63	0.969231	1.652850	
		64	1.000000	1.666667	Mid Scale
		65	1.031746	1.680628	
		66	1.064516	1.694737	
		⋮	⋮	⋮	⋮
		⋮	⋮	⋮	⋮
		124	31.000000	2.878788	
		125	41.666667	2.908397	
126	63.000000	2.938462			
127	127.000000	2.968992			
128	Divide Error <sup>(3)</sup>	3.000000	Full Scale		

**Note 1:** Gain =  $( (R_{AB} / \# \text{ of Resistors}) * \text{Wiper Code} ) / ( ( \# \text{ of Resistors} - \text{Wiper Code} ) / \# \text{ of Resistors} ) * R_{AB}$

**2:** Uses  $R_1 = R_2 = 10\text{ k}\Omega$ .

**3:** Theoretical calculations. At full scale in the simplified circuit a divide by 0 error results.

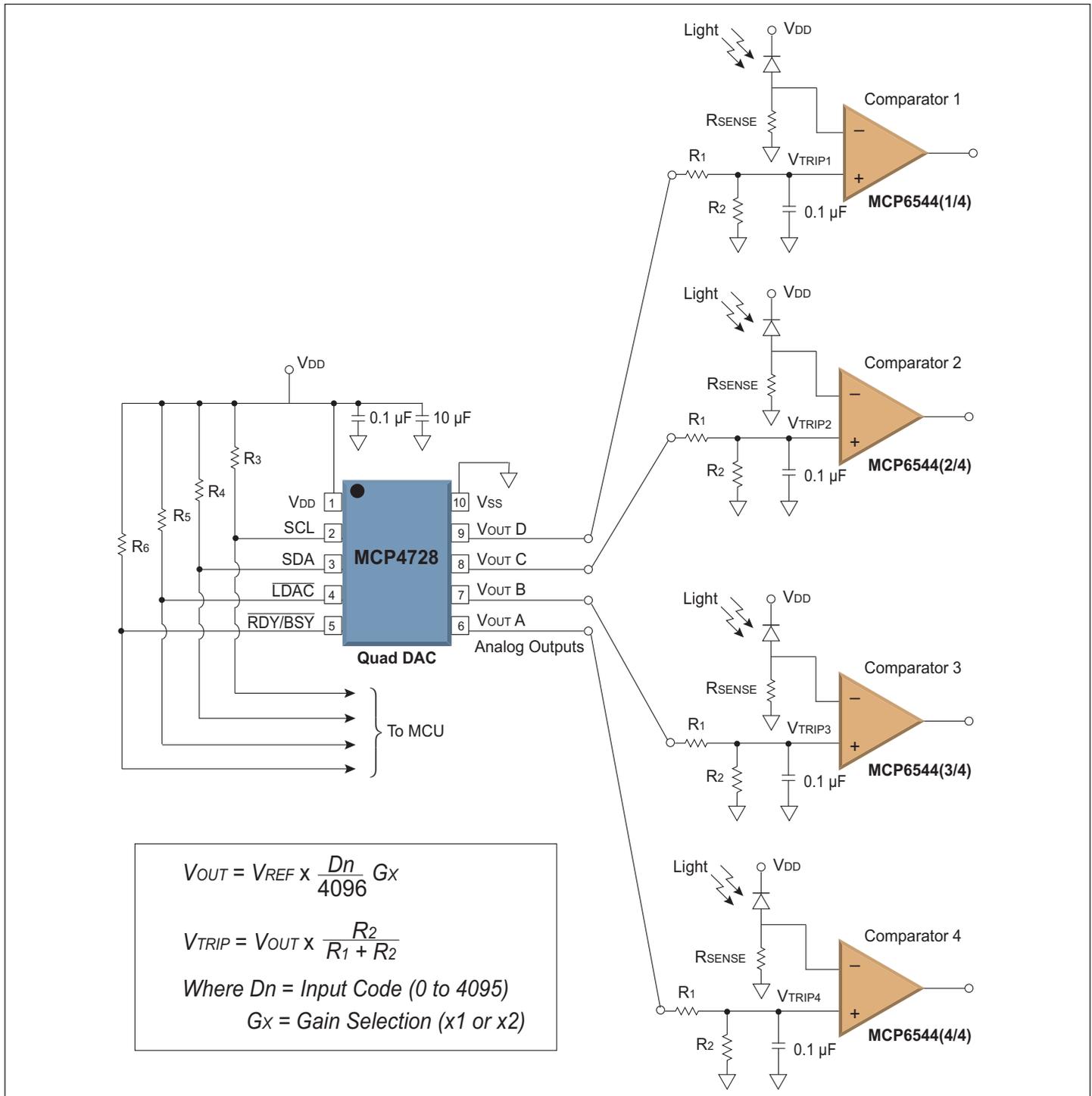
# Sensor Circuit Calibration using a DAC

## Setting the DC Set Point for Sensor Circuit

A common DAC application is digitally controlling the set point and/or calibration of parameters in a signal chain. The figure below shows controlling the DC set point of a light detector sensor using the **MCP4728** 12-bit quad DAC device. The DAC provides 4096 output steps. If  $G = 1$  and internal reference voltage options are selected, then the internal 2.048 V<sub>REF</sub> would produce 500  $\mu\text{V}$  of resolution. If  $G = 2$  is

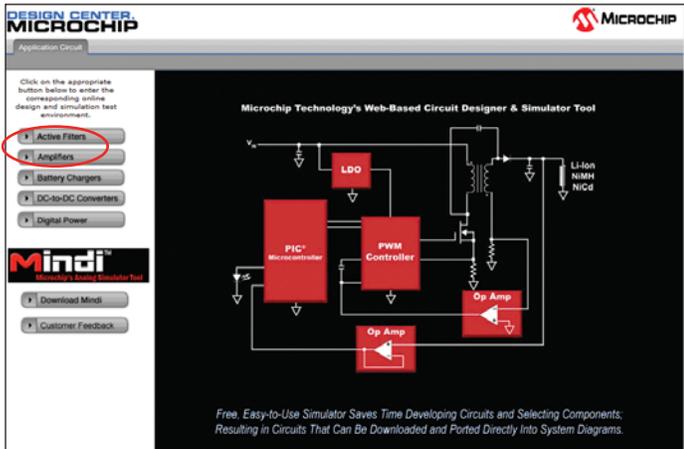
selected, the internal 2.048 V<sub>REF</sub> would produce 1 mV of resolution. If a smaller output step size is desired, the output range would need to be reduced. So, using gain of 1 is a better choice than using gain of 2 configuration option for smaller step size, but its full-scale range is one half of that of the gain of 2. Using a voltage divider at the DAC output is another method for obtaining a smaller step size.

## Setting the DC Set Point



# Mindi™ Amplifier Designer & Simulator

## Mindi™ Amplifier Designer & Simulator

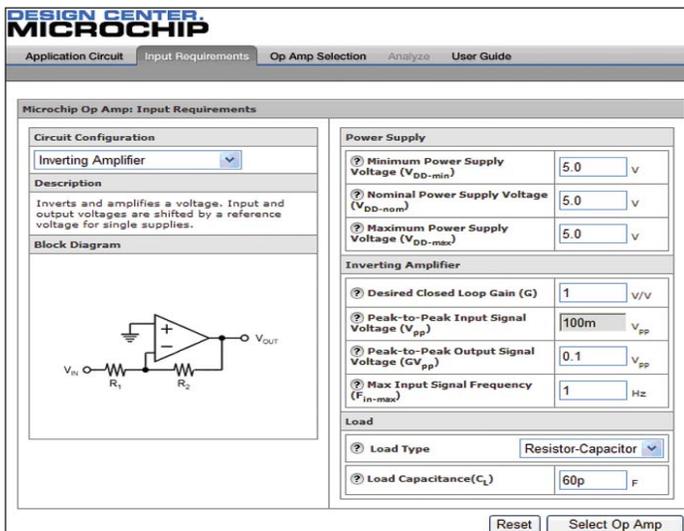


The Mindi Amplifier Designer & Simulator is an Application Circuit that generates full schematic diagrams of an amplifier circuit with recommended component values and displays the signal responses in frequency and time domains.

This application circuit allows the following designs:

- Inverting Amplifier
- Non-inverting Amplifier
- Voltage Follower
- Difference Amplifier
- Inverting Summing Amplifier
- Inverting Comparator
- Inverting Differentiator
- Inverting Integrator

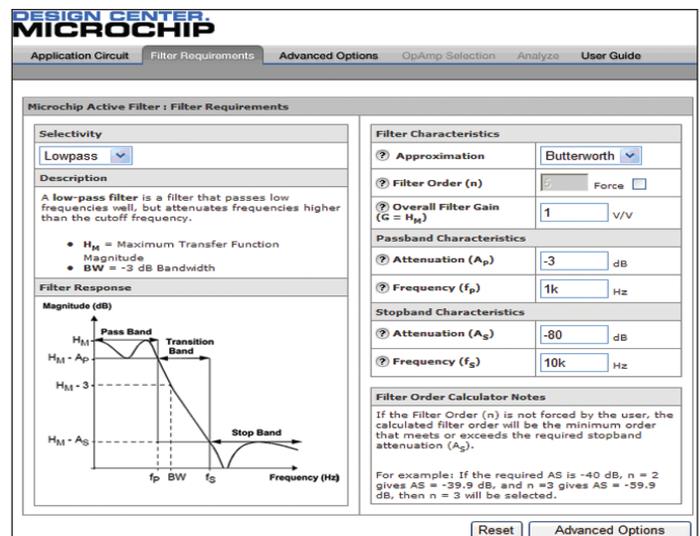
Once the amplifier characteristics have been identified, the Mindi Amplifier Designer & Simulator can generate and simulate the schematic of the amplifier circuit. For maximum design flexibility, changes in resistor and capacitor values can be implemented to fit the demands of the application. The tool also generates a Design Summary of the designed amplifier, including Design Requirements, Application Schematic, Result Plot and Bill of Materials (BOM). Users can directly download the schematic, BOM and Mindi offline version.



## Mindi™ Active Filter Designer & Simulator

The Mindi Active Filter Designer & Simulator is an Application Circuit within the Mindi Circuit Designer & Simulator that provides full schematic diagrams of the active filter circuit with recommended component values and displays the signal responses in frequency and time domains.

The Mindi Active Filter Designer & Simulator allows the design of low-pass filters up to an 8th order filter with Chebychev, Bessel or Butterworth approximations from frequencies of 0.1 Hz to 1 MHz. It also can be used to design band-pass and high-pass filters with Chebychev and Butterworth approximations. The circuit topologies supported by the tool are the Sallen Key and Multiple Feedback (MFB). The low-pass filters can use either the Sallen Key or MFB, the band-pass filter is available with the MFB and the high-pass filter uses the Sallen Key.



Users can select a flat pass-band or sharp transition from pass-band to stop-band. Other options, such as minimum ripple factor, sharp transition and linear phase delays are available. Once the filter characteristics have been identified, the Mindi Active Filter Designer & Simulator can generate and simulate the schematic of filter circuit. For maximum design flexibility, changes in resistor and capacitor values can be implemented to fit the demands of the application. The tool will recalculate all values to meet the desired response, allowing real-world values to be substituted or changed as part of the design process. The tool also generates a Bill of Materials (BOM) of the designed filter.

Both of these tools are available on the Microchip web site ([www.microchip.com](http://www.microchip.com)) under "Design & Simulation Tools" or on the Mindi home page (<http://www.microchip.com/mindi>). The op amps and evaluation boards can also be ordered from the Microchip web site.

# Development Tools

These following development boards support the the development of signal chain applications. These product families may have other demonstration and evaluation boards that may also be useful. For more information visit [www.microchip.com/analogtools](http://www.microchip.com/analogtools)

## ADCs

### MCP3421 Battery Fuel Gauge Demo (MCP3421DM-BFG)



The MCP3421 Battery Fuel Gauge Demo Board demonstrates how to measure the battery voltage and discharging current using the MCP3421. The MCU algorithm calculates the battery fuel being used.

This demo board is shipped with 1.5V AAA non-rechargeable battery. The board can also charge a single-cell 4.2V Li-Ion battery.

### MCP3551 Tiny Application (Pressure) Sensor Demo (MCP355XDM-TAS)



This 1" x 1" board is designed to demonstrate the performance of the MCP3550/1/3 devices in a simple low-cost application. The circuit uses a ratiometric sensor configuration and uses the system power supply as the voltage reference. The

extreme common mode rejection capability of the MCP355X devices, along with their excellent normal mode power supply rejection at 50 and 60 Hz, allows for excellent system performance.

### MCP3551 Sensor Application Developer's Board (MCP355XDV-MS1)



The MCP355X Sensor Developer's Board allows for easy system design of high resolution systems such as weigh scale, temperature sensing, or other small signal systems requiring precise signal

conditioning circuits. The reference design includes LCD display firmware that performs all the necessary functions including ADC sampling, USB communication for PC data analysis, LCD display output, zero cancellation, full scale calibration, and units display in gram (g), kilogram (kg) or ADC output units.

### MCP3901 ADC Evaluation Board for 16-bit MCUs (MCP3901EV-MCU16)



The MCP3901 ADC Evaluation Board for 16-bit MCUs system provides the ability to evaluate the performance of the MCP3901 dual channel ADC. It also provides a development platform for 16-bit PIC based applications, using existing 100-pin PIM systems.

## DACs

### MCP4725 PICtail™ Plus Daughter Board (MCP4725DM-PTPLS)



This daughter board demonstrates the MCP4725 (12 bit DAC with non-volatile memory) features using the Explorer 16 Development Board and the PICkit Serial Analyzer.

### MCP4725 SOT-23-6 Evaluation Board (MCP4725EV)



The MCP4725 SOT-23-6 Evaluation Board is a quick and easy evaluation tool for the MCP4725 12-bit DAC device. It works with Microchip's popular PICkit™ Serial

Analyzer or independently with the customer's applications board. The PICkit Serial Analyzer is sold separately.

### MCP4728 Evaluation Board (MCP4728EV)



The MCP4728 Evaluation Board is a tool for quick and easy evaluation of the MCP4728 4-channel 12-bit DAC device. It contains the MCP4728 device and connection pins for the Microchip's popular PICkit™ Serial Analyzer. The PICkit Serial Analyzer is sold separately.

## Op Amps

### MCP6031 Photodiode PICtail™ Plus Demo Board (MCP6031DM-PTPLS)



The MCP6031 Photodiode PICtail Plus Demo Board demonstrates how to use a transimpedance amplifier, which consists of MCP6031 high precision op amp and external resistors, to convert photo-current to voltage.

### MCP651 Input Offset Evaluation Board (MCP651EV-VOS)



The MCP651 Input Offset Evaluation Board is intended to provide a simple means to measure the MCP651 Input Offset Evaluation Board op amp's input offset voltage under a variety of operating conditions. The measured input offset voltage ( $V_{OSr}$ ) includes the input offset voltage specified in the data sheet ( $V_{OS}$ ) plus changes due to: power supply voltage (PSRR), common mode voltage (CMRR), output voltage (AOL), input offset voltage drift over temperature ( $\Delta V_{OS}/\Delta T_A$ ) and 1/f noise.

# Development Tools

## MCP6V01 Input Offset Demo Board (MCP6V01DM-VOS)



The MCP6V01 Input Offset Demo Board is intended to provide a simple means to measure the MCP6V01/2/3 op amps input offset voltage ( $V_{os}$ ) under a variety of bias conditions. This  $V_{os}$  includes the specified input offset voltage value found in the data

sheet plus changes due to power supply voltage (PSRR), common mode voltage (CMRR), output voltage (AOL) and temperature (IV $_{os}$ /ITA).

## MCP661 Line Driver Demo Board (MCP661DM-LD)



This demo board uses the MCP661 in a very basic application for high speed op amps; a 50 $\Omega$  line (coax) driver. The board offers a 30 MHz solution, high speed PCB

layout techniques and a means to test AC response, step response and distortion. Both the input and the output are connected to lab equipment with 50 $\Omega$  BNC cables. There are 50 $\Omega$  terminating resistors and transmission lines on the board. The op amp is set to a gain of 2V/V to overcome the loss at its output caused by the 50 $\Omega$  resistor at that point. Connecting lab supplies to the board is simple; there are three surface mount test points provided for this purpose.

## Amplifier Evaluation Board 1 (MCP6XXXEV-AMP1)



The MCP6XXX Amplifier Evaluation Board 1 is designed to support inverting/non-inverting amplifiers, voltage followers, inverting/non-inverting comparators, inverting/non-inverting differentiators.

## Amplifier Evaluation Board 2 (MCP6XXXEV-AMP2)



The MCP6XXX Amplifier Evaluation Board 2 supports inverting summing amplifiers and non-inverting summing amplifiers.

## Amplifier Evaluation Board 3 (MCP6XXXEV-AMP3)



The MCP6XXX Amplifier Evaluation Board 3 is designed to support the difference amplifier circuits which are generated by the Mindi™ Amplifier Designer.

## Amplifier Evaluation Board 4 (MCP6XXXEV-AMP4)



The MCP6XXX Amplifier Evaluation Board 4 is designed to support the inverting integrator circuit.

## Thermocouple Reference Design (TMPSNSRD-TCPL1)



The Thermocouple Reference Design demonstrates how to instrument a Thermocouple and accurately sense temperature over the entire Thermocouple measurement range. This solution uses the MCP3421 18-bit Analog-to-Digital Converter (ADC) to measure voltage across the Thermocouple.

## MCP6V01 Thermocouple Auto-Zero Reference Design (MCP6V01RD-TCPL)



The MCP6V01 Thermocouple Auto-Zeroed Reference Design demonstrates how to use a difference amplifier system to measure electromotive force (EMF) voltage at the cold junction of thermocouple in order to accurately measure temperature at the hot junction. This can be done by using the MCP6V01 auto-zeroed op amp because of its ultra low offset voltage ( $V_{os}$ ) and high common mode rejection ratio (CMRR).

## MCP6XXX Active Filter Demo (MCP6XXXDM-FLTR)



This kit supports Mindi™ Active Filter Designer & Simulator and active filters designed by FilterLab® V2.0. These filters are all pole and are built by cascading first and second order sections.

## Temp Sensors

### MCP9800 Temp Sensor Demo Board (MCP9800DM-TS1)



The MCP9800 Temperature Sensor Demo Board demonstrates the sensor's features. Users can connect the demo board to a PC with USB interface and evaluate the sensor performance. The

7-Segment LED displays temperature in degrees Celsius or degrees Fahrenheit; the temperature alert feature can be set by the users using an on board potentiometer. An alert LED is used to indicate an over temperature condition. In addition, temperature can be datalogged using the Microchip Thermal Management Software Graphical User Interface (GUI). The sensor registers can also be programmed using the GUI.

### MCP6S26 PT100 RTD Evaluation Board (TMPSNS-RTD1)



The PT100 RTD Evaluation Board demonstrates how to bias a Resistive Temperature Detector (RTD) and accurately measure temperature. Up to two RTDs can be connected. The

RTDs are biased using constant current source and the output voltage is scaled using a difference amplifier. In addition to the difference amplifier, a multiple input channel Programmable Gain Amplifier (PGA) MCP6S26 is used to digitally switch between RTDs and increase the scale up to 32 times.

# Development Tools

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## RTD Reference Design Board (TMPSNSRD-RTD2)

The RTD Reference Design demonstrates how to implement Resistive Temperature Detector (RTD) and accurately measure temperature. This solution uses the MCP3551 22-bit Analog-to-Digital Converter (ADC) to measure voltage across the RTD. The ADC and the RTD are referenced using an onboard reference voltage and the ADC inputs are directly connected to the RTD terminals. This provides a ratio metric temperature measurement. The solution uses a current limiting resistor to bias the RTD. It provides a reliable and accurate RTD instrumentation without the need for extensive circuit compensation and calibration routines.

In addition, the this reference design includes a silicon temperature sensor, MCP9804. This sensor is used for comparison only, it is not needed to instrument an RTD. The MCP3551 and MCP9804 outputs are read using a USB PIC microcontroller. This controller is also connected to a PC using USB interface. The thermal management software is used plot the RTD temperature data in stripchart format.

## Thermocouple Reference Design Board (TMPSNSRD-TCPL1)

The Thermocouple Reference Design demonstrates how to implement a thermocouple and accurately sense temperature over the entire thermocouple measurement range. This solution uses the MCP3421 18-bit Analog-to-Digital Converter (ADC) to measure voltage across the Thermocouple. The ADC has an internal 2.048V reference voltage and a Programmable Gain Amplifier with 1, 2, 4, 8 V/V. At a Gain of 8 V/V the PGA effectively adds 3 LSb to the ADC. This increases the ADC resolution to 21-bit or 2  $\mu\text{V}/\text{LSb}$ . Therefore, the Thermocouple EMF voltage is measured with 2  $\mu\text{V}$  resolution. For K-type thermocouple, measurement system provides a  $\pm 0.05^\circ\text{C}$  resolution. The cold-junction compensation is done using a  $\pm 1^\circ\text{C}$  accurate 0.0625 $^\circ\text{C}$  resolution silicon temperature sensor, the MCP9804. This solution provides a reliable and accurate Thermocouple instrumentation without the need for extensive circuit compensation and calibration routines.

# Related Support Material

The following literature is available on the Microchip web site: [www.microchip.com/appnotes](http://www.microchip.com/appnotes). There are additional application notes that may be useful.

## Sensor Conditioning Circuits Overview

### AN866: Designing Operational Amplifier Oscillator Circuits For Sensor Applications

Operational amplifier (op amp) oscillators can be used to accurately measure resistive and capacitive sensors. Oscillator design can be simplified by using the procedure discussed in this application note. The derivation of the design equations provides a method to select the passive components and determine the influence of each component on the frequency of oscillation. The procedure will be demonstrated by analyzing two state-variable RC op-amp oscillator circuits.

### AN895: Oscillator Circuits for RTD Temperature Sensors

This application note shows how to design a temperature sensor oscillator circuit using Microchip's low-cost MCP6001 operational amplifier (op amp) and the MCP6541 comparator. Oscillator circuits can be used to provide an accurate temperature measurement with a Resistive Temperature Detector (RTD) sensor. Oscillators provide a frequency output that is proportional to temperature and are easily integrated into a microcontroller system.

### AN990: Analog Sensor Conditioning Circuits – An Overview

Analog sensors produce a change in an electrical property to indicate a change in its environment. This change in electrical property needs to be conditioned by an analog circuit before conversion to digital. Further processing occurs in the digital domain but is not addressed in this application note.

## Delta-Sigma ADCs

### AN1007: Designing with the MCP3551 Delta-Sigma ADC

The MCP3551 delta-sigma ADC is a high-resolution converter. This application note discusses various design techniques to follow when using this device. Typical application circuits are discussed first, followed by a section on noise analysis.

### AN1030: Weigh Scale Applications for the MCP3551

This application note focusses specifically on load cells, a type of strain gauge that is typically used for measuring weight. Even more specifically, the focus is on fully active, temperature compensated load cells whose change in differential output voltage with a rated load is 2 mV to 4 mV per volt of excitation (the excitation voltage being the difference between the +Input and the -Input terminals of the load cell).

### AN1156: Battery Fuel Measurement Using Delta-Sigma ADC Devices

This application note reviews the battery fuel measurement using the MCU and ADC devices. Developing battery fuel measurement in this manner provides flexible solutions and enables economic management.

### DS21841: Analog-to-Digital Converter Design Guide

## SAR ADCs

### AN246: Driving the Analog Inputs of a SAR A/D Converter

This application note delves into the issues surrounding the SAR converter's input and conversion nuances to insure that the converter is handled properly from the beginning of the design phase.

### AN688: Layout Tips for 12-Bit A/D Converter Application

This application note provides basic 12-bit layout guidelines, ending with a review of issues to be aware of. Examples of good layout and bad layout implementations are presented throughout.

### AN693: Understanding A/D Converter Performance Specifications

This application note describes the specifications used to quantify the performance of A/D converters and give the reader a better understanding of the significance of those specifications in an application.

### AN842: Differential ADC Biasing Techniques, Tips and Tricks

True differential converters can offer many advantages over single-ended input A/D Converters (ADC). In addition to their common mode rejection ability, these converters can also be used to overcome many DC biasing limitations of common signal conditioning circuits.

### AN845: Communicating With The MCP3221 Using PIC Microcontrollers

This application note will cover communications between the MCP3221 12-bit A/D Converter and a PIC microcontroller. The code supplied with this application note is written as relocatable assembly code.

## Passive Keyless Entry (PKE)

### TB090: MCP2030 Three-Channel Analog Front-End Device Overview

This tech brief summarizes the technical features of the MCP2030 and describes how the three channel stand-alone analog front-end device can be used for various bidirectional communication applications.

### AN1024: PKE System Design Using the PIC16F639

This application note described how to make hands-free reliable passive keyless entry applications using the PIC16F639 – a dual die solution device that includes both MCP2030 and PIC16F636.

## Utility Metering

Refer to **DS01008: Utility Metering Solutions**

# Related Support Material

## Digital Potentiometers

### **AN691: Optimizing the Digital Potentiometer in Precision Circuits**

In this application note, circuit ideas are presented that use the necessary design techniques to mitigate errors, consequently optimizing the performance of the digital potentiometer.

### **AN692: Using a Digital Potentiometer to Optimize a Precision Single Supply Photo Detect**

This application note shows how the adjustability of the digital potentiometer can be used to an advantage in photosensing circuits.

### **AN1080: Understanding Digital Potentiometer Resistance Variations**

This application note discusses how process, voltage and temperature effect the resistor network's characteristics, specifications and techniques to improve system performance.

## Op Amps

### **AN679: Temperature Sensing Technologies**

Covers the most popular temperature sensor technologies and helps determine the most appropriate sensor for an application.

### **AN681: Reading and Using Fast Fourier Transformation (FFT)**

Discusses the use of frequency analysis (FFTs), time analysis and DC analysis techniques. It emphasizes Analog-to-Digital converter applications.

### **AN684: Single Supply Temperature Sensing with Thermocouples**

Focuses on thermocouple circuit solutions. It builds from signal conditioning components to complete application circuits.

### **AN695: Interfacing Pressure Sensors to Microchip's Analog Peripherals**

Shows how to condition a Wheatstone bridge sensor using simple circuits. A piezoresistive pressure sensor application is used to illustrate the theory.

### **AN699: Anti-Aliasing, Analog Filters for Data Acquisition Systems**

A tutorial on active analog filters and their most common applications.

### **AN722: Operational Amplifier Topologies and DC Specifications**

Defines op amp DC specifications found in a data sheet. It shows where these specifications are critical in application circuits.

### **AN723: Operational Amplifier AC Specifications and Applications**

Defines op amp AC specifications found in a data sheet. It shows where these specifications are critical in application circuits.

### **AN866: Designing Operational Amplifier Oscillator Circuits For Sensor Applications**

Gives simple design procedures for op amp oscillators. These circuits are used to accurately measure resistive and capacitive sensors.

### **AN884: Driving Capacitive Loads With Op Amps**

Explains why all op amps tend to have problems driving large capacitive loads. A simple, one resistor compensation scheme is given that gives much better performance.

### **AN951: Amplifying High-Impedance Sensors – Photodiode Example**

Shows how to condition the current out of a high-impedance sensor. A photodiode detector illustrates the theory. AN990: Analog Sensor Conditioning Circuits – An Overview Gives an overview of the many sensor types, applications and conditioning circuits.

### **AN1014: Measuring Small Changes in Capacitive Sensors**

This application note shows a switched capacitor circuit that uses a PIC microcontroller, and minimal external passive components, to measure small changes in capacitance. The values are very repeatable under constant environmental conditions.

### **AN1016: Detecting Small Capacitive Sensors Using the MCP6291 and PIC16F690 Devices**

The circuit discussed here uses an op amp and a microcontroller to implement a dual slope integrator and timer. It gives accurate results, and is appropriate for small capacitive sensors, such as capacitive humidity sensors.

### **AN1177: Op Amp Precision Design: DC Errors**

This application note covers the essential background information and design theory needed to design a precision DC circuit using op amps.

### **AN1228: Op Amp Precision Design: Random Noise**

This application note covers the essential background information and design theory needed to design low noise, precision op amp circuits. The focus is on simple, results oriented methods and approximations useful for circuits with a low-pass response.

### **AN1258: Op Amp Precision Design: PCB Layout Techniques**

This application note covers Printed Circuit Board (PCB) effects encountered in high (DC) precision op amp circuits. It provides techniques for improving the performance, giving more flexibility in solving a given design problem. It demonstrates one important factor necessary to convert a good schematic into a working precision design.

### **AN1297: Microchip's Op Amp SPICE Macro Models**

This application note covers the function and use of Microchip's op amp SPICE macro models. It does not explain how to use the circuit simulator but will give the user a better understanding how the model behaves and tips on convergence issues.

# Related Support Material

## Programmable Gain Amplifier (PGA)

### **AN248: Interfacing MCP6S2X PGAs to PIC Microcontrollers**

This application note shows how to program the six channel MCP6S26 PGA gains, channels and shutdown registers using the PIC16C505 microcontroller.

### **AN865: Sensing Light with a Programmable Gain Amplifier**

This application notes discusses how Microchip's Programmable Gain Amplifiers (PGAs) can be effectively used in position photo sensing applications minus the headaches of amplifier stability.

### **AN897: Thermistor Temperature Sensing with MCP6SX2 PGAs**

Shows how to use a Programmable Gain Amplifier (PGA) to linearize the response of a thermistor, and to achieve a wider temperature measurement range.

## Temperature Sensing

### **AN929: Temperature Measurement Circuits for Embedded Applications**

This application note shows how to select a temperature sensor and conditioning circuit to maximize the measurement accuracy and simplify the interface to the microcontroller.

### **AN981: Interfacing a MCP9700 Analog Temperature Sensor to a PIC Microcontroller**

Analog output silicon temperature sensors offer an easy-to-use alternative to traditional temperature sensors, such as thermistors. The MCP9700 offers many system-level advantages, including the integration of the temperature sensor and signal-conditioning circuitry on a single chip. Analog output sensors are especially suited for embedded systems due to their linear output. This application note will discuss system integration, firmware implementation and PCB layout techniques for using the MCP9700 in an embedded system.

### **AN988: Interfacing a MCP9800 I<sup>2</sup>C™ Digital Temperature Sensor to a PIC Microcontroller**

This application note will discuss system integration, firmware implementation and PCB layout techniques for using the MCP9800 in an embedded system.

### **AN1001: IC Temperature Sensor Accuracy Compensation with a PIC Microcontroller**

This application note derives an equation that describes 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.

### **AN1154: Precision RTD Instrumentation for Temperature Sensing**

Precision RTD (Resistive Temperature Detector) instrumentation is key for high performance thermal management applications. This application note shows how to use a high resolution Delta-Sigma Analog-to-Digital converter, and two resistors to measure RTD resistance ratiometrically. A  $\pm 0.1^\circ\text{C}$  accuracy and  $\pm 0.01^\circ\text{C}$  measurement resolution can be achieved across the RTD temperature range of  $-200^\circ\text{C}$  to  $+800^\circ\text{C}$  with a single point calibration.

### **AN1306: Thermocouple Circuit Using MCP6V01 and PIC18F2550**

This application note shows how to use a difference amplifier system to measure electromotive force (EMF) voltage at the cold junction of thermocouple in order to accurately measure temperature at the hot junction. This can be done by using the MCP6V01 auto-zeroed op amp because of its extremely low input offset voltage ( $V_{os}$ ) and very high common mode rejection ratio (CMRR). The microcontroller PIC18F2550 used in this circuit has internal comparator voltage reference ( $CV_{REF}$ ). This solution minimizes cost by using resources internal to the PIC18F2550 to achieve reasonable resolution without an external ADC.

# LINEAR

LINEAR – Op Amps											
Device	# per Package	GBWP (kHz) Typ.	I <sub>Q</sub> (μA/amp.) Typ.	V <sub>OS</sub> (±μV) Max.	Supply Voltage (V)	Temperature Range (°C)	Rail-to-Rail I/O	Features	Packages	Featured Demo Board	Op Amp Category
MCP6031/2/3/4	1,2,1,4	10	1	150	1.8 to 5.5	-40 to +125	I/O	Low Power Mode on MCP6033	SOIC, MSOP, TSSOP, DFN, SOT-23	MCP6031DM-PCTL, SOIC8EV, SOIC14EV	Low Offset, Low Power
MCP6041/2/3/4	1,2,1,4	14	1	3,000	1.4 to 6.0	-40 to +85, -40 to +125	I/O	Low Power Mode on MCP6043	PDIP, SOIC, MSOP, TSSOP, SOT-23	SOIC8EV, SOIC14EV	General Purpose, Low Power
MCP6141/2/3/4	1,2,1,4	100	1	3,000	1.4 to 6.0	-40 to +85, -40 to +125	I/O	GMIN = 10, Low Power Mode on MCP6143	PDIP, SOIC, MSOP, TSSOP, SOT-23	SOIC8EV, SOIC14EV	General Purpose, Low Power
MCP606/7/8/9	1,2,1,4	155	25	250	2.5 to 6.0	-40 to +85	O	Low Power Mode on MCP608	PDIP, SOIC, TSSOP, DFN, SOT-23	SOIC8EV, SOIC14EV	Low Offset
MCP616/7/8/9	1,2,1,4	190	25	150	2.3 to 5.5	-40 to +85	O	Low Power Mode on MCP618	PDIP, SOIC, TSSOP	SOIC8EV, SOIC14EV	Low Offset
MCP6231/1R/1U/2/4	1,1,1,2,4	300	30	5,000	1.8 to 6.0	-40 to +125	I/O	–	PDIP, SOIC, MSOP, TSSOP, DFN, SOT-23, SC-70	VSUPEV2, SOIC8EV, SOIC14EV	General Purpose
MCP6051/2/4	1,2,4	385	45	150	1.8 to 6.0	-40 to +125	I/O	–	SOIC, TSSOP, TDFN	SOIC8EV, SOIC14EV	Low Offset
MCP6241/1R/1U/2/4	1,1,1,2,4	550	70	5,000	1.8 to 5.5	-40 to +125	I/O	–	PDIP, SOIC, MSOP, TSSOP, DFN, SOT-23, SC-70	VSUPEV2, SOIC8EV, SOIC14EV	General Purpose
MCP6061/2/4	1,2,4	730	90	150	1.8 to 6.0	-40 to +125	I/O	–	SOIC, TSSOP, TDFN	SOIC8EV, SOIC14EV	Low Offset
MCP6001/1R/1U/2/4	1,1,1,2,4	1,000	170	4,500	1.8 to 6.0	-40 to +85, -40 to +125	I/O	–	PDIP, SOIC, MSOP, TSSOP, SOT-23, SC-70	MCP6SX2DM-PICTLPD, SOIC8EV, SOIC14EV	General Purpose
MCP6071/2/4	1,2,4	1,200	170	150	1.8 to 6.0	-40 to +125	I/O	–	SOIC, TSSOP, TDFN	SOIC8EV, SOIC14EV	Low Offset
MCP6271/1R/2/3/4/5	1,1,2,1,4,2	2,000	240	3,000	2.0 to 6.0	-40 to +125	I/O	Low Power Mode on MCP6273, Cascaded Gain with MCP6275	PDIP, SOIC, MSOP, TSSOP, SOT-23	MCP6XXDM-FLTR, SOIC8EV, SOIC14EV	General Purpose
MCP601/1R/2/3/4	1,1,2,1,4	2,800	325	2,000	2.7 to 6.0	-40 to +85, -40 to +125	O	Low Power Mode on MCP603	PDIP, SOIC, TSSOP, SOT-23	SOIC8EV, SOIC14EV	General Purpose
MCP6286	1	3,500	720	1,500	2.2 to 5.5	-40 to +125	O	Low Noise	SOT-23	VSUPEV2	Low Noise
MCP6281/1R/2/3/4/5	1,1,2,1,4,2	5,000	570	3,000	2.2 to 6.0	-40 to +125	I/O	Low Power Mode on MCP6283, Cascaded Gain with MCP6285	PDIP, SOIC, MSOP, TSSOP, SOT-23	VSUPEV2, SOIC8EV, SOIC14EV	General Purpose
MCP6021/1R/2/3/4	1,1,2,1,4	10,000	1,350	500, 250	2.5 to 5.5	-40 to +85, -40 to +125	I/O	Low Power Mode on MCP6023	PDIP, SOIC, MSOP, TSSOP, SOT-23	MCP6XXEV-AMP1, SOIC8EV, SOIC14EV	Low Offset
MCP6291/1R/2/3/4/5	1,1,2,1,4,2	10,000	1,300	3,000	2.4 to 6.0	-40 to +125	I/O	Low Power Mode on MCP6293, Cascaded Gain with MCP6295	PDIP, SOIC, MSOP, TSSOP, SOT-23	PIC16F690DM-PCTLHS, SOIC8EV, SOIC14EV	General Purpose
MCP621	1,2,2	20,000	3,600	200	2.5 to 5.5	-40 to +125	O	mCal (offset correction, low power mode)	SOIC, MSOP, DFN	MCP651EV-VOS	High Speed, High Output Drive, Low Offset
MCP631/2/3/5	1,2,1,2	24,000	3,600	8,000	2.5 to 5.5	-40 to +125	O	Low Power Mode on MCP633/5	SOIC, MSOP, DFN	MCP651EV-VOS	High Speed, High Output Drive
MCP651/2/5	1,2,2	50,000	9,000	200	2.5 to 5.5	-40 to +125	O	mCal (offset correction, low power mode)	SOIC, MSOP, DFN	MCP651EV-VOS	High Speed, High Output Drive, Low Offset
MCP661/2/3/5	1,2,1,2	60,000	9,000	8,000	2.5 to 5.5	-40 to +125	O	Low Power Mode on MCP663/5	SOIC, MSOP, DFN	MCP661DM-LD	High Speed, High Output Drive
LINEAR – Op Amps Auto-Zero											
Device	# per Package	GBWP (kHz) Typ.	I <sub>Q</sub> (μA/amp.) Typ.	V <sub>OS</sub> (±μV) Max.	Supply Voltage (V)	Temperature Range (°C)	Rail-to-Rail I/O	Features	Packages	Featured Demo Board	Op Amp Category
MCP6V01/2/3	1,2,1	1,300	400	2	1.8 to 5.5	-40 to +125	I/O	Low Power Mode on MCP6V03	SOIC, DFN, TDFN	MCP6V01DM-VOS, MCP6V01RD-TCPL	Auto-zeroed
MCP6V06/7/8	1,2,1	1,300	400	3	1.8 to 5.5	-40 to +125	I/O	Low Power Mode on MCP6V08	SOIC, DFN, TDFN	MCP6V01DM-VOS, MCP6V01RD-TCPL	Auto-zeroed

## LINEAR – Comparators

Device	# per Package	V <sub>REF</sub> (V)	Typical Propagation Delay (μs)	I <sub>Q</sub> Typical (μA)	V <sub>OS</sub> Max (mV)	Operating Voltage (V)	Temperature Range (°C)	Features	Packages
MCP6541	1	–	4	1	5	1.6 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output	5-pin SOT-23 <sup>(S,R,U)</sup> , 5-pin SC-70 <sup>(S,U)</sup> , 8-pin PDIP, 8-pin SOIC, 8-pin MSOP
MCP6542	2	–	4	1	5	1.6 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output	8-pin PDIP, 8-pin SOIC, 8-pin MSOP
MCP6543	1	–	4	1	5	1.6 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output, Chip Select	8-pin PDIP, 8-pin SOIC, 8-pin MSOP
MCP6544	4	–	4	1	5	1.6 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output	14-pin PDIP, 14-pin SOIC, 14-pin TSSOP
MCP6546	1	–	4	1	5	1.6 to 5.5	-40 to +125	Open-drain, 9V, Rail-to-Rail Input/Output	5-pin SOT-23 <sup>(S,R,U)</sup> , 5-pin SC-70 <sup>(S,U)</sup> , 8-pin PDIP, 8-pin SOIC, 8-pin MSOP
MCP6547	2	–	4	1	5	1.6 to 5.5	-40 to +125	Open-drain, 9V, Rail-to-Rail Input/Output	8-pin PDIP, 8-pin SOIC, 8-pin MSOP
MCP6548	1	–	4	1	5	1.6 to 5.5	-40 to +125	Open-drain, 9V, Rail-to-Rail Input/Output, Chip Select	8-pin PDIP, 8-pin SOIC, 8-pin MSOP
MCP6549	4	–	4	1	5	1.6 to 5.5	-40 to +125	Open-drain, 9V, Rail-to-Rail Input/Output	14-pin PDIP, 14-pin SOIC, 14-pin TSSOP
MCP6561	1	–	0.047	100	10	1.8 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output	5-pin SOT-23 <sup>(S,R,U)</sup> , 5-pin SC-70 <sup>(S)</sup>
MCP6562	2	–	0.047	100	10	1.8 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output	8-pin SOIC, 8-pin MSOP
MCP6564	4	–	0.047	100	10	1.8 to 5.5	-40 to +125	Push-Pull, Rail-to-Rail Input/Output	14-pin SOIC, 14-pin TSSOP
MCP6566	1	–	0.047	100	10	1.8 to 5.5	-40 to +125	Open-Drain, Rail-to-Rail Input/Output	5-pin SOT-23 <sup>(S,R,U)</sup> , 5-pin SC-70 <sup>(S)</sup>
MCP6567	2	–	0.047	100	10	1.8 to 5.5	-40 to +125	Open-Drain, Rail-to-Rail Input/Output	8-pin SOIC, 8-pin MSOP
MCP6569	4	–	0.047	100	10	1.8 to 5.5	-40 to +125	Open-Drain, Rail-to-Rail Input/Output	14-pin SOIC, 14-pin TSSOP

Legend: S = Standard Pinout; R = Reverse Pinout; U = Alternative Pinout

## LINEAR – Programmable Gain Amplifiers (PGA)

Device	Channels	-3 dB BW (MHz) Typ.	I <sub>Q</sub> (μA) Max.	V <sub>OS</sub> (±μV) Max.	Operating Voltage (V)	Temperature Range (°C)	Features	Packages
MCP6S21/2/6/8	1, 2, 6, 8	2 to 12	1.1	275	2.5 to 5.5	-40 to +85	SPI, 8 Gain Steps, Software Shutdown	PDIP, SOIC, MSOP, TSSOP
MCP6S912,3	1, 2, 2	1 to 18	1.0	4000	2.5 to 5.5	-40 to +125	SPI, 8 Gain Steps, Software Shutdown, V <sub>REF</sub>	PDIP, SOIC, MSOP

## MIXED SIGNAL

### MIXED SIGNAL – Delta-Sigma A/D Converters

Device	Resolution (bits)	Max. Sample Rate (samples/sec)	# of Input Channels	Interface	Supply Voltage (V)	Typical Supply Current (μA)	Typical INL (ppm)	Temperature Range (°C)	Features	Packages	Featured Demo Board
MCP3421	18	3.75	1 Diff	I <sup>2</sup> C™	2.7 to 5.5	145 (continuous) 39 (one shot)	10	-40 to +85	PGA: 1, 2, 4 or 8 Internal voltage reference	SOT-23-6	MCP3421EV
MCP3422	18	3.75	2 Diff	I <sup>2</sup> C™	2.7 to 5.5	145	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	SOIC-8, MSOP-8, DFN-8	MCP3422EV, MCP3421DM-BFG
MCP3423	18	3.75	2 Diff	I <sup>2</sup> C™	2.7 to 5.5	145	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	MSOP-10, DFN-10	MCP3423EV
MCP3424	18	3.75	4 Diff	I <sup>2</sup> C™	2.7 to 5.5	145	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	SOIC-14, TSSOP-14	MCP3424EV
MCP3425	16	15	1 Diff	I <sup>2</sup> C™	2.7 to 5.5	155	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	SOT-23-6	MCP3425EV, MCP3421DM-BFG
MCP3426	16	15	2 Diff	I <sup>2</sup> C™	2.7 to 5.5	145	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	SOIC-8, MSOP-8, DFN-8	–
MCP3427	16	15	2 Diff	I <sup>2</sup> C™	2.7 to 5.5	145	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	MSOP-10, DFN-10	–
MCP3428	16	15	4 Diff	I <sup>2</sup> C™	2.7 to 5.5	145	10	-40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	SOIC-14, TSSOP-14	–

**MIXED SIGNAL – Delta-Sigma A/D Converters (Continued)**

Device	Resolution (bits)	Max. Sample Rate (samples/sec)	# of Input Channels	Interface	Supply Voltage (V)	Typical Supply Current ( $\mu$ A)	Typical INL (ppm)	Temperature Range ( $^{\circ}$ C)	Features	Packages	Featured Demo Board
MCP3550-50	22	13	1 Diff	SPI	2.7 to 5.5	120	2	-40 to +85	50 Hz noise rejection > 120 dB	SOIC-8, MSOP-8	MCP3551DM-PCTL
MCP3550-60	22	15	1 Diff	SPI	2.7 to 5.5	140	2	-40 to +85	60 Hz noise rejection > 120 dB	SOIC-8, MSOP-8	MCP3551DM-PCTL
MCP3551	22	14	1 Diff	SPI	2.7 to 5.5	120	2	-40 to +85	Simultaneous 50/60 Hz rejection	SOIC-8, MSOP-8	MCP3551DM-PCTL
MCP3553	20	60	1 Diff	SPI	2.7 to 5.5	140	2	-40 to +85	–	SOIC-8, MSOP-8	MCP3551DM-PCTL
MCP3901	16	64000	2 Diff	SPI	4.5 to 5.5	2050	15	-40 to +85	Two ADC Cores, 16/24 bits, High Sample Speed (64 ksp/s), PGA: 1, 2, 4, 8, 16 or 32	SSOP-20, QFN-20	MCP3901EV-MCU16

**MIXED SIGNAL – Successive Approximation Register (SAR) A/D Converters**

Part #	Resolution (bits)	Max. Sample Rate (samples/sec)	# of Input Channels	Input Type	Interface	Input Voltage Range (V)	Max. Supply Current ( $\mu$ A)	Max. INL	Temperature Range ( $^{\circ}$ C)	Packages	Featured Demo Board
MCP3001	10	200	1	Single-ended	SPI	2.7 to 5.5	500	$\pm$ 1 LSB	-40 to +85	PDIP-8, SOIC-8, MSOP-8, TSSOP-8	–
MCP3002	10	200	2	Single-ended	SPI	2.7 to 5.5	650	$\pm$ 1 LSB	-40 to +85	PDIP-8, SOIC-8, MSOP-8, TSSOP-8	–
MCP3004	10	200	4	Single-ended	SPI	2.7 to 5.5	550	$\pm$ 1 LSB	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	–
MCP3008	10	200	8	Single-ended	SPI	2.7 to 5.5	550	$\pm$ 1 LSB	-40 to +85	PDIP-16, SOIC-16	–
MCP3021	10	22	1	Single-ended	I <sup>2</sup> C™	2.7 to 5.5	250	$\pm$ 1 LSB	-40 to +125	SOT-23A-5	MCP3221DM-PCTL, MXSIGDM
MCP3221	12	22	1	Single-ended	I <sup>2</sup> C™	2.7 to 5.5	250	$\pm$ 2 LSB	-40 to +125	SOT-23A-5	MCP3221DM-PCTL, MXSIGDM
MCP3201	12	100	1	Single-ended	SPI	2.7 to 5.5	400	$\pm$ 1 LSB	-40 to +85	PDIP-8, SOIC-8, MSOP-8, TSSOP-8	DV3201A, DVMCPA, MXSIGDM
MCP3202	12	100	2	Single-ended	SPI	2.7 to 5.5	550	$\pm$ 1 LSB	-40 to +85	PDIP-8, SOIC-8, MSOP-8, TSSOP-8	DV3201A, DVMCPA, MXSIGDM
MCP3204	12	100	4	Single-ended	SPI	2.7 to 5.5	400	$\pm$ 1 LSB	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	DV3204A, DVMCPA, MXSIGDM
MCP3208	12	100	8	Single-ended	SPI	2.7 to 5.5	400	$\pm$ 1 LSB	-40 to +85	PDIP-16, SOIC-16	DV3204A, DVMCPA, MXSIGDM
MCP3301	13	100	1	Differential	SPI	2.7 to 5.5	450	$\pm$ 1 LSB	-40 to +85	PDIP-8, SOIC-8, MSOP-8, TSSOP-8	DV3201A, DVMCPA, MXSIGDM
MCP3302	13	100	2	Differential	SPI	2.7 to 5.5	450	$\pm$ 1 LSB	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	DV3204A, DVMCPA, MXSIGDM
MCP3304	13	100	4	Differential	SPI	2.7 to 5.5	450	$\pm$ 1 LSB	-40 to +85	PDIP-16, SOIC-16	DV3204A, DVMCPA, MXSIGDM

**MIXED SIGNAL – D/A Converters**

Part #	Resolution (Bits)	DACs per Package	Interface	V <sub>REF</sub>	Output Settling Time ( $\mu$ s)	DNL (LSB)	Typical Standby Current ( $\mu$ A)	Typical Operating Current ( $\mu$ A)	Temperature Range ( $^{\circ}$ C)	Packages	Featured Demo Board
MCP4725	12	1	I <sup>2</sup> C™	V <sub>DD</sub>	6	0.75	1	210	-40 to +125	SOT-23-6	MCP4725DM-PTPLS, MCP4725EV
MCP4728	12	4	I <sup>2</sup> C™	Int/ V <sub>DD</sub>	6	0.75	0.04	800	-40 to +125	MSOP-10	MCP4728EV
MCP4821	12	1	SPI	Y	4.5	1	0.3	330	-40 to +125	PDIP-8, SOIC-8, MSOP-8	–
MCP4822	12	2	SPI	Y	4.5	1	0.3	415	-40 to +125	PDIP-8, SOIC-8, MSOP-8	–
MCP4921	12	1	SPI	Ext	4.5	0.75	1	175	-40 to +125	PDIP-8, SOIC-8, MSOP-8	–
MCP4922	12	2	SPI	Ext	4.5	0.75	1	350	-40 to +125	PDIP-14, SOIC-14, TSSOP-14	–
TC1320	8	1	SMbus/ I <sup>2</sup> C™	Ext	10	$\pm$ 0.8	0.1	350	-40 to +85	SOIC-8, MSOP-8	–
TC1321	10	1	SMbus/ I <sup>2</sup> C™	Ext	10	$\pm$ 2	0.1	350	-40 to +85	SOIC-8, MSOP-8	–

**MIXED SIGNAL – Digital Potentiometers**

Device	# of Taps	# per Package	Interface	V <sub>DD</sub> Operating Range <sup>(1)</sup>	Volatile/ Non-Volatile	Resistance (ohms)	INL (Max.)	DNL (Max.)	Temperature Range (°C)	Packages	Featured Demo Board
MCP4011	64	1	U/D	1.8V to 5.5V	Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOIC-8	MCP402XEV, MCP4XXXDM-DB
MCP4012	64	1	U/D	1.8V to 5.5V	Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOT-23-6	MCP402XEV, SC70EV
MCP4013	64	1	U/D	1.8V to 5.5V	Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOT-23-6	MCP402XEV, SC70EV
MCP4014	64	1	U/D	1.8V to 5.5V	Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOT-23-5	MCP402XEV, SC70EV
MCP4017	128	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	SC-70-6	SC70EV
MCP4018	128	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	SC-70-6	SC70EV
MCP4019	128	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	SC-70-5	SC70EV
MCP40D17	128	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	SC-70-6	SC70EV
MCP40D18	128	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	SC-70-6	SC70EV
MCP40D19	128	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	SC-70-5	SC70EV
MCP4021	64	1	U/D	2.7V to 5.5V	Non-Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOIC-8	MCP402XEV, MCP4XXXDM-DB
MCP4022	64	1	U/D	2.7V to 5.5V	Non-Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOT-23-6	MCP402XEV, SC70EV
MCP4023	64	1	U/D	2.7V to 5.5V	Non-Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOT-23-6	MCP402XEV, SC70EV
MCP4024	64	1	U/D	2.7V to 5.5V	Non-Volatile	2.1K, 5K, 10K, 50K	±0.5 LSb	±0.5 LSb	-40 to +125	SOT-23-5	MCP402XEV, SC70EV
MCP41010	256	1	SPI	2.7V to 5.5V	Volatile	10K	±1 LSb	±1 LSb	-40 to +85	PDIP-8, SOIC-8	MCP4XXXDM-DB
MCP41050	256	1	SPI	2.7V to 5.5V	Volatile	50K	±1 LSb	±1 LSb	-40 to +85	PDIP-8, SOIC-8	MCP4XXXDM-DB
MCP41100	256	1	SPI	2.7V to 5.5V	Volatile	100K	±1 LSb	±1 LSb	-40 to +85	PDIP-8, SOIC-8	MCP4XXXDM-DB
MCP42010	256	2	SPI	2.7V to 5.5V	Volatile	10K	±1 LSb	±1 LSb	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	MCP4XXXDM-DB
MCP42050	256	2	SPI	2.7V to 5.5V	Volatile	50K	±1 LSb	±1 LSb	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	MCP4XXXDM-DB
MCP42100	256	2	SPI	2.7V to 5.5V	Volatile	100K	±1 LSb	±1 LSb	-40 to +85	PDIP-14, SOIC-14, TSSOP-14	MCP4XXXDM-DB
MCP4131	129	1	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4132	129	1	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4141	129	1	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4142	129	1	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4151	257	1	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4152	257	1	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4161	257	1	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4162	257	1	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	PDIP-8, SOIC-8, MSOP-8, DFN-8	MCP42XXDM-PTPLS
MCP4231	129	2	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	PDIP-14, SOIC-14, TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP42XXDM-PTPLS
MCP4232	129	2	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	MSOP-10, DFN-10	MCP42XXDM-PTPLS
MCP4241	129	2	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	PDIP-14, SOIC-14, TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP42XXDM-PTPLS
MCP4242	129	2	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	-40 to +125	MSOP-10, DFN-10	MCP42XXDM-PTPLS
MCP4251	257	2	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	PDIP-14, SOIC-14, TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP42XXDM-PTPLS
MCP4252	257	2	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	MSOP-10, DFN-10	MCP42XXDM-PTPLS
MCP4261	257	2	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	PDIP-14, SOIC-14, TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP42XXDM-PTPLS
MCP4262	257	2	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	-40 to +125	MSOP-10, DFN-10	MCP42XXDM-PTPLS
MCP4351	257	4	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1.0 LSb	±0.5 LSb	-40 to +125	TSSOP-20, QFN-20	TSSOP20EV
MCP4352	257	4	SPI	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1.0 LSb	±0.5 LSb	-40 to +125	TSSOP-14	TSSOP20EV

Note 1: Analog characteristics may be tested at different voltage ranges.

**MIXED SIGNAL – Digital Potentiometers (Continued)**

Device	# of Taps	# per Package	Interface	V <sub>DD</sub> Operating Range <sup>(1)</sup>	Volatile/ Non-Volatile	Resistance (ohms)	INL (Max.)	DNL (Max.)	Temperature Range (°C)	Packages	Featured Demo Board
MCP4361	257	4	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1.0 LSB	±0.5 LSB	-40 to +125	TSSOP-20, QFN-20	TSSOP20EV
MCP4362	257	4	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1.0 LSB	±0.5 LSB	-40 to +125	TSSOP-14	TSSOP20EV
MCP4531	129	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4532	129	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4541	129	1	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4542	29	1	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4551	257	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4552	257	1	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4561	257	1	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4562	257	1	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	MSOP-8, DFN-8	MCP46XXDM-PTPLS
MCP4631	129	2	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	TSSOP-14, QFN-16	MCP4XXDM-DB, MCP46XXDM-PTPLS
MCP4632	129	2	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	MSOP-10, DFN-10	MCP46XXDM-PTPLS
MCP4641	129	2	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	TSSOP-14, QFN-16	MCP4XXDM-DB, MCP46XXDM-PTPLS
MCP4642	129	2	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSB	±0.25 LSB	-40 to +125	MSOP-10, DFN-10	MCP46XXDM-PTPLS
MCP4651	257	2	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	TSSOP-14, QFN-16	MCP4XXDM-DB, MCP46XXDM-PTPLS
MCP4652	257	2	I <sup>2</sup> C™	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	MSOP-10, DFN-10	MCP46XXDM-PTPLS
MCP4661	257	2	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	TSSOP-14, QFN-16	MCP4XXDM-DB, MCP46XXDM-PTPLS
MCP4662	257	2	I <sup>2</sup> C™	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSB	±0.5 LSB	-40 to +125	MSOP-10, DFN-10	MCP46XXDM-PTPLS

**Note 1:** Analog characteristics may be tested at different voltage ranges.

## THERMAL MANAGEMENT

**THERMAL MANAGEMENT PRODUCTS – Temperature Sensors**

Part #	Typical Accuracy (°C)	Maximum Accuracy @ 25°C (°C)	Maximum Temperature Range (°C)	V <sub>CC</sub> Range (V)	Maximum Supply Current (µA)	Resolution (bits)	Packages	Featured Demo Board
<b>Serial Output Temperature Sensors</b>								
MCP9800	±0.5	±1	-55 to +125	+2.7 to +5.5	400	9-12	SOT-23-5	MCP9800DM-TS1
MCP9801	±0.5	±1	-55 to +125	+2.7 to +5.5	400	9-12	SOIC-8 150 mil, MSOP-8	MCP9800DM-TS1
MCP9802	±0.5	±1	-55 to +125	+2.7 to +5.5	400	9-12	SOT-23-5	MCP9800DM-TS1
MCP9803	±0.5	±1	-55 to +125	+2.7 to +5.5	400	9-12	SOIC-8 150 mil, MSOP-8	MCP9800DM-TS1
MCP9804	±0.25	±1	-40 to +125	+2.7 to +5.5	400	12-bits	MSOP-8, DFN-8	TMPSNSRD-RTD2, TMPSNSRD-TCPL1
MCP9805	±2	±3	-40 to +125	3.0 to 3.6	500	10	TSSOP-8, DFN-8	–
MCP98242	±2	±3	-40 to +125	3.0 to 3.6	500	10	TSSOP-8, DFN-8, TDFN-8, UDFN-8	–
MCP98243	±0.5	±3	-40 to +125	3.0 to 3.6	500	11	TSSOP-8, DFN-8, TDFN-8, UDFN-8	–
TC72	±0.5	±2	-55 to +125	+2.7 to +5.5	400	10	MSOP-8, DFN-8	TC72DM-PICTL
TC74	±0.5	±2	-40 to +125	+2.7 to +5.5	350	8	SOT-23-5, TO-220-5	TC74DEMO
TC77	±0.5	±1	-55 to +125	+2.7 to +5.5	400	12	SOIC-8 150 mil, SOT-23-5	TC77DM-PICTL
TCN75	±0.5	±3	-55 to +125	+2.7 to +5.5	1000	9	SOIC-8 150 mil, MSOP-8	–
TCN75A	±0.5	±3	-40 to +125	+2.7 to +5.5	400	9-12	SOIC-8 150 mil, MSOP-8	–

## THERMAL MANAGEMENT PRODUCTS – Temperature Sensors

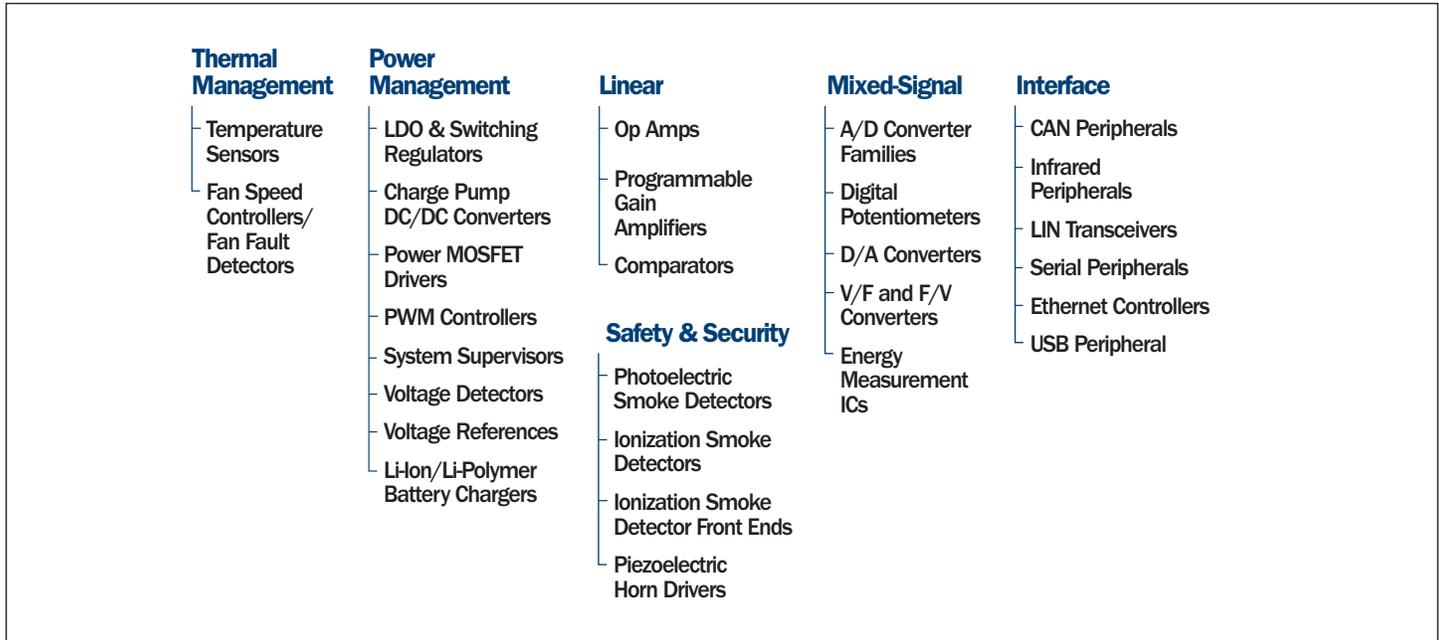
Part #	Typical Accuracy (°C)	Maximum Accuracy @ 25°C (°C)	Maximum Temperature Range (°C)	Vcc Range (V)	Maximum Supply Current (µA)	Resolution (bits)	Packages	Featured Demo Board
<b>Logic Output Temperature Sensors</b>								
MCP9509	±0.5	NA	-40 to +125	2.7 to 5.5	50	–	SOT-23-5	–
MCP9510	±0.5	NA	-40 to +125	2.7 to 5.5	80	–	SOT-23-6	–
TC620	±1	±3	-55 to 125	4.5 to 18	400	–	PDIP-8, SOIC-8 150 mil	–
TC621	±1	±3	-55 to 125	4.5 to 18	400	–	PDIP-8, SOIC-8 150 mil	–
TC622	±1	±5	-40 to +125	4.5 to 18	600	–	PDIP-8, SOIC-8 150 mil, TO-220-5	–
TC623	±1	±3	-40 to +125	2.7 to 4.5	250	–	PDIP-8, SOIC-8 150 mil	–
TC624	±1	±5	-40 to +125	2.7 to 4.5	300	–	PDIP-8, SOIC-8 150 mil	–
TC6501	±0.5	±4	-55 to 135	2.7 to 5.5	40	–	SOT-23-5	–
TC6502	±0.5	±4	-55 to 135	2.7 to 5.5	40	–	SOT-23-5	–
TC6503	±0.5	±4	-55 to 135	2.7 to 5.5	40	–	SOT-23-5	–
TC6504	±0.5	±4	-55 to 135	2.7 to 5.5	40	–	SOT-23-5	–
<b>Voltage Output Temperature Sensors</b>								
MCP9700	±1	±4	-40 to +150	2.3 to 5.5	6	–	SC-70-5, SOT-23-3, TO-92-3	MCP9700DM-PCTL
MCP9700A	±1	±2	-40 to +150	2.3 to 5.5	6	–	SC-70-5, SOT-23-3, TO-92-3	MCP9700DM-PCTL
MCP9701	±1	±4	-40 to +125	+3.1 to +5.5	6	–	SC-70-5, SOT-23-3, TO-92-3	MCP9700DM-PCTL
MCP9701A	±1	±2	-40 to +125	+3.1 to +5.5	6	–	SC-70-5, SOT-23-3, TO-92-3	MCP9700DM-PCTL
TC1046	±0.5	±2	-40 to +125	2.7 to 4.4	60	–	SOT-23-3	–
TC1047	±0.5	±2	-40 to +125	2.7 to 4.4	60	–	SOT-23-3	TC1047ADM-PICTL
TC1047A	±0.5	±2	-40 to +125	+2.5 to +5.5	60	–	SOT-23-3	TC1047ADM-PICTL
TC1047A	±0.5	±2	-40 to +125	+2.5 to +5.5	60	–	SOT-23B-3	–

## POWER MANAGEMENT

### POWER MANAGEMENT – Voltage References

Part #	Vcc Range (V)	Output Voltage (V)	Max. Load Current (mA)	Initial Accuracy (max.%)	Temperature Coefficient (ppm/°C)	Maximum Supply Current (µA @ 25°C)	Packages
MCP1525	2.7 to 5.5	2.5	±2	±1	50	100	SOT-23B-3, TO-92-3
MCP1541	4.3 to 5.5	4.096	±2	±1	50	100	SOT-23B-3, TO-92-3

# Stand-Alone Analog and Interface Portfolio



## Analog and Interface Attributes

### Robustness

- MOSFET Drivers lead the industry in latch-up immunity/stability
- High performance LIN and CAN transceivers

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- 600 nA/1.4V/14 kHz bandwidth op amps
- 1.8V charge pumps and comparators
- 1.6  $\mu$ A LDOs
- Low power ADCs with one-shot conversion

### 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
- Industry's first 12-bit quad DAC with non-volatile EEPROM
- Delta-Sigma ADCs feature on-board PGA and voltage reference
- Highly integrated charging solutions for Li-ion and LiFePO4 batteries

### Space Savings

- Resets and LDOs in SC70 package, A/D and D/A converters in 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
- Industry's first op amp featuring on-demand calibration via mCal technology
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