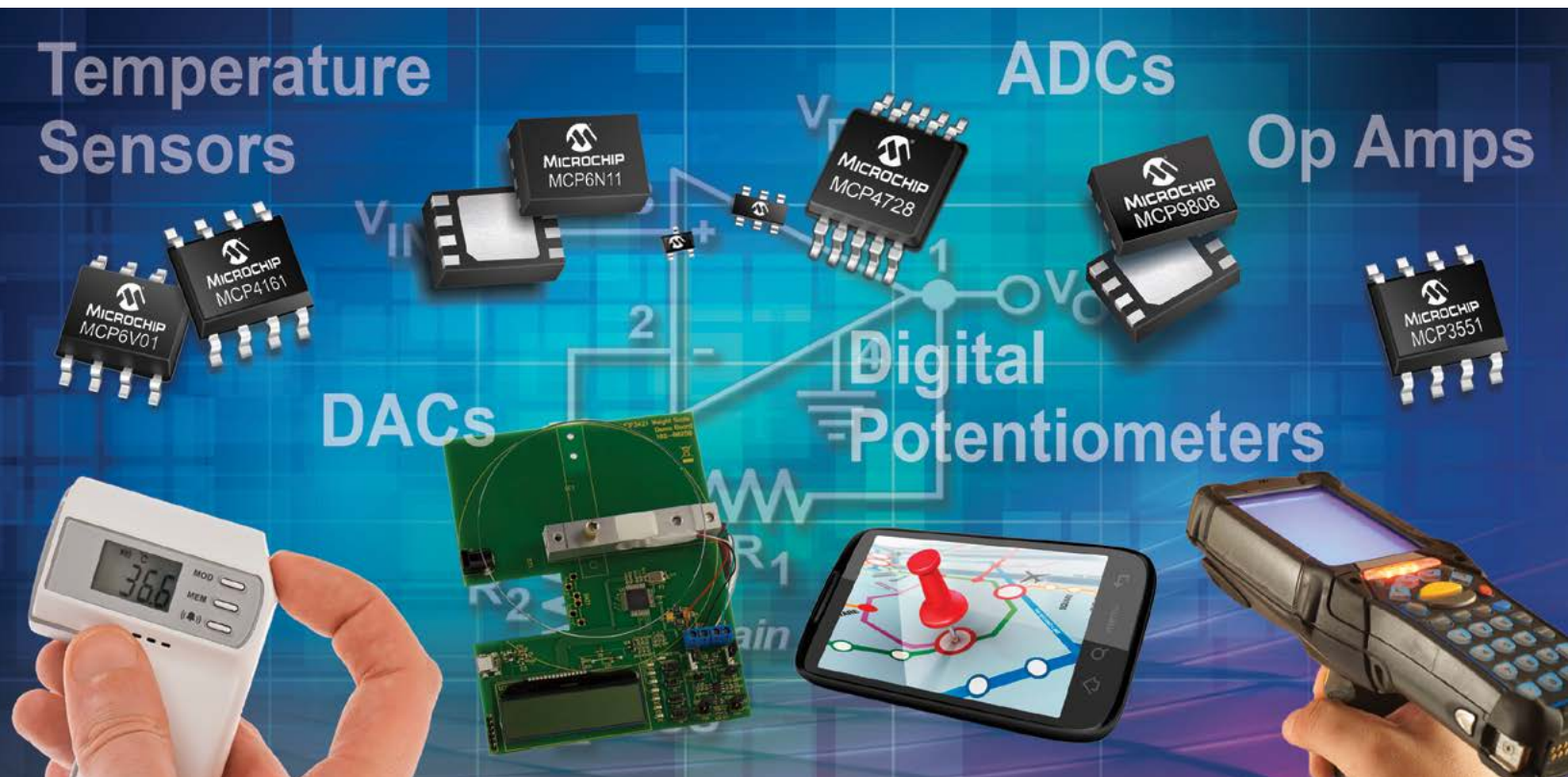# MICROCHIP

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.

| Operational Amplifiers	Instrumentation Amplifiers	Comparators	Analog-to-Digital Converters	Digital Potentiometers	Digital-to-Analog Converters	Voltage References	Temperature Sensors
MCP6XX	MCP6NXX	MCP654X	MCP30XX	MCP40XX	MCP47XX	MCP1525	MCP98XX
MCP6XXX		MCP656X	MCP32XX	MCP40D1X	MCP48XX	MCP1541	MCP9700/A
MCP6VXX		MCP65R4X	MCP33XX	MCP41XX	MCP49XX		MCP9701/A
MCP6HXX			MCP34XX	MCP42XX	MCP47DA1		
			MCP35XX	MCP43XX	MCP47A1		
			MCP39XX	MCP45XX	TC132X		
				MCP46XX			
				MCP41XXX			
				MCP42XXX			

www.microchip.com
www.microchip.com/analogtools

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 values using op amps, analog-to-digital or voltage-to-frequency converters, and are 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. In 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
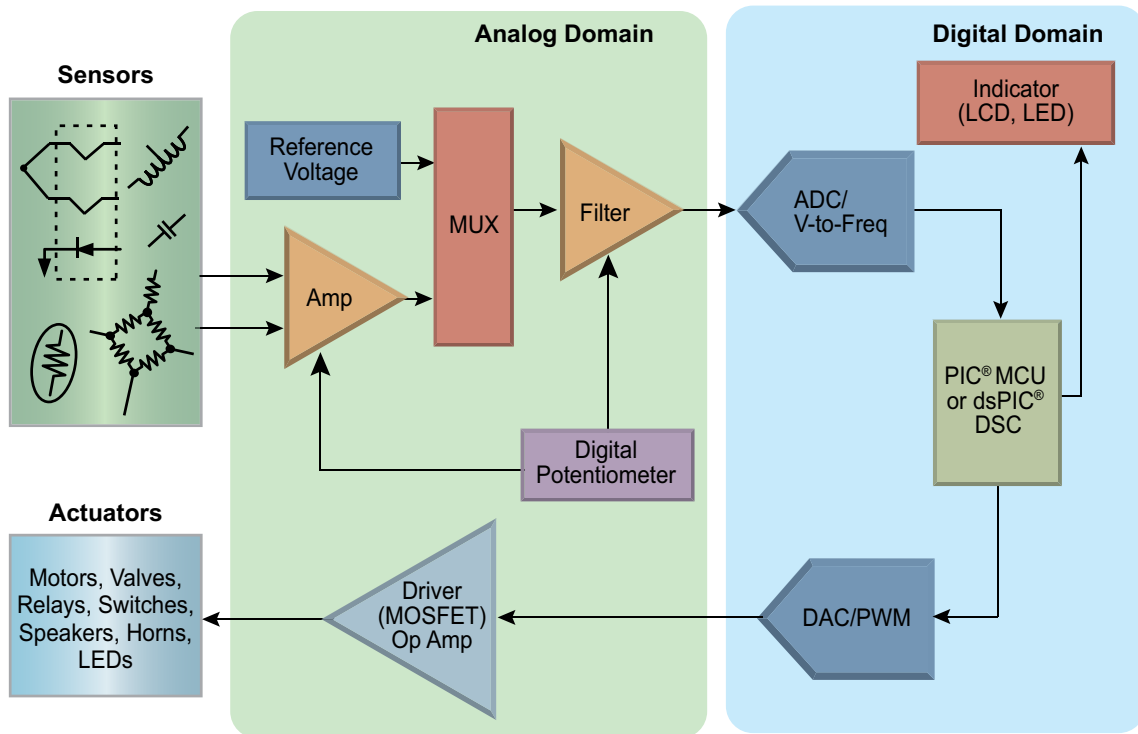
Sensor Overview

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 driven 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
Magnetic	Hall Effect	Voltage
	Magneto-Resistive	Resistance
Temperature	Thermocouple	Voltage
	RTD	Resistance
	Thermistor	Resistance
	IC	Voltage
	Infrared	Current
Humidity	Capacitive	Capacitance
	Infrared	Current
Force, Weight, Torque, Pressure	Strain Gauge	Resistance/Voltage
	Load Cell	Resistance
	Piezoelectric	Voltage or Charge
	Mechanical Transducer	Resistance, Voltage, Capacitance
Motion and Vibration	LVDT	AC Voltage
	Piezoelectric	Voltage or Charge
	Microphone	Voltage
	Ultrosonic	Voltage, Resistive, Current
	Accelerometer	Voltage
Flow	Magnetic Flowmeter	Voltage
	Mass Flowmeter	Resistance/Voltage
	Ultrasound/Doppler	Frequency
	Hot-wire Anemometer	Resistance
	Mechanical Transducer (turbine)	Voltage
Fluid Level and Volume	Ultrasound	Time Delay
	Mechanical Transducer	Resistance/Voltage
	Capacitor	Capacitance
	Switch	On/Off
	Thermal	Voltage
Touch	Capacitance	Voltage
	Inductance	Current
	Resistance	Frequency
Proximity	Capacitance	Voltage, Frequency
	Inductance	Current, Frequency
	Resistance	Voltage, Current
Light	Photodiode	Current
Chemical	pH Electrode	Voltage
	Solution Conductivity	Resistance/Current
	CO Sensor	Voltage or Charge
	Photodiode (turbidity, colorimeter)	Current
	Ion Sensor	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 0.45 µA and 6 mA, with a Gain Bandwidth Product (GBWP) between 9 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, Precision (including EPROM Trimmed and mCal Technology) and Zero-Drift.

Instrumentation Amplifiers (INA)

Microchip has expanded its portfolio of amplifiers with the industry's first instrumentation amplifier featuring mCal technology. The **MCP6N11** features rail-to-rail input and output, 1.8V operation and low offset/offset drift.

Comparators

Microchip offers a broad portfolio of low-power and high-speed comparators. The **MCP6541** and **MCP6561** family of comparators provide ultra low power, 600 nA typical, and higher speed with 40 ns propagation delay, respectively. Both families of comparators are available with single, dual and quad, as well as with push-pull and open-drain output options (for **MCP6546** and **MCP6566**). The **MCP65R41** and **MCP65R46** family of push-pull and open-drain output comparators are offered with integrated reference voltages of 1.21V and 2.4V receptively. This family provides ±1% typical tolerance while consuming 2.5 µA and high speed with 4µs propagation delay. These comparators operate with a single-supply voltage as low as 1.8V to 5.5V, which makes them ideal for low cost and/or battery powered applications.

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 µA typical current consumption in a small 8-pin MSOP package. The **MCP3421** is a single channel 18-bit 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 **MCP3911** analog front end offer two simultaneously sampled 24-bit Delta-Sigma ADCs making it ideal for voltage and current measurement, and other data acquisition applications.

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.

Product Overviews

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.

Temperature Sensors

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 the application requirements. Key features include high accuracy (such as **MCP9808**, with ±0.5°C maximum accuracy from −20°C to 100°C), low power, extended temperature range and small packages. In addition, other Microchip products can be used to support Thermocouple, RTD and Thermistor applications.

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 I2C™ 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's family of Digital-to-Analog Converters (DACs) offer a wide range of options. These devices support the 6-bit through 12-bit applications. Offering both volatile and non-volatile options, and standard SPI and I2C digital interfaces. These devices are offered in small packages such as 6-lead SC70, SOT-23 and DFN (2 × 2) for the single output devices and 10-pin MSOP for quad output devices. Some versions support selecting either the device V_{DD}, the external voltage reference or an internally generated voltage reference source from the DAC circuitry. Devices with nonvolatile memory (EEPROM) allow the device to retain the programmed output code and DAC state through power down events.

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 or humidity) is required.

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
  - Zero-drift op amps
  - Low noise op amps
- Rail-to-rail input/output
  - Most op amp families
- High input impedance
  - Op amps with CMOS inputs
- Low power and portable applications
  - Low power op amps
- High voltage
  - High voltage op amps
- High bandwidth and slew rate
  - High speed op amps
- Load drive
  - High output drive op amps

Classic Gain Amplifier

MCP6XX,
MCP6XXX

V_{OUT}

pH Monitor
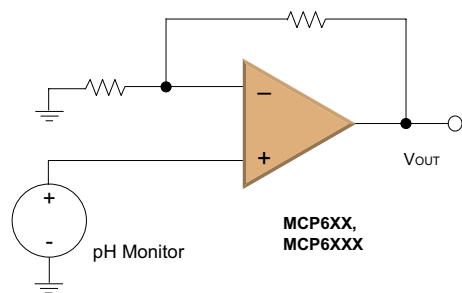
High Side Current Sensing Amplifier
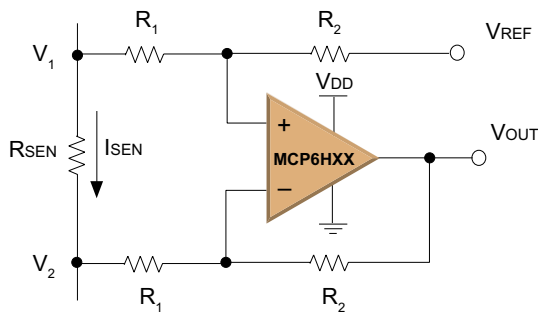
$R_{SEN} \ll R_1, R_2$

$$V_{OUT} = (V_1 - V_2)\left(\frac{R_2}{R_1}\right) + V_{REF}$$
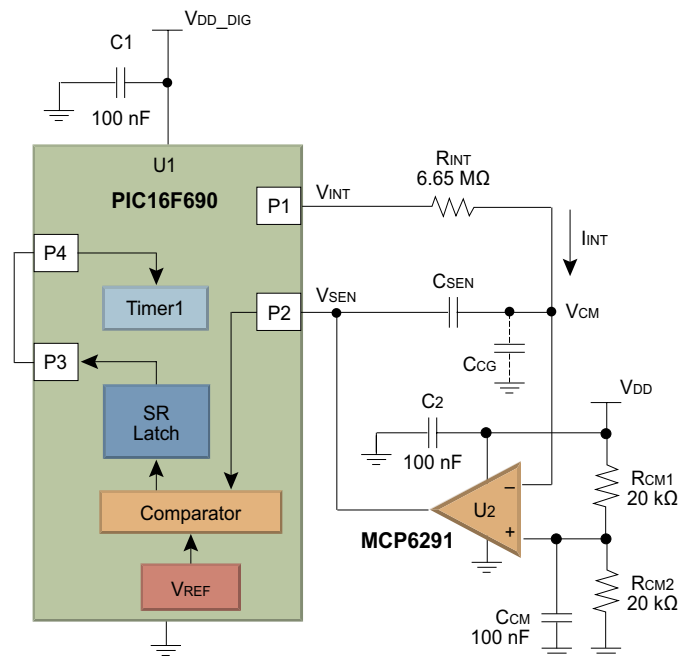
Sensors and Applications

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
- Sensing resistor for current detection

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 V_{OS}

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
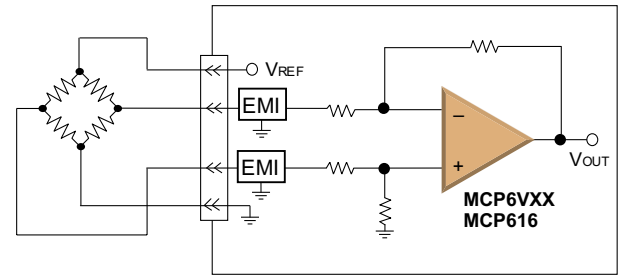
Thermocouple Circuit Using an INA
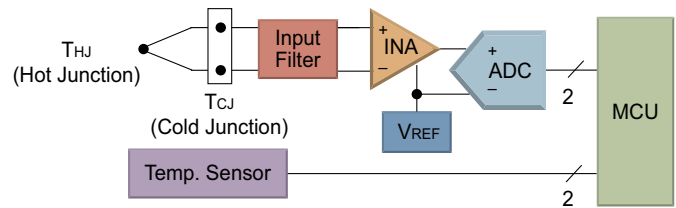
Weight and Pressure Sensing Applications

Weight and pressure measurement have been among the most popular applications for medical, industrial, automotive and consumer industries. In recent years, the MEMS pressure/accelerometer devices have become widely used in many applications and support our modern life style. The majority of weight scale and pressure measurement circuits use bridge type ratiometric configuration. In this case, the output voltage range from the sensor circuit is proportional to the excitation voltage. The following circuit shows an example weight measurement application. In the figure, the output from the load cell is amplified by the low noise op amplifier and fed to the **MCP3421** 18-bit delta sigma ADC.

Example of Weight Measurement Circuit Configuration (MCP3421DM-WS)
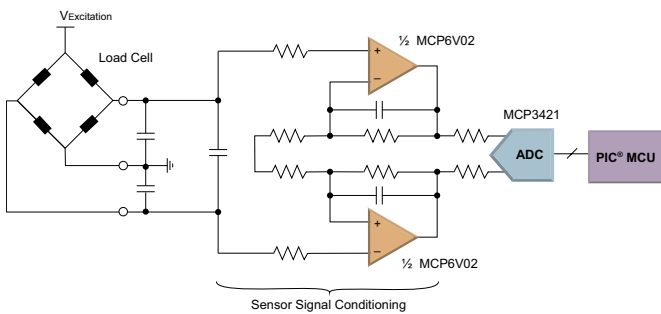
The following circuit shows an example of pressure measurement using the **MCP3551** 22-bit Delta-Sigma ADC. In this example, the **MCP3551** is directly connected to the **NPP-301** sensor output without using the sensor signal conditioning circuit. Since the **MCP3551** uses an external reference input, the same supply voltage is used for the ADC reference and V_{DD}, and the sensor excitation. Therefore, the variation in the sensor excitation source is naturally cancelled out.

Example of Pressure Measurement Circuit Configuration using the MCP3551 Device
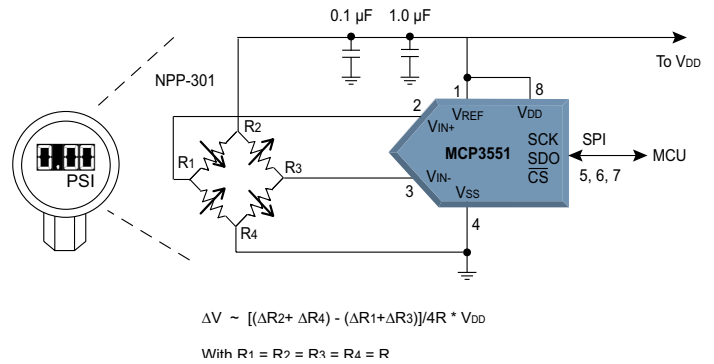
$$\Delta V \sim [(\Delta R_2 + \Delta R_4) - (\Delta R_1 + \Delta R_3)]/4R * V_{DD}$$

With $R_1 = R_2 = R_3 = R_4 = R$

Voltage and Current Measurement

DC Voltage and Current Measurement

DC voltage and current measurement can be easily done by using low speed high resolution Delta Sigma ADC such as **MCP3421** and **MCP3422** family devices. The **MCP3421** is a single channel device while the **MCP3422** is a dual channel device, which can measure the voltage and current using the same device.

The following circuits show simple example of Battery voltage and current measurement using the **MCP3421**. The **MCP3421** uses internal reference voltage of 2.048V. If the input voltage is greater than the reference, it needs a voltage divider to bring down the input full scale range below the reference voltage. This example is shown in example circuit (a). In the current measurement, the ADC is simply connected across a simple shunt current sensor as shown in the figure. The current is calculated using the measured voltage value and a known shunt's resistance value. The **MCP3421** has a differential input and the MSb in the output bit represents the direction of the current.
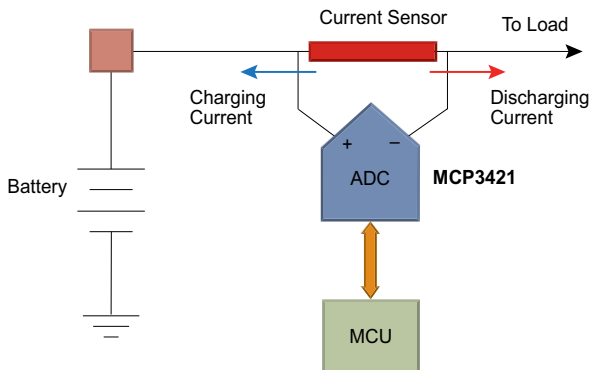
Voltage Measurement Using MCP3421 Device

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

(b) If $V_{REF} > V_{BAT}$
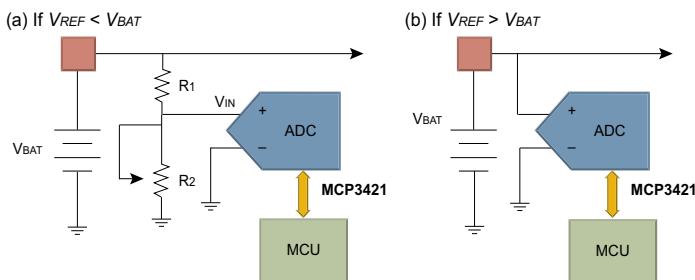
$$V_{IN} = \left(\frac{R2}{R1 + R2} \right) \bullet \left(V_{BAT} \right)$$

$$V_{Measured} = ADC\ Output\ Codes \bullet LSB \bullet \frac{(R1 + R2)}{R2} \bullet \frac{1}{PGA}$$

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

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

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.

Battery Fuel Management by Measuring Battery Voltage and Current

By measuring the battery voltage and current, an intelligent battery fuel management algorithm can be developed. The figure below shows an example of battery fuel management circuit. The **MCP3422** measures both voltage and current draws of the battery, and the system tracks how much the battery fuel has been used and remained. The MCU controls the **MCP73831** for the recharging of the single cell Li-Ion battery

Example Circuit for Battery Fuel Management by measuring Battery Voltage and Current
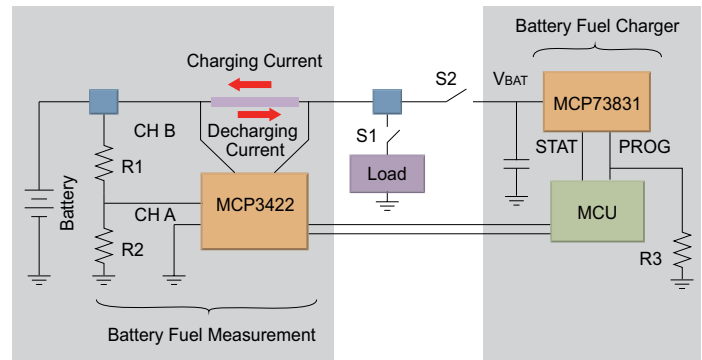
Voltage and Current Measurement

AC Voltage and Current Measurement

AC voltage and current measurement can be done by using energy metering Delta Sigma ADC such as **MCP39XX** devices. The Three-Phase Current and Voltage Measurement figure below shows an example of measuring three-phase current using the **MCP3911**. The measured data is processed by the PIC24F.

Shunt resistors are a common and low cost method for current sensing. Isolated methods include the use of Current transformers and Rogowski coils. The Current Measurement using Rogowski Coil figure shows an example of the current measurement using the Rogowski coil. The Rogowski coil picks-up the electro-magnetic field (EMF) produced by the current at the center. This EMF is measured as voltage. The voltage is integrated so that the output is a voltage that represents the current waveform.

Example of Three-Phase Current and Voltage Measurement Using the MCP3911 Energy Metering Delta-Sigma ADC
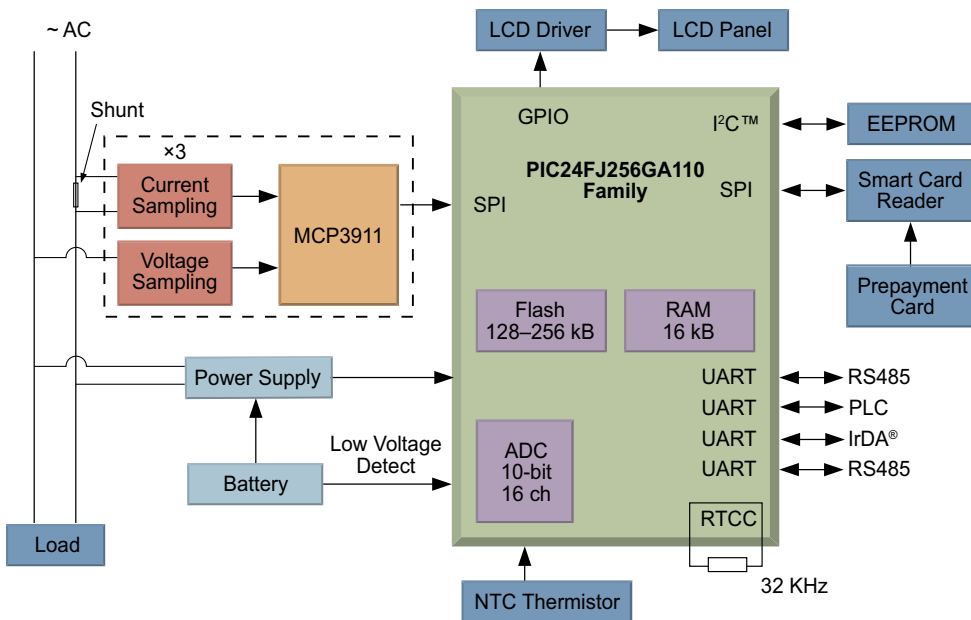
Current Measurement Using Rogowski Coil
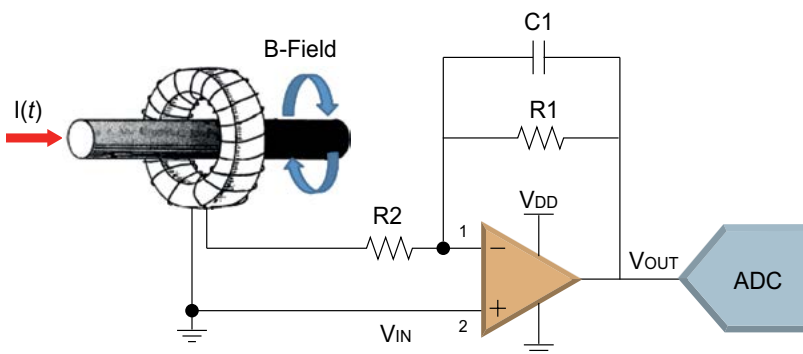
Temperature Sensing Solutions

Thermistor Solution

Thermistors are non-linear and require a look up table for compensation. The solution is to use Microchip's Linear Active Thermistors, the **MCP9700** and the **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 at the non-linear region and noise immunity circuit development overhead can be avoided by using the low-cost Linear Active Thermistors. The voltage output pin (V$_{OUT}$) can be directly connected to the ADC input of a microcontroller. The **MCP9700/9700A** and **MCP9701/9701A** temperature coefficients are scaled to provide a 1°C/bit resolution for an 8-bit ADC with a reference voltage of 2.5V and 5V, respectively. The MCP9700 and MCP9701 sensors output can be compensated for improved sensor accuracy as shown below, refer to the AN1001 application note.

MCP9700 and MCP9701 Key Features

- SC70, TO92 packages
- Operating temperature range: −40°C to +150°C
- Temperature Coeffi cient: 10 mV/°C (MCP9700)
- Temperature Coeffi cient: 19.5 mV/°C (MCP9701)
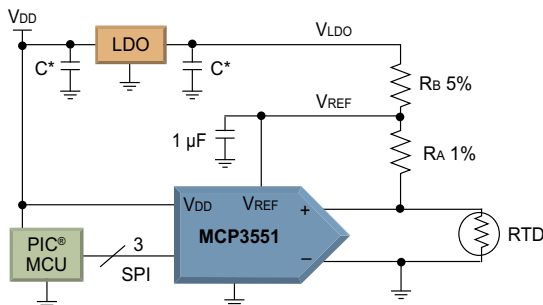- Low power: 6 μA (typ.)

Applications

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

Typical Sensor Accuracy Before and After Compensation
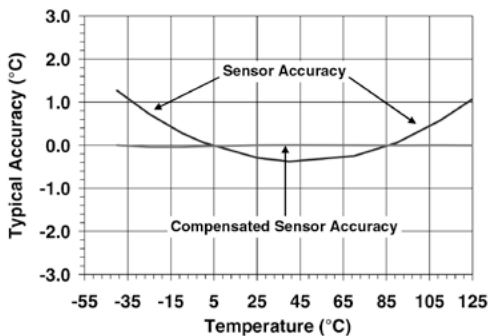
Resistive Temperature Detector (RTD) Solutions

RTD Solution with Precision Delta-Sigma ADC

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. Microchip's RTD solution uses a high performance Delta-Sigma Analog to Digital converter, two external resistors, and a reference voltage to measure RTD resistance or temperature 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, R$_A$, 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

R$_A$ = Biasing resistor

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

For instance, a 2V ADC reference voltage (V$_{REF}$) results in a 1 μV/LSb (Least Significant Bit) resolution. Setting R$_A$ = 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.

This solution can be evaluated using Microchip's RTD Reference Design Board (TMPSNSRD-RTD2).

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

*See LDO Data Sheet at: **www.microchip.com/LDO**
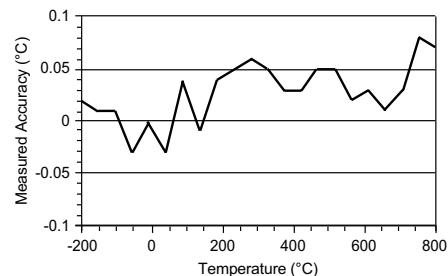
Temperature Sensing Solutions

Resistive Temperature Detector (RTD) Solutions

RTD Solution with RC Oscillators

RC oscillators offer several advantages in precision sensing applications. They do not require an Analog-to-Digital Converter (ADC), and oscillator can be directly connected to an Input/Output pin of a microcontroller to measure change in frequency proportional to sensor output. The accuracy of the frequency measurement is directly related to the quality of the microcontroller's clock signal, and high-frequency oscillators for the controller are available with accuracies of better than 10 ppm.

The oscillator circuits shown in the Oscillator Circuits For Sensors section can be used for this method. The variable resistor of the circuits (Figure: Oscillator Circuits for Resistive Sensors) are replaced with the RTD sensor. There is an example of a state variable RC oscillator, which provides an output frequency that is proportional to the square root of the product of the two RTD resistances ($\alpha\ 1/(R1 \times R2)^{1/2}$). A second example shows the relaxation oscillator (or astable multi-vibrator), which provides a square wave output with a single comparator.

The state variable RC oscillator is good for precision applications, while the relaxation oscillator is an alternative for cost-sensitive applications.

RTD Solution with Instrumentation Amplifier

This Wheatstone bridge reference design board demonstrates the performance of Microchip's **MCP6N11** instrumentation amplifier (INA) and a traditional three op amp INA using Microchip's **MCP6V26** and **MCP6V27** auto-zeroed op amps. The input signal comes from an RTD temperature sensor in a Wheatstone bridge. Real world interference is added to the bridge's output, to provide realistic performance comparisons. Data is gathered and displayed on a PC, for ease of use. The USB PIC® microcontroller and included Graphical User Interface (GUI) provides the means to configure the board and collect sample data.

MCP6N11 and MCP6V2X Wheatstone Bridge Reference Design (ARD00354)
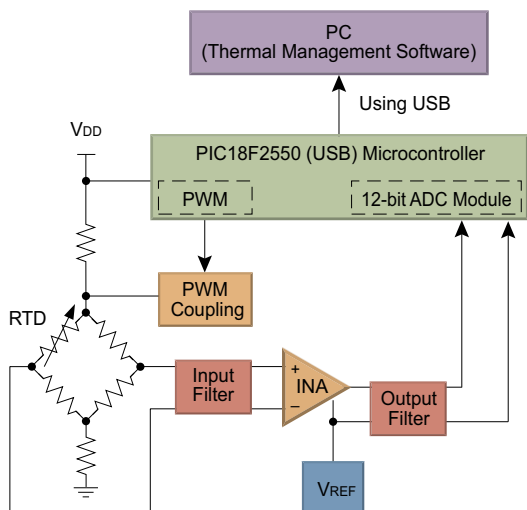
Thermocouple Sensor Solutions

Thermocouple Solution with Precision Delta-Sigma ADC

Delta-Sigma ADCs can be used to directly measure thermocouple voltage. Microchip's **MCP3421** ADC can be used to accurately measure temperature using a Thermocouple. The device provides a plug and play solution for various types of thermocouples, greatly simplifying the circuit design. In this case, the Thermocouple linearization routine is implemented in firmware or software. Cold Junction Compensation is implemented using Microchip's stand alone digital temperature sensors, such as the ±0.5C accurate **MCP9808**.

This solution can be evaluated using Microchip's Thermocouple Reference Design Board (TMPSNSRD-TCPL1).

Thermocouple Solution with Auto-Zero'ed Op Amp
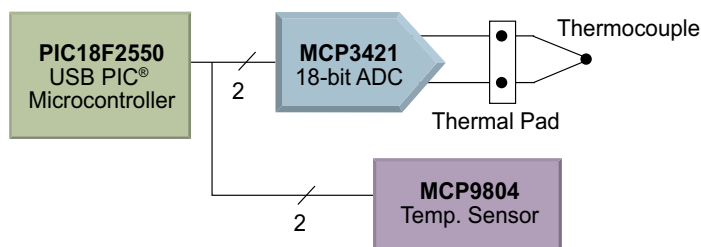
Microchip's auto-zeroed op amp can be used to accurately measure thermocouple voltage. The MCP6V01 op amp ultra low offset voltage and high common mode rejection makes it ideal for low cost thermocouple applications.

The **MCP6V01** Thermocouple Auto-Zeroed Reference design demonstrates how to accurately measure temperature (MCP6V01RD-TCPL).

Wireless Temperature Monitoring Solution
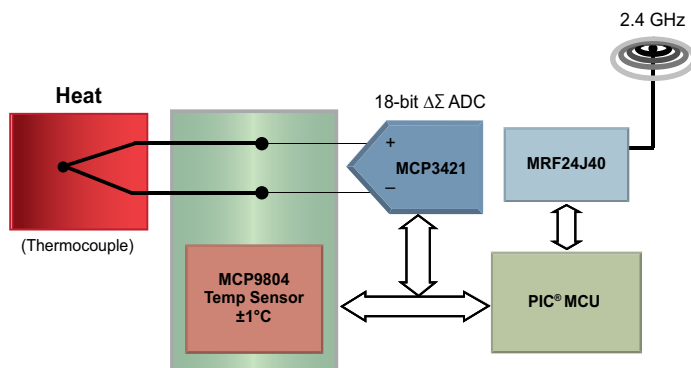
Temperature Sensing Solutions

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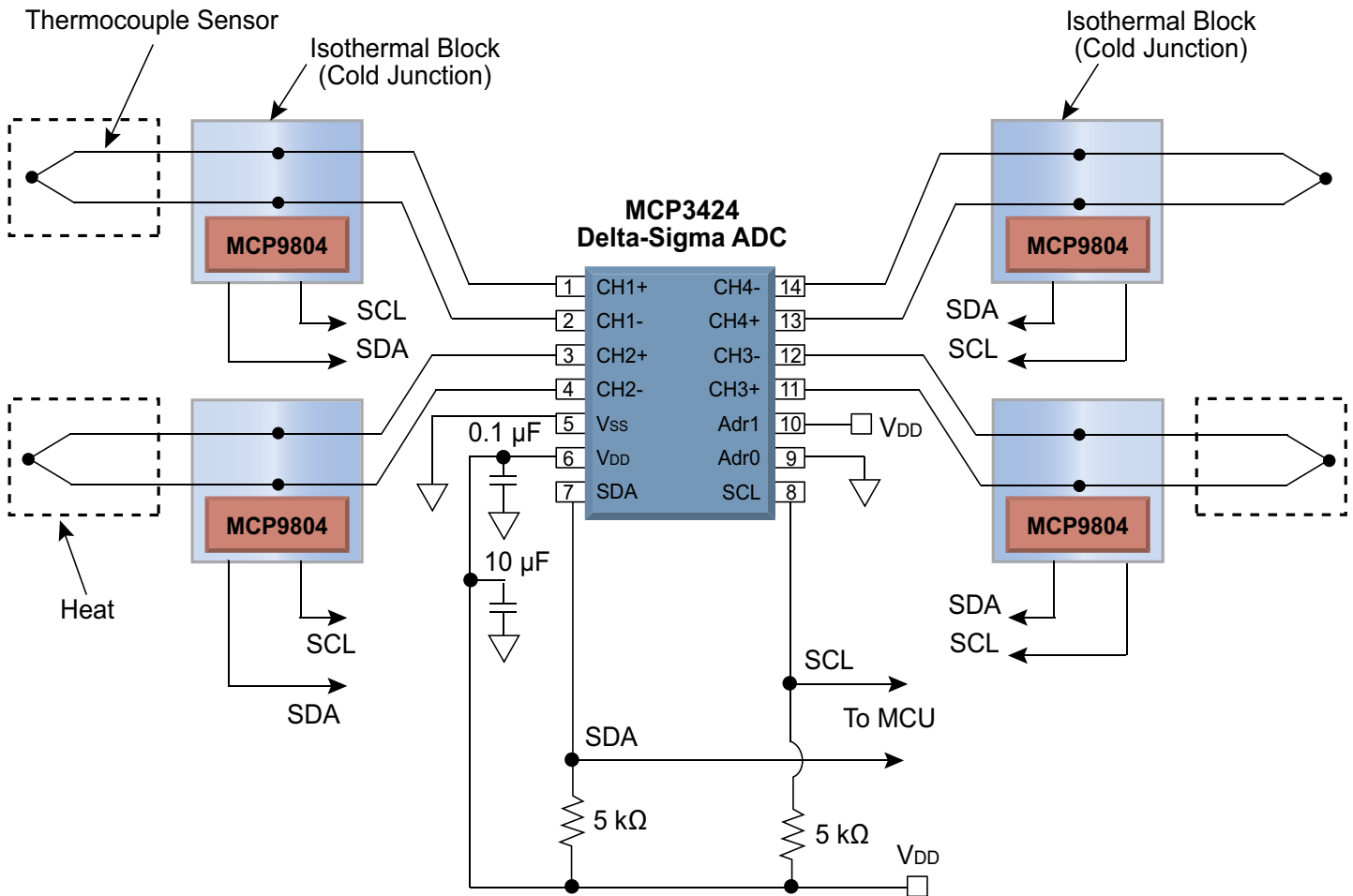
Programmable Gain

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 and 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 R_1, R_2, and Pot_1 can be used to tune the gain of the inverting amplifier, and the simplified circuit (b) which removes resistors R_1 and R_2 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 R_1 and R_2 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 following equation shows how to calculate the gain for the simplified circuit (figure below). The gain is the ratio of the digital potentiometers wiper position on the R_{AB} resistor ladder. As the wiper moves away from the midscale value, the gain will either become greater then one (as wiper moves towards Terminal A), or less then one (as wiper moves towards Terminal B).

Inverting Amplifier with Programmable Gain Circuits

Generic Circuit (a)

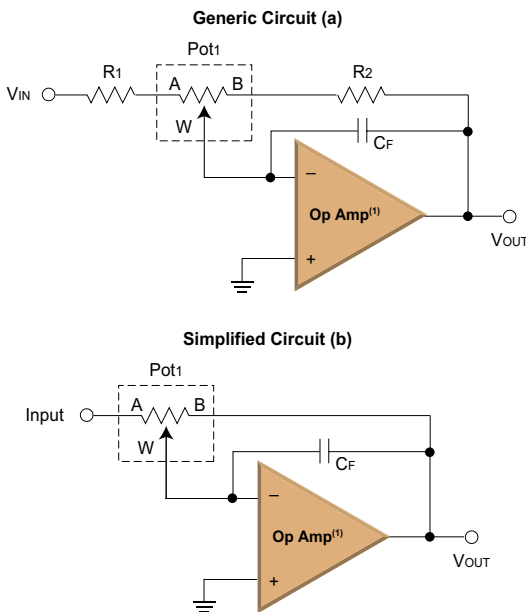

Simplified Circuit (b)

Note 1: A general purpose op amp, such as the MCP6001.

The feedback capacitor (C_F) is used for circuit stability.

The device's wiper resistance (R_W) 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 Amplifier

The **MCP6SX2** PGA Thermistor PICtail Demo Board features the **MCP6S22** and **MCP6S92** Programmable Gain Amplifiers (PGA). These devices overcome the non-linear response of a NTC thermistor, multiplex between two inputs and provide gain. It demonstrates the possibility of measuring multiple sensors and reducing the number of PIC microcontroller I/O pins used. Two on-board variable resistors allow users to experiment with different designs on the bench.

A complete solution is achieved by interfacing this board to the PICkit™ 1 Flash Starter Kit (see DS40051) and the Signal Analysis PICtail Daughter Board (see DS51476).

MCP6SX2 PGA Thermistor PICtail™ Demo Board (MCP6SX2DM-PICTLTH)
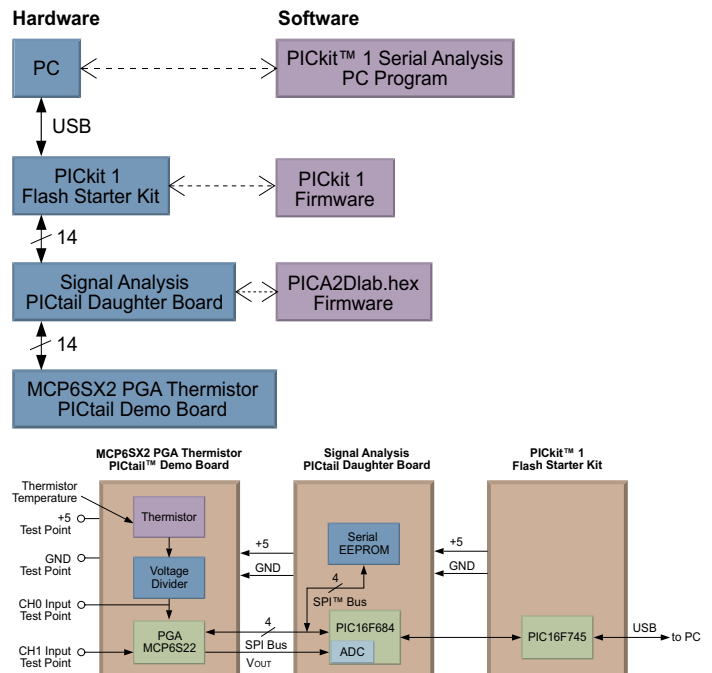
Sensor Calibration/Compensation

Sensor Characteristics

Sensor characteristics vary, both for device to device as well as for a given device over the operating conditions. To optimize system operation, this sensor variation may require some compensation. This compensation may simply address device to device variation, or be more dynamic to also address the variations of the device over the operating conditions. The system voltage and temperature may effect the sensor output characteristics such as output voltage offset and linearity. This conditioning circuit can also be used to optimize the range of the sensors conditioned signal into the Analog-to-Digital conversion circuit.
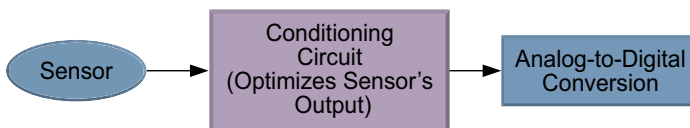
Depending on the sensor, the sensor's output may either be voltage or a current. A possible compensation circuit for each output type will be discussed.

In this first case, the sensor generates an output voltage. Temperature sensors are typical sensors that generate a voltage output which varies unit to unit.

Voltage Control

A simple voltage control circuit (see figure below) can ensure that the sensors output voltage is optimized to the input range of the next stage in the signal chain. This circuit is a gain amplifier, where the R_1 and R_2 resistances determine the amplifier's gain. The amplifier's output voltage range is limited by the V_{DD} and V_{SS} voltages. Controlling the V_{OS} voltage can optimize the V_{OUT} voltage profile, based on the sensor's output voltage (V_{SEN}).

Inverting Amplifier (Voltage Gain)

Either a DAC or a Digital Potentiometer can be used to control the voltage at V_{OS}. This device can be a non-volatile version so that at system power up the V_{OS} voltage is at the calibrated voltage, programmed during manufacturing test, to address the sensor's device to device variation. If dyn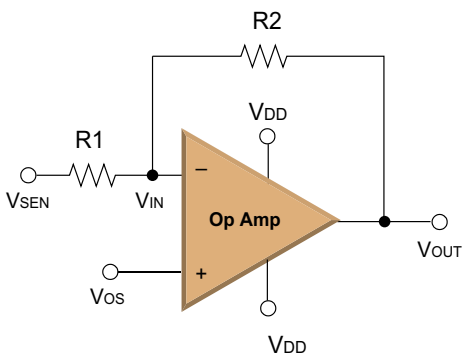amic control is desired, the DAC or Digital Potentiometer can be interfaced to a microcontroller so that dynamic changes to the V_{OS} voltage compensate for the system conditions and non-linearity of the sensor.

Typically during the manufacturing stage the test system will write this compensation data into some non-volatile memory in the system which the microcontroller will use during normal operation to adjust the V_{OS} voltage.

In this second case, the sensor generates an output current. Photodiodes are a typical sensors that generate a current output, and can vary ±30% at +25°C (unit-to-unit).

Current to Voltage

A simple current to voltage converter circuit (see Figure below), is used to create a voltage on the output of the op amp (V_1), which can then be compensated. In this circuit, the photodiodes I_{PD} current times the R_F resistance equals the voltage at the op amps output (V_1). The R_F resistance needs to be selected so that at the minimum $I_{PD(MAX)}$ current, the V_{OUT} voltage is at the maximum input voltage for the next stage of the signal chain. Typically this will be done when the DAC or Digital Potentiometer is at Full Scale (so $V_{OUT} \approx V_1$). For photodiodes where the $I_{PD(MAX)}$ current exceeds the minimum $I_{PD(MAX)}$ current (increasing the V_1 voltage), the DAC or Digital Potentiometer Wiper code be programmed to attenuate the that V_1 voltage to the desired V_{OUT} max voltage. This then compensates for the variation of the photodiode's I_{PD} current.

Photodiode Calibration (Trans-Impedance Amplifier)

This device can be a non-volatile version so that at system power up the voltage attenuation is at the level, programmed during manufacturing test, to address the sensor's device to device variation. If dynamic control is desired, the DAC or Digital Potentiometer can be interfaced to a microcontroller so that dynamic changes to the voltage attenuation compensate for the system conditions and non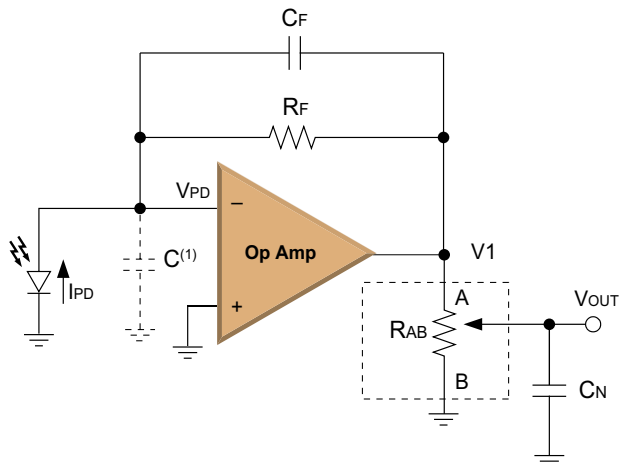-linearity of the sensor. Typically during the manufacturing stage the test system will write this compensation data into some non-volatile memory in the system which the microcontroller will use during normal operation to adjust the voltage attenuation.

C_F may be used to stabilize the op amp. Additional information on Amplifying High-Impedance Sensors is available in Application Note AN951.

Sensor Calibration/Compensation

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_{REF} would produce 500 µV of resolution.

If G = 2 is selected, the internal 2.048 V_{REF} 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

$$V_{OUT} = V_{REF} \times \frac{Dn}{4096} G_X$$

$$V_{TRIP} = V_{OUT} \times \frac{R_2}{R_1 + R_2}$$

Where Dn = Input Code (0 to 4095)

G_X = Gain Selection (x1 or x2)
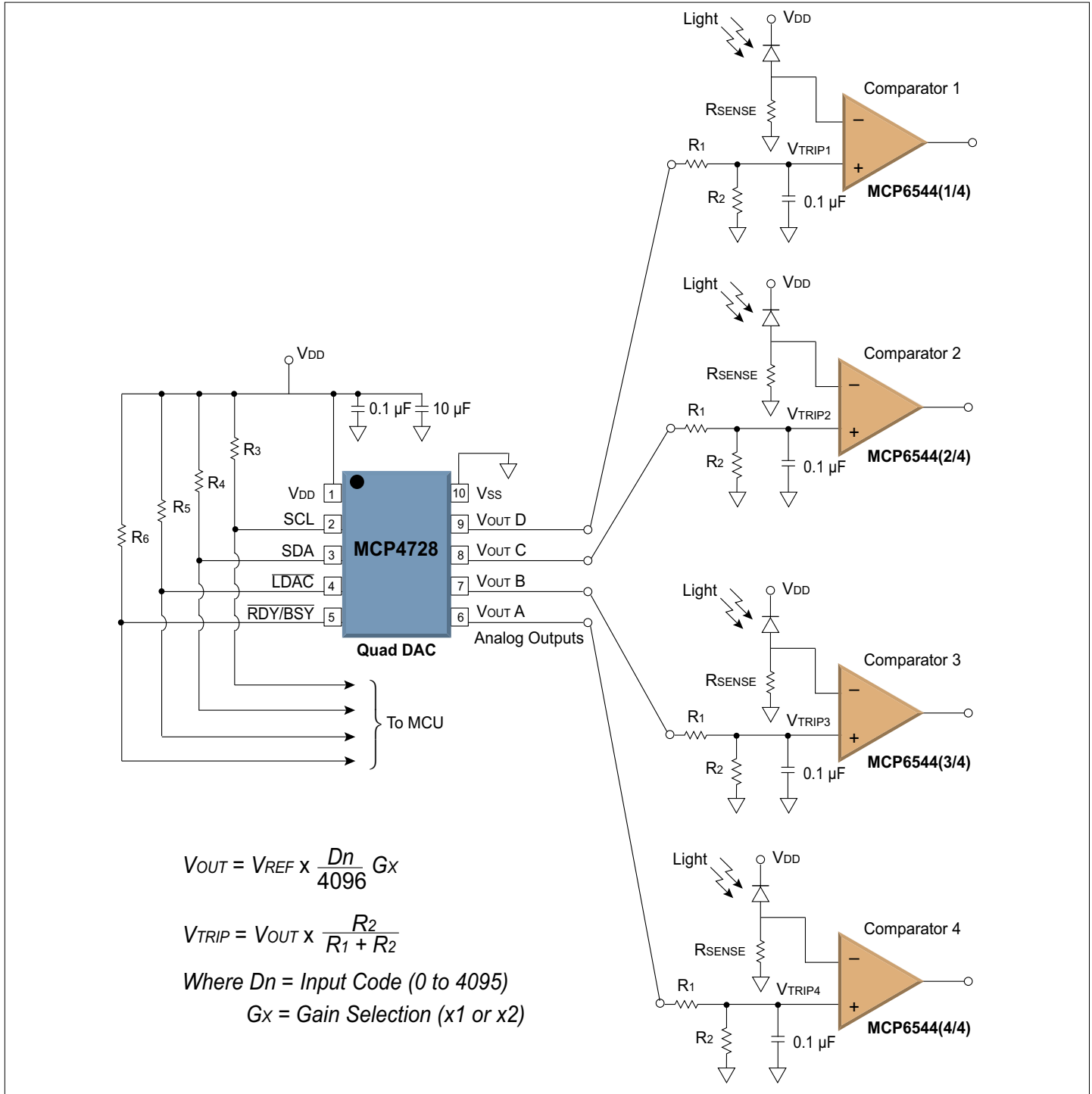
Oscillator Circuits For Sensors

Oscillator Circuits for Sensors

RC oscillators can accurately and quickly measure resistive and capacitive sensors. The oscillator period (or frequency) is measured against a reference clock signal, so no analog-to-digital convertor is needed.

State-Variable Oscillators

State-variable oscillators have reliable start-up, low sensitivity to stray capacitances and multiple output configurations (sine wave or square wave). They can use one or two resistive sensors, and they can use one or two capacitive sensors.

Some of their advantages and features are:

- Precision
- Reliable oscillation startup
- Sine or square wave output
- Frequency $\propto 1/(R_1 R_2 C_1 C_2)^{1/2}$

Relaxation Oscillators

Relaxation oscillators have reliable start-up, low cost and square wave output. They can use a resistive sensor or a capacitive sensor.

Some of their advantages and features are:

- Low cost
- Reliable oscillation startup
- Square wave output
- Frequency $\propto 1/(R_1 C_1)$

Sensors and Applications

These oscillator circuits are applicable to various type of sensors.

Resistive Sensors

- RTDs
- Thermistors
- Humidity

Capacitive Sensors

- Humidity
- Pressure (e.g., absolute quartz)
- Fluid 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.

Oscillator Circuits for Resistive Sensors
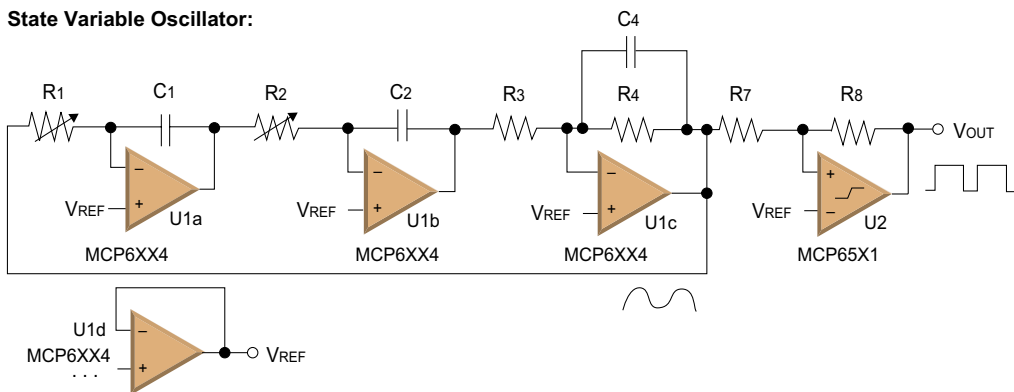
Notes: In AN895, R_1 = RTD$_A$ and R_2 = RTD$_A$. A resistive divider to V$_{DD}$ sets V$_{REF}$ (V$_{DD}$/2 is recommended).
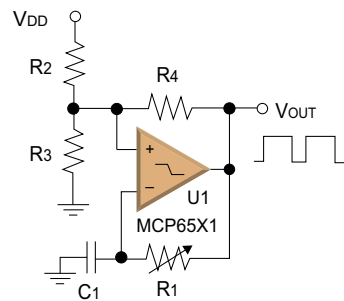
Note: In AN895, R_1 = RTD.

Oscillator Circuits for Capacitive Sensors
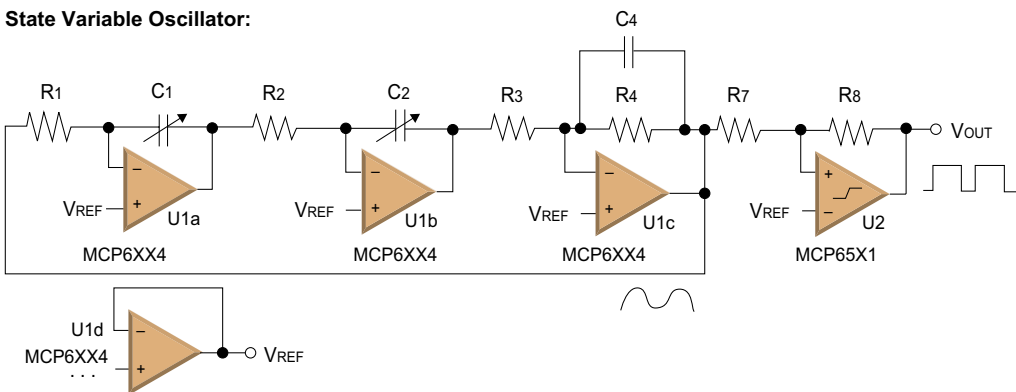
Notes: A resistive divider to V$_{DD}$ sets V$_{REF}$ (V$_{DD}$/2 is recommended).
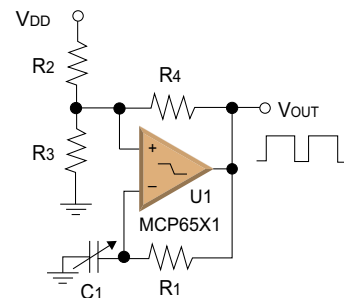
Development Software

FilterLab® Software

Microchip's FilterLab software is an innovative software tool that simplifies analog active filter (using op amps) design. Available at no cost from the Microchip website at www.microchip.com/filterlab, the FilterLab design tool provides full schematic diagrams of the filter circuit with component values. It also outputs the filter circuit in SPICE format, which can be used with the macro model to simulate actual filter performance.

SPICE Macro Models

The SPICE macro models for linear ICs (op amps and comparators) are available on the Microchip website at www.microchip.com/spicemodels. The models were written and tested in PSPICE owned by Orcad (Cadence). For other simulators, they may require translation. The models cover a wide aspect of the linear ICs' electrical specifications. Not only do the models cover voltage, current and resistance of the linear ICs, but they also cover the temperature and noise effects on the behavior of the linear ICs. The models have not been verified outside the specification range listed in the linear ICs' datasheet. The models' behavior under these conditions cannot be guaranteed to match the actual linear ICs' performance. Moreover, the models are intended to be an initial design tool. Bench testing is a very important part of any design and cannot be replaced with simulations. Also, simulation results using these macro models need to be validated by comparing them to the datasheet specifications and characteristcs curves.
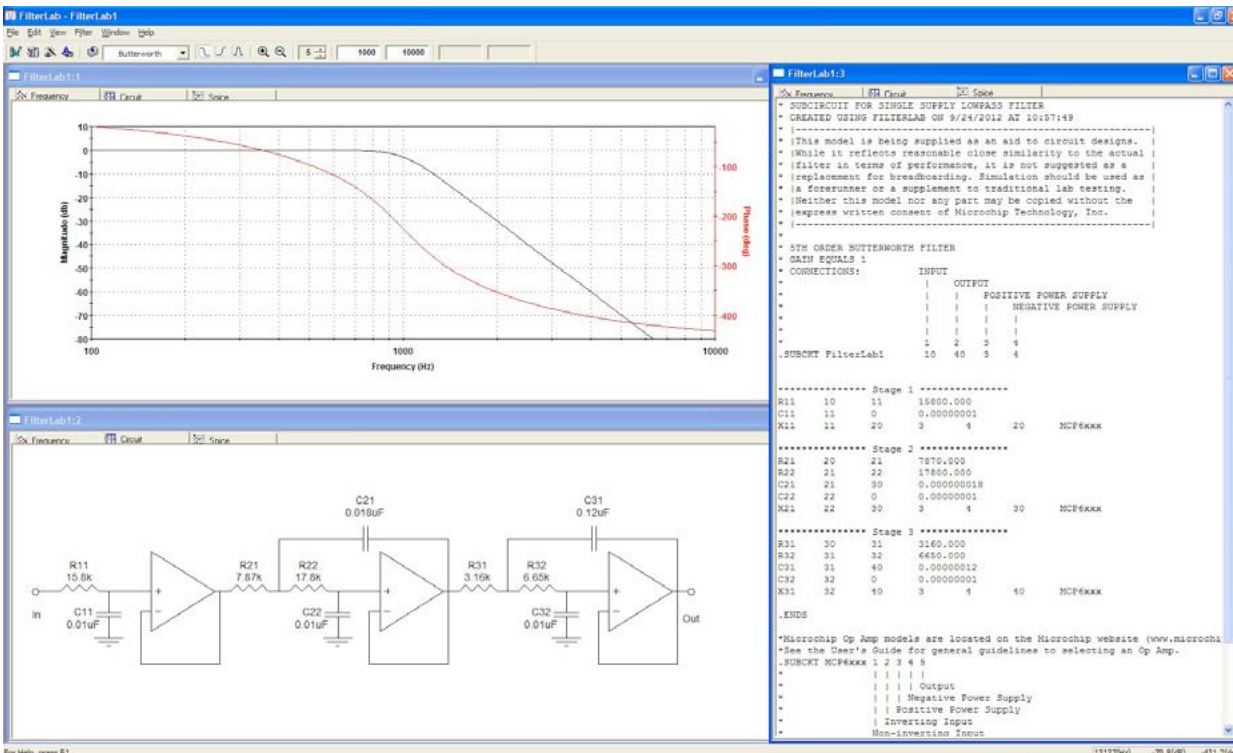
SPICE Macro Model Example

Filter Lab Window

Development Tools

These following development boards support 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.

Reference Designs

Battery

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.

Pressure

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

This 1" × 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.

Photodiode

MCP6031 Photodiode PICtail Plus Demo Board (MCP6031DM-PTPLS)

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

Temperature Sensors

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).

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.

MCP6N11 and MCP6V2X Wheatstone Bridge Reference Design (ARD00354)

This board demonstrates the performance of Microchip's MCP6N11 instrumentation amplifier (INA) and a traditional three op amp INA using Microchip's MCP6V26 and MCP6V27 auto-zeroed op amps. The input signal comes from an RTD temperature sensor in a Wheatstone bridge.

Development Tools

Demonstration Boards

ADCs

MCP3911 ADC Evaluation Board for 16-bit MCUs (ADM00398)

The MCP3911 ADC Evaluation Board for 16-Bit MCUs system provides the ability to evaluate the performance of the MCP3911 dual-channel ADC. It also provides a development platform for 16-bit PIC-based applications, using existing 100-pin PIM systems compatible with the Explorer-16 and other high pin count PIC demo boards. The system comes with a programmed PIC24FJ256GA110 PIM module that communicates with the included PC software for data exchange and ADC configuration.

MCP3421 Weight Scale Demo Board (MCP3421DM-WS)

The MCP3421 Weight Scale Demo Board is designed to evaluate the performance of the low-power consumption, 18-bit ADC in an electronic weight scale design. Next to the MCP3421 there is a low-noise, auto-zero MCP6V07 op amp. This can be used to investigate the impact of extra gain added before the ADC for performance improvement. The PIC18F4550 is controlling the LCD and the USB communication with the PC. The GUI is used to indicate the performance parameters of the design and for calibration of the weight scale.

MCP3421 Battery Fuel Gage Demo Board (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 demo board displays the following parameters:
(a) Measured battery voltage.
(b) Measured battery discharging current.
(c) Battery Fuel Used (calculated).

The MCP3421 Battery Fuel Gauge Demo Board also can charge a single-cell 4.2V

Li-Ion battery. This feature, however, is disabled by firmware since the demo kit is shipped to customer with non-rechargeable 1.5V AAA battery.

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.

Digital Potentiometers

MCP42XX PICtail Plus Daughter Board (MCP42XXDM-TPTLS)

The MCP42XX PICtail Plus Daughter Board is used to demonstrate the operation of the MCP42XX Digital Potentiometers. This board is designed to be used in conjunction with either the PIC24 Explorer 16 Demo Board or the PICkit Serial Analyzer.

MCP402X Non-Volatile Digital Potentiometer Evaluation Board (MCP402XEV)

The MCP402XEV is a low cost evaluation board that quickly enables the user to exercise all of the features of the MCP402X Non-Volatile Digital Potentiometer. A 6 pin PIC10F206-I/OT with FLASH memory is utilized to generate all of the Low-Voltage (LV) and High-Voltage (HV) MCP402X serial commands when the 2 momentary switches are depressed in various sequences. This enables the user to Increment and Decrement the wiper, save the setting to EEPROM & exercise the WiperLock™ feature.

Op Amps and PGAs

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_{OST} 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 (Vos) under a variety of bias conditions. This Vos 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 (IVos/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 50Ω 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 50Ω BNC cables. There are 50Ω 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 50Ω 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.

MCP6H04 Evaluation Board Instrumentation Amplifier (ADM00375)

The MCP6H04 Intrumentation Amplifier board is designed to support signal conditioner from sensors example current sensor.

MCP6SX2 PGA Thermistor PICtail Demo Board (MCP6SX2DM-PCTLTH)

The MCP6SX2 PGA Thermistor PICtail Demo Board features the MCP6S22 and MCP6S92 Programmable Gain Amplifiers (PGA). These devices help overcome the non-linear response of the on-board NTC thermistor. These devices have user selectable inputs which allow the possibilities of temperature correcting another sensor.

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.

Humidity Sensor PICtail Demo Board (PIC16F690DM-PCTLHS)

This board uses the MCP6291 and PIC16F690 to measure the capacitance of a relative humidity sensor. The board can also measure small capacitors in different ranges of values using a dual slope integration method. This board also supports the application note AN1016.

Temperature 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 data logged 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.

Related Support Material

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

Application Related Documentation

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.

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

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.

Utility Metering

DS01008: Utility Metering Solutions

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.

AN1316A: Using Digital Potentiometers for Programmable Amplifier Gain

This application note discusses implementations of programmable gain circuits using an op amp and a digital potentiometer. This discussion includes implementation details for the digital potentiometer's resistor network.

Related Support Material

Op Amps

AN1302: Current Sensing Circuit Concepts and Fundamentals

This application note provides an overview of current sensing circuit concepts and fundamentals. It introduces current sensing techniques and focuses on three typical high-side current sensing implementations, with their specific advantages and disadvantages.

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.

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.

Related Support Material

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.

AN1353: Rectifiers, Op Amp Peak Detectors and Clamps

This application note covers a wide range of application, such as half-wave rectifiers, full-wave rectifiers, peak detectors and clamps.

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.

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 ±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.

Product Related Documentation

Sensor Conditioning Circuits Overview

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.

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).

SAR ADCs

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.

Related Support Material

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.

Op Amps

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.

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

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^{2}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.

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 (Vos) 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: Op Amps

Device	# per Package	GBWP (kHz) Typ.	I$_Q$ (µA/amp.) Typ.	Vos (±µV) Max.	Supply Voltage (V)	Temperature Range (°C)	Rail-to-Rail I/O	Features	Packages	Featured Demo Board	Op Amp Category
MCP6441/2/4	1, 2, 4	9	0.45	4,500	1.8 to 6.0	−40 to +125	I/O	Low Quiescent Current	SOIC, MSOP, 2 × 3 TDFN, TSSOP, SOT-23, SC-70	SOIC8EV, SOIC14EV	–
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
MCP6401/2/4	1, 2, 4	1,000	45	4,500	1.8 to 6.0	−40 to +125/150	I/O	Low Quiescent Current	SOIC, MSOP, 2 × 3 TDFN, TSSOP, SOT-23, SC-70	SOIC8EV, SOIC14EV	–
MCP6L01/2/4	1, 2, 4	1,000	85	5,000	1.8 to 6.0	−40 to +125	I/O	–	PDIP, SOIC, MSOP, TSSOP, SOT-23, SC-70	–	–
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
MCP6H01/2/4	1, 2, 4	1,200	135	3,500	3.5 to 16	−40 to +125	O	High Voltage	SOIC, 2 × 3 TDFN, TSSOP, SOT-23, SC-70	–	–
MCP6H81/2/4	1, 2, 4	5,500	700	1,000	3.5 to 12V	−40 to +125	O	High Voltage	SOIC, TDFN, TSSOP	–	–
MCP6H91/2/4	1, 2, 4	10,000	2,000	1,000	3.5 to 12V	−40 to +125	O	High Voltage	SOIC, TDFN, TSSOP	–	–
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	MCP6XXXDM-FLTR, SOIC8EV, SOIC14EV	General Purpose
MCP6L71/2/3/4	1, 2, 1, 4	2,000	150	4,000	2.0 to 6.0	−40 to +125	I/O	Low Power Mode on MCP6L73	PDIP, SOIC, MSOP, TSSOP, SOT-23	MCP6XXXDM-FLTR, SOIC8EV, SOIC14EV	–
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
MCP6L1/2/4	1, 2, 4	2,800	200	3,000	2.7 to 6.0	−40 to +125	O	–	PDIP, SOIC, TSSOP, SOT-23	SOIC8EV, SOIC14EV	–
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	MCP6XXXEV-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
MCP6L91/2/4	1, 2, 4	10,000	850	4,000	2.4 to 6.0	−40 to +125	I/O	–	PDIP, SOIC, MSOP, TSSOP, SOT-23	PIC16F690DM-PCTLHS, SOIC8EV, SOIC14EV	–

LINEAR: Op Amps (Continued)

Device	# per Package	GBWP (kHz) Typ.	IQ (µA/amp.) Typ.	VOS (±µV) Max.	Supply Voltage (V)	Temperature Range (°C)	Rail-to-Rail I/O	Features	Packages	Featured Demo Board	Op Amp Category
MCP621/1S/2/3/4/5/9	1, 2, 3, 1, 4, 2, 4	20,000	2,500	200	2.5 to 5.5	−40 to +125	O	mCal (offset correction), Low Power Mode on MCP623/5/9	SOT-23, SOIC, MSOP, DFN, TSSOP, QFN	MCP651EV-VOS	High Speed, High Output Drive, Low Offset
MCP631/2/3/4/5/9	1, 2, 1, 4, 2, 4	24,000	2,500	8,000	2.5 to 5.5	−40 to +125	O	Low Power Mode on MCP633/5/9	SOIC, MSOP, DFN, TSSOP, QFN	MCP651EV-VOS	High Speed, High Output Drive
MCP651/1S/2/3/4/5/9	1, 1, 2, 1, 4, 2, 4	50,000	6,000	200	2.5 to 5.5	−40 to +125	O	mCal (offset correction), Low Power Mode on MCP653/5/9	SOT-23, SOIC, MSOP, DFN, TSSOP, QFN	MCP651EV-VOS	High Speed, High Output Drive, Low Offset
MCP661/2/3/4/5/9	1, 2, 1, 4, 2, 4	60,000	6,000	8,000	2.5 to 5.5	−40 to +125	O	Low Power Mode on MCP663/5/9	SOIC, MSOP, DFN, TSSOP, QFN	MCP661DM-LD	High Speed, High Output Drive

LINEAR: Zero-Drift Op Amps

Device	# per Package	GBWP (kHz) Typ.	IQ (µA/amp.) Typ.	VOS (±µV) Max.	Supply Voltage (V)	Temperature Range (°C)	Rail-to-Rail I/O	Features	Packages	Featured Demo Board	Op Amp Category
MCP6V11	1	80	7.5	8	1.6 to 5.5	−40 to +125	I/O	–	SOT-23, SC-70	–	–
MCP6V31	1	300	23	8	1.6 to 5.5	−40 to +125	I/O	–	SOT-23, SC-70	–	–
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: Instrumentation Amplifiers

Device	# per Package	GBWP (kHz) Typ.	IQ (µA/amp.) Typ.	VOS (±µV) Max.	VOS Drift Max. (µV/°C)	Supply Voltage (V)	Temperature Range (°C)	Rail-to-Rail I/O	Features	Packages	Featured Demo Board
MCP6N11	1	500	800	350	2.7	1.8 to 5.5	−40 to +125	I/O	mCal (offset correction)	SOIC, 2 × 3 TDFN	ARD00354

LINEAR: Comparators

Device	# per Package	VREF (V)	Typical Propagation Delay (µs)	IQ Typical (µA)	VOS 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 (S,R,U), 5-pin SC-70 (S,U), 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 (S,R,U), 5-pin SC-70 (S,U), 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
MCP65R41	1	1.21/2.4	4	2.5	10	1.8 to 5.5	−40 to +125	Push-Pull, Rail-to-Rail Input/Output , VREF	6-SOT-23
MCP65R46	1	1.21/2.4	4	2.5	10	1.8 to 5.5	−40 to +125	Open Drain, Rail-to-Rail Input/Output , VREF	6-SOT-23
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 (S,R,U), 5-pin SC-70 (S)
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 (S,R,U), 5-pin SC-70 (S)
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

S = Standard Pinout, R = Reverse Pinout, U = Alternate Pinout

LINEAR: Programmable Gain Amplifiers (PGA)

Device	Channels	−3 dB BW (MHz) Typ.	I_Q (µA) Max.	V_OS (±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_REF	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	I²C™	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	2.7 to 5.5	145	10	−40 to +85	PGA: 1, 2, 4, or 8 Internal voltage reference	SOIC-14, TSSOP-14	–
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	16/24	64000	2 Diff	SPI	4.5 to 5.5	2050	15	−40 to +125	Two ADCs, Programmable Data Rate, PGA, Phase Compensation	SSOP-20, QFN-20	MCP3901EV-MCU16
MCP3903	16/24	64000	6 Diff	SPI	4.5 to 5.5	8300	15	−40 to +125	Six ADCs, Programmable Data Rate, PGA, Phase Compensation	SSOP-28	ADM00310
MCP3911	16/24	64000	2 Diff	SPI	2.7 to 3.6	1700	5	−40 to +125	Two ADCs, Programmable Data Rate, PGA, Phase Compensation	SSOP-20, QFN-20	ADM00398

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 (µA)	Max. INL	Temperature Range (°C)	Packages	Featured Demo Board
MCP3001	10	200	1	Single−ended	SPI	2.7 to 5.5	500	±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	±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	±1 LSB	−40 to +85	PDIP−14, SOIC−14, TSSOP−14	–
MCP3008	10	200	8	Single−ended	SPI	2.7 to 5.5	550	±1 LSB	−40 to +85	PDIP−16, SOIC−16	–
MCP3021	10	22	1	Single−ended	I2C™	2.7 to 5.5	250	±1 LSB	−40 to +125	SOT−23A−5	MCP3221DM-PCTL, MXSIGDM
MCP3221	12	22	1	Single−ended	I2C	2.7 to 5.5	250	±2 LSB	−40 to +125	SOT−23A−5	MCP3221DM-PCTL, MXSIGDM
MCP3201	12	100	1	Single−ended	SPI	2.7 to 5.5	400	±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	±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	±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	±1 LSB	−40 to +85	PDIP−16, SOIC−16	DV3204A, DVMCPA, MXSIGDM
MCP3301	13	100	1	Differential	SPI	2.7 to 5.5	450	±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	±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	±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_{REF}	Output Settling Time (µs)	DNL (LSB)	Typical Standby Current (µA)	Typical Operating Current (µA)	Temperature Range (°C)	Packages	Featured Demo Board
MCP47A1	6	1	I²C™	Ext	15	0.05	90	130	−40 to +125	SC-70	–
MCP47DA1	6	1	I²C	Ext	6	0.025	90	130	−40 to +125	SOT-23-6, SC-70	–
MCP4706	8	1	I²C	V_{DD}, Ext	6	0.05	0.09	210	−40 to +125	SOT-23-6	ADM00317
MCP4716	10	1	I²C	V_{DD}, Ext	6	0.188	0.09	210	−40 to +125	SOT-23-6	ADM00317
MCP4725	12	1	I²C	V_{DD}	6	0.75	1	210	−40 to +125	SOT−23−6	MCP4725DM-PTPLS, MCP4725EV
MCP4726	12	1	I²C	V_{DD}, Ext	6	0.75	0.09	210	−40 to +125	SOT-23-6	MCP4725DM-PTPLS, MCP4725EV, ADM00317
MCP4728	12	4	I²C	Int/V_{DD}	6	0.75	0.04	800	−40 to +125	MSOP−10	MCP4728EV
MCP4801	8	1, 2	SPI	Int	4.5	0.5	0.3	330	−40 to +125	PDIP-8, SOIC-8, MSOP-8, 2 × 3 DFN-8	–
MCP4802	8	1, 2	SPI	Int	4.5	0.5	0.3	415	−40 to +125	PDIP-8, SOIC-8, MSOP-8, 2 × 3 DFN-8	–
MCP4811	10	1, 2	SPI	Int	4.5	0.5	0.3	330	−40 to +125	PDIP-8, SOIC-8, MSOP-8, 2 × 3 DFN-8	–
MCP4812	10	1, 2	SPI	Int	4.5	0.5	0.3	415	−40 to +125	PDIP-8, SOIC-8, MSOP-8, 2 × 3 DFN-8	–
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	–
MCP4901	8	1, 2	SPI	Ext	4.5	0.5	1	175	−40 to +125	PDIP-8, SOIC-8, MSOP-8, PDIP-14, SOIC-14, TSSOP-14	–
MCP4902	8	1, 2	SPI	Ext	4.5	0.5	1	350	−40 to +125	PDIP-8, SOIC-8, MSOP-8, PDIP-14, SOIC-14, TSSOP-14	–

MIXED SIGNAL: D/A Converters (Continued)

Part #	Resolution (Bits)	DACs per Package	Interface	V$_{REF}$	Output Settling Time (μs)	DNL (LSB)	Typical Standby Current (μA)	Typical Operating Current (μA)	Temperature Range (°C)	Packages	Featured Demo Board
MCP4911	10	1, 2	SPI	Ext	4.5	0.5	1	175	−40 to +125	PDIP-8, SOIC-8, MSOP-8, PDIP-14, SOIC-14, TSSOP-14	–
MCP4912	10	1, 2	SPI	Ext	4.5	0.5	1	350	−40 to +125	PDIP-8, SOIC-8, MSOP-8, PDIP-14, SOIC-14, TSSOP-14	–
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/I²C	Ext	10	±0.8	0.1	350	−40 to +85	SOIC-8, MSOP-8	–
TC1321	10	1	SMbus/I²C	Ext	10	±2	0.1	350	−40 to +85	SOIC-8, MSOP-8	–

MIXED SIGNAL: Digital Potentiometers

Device	# of Taps	# per Package	Interface	V$_{DD}$ Operating Range[1]	Volatile/ Non-Volatile	Resistance (Ω)	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	I²C™	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	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

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

Device	# of Taps	# per Package	Interface	V_DD Operating Range[1]	Volatile/ Non-Volatile	Resistance (Ω)	INL (Max.)	DNL (Max.)	Temperature Range (°C)	Packages	Featured Demo Board
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 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 LSb	±0.5 LSb	−40 to +125	TSSOP-14	TSSOP20EV
MCP4361	257	4	SPI	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 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 LSb	±0.5 LSb	−40 to +125	TSSOP-14	TSSOP20EV
MCP4531	129	1	I²C™	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	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	I²C	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	−40 to +125	TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP46XXDM-PTPLS
MCP4632	129	2	I²C	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	I²C	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±0.5 LSb	±0.25 LSb	−40 to +125	TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP46XXDM-PTPLS
MCP4642	129	2	I²C	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	I²C	1.8V to 5.5V	Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	−40 to +125	TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP46XXDM-PTPLS
MCP4652	257	2	I²C	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	I²C	2.7V to 5.5V	Non-Volatile	5K, 10K, 50K, 100K	±1 LSb	±0.5 LSb	−40 to +125	TSSOP-14, QFN-16	MCP4XXXDM-DB, MCP46XXDM-PTPLS
MCP4662	257	2	I²C	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

THERMAL MANAGEMENT

THERMAL MANAGEMENT: Temperature Sensors							
Part #	Typical Accuracy (°C)	Maximum Accuracy @ 25 (°C)	Maximum Temperature Range (°C)	Vcc Range (V)	Maximum Supply Current (µA)	Resolution (bits)	Packages	Featured Demo Board
Serial Output Temperature Sensors								
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	–
MCP9808	±0.25	±0.5	−40 to +125	2.7 to 5.5	400	12	MSOP-8, DFN-8	–
MCP9843	±0.5	±3	−40 to +125	3.0 to 3.6	500	12	TSSOP-8, DFN-8, TDFN-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	–
Logic Output Temperature Sensors								
MCP9501/2/3/4	±1	±4	−40 to +125	2.7 to 5.5	40	–	SOT-23-5	–
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	–
Voltage Output Temperature Sensors								
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

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

Thermal Management

- Temperature Sensors
- Fan Speed Controllers/ Fan Fault Detectors

Motor Drivers

- Stepper and DC
- 3-Phase Brushless DC Fan Controller

Power Management

- LDO & Switching Regulators
- Charge Pump DC/DC Converters
- Power MOSFET Drivers
- PWM Controllers
- System Supervisors
- Voltage Detectors
- Voltage References
- Li-Ion/Li-Polymer Battery Chargers

Linear

- Op Amps
- Instrumentation Amplifiers
- Programmable Gain Amplifiers
- Comparators

Safety & Security

- Photoelectric Smoke Detectors
- Ionization Smoke Detectors
- Ionization Smoke Detector Front Ends
- Piezoelectric Horn Drivers

Mixed-Signal

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

Interface

- CAN Peripherals
- Infrared Peripherals
- LIN Transceivers
- Serial Peripherals
- Ethernet Controllers
- USB Peripheral

Analog and Interface Attributes

Robustness

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

Low Power/Low Voltage

- Op Amp family with the lowest power for a given gain bandwidth
- High efficiency, low start-up (0.65V) boost regulators
- 450 nA/1.4V/9 kHz bandwidth op amps
- 1 µA comparators
- 1.6 µA 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
- Highly integrated dual H-bridge drivers for bi-polar stepper motors or brushed DC motors

Space Savings

- Resets and LDOs in SC70 package, A/D and D/A converters in SOT-23 package
- uDFN for height limited applications

Accuracy

- Low input offset voltages
- High gains
- ±0.5°C temperature sensors industry leading energy measurement AFEs with 94.5 dB SINAD

Innovation

- First stand-alone sensorless, full-wave sinusoidal 3-Phase BLDC Motor Drivers
- Industry's first op amp featuring on-demand calibration via mCal technology
- Digital potentiometers feature WiperLock™ technology to secure EEPROM

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