



# MICROCHIP

## Analog-to-Digital Converter Design Guide

High-Performance, Stand-Alone A/D Converters for a Variety of Embedded Systems Applications



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

### Dual-Slope Converters

TC500A  
TC7109A  
TC510  
TC514  
TC530  
TC534

### Successive Approximation Register (SAR) Converters

MCP300X  
MCP3021  
MCP320X  
MCP3221  
MCP330X

### BCD Output Converters

TC835  
TC7135  
TC14433A

### Binary Output Converter

TC850

### Display Analog-to-Digital Converters

TC7106A  
TC7116A  
TC7117A  
TC7126A  
TC7136  
TC820

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

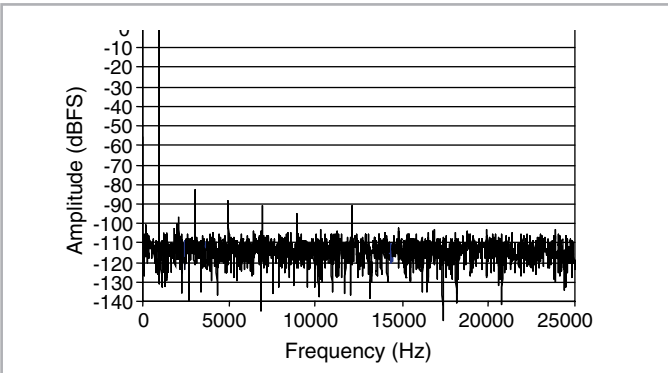
## SELECTING THE RIGHT ADC

Selecting the most suitable A/D converter (ADC) for your application is based on more than just the precision or bits. Different architectures are available, each exhibiting advantages and disadvantages in various data-acquisition systems. The required accuracy or precision of the system puts you in a category based on the number of bits required. It is important to always design your system to allow for more bits than initially required: if an application calls for 10 bits of accuracy, choose a 12-bit converter. The achievable accuracy of a converter will always be less than the total number of bits available.

Depending on the system requirements, your accuracy might be better expressed in micro-volts, decibels or LSBs (least significant bits). A FFT showing the frequency spectrum of a device can be useful in determining the noise performance of a given device. All Microchip stand-alone ADCs show typical performance data for AC specifications, such as THD, SINAD and SNR. The following table shows performance, in dB and V/V, for 8- through 24-bit converters.

Typically, an amplifier is required if the magnitude of the input signal is significantly lower than the full-scale input range of the ADC. However, by selecting an ADC with a higher resolution, the need for an amplifier can be eliminated.

Performance Table — 8- Through 24-bit Converters

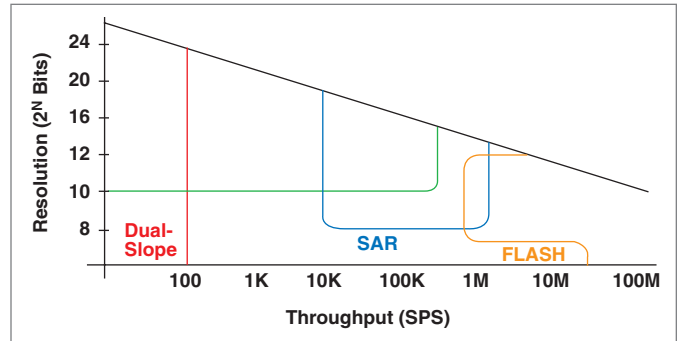


# of Bits	$2^n$	LSB (FS = 1V)	Resolution (%)	Resolution (ppm)	Resolution (dB)
8	256	3.91 mV	0.391	3910	48.16
10	1024	977 $\mu$ V	0.0977	977	60.21
12	4096	244 $\mu$ V	0.0244	244	72.25
14	16384	61 $\mu$ V	0.0061	61	84.29
16	65536	15.3 $\mu$ V	0.00153	15.3	96.33
18	262144	3.81 $\mu$ V	0.000381	3.81	108.37
20	1048576	954 nV	9.54E-05	0.954	120.41
22	4194304	238 nV	2.38E-05	0.238	132.45
24	16777216	59.5 nV	5.95E-06	0.0595	144.49

Successive Approximation Register (SAR) converters typically range from 8 to 16 bits. Delta-sigma converters ( $\Delta\Sigma$ ) can achieve an accuracy of up to 24 bits and will be covered in more detail in a subsequent design guide.

The figure below shows the different architectures vs. bits and bandwidth.

Architecture vs. Bits and Bandwidth



### Two Application Examples:

#### Seismic Recording

16 different devices are connected to a central processing unit to monitor vibrations. Each device measures the signal at an extremely fast rate, less than 100  $\mu$ S. High accuracy is not required due to the large signal size, but speed is of the utmost importance. A high-speed SAR converter would be the best selection for this application.

#### Voice-Band Recording

The human ear can detect signals from roughly 20 Hz up to 20 kHz. If the application is a telephone intercom system where high-fidelity audio is not a concern, 60-70 dB of dynamic range is sufficient. Based on these bandwidth and dynamic range requirements, either a medium speed (50-200 ksp/s) SAR or delta-sigma converter would work in this application.

## ADC BY ARCHITECTURE – SAR CONVERTERS

SAR (Successive Approximation Register) applies to the converter that uses approximation to convert the analog input signal into a digital output code. SAR converters typically lie in the 8- to 16-bit range and can have sample speeds up to 1 MSPS.

One major benefit of a SAR converter is its ability to be connected to multiplexed inputs at a high data acquisition rate. The input is sampled and held on an internal capacitor, and this charge is converted to a digital output code using the successive approximation routine. Since this charge is held throughout the conversion time, only the initial sample and hold period or acquisition time is of concern to a fast-changing input. The conversion time is the same for all conversions. This makes the SAR converter ideal for many real-time applications, including motor control, touch-screen sensing, medical and other data acquisition systems.

When designing a system with a SAR converter, the following specifications and terms should be understood:

**Acquisition Time** – The time required for the sampling mechanism to capture the voltage after the sample command is given for the hold capacitor to charge.

**Conversion Time** – The time required for the A/D converter to complete a single conversion once the signal has been sampled.

**Throughput Rate or Samples Per Second (SPS)** – The time required for the converter to sample, acquire, digitize, prepare, and output a conversion.

**Integral Non-Linearity (INL)** – Specification most relevant to the overall accuracy of the converter. INL is the maximum deviation of a transition point of a conversion to the corresponding transition point of an ideal conversion. INL represents cumulative DNL errors.

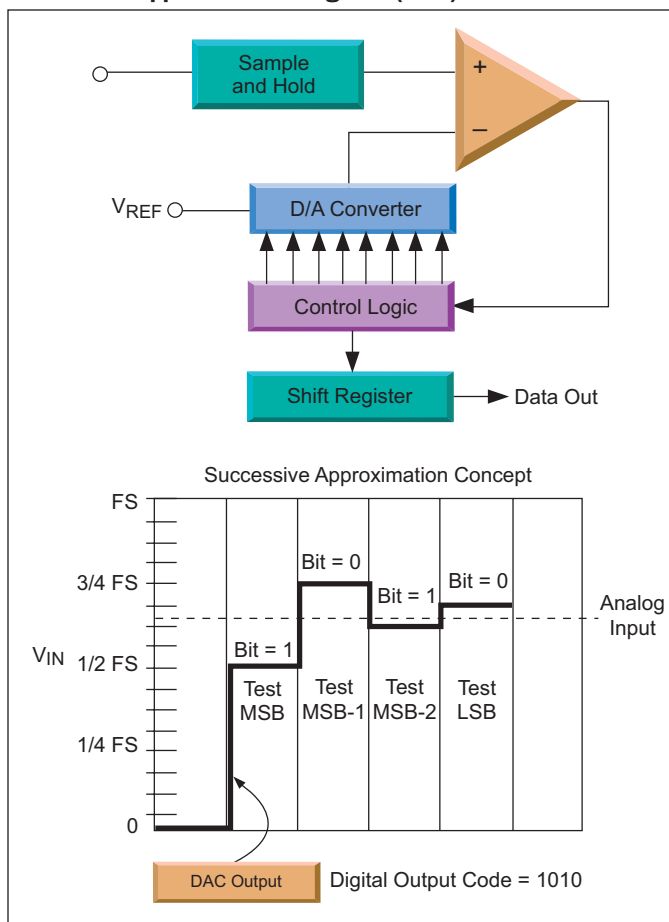
**Differential Non-Linearity (DNL)** – The error in width between output conversion codes. The maximum deviation in code width from the ideal 1 LSB code width ( $FSR/2^n$ ). DNL errors of less than  $-1$  correspond to a missing code.

**Missing Code** – The situation where an A/D converter will never output a specified code regardless of the input voltage.

**Monotonic** – Implies that an increase (or decrease) in the analog input voltage will always produce no change or an increase (or decrease) in output code. Monotonicity does **not** imply that there are **no** missing codes.

**Bipolar vs. Unipolar Output** – Differential converters give a bipolar output corresponding to positive and negative numbers. The binary output scheme is usually two's complement. A unipolar output corresponding to a positive output, from 0 to  $V_{REF}$ .

### Successive Approximation Register (SAR) ADC



# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

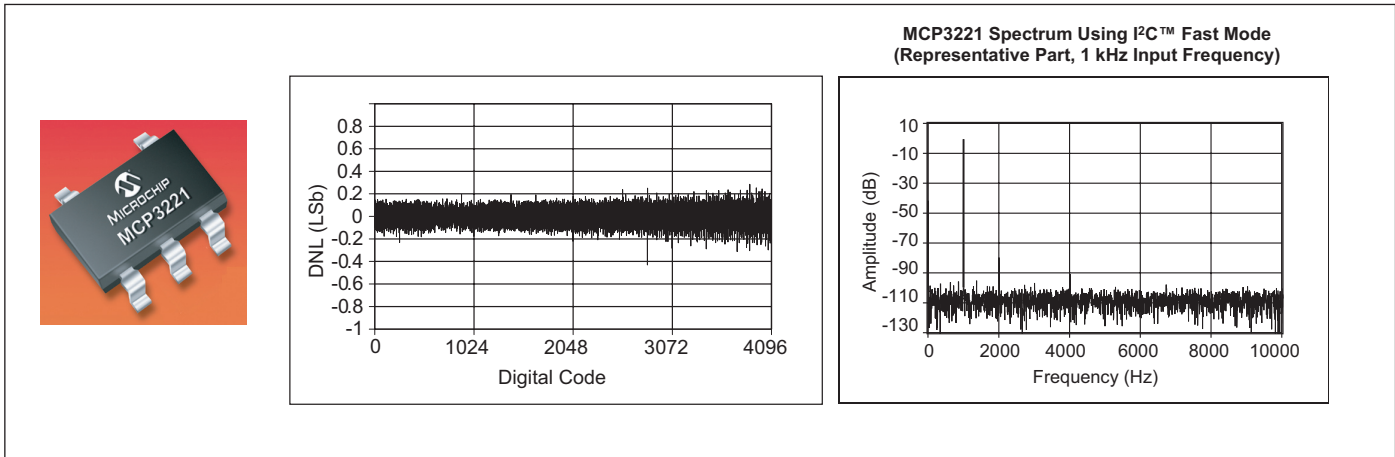
## SAR CONVERTERS – INDUSTRY’S LOWEST-POWER ADCs IN SOT-23A PACKAGES

The **MCP3021** and **MCP3221** are low-power, tiny 10- and 12-bit SAR ADCs that are ideal for battery powered or portable data acquisition systems. Based on advanced CMOS architecture, these devices draw only 180  $\mu\text{A}$  at 400 kHz  $\text{I}^2\text{C}^{\text{TM}}$  clock. With a 33 kHz  $\text{I}^2\text{C}$  clock, the current drops to less than 30  $\mu\text{A}$ . With only 1  $\mu\text{A}$  standby current, the MCP3221 is currently the world’s lowest-power, 12-bit ADC in a small SOT-23A package. Communication to either device is performed using a 2-wire  $\text{I}^2\text{C}$  compatible interface.

An on-chip conversion clock enables independent timing between the conversion clock, and the serial communication data rate.

The devices are also addressable, allowing up to eight devices on a single 2-wire bus. The MCP3021 and MCP3221 run on a single supply voltage that operates over a broad voltage range of 2.7V to 5.5V. Accuracy is superb, providing less than  $\pm 1$  LSB of differential non-linearity (DNL) and less than  $\pm 2$  LSB of integral non-linearity (INL).

### MCP3221 Functional Block Diagram and DNL vs. Digital Code Graph



### MCP3021 and MCP3221 Key Features:

- 10-bit resolution (**MCP3021**)
- 12-bit resolution (**MCP3221**)
- 22 ksp/s in  $\text{I}^2\text{C}^{\text{TM}}$  Fast Mode
- $\pm 1$  LSB DNL,  $\pm 1$  LSB INL max. (**MCP3021**)
- $\pm 1$  LSB DNL,  $\pm 2$  LSB INL max. (**MCP3221**)
- On-chip sample and hold
- $\text{I}^2\text{C}$  compatible serial interface with up to 8 devices on a single 2-wire bus:
  - 100 kHz  $\text{I}^2\text{C}$  Standard Mode
  - 400 kHz  $\text{I}^2\text{C}$  Fast Mode
- Single-supply specified operation: 2.7V to 5.5V
- Low-power CMOS technology:
  - 5 nA standby current
  - 250  $\mu\text{A}$  active current at 5V, 100 ksp/s
- Temperature range:
  - Industrial:  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  (**MCP3221**)
  - Extended:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$

### MCP3021 and MCP3221 Applications:

- Data Logging
- Multi-zone Monitoring
- Hand-held Portable Applications
- Battery-powered Test Equipment
- Remote or Isolated Data Acquisition
- Voice-band AC Applications up to 8 kHz

### ADC Product Specifications

Device	Resolution (bits)	Maximum Sampling Rate (samples/sec)	# of Input Channels	Input Type	Interface	Input Voltage Range (V)	Active Current Max. ( $\mu\text{A}$ )	Max. INL	Temperature Range ( $^{\circ}\text{C}$ )	Packages
MCP3021	10	22	1	Single-ended	$\text{I}^2\text{C}^{\text{TM}}$	2.7 to 5.5	250	+1 LSB	-40 to +85	5 SOT-23A
MCP3221	12	22	1	Single-ended	$\text{I}^2\text{C}$	2.7 to 5.5	250	$\pm 2$ LSB	-40 to +125	5 SOT-23A

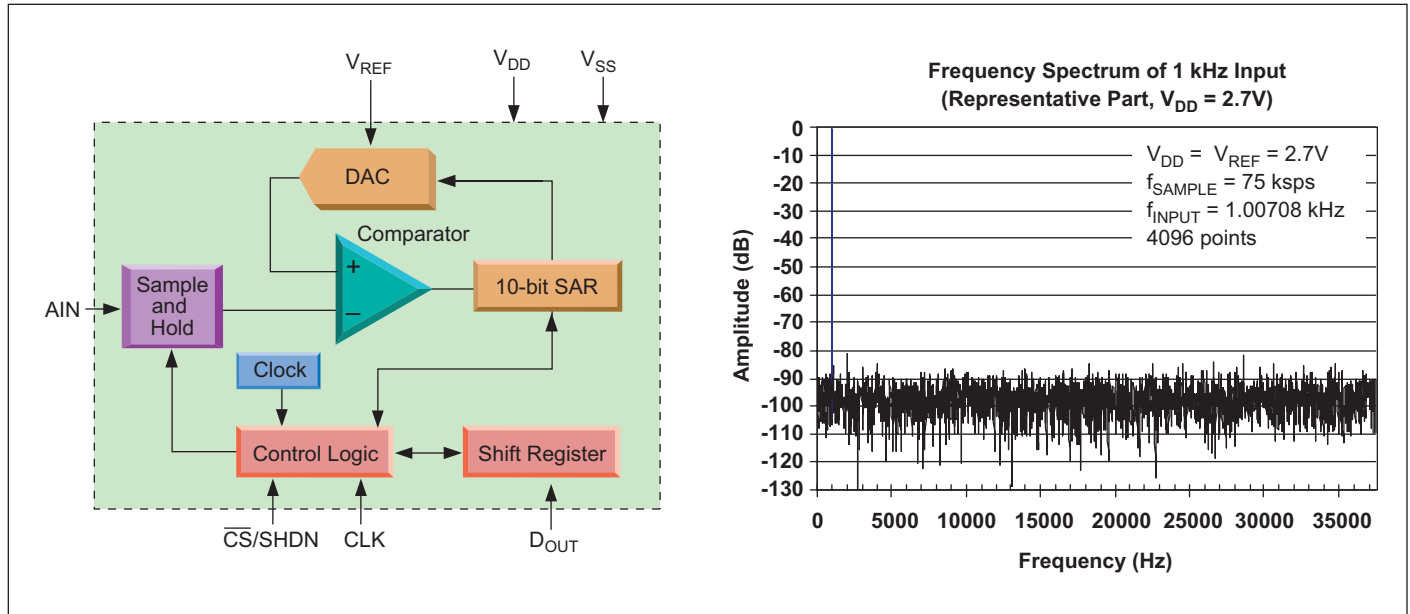
# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

## SAR CONVERTERS – LOW-POWER 100 KSPS AND 250 KSPS, 10 AND 12-BIT ADCs

The **MCP3001** and **MCP3201** are 10- and 12-bit SAR ADCs that offer standby currents of less than 1  $\mu\text{A}$ , and active currents of 300  $\mu\text{A}$  at 100 ksp/s. Both devices offer on-board sample and hold circuitry.

Each device has one pseudo-differential input with exceptional linearity specifications of  $\pm 1$  LSB DNL and  $\pm 1$  LSB INL over temperature.

Communication with the device is accomplished by using a simple serial interface compatible with the SPI™ protocol. Both devices operate over a broad voltage range of 2.7V to 5.5V.



### MCP3001 and MCP3201 Key Features:

- 10-bit resolution (**MCP3001**)
- 12-bit resolution (**MCP3201**)
- $\pm 1$  LSB DNL,  $\pm 1$  LSB INL max. (**MCP3001**)
- $\pm 1$  LSB DNL,  $\pm 1$  LSB INL max. (**MCP3201**)
- On-chip sample and hold
- SPI™ serial interface (modes 0,0 and 1,1)
- Single-supply specified operation: 2.7V to 5.5V
- 10-bit, 75 ksp/s max sampling rate at  $V_{DD} = 2.7V$  (**MCP3001**)
- 10-bit, 200 ksp/s max sampling rate at  $V_{DD} = 5V$  (**MCP3001**)
- 12-bit, 50 ksp/s max sampling rate at  $V_{DD} = 2.7V$  (**MCP3201**)
- 12-bit, 100 ksp/s max sampling rate  $V_{DD} = 5V$  (**MCP3201**)
- Low-power CMOS technology:
  - 500 nA standby current
  - 300  $\mu\text{A}$  active current at 5V, 100 ksp/s
- Temperature range:
  - Industrial:  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$

### MCP3001 and MCP3201 Applications:

- Sensor Interface
- Process Control
- Data Acquisition
- Battery-Operated Systems

### ADC Product Specifications

Device	Resolution (bits)	Maximum Sampling Rate (samples/sec)	# of Input Channels	Input Type	Interface	Input Voltage Range (V)	Active Current Max. ( $\mu\text{A}$ )	Max. INL	Temp. Range ( $^{\circ}\text{C}$ )	Packages
MCP3001	10	200	1	Pseudo-Diff.	SPI™	2.7 to 5.5	400	+1 LSB	-40 to +85	8 PDIP, MSOP, SOIC, TSSOP
MCP3201	12	100	1	Single-ended	SPI	2.7 to 5.5	400	$\pm 1$ LSB	-40 to +85	8 PDIP, SOIC, TSSOP

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

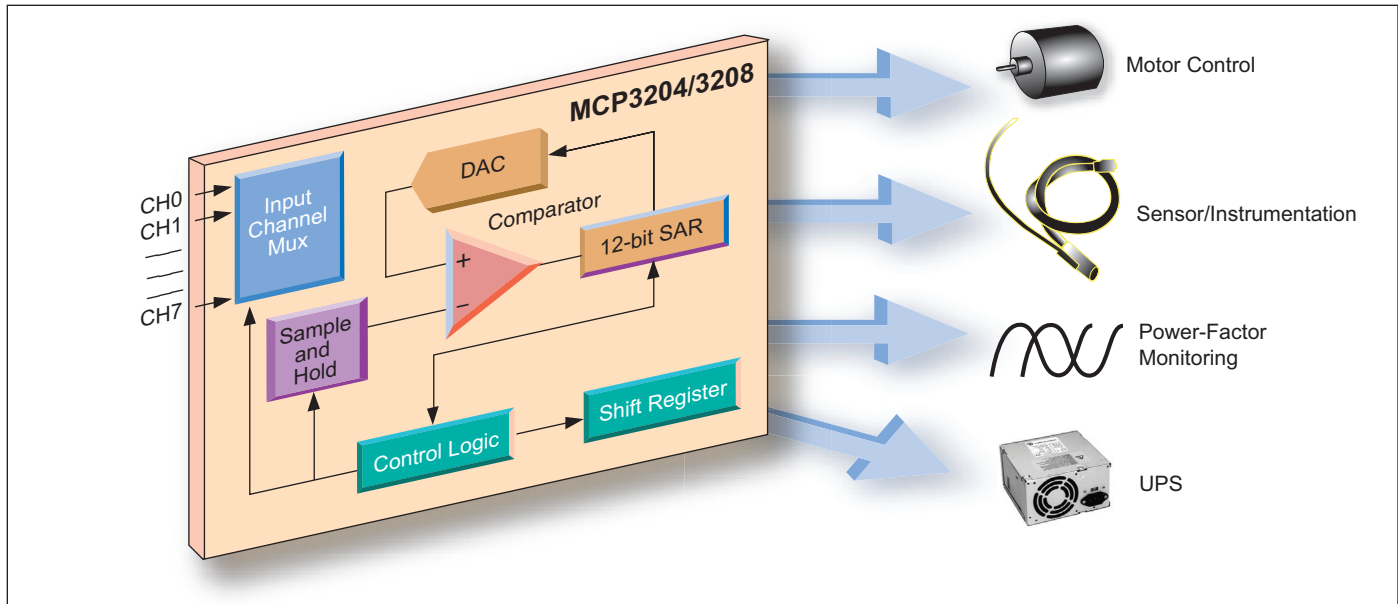
## SAR CONVERTERS – LOW-POWER, MULTI-CHANNEL ADCs – IDEAL FOR PORTABLES

With 2, 4, and 8 channels that are configurable as either pseudo-differential or single-ended, the **MCP3X02/4/8** converters are versatile and powerful ADCs. Industry-leading low-power technology offers low current consumption for these multi-channel devices: <1  $\mu\text{A}$  standby and 250  $\mu\text{A}$  at 100 ksp/s.

With exceptional INL and DNL performance ( $\pm 1$  LSB) across broad voltage and temperature ranges (2.7V to 5.5V and -40 to +85°C), multi-channel applications requiring superb linearity are ideal for these devices.

These dual-channel devices are programmable to either 2 pseudo-differential pairs or 4 single-ended inputs.

The quad-channel devices are programmable to provide 4 pseudo-differential pairs or 8 single-ended inputs. Communication is accomplished using an industry standard serial SPI™ protocol.



### MCP3X02/4/8 ADC Key Features:

- 10-bit and 12-bit resolution
- $\pm 1$  LSB DNL,  $\pm 1$  LSB INL max.
- $\pm 1$  LSB DNL,  $\pm 1$  LSB INL max.
- On-chip sample and hold
- SPI™ serial interface (modes 0,0 and 1,1)
- Single-supply specified operation: 2.7V to 5.5V
- Low-power CMOS technology:
  - 500 nA standby current
  - 300  $\mu\text{A}$  active current at 5V, 100 ksp/s

### MCP3X02/4/8 ADC Applications:

- Multi-channel Data Acquisition Portables
- Sensor Interface
- Process Control
- Data Acquisition
- Battery Operated Systems

### ADC Product Specifications

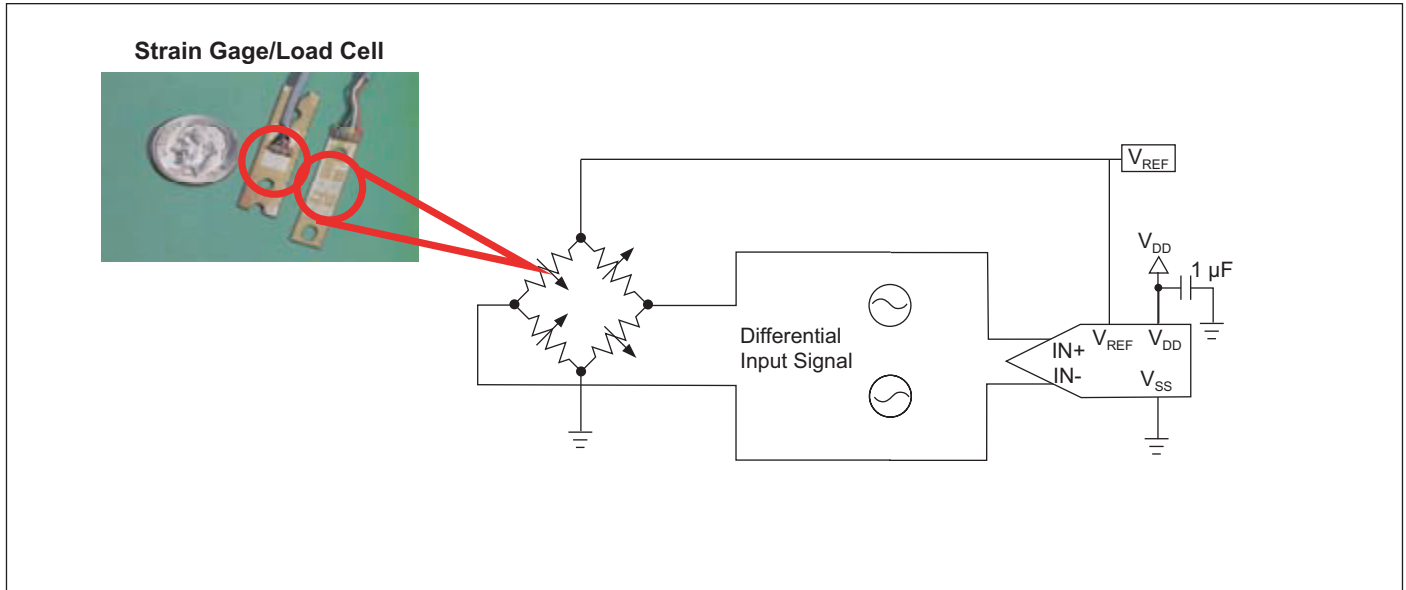
Device	Resolution (bits)	Maximum Sampling Rate (samples/sec)	# of Input Channels	Input Type	Interface	Input Voltage Range (V)	Active Current Max. ( $\mu\text{A}$ )	Max. INL	Temp. Range (C°)	Packages
MCP3002	10	200	2	Single-ended or Pseudo-Differential	I <sup>2</sup> C™	2.7 to 5.5	250	+1 LSB	-40 to +85	8 PDIP, MSOP, SOIC, TSSOP
MCP3004	12	200	4	Single-ended or Pseudo-Differential	SPI™	2.7 to 5.5	400	+1 LSB	-40 to +85	14 PDIP, SOIC, TSSOP
MCP3008	12	200	4	Single-ended or Pseudo-Differential	SPI	2.7 to 5.5	400	+1 LSB	-40 to +85	14 PDIP, SOIC, TSSOP
MCP3202	12	100	2	Single-ended	SPI	2.7 to 5.5	550	$\pm 1$ LSB	-40 to +85	8 PDIP, SOIC, TSSOP
MCP3204	12	100	4	Single-ended	SPI	2.7 to 5.5	400	$\pm 1$ LSB	-40 to +85	14 PDIP, SOIC, TSSOP
MCP3208	12	100	8	Single-ended	SPI	2.7 to 5.5	400	$\pm 1$ LSB	-40 to +85	16 PDIP, SOIC

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

## SAR CONVERTERS – 13-BIT DIFFERENTIAL INPUT ADC – IDEAL FOR INTERFACING TO SENSORS

The **MCP330X** family of data converters offers true differential input with a bipolar two's complement output. Strain gauges, wheatstone bridges, and AC signals are all ideally interfaced to the differential input ADCs. These ADCs provide single differential input, two differential input or four differential inputs.

The low power consumption of these devices at up to 100 ksp/s, in addition to their high resolution, makes these sensors ideal for portable AC measurement applications.



### MCP330X ADC Key Features:

- Full Differential Inputs with a 13-bit Resolution
- $\pm 1$  LSB DNL max.
- $\pm 1$  LSB INL max.
- $\pm 2$  LSB INL max.
- Number of Single-ended Inputs:
  - 1 (MCP3301)
  - 4 (MCP3302)
  - 8 (MCP3304)
- On-chip sample and hold
- SPI™ serial interface (modes 0,0 and 1,1)
- Single-supply specified operation: 2.7V to 5.5V
- Low-power CMOS technology:
  - 500 nA standby current
  - 300  $\mu$ A active current at 5V, 100 ksp/s
- 100 ksp/s sampling rate with 5V supply current
- Temperature Range: -40°C to +85°C

### MCP330X ADC Applications:

- Remote Sensors
- Battery Operated Systems
- Transducer Interface

### ADC Product Specifications

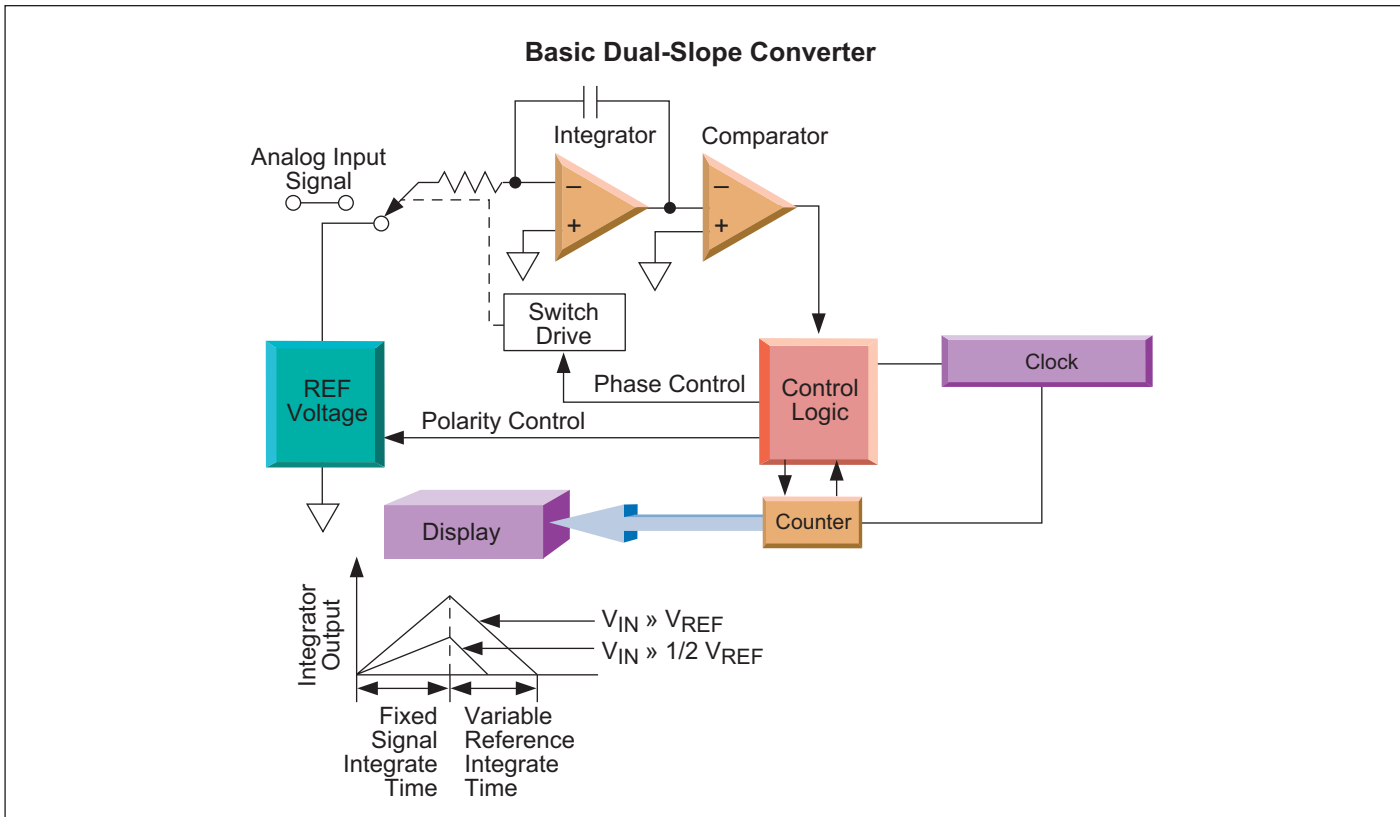
Device	Resolution (bits)	Maximum Sampling Rate (samples/sec)	# of Input Channels	Input Type	Interface	Input Voltage Range (V)	Active Current Max. ( $\mu$ A)	Max. INL	Temp. Range (C°)	Packages
MCP3301	13	100	1	Differential	SPI™	2.7 to 5.5	450	+1 LSB	-40 to +85	8 PDIP, MSOP, SOIC
MCP3302	13	100	2	Differential	SPI	2.7 to 5.5	450	$\pm 1$ LSB	-40 to +85	14 PDIP, SOIC, TSSOP
MCP3304	13	100	4	Differential	SPI	2.7 to 5.5	450	$\pm 1$ LSB	-40 to +85	16 PDIP, SOIC

## ADC BY ARCHITECTURE – DUAL-SLOPE /INTEGRATING

A dual-slope converter operates by charging a capacitor from the input voltage during a fixed time, and then discharging it to zero. Actual data conversion is accomplished in two phases: input signal integration and reference voltage de-integration.

The integrator output is initialized to 0V prior to the start of integration. During integration, analog switch  $S_1$  connects  $V_{IN}$  to the integrator input, where it is maintained for a fixed time period ( $t_{INT}$ ).

The application of  $V_{IN}$  causes the integrator output to depart 0V at a rate determined by the magnitude of  $V_{IN}$ , and a direction determined by the polarity of  $V_{IN}$ . The de-integration phase is initiated immediately at the expiration of  $t_{INT}$ .



During de-integration,  $S_1$  connects a reference voltage (having a polarity opposite that of  $V_{IN}$ ) to the integrator input. At the same time, an external precision timer is started. The de-integration phase is maintained until the comparator output changes states, indicating the integrator has returned to its starting point of 0V. When this occurs, the precision timer is stopped. The de-integration time period ( $t_{DEINT}$ ), as measured by the precision timer, is directly proportional to the magnitude of the applied input voltage.

A simple mathematical equation relates the input signal, reference voltage and integration time:

$$(1/R_{INT}C_{INT}) * \text{integral} [ V_{IN} (t) dt ] \text{ from } t = 0 \text{ to } t = t_{INT}$$

For a constant  $V_{IN}$  :

$$V_{IN} = V_{REF} * (t_{DEINT} / t_{INT})$$

The dual-slope converter accuracy is unrelated to the integrating resistor and capacitor values as long as they are stable during a measurement cycle.

An inherent benefit is noise immunity. Input noise spikes are integrated (averaged to zero) during the integration periods. Integrating ADCs are immune to the large conversion errors that plague successive approximation converters in high-noise environments.

Integrating converters provide inherent noise rejection, with at least a 20 dB/decade attenuation rate. Interference signals with frequencies at integral multiples of the integration period are, theoretically, completely removed since the average value of a sine wave of frequency ( $1/t$ ) averaged over a period ( $t$ ) is zero.



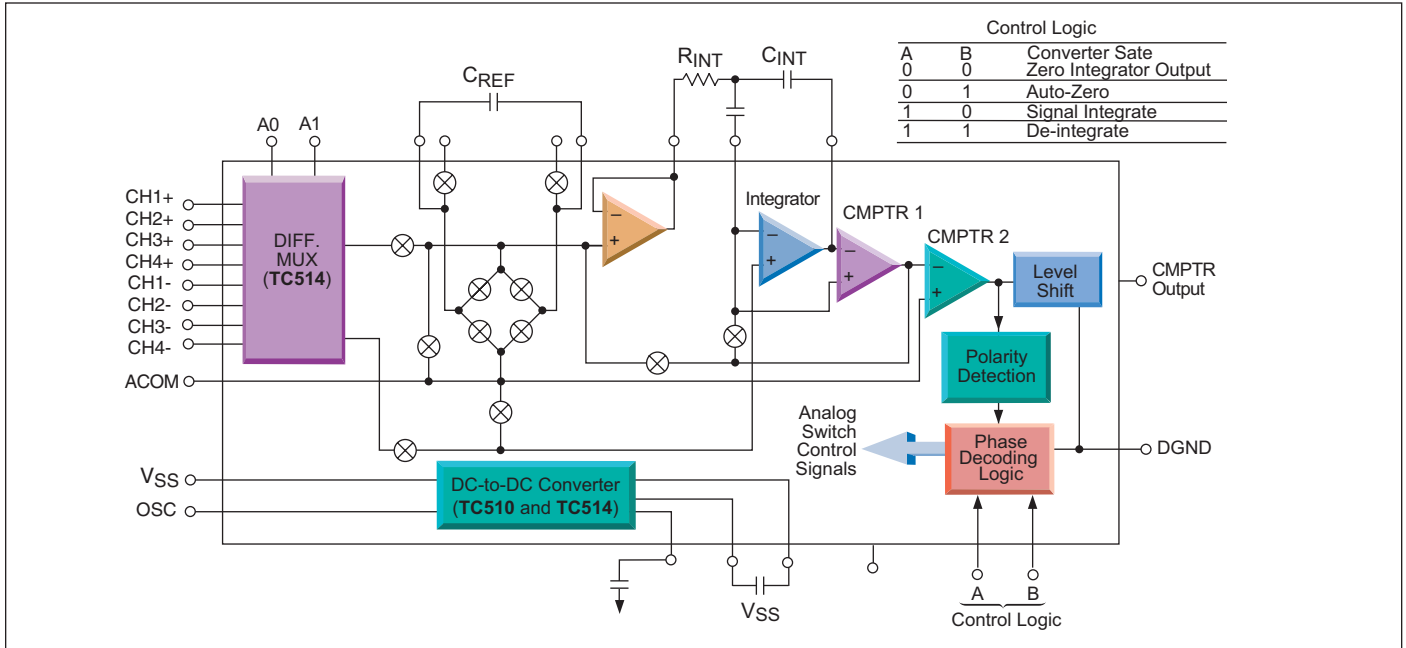
# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

## DUAL-SLOPE – 17-BIT PLUS SIGN SERIAL ADC

### Accepts Bipolar Inputs of Up to $\pm 4.2V$

The **TC5XX** family are precision analog front ends that implement dual-slope ADCs with a maximum resolution of 17 bits plus sign. The TC500 is the base device that requires both positive and negative power supplies, while the TC510 adds on-board power supply conversion for single-supply operation.

The conversion speed of the converter is configurable, with the user being able to trade conversion speed for resolution. With single and multi-channel devices, the TC5XX is a powerful family of dual-slope converters. A 50/60 Hz noise rejection, low-power operation, and minimum I/O connections, make these devices suitable for a variety of data acquisition systems.



### TC5XX Key Features:

- Precision (up to 17 bits) A/D Converter “Front End”
- 3-Pin Control Interface to Microprocessor
- Flexible: User Can Trade-off Conversion Speed for Resolution
- Single-Supply Operation (TC510/TC514)
- 4 Input, Differential Analog MUX (TC514)
- Automatic Input Voltage Polarity Detection
- Wide Analog Input Range:  $\pm 4.2V$  (TC500A/TC510)

### TC5XX Key Features (Cont.)

- Directly Accepts Bipolar and Differential Input Signals
- Low Power Dissipation:  
10 mW - (TC500/TC500A), 18 mW - (TC510/TC514)

### TC5XX Applications:

- Precision Analog Signal Processor
- Precision Sensor Interface
- High-Accuracy DC Measurements

### ADC Product Specifications

Part	Supply Voltage (V)	Input Voltage Range (V)	Resolution Input (V)	Sampling Rate (Conv/s)	Input Channels	Data Interface	Temp. Range (°C)	Features	Packages
TC500A	$\pm 4.5$ to $\pm 7.5$	$V_{SS} + 1.5V$ to $V_{DD} - 1.5V$	Up to 17 bits	4 to 10	1	3-Wire	0 to +70	Differential input range, Programmable resolution/conversion time	16 PDIP, SOIC, CerDIP
TC510	+4.5 to +5.5	$V_{SS} + 1.5V$ to $V_{DD} - 1.5V$	Up to 17 bits	4 to 10	1	3-Wire	0 to +70	Differential input range, Programmable resolution/conversion time, Charge pump (-V) output pin	24 PDIP, SOIC
TC514	+4.5 to +5.5	$V_{SS} + 1.5V$ to $V_{DD} - 1.5V$	Up to 17 bits	4 to 10	4	3-Wire	0 to +70	Differential input range, Programmable resolution/conversion time, Charge pump (-V) output pin	28 PDIP, 28 SOIC
TC520A	+4.5 to +5.5	—	—	—	—	Serial Port	0 to +70	Optional serial interface adapter for TC500/A/510/514	14 PDIP, 16 SOIC
TC530	+4.5 to +5.5	$V_{SS} + 1.5V$ to $V_{DD} - 1.5V$	Up to 17 bits	3 to 10	1	Serial Port	0 to +70	Differential input range, Programmable resolution/conversion time, Charge pump (-V) output pin	28 PDIP, 28 SOIC
TC534	+4.5 to +5.5	$V_{SS} + 1.5V$ to $V_{DD} - 1.5V$	Up to 17 bits	3 to 10	4	Serial Port	0 to +70	Differential input range, Programmable resolution/conversion time, Charge pump (-V) output pin	40 PDIP, 44 PQFP

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

## ADC BY ARCHITECTURE – 3½ and 4½-DIGIT ADCs WITH SEGMENT DRIVE

With a complete data acquisition system on-chip, these devices directly drive multiplexed, liquid crystal displays (LCDs). The **TC7107A** drives common anode light emitting diode (LED) displays directly with 8 mA per segment. Seven segment decoders, digit and polarity drivers, voltage references, and clock circuits are all integrated on the chips.

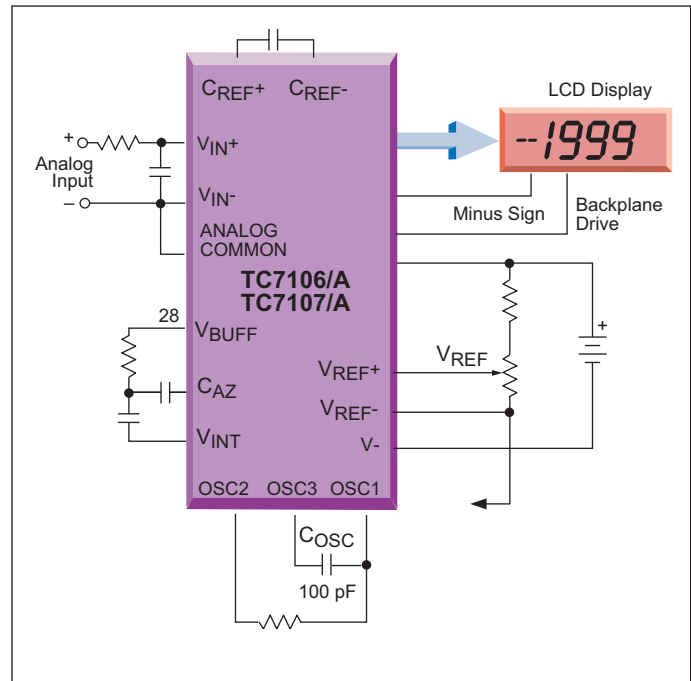
A low-cost, high-resolution indicating meter requires only a display and a handful of resistors and capacitors. 3½ digit and 4½ digit options, along with extended features and power options, make the **TC711X**, **TC712X**, and **TC713X** devices ideal for multimeters and digital measurement devices.

### TC71XX Key Features:

- Internal References with Low Temperature Drift
  - TC7126: 80 ppm/°C Typical
  - TC7117: 20 ppm/°C Typical
- Directly Drives LCD or LED display
- Convenient 9V Battery Operation
  - TC7116/TC7136/TC7126
- Differential Input Operation
- Industrial Temperature Range: -40°C to 85°C

### TC71XX Applications:

- Full-featured Multimeters
- Bridge Readouts
- Digital Measurement Devices
- Portable Instrumentation



### ADC Product Specifications

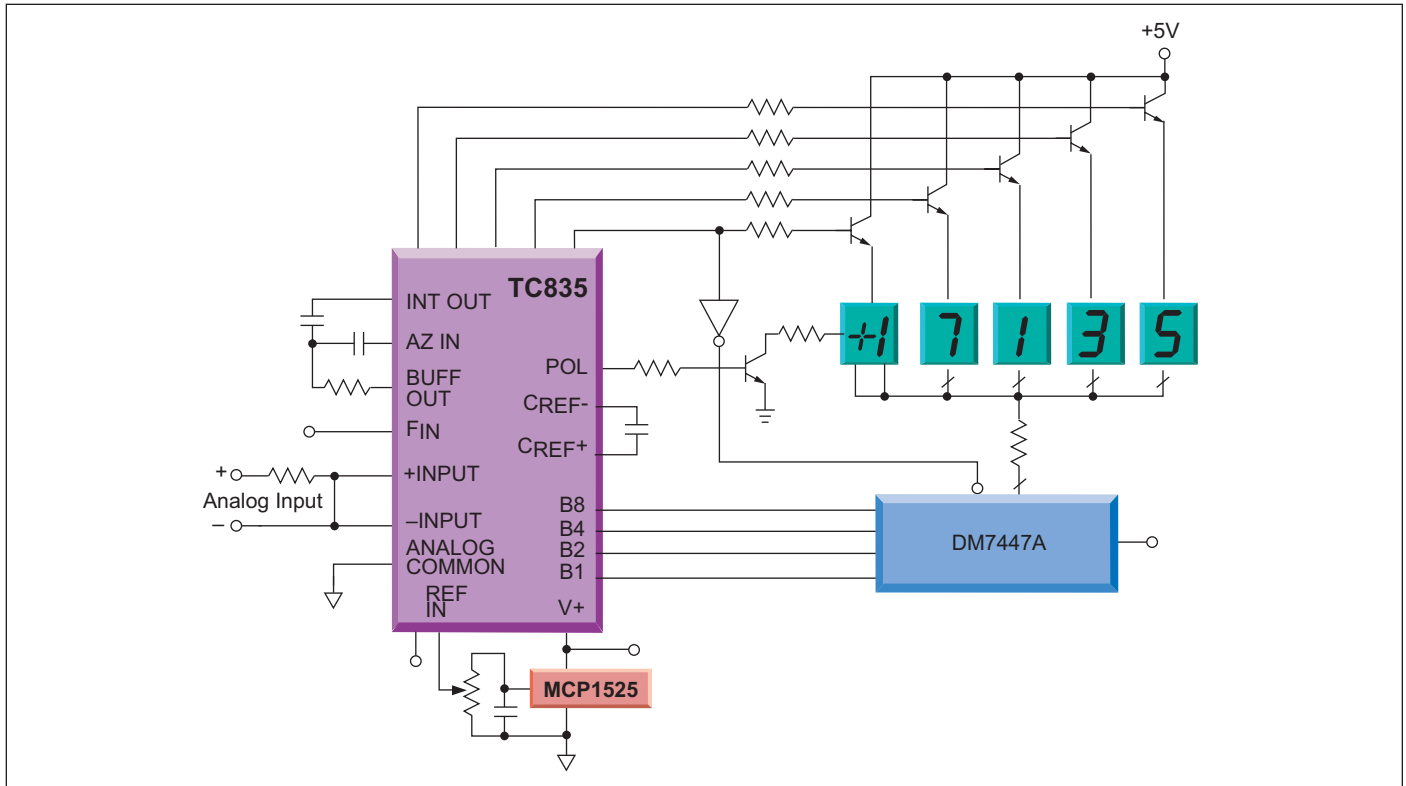
Part	Display Type	Supply Voltage (V)	Resolution (Digits)	Resolution (Counts)	Power (mV)	Temp. Range (°C)	Features	Packages
TC7106A	LCD	9	3.5 Digit High Power LCD	±2,000	10	-25 to +85	For DMM, DPM, Data logger applications	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC7107A	LED	±5	3.5	±2,000	10	-25 to +85	For DMM, DPM, Data logger applications	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC7116A	LCD	9	3.5 with Hold	±2,000	10	-25 to +85	Hold function	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC7117A	LED	±5	3.5	±2,000	10	-25 to +85	Hold function	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC7126A	LCD	9	3.5	±2,000	0.5	-25 to +85	Low Power TC7106	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC7129	LCD	9	4.5 with LCD	±20,000	0.5	0 to +70	Lowest noise ±3 mV sensitivity	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC7136A	LCD	9	3.5 Digit Low Power	±2,000	0.5	0 to +70	Low-power Noise TC7106	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP
TC820	LCD	9	3.75	±4,000	10	0 to +70	DMM plus frequency counter and logic probe	40 PDIP, 44 PLCC, 44 PQFP, 40 CerDIP

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

## ADC BY ARCHITECTURE – 4½-DIGIT ADC WITH BCD OUTPUT

These 4-1/2-digit A/D converters offer 50 ppm (1 part in 20,000) resolution, with a maximum nonlinearity error of 1 count. An auto-zero cycle reduces zero error to below 10 µV and zero drift to 0.5 µV/°C. Source impedance errors are minimized by a 10 pA maximum input current. Rollover error is limited to ±1 count.

Microprocessor-based measurement systems are supported by BUSY, STROBE, and RUN/HOLD control signals. Remote data acquisition systems with data transfer via UARTs are also possible. The additional control pins and multiplexed BCD outputs are ideal for display or microprocessor-based measurement systems.



### Key Features:

- Industry standard pin-out, compatible with ICL7135, MAX7135, SI7135
- Low Rollover Error: ±1 Count Max
- Nonlinearity Error: ±1 Count Max
- Reading for OV Input
- True Polarity Indication at Zero for Null Detection
- Multiplexed BCD Data Output
- TTL-Compatible Outputs
- Differential Input
- Control Signals Permit Interface to UARTs and Microprocessors

### Key Features (Cont.)

- Blinking Display Visually Indicates Overrange Condition
- Low Input Current: 1 pA
- Low Zero Reading Drift: 2 µV/°C
- Auto-Ranging Supported with Overrange and Underrange

### Applications:

- Personal Computer Data Acquisition
- Scales, Panel Meters, Process Controls
- HP-IL Bus Instrumentation

### ADC Product Specifications

Part	Description	Supply Voltage (V)	Input Voltage Range (V)	Resolution (Digits)	Resolution (Counts)	Max Power (mW)	Data Interface	Temp. Range (°C)	Features	Packages
TC14433A	BCD A/D	±4.5 to ±5	±199.9 mV to 1.999V	3.5	±2,000	20	MUXed BCD	-40 to +85	For DMM, Data loggers	24 PDIP, 28 PLCC, 24 CerDIP
TC7135	BCD A/D	±5	V <sub>SS</sub> + 1.0V to V <sub>DD</sub> - 1.0V	4.5	±20,000	30	MUXed BCD	0 to +70	For DMM, Data loggers	28 PLCC, 28 PDIP, 64 PQFP
TC835	BCD A/D	±5	V <sub>SS</sub> + 1.0V to V <sub>DD</sub> - 0.5V	4.5	±20,000	30	MUXed BCD	0 to +70	Upgrade to TC7135	64 PQFP, 44 PQFP, 28 PDIP

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

## ADC BY ARCHITECTURE – 15-BIT BINARY OUTPUT ADC INCLUDES AUTO-ZEROED AMPLIFIERS

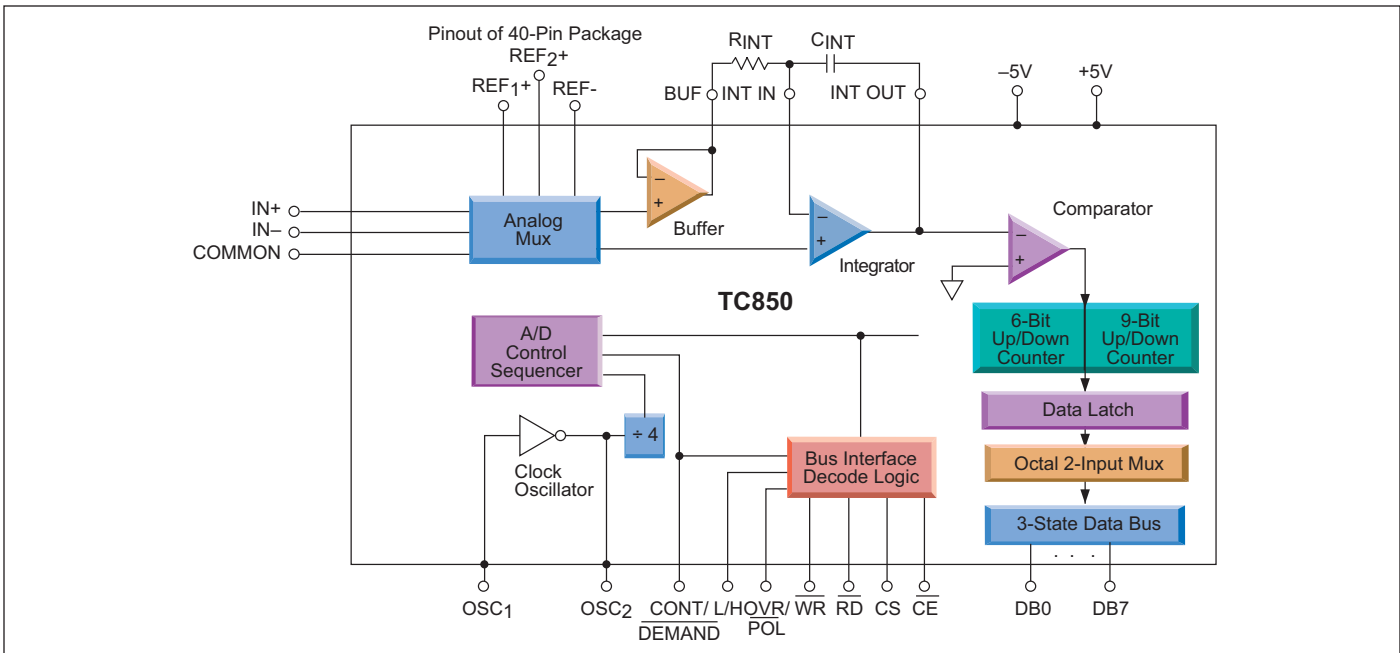
The **TC850** is a monolithic CMOS A/D converter (ADC) with a resolution of 15-bits plus sign. It combines a chopper-stabilized buffer and integrator with a unique multi-slope integration technique that increases conversion speed. The result is a 16-time improvement in speed over previous 15-bit, monolithic integrating ADCs (from 2.5 conversions per second up to 40 per second). Faster conversion speed is especially welcome in systems with human interface, such as digital scales.

The TC850 incorporates an ADC and a microprocessor-compatible digital interface. Only a voltage reference and a few, noncritical, passive components are required to form a complete 15-bit plus sign ADC. CMOS processing provides the TC850 with high-impedance and differential inputs. Input bias current is typically only 30 pA, permitting direct interface to sensors.

Input sensitivity of 100  $\mu\text{V}$  per Least Significant Bit (LSB) eliminates the need for precision external amplifiers.

The internal amplifiers are auto-zeroed, ensuring a zero digital output with 0V analog input. Zero-adjustment potentiometers or calibrations are not required.

The TC850 outputs data on an 8-bit, 3-state bus. Digital inputs are CMOS-compatible, while outputs are TTL/CMOS-compatible. Chip-enable and byte-select inputs, combined with an end-of-conversion output, ensures easy interfacing to a wide variety of microprocessors. Conversions can be performed continuously or on command. In Continuous mode, data is read as three consecutive bytes and manipulation of address lines is not required. Operating from  $\pm 5\text{V}$  supplies, the TC850 dissipates only 20 mW.



### Key Features:

- 15-bit Resolution Plus Sign Bit
- Up to 40 Conversions per Second
- Integrating ADC Technique
  - Monotonic
  - High Noise Immunity
  - Auto-zeroed Amplifiers Eliminate Offset Trimming
- Wide Dynamic Range: 96 dB
- Low Input Bias Current: 30 pA
- Low Input Noise: 30  $\mu\text{V}_{\text{P-P}}$
- Sensitivity: 100  $\mu\text{V}$
- Flexible Operational Control
- Continuous or On-demand Conversions

- Data Valid Output
- Bus Compatible, 3-State Data Outputs
  - 8-bit Data Bus
  - Simple  $\mu\text{P}$  Interface
  - Two Chip Enables
  - Read ADC Result Like Memory
- $\pm 5\text{V}$  Power Supply Operation: 20 mW

### Applications:

- Precision Analog Signal Processor
- Precision Sensor Interface
- High Accuracy DC Measurements

### ADC Product Specifications

Part	Description	Supply Voltage (V)	Input Voltage Range (V)	Resolution (Digits)	Resolution (Counts)	Max Power (mW)	Data Interface	Temp. Range (°C)	Features	Packages
TC850	Binary A/D	$\pm 5$	$V_{\text{SS}} + 1.5\text{V}$ to $V_{\text{DD}} - 1.5\text{V}$	15-bit	$\pm 32,768$	35	8-bit Parallel	-25 to +70	Highest conversion speed (40 conv/sec)	44 PLCC, 40 PDIP, 40 CerDIP

# High-Performance, Stand-Alone ADCs for a Variety of Embedded Systems Applications

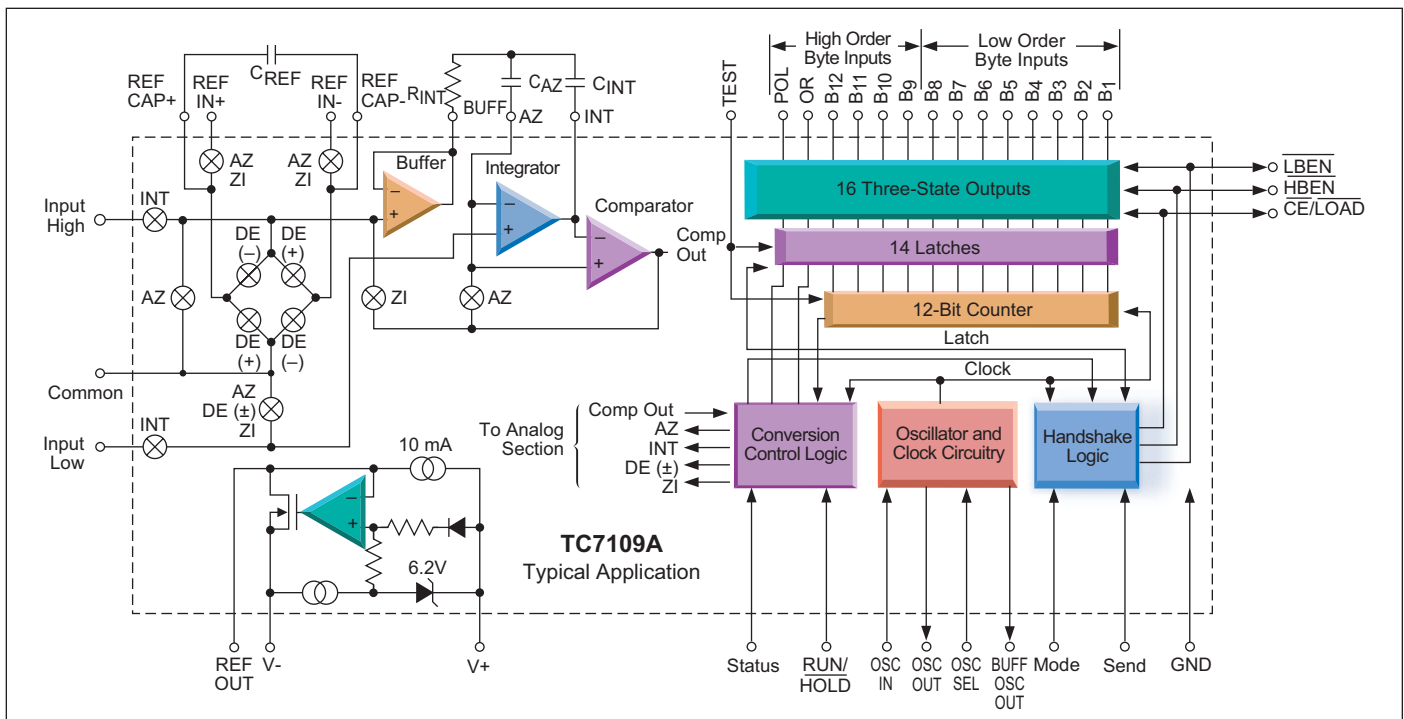
## ADC BY ARCHITECTURE – 12-BIT DUAL-SLOPE WITH SERIAL AND PARALLEL BINARY OUTPUT

The **TC7109A** is a 12-bit plus sign, CMOS low-power Analog-to-Digital converter. Only eight passive components and a crystal are required to form a complete dual-slope integrating ADC.

The improved  $V_{OH}$  source current and other TC7109A features make it an attractive per-channel alternative to analog multiplexing for many data acquisition applications. These features include typical input bias current of 1 pA, drift of less than 1  $\mu\text{V}/^\circ\text{C}$ , input noise typically 15  $\mu\text{VP-P}$  and auto-zero. True differential input and reference allow measurement of bridge-type transducers, such as load cells, strain gauges, and temperature transducers.

The TC7109A provides a versatile digital interface. In the Direct mode, chip select and HIGH/LOW byte enable control parallel bus interface. In the Handshake mode, the TC7109A will operate with industry standard UARTs in controlling serial data transmission – ideal for remote data logging. Control and monitoring of conversion timing is provided by the RUN/HOLD input and STATUS output.

For applications requiring more resolution, see the TC500, 15-bit plus sign ADC data sheet.



### Key Features:

- Zero Integrator Cycle for Fast Recovery from Input Overloads
- Eliminates Cross-Talk in Multiplexed Systems
- 12-Bit Plus Sign Integrating A/D Converter with Overrange Indication
- Sign Magnitude Coding Format
- True Differential Signal Input and Differential Reference Input
- Low Noise: 15  $\mu\text{VP-P}$  Typ.
- Input Current: 1 pA Typ.
- No Zero Adjustment Needed
- TTL Compatible, Byte Organized Tri-state Outputs
- UART Handshake Mode for Simple Serial Data Transmissions

### Applications:

- Ideal for remote data logging
- Bridge-type Transducer Measurements
  - Load Cells
  - Strain Gauges
  - Temperature Transducers

### ADC Product Specifications

Part	Supply Voltage (V)	Input Voltage Range (V)	Resolution (Digits)	Sampling Rate (Conv/s)	Input Channels	Data Interface	Temp. Range ( $^\circ\text{C}$ )	Features	Packages
TC7109A	$\pm 5$	$V_{SS} + 1.5\text{V}$ to $V_{DD} - 1.0\text{V}$	12 bits plus sign bit	$\pm 32,768$	1	Parallel or Serial	-25 to +85	Differential Input Range	44 PDIP, 40 CerDIP, 44 PLCC, 44 PQFP

## DEVELOPMENT TOOLS

### MXLAB® Software Tool

The MXLAB software tool provides data acquisition, analysis and display in a Windows® system environment. Additionally, analysis can be made of the digital potentiometer shutdown, reset and daisy-chain operations. The MXLAB software can determine digital potentiometer settings based on gain inputs (dB or V/V), filter cutoff frequencies and offset voltage levels. The MXLAB software can be downloaded free from the Microchip web site at [www.microchip.com](http://www.microchip.com).

The MXLAB Windows software contains a variety of tools to interface to the MXDEV® Analog Evaluation System. These tools provide different methods for troubleshooting the analog circuit in either the time or frequency domain:

- Fast Fourier Transform (FFT)
- Histogram
- Oscilloscope
- Real-time numeric
- Real-time stripchart
- Data List

### MXDEV® Analog Evaluation System

The MXDEV® Analog Evaluation System is a versatile and easy-to-use system for evaluating Microchip's MCP mixed-signal products. The system is used with a PC and consists of two parts: the DVMCPA Driver Board with associated MXLAB software, which provides data acquisition, analysis and display in a Windows environment; and the DVxxxx Evaluation Board, which contains the device to be evaluated.

Evaluation boards are currently available for the MCP3001/02 and MCP3004/08 10-bit ADCs, the MCP3201/02 and MCP3204/08 12-bit ADCs, and the MCP42XXX digital potentiometers.

For the DV320x A/D converter evaluation boards, the input signal is either from an on-board potentiometer or an external source. In addition, low-pass filters can be inserted into the signal path for further flexibility. A prototype area allows the addition of custom circuitry to make a powerful tool for evaluation and development.

The DV42xxx digital potentiometer evaluation board shows the MCP42xxx being used in many popular digital applications. These circuits include programmable gain circuits, a programmable filter circuit and a programmable circuit. Digital potentiometer tools within the MXLAB system calculate wiper values for these circuits based on user inputs of gain (in dB or V/V), filter cutoff frequency and approximation method, and offset voltage. In addition, an ADC is on-board that allows analysis of these circuits, using the time and frequency domain tools of the MXLAB software.

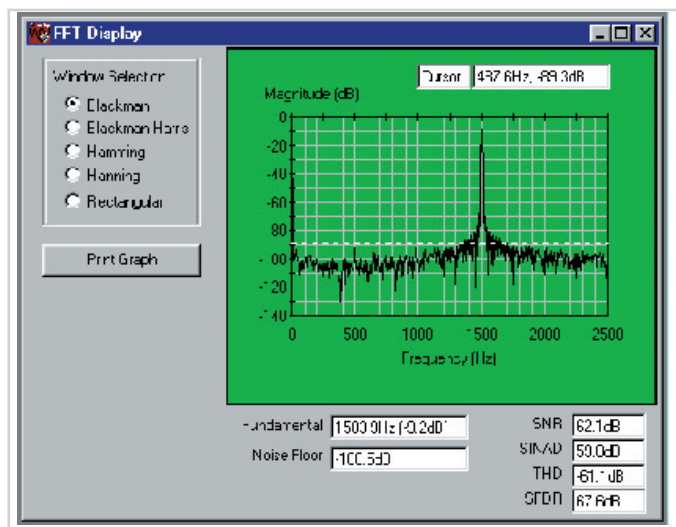
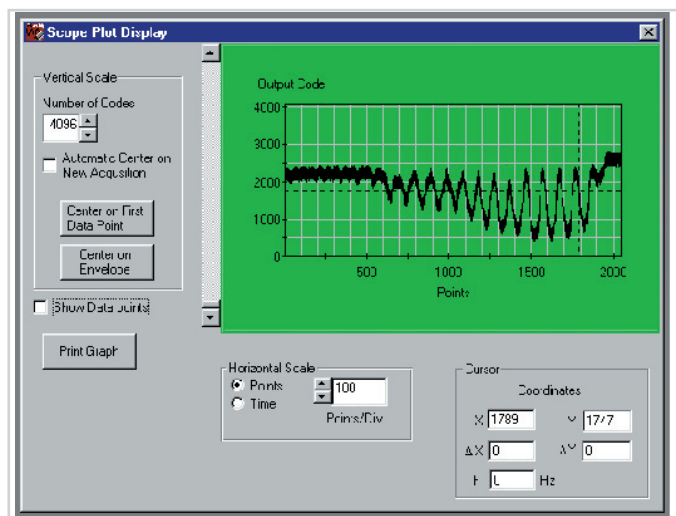
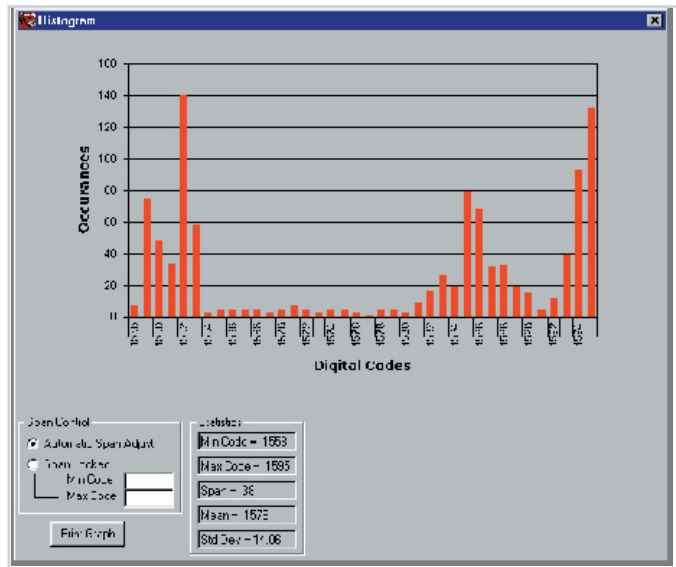
#### Microchip Ordering Part Numbers;

[DVMCPA](#) MXDEV Analog Evaluation Driver Board Version 1  
[DV3201A](#) MCP3001/3002 & MCP3201/02 A/D Converter Evaluation Board

[DV3204A](#) MCP3004/3008 & MCP3204/08 A/D Converter Evaluation Board

[DV42xxx](#) MCP42xxx Digital Potentiometer

### MXLAB® Screen Captures



## RELATED SUPPORT MATERIAL

The following Application Notes are available on the Microchip website: [www.microchip.com](http://www.microchip.com).

### Application Notes:

**AN246:** *Driving the Analog Inputs of a SAR A/D Converter*  
Driving any A/D Converter (ADC) can be challenging if all issues and trade-offs are not understood from the beginning. With Successive Approximation Register (SAR) ADCs, the sampling speed and source impedance should be taken into consideration if the device is to be fully utilized. This application note discusses 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.

**AN681:** *Reading and Using Fast Fourier Transformation (FFT)*  
This application note focuses on the use of FFT plots to illustrate the performance of A/D converters. FFTs can help identify noise interference, power supply, and analog device performance.

**AN688:** *Layout Tips for 12-Bit A/D Converter Application*  
This application note describes basic A/D converter layout guidelines, ending with a review of issues to be aware of. Examples of good and bad layout techniques are provided.

**AN693:** *Understanding A/D Converter Performance Specifications*. This application note describes the specifications used to quantify the performance of A/D converters and gives the reader a better understanding of the significance of those specifications in an application.

**AN695:** *Interfacing Pressure Sensors to Microchip's Analog Peripherals* This application note concentrates on the signal conditioning path of the piezoresistive sensing element from sensor to microcontroller. It shows how the electrical output of this sensor can be gained, filtered and digitized in order to prepare it for the microcontroller's calibration routines.

**AN780:** *15-Kilogram Scale Using the TC500A and the TC520*  
A 15 kg weighing scale was designed using Microchip's TC500A Analog Processor and the TC520 16-bit Controller. The scale is required to resolve down to 1/8 gram and correct to within 6-1/2 grams.

**AN781:** *Solving Sensor Offset Problems with TC7106*  
Design engineers sometimes have to interface the TC7106 and similar ADCs to "non-ideal" sensors. A very common problem is that the sensor often does not give a "zero" output where the design wants a zero reading.

**AN783:** *+5V Power Supply Operation with TC7106A/7107A*  
This application note describes how the TC7106A/7107A 3-1/2 digit analog-to-digital converters with liquid crystal display drive can be powered from ±5V power supplies using low-cost regulators, such as the TC55 (+5V).

**AN785:** *Simplify A/D Converter Interface with Software*  
Unfortunately, many display-oriented ADCs are difficult to interface due to the multiplexed BCD format of the outputs. An exception is the 4-1/2 digit TC7135 ADC, which provides a "strobe" output.

**AN788:** *Numerical-Integration Techniques Speed Dual-Slope A/D Conversion*. By using low-cost microprocessors and a program-controlled, numerical-integration technique, you can achieve good noise rejection and take full advantage of the higher speeds offered by dual-slope A/D converters, such as the TC7109.

**AN789:** *Integrating Converter Analog Processor – TC500A*  
Today, design engineers rely more on microprocessors and microcontrollers to support their applications. Compatible Analog-to-Digital (A/D) and Digital-to-Analog (D/A) converters have greatly increased the flexibility of interface and control circuits.

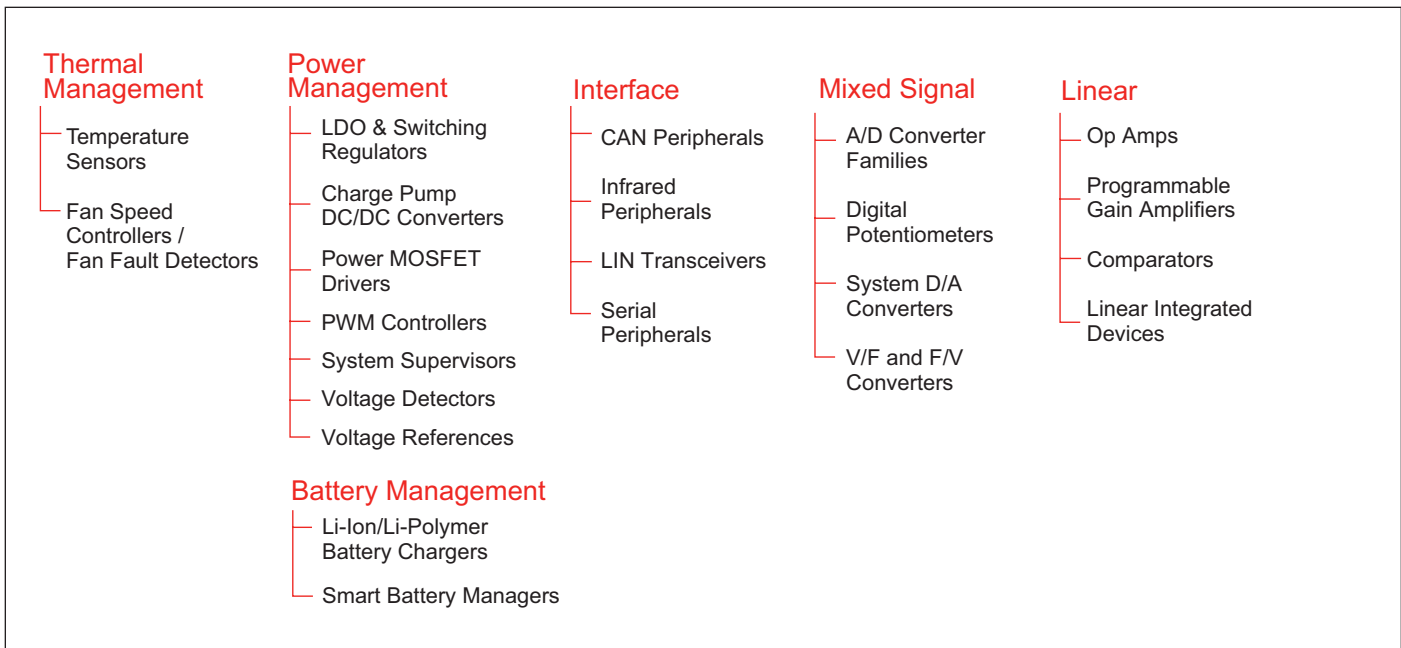
**AN796:** *TC7109 Records Remote Data Automatically*  
The TC7109 analog-to-digital converter, a 2 Kbytes CMOS static RAM, and some gates and counters can be combined to form a low-cost, flexible, stand-alone data-logging system.

**AN842:** *Differential ADC Biasing Techniques, Tips and Tricks*  
This application note discusses differential input configurations and their operation circuits to implement these input modes and techniques in choosing the correct voltage levels.

**AN845:** *Communicating with The MCP3221 Using PICmicro® Microcontrollers*. This application note covers communications between the MCP3221 device and a PICmicro® microcontroller. Hardware and software implementations of the I<sup>2</sup>C™ protocol are covered.

### Demonstration/Evaluation Board and User Guide:

**MCP3XXX Evaluation Kit User's Guide (DS51220):**  
This document describes how to use the MCP3XXX Evaluation Board to evaluate Microchip's stand-alone MCP3XXX A/D converters.



Microchip Technology Inc. is a leading provider of microcontroller, analog and memory products that provide risk-free product development, lower total system cost and faster time-to-market for thousands of diverse customer applications worldwide. Microchip's commitment to quality and innovation coupled with world-class development tools, dependable delivery and outstanding technical support sets us apart.

## Analog & Interface Attributes

### Robustness

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

### Low-Power/Low-Voltage

- Op Amp family with the lowest power for a given gain bandwidth
- 600 nA/1.4V/10 kHz bandwidth Op Amps
- 1.8V charge pumps and comparators
- Lowest power 12-bit ADC in SOT-23 package

### Integration

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

### Space Savings

- Resets and LDOs in SC70, ADCs in 5-lead SOT-23A
- CAN and IrDA® standard protocol stack embedded in an 18-pin package

### Accuracy

- Offset trimmed after packaging using non-volatile memory

### Innovation

- Low pin-count embedded IrDA® standard stack, FanSense™ technology
- Select Mode™ operation

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