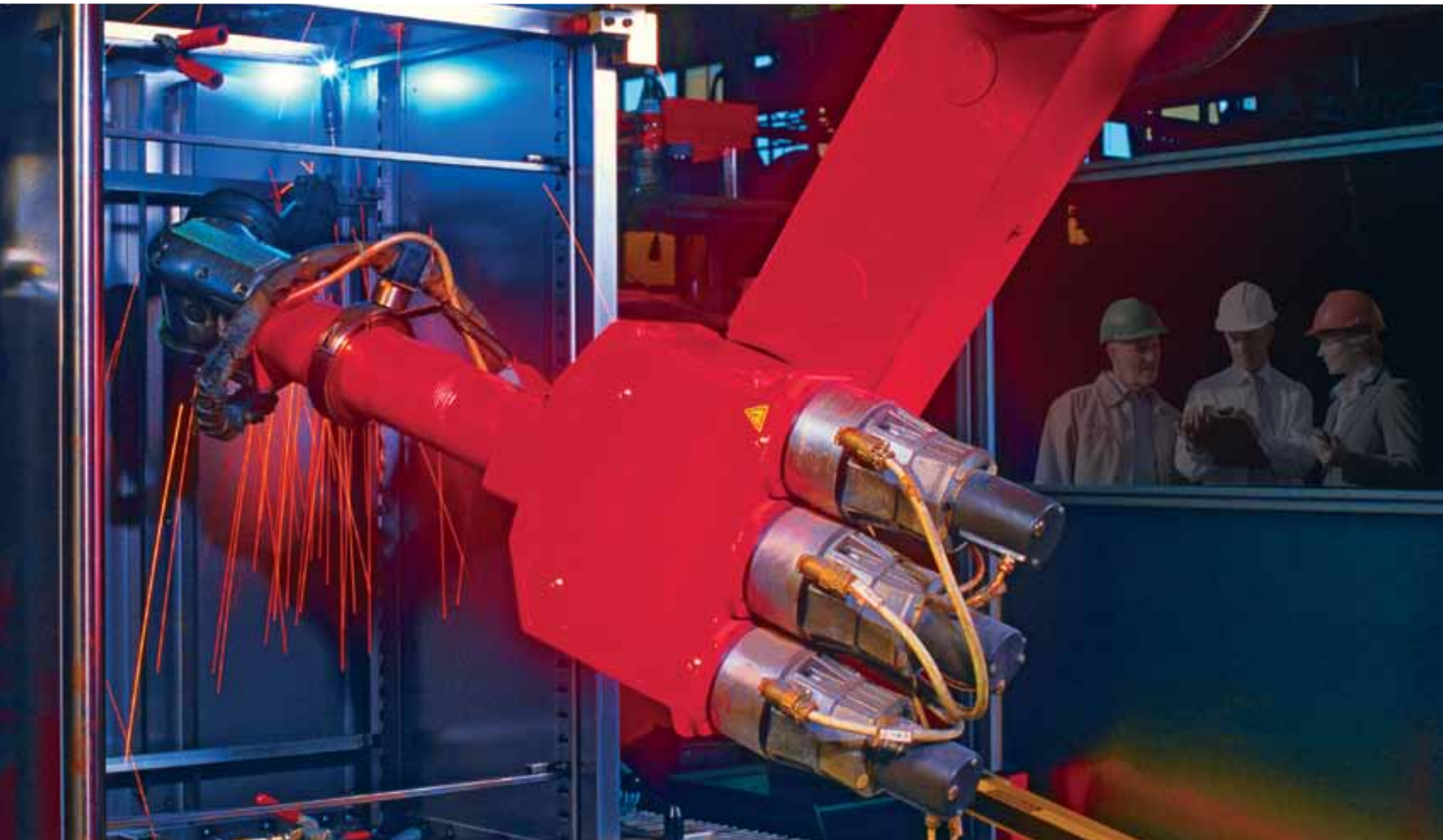


Industrial

Solutions Guide



Edition 1. May 2010

MAXIM
INNOVATION DELIVERED®



A message from the CEO

Dear Customers,

Over 27 years ago Maxim was built on the foundation of providing high-quality integrated circuits for products in the industrial marketplace. In fact, I started designing some of Maxim's first data converters in 1984.

Maxim continues to build on its industrial foundation, with more than 25% of its \$2 billion revenue coming today from industrial products. And our mission continues to be to deliver solutions to our industrial customers that add value to their end products.

The *Industrial: Solutions Guide* highlights six specific functions and types of industrial equipment. The guide focuses on the Maxim® products that that will bring you the most value to that specific type of equipment.

We reviewed the 6300 products in our catalog, and selected the best ones for each function or equipment. We listed the benefits of these products— whether it is smaller size, greater accuracy, lower power, or something else—in an easy-to-read format. And we have backed up our claims with hard technical facts so you can compare us to competing solutions.

In addition to identifying our best products and highlighting them in the *Industrial: Solutions Guide*, we have trained our direct sales force and worldwide distributors so they understand the technical and marketing needs of your products. In this way they can provide you high-quality support. They are focused on meeting with you and discussing your needs and our offerings.

I am certain that you will see that Maxim remains focused on being the leading solutions provider for industrial equipment, both in terms of innovative products and knowledgeable support.

Finally, I welcome your questions and comments about Maxim and this solutions guide. Let me know what you think. You can reach me at: tunc@maxim-ic.com.

Thank you,

A handwritten signature in blue ink that reads "Tunc Doluca". The signature is fluid and cursive, with a long horizontal line extending from the end.

Tunç Doluca

President and Chief Executive Officer

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Overview



Overview

Programmable logic controllers (PLCs) have been an integral part of factory automation and industrial process control for decades. PLCs control a wide array of applications from simple lighting functions to environmental systems to chemical processing plants. These systems perform many functions, providing a variety of analog and digital input and output interfaces; signal processing; data conversion; and various communication protocols. All of the PLC's components and functions are centered around the controller, which is programmed for a specific task.

The basic PLC module must be sufficiently flexible and configurable to meet the diverse needs of different factories and applications. Input stimuli (either analog or digital) are received from machines, sensors, or process events in the form of voltage or current. The PLC must accurately interpret and convert the stimulus for the CPU which, in turn, defines a set of instructions to the output systems that control actuators on the factory floor or in another industrial environment.

Modern PLCs were introduced in the 1960s, and for decades the general function and signal-path flow changed little. However, twenty-first-century process control is placing

new and tougher demands on a PLC: higher performance, smaller form factor, and greater functional flexibility. There must be built-in protection against the potentially damaging electrostatic discharge (ESD), electromagnetic interference and radio frequency interference (RFI/EMI), and high-amplitude transient pulses found in the harsh industrial setting.

Robust design

PLCs are expected to work flawlessly for years in industrial environments that are hazardous to the very microelectronic components that give modern PLCs their excellent flexibility and precision. No mixed-signal IC company understands this better than Maxim. Since our inception, we have led the industry with exceptional product reliability and innovative approaches to protect high-performance electronics from real environmental dangers, including high levels of ESD, large transient voltage swings, and EMI/RFI. Designers have long endorsed Maxim's products because they solve difficult analog and mixed-signal design problems and continue solving those problems year after year.

Higher integration

PLCs have from four to hundreds of input/output (I/O) channels in a wide variety of form factors, so size and power can be as important as system accuracy and reliability. Maxim leads the industry in integrating the right features into ICs, thereby reducing the overall system footprint and power demands and making designs more compact. Maxim has hundreds of low-power, high-precision ICs in the smallest available footprints, so the system designer can create precision products that meet strict space and power requirements.

Factory automation, a short history

Assembly lines are a relatively new invention in human history. There have likely been many parallel inventions in many countries, but here we will mention just a few highlights from the U.S.

Samuel Colt, the U.S. gun manufacturer, demonstrated interchangeable parts in the mid-1800s. Previously each gun was assembled with individually made pieces that were filed to fit. To automate that assembly process, Mr. Colt placed all the pieces for ten guns in separate bins and then assembled a gun by randomly pulling pieces from the bins. Early in the twentieth century Henry Ford expanded mass-production techniques. He designed fixed-assembly stations with cars moving between positions. Each employee learned just a few assembly tasks and performed those tasks for days on end. In 1954 George Devol applied for U.S. Patent 2,988,237, which enabled the first industrial robot named Unimate. By the late 1960s General Motors® used a PLC to assemble automobile automatic transmissions. Dick Morley, known as the "father" of the PLC, was involved with the production of the first PLC for GM®, the Modicon. Morley's U.S. Patent 3,761,893 is the basis of many PLCs today. (For more information on the above four inventors, please see: www.wikipedia.org/; for their patents, search: <http://patft.uspto.gov/netahtml/PTO/srchnum.htm>).

Basic PLC operation

How simple can process control be? Consider a common household space heater.

The heater's components are enclosed inside one container, which

Programmable logic controllers (PLCs)

Overview

makes system communications easy. Expanding on this concept is a household forced-air heater with a remote thermostat. Here the communication paths are just a few meters and a voltage control is typically utilized.

Think now beyond a small, relatively simple process-control system. What controls and configuration are necessary in a factory?

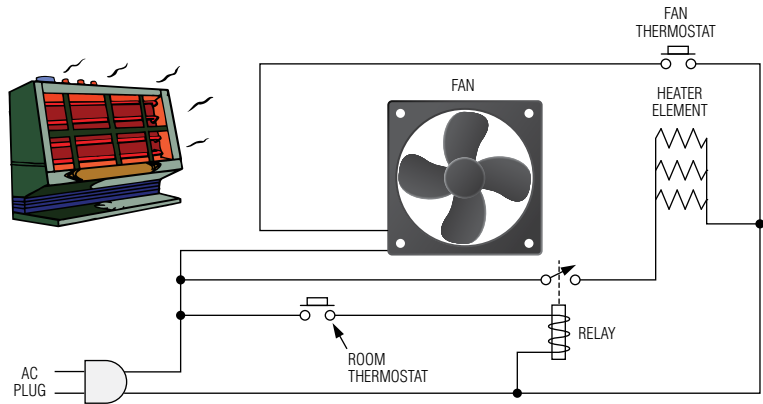
The resistance of long wires, EMI, and RFI make voltage-mode control impractical. Instead, a current loop is a simple, but elegant solution. In this design wire resistance is removed from the equation because Kirchhoff's law tells us that the current anywhere in the loop is equal to all other points in the loop. Because the loop impedance and bandwidth are low (a few hundred ohms and $< 100\text{Hz}$), EMI and RFI spurious pickup issues are minimized. A PLC system is useful for properly controlling such a factory system.

Current communication for PLCs

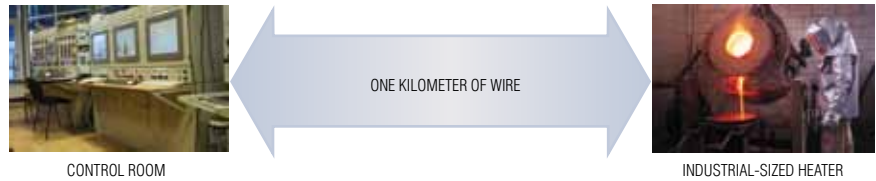
Current-control loops evolved from early twentieth-century teletype impact printers, first as 0–60mA loops and later as 0–20mA loops. Advances in PLC systems added 4–20mA loops.

A 4–20mA loop has several advantages. Older discrete component designs required careful design calculations; circuitry was comparatively large compared to today's integrated 4–20mA ICs. Maxim has introduced several 20mA devices, including the MAX15500 and MAX5661, which greatly simplify the design of a 4–20mA PLC system.

Any measured current-flow level indicates some information. In practice, the 4–20mA current loops operate from a 0mA to 24mA current range. However, the electrical current ranges from 0mA to 4mA and 20mA to 24mA are used for diagnostics



A household electric heater serves as a simple example of process control.



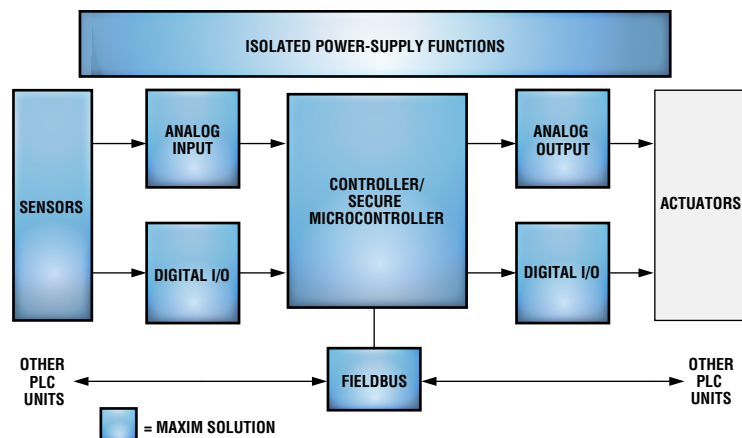
Longer-range factory communications.

and system calibration. Since current levels below 4mA and above 20mA are used for diagnostics, one might conclude that readings between 0mA and 4mA could indicate a broken wire in the system. Similarly, a current level between 20mA and 24mA could indicate a potential short circuit in the system.

An enhancement for 4–20mA communications is the highway-addressable remote transducer (HART™ system) which is backward

compatible with 4–20mA instrumentation. A HART system allows two-way communications with smart, microprocessor-based, intelligent field devices. The HART protocol allows additional digital information to be carried on the same pair of wires with the 4–20mA analog current signal for process-control applications.

PLCs can be described by separating them into several functional groups. Many PLC manufacturers will organize these functions into individual



Simplified PLC block diagram. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

modules; the exact content of each of these modules will likely be as diverse as are the applications. Many modules have multiple functions that can interface with multiple sensor interfaces. Yet other modules or expansion modules are often

dedicated to a specific application such as a resistance temperature detector (RTD), sensor, or thermocouple sensor. In general, all modules have the same core functions: analog input, analog output, distributed control (e.g., a fieldbus), interface,

digital input and outputs (I/Os), CPU, and power. We will examine each of these core functions in turn, and leave sensors and sensor interfaces for a separate section.

www.maxim-ic.com/plc

Analog input function

Overview

The analog input portion of a PLC accepts analog signals from a variety of sensors and factory or field wiring. These sensors are used to convert physical phenomena such as light, temperature, sound, gas, or vibration from mechanical signals into electrical representations. In the analog-input signal path, signals are conditioned for maximum integrity, range, and resolution before being sampled by the analog-to-digital converters (ADCs). In the industrial environment common to PLCs, there is a wide variety of signal levels, signal bandwidths, and noise sources. It is, therefore, essential to reject as much of the irrelevant information as possible. Equally important, the maximum amount of relevant information must be retained when the signals are converted from the analog to the digital domain.

The PLC's analog input accepts voltage and current inputs from remote sensors. Voltage inputs can have different amplitudes, the most common of which are either 0 to 10V, or 0 to 5V, $\pm 10V$, or $\pm 5V$. The most popular current-input standard is 4–20mA, although $\pm 20mA$ is sometimes used. Despite its name, the 4–20mA standard accepts 0–24mA both to detect an open input ($< 3.6mA$) and overrange ($> 20mA$), and to allow headroom for calibration. To guarantee that the current loop is never broken, the current input is typically terminated into a relatively low-value resistor (e.g., 50 Ω to 250 Ω) prior to the signal-conditioning analog chain.

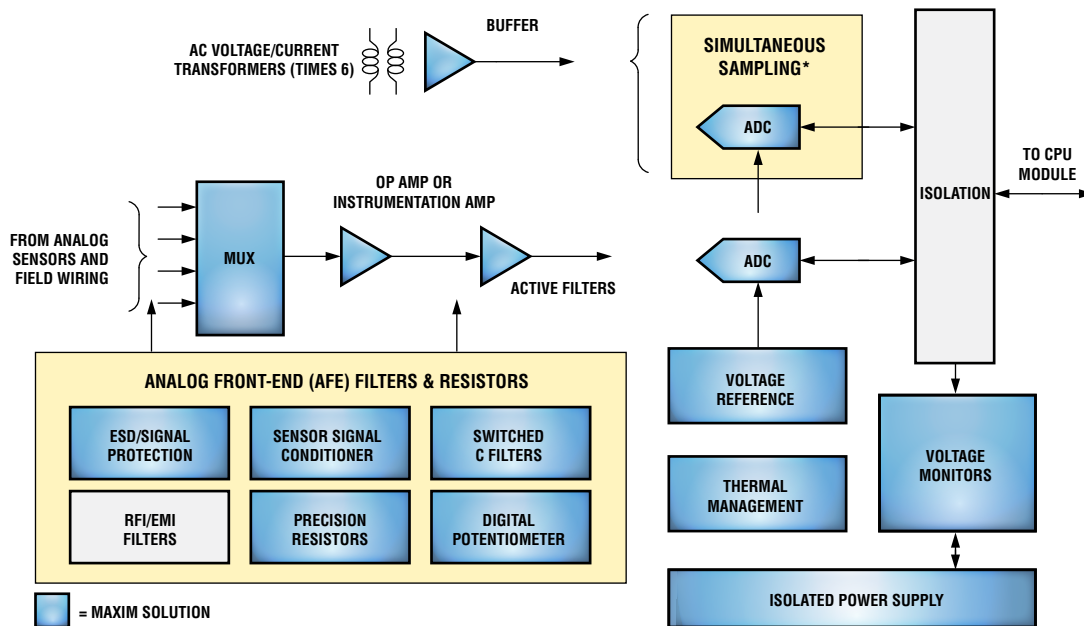
followed by a common amplifying signal path into an ADC, or with individual amplifying channels and a multiplexer prior to the ADC. The input stage is commonly required to cope with both positive and negative high voltages (e.g., $\pm 30V$ or higher). This protects the PLC's analog-input card from external fault conditions and lets the input module accommodate variable common-mode voltages on the long lines that connect to the remote sensors. Low-temperature drift and low noise are also critical requirements of the analog signal path. The errors at $+25^{\circ}C$ are typically calibrated out in software. The drift over temperature can also be removed, although it is not removed in many systems and thus becomes a critical specification.

The signal chain

Various implementations of the signal chain are possible, with simultaneous-sampling ADCs and independent conditioning amplifiers, or with a multiplexer as the first stage

Analog-to-digital conversion

Standard PLC designs typically require a high-accuracy ADC. The bandwidth of the input signal



*Designers can choose among multiple ADCs for this function.

Maxim's extensive product offerings are found throughout this block diagram of PLC analog-input functions. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

dictates the ADC's maximum sampling rate. The signal-to-noise ratio (SNR) and spurious-free dynamic range (SFDR) specifications dictate the ADC's resolution, filtering requirements, and gain stages. It is also important to determine how the ADC will interface to the microcontroller or CPU. For example, high-bandwidth applications perform better using a parallel or fast serial interface. With its two-line digital interface, however, I²C is ideal for slower systems. When the results from the analog-input measurement are transferred through a 4–20mA loop, PLC designers can choose between an ADC with a separate digital-to-analog converter (DAC), an integrated DAC that can drive the 4–20mA lines directly, or a high-voltage op amp configured as a precision current source. Applications that require extraction of phase information between channels are well suited for multiple ADCs or simultaneous-sampling ADCs.

Although PLCs are used in distinct ways, many PLC designs share some common factors. For example, the most used ADCs and DACs are 16 bits. Maxim offers over a hundred 16-bit ADCs and DACs for a wide range of input and output voltages, and this broad product offering is a distinct advantage for the PLC designer. Consider a situation where using sensors with varying accuracies could dictate the need for three ADCs with 12-, 14-, and 16-bit resolution. But to reduce cost and complexity, it may be best to discard bits for some sensors and utilize the higher resolution only where it is needed. In this case, a designer may choose to multiplex the analog signals to a differential input amplifier or programmable gain amplifier (PGA) into a single 16-bit ADC.

When choosing a multiplexer, sensor reaction speed must be considered. This means that a designer needs



to determine the input bandwidth and how quickly the switches will be opening and closing. Slow-response sensors measuring signals such as temperature and humidity can be sensed every few seconds. Faster changes like speed, position, and torque typically need to be sensed at least thousands of times per second. Similarly, on the output side DACs can be multiplexed depending on how often the outputs must be serviced to maintain control.

Signal conditioning and calibration

There are many design challenges when selecting the analog-input signal-path components. The inputs to the multiplexer and the ADC require analog signal conditioning such as filtering; converting currents to voltages; and changing gain, offset, impedance, and bias. Caution must be taken both to anticipate the expected voltage amplitude and signal polarity, and to understand the unexpected like unwanted voltage or current transients. Maxim provides a wide selection of operational amplifiers, instrumentation amps, PGAs, precision resistors, filters, references, ADCs, and multiplexers to aid the PLC design.

Calibration improves system performance and increases accuracy (see chapter titled *"Trim, calibrate, and adjust"* on page 143. The MAX9939, a PGA with an SPI™ interface, is ideally suited for a thermocouple application as it provides the needed level-shifting circuitry to signal condition both negative and positive sensor signals. The MAX9939's inputs

provide ±16V transient protection to prevent damage to the PLC system.

Multiplexers (muxes) are useful for switching multiple input channels. A mux that meets high-voltage-supply requirements (up to ±35kV) or is fault protected against overvoltage conditions, can help eliminate expensive external circuitry such as voltage-dividers and opto relays. A low, matching on-resistance (R_{ON}) is essential for low distortion to improve circuit reliability, and low-leakage currents are critical for minimizing voltage-measurement errors. Maxim's product portfolio includes more than 15 fault-protected/high-voltage, low-leakage, and low-R_{ON} muxes ideal for PLC applications.

The designer will choose the physical position for the signal-conditioning circuits. That placement may require the sensor signal to be conditioned before it is transmitted to the input ADC.

The sensor's output can be very small or very large, which would require gain or attenuation stages (respectively) to maximize the ADC's dynamic input range. These conditioning stages are usually implemented with PGAs or discrete op amps and precision resistor-dividers. The ADC and amplifier work in tandem to achieve the best signal-to-noise ratio (SNR) within the cost, power, and size budgets. Another alternative is to use an ADC with the conditioning stages integrated. Regardless of how the signal-conditioning stages are implemented, the voltage range, low-temperature drift, and low noise are among the most critical specifications when determining the best architecture.

The industrial environment presents numerous noise sources, such as 50HZ/60Hz power-line mains which get coupled into the signal. These unwanted noise signals put an artificial limit on the gain stages and

Programmable logic controllers (PLCs)

Analog input function

should be rejected before the gain stages. This is best accomplished using Maxim's PGAs or differential amplifiers with a high common-mode rejection ratio (CMRR). Maxim has a variety of laser-trimmed, matching resistor-dividers for precise gain and attenuation; there are also trimmable calibration potentiometers

for programmability, and ADCs with differential inputs and PGAs integrated in a single IC.

Lowpass or bandpass filtering before the ADC sampling network is necessary for anti-aliasing requirements and for rejecting noise sources at other frequencies. PLC designers

have a choice between active filters implemented with op amps or switched-capacitor filters with a very sharp (up to 8-pole) rolloff and a programmable cut-off frequency. Maxim provides a selection of 5th- and 8th-order, switched-capacitor and continuous-time filters ideal for anti-aliasing.

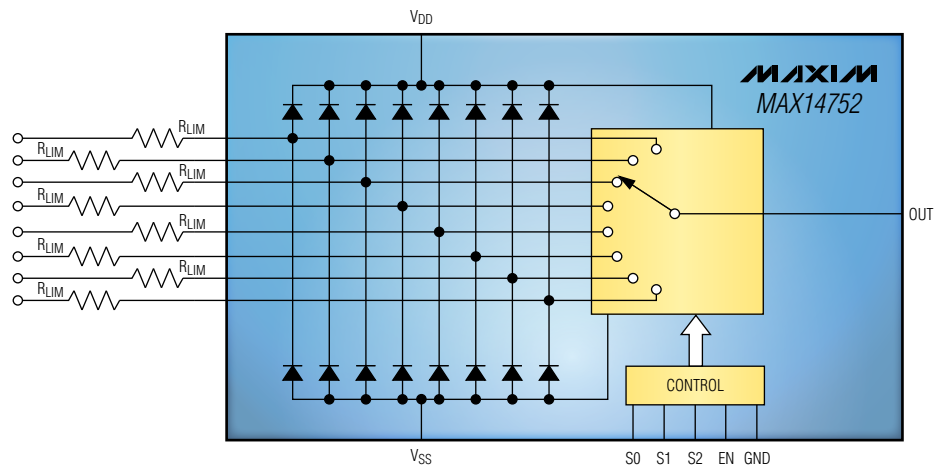
Eliminate external overvoltage protection (OVP) circuitry and reduce BOM complexity with high-voltage multiplexers

MAX14752/MAX14753

The MAX14752/MAX14753 are 8-to-1 and dual 4-to-1 (respectively) high-voltage analog multiplexers designed for high-voltage PLC applications. Both devices operate with dual supplies of $\pm 10\text{V}$ to $\pm 36\text{V}$ or a single supply of 20V to 72V, and a low 0.03Ω (typ) R_{ON} flatness. Logic levels for the channel-select interface are defined by the device enable (EN) input to help interface with multivoltage systems. The MAX14752/MAX14753 are packaged in the standard 16-pin TSSOP, and are pin compatible with the industry-standard DG408/DG409. Both multiplexers are specified over the extended -40°C to $+85^\circ\text{C}$ operating temperature range.

Benefits

- **High supply voltage eliminates external OVP diodes and opto relays**
 - Wide, single 72V (max) power-supply range; dual $\pm 36\text{V}$ (max) power-supply range
 - Internal protection diodes can be used for OVP
 - Rain-to-rail operation gives large dynamic range
- **Excellent R_{ON} flatness for high-accuracy measurements**
 - 0.03Ω (typ) R_{ON} flatness over common-mode voltage
- **Flexible logic levels for interfacing with multivoltage systems**
 - Device enable (EN) defines voltage logic level of channel-select inputs
- **Easy upgrade path**
 - Pin compatible with industry-standard MAX308/MAX309/DG408/DG409



Input overvoltage and undervoltage clamping with the MAX14752.

Programmable logic controllers (PLCs)

Analog input function

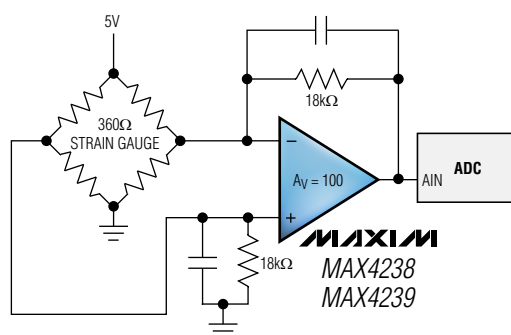
Improve accuracy with precision over time and precision over temperature from ultra-high-precision op amps

MAX4238/MAX4239

The MAX4238/MAX4239 are low-noise, low-drift, ultra-high-precision amplifiers. They offer near-zero DC offset and drift by using patented autocorrelating zeroing techniques.* This method constantly measures and compensates the input offset, thereby eliminating drift over time and temperature and the effect of 1/f noise.

Benefits

- **Maintain system calibration and accuracy over time and temperature with low-temperature coefficients**
 - Autozero technology reduces voltage offset temperature coefficient (TCV_{OS}) to $10\text{nV}/^\circ\text{C}$ and V_{OS} to only $2.5\mu\text{V}$ (max)
- **Improve system accuracy and resolution with low-input voltage noise**
 - No 1/f component ensures low-distortion signal conditioning below 0.1Hz with 30nV input-voltage noise density



The MAX4238/MAX4239 op amps are ideal for driving ADCs.

*U.S. Patent #6,734,723.

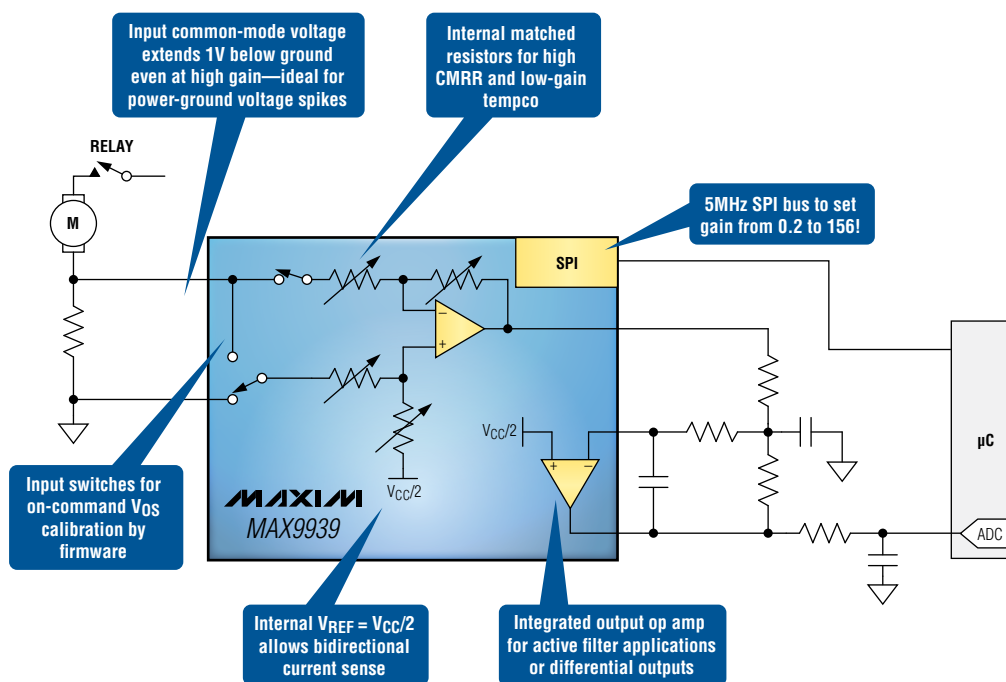
Reduce component count with precision differential PGA that supports positive and negative sensor signals

MAX9939

The MAX9939 is a precision, differential-input PGA ideal for conditioning wide-dynamic-range signals like those found in automotive current sense, medical instrumentation, and industrial data-acquisition applications. The MAX9939 features SPI-programmable differential gains from 0.2V/V to 157V/V, input V_{OS} compensation, and an output amplifier that can be configured either as a high-order active filter or to provide a differential output.

Benefits

- **No extra components needed for a wide range of sensor-input voltages**
 - 0.2V/V to 157V/V SPI-programmable gains
- **Enhanced SNR performance reduces effects of unwanted signal noise**
 - Differential-input and differential-output configuration improves the signal-conditioning resolution and accuracy
- **Improved signal-path robustness**
 - Inputs can withstand $\pm 16V$ transients



The MAX9939 uses matched resistors to provide a wide range of gains.

Programmable logic controllers (PLCs)

Analog input function

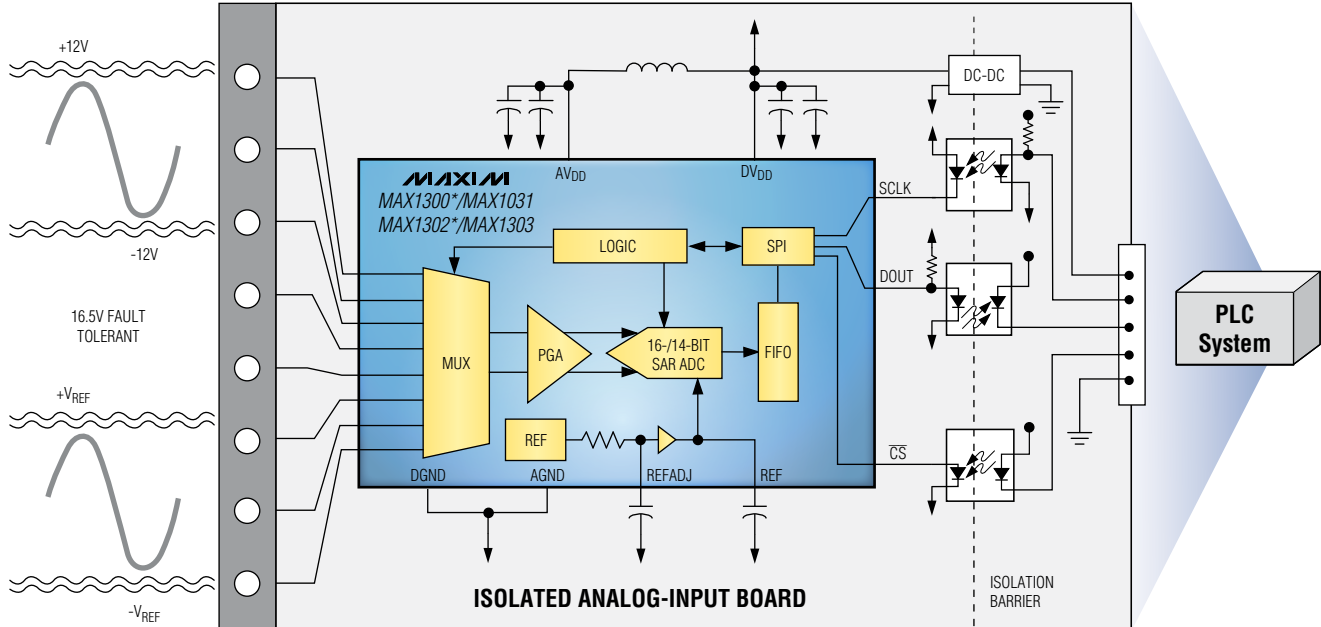
16-bit ADC with software-programmable input ranges on each ADC channel saves design time

MAX1300*/MAX1301/MAX1302*/MAX1303

The MAX1300–MAX1303 ADC family is an ideal fit for PLC applications because they measure many unique unipolar and bipolar input ranges, all with 16-bit operation and no missing codes. The eight single-ended or differential input ranges vary from as low as a unipolar 0 to 2.048V full scale up to a bipolar $\pm 12.288\text{V}$ full scale. Each input channel can be programmed by software for a different input range, making the MAX1300 family highly versatile. By eliminating analog front-end (AFE) stages, these ADCs also reduce cost and area, while increasing accuracy. The ADCs are also available with 14-bit resolution and 4 or 8 channels.

Benefits

- **Reduce complexity and cost by eliminating external gain stages and muxes**
 - Each ADC measures eight unique bipolar and unipolar input ranges
 - Multiple software-programmable input ranges up to $\pm 12.288\text{V}$ full scale
- **Flexible, easy-to-reuse circuit for multiple applications**
 - 16-bit and 14-bit resolution in the same package
- **Eliminate external protection components and save space and cost**
 - Up to $\pm 16.5\text{V}$ analog-input protection



The MAX1300–MAX1303 ADCs reduce cost by offering programmable input-voltage ranges.

* Future product—contact factory for availability.

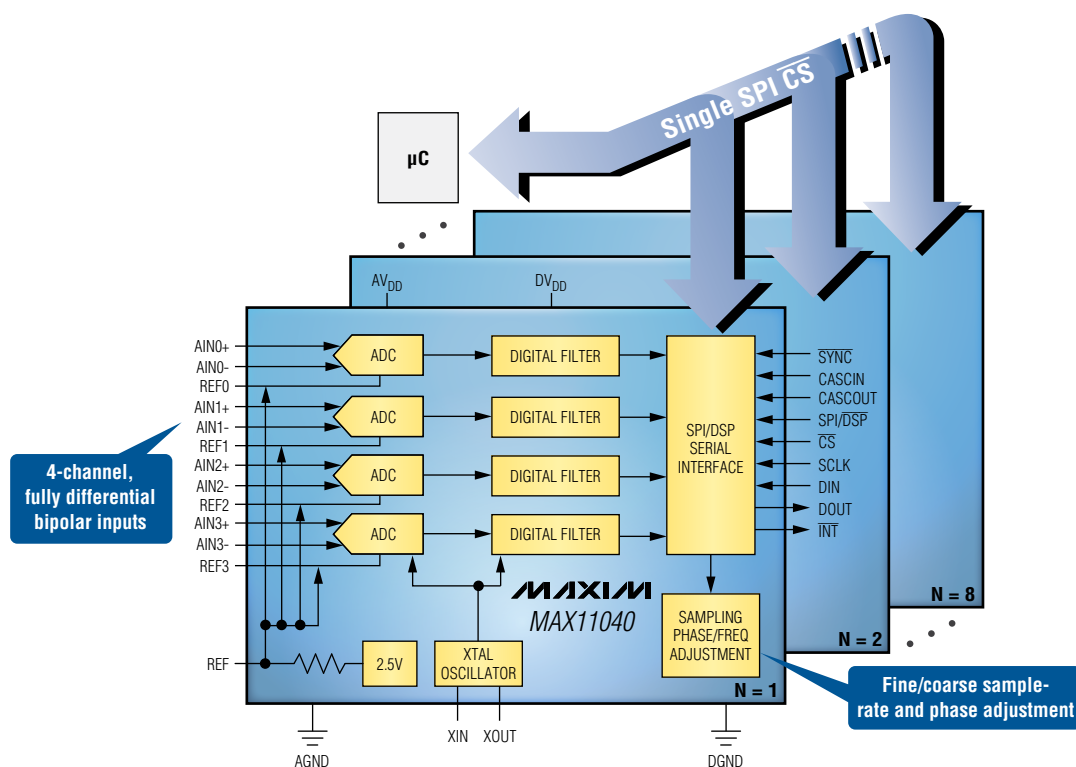
ADC eases firmware complexity by capturing accurate phase and magnitude information on up to 32 channels

MAX11040

The MAX11040 sigma-delta ADC offers 117dB SNR, four differential channels, and simultaneous sampling that is expandable to 32 channels (eight MAX11040 ADCs in parallel). With programmable phase and sampling rate, the MAX11040 is ideal for high-precision, phase-critical measurements within a noisy PLC environment. With a single command, the MAX11040's SPI-compatible serial interface allows data to be read from all the cascaded devices. Four modulators simultaneously convert each fully differential analog input with a 0.25ksps to 64ksps programmable data-output-rate range. The device achieves 106dB SNR at 16ksps and 117dB SNR at 1ksps.

Benefits

- **Simplifies digital interface to a microcontroller**
 - Eight MAX11040 ADCs can be daisy-chained through the SPI interface
- **Easily measures a wide dynamic range**
 - 106dB SNR allows users to measure both very small and large input voltages
- **Easily measures the phase relationship between multiple input channels**
 - Simultaneous sampling preserves phase integrity on multiple channels



The MAX11040 can be cascaded up to 32 channels.

Analog output functions

Overview

The analog output remotely controls activities and functions. It can be part of a complex loop like a PLC or a proportional-integral-derivative (PID) system, or it can perform a simple function such as turning a light or fan on and off.

The analog output primarily takes commands from the microprocessor and translates them into analog and digital signals to control motors, valves, and relays. As an example, a digital word from the CPU can be converted to an analog voltage or current by a DAC and signal-conditioning circuitry. A proper signal is tailored for each output with any needed signal conditioning provided, including bias, offset, and gain calibration. Calibration issues are discussed in the chapter entitled "Trim, calibrate, and adjust" on page 143.

Producing discrete, selectable, voltage- (bipolar and unipolar) or current-output conditioning circuits can be an intimidating task. This is especially true as one begins to

understand the necessity of controlling full-scale gain variations and the multiple reset levels for bipolar and unipolar voltages and different output-current levels.

Signal protection

The analog output circuitry is connected to wiring, long and short in the field or factory, so the output module must protect the system from ESD, RFI, and EMI. Voltage outputs tend to be appropriate for short-distance transmission wiring; current outputs are commonly used on long cables to reduce EMI from sources like arcing switches and motors.

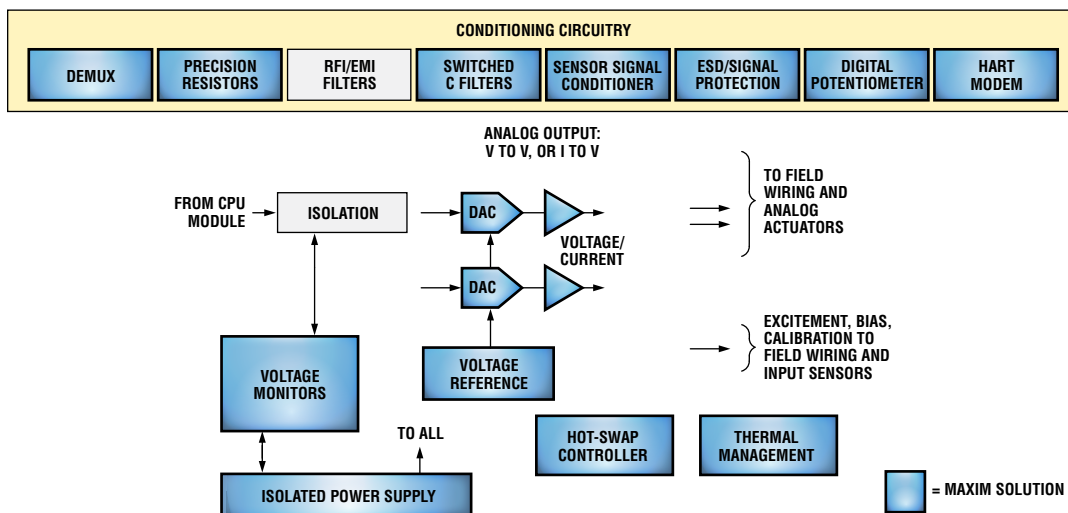
Signal monitoring

Output signal-monitoring functions, including detection and reporting of intermittent wire faults, are important safety considerations. Cabling in the field or factories is subject to movement and vibration which, in time, will cause wires to open or short to other conductors. Equipment and personnel must remain safe, which necessitates



careful monitoring. As a cable is failing, there is usually a period of intermittent operation prior to complete failure. The intermittent operation offers an opportunity to detect the error before complete failure occurs. As an important part of preventive maintenance, this failure detection improves safety and helps to minimize any plant downtime.

Because EMI, RFI, and power-surge conditions can be extreme in a factory, any monitoring must be reliable and not subject to nuisance tripping. Error reporting must be robust. In practice, reporting is done by establishing minimum timeout periods for detecting and reporting errors. A large noise pulse, for example, can appear like a



Maxim's product offerings are found throughout this block diagram of PLC analog-output functions. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

momentary cable interruption, but that is not necessarily the case. The mechanical cable interruption will tend to last longer than the noise pulse. The noise pulse is typically caused by capacitive or inductive coupling of a large change in current in a second cable running close to the communications cable. This noise interruption can occur when a large motor is turned on or off, and the transition (rise or fall time) of the change in current is seen as a differentiated pulse of short duration on the communications cable. Consequently, waiting for a short time (a fraction of a second) allows the fault detector to distinguish between a real cable intermittent fault and a noise pulse. The detection period must be long enough to avoid false error reports caused by fast transients that are part of the harsh environment, and yet short enough to catch short mechanical cable errors.

Extra safety is provided if more conditions than just cable health are monitored. Chip temperature, and thus the environment over temperature, is one important example. The field or factory can be spread over several acres, so monitoring power-supply voltage drops or brownout is also important for system reliability.

Managing an output fault

If an output fault occurs, errors must be latched and presented to a hardware interrupt pin. This gives the system microprocessor time to react to short cable outages. By definition, intermittent cable faults will be asynchronous and many will occur while the processor is busy. The interrupt is generated so the processor can then poll the output device registers for the exact condition and clear the interrupt.

The output to the field or factory needs to be protected against

common wiring errors and shorts. Some faults cannot be tolerated, such as a direct lightning hit. However, the outputs should withstand reasonable fault voltages. The most common errors are shorts to ground or the 24V power supply, and these errors should be tolerated without the need to replace components.

Managing system functions

Some sensors require excitation to function, and the output module supplies such signals. Typical examples are an AC signal for capacitive and variable reluctance sensors or a DC signal for a simple LED in a back-lighted switch.

The analog output can also provide other system-management functions that include monitoring the local isolated power supply, board temperature, and calibration.

Programmable logic controllers (PLCs)

Analog output functions

Eliminate 31 DACs and reduce system cost with a 32-output sample/hold amplifier

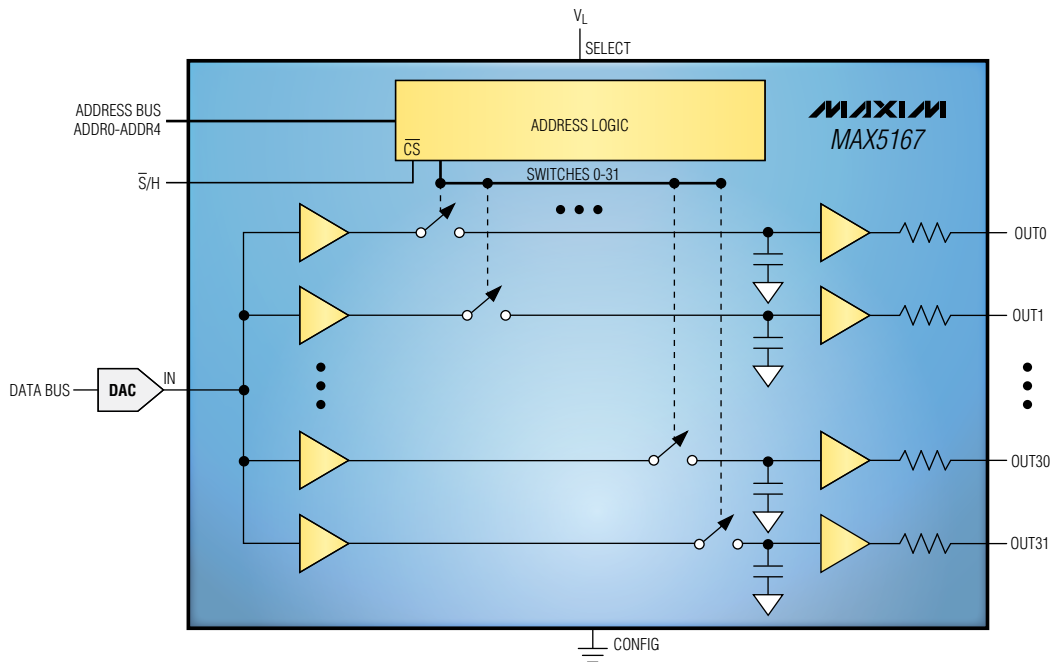
MAX5167

The MAX5167 contains 32 buffered sample/hold amplifier circuits with internal hold capacitors. The internal hold capacitors minimize leakage current, dielectric absorption, feedthrough, and required board space. The hold capacitors also provide fast 2.5 μ s (typ) acquisition time while maintaining a relatively low 1mV/s (typ) droop rate. This performance makes the MAX5167 sample/hold amplifier ideal for high-speed sampling.

The MAX5167 has five address lines as inputs to a demultiplexer which selects one of the 32 outputs. The analog input is connected to the addressed sample/hold amplifiers when directed by the control logic.

Benefits

- **Highly integrated and easy to design in**
 - 32-channel sample/hold
 - Output clamps on each channel
 - Wide +7V to -4V output voltage range
 - Cascade two MAX5167s to form 64 output channels
- **Unparalleled accuracy and linearity meet system error budget**
 - 0.01% accuracy of acquired signal
 - 0.01% linearity error
 - Fast 2.5 μ s acquisition time
 - Low 1mV/s droop rate
 - Low 0.25mV hold step



Block diagram of the MAX5167.

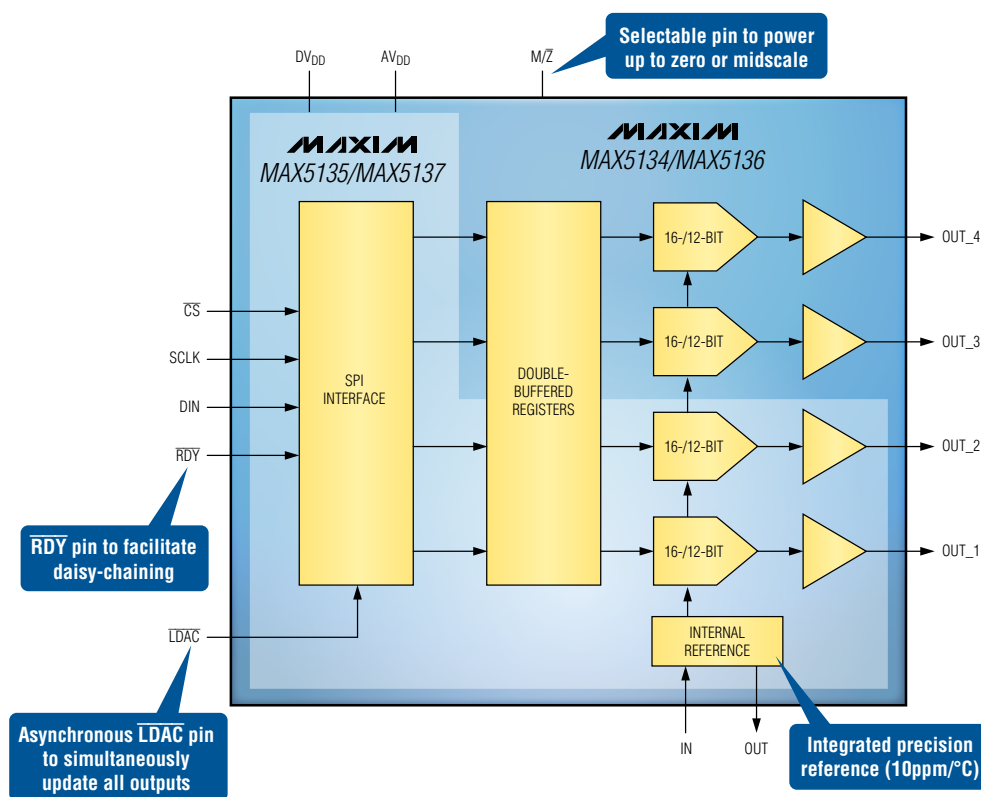
System flexibility and reduced cost with multichannel DACs

MAX5134/MAX5135/MAX5136/MAX5137

The MAX5134–MAX5137 are pin- and software-compatible, 16-bit and 12-bit DACs offering low power, buffered voltage output, and high linearity. They use a precision internal reference or a precision external reference for rail-to-rail operation. The MAX5134–MAX5137 accept a wide 2.7V to 5.25V supply-voltage range to accommodate most low-power and low-voltage applications.

Benefits

- **Flexible upgrade path**
 - 2-/4-channel, 16-/12-bit DACs are pin and software compatible
- **Save cost and board space**
 - Parts accept an SPI/QSPI™-/MICROWIRE™-/DSP-compatible serial interface
 - 4mm x 4mm package
 - A READY output enables easy daisy-chaining of several MAX5134–MAX5137 and other compatible devices
 - Double-buffered hardware and software LDAC provides simultaneous output updates
- **Improve safety**
 - Hardware input for resetting the DAC outputs to zero or midscale on power-up or reset



Block diagram of the MAX5134–MAX5137 DACs.

Programmable logic controllers (PLCs)

Analog output functions

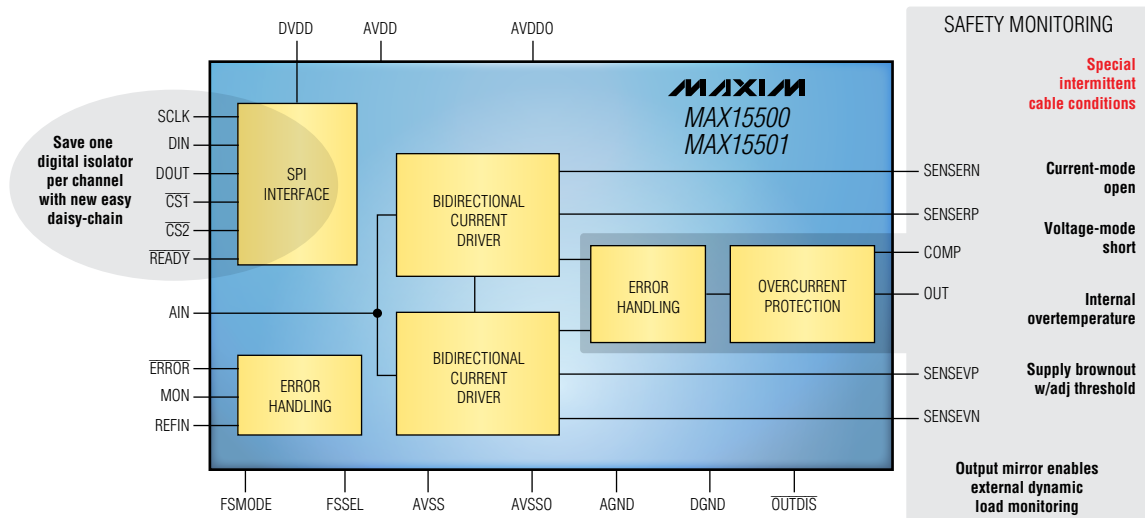
Enhance system safety and reliability with an output conditioner

MAX15500/MAX15501

The MAX15500/MAX15501 analog output conditioners provide a programmable current up to $\pm 24\text{mA}$, or a voltage up to $\pm 12\text{V}$ proportional to a control voltage signal. The control voltage is typically supplied by an external DAC with an output voltage range of 0 to 4.096V (MAX15500) and 0 to 2.5V (MAX15501). The output current and voltage are selectable as either unipolar or bipolar. The MAX15500/MAX15501 are programmed through an SPI interface capable of daisy-chained operation.

Benefits

- **Enhance reliability**
 - Outputs are protected against over-current conditions
 - Outputs are protected against a short to ground or supply voltages up to $\pm 35\text{V}$
- **Ease equipment installation and improve diagnostics**
 - Output current and voltage are selectable as unipolar or bipolar
 - Monitor for overtemperature and supply brownout conditions with programmable threshold
 - Extensive error reporting through the SPI interface and an additional open-drain interrupt output
 - Analog output to monitor load conditions



Block diagram of the MAX15500/MAX15501.

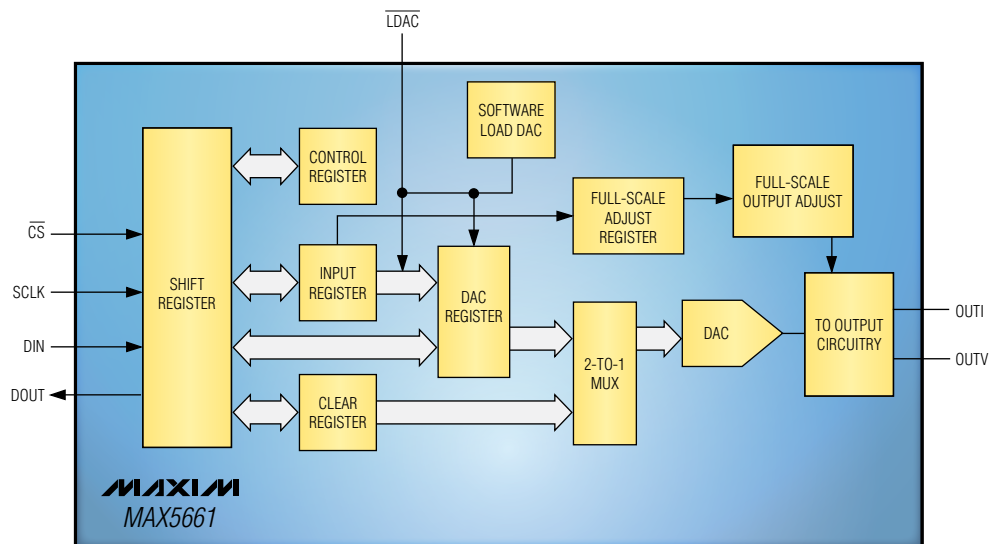
16-bit DAC with integrated voltage-and current-output conditioner reduces board area and eliminates external components

MAX5661

The MAX5661 DAC controls output voltage, output current, and output gain adjustments. This device reduces the challenges that designers face when laying out their analog and mixed-signal boards.

Benefits

- **Simplifies board design**
 - Software-selectable voltage output or current output
- **Eliminates external components**
 - Integrated output buffer
 - No additional discrete components required for switching between output modes
- **Improves system reliability**
 - Supports analog power supplies up to 37.5V



A simplified block diagram of the MAX5661.

Programmable logic controllers (PLCs)

Analog output functions

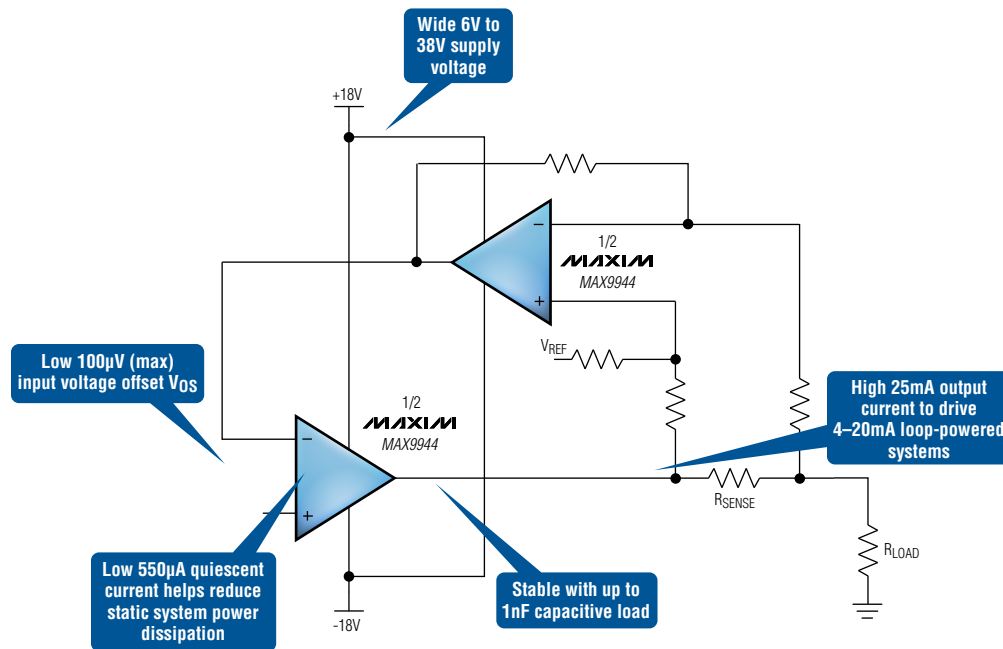
Improve system accuracy for high-voltage applications in a harsh environment with high-precision output conditioners and drivers

MAX9943/MAX9944

The MAX9943/MAX9944 are high-voltage amplifiers (6V to 38V) that offer precision ($100\mu\text{V}_{\text{OS}}$), low drift ($0.4\mu\text{V}/^\circ\text{C}$), and low $550\mu\text{A}$ power consumption. The devices are ideal for sensor signal conditioning, high-performance industrial instrumentation, and loop-powered systems (e.g., 4mA–20mA transmitters).

Benefits

- **Easily drive 24V 4–20mA lines throughout factory floors**
 - High supply-voltage operation and high-output drive exceed current-mode communication requirements



The MAX9944 accurately drives loads.

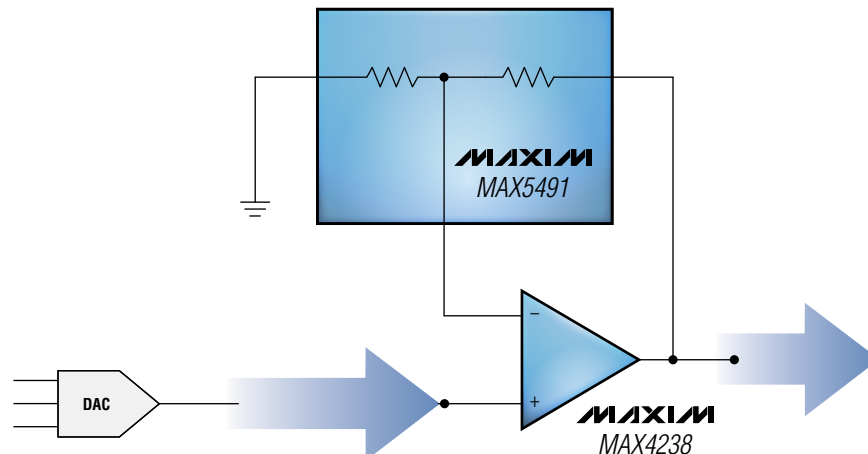
Resistor network saves cost and space without sacrificing system precision

MAX5490/MAX5491/MAX5492

The MAX5490 family of precision resistor-dividers consists of two accurately matched resistors with access to the ends and center of the divider. This family offers excellent resistance matching of 0.035% (A grade), 0.05% (B grade), and 0.1% (C grade). It includes an extremely low resistance-ratio temperature drift of 2ppm/°C over -40°C to +85°C, and has an end-to-end resistance of 30kΩ. Resistance ratios from 1:1 to 30:1 are available, as are ten standard ratios.

Benefits

- **Inexpensive and easy to use**
 - Up to 80V operating voltage across sum of R1 and R2
 - Resistance ratios from 1:1 to 30:1
 - Tight initial ratio accuracy
 - Three grades: 0.035%, 0.05%, and 0.1%
 - Low 2ppm/°C resistor-ratio drift
- **Saves board space**
 - Tiny 3-pin SOT23 package



Implementing a robust, precision analog output with the MAX5491.

Programmable logic controllers (PLCs)

Analog output functions

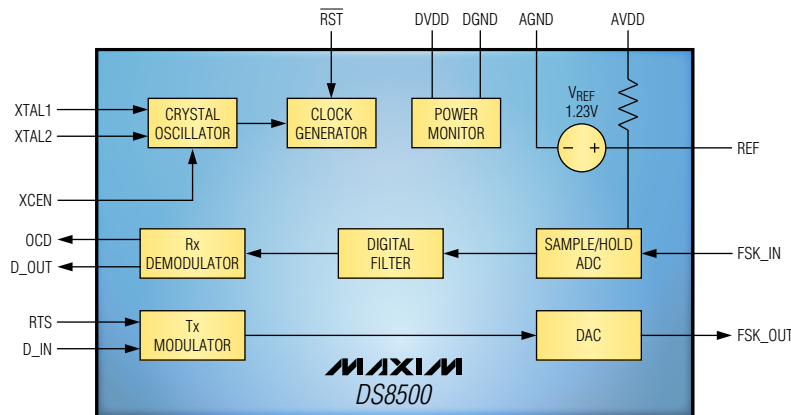
Save space in low-power process-control equipment with a single-chip HART modem

DS8500

The DS8500 is a single-chip modem with HART capabilities that satisfy the HART physical-layer requirements. This device operates in half-duplex fashion, and integrates the modulation and demodulation of the 1200Hz/2200Hz FSK signal while consuming very low power. It only needs a few external components because of the integrated digital-signal processing.

Benefits

- **Higher density due to low-power draw**
 - 285µA (max) current consumption
- **Saves space**
 - Fewest external components due to the built-in digital-receive filter
 - 20-pin, 5mm x 5mm x 0.8mm TQFN package
- **Easily available crystal**
 - Uses a standard 3.6864MHz clock input
- **Robust signaling due to lowest harmonic distortion**
 - Sinusoidal output signal



Block diagram of the DS8500.

Fieldbus functions

Overview

A fieldbus is the communication medium used in industrial automation systems and in process control to interconnect subsystems that are spatially dispersed. Distributed control allows local, hierarchical control. There is an important advantage of such a noncentralized control strategy: it avoids high processing power and extensive cabling. Control subsystems can be located close to the sensors and actuators in the field. An example of a fieldbus network is an automobile assembly line, where the fieldbus interconnects controllers located at each assembly stage.

Basic composition of a fieldbus

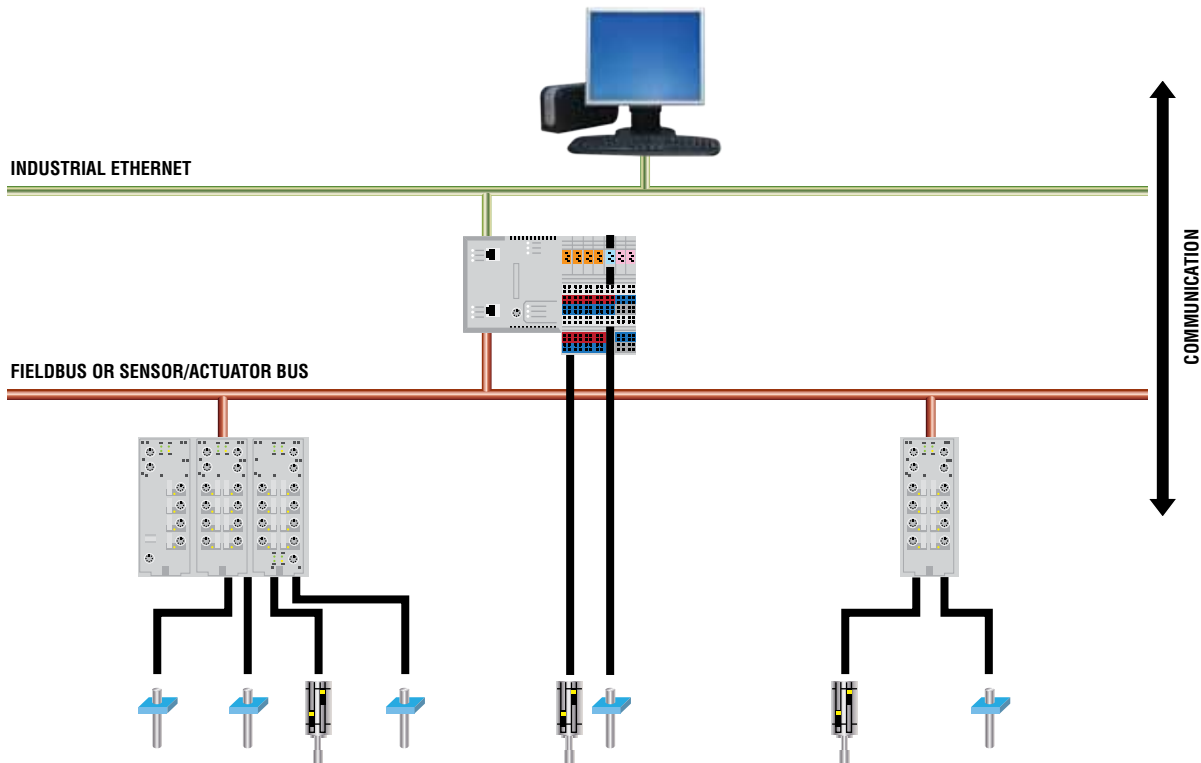
A PLC system has a hierarchical structure in which the upper levels of the fieldbus network use Ethernet-based networking. This hierarchy melds with the other corporate-management IT systems.

Fieldbuses are bidirectional, digital, serial networks. CANopen, CCLINK, ControlNet, DeviceNet, Ethernet, Interbus, Modbus®, and PROFIBUS are examples of fieldbus networks. PROFIBUS DP (decentralized peripheral) has become one of the most commonly used fieldbuses for factory automation. PROFIBUS DP is

primarily used to network multiple controllers in decentralized locations.

The physical layer of a fieldbus is commonly based on RS-485, CAN, and Ethernet. The fieldbus connects to a PLC subsystem with a fieldbus module, as shown below.

The fieldbus module bridges the PLC's system backplane to the fieldbus. The backplane, which is common to all modules in the PLC system, can be based on half- or full-duplex RS-485. RS-485 is ideally suited to backplane interconnect in industrial applications because of its high-EMI tolerance, high speed, and hot-plug capability.



The fieldbus supports communications throughout the factory.

Programmable logic controllers (PLCs)

Fieldbus functions

In the fieldbus module the controller converts the backplane protocol to the fieldbus protocol. Universal asynchronous receiver-transmitters (UARTs) define the fieldbus data rates, ensure data integrity, and interface to either the RS-485 or PROFIBUS transceivers.

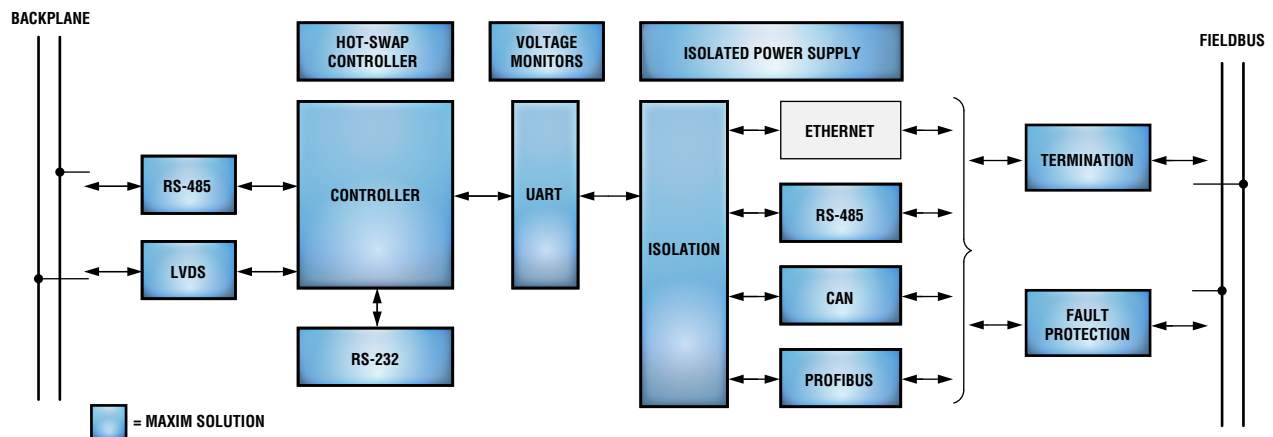
Harsh conditions typical of industrial applications can make protecting the interface cabling and devices a challenge. It is crucial, therefore,

that both the device(s) and system withstand harsh conditions. Only in this way can one ensure that the PLC system's signal integrity and system reliability are maintained.

To ensure that the system is protected in harsh industrial environments, PLC designers need to incorporate quite specific safeguards:

- Protection from high ESD: up to $\pm 35\text{kV}$ (HBM) and $\pm 20\text{kV}$ (Air Gap, IEC 61000-4-2)

- Fault protection: tolerance to shorts up to $\pm 80\text{V}$
- Isolation to allow large common-mode ground differentials
- Line termination to reduce reflections on the cables
- Automotive temperature grade (-40°C to $+125^\circ\text{C}$)



The fieldbus is connected to the PLC backplane by the fieldbus module. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Transceiver meets PROFIBUS DP standards and protects against $\pm 35\text{kV}$ ESD

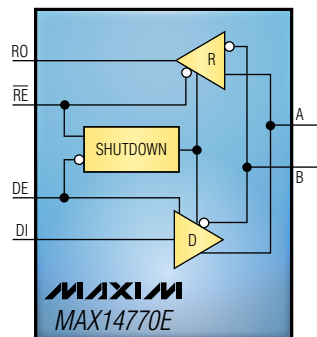
MAX14770E

The MAX14770E PROFIBUS DP transceiver meets strict PROFIBUS standards with a high-output-drive differential (greater than 2.1V) and an 8pF bus capacitance. The high-ESD protection ($\pm 35\text{kV}$, HBM), high-automotive-temperature grade, and space-saving 8-pin TQFN package make the MAX14770E ideal for space-constrained, harsh industrial environments.



Benefits

- **Easy to connect to PROFIBUS networks**
 - Meets EIA 61158-2 Type 3 PROFIBUS DP specifications
 - -40°C to $+125^{\circ}\text{C}$ temperature range for use in extreme conditions
- **Space-saving**
 - Tiny 8-pin, 3mm x 3mm TDFN package
- **Industry's highest ESD protection improves reliability**
 - $\pm 35\text{kV}$ Human Body Model (HBM)
 - $\pm 20\text{kV}$ IEC 61000-4-2 (Air Gap)
 - $\pm 10\text{kV}$ IEC 61000-4-2 (Contact)



Block diagram of the MAX14770E.

RS-485 transceivers with integrated termination simplify equipment installation

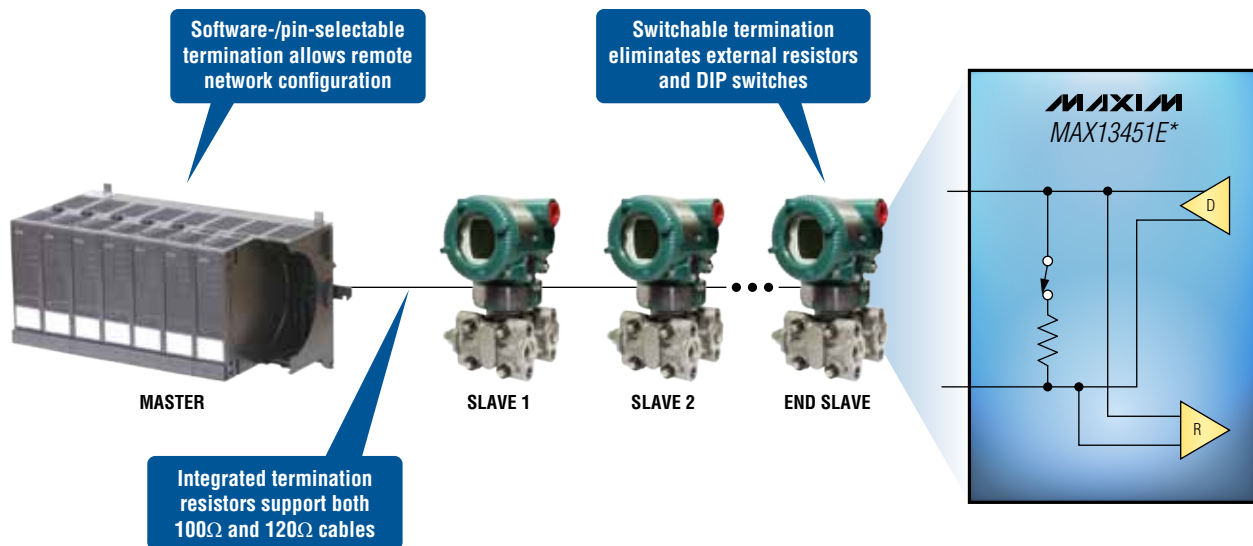
MAX13450E*/MAX13451E*

RS-485 half-duplex and full-duplex networks operating at high data rates must have their transmission lines terminated at both ends in order to minimize reflections from termination-impedance mismatch. To perform the termination, typically discrete resistors are either put into the equipment or added externally at the end-point devices on the line. Most commonly, 120Ω transmission lines are used in RS-485 applications. Recently, however, 100Ω lines have become preferred because they use Ethernet cables.

The new RS-485 transceivers like the MAX13450E/MAX13451E eliminate the need for external termination resistors because they integrate pin-selectable 100Ω/120Ω resistors. The integrated logic-level translation (V_L pin) provides compatibility with mixed-voltage systems.

Benefits

- **Flexible configurations interface to many applications, thus reducing inventory**
 - Pin-selectable 100Ω/120Ω termination resistors eliminate external components
 - Pin-selectable slew-rate limiting improves EMI performance
 - Integrated V_L pin (down to 1.62V) allows interfacing with mixed-voltage systems
- **Integrated protection is ideal for harsh environments**
 - Thermal shutdown at +150°C
 - Fail-safe operation
 - High ±30kV (HBM) ESD protection
- **Robust, -40C to +125°C automotive temperature grade**
- **Fault output warns user of short circuits**



RS-485 transceivers integrate all functions needed for robust industrial communications.

* Future product—contact factory for availability.

Isolated RS-485 transceiver reduces BOM complexity

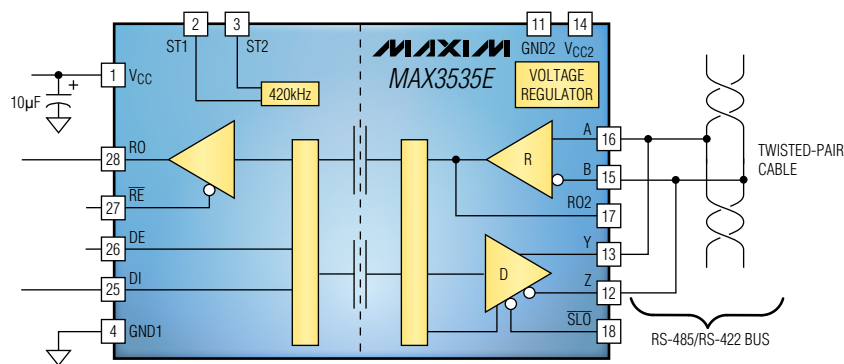
MAX3535E

Galvanic isolation between the PLC's backplane and the fieldbus is required due to the harsh conditions and large common-mode voltages that can occur between remotely located subsystems. Maxim offers RS-485 transceivers with integrated isolation based on capacitors, transformers, and optical techniques.

The MAX3535E RS-485 transceiver is designed for applications where galvanic isolation is required up to $\pm 2500V$. By integrating the full half-bridge driver and rectifier, the MAX3535E offers ease of use. It provides extended ESD protection up to $\pm 15kV$.

Benefits

- **Eliminates the need for external isolation circuitry**
 - $2500V_{RMS}$ RS-485 bus isolation using on-chip high-voltage capacitors
- **High-ESD protection up to $\pm 15kV$ ESD**
 - 3.0V to 5.5V operation for interfacing with multivoltage systems



Block diagram of the MAX3535E. Dashed line signifies isolation barrier.

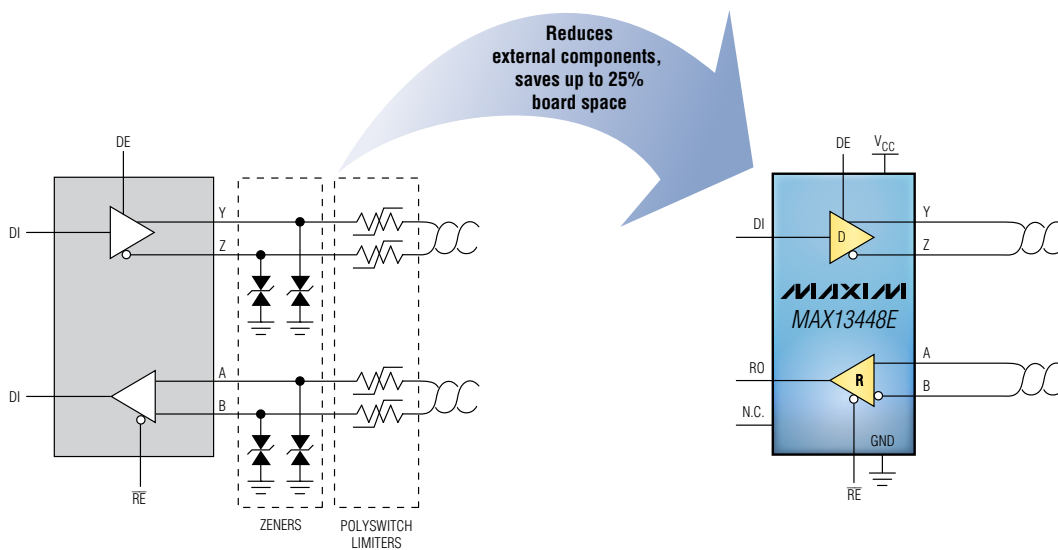
Fault-protected RS-485 transceivers make equipment more robust

MAX13448E, MAX3440E–MAX3444E, MAX13442E/MAX13443E/MAX13444E, MAX3430

In applications where power and data are distributed over the same cable, there is a potential for miswiring, cable shorts, or surges on the communication bus. Maxim's RS-485 MAX13448E, MAX13442E, MAX3430, and MAX3440E transceiver families offer fault protection up to $\pm 80V_{DC}$.

Benefits

- **Reduce board space by 25% with integrated fault-protection circuitry**
- **Highest fault protection from an integrated transceiver**
 - Fault protection up to $\pm 80V_{DC}$
- **Flexible configurations allow interfacing with multiple systems**
 - Wide 3.3V to 5V supply range allows interfacing with full- and half-duplex RS-485
- **High integration reduces Bill of Materials (BOM) complexity**
 - Slew-rate limiting facilitates error-free data transmission
 - True fail-safe operation
 - Hot-swap capability
- **ESD protection up to $\pm 15kV$ (HBM)**



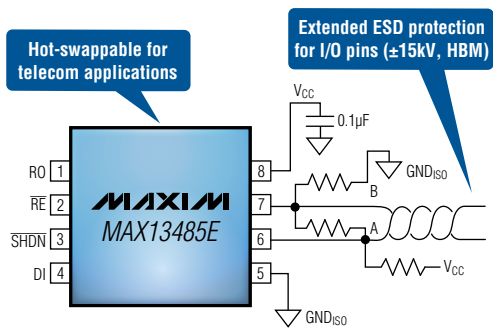
Part	V _{CC} Supply (V)	Configuration	Fault Protection (V)
MAX13448E	3.3 to 5	Full	± 80
MAX3440E–MAX3444E	5	Half	± 60
MAX13442E–MAX13444E	5	Half	± 80
MAX3430	3.3	Half	± 80

Maxim's RS-485 family offers high levels of integration which saves board space and reduces cost.

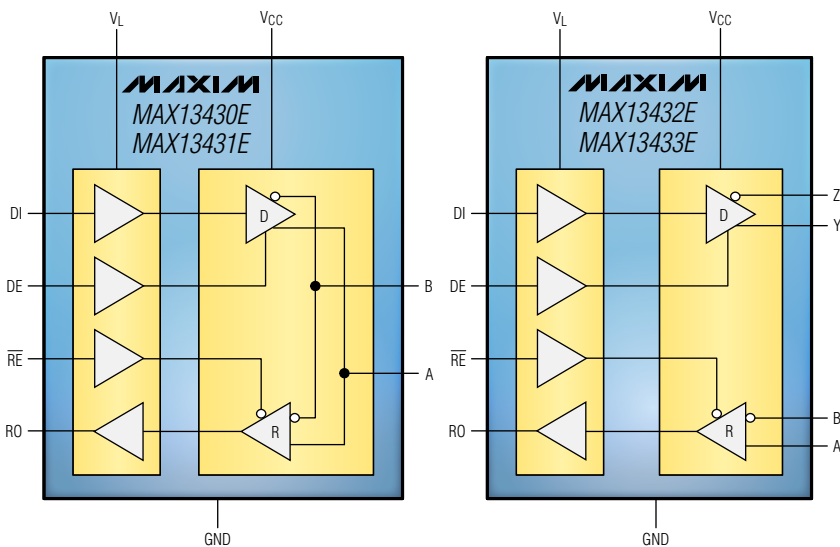
Industry's smallest RS-485 transceivers save board space and reduce BOM complexity

MAX13485E/MAX13486E, MAX13430E–MAX13433E

As industrial modules become smaller, pressure mounts for PLC designers to shrink their PCBs and transition from the traditional industry-standard packages like SO, SSOP, and PDIP. Maxim offers a full family of RS-485 transceivers available in tiny μ DFN/TDFN packages with integrated features that reduce BOM complexity, board space, and cost.



Packaged in a μ DFN, the MAX13485E saves more than 50% board space compared to the competition.



Typical operating circuits of the MAX13430E product family.

Benefits

MAX13485E/MAX13486E

- **Smallest footprint enables compact designs**

- Space-saving, tiny 8-pin μ DFN (2mm x 2mm) package

- **High integration reduces BOM complexity**

- Hot-swap operation eliminates false transitions during power-up/live insertion
- Enhanced slew-rate limiting facilitates error-free data transmission
- Low-power shutdown modes reduce power consumption during idle operation

MAX13430E–MAX13433E

- **Smallest footprint enables compact designs**

- Available in tiny 10-pin TDFN/ μ MAX[®] (3mm x 3mm) packages

- **Flexible configurations for interfacing to many applications, thus reducing inventory**

- Wide 3V to 5V supply reduces need for 5V supply
- Integrated V_L pin allows interface with low-voltage logic (down to 1.62V logic) field-programmable gate arrays (FPGAs) and application-specific ICs (ASICs)
- Enhanced slew-rate limiting facilitates error-free data transmission
- High ± 30 kV (HBM) ESD protection provides the industry's most robust protection

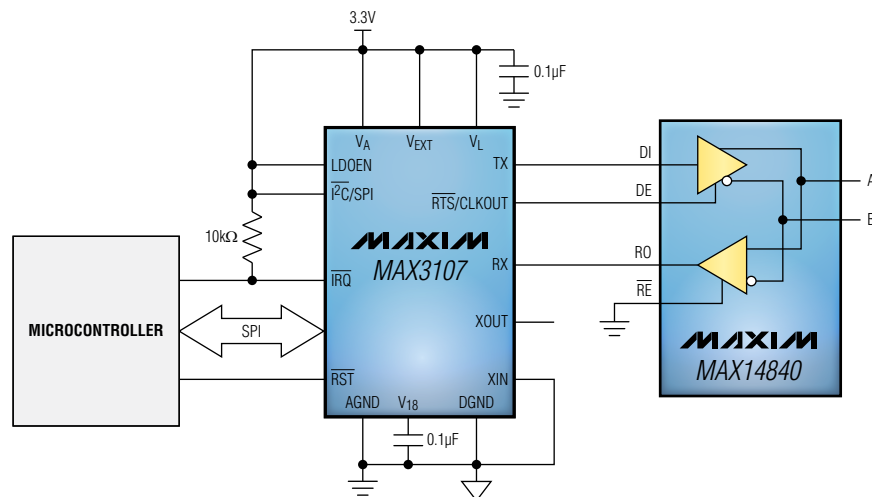
Advanced SPI/I²C UART enhances system flexibility and functionality, reduces load on the microcontroller

MAX3107

The MAX3107 serial UART bridges SPI or I²C to an asynchronous communication interface like RS-485, RS-232, PROFIBUS DP, or IrDA®. RS-485 and PROFIBUS DP work up to high data-rates which many UARTs embedded on today's microcontrollers cannot support. With two 128-word FIFOs and an integrated oscillator, this UART requires only a simple host controller for high-speed operation. Working at these high rates, the MAX3107 supports today's demanding high-speed applications.

Benefits

- **Reduces cost of high-speed communication interfaces**
 - 128-byte FIFOs
 - Automatic half-duplex transceiver control
 - High 24Mbps (max) data rates
- **High integration saves cost and space**
 - Integrated oscillator reduces need for an external crystal
- **Advance on-board clocking allows near-limitless baud-rate generation**
 - Integrated PLL, divider, and a fractional baud-rate generator yield high accuracy and freedom in baud-rate programming
- **Enables high density and compact PLC designs**
 - Tiny 24-pin, TQFN (3.5mm x 3.5mm) and standard SSOP packages



The MAX3107 in an RS-485 half-duplex application.

Digital I/O functions

Overview

Digital I/Os interface to industrial sensors and actuators and communicate with digitized information. The sensors and actuators are located in the field and, thus, are represented on the lowest level of the control system's hierarchy. In contrast to analog I/O modules, digital I/O modules send or receive digitized information, which is either 1-bit (binary) information or quantized values. The information flow can be uni- or bidirectional, depending on the interface type.

There is a significant advantage to using digitized information: digitized data is more tolerant of noise. This is important, because interference on the programmable-logic-controller

communication link is higher than typically found with analog communication. Consequently digital I/O functions allow longer cable runs at low data rates.

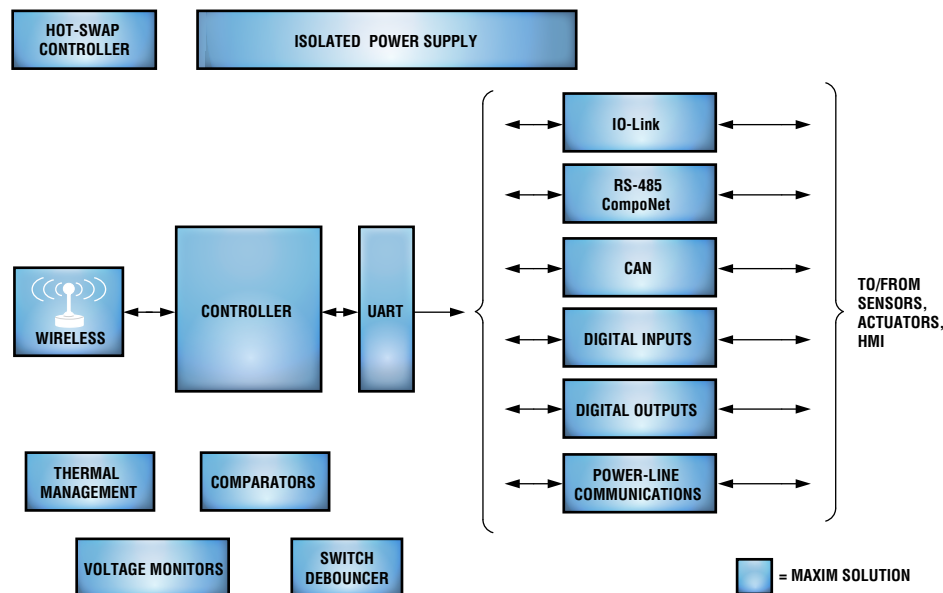
Interface types

Common digital interfaces are 24V digital I/Os. The 24V digital interfaces are unidirectional and based either on two-, three-, or four-wire cabling. A 24V digital I/O provides both the 24V and ground supplies to the sensor/actuator, as well as one or two (unidirectional) data lines.

IO-Link® is a new sensor/actuator interface technology based on 24V I/Os. In an IO-Link system the data line is bidirectional and supports data rates up to 230kpbs. The IO-Link

point-to-point interface connects one sensor or actuator to one digital I/O port. Remote configuration, diagnostics, and monitoring of the peripherals is enabled with intelligent and configurable sensors.

The CompoNet® network uses RS-485 differential signaling to communicate with sensors and actuators at high data rates. A master-slave network, CompoNet allows one master to control up to 384 slaves. Optional 24V powering of up to 5A is allowed over the same cable. The sensors and actuators are typically powered by a 24V supply, which is isolated from the system's backplane. This function is shown on the block diagram in the *Isolated power-supply functions* section below.



With an industrial digital I/O interface, 1-bit or quantized data flow to and from the sensors and actuators is easy. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

IO-Link master transceiver enables high-density IO-Link masters

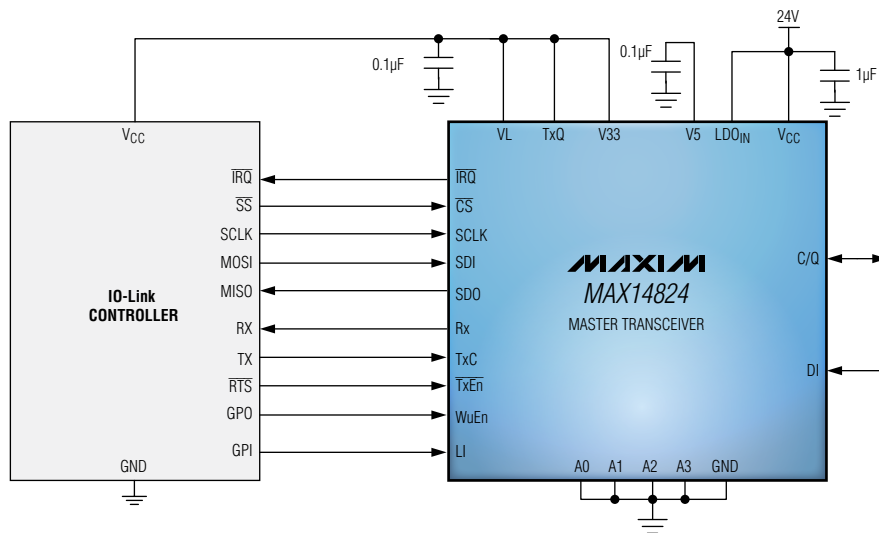
MAX14824*

The MAX14824 is an IO-Link master transceiver designed for high-channel-count IO-Link port-count applications. The MAX14824 integrates an IO-Link physical interface with an additional digital input and two regulators. A high-speed 12MHz SPI interface allows fast programming and monitoring of the IO-Link interface. A slave transceiver is located on the sensors/actuators.

The MAX14824's in-band addressing and selectable SPI addresses enable multiple devices to be cascaded. The device supports the standard IO-Link data rates and features slew-rate selection to reduce EMI. The driver is guaranteed to drive up to 300mA (min) load currents. Internal wake-up circuitry automatically determines the correct wake-up polarity, thus allowing the use of simple UARTs for wake-up pulse generation. The MAX14824 is available in a 4mm x 4mm, 24-pin TQFN and operates over the extended -40°C to +85°C temperature range.

Benefits

- **Optimal digital I/O solution lowers cost for high-port-count IO-Link systems**
 - SPI in-band addressing reduces hardware costs
 - Digital input enables high-density, digital-input designs
- **High-power drive allows use in digital outputs**
 - 300mA drive current drives high-power valves
- **High integration reduces load on processor**
 - Automatic wake-up generation allows use of simple processors



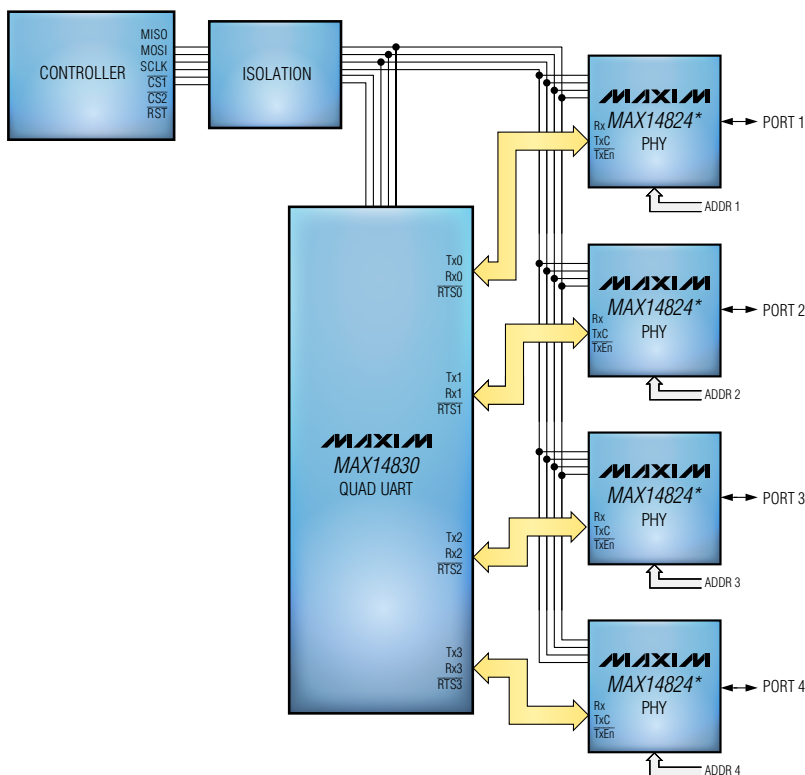
A MAX14824 block diagram of an IO-Link transceiver interfacing to an IO-Link controller to enable 24V, high-speed, bidirectional digital communication.

* Future product—contact factory for availability.

Simplest, most economical solution for high-port-count IO-Link systems

MAX14830*

The MAX14830 is an advanced quad, serial UART with 128-word FIFOs for high-port-count I/O systems like an IO-Link system. By reducing the number of signals that need be isolated, the serial I²C/SPI host interface is optimized for industrial systems that require galvanic isolation. Many advanced UART and transceiver control features remove timing-critical tasks from the host controller.



Block diagram of the MAX14830 quad UART.

Benefits

- **Intelligent features lower BOM cost**
 - A scalable architecture based on only one host controller eases software development and reduces cost
 - Handles most low-level transceiver control autonomously, reducing the need for powerful and expensive controllers
 - Reduces isolation needs, which eliminates the need for expensive isolation components
 - Small 48-pin, 7mm x 7mm TQFN package enables small, high-port-count systems
- **Advanced clocking scheme simplifies baud-rate generation**
 - Internal oscillator reduces need for external crystal and lowers cost
 - Integrated PLL, divider, and fractional baud-rate generator allow considerable flexibility in baud-rate programming and independence of reference clock, thus simplifying clock design
 - Four timers produce programmable clock outputs, which mitigate the need for and cost of LED blinking

* Future product—contact factory for availability.

CPU functions

Overview

The CPU functions for a PLC include the processor, memory, and support circuitry required to execute the programmed instructions and communicate with the various I/O functions.

System monitoring functions are performed by the CPU's power-supply voltage monitors; watchdog timers (WDTs) and reset circuits; and thermal monitors for critical devices and hot spots. The CPU module also includes components

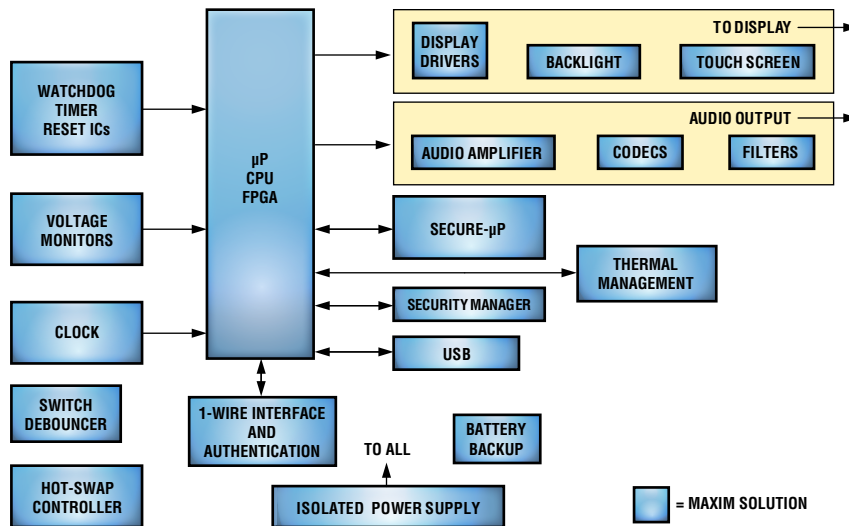
to enable communications to other modules, PLCs, PCs, and the human interface (e.g., switch debounce, displays, audio). Isolated power supplies, hot-swap controllers, and battery backup combine for power management.

Security functions

Security and authentication components prevent unauthorized system control or access to system data. The complexity of security components varies depending on the level of security required. Typical security

components include security managers with tamper detection and nonimprinting memory, secure microcontrollers with authentication, and 1-Wire® authentication devices with an integrated SHA-1 algorithm.

Secure components require several specific features, including tamper detection; fast-erasing memory for storage of secret data; analysis-resistant encryption engines; and support for PCI PED 2.1, FIPS 140.2 (level 3 and above), EMV® 4.1, and Common Criteria requirements.



Block diagram of PLC CPU functions. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Smallest secure microcontroller minimizes system size

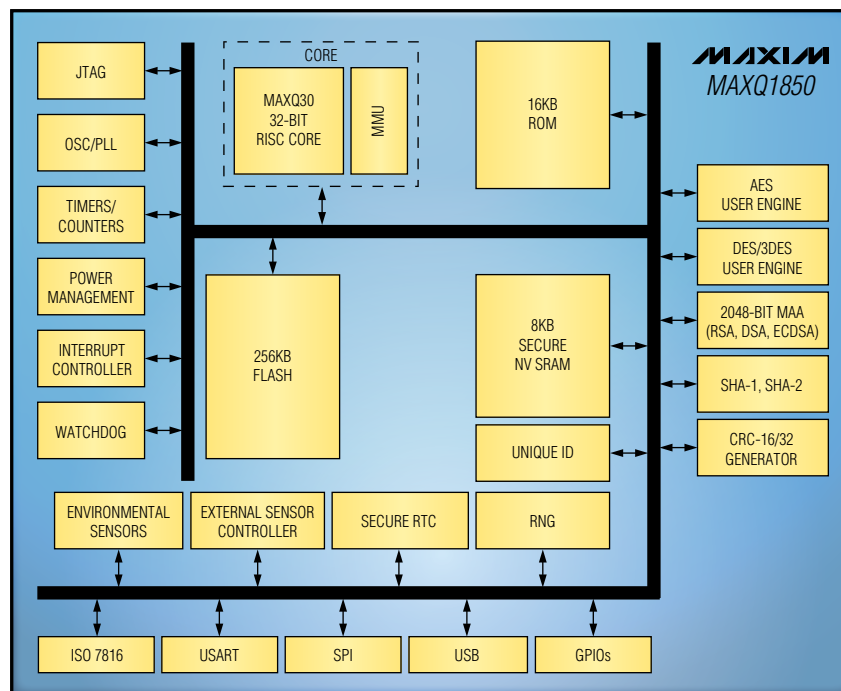
MAXQ1850

The MAXQ1850 is the industry's smallest, high-security microcontroller. This single-cycle RISC processor executes 16-bit instructions and uses a 32-bit data path for unmatched processing efficiency and C code optimization. With hardware-accelerated symmetric and asymmetric encryption routines, it has the flexibility to be a stand-alone controller or a coprocessor depending on the secure application's requirement.

System cost is highly optimized with integrated active tamper sensors. These sensors detect and react to attacks by erasing the internal, secure 8KB battery-backed nonvolatile SRAM. The microcontroller only uses 130nA to back up the secure SRAM and operate the tamper sensors.

Benefits

- **Improve system security**
 - Cryptographic hardware accelerators for RSA, DSA, ECDSA, SHA-1, SHA-2, AES, DES, and 3DES
 - Security supervisor provides tamper detection and response
 - Cryptography engine execution at 65MHz
- **Smallest board space requirement**
 - 6mm x 6 mm, 40-pin TQFN package
 - 7mm x 7mm, 49-ball CSBGA package



Block diagram of the MAXQ1850.

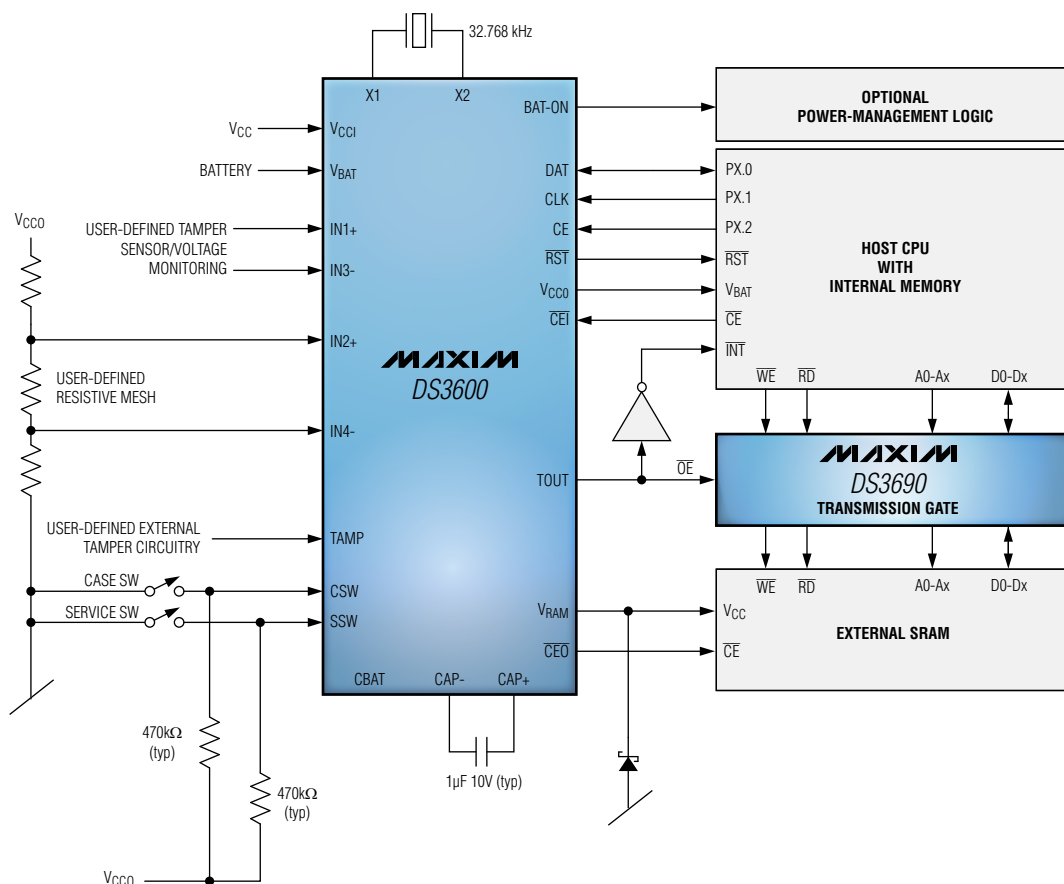
Security managers protect encryption keys from intruders

DS3600

Security managers provide comprehensive data protection. The DS3600 single-chip solution provides security, tamper detection, encryption key storage, and encryption key destruction in the event of tampering. The DS3600 is packaged in a CSBGA for an added level of security.

Benefits

- **Improved system security**
 - Supports the highest security-level requirements of the FIPS 140.2, Common Criteria, PCI PED, and EMV 4.1 certification agencies
 - Multilevel tamper detection
 - Keys and/or other critical data are immediately and completely erased as a response to a qualified tamper
 - Patented on-chip nonimprinting memory*



The DS3600 secure supervisor in a typical security application.

*U.S. Patent #7,379,325.

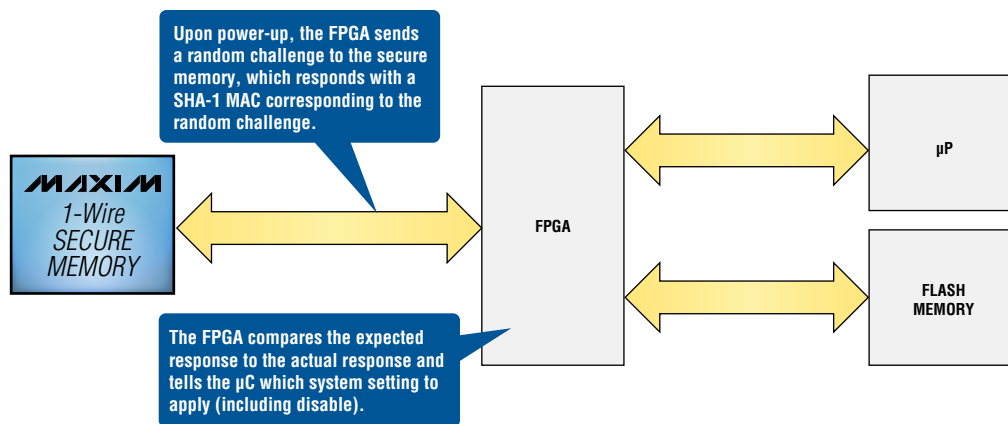
1-Wire SHA-1 authenticators securely protect control modules from unauthorized cloning or feature modification

DS28E01-100, DS28E02, DS28E10

1-Wire secure memories utilize a SHA-1-based, crypto-strong, secure challenge-and-response authentication sequence. Thus authentication enables FPGAs and CPUs to differentiate between authorized and cloned environments. The determination of authorized or cloned either sets the system to normal operation, or disables the module to protect the design investment from being copied. Additionally, module operational features set with EPROM data values are SHA-1 protected against unauthorized modification.

Benefits

- **Improved system security**
 - Crypto-strong authentication based on FIPS 180-3-defined SHA-1
 - Sophisticated physical security protects against die-level attacks
 - Protected NV EPROM or one-time-programmable (OTP) memory for data storage
 - Optional, confidential preprogramming of customer-defined secure data by Maxim*
- **Minimal I/O pin and resource impact on the FPGA or CPU design**
 - Consumes only one I/O pin for total operation
 - Single dedicated contact for communication and power
 - Small code/gate/memory footprint for CPU and FPGA implementation



Block diagram of FPGA secure authentication using a 1-Wire secure memory device.

* For more information, please see: application note 4594, "Protect Your FPGA Against Piracy: Cost-Effective Authentication Scheme Protects IP in SRAM-Based FPGA Designs"; application note 3826, "Xilinx® FPGA IFF Copy Protection with 1-Wire® SHA-1 Secure Memories"; and 1-Wire FPGA Security Flash™ Tutorial FPGA Security, Flash™ tutorial.

Isolated power-supply functions

Overview

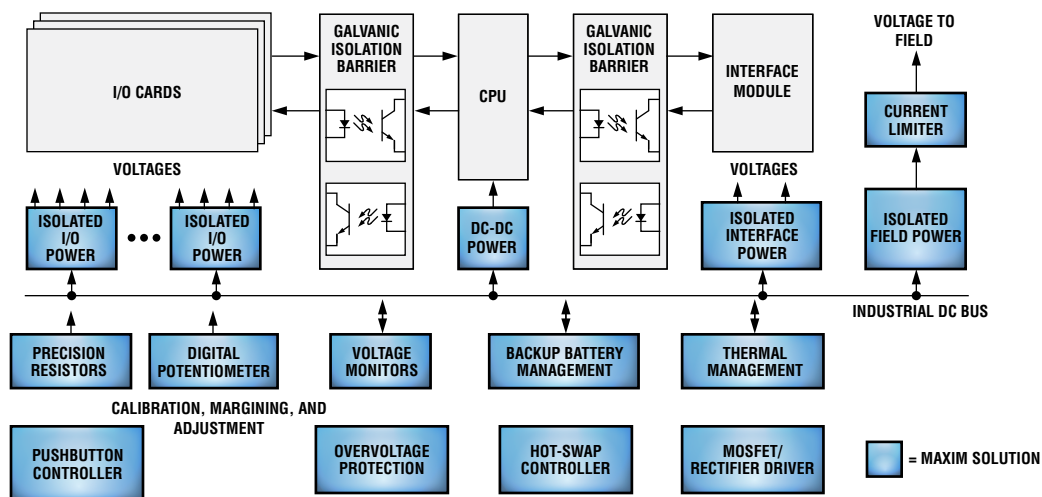
Typically PLCs have a backplane power rail of about 24V DC, although the actual voltage can differ, usually from 12V to 48V. The power comes from an isolated DC-DC converter connected to a factory AC-DC supply. A PLC can be equipped with an auxiliary battery with a special OR-ing controller. Together, this configuration forms an uninterruptible power supply (UPS) to ensure continued operation in the event of an AC power-line brownout or failure. During AC faults the battery supplies the power rail to the backplane.

Power functions

The whole PLC power network is quite complicated with a variety of protection, isolation, and post-regulation functions. This power function can also be duplicated in a system to allow hot backup and hot-swapping in case of a power fault.

PLC functions take power from the power rail and are organized into separate functional modules that have hot-swap controllers to prevent inrush current surges during hot installation/removal. The modules' power inputs can usually withstand

a higher voltage than the power rail, because high-voltage spikes can occur at those inputs. Each functional module has its own local converters to generate regulated 5V, 3.3V, and other local power rails. The CPU typically requires even lower voltages for a high-performance controller's core and/or FPGA. Analog I/Os can require $\pm 15V$ or higher voltages for op amps and/or analog-output conditioners. A PLC can also provide a regulated power output of 24V for smart sensors, other remote equipment, and analog current-loop interfaces.



Block diagram of isolated power-supply functions. For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

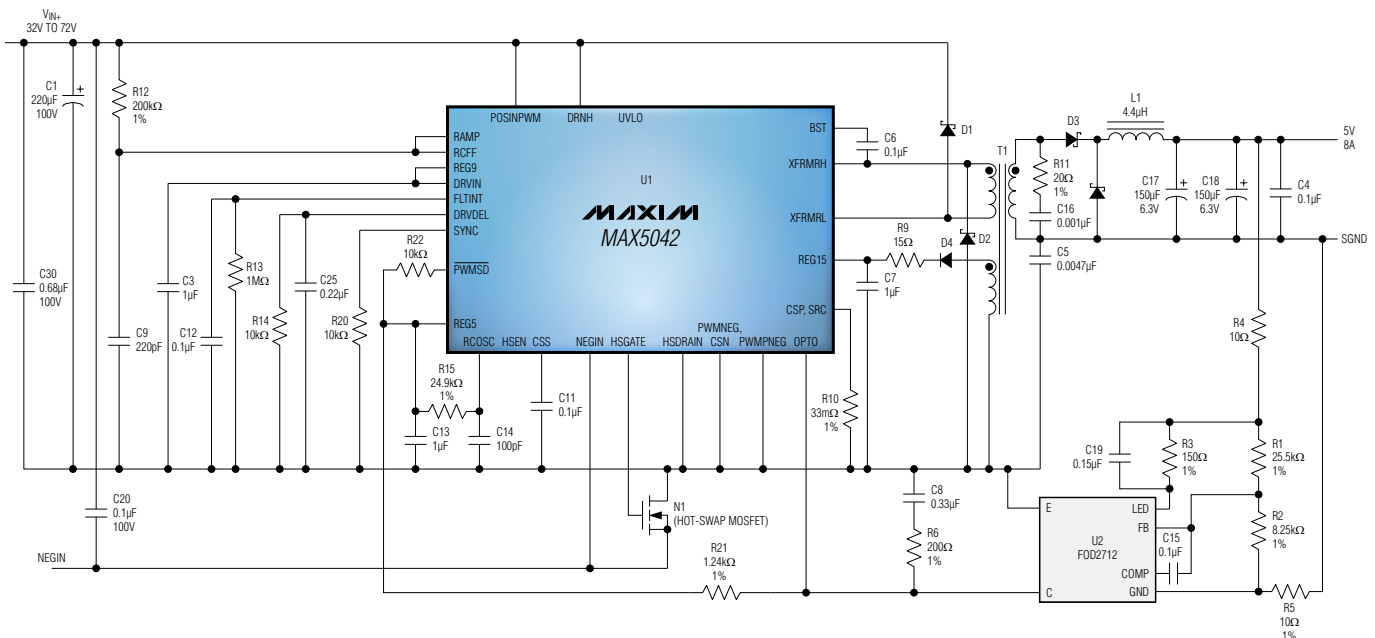
Simplify industrial-bus power design with integrated hot-swap controllers and FETs that power devices

MAX5042/MAX5043

The MAX5042/MAX5043 are isolated, multimode, pulse-width-modulated (PWM) power ICs. They feature integrated switching power MOSFETs connected in a voltage-clamped, two-transistor, power-circuit configuration. These devices operate from a wide 20V to 76V input voltage range. The MAX5042 includes a hot-swap controller to plug into a live power backplane with a MAX5058/MAX5059 rectifier driver. Operating at up to a 500kHz switching frequency, these devices provide up to 50W of output power.

Benefits

- **Eliminate external components to simplify power design**
 - Connect directly to the industrial backplane across a wide voltage range
- **Cut costs by eliminating external hot-swap controller and switch**



MAX5042 typical application circuit, a 48V power supply with hot-swap capability.

Programmable logic controllers (PLCs)

Isolated power-supply functions

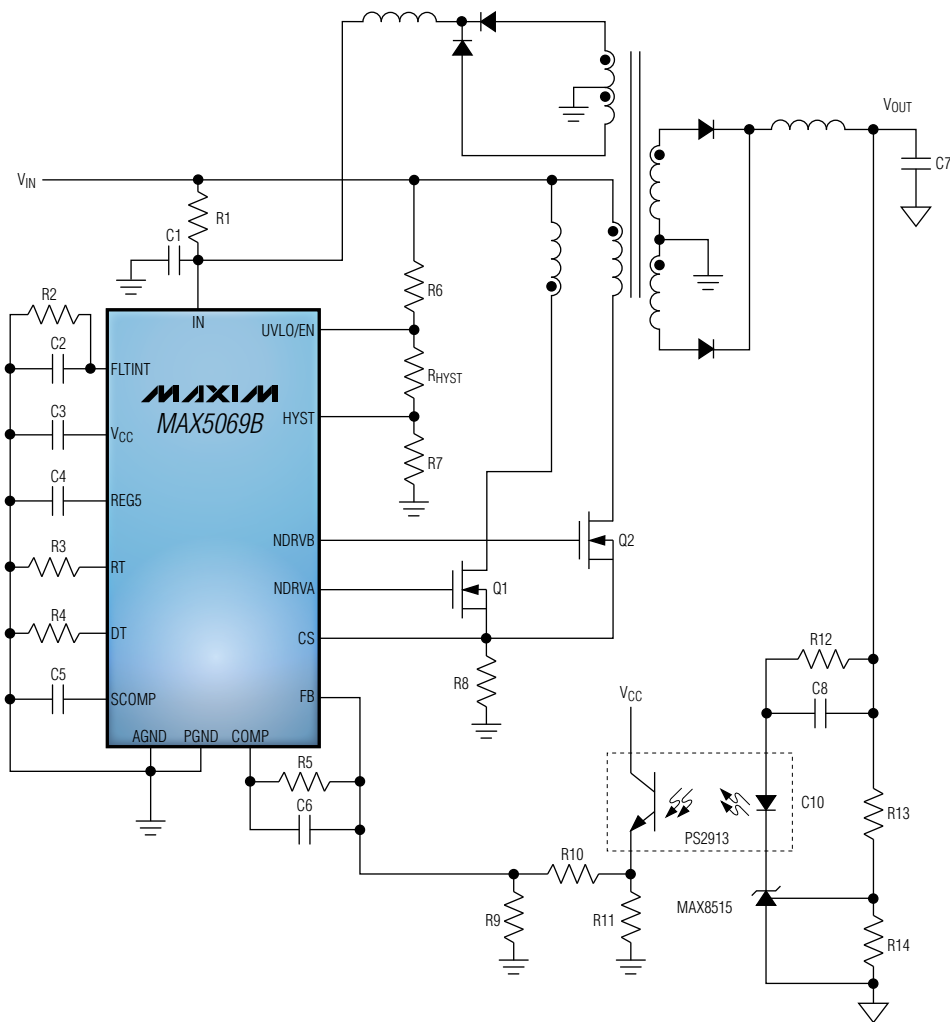
Reduce system downtime with current-mode PWM controller with integrated hot-swap

MAX5069

The MAX5069 is a high-frequency, current-mode PWM controller with dual MOSFET drivers. The IC integrates everything necessary for implementing AC-DC or DC-DC fixed-frequency power supplies. Isolated or nonisolated, push-pull and half-/full-bridge power supplies are easily constructed using either primary- or secondary-side regulation. An input undervoltage lockout (UVLO) programs the input-supply startup voltage and ensures proper operation during brownout conditions. The MAX5069 operates at over 100W.

Benefits

- Simplifies design by supporting high-load currents
- Cut costs by eliminating external hot-swap controller and switch



Secondary-side, regulated, isolated power supply. The dashed line encompasses both functions of the optoisolator.

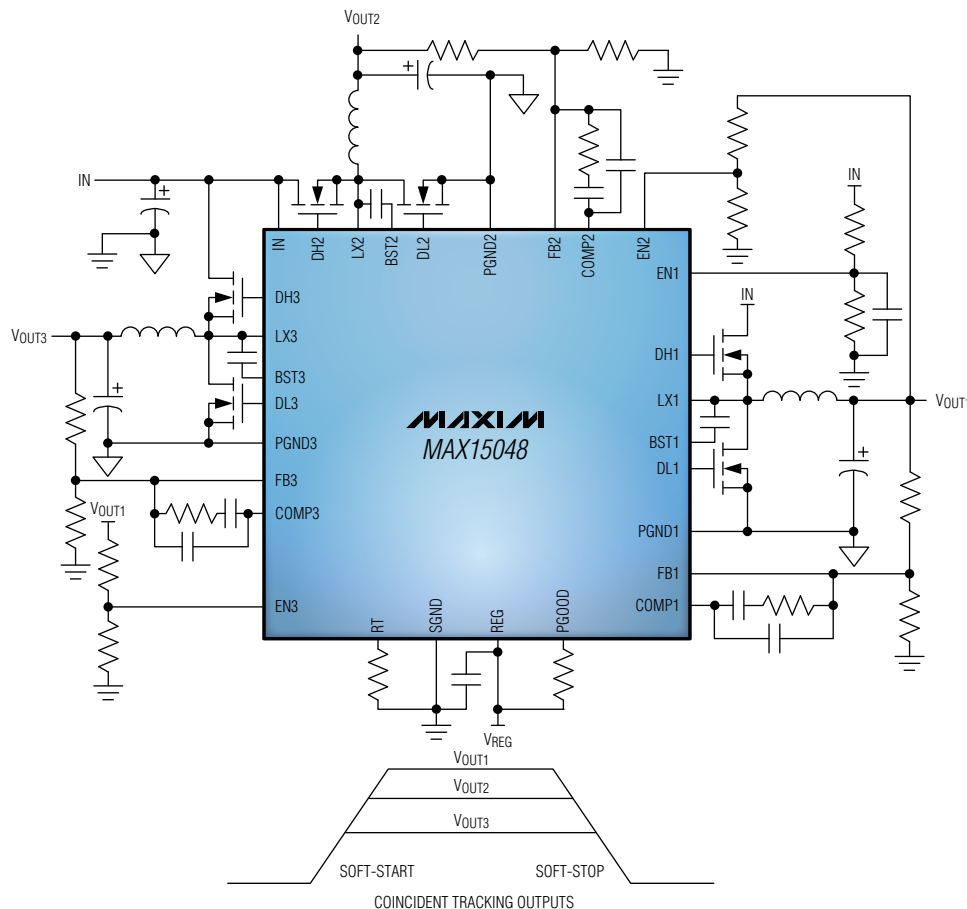
Save space and costs by integrating three switching controllers

MAX15048/MAX15049

The MAX15048/MAX15049 are triple-output, PWM, step-down DC-DC controllers with tracking (MAX15048) and sequencing (MAX15049) options. The devices operate over the 4.7V to 23V input voltage range. Each PWM controller provides an adjustable output down to 0.6V and delivers up to 15A of load current with excellent load and line regulation. The options of coincident or ratiometric tracking (MAX15048) or output sequencing (MAX15049) allow tailoring of the power-up/power-down sequence, depending on the system requirements.

Benefits

- Simplify design of power supplies for CPUs and FPGAs with built-in tracking and sequencing
- Handle high-load currents seamlessly with an external switch



Typical operating circuit of the MAX15048.

Programmable logic controllers (PLCs)

Isolated power-supply functions

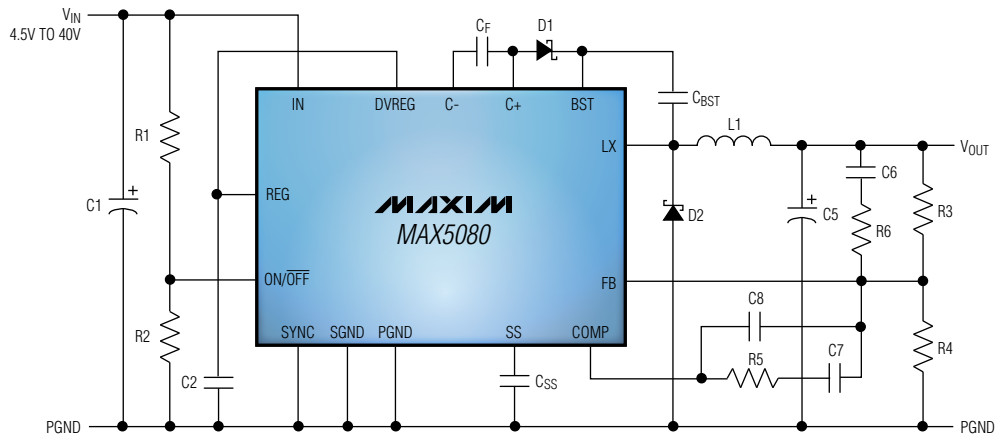
Save cost with integrated DC-DC converters that power off an industrial bus

MAX5080/MAX5081

The MAX5080/MAX5081 are 250kHz, PWM, step-down DC-DC converters with an on-chip high-side switch. The input voltage range is 4.5V to 40V for the MAX5080 and 7.5V to 40V for the MAX5081. The devices' output is adjustable from 1.23V to 32V and can deliver up to 1A of load current. Both devices utilize a voltage-mode control scheme for good noise immunity in a high-voltage switching environment. External compensation allows maximum flexibility with a wide selection of inductor values and capacitor types.

Benefits

- **Simplify design by connecting directly to an industrial power backplane**
- **Save cost by integrating switches and voltage-mode controller**



Typical operating circuit for the MAX5080.

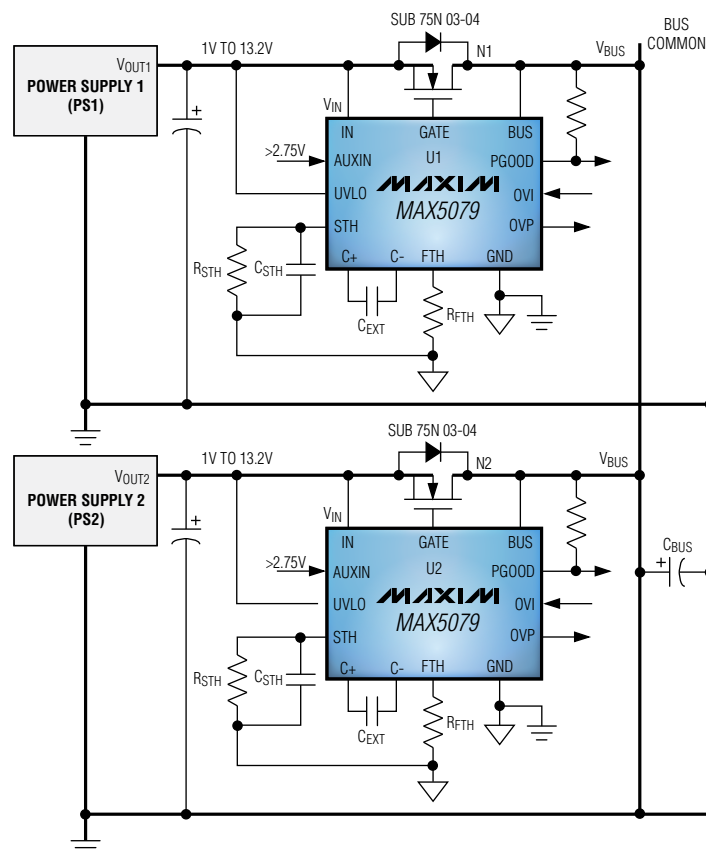
OR-ing FET controller supports main and battery-backup power to improve system reliability

MAX5079

The MAX5079 OR-ing MOSFET controller replaces OR-ing diodes in high-reliability, redundant, parallel-connected power supplies. The controller allows the use of low- R_{ON} , n-channel power MOSFETs to replace Schottky diodes. The MAX5079 operates from 2.75V to 13.2V and includes a charge pump to drive the high-side n-channel MOSFET. Operating over the -40°C to $+85^{\circ}\text{C}$ temperature range, the MAX5079 is available in a space-saving 14-pin TSSOP package.

Benefits

- **Eliminates expensive external components**
 - Build redundant systems without the power-dissipation disadvantages of Schottky diodes
- **Reduces costs**
 - Low-power dissipation
 - Smaller size in space-saving TSSOP package
 - Eliminates heatsinks for high-power applications



Typical operating circuit for the MAX5079 supporting a main and backup power supply.

Programmable logic controllers (PLCs)

Isolated power-supply functions

Simplify isolated power-supply design with a highly integrated transformer driver

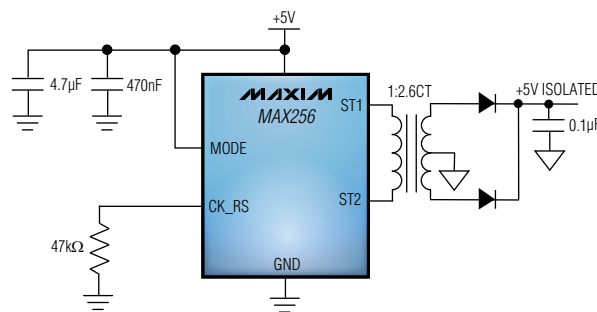
MAX256

For systems that require a low-watt, isolated power supply, a typical closed-loop switching regulator can add unnecessary cost and complexity. The MAX256 simplifies an isolated power-supply design. It is easily used for implementing an unregulated, full-bridge forward converter with an output power of up to 3W from an input voltage of 3V to 5.5V.

The device integrates an on-board oscillator, protection circuitry, and internal FET drivers to provide up to 3W of power to the primary winding of a transformer. The MAX256 operates with an internal programmable oscillator, or it can be driven by an external clock for improved EMI performance. The MAX256 is available in an 8-pin, thermally enhanced SO package. The device is specified for the -40°C to +125°C automotive temperature range.

Benefits

- **Integrated protection circuitry prevents system-level failures**
 - Thermal shutdown
 - Undervoltage lockout (UVLO)
 - Watchdog protection in clock circuitry
- **Internal/external clocking modes allow system performance to be optimized**
 - Integrated internal oscillator eliminates the need for an external clock/oscillator
 - External clock-synchronization mode improves EMI performance
- **Integrated push-pull drivers reduce BOM complexity and board space**



The MAX256 can be used in an unregulated 3W power supply.

Recommended solutions

Analog input function

Part	Description	Features	Benefits
Active filters			
MAX7409/10 MAX7413/14	5th-order, switched-capacitor, lowpass filters (Bessel or Butterworth)	Clock or capacitor-adjustable corner frequency to 15kHz; 1.2mA supply current	Save space over discrete implementations
MAX7422–MAX7425	5th-order, switched-capacitor, lowpass filters (elliptic, Butterworth, or Bessel)	Clock or capacitor-adjustable corner frequency to 45kHz; 3mA supply current; 8-pin μ MAX package	Save space over discrete implementations
MAX274/75	4th-order/8th-order, 150kHz/300kHz lowpass/bandpass filters	Resistor programmable; continuous-time filters; -86dB THD	Ease anti-aliasing filtering
ADCs			
MAX11040	24-bit, 4-channel, simultaneous-sampling sigma-delta ADC	64ksps; internal reference; 38-pin TSSOP package	Reduces firmware complexity, capturing accurate phase and magnitude information on up to 32 channels
MAX11200*–MAX11203*, MAX11205*–MAX11213*	24-/20-/18-/16-bit, ultra-low power, single-channel, delta-sigma ADCs with internal buffers	3V supply; 0.45mW, industry-leading effective resolution per unit power; 16-pin QSOP package	Four integrated GPIOs save cost by eliminating isolators between multiplexer and microcontroller
MAX1162 MAX1167/68	16-bit, 200ksps, 1-/4-/8-channel SAR ADCs	16 bits, no missing codes; single 5V supply; unipolar 0V to 5V input range; tiny μ MAX/QSOP packages	Low 12.5mW power dissipation preserves battery life
MAX1300*/01/ 02*/03	16-bit, 8-/4-channel SAR ADCs with software-programmable input ranges	115ksps; up to \pm 12V bipolar input range or down to 0 to 2.048V unipolar range; \pm 16.5V overvoltage protection (OVP)	Software-programmable input ranges save design time, eliminate external circuitry
MAX1402/03	18-bit, 5-channel, sigma-delta ADCs	4.8ksps; 0.75mW; 28-pin SSOP package	Precision current-output sources eliminate signal-conditioning circuitry
Hot-swap controllers			
MAX5924/25/26	1V to 13.2V hot-swap controllers require no R_{SENSE}	Need no sense resistor; hot-swap voltage rails down to 1V	Save cost and board space; hot-swap wide 1V to 13.2V range of supplies
MAX5932	Positive high-voltage, hot-swap controller	Hot swaps 9V to 80V supplies; overcurrent, overvoltage, and undervoltage protection; pin and function compatible with LTC1641-1	One device accommodates wide range of backplane supply voltages; provides robust protection against overcurrent, undervoltage, and overvoltage faults
MAX5943	7.5V to 37V hot-swap controller with diode OR-ing	Integrates low-voltage-drop OR-ing and hot-swap function; programmable current-limit/circuit-breaker function; UL [®] -recognized FireWire [®] /IEEE 1394 [™] protective circuit	Integrated hot-swap and diode OR-ing function save space; robust/proven solution passed UL testing and is proven for FireWire applications
Multiplexers			
MAX4578/79	Midvoltage, single 8:1/dual 4:1 calibration multiplexers	Dual \pm 20V supply; on-chip gain and offset divider networks; low 0.005nA (typ) off-leakage current	Integrated precision resistor-dividers allow precision ADC calibration and system self-monitoring
MAX354/55	Fault-protected analog multiplexers	Fault protection up to \pm 40V; 0.02nA (typ) leakage currents; digital inputs are CMOS/TTL compatible	High fault protection eliminates external protection circuitry; pin compatible with industry-standard DG508/DG509 for easy upgrading
MAX14752/53	High-voltage 8:1 and dual 4:1 analog multiplexers	Wide \pm 10V to \pm 36V (max) power-supply range; 60 Ω (typ) on-resistance; low 0.03 Ω (typ) R_{ON} flatness over common-mode voltage	High supply voltage eliminates external protection circuitry; pin compatible with industry-standard DG408/DG409 for easy upgrades

(Continued on next page)

*Future part—contact factory for availability.

Programmable logic controllers (PLCs)

Recommended solutions

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Operational amplifiers			
MAX9943/44	38V precision, single and dual op amps	Wide 6V to 38V supply range; low 100 μ V (max) input offset voltage; drive 1nF loads	Wide operating voltage range and precision performance under most capacitive loads
MAX9945	38V CMOS-input precision op amp	Wide 4.75V to 38V supply range; low input-bias current; rail-to-rail output swing	High voltage and low femto-amp input-bias current easily allow high-voltage interfacing with ultra-high ohmic sensors
MAX410/MAX412/MAX414	28MHz, 10V, low-noise, precision, single/dual/quad series op amps	2.4nV/ $\sqrt{\text{Hz}}$; 250 μ V (max) offset; 28MHz gain bandwidth (GBW)	High-accuracy signal conditioning at low frequencies and at high gain
MAX4238/39	Industry's lowest offset, low-noise rail-to-rail output op amps	2 μ V (max) offset; 25nV/ $\sqrt{\text{Hz}}$; 6.5MHz GBW and no 1/f input-noise component	Continuous precision signal conditioning at low frequencies over time and temperature
MAX9939	SPI-programmable-gain amp (PGA) with on-demand calibration and differential in/out configurations	Input supports negative voltages; wide gain-configuration range; input-error-nulling feature	Calibration on demand improves system accuracy, minimizes harsh environmental noise
Precision resistors			
MAX5490/91/92	Precision-matched thin-film resistor-dividers	Ratiometric 1ppm/ $^{\circ}\text{C}$ (typ) temperature drift; 80V working voltage	Maintain system accuracy over temperature variations; work well in high-voltage applications
MAX5427/28/29	Low cost, one-time-programmable (OTP) digital potentiometers with up/down interface	1 μ A (max) standby current (no programming); 35ppm/ $^{\circ}\text{C}$ end-to-end and 5ppm/ $^{\circ}\text{C}$ ratiometric tempco	Increase power savings and provide better measurement stability over temperature changes
MAX5494–MAX5499	10-bit, dual, nonvolatile voltage-dividers or variable resistors with SPI interface	1 μ A (max) standby current (no programming); 35ppm/ $^{\circ}\text{C}$ end-to-end and 5ppm/ $^{\circ}\text{C}$ ratiometric tempco	Improve power savings and increase performance over temperature variations
Signal conditioners			
MAX1452	Low-cost, precision sensor signal conditioner	Multitemperature calibration; current and voltage excitation; fast 150ns response; single-pin programmable; 4–20mA applications	Highly accurate; simplifies designs in multiple platforms; reduces inventory and cost
MAX1464	Low-power, low-noise, multichannel, digital sensor conditioner	Integrated 16-bit ADC, DACs, and CPU; programmable compensation algorithm; digital, analog, and PWM outputs; 4–20mA application	Directly interfaces with microprocessors/controllers; provides amplification, calibration, linearization, and temperature compensation for a variety of sensors
Thermal management			
DS600	Precision, analog-output temperature sensor	Industry's highest accuracy: $\pm 0.5^{\circ}\text{C}$ from -20°C to $+100^{\circ}\text{C}$	Best cold-junction compensation accuracy for superior thermocouple measurement
DS7505	Low-voltage, precision digital thermometer and thermostat	$\pm 0.5^{\circ}\text{C}$ accuracy from 0°C to $+70^{\circ}\text{C}$; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply-voltage reduction from LM75
MAX6631	Low-power, digital temperature sensor	$\pm 1^{\circ}\text{C}$ accuracy from 0°C to $+70^{\circ}\text{C}$; 50 μ A (max) supply current	Low supply current extends battery life
MAX6675	K-type thermocouple-to-digital converter	Built-in cold-junction compensation	Simplest thermocouple interface; no external components needed
Voltage supervisors			
MAX16023/24	Battery-backup switchover ICs with integrated regulated output	Low power; small TDFN package; integrated regulated output	Conserve power
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; saves space in small modules

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage supervisors (continued)			
MAX6495	72V overvoltage protector	Protects against transients up to 72V; small, 6-pin TDFN-EP package	Increases system reliability by preventing component damage due to high-voltage transients; saves space; easy to use.
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable thresholds	Integration shrinks design size
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing; 3 μ A supply current	Versatile for easy design reuse; saves space in small modules
MAX6816/17/18	Single/dual/octal switch debouncers	\pm 15kV ESD protection	High reliability; easy to use

For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Programmable logic controllers (PLCs)

Recommended solutions

Recommended solutions *(continued)*

Analog output functions

Part	Description	Features	Benefits
HART			
DS8500	HART modem	HART compliant; integrated digital filter; 5mm x 5mm x 0.8mm TQFN package; 3.6864MHz clock; 285µA active-mode current	Power-saving; single-chip solution with small PCB foot print
Demultiplexer			
MAX5167	32-channel sample/hold amplifier with output-clamping diodes	2.5µs acquisition time; 0.01% accuracy of acquired signal	Replaces 31 DACs, saving cost and space
Operational amplifiers			
MAX9943/44	38V high-output-drive, single and dual op amps	Output voltage swing to 38V; output-current drive exceeds 50mA; drives 1nF load	Easily drive 4–20mA loops at 24V
MAX4230–MAX4234	High-output-drive, 10MHz, 10V/µs rail-to-rail input/output (RRIO) single/dual/quad op amps	200mA peak current output; RRIO; consumes only 1mA and drives 780pF	RF immunity design, output current and slew rate ideal for driver applications, active filters, or buffers
MAX4475–MAX4478	Low noise, low distortion, 10MHz single/dual/quad op amps	Low THD+N (0.0002%); low 4.5nV/√Hz noise; low offset voltage (350µV, max); up to 42MHz GBW	Ideal to drive ADCs without adding additional noise but maintaining the effective number of system bits (ENOB)
MAX9650/51	High-current, high-voltage, RRIO, single and dual op amps	20V operating voltage; 1.3A peak-current drive; 40V/µs slew rate	Handle system outputs in rugged industrial environments
Precision DACs			
MAX5134–MAX5139	1-/2-/4-channel, 16-/12-bit DACs with pin-programmable zero or midscale power-up	Output set to zero or midscale upon power-up	Add additional safety during power-up
MAX5661	Single-channel DAC with 16-bit voltage- or current-buffered output	16-bit, current or voltage-buffered output; integrated high-voltage current and voltage amplifiers; serial interface	Reduces external component count; reduces cost
MAX5500	4-channel, 12-bit DAC with precision amplifier-output conditioners	Output conditioners; 0.85mA of quiescent current (I_Q)	Needs no external amplifiers; makes equipment more compact
Output conditioners			
MAX15500/01	Analog output conditioners	Programmable current (up to 24mA) and voltage (up to ±10V) drive	Reduce board complexity by integrating current and voltage drive
Signal conditioners			
MAX1452	Low-cost, precision sensor signal conditioner	Multitemperature calibration; current and voltage excitation; fast 150ns response; single-pin programmable; 4–20mA applications	Highly accurate; simplifies designs in multiple platforms; reduces inventory and cost.
MAX1464	Low-power, low-noise, multichannel, digital sensor conditioner	Integrated 16-bit ADC, DACs, and CPU; programmable compensation algorithm; digital, analog, and PWM outputs; 4–20mA applications	Directly interfaces with microprocessors and controllers; provides amplification, calibration, linearization, and temperature compensation for a variety of sensors
Thermal management			
MAX6631	Low-power digital temperature sensor	±1°C accuracy from -0°C to +70°C; 50µA (max) supply current	Very low supply current for minimal impact on system power usage
DS7505	Low-voltage, precision digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply voltage reduction from LM75

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Thermal management (continued)			
DS18B20	Precision 1-Wire digital temperature sensor	±0.5°C accuracy; 1-Wire interface; 64-bit, factory-lasered ID code	Connects multiple precision temperature sensors with less wire than any competitive solution
Voltage supervisors			
MAX16023/24	Battery-backup switchover ICs with integrated regulated output	Low power; small TDFN package; integrated regulated output	Conserve power
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; saves space in small modules
MAX6495	72V overvoltage protector	Protects against transients up to 72V; small, 6-pin TDFN-EP package	Increases system reliability by preventing component damage due to high-voltage transients; saves space; easy to use
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable thresholds	Integration shrinks design size
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing; 3µA supply current	Versatile for easy design reuse; saves space in small modules

For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Programmable logic controllers (PLCs)

Recommended solutions

Recommended solutions *(continued)*

Fieldbus functions

Part	Description	Features	Benefits
Interface transceivers			
MAX14770	PROFIBUS transceiver	±35kV (HBM) ESD tolerance; -40°C to +125°C automotive temperature range; small (3mm x 3mm) TQFN package	Industry's highest ESD protection makes PLC more robust
MAX13450E/51E	RS-485 transceivers with pin-selectable termination resistors	Integrated 100Ω and 120Ω termination resistors; FAULT indication; flexible logic interface	Allow remote configuration of the line termination, which simplifies system installation
MAX3535E	Isolated RS-485 transceiver	3V to 5V operation; 2500V _{RMS} isolated RS-485/RS-422 transceivers; ±15kV ESD protection	Eliminates the need for external isolation components
MAX13442E/43E/44E	Fault-protected RS-485 transceivers	±80V fault protected half-duplex operation; 5V transceivers (250kHz/10MHz)	Simplify design by eliminating external components such as TVSs and PTCs
MAX13430E	RS-485 transceiver with V _L pin in tiny μDFN	3.3V to 5V operation; integrated V _L pin (down to 1.6V); 10-pin μMAX/μDFN packages	Tiny packages with integrated V _L pin save board space; V _L pin communicates with low-voltage FPGAs and microcontrollers
MAX253	Transformer driver for isolated power with RS-485/PROFIBUS interfaces	Single 5V or 3.3V supply; low-current shutdown mode: 0.4μA; pin-selectable frequency of 350kHz or 200kHz; μMAX package	Simple open-loop circuit speeds power-supply design and shortens time to market
MAX3107	SPI/I ² C UART with integrated oscillators	24Mbps (max) data rate; 128B FIFOs; automatic RS-485 transceiver control; 4 GPIOs; 24-pin SSOP or small 3.5mm x 3.5mm TQFN packages	Serial interface and large FIFOs with high integration reduce performance requirements and cost of host controllers

For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Recommended solutions *(continued)*

Digital I/O functions

Part	Description	Features	Benefits
Digital I/O modules			
MAX14830*	Quad SPI/I ² C UART with 128 byte FIFOs	24Mbps (max) data rate; integrated oscillator; automatic transceiver control; 16 GPIOs; 7mm x 7mm, 48-pin TQFN package	Serial Interface reduces cost for isolators; allows scalable architectures; simplifies design; reduces overall cost
MAX14824*	IO-Link master transceiver	IO-Link master transceiver; a Type 1 and Type 2 digital input; addressable SPI interface	Addressable SPI reduces cost for isolation in high-port-count masters
Power-line communications modems			
MAX2990	10MHz to 490MHz OFDM-based power-line communications modem	Combines the physical layer (PHY) and media access controller (MAC); 100kbps data rate over the power line	Removes wires by using the AC power line to transmit data
MAX2991	Integrated analog front-end (AFE) receiver for power-line communications	For operation with MAX2990; integrates on-chip band-select filter, VGA, and 10-bit ADC for the Rx path; built-in 62dB dynamic-range automatic gain control (AGC) and DC-offset cancellation	Improves reliability and reduces system cost by integrating the AFE for the MAX2990; AGC and DC-offset cancellation provide high-receiver sensitivity and added reliability
RF transceivers			
MAX7030	Low-cost, factory-programmed ASK/OOK transceiver	Low current; compact package; superior sensitivity; no programming interface required	Extends battery life; smaller size; provides longer range; facilitates faster and simpler product design
MAX7031	Low-cost, factory-programmed FSK transceiver	Low current; compact package; superior sensitivity; no programming interface required	Extends battery life; smaller size; provides longer range; facilitates faster and simpler product design
MAX7032	Low-cost, frequency-programmable ASK/FSK/OOK transceiver	Low current; compact package; superior sensitivity; fully programmable 300MHz to 450MHz	Extends battery life; smaller size; provides longer range and maximum flexibility
Thermal management			
DS7505	Low-voltage, precision digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply voltage reduction from LM75
DS18B20	Precision 1-Wire digital temperature sensor	±0.5°C accuracy; 1-Wire interface; 64-bit, factory-lasered ID code	Connects multiple precision temperature sensors with less wire than any competitive solution
MAX6631	Low-power, ±0.5°C accurate, digital temperature sensor	±1°C accuracy from -0°C to +70°C; 50µA (max) supply current	Very low supply current for minimal impact on system power usage
Voltage supervisors			
MAX16023/24	Battery-backup switchover ICs with integrated regulated output	Low power; small TDFN package; integrated regulated output	Conserve power

(Continued on next page)

*Future part—contact factory for availability.

Programmable logic controllers (PLCs)

Recommended solutions

Recommended solutions *(continued)*

Part	Description	Features	Benefits
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; saves space in small modules
MAX6495	72V overvoltage protector	Protects against transients up to 72V; small, 6-pin TDFN-EP package	Increases system reliability by preventing component damage due to high-voltage transients; saves space; easy to use
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable thresholds	Integrates three voltage monitors into one to shrink design size
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing; 3 μ A supply current	Versatile for easy design reuse; saves space in small modules

For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Recommended solutions *(continued)*

CPU functions

Part	Description	Features	Benefits
Microcontrollers			
MAXQ1850	32-bit secure microcontroller	256kB flash; 8kB, secure battery-backed SRAM; DES/3DES, AES; 16MHz; SPI/USB interface	High security; tamper detection
MAXQ1004*	1-Wire and SPI authentication 16-bit microcontroller	1.7V to 3.6V supply range; 6MHz internal oscillator; 10-bit ADC; SPI interface; AES; random number generator (RNG); temp sensor	Low-power data/code authentication
MAXQ2010	Low power 16-bit mixed-signal LCD microcontroller	64kB flash; 8-channel, 12-bit SAR ADC; 160-segment LCD, hardware (HW) multiplier; SPI/I ² C and two USARTs interface; 370nA stop-mode current	High integration in a single chip; low power consumption
MAXQ8913	16-bit mixed-signal microcontroller	64kB flash; 7-channel, 12-bit SAR ADC; dual, 10-bit differential DACs; dual, 8-bit single-ended DACs; four op amps; a temp sensor; two current sinks; USART/SPI/I ² C interface	High integration provides a true mixed-signal one-chip solution
MAXQ1103	32-bit secure microcontroller	External memory support; 512kB flash; 1kB, secure battery-backed SRAM; DES/3DES; 25MHz	External code integrity check; tamper detection
Secure supervisors			
DS3600	Secure supervisor with 64B nonimprinting, battery-backed encryption-key SRAM	Nonimprinting critical security-parameter storage memory; SPI interface; external memory controller	Improves system security by protecting encryption keys from intruders
DS3640	I ² C secure supervisor with 1kB nonimprinting, battery-backed encryption-key SRAM	Nonimprinting memory; I ² C interface; monitors for external tampering; low power consumption	Improves system security by protecting encryption keys from intruders
DS3644	1kB secure memory with programmable tamper-detection hierarchy and RTC	Nonimprinting, critical security-parameter storage memory; 10 different tamper inputs (window comparator inputs, CMOS-level inputs, fixed reference comparator inputs); configurable, two-level hierarchical nonimprinting memory; I ² C interface; external memory controller	Improves system security by protecting encryption keys from intruders
DS3645	Secure encryption-key controller with 4kB of SRAM	10 different tamper inputs (window comparator inputs, CMOS-level inputs, fixed reference comparator inputs); I ² C interface; external memory controller	Improves system security by protecting encryption keys from intruders
MAX36051B	Secure supervisor with 128B of secure memory	Nonimprinting, critical security-parameter storage memory; ultra-low < 3μW standby power consumption; SPI interface	Improves system security by protecting encryption keys from intruders
LED backlighting			
MAX16814 MAX16838	4-/2-channel high-brightness (HB) LED drivers with integrated DC-DC controller	150mA/channel capability; 4.75V to 40V input voltage; adaptive boost control	Fit in small board area and lowers BOM cost
MAX16826	Programmable, 4-channel HB LED driver with integrated DC-DC controller	4.75V to 24V input voltage; up to > 300mA/channel current capability; I ² C interface	Easily controllable from a microcontroller
MAX16809	16-channel LED driver with integrated DC-DC controller	8V to 26.5V input voltage; 55mA/channel current capability	Reduces BOM complexity

(Continued on next page)

*Future part—contact factory for availability.

Programmable logic controllers (PLCs)

Recommended solutions

Recommended solutions *(continued)*

Part	Description	Features	Benefits
LED backlighting (continued)			
MAX8790A	6-channel white-LED (WLED) driver for LCD panel applications	4.5V to 26V input voltage; 15mA to 25mA (adj), full-scale LED current; adaptive boost control	Compact design
Thermal management			
DS7505	Low-voltage, precision digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply voltage reduction from LM75
DS18B20	Precision 1-Wire digital temperature sensor	±0.5°C accuracy; 1-Wire interface; 64-bit, factory-lasered ID code	Connects multiple precision temperature sensors with less wire than any competitive solution
MAX6602	5-channel precision temperature monitor	One local and four remote digital sensing channels; ±1°C accuracy	Reduces board space compared to five separate temperature sensors
Touch-screen controllers			
MAX11800	Resistive touch-screen controller	FIFO; spatial filtering; SPI interface	Offloads host processor to perform other functions
MAX11801	Resistive touch-screen controller	FIFO; spatial filtering; I ² C interface	Offloads host processor to perform other functions
MAX11802	Resistive touch-screen controller with SPI interface	SPI interface	Reduces cost
MAX11803	Resistive touch-screen controller with I ² C interface	I ² C interface	Reduces cost
MAX11811	Resistive touch-screen controller with haptics driver	Integrated haptics driver; I ² C interface	Conveniently adds touch feedback to resistive touch screens
Voltage supervisors			
MAX16023/24	Battery-backup switchover ICs with integrated regulated output	Low power; small TDFN package; integrated regulated output	Conserve power
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; saves space in small modules
MAX6495	72V overvoltage protector	Protection against transients up to 72V; small, 6-pin TDFN-EP package	Increases system reliability by preventing component damage due to high-voltage transients; saves space; easy to use
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable thresholds	Integrates three voltage monitors to shrink design size
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing; 3µA supply current	Versatile for easy design reuse; saves space in small modules

For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Recommended solutions *(continued)*

Isolated power-supply functions

Part	Description	Features	Benefits
DC-DC converters and controllers			
MAX5080/81	Step-down DC-DC converters with integrated switch	4.5V/7.5V to 40V V_{IN} ; 1.23V to 32V V_{OUT} ; switch to pulse-skip mode at light loads; integrated high-side switch	Save cost with integrated DC-DC converters that power directly off an industrial bus
MAX5072	Dual-output buck or boost converter with integrated switch	4.5V to 5.5V or 5.5V to 23V V_{IN} ; 0.8V (buck) to 28V (boost) V_{OUT} ; configure each output as buck or boost	Improves reliability with controlled inrush current, thermal shutdown, short-circuit protection
MAX15023	Wide 4.5V to 28V input, dual-output synchronous buck controller	4.5V to 28V V_{IN} ; $V_{OUT} = 0.6V$ to $0.85 \times V_{IN}$; hiccup mode	Thermal shutdown and short-circuit-protection protect system
MAX15034	Single-/dual-output synchronous buck controller for high-current applications	4.75V to 5.5V or 5V to 28V V_{IN} ; $V_{OUT} = 0.61V$ to 5.5V; 25A or 50A output	Thermal shutdown and monotonic start protect devices, improve reliability
MAX15048/49	3-channel DC-DC controllers with tracking/sequencing	4.7V to 23V V_{IN} ; $V_{OUT} = 0.6V$ to 19V; tracking across the three outputs; power sequencing	Save space and costs by integrating three switching controllers
Isolated power-supply controllers and converters			
MAX5094/95	High-performance single-ended, current-mode PWM controllers	Adjustable frequency; high-voltage startup; internal error amplifier; thermal shutdown	Enhance reliable operation of high-performance PLCs with short 60ns delay from current sense to output
MAX5042	Two-switch, voltage-mode PWM power IC with integrated power MOSFETs and hot-swap controller	Adjustable frequency; high-voltage start-up; internal error amplifier; synchronizable frequencies; synchronous rectifier driver	Integrated hot-swap controller and MOSFETs cut costs and connect directly to 48V bus; simplifies board design
MAX5070	Single-ended current-mode PWM controller	Adjustable frequency; high-voltage startup; internal error amplifier	Enhances reliable operation with less than half the delay of competing solutions from current sense to output
MAX5069	High-frequency current-mode PWM controller with accurate oscillator and dual FET drivers	Adjustable frequency; high-voltage startup; internal error amplifier; synchronizable frequencies	Lowers BOM costs using a smaller inductor and output filter capacitor for 100W applications
MAX5014	Current-mode PWM controller with integrated start up circuit	High-voltage startup	Lowers BOM cost and simplifies design; eliminates the need for external startup components for 75W applications
MAX256	3W primary-side transformer H-bridge driver for isolated supplies	Isolated power supply up to 3W	Simple open-loop circuit speeds power-supply design; reduces time to market
MOSFET/rectifier drivers			
MAX5079	OR-ing MOSFET controller	Ultra-fast 200ns turn-off	Reduces cost/size/power in high-power applications by replacing Schottky diodes
MAX5075	Push-pull FET driver with clock output and integrated oscillator	Adjustable frequency; synchronizable frequencies; undervoltage lockout (UVLO)	Lowers overall system cost of unregulated isolated power supplies/modules that drive PLCs
MAX5059	Parallelable, secondary-side synchronous rectifier driver and feedback-generator controller IC	Internal error amplifier; synchronizable frequencies; synchronous rectifier driver; thermal shutdown; UVLO	Simplifies design; lowers BOM costs with integrated digital-output margining circuit
MAX15024/25	FET drivers	Single/dual operation; 16ns; high sink/source current	Simplify design with a very low propagation delay and a thermally enhanced package
MAX5048 MAX5054/55/56/57 MAX5078	FET drivers	4A to 7.6A; 12ns to 20ns; single/dual MOSFET drivers	Increase flexibility for modular PLC supplies with inverting/noninverting inputs to control the MOSFET

(Continued on next page)

Programmable logic controllers (PLCs)

Recommended solutions

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Thermal management			
DS7505	Low-voltage, precision digital thermometer and thermostat	$\pm 0.5^{\circ}\text{C}$ accuracy from 0°C to $+70^{\circ}\text{C}$; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply voltage reduction from LM75
MAX6602	5-channel precision temperature monitor	Local and four remote digital sensing channels; $\pm 1^{\circ}\text{C}$ accuracy	Reduces board space compared to five separate temperature sensors
MAX6509	Resistor-programmable temperature switches	Resistor-programmable trip temperature; 6-pin SOT23 package	Simple protection against damage from overtemperature events
MAX6639	2-channel temperature monitor and PWM fan controller	Internal and external temperature measurement; closed-loop RPM control	Closed-loop control over fan speed minimizes noise and power
Voltage supervisors			
MAX16023/24	Battery-backup switchover ICs with integrated regulated output	Low power; small TDFN package; integrated regulated output	Conserve power
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; saves space in small modules
MAX6495	72V overvoltage protector	Protection against transients up to 72V; small, 6-pin TDFN-EP package	Increases system reliability by preventing component damage due to high-voltage transients; saves space; easy to use
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable thresholds	Integrates three voltage monitors to shrink design size
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing; 3 μA supply current	Versatile for easy design reuse; saves space in small modules

For a list of Maxim's recommended PLC solutions, please go to: www.maxim-ic.com/plc.

Overview

Industrial processes use sensors to monitor physical properties. Examples include temperature in a furnace, pressure in a chamber, environmental humidity, gas or liquid flows through pipes, weights of ingredients, and current flow in motor windings.

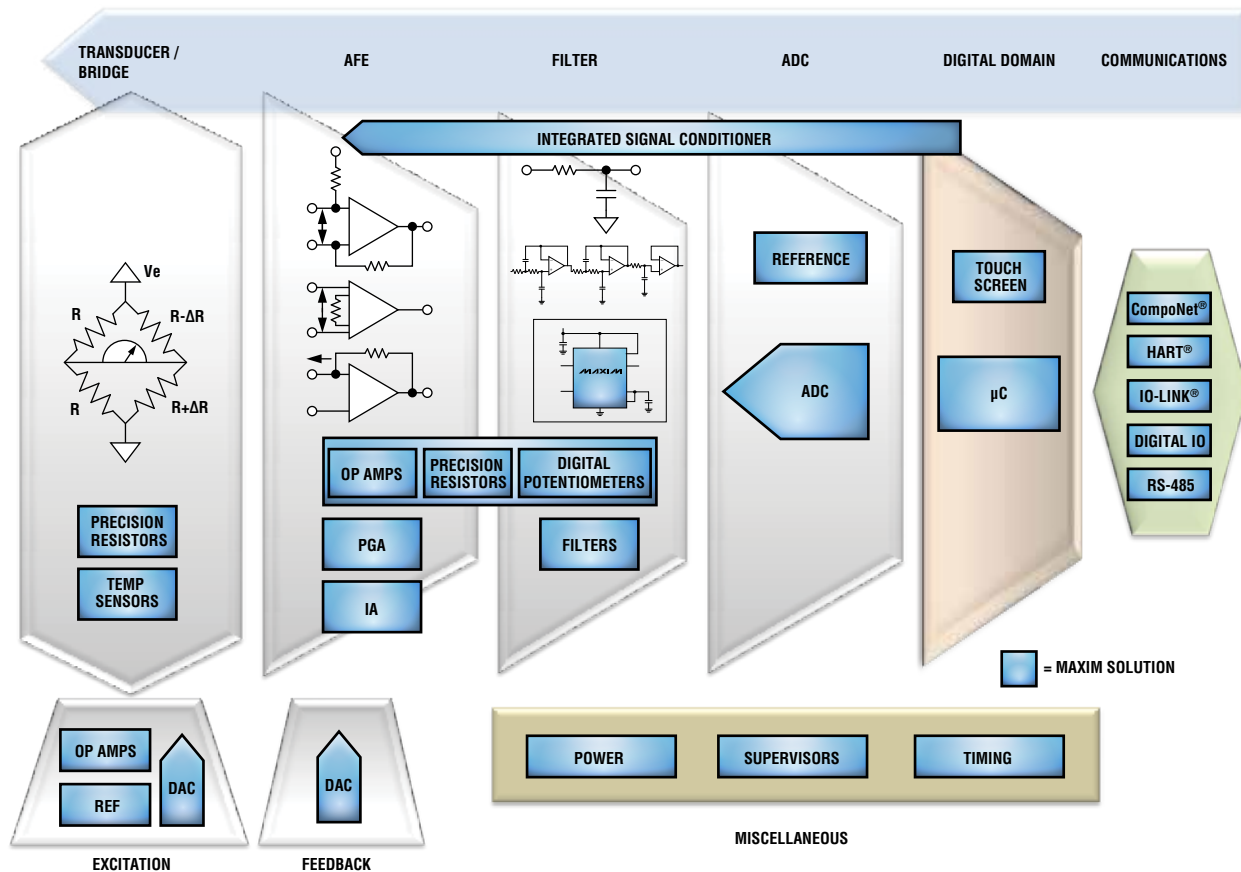
A complete sensor assembly includes: a transducer (commonly called a sensor); signal conditioning and communications circuitry; a housing; and a connector. The transducer converts physical properties such as weight, pressure, temperature, humidity, or light to

an electrical signal. Some transducers are resistive elements that require external excitation to create a measurable voltage. Other transducers generate their own voltages or currents in response to physical properties such as light, temperature, or sound.

The signals coming from transducers are usually very small and require optimized interface circuits to provide adequate gains without introducing noise that reduces accuracy. Sensor assemblies are often located far from the digital processing circuitry, so EMI protec-

tion, isolation, and low power are often required. Besides the signal chain, there are sometimes stringent requirements for power management, communication (among devices/systems), and secure data transmission.

Maxim provides ICs that address all aspects of the sensor signal chain, from conditioning to capture, transmission to timing, and power to precision. With Maxim, you will most likely find the right solution for your sensor application.



Block diagram of a basic sensor system for industrial processes. For a list of Maxim's recommended sensor solutions, please go to: www.maxim-ic.com/sensor.

www.maxim-ic.com/sensor

Pressure sensors and weigh scales (force sensing)

Overview

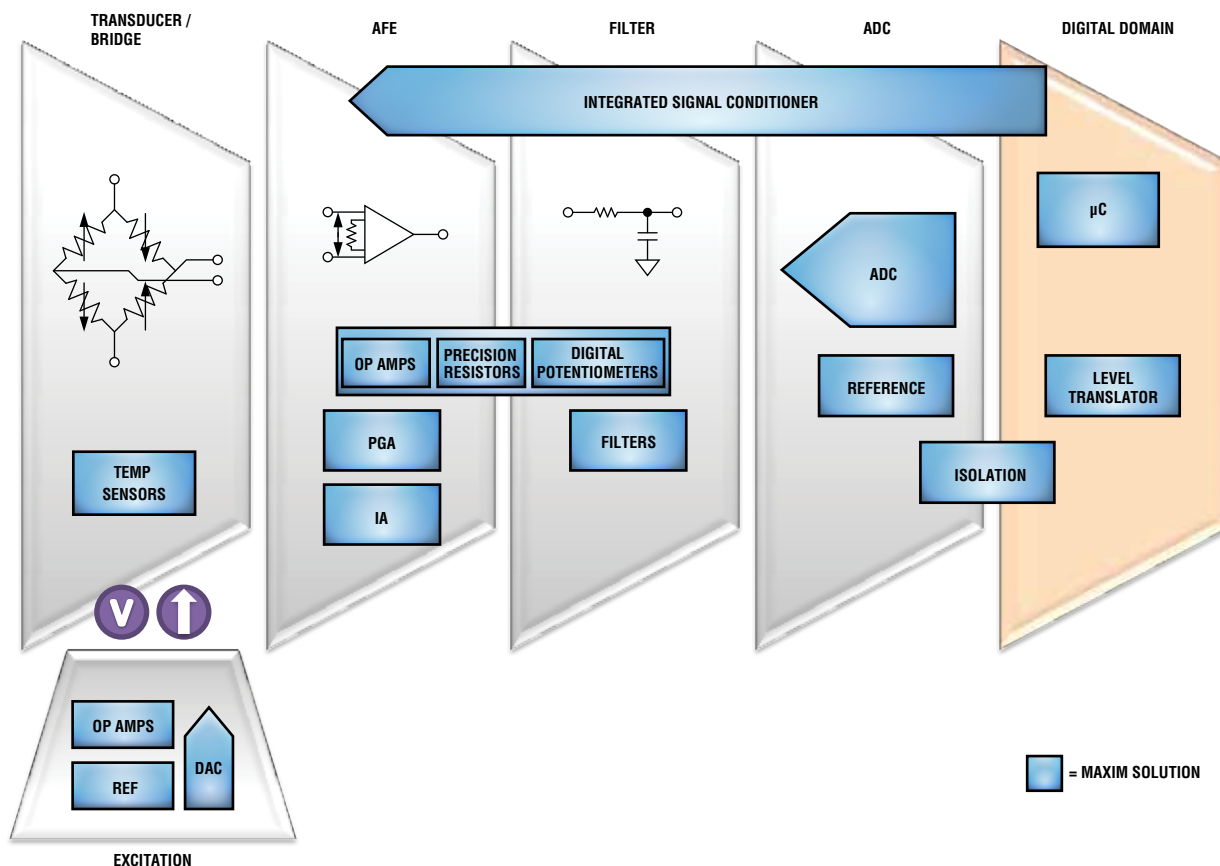
The need to detect and measure pressure and weight is a very common requirement for modern industrial control and system monitoring. Pressure measurement is especially important, as it is also used indirectly to measure flow, altitude, and other properties. Pressure- and weight-measurement devices can be regarded as “force sensors,” since force is the property that affects the transducers’ outputs. The applications for force sensors are vast and range from vacuum gauges, to heavy machinery weigh scales, industrial hydraulic equipment, and manifold absolute pressure (MAP) sensors for internal-combustion engines. Each application has its own diverse needs for precision, accuracy, and cost.



Although there are several methods and technologies for measuring pressure and weight (force sensing), the most commonly used measurement element is the strain gauge.

The two most common types of strain gauges are the metal-foil type used in a variety of weight/pressure sensors and the semiconductor-based piezoresistive transducers, widely used to measure pressure. Compared to metal-foil-type transducers, piezoresistive transducers are more sensitive with better linearity, but have large temperature dependence and large initial offsets.

In principle, all strain gauges react to an applied force by varying a resistance value. Therefore, in the presence of electrical excitation they effectively convert a pressure or weight to an electrical signal. Usually, one, two, or four of these active resistive elements (strain gauges) are arranged in a Wheatstone bridge configuration (sometimes called a



Block diagram of the signal chain in a force-sense application. For a list of Maxim's recommended pressure-sensor solutions, please go to: www.maxim-ic.com/psi.

Pressure sensors and weigh scales (force sensing)

load cell) to produce a differential output voltage in response to pressure or weight.

Engineers can design a sensor module that meets the unique requirements of diverse force-sensing applications. A successful design will include the suitable sensing element for the physical property and an appropriately designed signal chain.

Complete signal-chain solutions

The sensor signal chain must handle extremely small signals in the presence of noise. Accurately measuring changes in the output voltage from a resistive transducer requires circuitry that provides the following electrical functions with precision: excitation, amplification, filtering, and acquisition. Some solutions may also require the use of digital-signal processing (DSP) techniques for signal manipulation, error compensation, digital gain, and user programmability.

Excitation

Accurate and stable voltage or current sources with low-temperature drift are generally used for sensor excitation. The sensor output is ratiometric (usually expressed in mV/V) to the excitation source. Consequently, the design typically has a common reference for both the analog-to-digital converter (ADC) and the excitation circuitry, or it uses the excitation voltage as the reference for the ADC. Additional ADC channels can be used to measure the excitation voltage accurately.

Transducer/bridge

This part of the signal chain consists of the strain-gauge transducers arranged in a load cell (Wheatstone bridge format), as briefly explained in the overview section above.

Amplification and level translation—the analog front-end (AFE)

In some designs the transducer's output-voltage range will be very small, with the required resolution reaching the nano-volt range. In such cases, the transducer's output signal must be amplified before it is applied to the ADC's inputs. To prevent this amplification step from introducing errors, low-noise amplifiers (LNAs) with extremely low offset voltage (V_{OS}) and low-temperature and offset drifts must be selected. A drawback of Wheatstone bridges is that the common-mode voltage is much larger than the signal of interest. This means that the LNAs must also have excellent common-mode rejection ratios (CMRRs), generally greater than 100dB. When single-ended ADCs are used, additional circuitry is required to remove large common-mode voltages before acquisition. Additionally, since the signal bandwidth is low, the 1/f noise of the amplifiers can introduce errors. Chopper-stabilized amplifiers are, therefore, often used. Some of these stringent amplifier requirements can be avoided by using a small portion of the full-scale range of a very-high-resolution ADC.

Acquisition—the ADC

When choosing the ADC, look at specifications like noise-free range or effective resolution which indicate how well an ADC can distinguish a fixed input level. Alternate terms might be noise-free counts or codes inside the range. Most high-accuracy ADC data sheets show these specifications as a table of peak-to-peak noise or RMS noise versus speed; sometimes the specifications are shown graphically as noise histogram plots.

Other ADC considerations include low-offset error, low-temperature

drift, and good linearity. For certain low-power applications, speed versus power is another important criterion.

Filtering

The bandwidth of the transducer signal is generally small and the sensitivity to noise is high. It is, therefore, useful to limit the signal bandwidth by filtering to reduce the total noise. Using a sigma-delta ADC can simplify the noise-filtering requirement because of the inherent oversampling in that architecture

Digital Signal Processing (DSP)—the digital domain

Besides the analog signal processing, the captured signals are further processed in the digital domain for signal extraction and noise reduction. It is common to find focused algorithms that cater to particular applications and their nuances. There are also generic techniques, such as offset and gain correction, linearization, digital filtering, and temperature- (and other dependent factors) based compensation that are usually applied in the digital domain.

Signal conditioning/integrated solutions

In some integrated solutions, all required functional blocks are integrated into a single IC commonly called a sensor signal conditioner. A signal conditioner is an application-specific IC (ASIC) that performs compensation, amplification, and calibration of the input signal, normally over a range of temperatures. Depending on the sophistication of the signal conditioner, the ASIC integrates some or all of the following blocks: sensor excitation circuitry, digital-to-analog converter (DAC), programmable gain amplifier (PGA), analog-to-digital converter (ADC), memory, multiplexer (MUX),

Sensors

Pressure sensors and weigh scales (force sensing)

CPU, temperature sensor, and digital interface.

Two types of signal conditioners are commonly used: analog signal-path conditioner (analog conditioner) and digital signal-path conditioner (digital conditioner). Analog condi-

tioners have a faster response time and provide a continuous-output signal, reflecting changes on the input signal. They generally have a hardwired (inflexible) compensation scheme. Digital conditioners, which are usually microcontroller based, have slower response times because

of latencies introduced by the ADC and DSP routines. The ADC resolution should be reviewed to minimize quantization errors. The biggest benefit of digital signal conditioners is the flexibility of the compensation algorithms which can be adapted to the user's application.

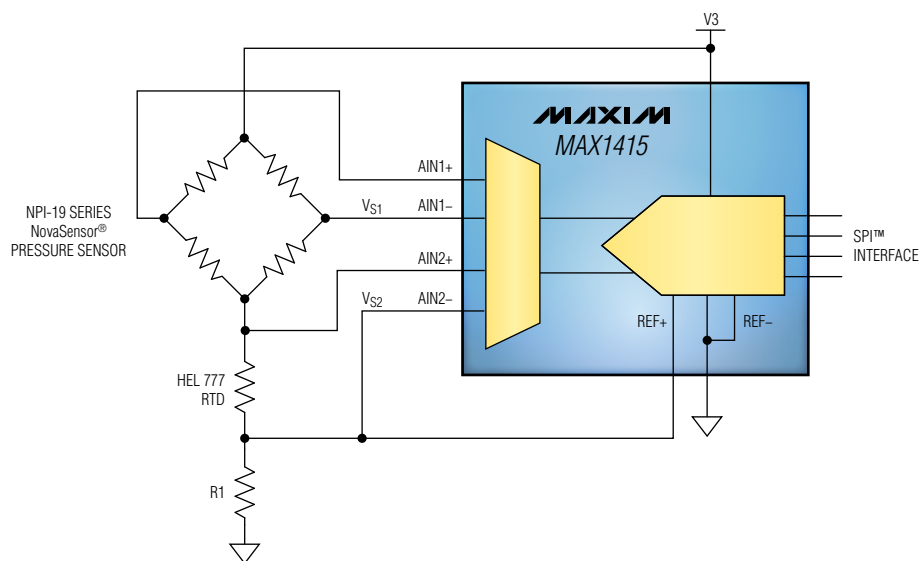
Flexible ADCs interface with a wide range of sensors

MAX1415/MAX1416, MX7705

Pressure sensors commonly have high temperature dependence. Therefore, the design should monitor temperature while measuring pressure. The MAX1415 features differential reference inputs which allow ratiometric measurement of the 3V excitation voltage. The two differential inputs allow pressure and temperature (using a resistance temperature detector, RTD) to be monitored with a single ADC.

Benefits

- **Distinguish signals better by matching sensor's output range to the ADC's input range**
 - On-chip PGA allows as low as 20mV full-scale range (FSR) to match sensor output
- **High integration reduces design complexity**
 - Built-in self- and system-calibration modes improve accuracy and shorten design time
 - Built-in digital filter for 50Hz/60Hz rejection removes unwanted power-line interference
- **Simplify design with features optimized for multichannel ratiometric/bridge-type designs**
 - Differential reference input for ratiometric measurement common to bridge-type circuits
 - Two differential channels measure pressure and temperature (common dependency)



Flexible MAX1415 ADC interfaces with pressure and temperature sensors.

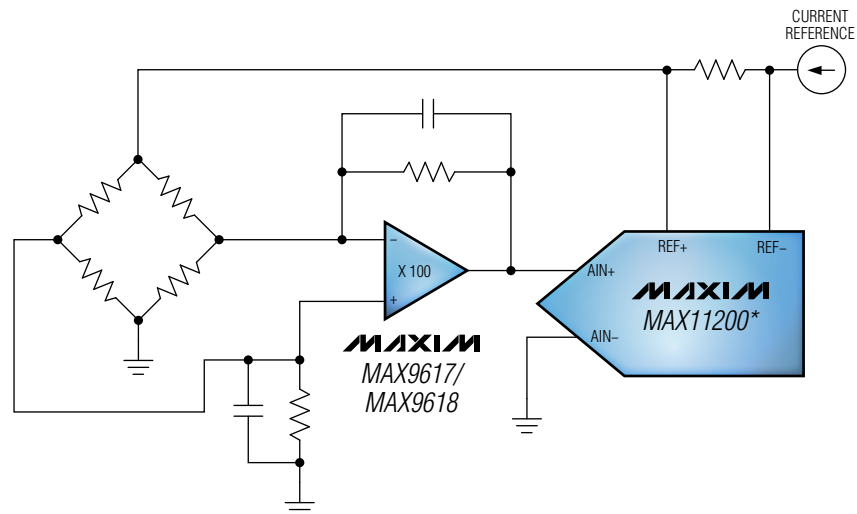
Maintain high accuracy over time and temperature

MAX9617/MAX9618, MAX11200*

One of the biggest challenges with interfacing to sensors is the low signal levels. Since the signal bandwidth (BW) lies in low hertz for many sensors, the $1/f$ noise of op amps is an important factor. Maxim's MAX9617/MAX9618 low-power ($< 100\mu\text{A}$) op amps offer the industry's lowest noise, autozero ($42\text{nV}/\sqrt{\text{Hz}}$) operation. These devices have the best-in-class peak-to-peak noise of $< 420\text{nV}_{\text{p-p}}$ for 0.1Hz to 10Hz BW. Coupled with the MAX11200, industry's leading low-power, 24-bit (21 noise-free bits) resolution, sigma-delta ADC, these op amps form an ideal circuit for capturing low-frequency, low-amplitude signals accurately.

Benefits

- **Minimize system calibration over time and temperature (MAX9617/MAX9618)**
 - Autozero op-amp technology reduces TCV_{OS} to $120\text{nV}/^\circ\text{C}$
- **Provides the most accurate measurements at the lowest power (MAX11200*)**
 - Highest resolution per-unit-power ADC for sensors on a 4–20mA loop: 21 bits of noise-free range at 10sps drawing close to $200\mu\text{A}$
 - Lowest $< 780\mu\text{W}$ noise density for low-frequency design
- **Distinguishes extremely small changes over a wide range of pressure or weight (MAX11200)**
 - 21 bits of noise-free range identify signals down to 500nV steps for wide-range, high-accuracy sensor applications
 - Industry's lowest noise, autozero op amp operation with $< 420\text{nV}_{\text{p-p}}$ noise from 0.1Hz to 10Hz
 - No $1/f$ component ensures low distortion below 0.1Hz in the signal-conditioning stage



Circuit using the MAX9617/MAX9618 op amps and the MAX11200 ADC achieves high accuracy over time and temperature.

*Future product—contact factory for availability.

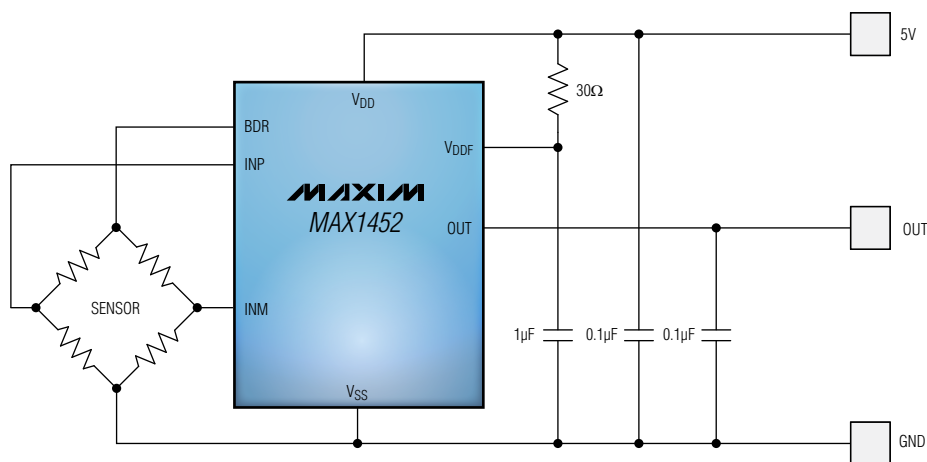
Low-cost, high-precision sensor signal conditioner simplifies sensor design

MAX1452

The MAX1452 is a versatile analog sensor signal conditioner that accepts output from all types of resistive elements. Its fully analog signal path enables a fast response and also provides current or voltage excitation for optimal design flexibility. Four integrated 16-bit DACs and a PGA provide high-resolution input compensation, amplification, and calibration. The MAX1452 includes on-chip flash memory and a temperature sensor that performs multitemperature-point compensation for accurate readings.

Benefits

- **Reduces Bill of Materials (BOM) cost**
 - High integration minimizes external components, requires no external trim components; to produce calibrated and accurate output
- **Removes all systematic errors for a highly accurate output**
 - Fully analog signal path provides a continuous output with no quantization error
 - Four 16-bit DACs (76 μ V resolution) provide compensation accuracy of full-span output (FSO) and offset
 - Multitemperature compensation allows calibration that approaches repeatability of the input signal
- **Reduces product development time and inventory complexity**
 - Suitable for use with many types of transducers and in multiple applications
 - Using same signal conditioner in many applications allows reuse of the application circuit
 - Can be used in products requiring voltage output or 4–20mA current loop



Low-cost and high-precision MAX1452 sensor signal conditioner in a ratiometric configuration.

Low-power, low-noise, multichannel sensor signal processor saves cost and board space

MAX1464

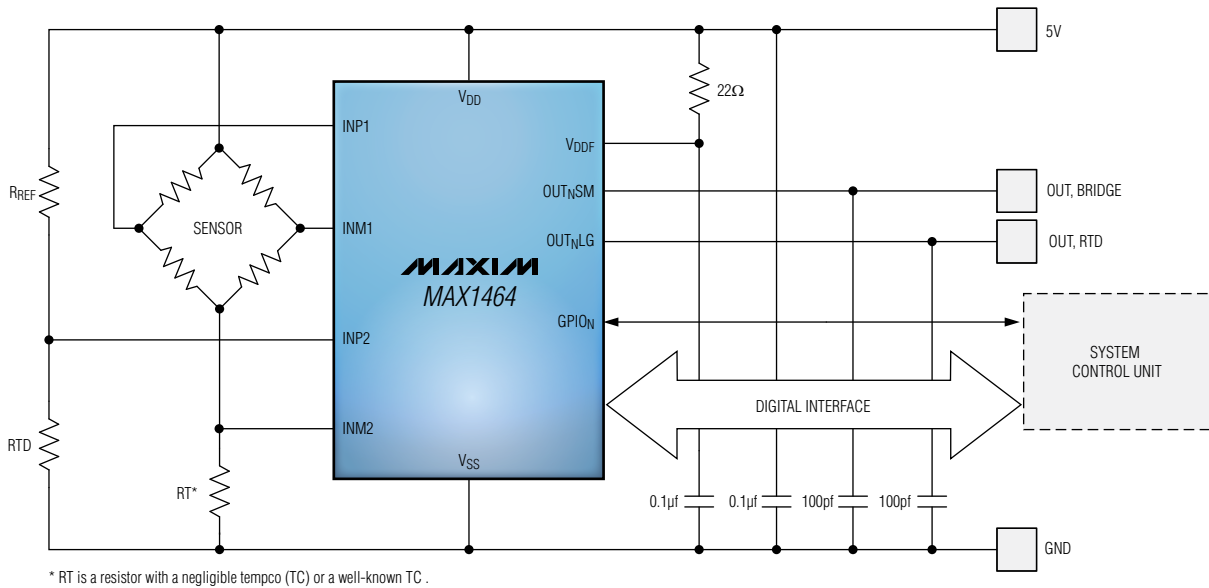
The MAX1464 is a highly integrated, digital, multichannel sensor signal conditioner optimized for industrial process-control and automotive applications. Typical implementations include pressure sensing, RTD and thermocouple linearization, weight sensing/classification, and remote process monitoring with limit indication. The MAX1464 simplifies designs and improves manufacturing efficiency by accepting sensors with either single-ended or differential outputs. It provides comprehensive temperature compensation without requiring any external trim components. A calibrated output signal can be driven independently through an SPI-compatible interface, voltage-output DACs, or PWM terminals. The MAX1464 integrates a 16-bit CPU; 4kB of flash memory for a user-programmable compensation algorithm and 128 bytes for user information; and two general-purpose inputs/outputs (GPIOs). It has a flexible dual op-amp output block and supports 4–20mA applications.

Benefits

- **Saves cost and board space by interfacing directly with a microprocessor or control unit**
 - SPI-compatible interface eliminates need for interface stage
 - GPIO terminals facilitate instrument control, system warning, and two-way signaling
- **Multichannel functionality reduces BOM cost, improves performance, and saves space**
 - Use one multichannel device instead of multiple devices, so measurements are more comparable and costs lowered
 - Highly integrated conditioner minimizes component requirements and saves board space
 - No external trim components required for a calibrated and accurate output
- **Adaptable compensation algorithm optimizes sensor performance**
 - User can customize the compensation algorithm suitable for the application
 - Compensation algorithm is stored in on-chip nonvolatile (NV) flash memory
- **Reduces product development time**
 - Flexible for use in products requiring digital output, voltage output, PWM output, or a 4–20mA current loop
 - Integrated microprocessor with only 16 instructions makes programming easy
 - Suitable for use with many types of transducers

(Block diagram on next page)

Low-power, low-noise, multichannel sensor signal processor saves cost and board space *(continued)*



The MAX1464 multichannel digital signal conditioner measures one differential and two single-ended inputs.

Temperature sensing

Overview

Temperature sensing is critically important for implementing three key functions in industrial systems.

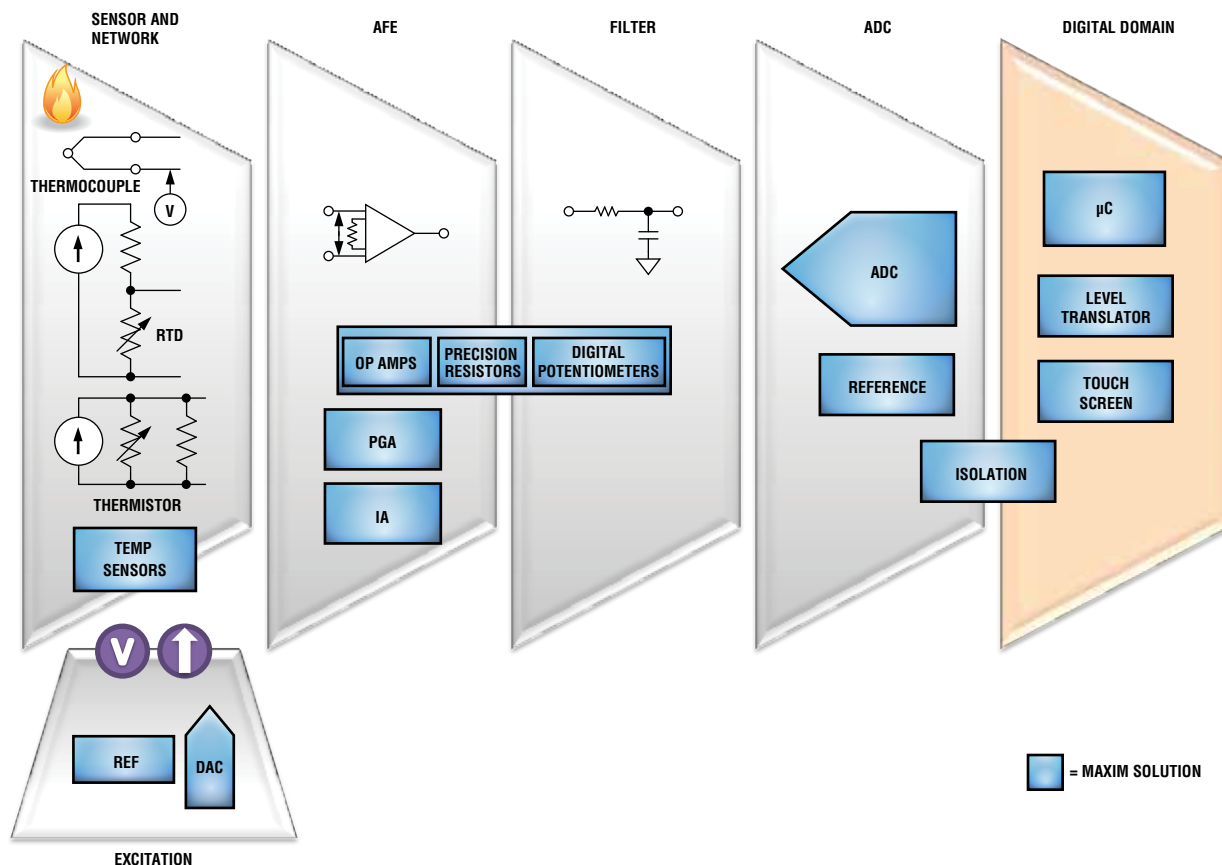
- 1. Temperature control**, for example in ovens, refrigeration, and environmental-control systems, depends on the measurement of temperature to make heating/cooling decisions.
- 2. Calibration** of a variety of transducers, oscillators, and other components often varies with temperature. Therefore, temperature must be measured to ensure the accuracy of sensitive system components.



- 3. Protection** of components and systems from damaging temperature excursions. Temperature sensing determines the appropriate action to take.

Thermistors, RTDs, thermocouples, and ICs are some of today's most widely used temperature-sensing technologies. Each design approach has its own strengths (e.g., cost, accuracy, temperature range) which make it appropriate for specific applications. Each of these technologies will be discussed below.

In addition to the industry's most comprehensive line of dedicated temperature-sensor ICs, Maxim manufactures all of the components necessary to interface a system to thermistors, RTDs, and thermocouples.



Block diagram of the signal chain in a temperature-sensing application. For a list of Maxim's recommended temperature-sensor solutions, please go to: www.maxim-ic.com/-40+85.

Thermistors

Thermistors are temperature-dependent resistors, usually made from semiconducting materials like metal-oxide ceramics or polymers. The most widely used thermistors have a negative temperature coefficient of resistance and, therefore, are often referred to as NTCs. There are also positive temperature coefficient (PTC) thermistors.

Thermistor characteristics include a moderate temperature range generally up to +150°C, although some are capable of much higher temperatures; low-to-moderate cost depending on accuracy; and poor, but predictable linearity. Thermistors are available in probes, in surface-mount packages, with bare leads, and in a variety of specialized packages. Maxim also manufactures ICs like the [MAX6682](#) and [MAX6698](#) that convert thermistor resistance to a digital format.

A thermistor is often connected to one or more fixed-value resistors to create a voltage-divider. The output of the divider is typically digitized by an ADC. The thermistor's nonlinearity can be corrected either by a lookup table or by calculation.

RTDs

Resistance temperature detectors (RTDs) are resistors whose resistance varies with temperature. Platinum is the most common, most accurate wire material; platinum RTDs are referred to as Pt-RTDs. Nickel, copper, and other metals can also be used to make RTDs.

RTD characteristics include a wide temperature range up to +750°C, excellent accuracy and repeatability, and reasonable linearity. For Pt-RTDs, the most common values for nominal resistance at 0°C are 100Ω and 1kΩ, although other values are available.

Signal conditioning for an RTD can be as simple as combining the RTD

with a precision, fixed resistor to create a voltage-divider, or it can be more complex, especially for wide-range temperature measurements. A common approach consists of a precision current source, a voltage reference, and a high-resolution ADC, as shown in **Figure 1**. Linearization can be performed with a lookup table, calculation, or external linear circuits.

Thermocouples

Thermocouples are made by joining two wires of dissimilar metals. The point of contact between the wires generates a voltage that is approximately proportional to temperature. There are several thermocouple types which are designated by letters. The most popular is the K type.

Thermocouple characteristics include a wide temperature range up to +1800°C; low cost, depending

on package; very-low-output voltage of about 40μV per °C for a K-type device; reasonable linearity; and moderately complex signal conditioning, i.e., cold-junction compensation and amplification.

Measuring temperature with a thermocouple is somewhat difficult because the thermocouple's output is low. Measurement is further complicated because additional thermocouples are created at the point where the thermocouple wires contact the copper wires (or traces) that connect to the signal-conditioning circuitry. This contact point is called the cold junction (see **Figure 2**). To accurately measure temperature with a thermocouple, a second temperature sensor must be added at the cold junction, as shown in **Figure 3**. Then the temperature measured at the cold junction is added to the value indicated by the measurement of the thermocouple

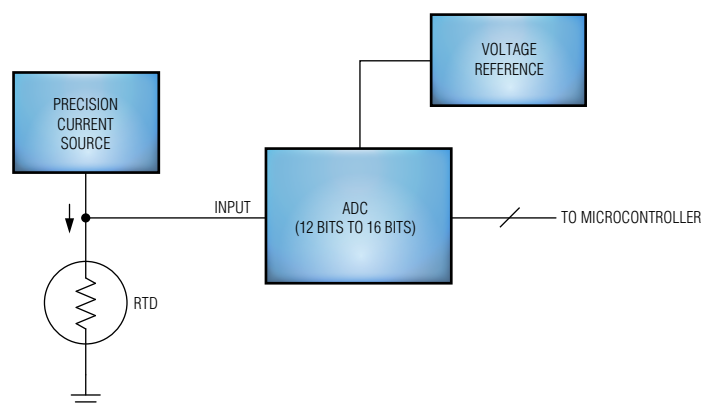


Figure 1. Simplified RTD signal-conditioning circuit.

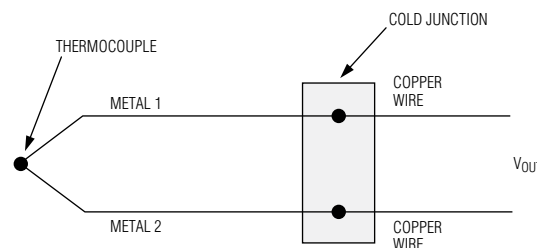


Figure 2. Simple thermocouple circuit. The junction between metal 1 and metal 2 is the main thermocouple junction. Other thermocouples are present where the metal 1 and metal 2 wires join with the measuring device's copper wires or PC-board (PCB) traces.

voltage. The example circuit in Figure 3 shows one implementation, which includes a number of precision components.

In addition to all of the components shown in Figure 3, Maxim manufactures the [MAX6674](#) and [MAX6675](#) which perform the signal-conditioning functions for K-type thermocouples. These devices simplify the design task and significantly reduce the number of components required to amplify, cold-junction compensate, and digitize the thermocouple's output.

Temperature-sensor ICs

Temperature-sensor ICs take advantage of the linear and predictable thermal characteristics of silicon PN junctions. Because they are active circuits built using conventional semiconductor processes, these ICs take a variety of forms. They include many features such as digital interfaces, ADC inputs, and fan-control functions that are not available in other technologies. The operating temperature range for temperature-sensor ICs extends as low as -55°C and as high as $+125^{\circ}\text{C}$, with a few products operating to an upper limit of around $+150^{\circ}\text{C}$. Descriptions of common types of temperature-sensor ICs follow.

Analog temperature sensors

Analog temperature-sensor ICs convert temperature to voltage or, in some cases, to current. The simplest voltage-output analog temperature sensors have just three active connections: ground, power-supply voltage input, and output. Other analog sensors with enhanced features have additional inputs or outputs, for example, comparator or voltage-reference outputs.

Analog temperature sensors use the thermal characteristics of bipolar transistors to develop an output voltage that is proportional to temperature. Gain and offset are applied to this voltage to provide a convenient relationship between the sensor's output voltage and the die temperature. Temperature accuracy can be excellent. The [DS600](#), for example, is the industry's most accurate analog temperature sensor, with guaranteed error less than $\pm 0.5^{\circ}\text{C}$ from -20°C to $+100^{\circ}\text{C}$.

Local digital temperature sensors

Integrating an analog temperature sensor with an ADC is an obvious way to create a temperature sensor with a direct digital interface. Such a device is normally called a digital temperature sensor or a local digital temperature sensor. "Local"

indicates that the sensor measures its own temperature. This operation contrasts with a remote sensor that measures the temperature of an external IC or a discrete transistor.

Basic digital temperature sensors simply measure temperature and allow the temperature data to be read by a number of interfaces including 1-Wire[®], I²C, PWM, and 3-wire. More complex digital sensors offer other features, such as over-/undertemperature outputs, registers to set trip thresholds for these outputs, and EEPROM. Maxim manufactures several local digital temperature sensors, including the [DS7505](#) and [DS18B20](#) that guarantee accuracy of $\pm 0.5^{\circ}\text{C}$ over a wide temperature range.

Remote digital temperature sensors

A remote digital temperature sensor is also called a remote sensor or a thermal diode sensor. The remote sensor measures the temperature of an external transistor, either a discrete transistor or one that is integrated on the die of another IC, as shown in **Figure 4**. Microprocessors, field-programmable gate arrays (FPGAs), and ASICs often include one or more sensing transistors, usually called thermal diodes, similar to the one shown in Figure 4.

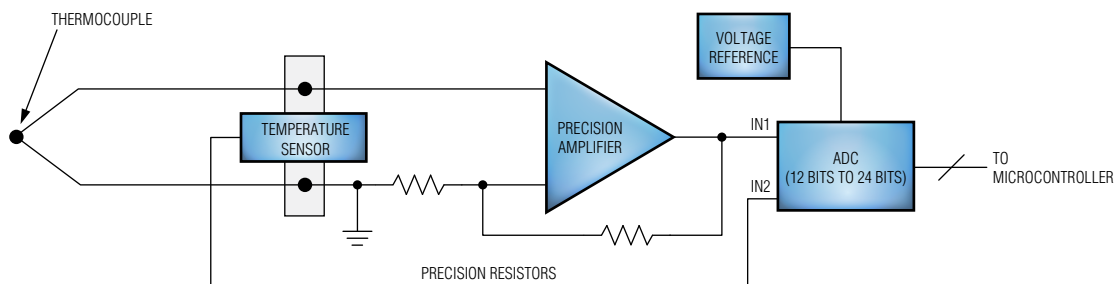


Figure 3. Example of a thermocouple signal-conditioning circuit.

There is an important advantage to remote temperature sensors: they allow you to monitor more than one hot spot with a single IC. A basic single remote sensor like the [MAX6642](#) in Figure 4 can monitor two temperatures: its own and an external temperature. The external location can be on the die of a target IC, as in Figure 4, or a hot spot on a

board that it monitors with a discrete transistor. Some remote sensors monitor as many as seven external temperatures. Thus, eight locations, consisting of ICs and board hot spots, are monitored from a single chip. Consider the [MAX6602](#) as an example. This temperature sensor has four remote diode inputs so it can monitor the temperatures

of a pair of FPGAs with integrated thermal diodes, two board hot spots using discrete transistors, and the temperature of the board at the MAX6602's location. Both the MAX6602 and the MAX6642 mentioned here achieve $\pm 1^\circ\text{C}$ accuracy when reading external thermal diodes.

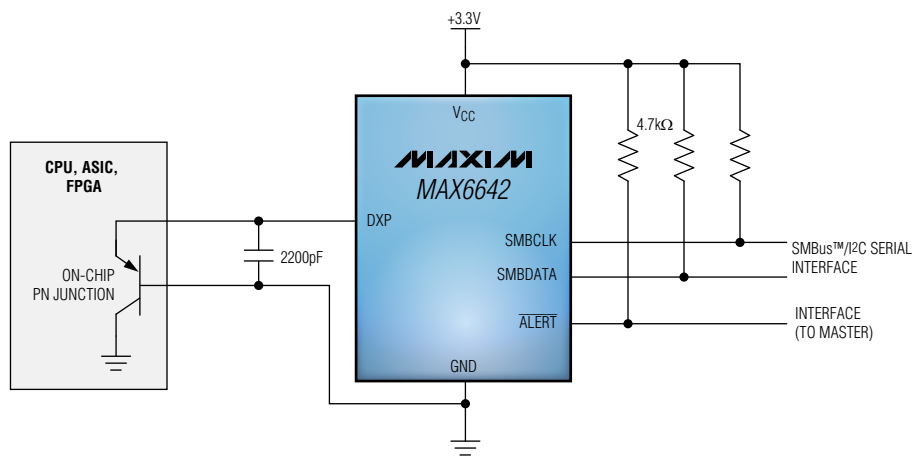


Figure 4. A remote temperature sensor, the [MAX6642](#), monitors the temperature of a sensing transistor (or thermal diode) on the die of an external IC.

Simple, integrated RTD-to-digital conversion

**MAX1402, MAX4236/
MAX4237**

Any appreciable resistance in the RTD's leads will cause errors in temperature measurement. Therefore, for long wire lengths use a 3- or 4-wire connection to eliminate lead-resistance errors. The circuit in **Figure A** is a 4-wire RTD interface using the MAX1402 oversampling ADC. The MAX1402 has two matched current sources, which significantly reduce the IC count in an RTD converter. One of the current sources provides excitation current for the RTD, in this case, a Pt100. Because the

excitation current does not flow through the sense leads, lead resistance will not affect the temperature-measurement accuracy. The second current source drives a precision resistor to generate the reference voltage for the ADC, thereby eliminating the need for an external voltage reference.

For best accuracy when using an RTD, apply linearity correction to the acquired data to compensate for the Pt100's nonlinearity. Also use gain correction to compensate for both the tolerance of the reference resistor and mismatch between the current sources.

The digital linearity correction can be avoided if a small amount of positive feedback is applied to an amplifier circuit, as shown in **Figure B**. The resulting linearity error from -100°C to $+200^{\circ}\text{C}$ is less than $\pm 0.05^{\circ}\text{C}$. This circuit does not compensate for long leads, so it should be used when the RTD is located near the measurement circuitry. For more details, refer to Maxim's application note 3450, "Positive Analog Feedback Compensates Pt100 Transducer."

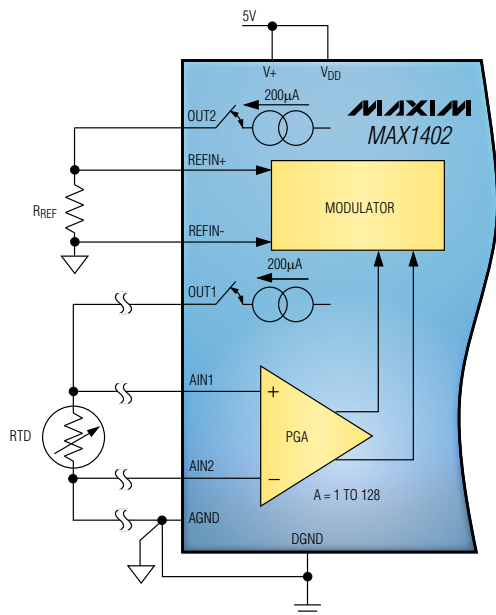


Figure A. Circuit diagram shows the MAX1402 ADC in a 4-wire interface for a Pt100 RTD.

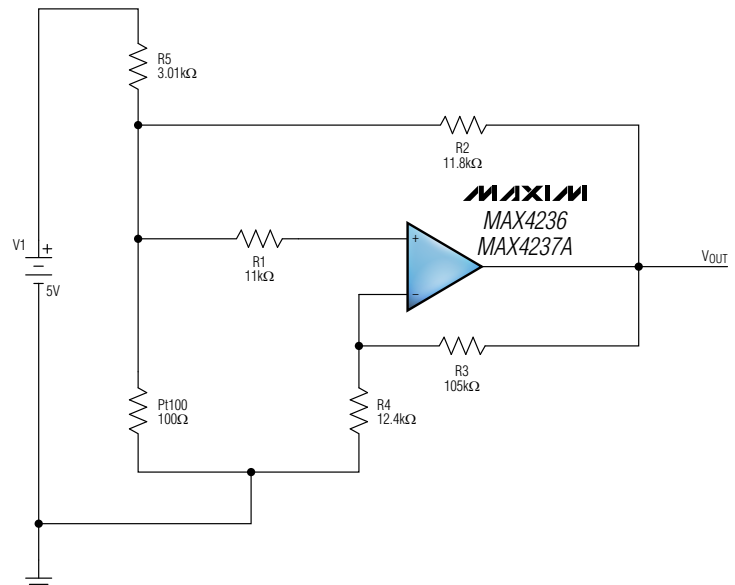


Figure B. A Pt100 linearizer circuit. Pt100 is compensated by one additional resistor. R2 provides a small positive feedback.

Complete thermocouple interface designs eliminate external components, use less space

DS600, MAX1416, MAX6133, MAX6675

The thermocouple circuit shown in **Figure A** uses the MAX1416 ADC that allows direct interfacing with thermocouples, thereby eliminating external components and reducing the overall footprint. The internal programmable gain amplifier (PGA) eliminates the need for an external precision amplifier; self-calibration avoids expensive calibration procedures during manufacture. The MAX1416 accommodates negative temperatures because its input

common-mode range extends 30mV below ground.

Cold-junction temperature is measured using a DS600 analog temperature sensor located at the thermocouple connector. With $\pm 0.5^\circ\text{C}$ accuracy, the DS600 provides the most accurate cold-junction compensation of any analog temperature-sensor IC on the market. Adding the cold-junction temperature to the temperature measured by the ADC corrects for the parasitic thermocouples created when the thermocouple connector is linked to the system.

Figure B shows a fully integrated thermocouple circuit using the MAX6675 thermocouple-to-digital interface IC. With the ADC, reference, gain, and cold-junction compensation all integrated, the MAX6675 measures positive temperature values from a K-type thermocouple and requires no external components. Using the MAX6675 thus reduces parts count, design time, and system complexity. The maximum measured temperature is $+1024.75^\circ\text{C}$. The 12-bit resolution results in an LSB value of 0.25°C

(continued on next page)

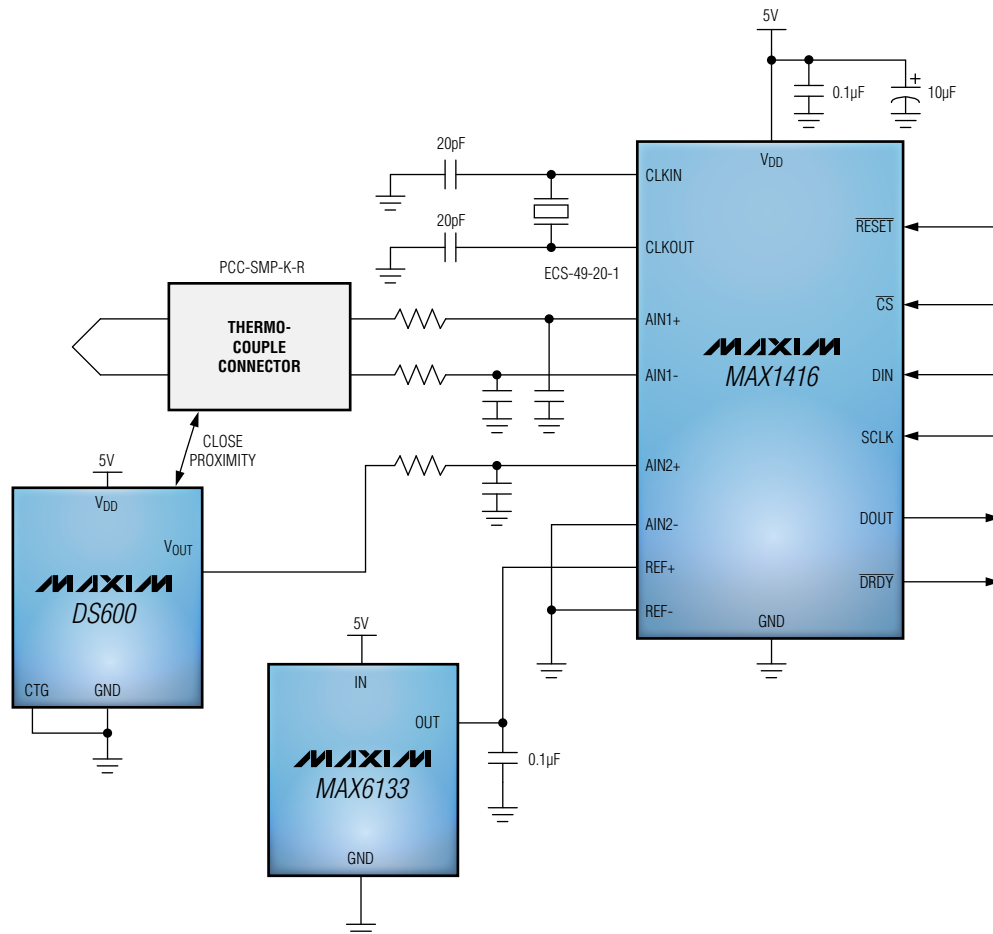


Figure A. A thermocouple measurement circuit in which the MAX1416 measures the thermocouple output and the DS600 measures the cold-junction temperature.

Complete thermocouple interface designs eliminate external components, use less space *(continued)*

For more information on temperature sensing, please refer to Maxim's Thermal Management Handbook at: www.maxim-ic.com/thermal-handbook.

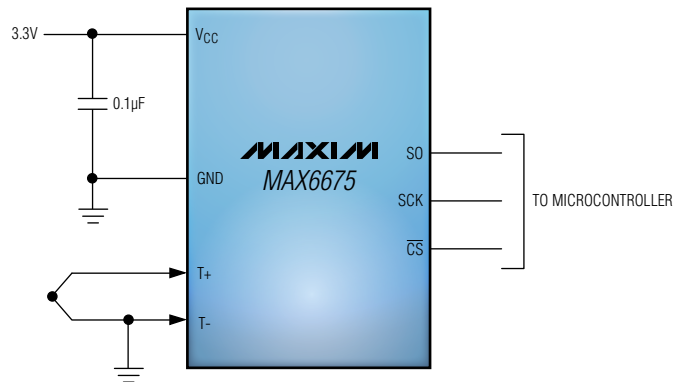


Figure B. The MAX6675 is a complete thermocouple-to-digital converter for K-type thermocouples.

Current, light, and proximity sensing

Overview

Current sensing is important in many applications and can be categorized into two popular approaches.

- In one approach current sensing is commonly used with higher currents and often in power-supply monitoring. Typical applications include short-circuit detection, transient detection, and reverse-battery detection.
- Current sensing is also used in applications that require much lower levels of current detection (down in the micro-amps), such as photodiodes that generate a small amount of current when exposed to light. Common applications are ambient light sensing, proximity detection, and light absorption-/reflection-based chemical process monitoring.

These current-sensing techniques employ current-sense amplifiers which are available in multiple configurations, or transimpedance amplifiers (TIAs). Each type of current-sensing amplifier is discussed below.

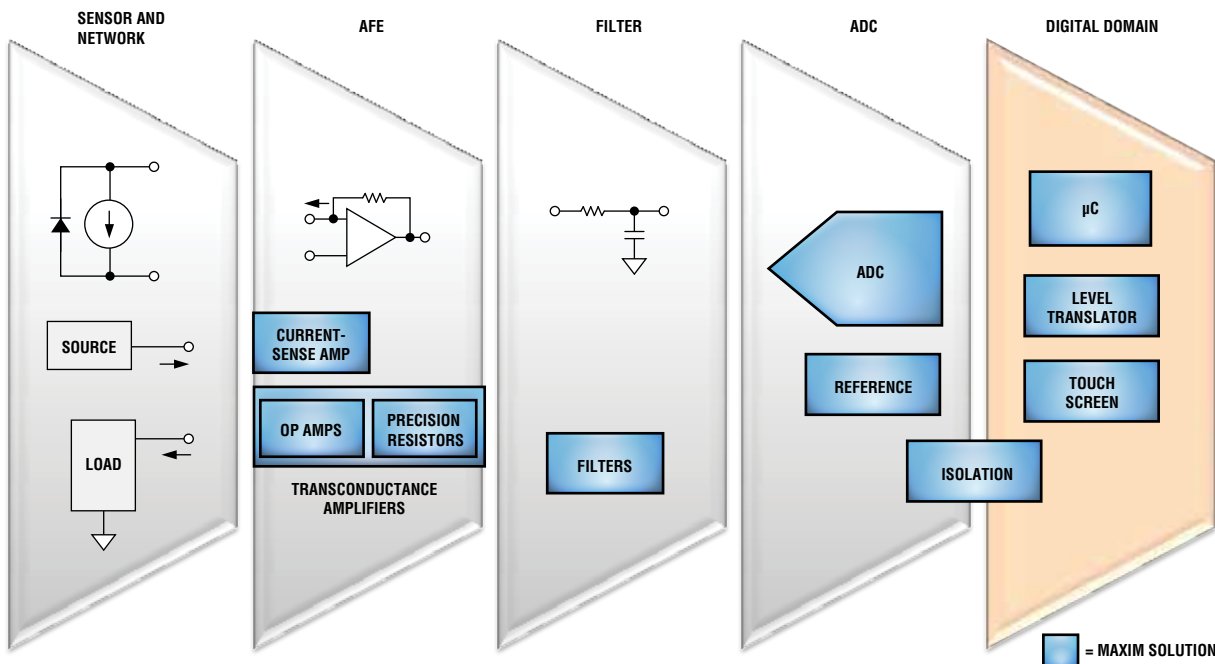
Current sensing using current-sense amplifiers

A variety of techniques are used to measure current, but by far the most popular is with a current-sense resistor. The basic principle of this approach is to amplify the voltage drop across the current-sense resistor by using an op-amp-based differential gain stage, and then to measure the resulting voltage. While discrete components can be used to build the amplifier circuit, integrated current-sense amplifiers have significant advantages over discrete implementations: better temperature drift,



smaller PC-board (PCB) area, and the ability to handle wide common-mode ranges.

Most current-sensing applications employ either the low-side or the high-side principle. In the low-side technique the sense resistor connects in series with the ground path. The circuit deals with



Block diagram of the signal chain in a current-sensing application. For a list of Maxim's recommended current-sensing solutions, please go to: www.maxim-ic.com/detect.



a low-input common-mode voltage, and the output voltage is ground referenced. However, the low-side sensing resistor adds undesirable extraneous resistance in the ground path. With the high-side principle, the sense resistor connects in series with the positive power-supply voltage. Here the load is grounded, but the high-side resistor must cope with relatively large common-mode signals.

High-side current-sense amplifiers from Maxim employ a current-sensing resistor placed between the positive terminal of the power supply and the supply input of the monitored circuit. This arrangement

avoids extraneous resistance in the ground plane, greatly simplifies the layout, and generally improves the overall circuit performance. The variety of unidirectional and bidirectional current-sense ICs from Maxim includes devices with and without internal sense resistors.

Light sensing with trans-impedance amplifiers (TIAs)

The second most popular current-measurement technique uses an op amp with very low input-bias current like a TIA, which converts the current input into a voltage output. This principle works for much smaller currents with large variations like those generated by photodiodes in light-sensing applications.

A simple photodiode is a very accurate transducer for sensing light. Light sensing is used in many different applications from power management based on sunlight, to sophisticated industrial process-control applications. Since

illuminance in a given situation can vary over a broad range (e.g., from 20klx to 100klx), a wide dynamic range can be a key requirement for a light sensor. An integrated solution like the [MAX9635*](#), which integrates a photodiode, amplifier, and analog-to-digital converter (ADC), provides a dynamic range of 0.03lx to 130,000lx.

Proximity sensing with a photodiode

While proximity sensing can be done in many ways, using a photodiode provides higher accuracy and conserves more power than other methods. When the light hits the photodiode, a current is generated proportional to the strength of the light intensity. A buffer stage with low-input noise and high bandwidth transfers this current to the rest of the system. An amplifier with low input-current noise, such as [MAX9945](#), provides accurate measurements.

Improve efficiency and increase reliability by monitoring a system's power

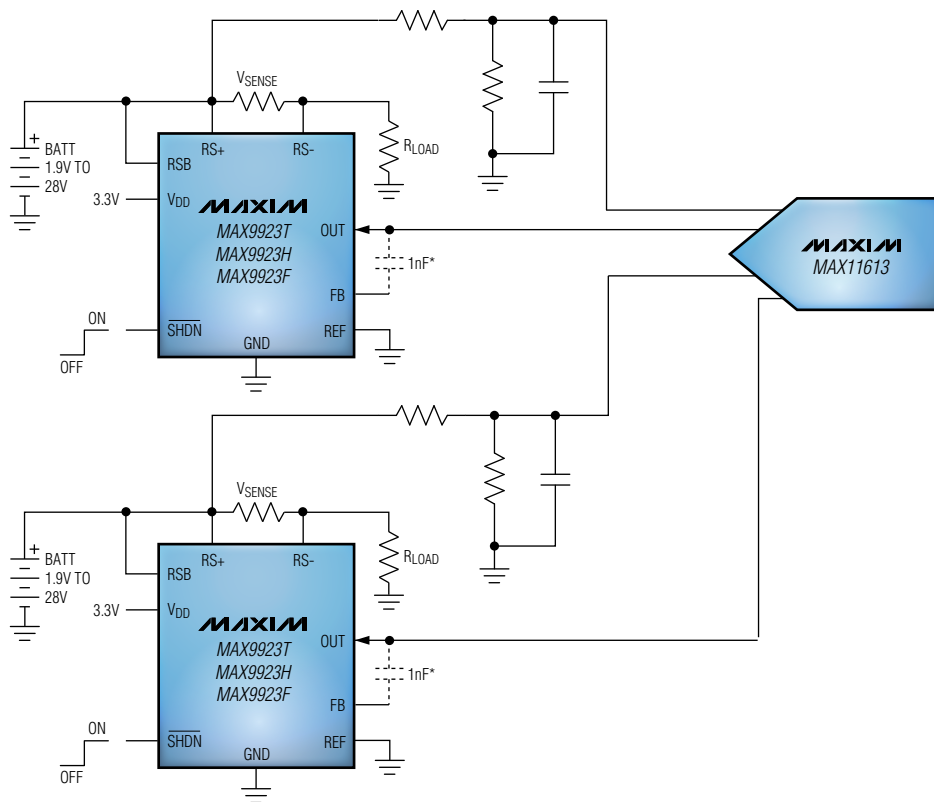
MAX9922/MAX9923, MAX11601, MAX11607, MAX11613 families

Here is a very common circuit found in applications for power monitoring. The MAX9923 current-sense amplifier amplifies the differential voltage across the current-sense resistor with extremely low offset and low noise.

The output of the MAX9923 and a resistor-divided output of the supply is fed to a low-cost, 4-channel 12-bit ADC, the MAX11613. While two independent supplies are shown here, the ADC could be monitoring voltage and current on a group of supplies. The MAX11601, MAX11607, MAX11613 families of ADCs are ideal for this application as they provide a low-cost, small package (μ MAX® or QSOP) I²C solution with 4 to 12 channels.

Benefits

- **Monitor current directly at the supply side for highly accurate sensing**
 - The MAX9922 allows direct interface to 28V signals
 - The MAX9922/MAX9923 use a patented spread-spectrum autozeroing technique* to remove offset and eliminate drift over time and temperature
 - 12-bit ADCs
- **Versatile and simple solutions accommodate a range of performance and cost-based requirements**
 - Pin-compatible 8-, 10-, and 12-bit ADCs in the same package
 - 4 to 12 ADC channels on a 2-wire I²C bus



*OPTIONAL NOISE REDUCTION

Circuit for monitoring a system's power supplies.

*U.S. Patent #6,847,257.

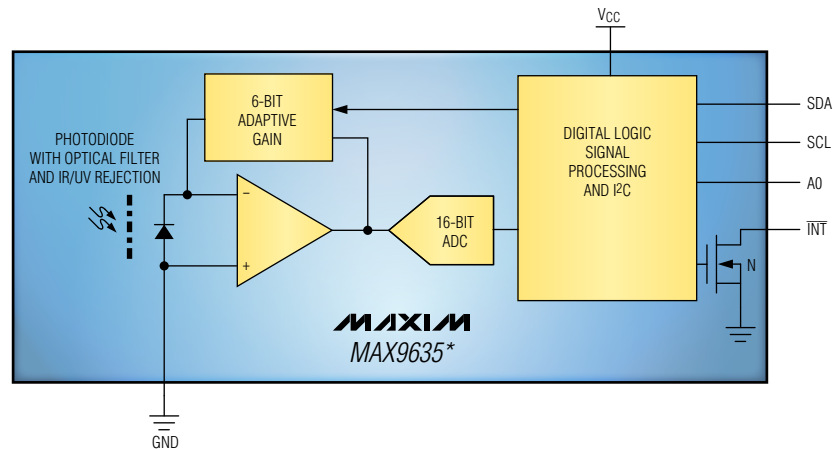
Save power, reduce system cost and complexity with a 22-bit, integrated ambient-light sensor

MAX9635*

The MAX9635 is a highly integrated ambient-light sensor with digital output. Its 1 μ A current consumption saves power in the system. The integrated ADC and an I²C communication channel reduce cost by eliminating external components. Space is also conserved, because this integrated solution has a 2mm x 2mm footprint. The added functionality of an adaptive gain block makes it easier to integrate this component into a system.

Benefits

- **Minimizes power requirements**
 - Ultra-low 1 μ A operating current consumption
 - V_{CC} is 1.7V to 3.6V and eliminates the need for different supply rails
- **Adaptable for a wide variety of applications**
 - Wide 0.03lx to 130,000lx sense range
 - Adjustable conversion time provides flexibility
- **High integration simplifies system design**
 - 6-bit adaptive gain control for autoranging reduces design complexity
 - Optical filters provide an optical response similar to the human eye, and block IR and UV light



Typical operating circuit for the 22-bit MAX9635 integrated ambient-light sensor.

*Future product—contact factory for availability.

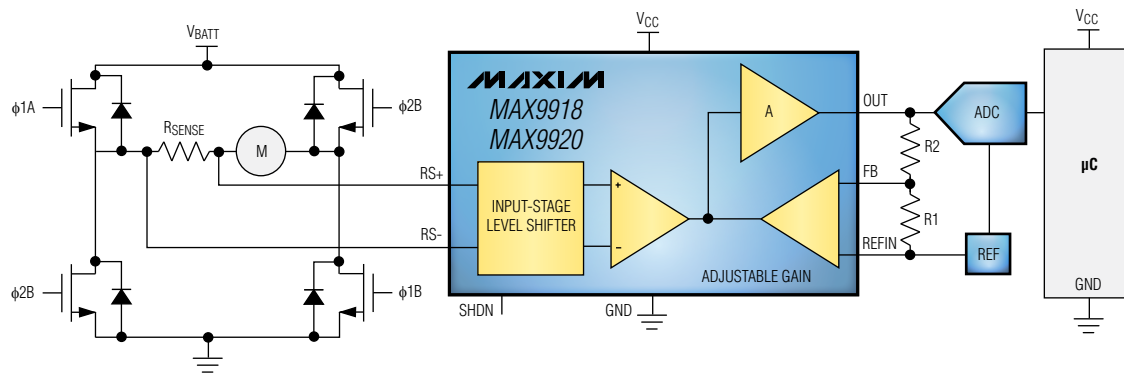
Get precise measurements in very harsh operating environments

MAX9918/MAX9919/MAX9920

The MAX9918/MAX9919/MAX9920 current-sense amplifiers provide uni-/bidirectional current sensing for very harsh environments where the input common-mode range can become negative. The amplifiers have a -20V to +75V common-mode operating range for measuring the current of inductive loads. The combination of uni-/bidirectional current measurement measures charge and discharge current into a system. The 4.5V to 5.5V single-supply operation reduces cost of the overall system.

Benefits

- **Industrial-grade products withstand very harsh operating environments**
 - -20V to +75V input common-mode operating range provides reliability while measuring the current of inductive loads
 - -40°C to +125°C automotive temperature range
- **Integrated functionality reduces system cost and shortens design cycle**
 - Uni-/bidirectional current sensing
 - Single 4.5V to 5.5V supply operation eliminates the need for a second supply
 - 400 μ V (max) input offset voltage (V_{OS})
 - 0.6% (max) gain accuracy error



Typical operating circuit for the MAX9918/MAX9920 current-sense amplifiers for harsh operating environments.

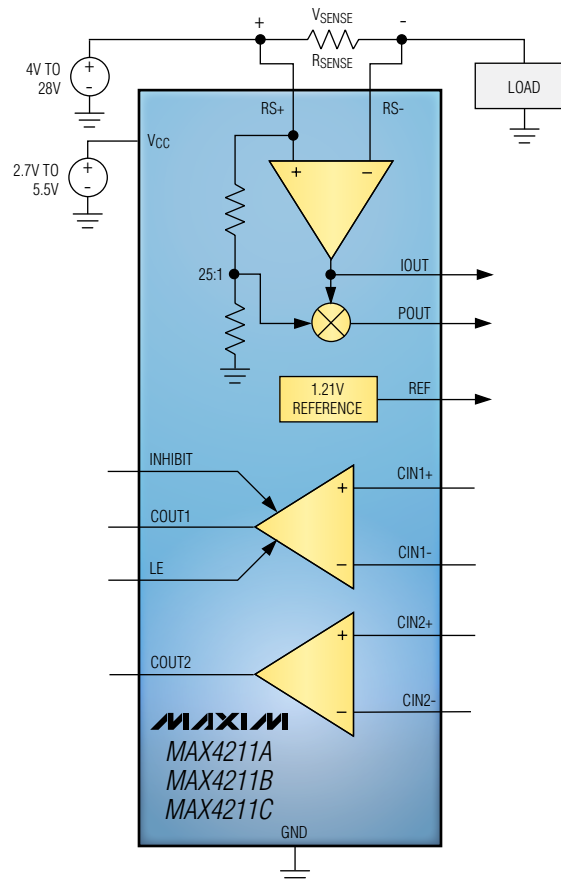
System diagnostics ensure longer up-time in harsh operating environments

MAX4211

The MAX4211 is a full-featured, continuous current and power monitor. The device combines a high-side current-sense amplifier, 1.21V bandgap reference, and two comparators with open-drain outputs to make detector circuits for overpower, overcurrent, and/or overvoltage conditions.

Benefits

- **Real-time power and current monitoring enhances system reliability**
 - $\pm 1.5\%$ (max) current-sense accuracy
 - $\pm 1.5\%$ (max) power-sense accuracy
 - 4V to 28V input-source voltage range
- **Integrated functionality reduces system cost and shortens design cycle**
 - Two integrated uncommitted comparators allow diagnostic alarm
 - Integrated 1.21V reference output
 - Three current/power-gain options provide flexibility in any industrial application



Typical operating circuit for the MAX4211 power and current monitor for harsh operating environments.

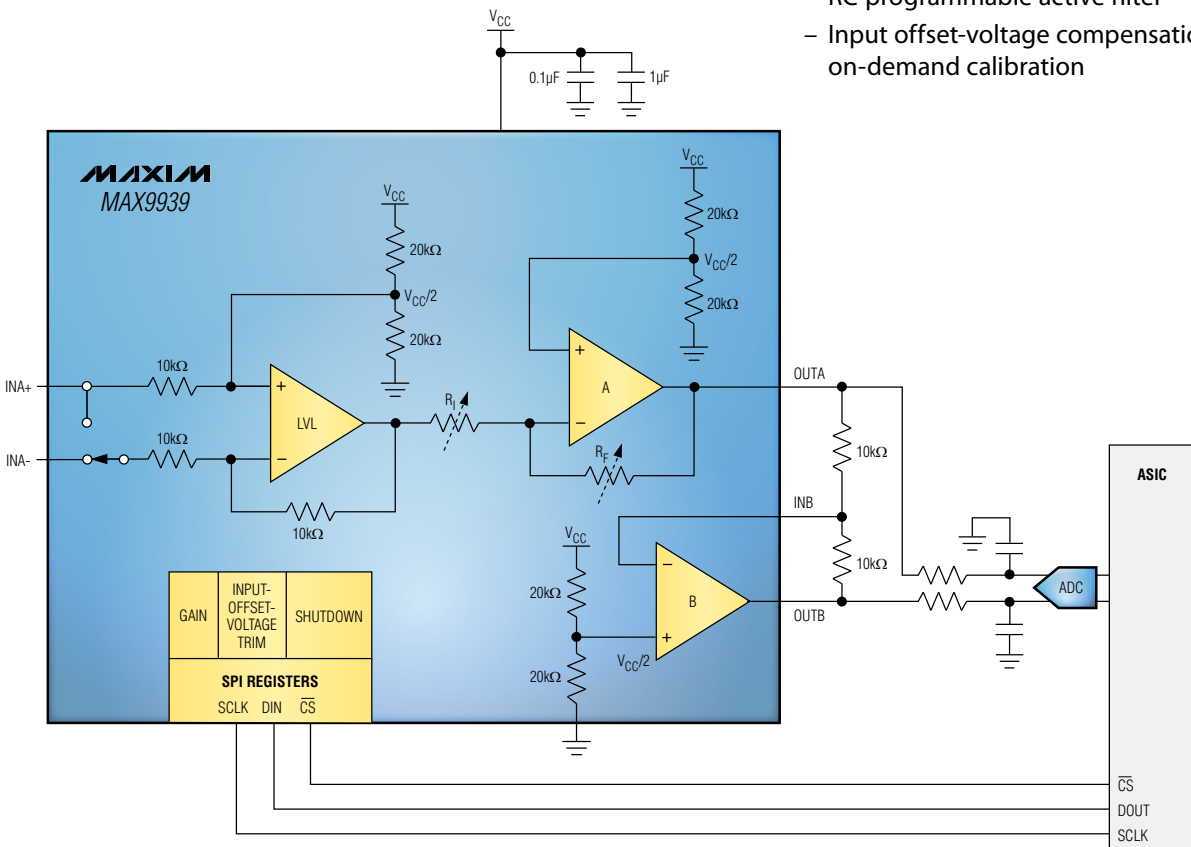
Improve system accuracy over temperature and minimize the effects of harsh environmental noise

MAX9939

The MAX9939 is a differential-input, programmable-gain amplifier (PGA). It features SPI™-programmable differential gains from 0.2V/V to 157V/V; input offset-voltage compensation for on-demand calibration; and an output amplifier that can be configured either as a high-order active filter or to provide a differential output. Using an input level-shifting amplifier stage, the MAX9939 processes signals both above and below ground.

Benefits

- **Differential input/output configuration minimizes harsh operating environmental noise**
 - Processes signals above and below ground using an input level-shifting amplifier stage; is ideal for thermocouple applications
 - Integrates an amplifier for a differential-output configuration
- **Integrated functionality reduces system complexity, maximizes flexibility and system robustness**
 - Optimized for high-signal bandwidth
 - Programmable gain with the SPI controls: 0.2V/V, 1V/V, 10V/V, 20V/V, 30V/V, 40V/V, 60V/V, 80V/V, 119V/V, and 157V/V
 - Embedded input protection to $\pm 16\text{V}$
 - Integrated amplifier for RC-programmable active filter
 - Input offset-voltage compensation for on-demand calibration



Functional diagram of the robust MAX9939 PGA.

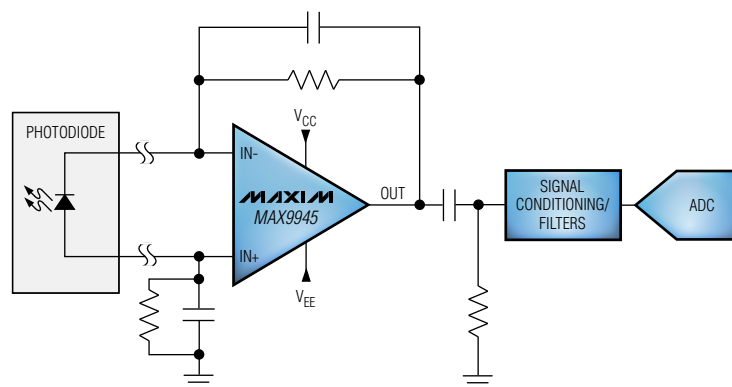
Maximize system accuracy in photodiode and high-ohmic sensor applications

MAX9945

The MAX9945 operational amplifier features an excellent combination of low-operating power and low-input-voltage noise. MOS inputs enable the MAX9945 to feature low 50fA input-bias currents and low ($15\text{nV}/\sqrt{\text{Hz}}$) input-current noise. The MAX9945 simplifies the interface between high-ohmic sensors or low-current TIA applications.

Benefits

- **Improves system's signal-to-noise ratio (SNR) for more accurate measurements**
 - 50fA low input-bias current
 - $1\text{fA}/\sqrt{\text{Hz}}$ low input-current noise
 - $15\text{nV}/\sqrt{\text{Hz}}$ low noise
- **High-voltage robust design simplifies mixed-voltage designs**
 - 4.75V to 38V single-supply voltage range
 - $\pm 2.4\text{V}$ to $\pm 19\text{V}$ dual-supply voltage range
 - Rail-to-rail output-voltage swing



Highly accurate light-sensor interface features the MAX9945 op amp.

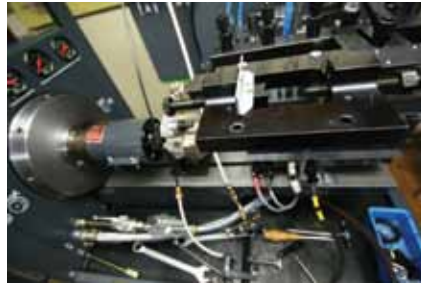
Hall-effect sensors

Overview

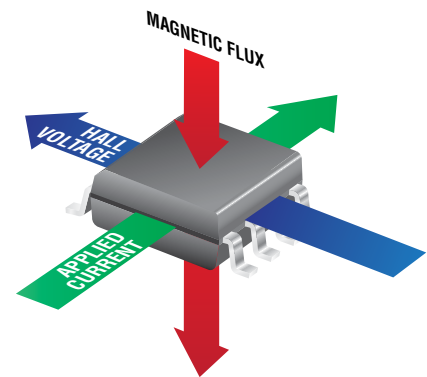
Hall-effect sensors are widely used in applications for status, position, angular, and proximity detection and for smart-sensing systems. Since Hall-effect sensors detect a magnetic field, they can operate in harsh environmental conditions. Their robustness and reliability are important benefits derived from a magnetic field.

Hall-effect sensors are used in motor applications where the speed, position, and direction of motors can be sensed and communicated to the system for real-time feedback. If there is an interruption to the motor, the sensor detects it so corrective action can be taken.

Typically, to detect the direction of movement, two Hall-effect sensors are used. Maxim's [MAX9641](#)*



combines two Hall-effect sensors and digital logic to provide position and direction outputs. As an additional help for detecting mechanical movements, single and dual Hall-effect switches can integrate a Hall-effect sensor, an amplifier, and an output stage. A Hall-effect switch can, for example, be placed on a stationary part and a magnet placed in a mechanical moving arm. When the arm aligns with the stationary part, the Hall-effect switch detects



the position and forwards the information to the microprocessor.

Hall-effect sensors improve robustness and repeatability compared to mechanical approaches. These sensors provide better reliability than photointerrupter-based systems which are not reliable in dusty, humid environments.

www.maxim-ic.com/detect

*Future product—contact factory for availability.

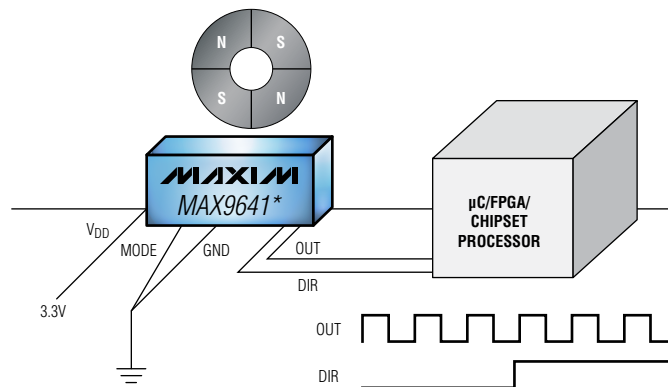
Simplify motion detection and system design with dual Hall-effect switch

MAX9641*

The MAX9641 is an ultra-low-power, dual, Hall-effect switch with adjustable threshold operation and selectable sampling frequency. Three programmable sampling periods (160 μ s, 500 μ s, and 50ms) provide flexibility for choosing the operating speed. The operating point of the Hall-effect switch can be easily adjusted to three points by setting the adjust pin. With logic communication built in, the user can retrieve information about the speed and direction of the magnet's movement. Combining two Hall-effect sensors into one chip reduces overall system cost.

Benefits

- **Simplifies system design with enhanced functionality**
 - User-selectable sampling period of 160 μ s, 500 μ s, and 50ms with an adjustable RATE pin
 - The switch's threshold point can be easily chosen by setting the ADJ pin
- **Simplifies the measurement of speed and direction**
 - Dual Hall-effect sensors integrated in a single IC
- **Reduces system cost**
 - Information for both direction and speed is gathered with a single IC
 - 1.7V to 5.5V supply voltage range is compatible with many system designs



Dual Hall-effect switch solution.

*Future product—contact factory for availability.

Sensor communications interface

A sensor communicates its sensed information with analog or digital techniques. Analog techniques are based on voltage or current loops. Digital information is communicated with CAN, CompoNet®, IO-Link®, RS-485, and other data interfaces.

Binary sensors only transmit single-bit information. Typically, the presence or absence of an object is detected and communicated with a logic level.

Also, when an object like a piston in a valve reaches a predefined critical distance, the sensor detects and communicates this to the programmable-logic-controller (PLC) system through a binary interface.

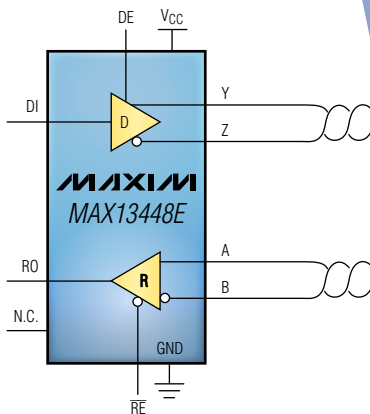
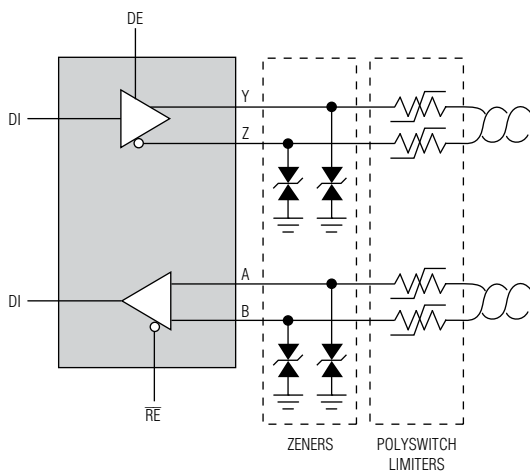
Sensor interfaces have to be robust against all forms of mishandling and EMI, since the industrial environments are harsh.



Fault-protected RS-485 transceivers make equipment more robust

MAX13448E, MAX3440E–MAX3444E, MAX13442E/MAX13443E/MAX13444E, MAX3430

In applications where power and data are distributed over the same cable, there is a potential for miswiring, cable shorts, or surges on the communication bus. Maxim's RS-485 transceivers offer fault protection up to $\pm 80V_{DC}$.



Reduces external components, saves up to 25% board space

Benefits

- **Reduce board space by 25% with integrated fault-protection circuitry**
 - Highest fault protection from an integrated transceiver
 - Fault protection up to $\pm 80V$
- **Flexible configurations interface with multiple systems**
 - Wide 3.3V to 5V supply range
 - Interfaces with full- and half-duplex systems
- **High integration reduces bill of materials (BOM) complexity and cost**
 - Integrated slew-rate limiting for error-free data transmission
 - True fail-safe operation
 - Hot-swap operation
- **Robust operation in harsh environments**
 - $\pm 15kV$ ESD protection

Part	V _{CC} Supply (V)	Configuration	Fault Protection (V)
MAX13448E	3.3 to 5	Full	± 80
MAX3440E–44E	5	Half	± 60
MAX13442E/43E/44E	5	Half	± 80
MAX3430	3.3	Half	± 80

Maxim's RS-485 family offers high levels of flexibility and integration.

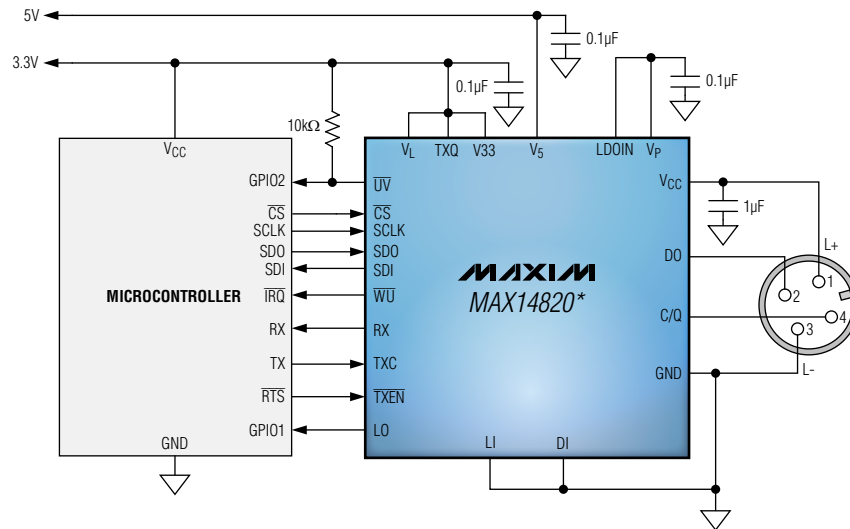
Reduce PCB footprint with an IO-Link/binary sensor interface

MAX14820*

The MAX14820 is a transceiver with a 24V binary interface for sensors and actuators. Designed for IO-Link device applications, it supports all the specified IO-Link data rates. The MAX14820 contains additional 24V digital inputs and outputs (I/Os). Two regulators generate common sensor signals and conditioning power requirements: 5V and 3.3V. The drivers are configurable to PNP, NPN, and push-pull. Configuration, monitoring, and alarms are accessed through an SPI™ interface. The device is thermally self-protected and all 24V interface pins are protected against reverse-polarity, shorts, and ESD.

Benefits

- **Industry's smallest package for compact designs**
 - Tiny 2.5mm x 2.5mm WLP and 4mm x 4mm TQFN
 - Requires minimal external components
- **Integration of all high-voltage functions optimizes sensor circuit partitioning, saves board space**
 - Integrated high-voltage regulators
 - Undervoltage detection
 - Two output drivers and two receivers
- **Single solution fits multiple application requirements, reduces inventory complexity**
 - Suitable for sensors and actuators
 - Suitable for binary sensor applications
 - Dual outputs and inputs fit most sensor needs
 - Dual output supplies power signal conditioning



The MAX14820 IO-Link/binary-sensor interface reduces PCB footprint.

*Future product—contact factory for availability.

Recommended solutions

Pressure sensors and weigh scale

Part	Description	Features	Benefits
ADCs			
MAX1415/16 MX7705	16-bit, low-power, 2-channel, sigma-delta ADCs	Two differential channels; PGA; single-supply operation	Highly flexible ADC; interfaces with a wide range of sensors
MAX1400/01/02/03	18-bit, 5-channel delta-sigma ADCs	Three differential channels; PGA; precision current sources for excitation; burn-out detection	High integration produces a more precise sensor that measures both pressure and temperature with one ADC
MAX11040	24-bit, 4-channel, simultaneous-sampling sigma-delta ADC	Cascadable up to 32 channels; 106dB SNR at 16ksp/s; overvoltage protection (OVP)	Eases design interface to sensors that require multichannel accurate amplitude and phase information
MAX11200*/01*/02*	Ultra-low-power, sigma-delta ADCs	21-bit noise-free range at 10sp/s; 3V supply; 0.45mW; four general-purpose inputs/outputs (GPIOs)	21 bits of noise-free range with minimal impact on power budget
Sensor signal conditioners			
MAX1452	Low-cost, precision, analog sensor signal conditioner	Multitemperature calibration; current and voltage excitation; fast 150ns response; single-pin programmable; 4–20mA applications	Provides a flexible signal-conditioning platform for a wide range of sensor applications, thus reducing inventory
MAX1464	Low-power, low-noise, multichannel, digital sensor signal processor	Integrates 16-bit ADC, DACs, and CPU; programmable compensation algorithm; digital, analog, and PWM outputs; 4–20mA applications	Accurate signal conditioner interfaces directly with microcontroller to save space
Amplifiers			
MAX9617/18	Ultra-precision, zero-drift op amps	1.5 MHz gain bandwidth (GBW); 59µA supply current; 10µV (max) zero-drift input offset voltage (V_{OS}); single and dual packaging versions	Provide high-precision measurements for a wide variety of low-frequency applications
MAX9943/44	High-voltage, precision, low-power op amps	Wide 6V to 38V supply range; 2.4 MHz GBW	Design flexibility for a wide range of applications

For a list of Maxim's recommended pressure-sensor solutions, please go to: www.maxim-ic.com/psi.

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Temperature sensing

Part	Description	Features	Benefits
Thermal management			
DS600	Precision analog-output temperature sensor	Industry's highest accuracy analog temp sensor: $\pm 0.5^{\circ}\text{C}$ from -20°C to $+100^{\circ}\text{C}$	Best cold-junction compensation accuracy for superior thermocouple measurement
DS7505	Low-voltage, precision, digital thermometer and thermostat	$\pm 0.5^{\circ}\text{C}$ accuracy from 0°C to $+70^{\circ}\text{C}$; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply-voltage reduction from LM75
DS18B20	Precision 1-Wire digital temperature sensor	$\pm 0.5^{\circ}\text{C}$ accuracy from -10°C to $+85^{\circ}\text{C}$; 1-Wire interface; 64-bit factory-lasered ID code	Connects multiple precision temperature sensors with fewer wires than any competitive solution
MAX6675	K-type thermocouple-to-digital converter	Built-in cold-junction compensation	Simplest thermocouple interface; no external components needed
ADCs			
MAX1300*/01/02*/03	16-bit, 8-/4-channel SAR ADCs with software-programmable input ranges	Input range from $\pm 12\text{V}$ to 0 to 2.048V; $\pm 16.5\text{V}$ overvoltage-protected inputs; PGA; internal reference	Reduce design complexity when working with sensors with multiple output ranges
MAX1415/16 MX7705	16-bit, low-power, 2-channel, sigma-delta ADCs	Two differential channels; PGA; single supply	Flexible ADC interfaces with a wide range of sensors
MAX1400/01/02/03	18-bit, 5-channel, sigma-delta ADCs	Three differential channels; precision current sources for excitation; burn-out detection	A single ADC simplifies temperature-sensor design for accurate thermocouple and RTD measurement
MAX11200*/01*/02*	Ultra-low-power, sigma-delta ADCs	21-bit noise-free range at 10sps; 3V supply; 0.45mW; 4 GPIOs	21 bits of noise-free range with minimal impact on power budget
Amplifiers			
MAX9617/18	Ultra-low-power, zero-drift op amps	1.5 MHz GBW; 59 μA supply current; 10 μV (max) zero-drift input offset voltage (V_{OS}); single and dual packaging versions	Provide high-precision measurements for a wide variety of low-frequency applications
MAX9943/44	High voltage, precision, low power op amps	Wide 6V to 38V supply range; 2.4 MHz GBW	Design flexibility for a wide range of applications
MAX9939	SPI programmable-gain amplifier (PGA) with on-demand calibration and differential in/out configuration	Input supports negative voltages; wide range of gain configurations; input-error nulling feature	Calibration on-demand improves system accuracy; minimizes harsh environmental noise

For a list of Maxim's recommended temperature-sensor solutions, please go to: www.maxim-ic.com/-40+85.

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Light sensing

Part	Description	Features	Benefits
ADCs			
MAX1168/67 MAX1162	16-bit, 200ksps, 8-/4-/1-channel SAR ADCs	16-bits, no missing codes; single 5V supply; unipolar 0 to 5V input range	Flexible and accurate solution for multichannel applications
MAX11200*/01*/02*	Ultra-low-power, sigma-delta ADCs	21-bit noise-free range at 10sps; 3V supply; 0.45mW; 4 GPIOs	Use lower power while enabling accurate measurements over a 20klx to 100klx range
Amplifiers			
MAX9635*	Ambient-light sensor with integrated ADC	1 μ A ultra-low power; 22-bit wide dynamic-range with automatic gain control (AGC)	Integrated ambient-light sensor saves power; reduces system cost and complexity
MAX9945	Low-noise, MOS-input, low-power op amp	4.75V to 38V supply voltage range; low input-bias current; low input-current noise	Low input-bias current (fA) maximizes system accuracy
MAX4230–MAX4234	High-output-drive, rail-to-rail I/O op amp series	200mA output-drive capability; 10MHz GBW; 10 μ V/s high slew rate	Provide drive to allow extended distance between sensors and acquisition system
MAX4475–MAX4478	Low-distortion, CMOS-input op amp series	0.0002% THD+N; low input-bias current; 10MHz GBW	Accurately reproduce the input signal for the ADC

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Current sensing

Part	Description	Features	Benefits
ADCs			
MAX11600– MAX11605 MAX11606– MAX11611 MAX11612– MAX11617	Multichannel, low-power, ADCs with I ² C interface	Low cost; 8-/12-bit; 4-/8-/12-channels; differential inputs; low power (6μA at 1ksp/s); I ² C	Sense multiple currents and voltages at low cost
MAX11618*– MAX11625* MAX11626*– MAX11633* MAX11634*– MAX11637* MAX11638*– MAX11643*	Multichannel, FIFO ADCs with an SPI interface	Low cost; 8-/12-bit; 8-/12-/16-channels; differential inputs; internal FIFO; SPI	Sense multiple currents and voltages at low cost with a family of SPI ADCs
Amplifiers			
MAX9918/19/20	Precision, uni-/bidirectional current-sense amplifiers	-20V to +75V input common-mode range (CMR); 400μV (max) input offset voltage (V _{OS}); choice of gains	Precise current monitoring for even negative common-mode voltages; needs no additional circuitry
MAX9922/23	Ultra-precision, high-side current-sense amplifiers	25μV (max) offset voltage (V _{OS}); > 0.5% gain accuracy; choice of gains	Allows precise current measurements even at very small sense voltages
MAX9928F/29F	Ultra-small, uni-/bidirectional, high-side current-sense amplifiers	-0.1V to +28V input CMRR with 20μA quiescent supply current; choice of gains	Save space for battery-monitoring applications
MAX4211	High-side power and current monitor with diagnostics for state of health	Real-time power and current monitor; programmable diagnostic detector	Integrated solution for current monitoring; speeds design

For a list of Maxim's recommended current-sensing solutions, please go to: www.maxim-ic.com/detect.

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Hall-effect sensors

Part	Description	Features	Benefits
Amplifiers			
MAX9639*	Ultra-low-power, Hall-effect sensor	50ms sampling rate; 1.7V to 5.5V operation; three threshold points of 1.5mT, 3mT, and 5mT	Integrated sensor and amplifier reduce cost
MAX9640*	Ultra-low-power, Hall-effect sensor	50ms sampling rate; 1.7V to 5.5V operation; sign output	Reduces system cost by giving the direction of an applied magnetic field
MAX9641*	Ultra-low-power, dual, Hall-effect sensor	Selection of 160µs/500µs/50ms sample periods; three threshold points of 1.5mT, 3mT, and 5mT; gives direction and speed of magnet movement	Simplifies Hall-effect system by integrating components with adjustable features

For a list of Maxim's recommended position-sensing solutions, please go to: www.maxim-ic.com/detect.

Sensor communications interface

Part	Description	Features	Benefits
Transceivers			
MAX14820*	IO-Link sensor actuator interface	Tiny 2.5mm x 2.5mm WLP and 4mm x 4mm TQFN packages; dual 24V outputs and dual 24V inputs; 300mA drive capability; IO-Link wake-up detection	IO-Link/binary sensor interface reduces PCB footprint
MAX13442E/43E/44E	Fault-protected RS-485 transceivers	±80V fault-protected RS-485; half-duplex; 5V (250kHz/10MHz)	Simplify design by eliminating external components such as transient voltage suppressors (TVSs) and overcurrent protectors

For a list of Maxim's recommended sensor-communications solutions, please go to: www.maxim-ic.com/sensor.

*Future part—contact factory for availability.

Overview



Electric motors consume almost 50% of the world's electricity. With the cost of energy rising steadily, industry is focused on replacing inefficient constant-speed motors and drives with microprocessor-based, variable-speed drives. This new motor-control technology will reduce energy consumption by more than 30% compared to the older drives. While these variable-speed controllers add cost to a motor, the forecasted energy savings and increased motor functionality should easily offset those initial expenses within a few years.

Popular motor designs

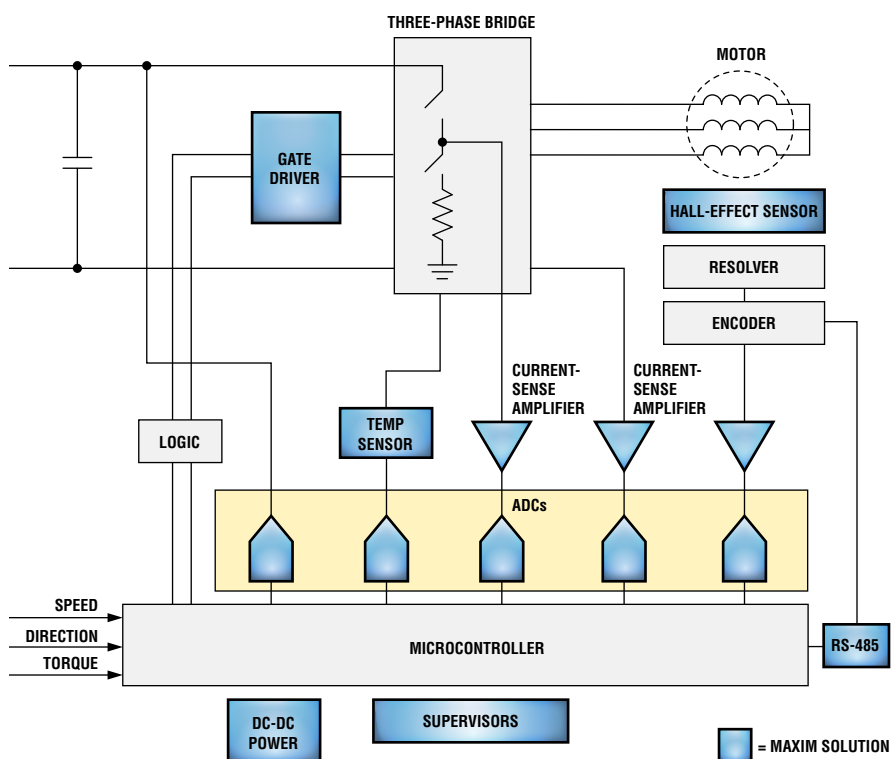
The DC motor, brushless DC, and AC induction motor are the popular motor designs used in today's industrial applications. Each of these motor types has its own unique characteristics, but they all operate on the same basic electromagnetic principle: when a conductor carrying current, such as a wire winding, is located in an external magnetic field perpendicular to the conductor, then the conductor will experience a force perpendicular to itself and to the external magnetic field.

DC motors: low cost and accurate drive performance

A DC motor was among the first motor types put to practical use, and it is still popular where low initial cost and excellent drive performance are required. In its simplest form, the stator (i.e., the stationary part of the motor) is a permanent magnet, and the rotor (i.e., the rotating part of the motor) carries an armature winding connected to a mechanical commutator which switches current on and off to the winding. The magnet establishes the field flux which interacts with the armature current to produce the electromagnetic torque, thereby enabling the motor to perform work. The motor's speed is controlled by adjusting the DC voltage applied to the armature winding.

Depending on the application, a full-bridge, half-bridge, or just a step-down converter is used to drive the armature winding. The switches in these converters are pulse-width modulated (PWMed) to achieve the desired voltage. Maxim's high-side or bridge-driver ICs like the [MAX15024](#)/[MAX15025](#) can be used to drive the FETs in the full- or half-bridge circuit.

DC motors are also widely used in servo applications where speed and accuracy are important. To meet speed and accuracy requirements, microprocessor-based closed-loop control and information about rotor position are essential. Maxim's [MAX9641*](#) Hall-effect sensor provides information about rotor position.



Block diagram of a typical industrial motor control.

For a list of Maxim's recommended motor-drive solutions, please go to: www.maxim-ic.com/motordrive.

AC induction motors: simplicity and ruggedness

An AC induction motor is popular in industry because of its simplicity and ruggedness. In its simplest form, this motor is a transformer with the primary-side voltage connected to the AC-power-voltage source and the secondary side shorted to carry the induced secondary current. The name “induction” motor derives from this induced secondary current. The stator carries a three-phase winding and the rotor is a simple design, commonly called a “squirrel cage,” in which the copper or aluminum bars are short-circuited at both the ends by cast-aluminum end rings. The absence of rotor windings and brushes makes this motor design especially reliable.



Rotor and stator of an induction motor.

When operated from the 60Hz voltage, the induction motor operates at a constant speed. However, when power electronics and a microprocessor-based system are used, the motor’s speed can be varied. The variable-speed drive consists of an inverter, signal conditioner, and microprocessor-based control. The inverter uses three

half bridges in which the top and the bottom switch are controlled in a complementary fashion. Maxim offers multiple half-bridge drivers like the [MAX15024/MAX15025](#) which control the top and bottom FETs independently.

Precise measurement of three-phase motor current, rotor position, and rotor speed are necessary for efficient closed-loop control of an induction motor. Maxim offers many high-side and low-side current amplifiers, Hall-effect sensors, and simultaneous-sampling analog-to-digital converters (ADCs) to accurately measure these parameters in the harshest environments.

A microprocessor uses data on the current and position to generate logic signals for the three-phase bridge. A popular closed-loop control technique called vector control decouples the vectors of field current from the stator flux so that it can be controlled independently to provide a fast transient response.

Brushless DC motors: high reliability and high-output power

A brushless DC (BLDC) motor has neither commutator nor brushes, so it requires less maintenance than a DC motor. It also offers more output power per frame size compared to induction and DC motors.

The stator of the BLDC motor is quite similar to that of the induction motor. The BLDC motor’s rotor, however,

can take different forms, but all are permanent magnets. Air-gap flux is fixed by the magnet and is unaffected by the stator current. The BLDC motor also requires some form of rotor position sensing. A Hall-effect device embedded in the stator is commonly used to sense the rotor’s position. When the rotor’s magnetic pole passes near the Hall-effect sensors, a signal indicates whether the north or the south pole passed. Maxim offers several Hall-effect sensors like the [MAX9641*](#), which simplifies designs and reduces system costs by integrating two Hall-effect sensors and digital logic to provide both positional and directional outputs of the magnet.

The importance of sensors, signal conversion, and data interfaces

Several types of sensors provide feedback information in the motor-control loop. These sensors also improve reliability by detecting fault conditions that can damage the motor. The following sections examine the role of sensors in motor control in greater detail. Specific attention will be given to current-sense amplifiers, Hall-effect sensors, and variable-reluctance (VR) sensors. Other important topics include monitoring and controlling multi-channel currents and voltages with high-speed analog-to-digital signal conversion (ADCs), and the encoder data interfaces needed for high-accuracy motor control.

* Future product—contact factory for availability.

Monitoring and measuring current for optimal motor control

Current monitoring

Current is a common signal to be sensed, monitored, and fed back to the motor-control loop. Current-sense amplifiers make it easier to monitor the current into and out of the system with a high level of precision. If current-sense amplifiers are used, no transducer is needed, as the electrical signal itself is being measured. Current-sense amplifiers detect shorts and transients, and they monitor power and reverse-battery conditions.

Current measurement

There is a variety of techniques to measure current, but by far the most popular uses a current-sense resistor. In this technique the voltage drop across the current-sense resistor is first amplified by an op amp set up in a differential gain stage, and then measured. Traditionally, this approach has been implemented with discrete components. However, discrete solutions also introduce some disadvantages such as the requirement for matched resistors, poor drift, and

a larger solution area. Fortunately, these multiple and varied disadvantages can be overcome by integrating current-sense amplifiers into the design. Not only do the amplifiers measure the current, but they also sense the direction of current, accommodate wide common-mode ranges, and provide more precise measurement.

Current measurement employs either the low-side principle in which the sense resistor connects in series with the ground path, or the high-side principle in which the sense resistor connects in series with the hot wire. In low-side measurement, the circuit has a low-input common-mode voltage, and the output voltage is ground referenced. The low-side resistor adds undesirable extraneous resistance in the ground path. In high-side measurement, the load is grounded, but the high-side resistor must cope with relatively large common-mode signals. High-side sensing also allows detection of fault conditions such as the motor case or winding that shorts to ground.



High-side current-sense amplifiers like the [MAX4080/MAX4081](#) employ a current-sensing resistor placed between the positive terminal of the power supply and the supply input of the monitored circuit. This arrangement avoids extraneous resistance in the ground plane, greatly simplifies the layout, and generally improves the overall circuit performance. Maxim's unidirectional and bidirectional current-sense ICs like the [MAX9918/MAX9919/MAX9920](#) are available with or without internal sense resistors. This variety of parts adds considerable flexibility to designs and simplifies part selection for a wide variety of ADCs and applications.

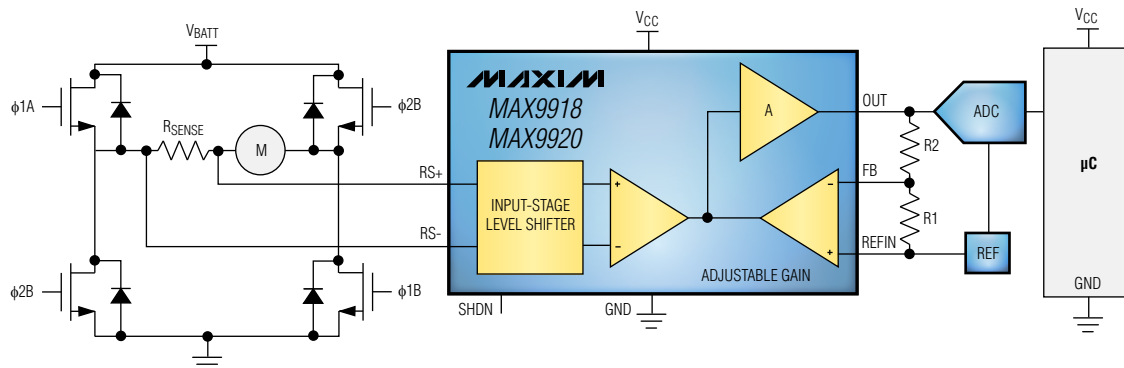
Precise current measurements ensure better motor control

MAX9918/MAX9919/MAX9920

The MAX9918/MAX9919/MAX9920 are current-sense amplifiers with a -20V to +75V input range. The devices provide unidirectional/bidirectional current sensing in very harsh environments where the input common-mode voltage can become negative. Uni-/bidirectional current sensing measures charge and discharge current in a system. The single-supply operation shortens the design time and reduces the cost of the overall system.

Benefits

- **Provide reliable operation in harsh motor-control environments**
 - 400 μ V (max) input offset voltage (V_{OS})
 - -20V to +75V common-mode voltage range provides reliability for measuring the current of inductive loads
 - -40°C to +125°C automotive temperature range
- **Integrated functionality reduces system cost and shortens design cycle**
 - Uni-/bidirectional current sensing
 - Single-supply operation (4.5V to 5.5V) eliminates the need for a second supply
 - 400 μ V (max) input offset voltage (V_{OS})
 - 0.6% (max) gain accuracy error



The MAX9918/MAX9920 current-sense amplifiers provide precise uni-/bidirectional current sensing in very harsh environments.

Sensing motor speed, position, and movement

Overview

Hall-effect sensors are used to sense the speed, position, and direction of motors. With integrated device logic, the sensors then communicate that data to the system for real-time feedback. The sensor also detects and reports any interruption to the motor so corrective action can be taken. Typically, to detect the direction of movement two Hall-effect sensors are used.

Commutation can be synchronized to Hall edges if the system has the same number of Hall-effect devices as motor phases, and if the mechanical geometry of the Hall-effect devices is correlated with the electrical geometry of the motor phases. Maxim's [MAX9641*](#) combines two Hall-effect sensors and sensor signal conditioning to provide both positional and directional outputs.

Hall-effect sensors can also be used with special Hall-effect sensor interface products like the [MAX9621](#). The interface devices provide several functions: protect against supply transients, sense and filter the current drawn by the Hall-effect sensors, and diagnose and protect against faults.

Hall-effect sensors improve robustness and repeatability, compared to mechanical photointerrupter-based systems which are compromised in environments with dust and humidity. Since Hall-effect sensors detect the magnetic field produced by a magnet or current, they can operate continuously in such harsh environmental conditions.

In some applications vibration, dust, and high temperature cause active sensors to operate improperly. In these situations passive elements can be used to sense the motor's operation and feed that data to the system with an interface IC. Alternatively, variable-reluctance (VR) sensors can be used in these extreme operating conditions.

VR sensors like the [MAX9924–MAX9927](#) have a coil to sense the speed and rotation of motors. When the toothed wheel of the shaft attached to a motor passes by the face of the magnet, the amount of magnetic flux passing through the magnet and, consequently, the coil varies. When the tooth is close to the sensor, the flux is at a maximum. When the tooth is further away, the



flux drops off. The rotating toothed wheel results in a time-varying flux that induces a proportional voltage in the coil. Subsequent electronics then process this signal to get a digital waveform that can be counted and timed more readily. Integrated VR-sensor interface solutions possess many advantages over other solutions, including enhanced noise immunity and accurate phase information.

*Future product—contact factory for availability.

Motor Control

Sensing motor speed, position, and movement

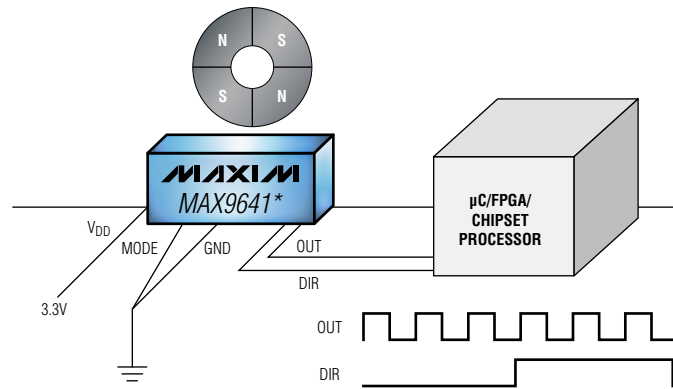
Simplify system design with flexible operating inputs

MAX9641*

The MAX9641 is an ultra-low-power, dual Hall-effect switch. Three programmable sampling periods of 160 μ s, 500 μ s, and 50ms give the designer flexibility to choose the operating speed. By setting the adjust pin, the MAX9641's operating point can be easily adjusted to three points which accommodate many different magnetic materials. Integrating two Hall-effect sensors into one chip reduces the overall system's cost. The user retrieves the information about the speed and direction of the magnet's movement with built-in logic communication.

Benefits

- **Enhanced functionality simplifies motor-control design**
 - Select the sampling period of 160 μ sec, 500 μ s, and 50ms by simply adjusting the RATE pin
 - Choose the threshold point of the switch by setting the ADJ pin
- **High integration simplifies measurement of speed and direction and reduces system cost**
 - Two Hall-effect sensors in a single IC
 - Direction and speed information is gathered simultaneously
 - 1.7V to 5.5V supply voltage range is compatible with many system designs



Dual Hall-effect switch solution.

*Future product—contact factory for availability.

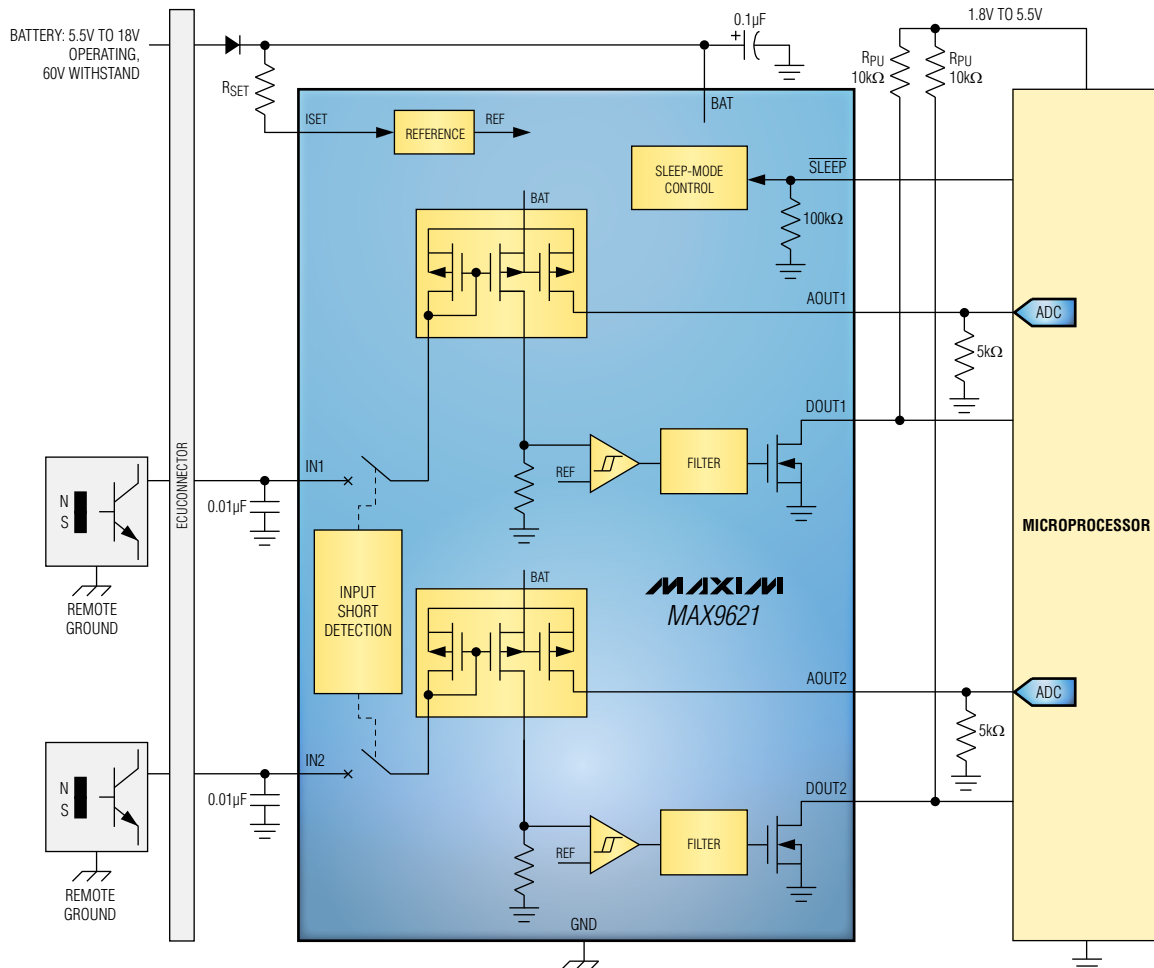
Highly accurate, reliable monitoring of motor speed and position with a sensor interface

MAX9621

The MAX9621 is a dual, 2-wire Hall-effect sensor interface with analog and digital outputs. This device enables a microprocessor to monitor the status of two Hall-effect sensors, either through the analog output by mirroring the sensor current for linear information, or through the filtered digital output. The input current threshold can be to the magnetic field. The MAX9621 provides a supply current to two 2-wire Hall-effect sensors and operates in the 5.5V to 18V voltage range. The high-side current-sense architecture eliminates the need for a ground-return wire without introducing ground shift. This feature saves 50% wiring cost.

Benefits

- **Integrated functionality eases motor-control design, reduces system cost**
 - Select the analog or digital output to monitor the Hall-effect sensor's condition
 - High-side current-sense architecture eliminates the need for a ground-return wire and saves 50% wiring cost
- **Reliable operation in a harsh environment**
 - Protects against up to 60V supply voltage transients
 - Detects a short-to-ground fault condition to protect the system



Functional diagram of the MAX9621 Hall-effect sensor interface.

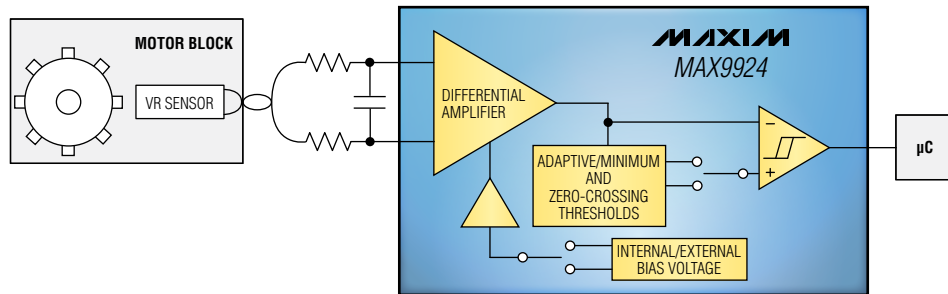
Improve performance and reliability in motor applications with a differential VR sensor interface

MAX9924–MAX9927

The MAX9924–MAX9927 VR, or magnetic coil, sensor interface devices are ideal for sensing the position and speed of motor shafts, camshafts, transmission shafts, and other rotating wheel shafts. These devices integrate a precision amplifier and comparator with selectable adaptive peak threshold and zero-crossing circuit blocks that generate robust output pulses, even in the presence of substantial system noise or extremely weak VR signals. The MAX9924–MAX9927 interface to both single-ended and differential VR sensors.

Benefits

- **High integration provides accurate phase information for precise sensing of rotor position**
 - Differential input stage provides enhanced noise immunity
 - Precision amplifier and comparator allow small-signal detection
 - Zero-crossing detection provides accurate phase information



Simplified block diagram of the MAX9924 VR sensor interface to a motor.



Monitoring and controlling multichannel currents and voltages

Overview

To monitor and control a motor, multiple currents and voltages need to be measured and the phase integrity between the channels preserved. Designers are faced with two choices for the ADC architecture: use multiple single-channel ADCs in parallel, a design that makes it very difficult to synch up the conversion timing; or use a simultaneous-sampling ADC. The simultaneous-sampling architecture uses either multiple ADCs in a single package, all with a single conversion trigger, or with multiple sample-and-hold amplifiers (also referred to as track-and-hold amplifiers) on the analog inputs. In the case of multiple sample-and-hold amplifiers, a multiplexer is still used between

the multiple analog inputs and the single ADC. Simultaneous sampling eliminates the need for complicated digital-signal-processing algorithms.

Sampling speeds of 100ksps or more are common for motor-control applications. At these speeds the ADC continuously monitors the motor for any indication of errors or potential damage. At the first sign of trouble, the system can correct itself or shut down when necessary. If the ADC does not sample fast enough, an error condition might not be identified early enough to be addressed.

The amount of dynamic measurement range varies for each motor-control application. In some cases 12 bits of resolution are sufficient. For the more precise motor-control



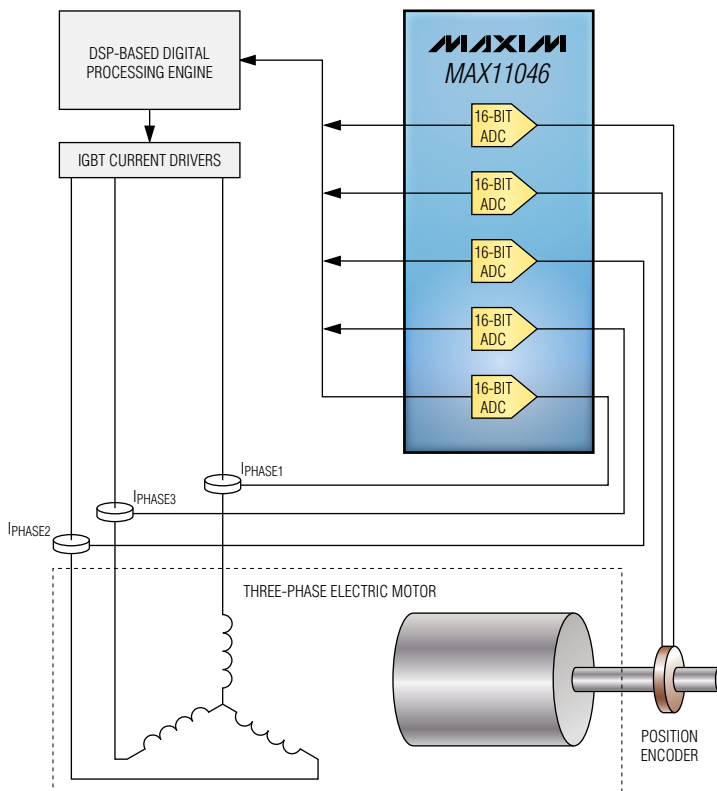
applications, however, 16 bits of resolution are a more common standard. A high-performance 16-bit ADC like the MAX11044 or MAX11049 allows a system to achieve better than 90dB of dynamic range.

Maxim offers a broad portfolio of simultaneous-sampling ADCs designed for motor control. Devices have both serial and parallel interfaces, and 12-, 14-, or 16-bit operation.

Resolve very fine motor adjustments and operate higher accuracy systems with simultaneous-sampling ADCs

MAX11044/MAX11045/MAX11046 MAX11047/MAX11048/MAX11049

The MAX11044–MAX11049 ADCs are an ideal fit for motor-control applications that require a wide dynamic range. With a 93dB signal-to-noise ratio (SNR), these ADCs detect very fine changes to motor currents and voltages, which enables a more precise reading of motor performance over time. The MAX11046/MAX11045/MAX11044 simultaneously sample eight, six, or four analog inputs, respectively. All ADCs operate from a single 5V supply. The MAX11044–MAX11046 ADCs measure $\pm 5V$ analog inputs, and the MAX11047–MAX11049 measure 0 to 5V. These ADCs also include analog input clamps which eliminate an external buffer on each channel.



The MAX11046 ADC simultaneously samples up to 8 analog-input channels.

Benefits

- **Industry-leading dynamic range allows early detection of error signals**
 - 93dB SNR and -105dB THD
- **Simultaneous sampling eliminates phase-adjust firmware requirements**
 - 8, 6, or 4-channel ADC options
- **Lower system cost by as much as 15% over competing simultaneous-sampling ADCs**
 - High-impedance input saves costly precision op amp
 - Bipolar input eliminates level shifter
 - Single 5V voltage supply
 - 20mA surge protection
- **Eliminate external protection components, saving space and cost**
 - Integrated analog-input clamps and small 8mm x 8mm TQFN package provide the highest density per channel

Monitoring and controlling multichannel currents and voltages

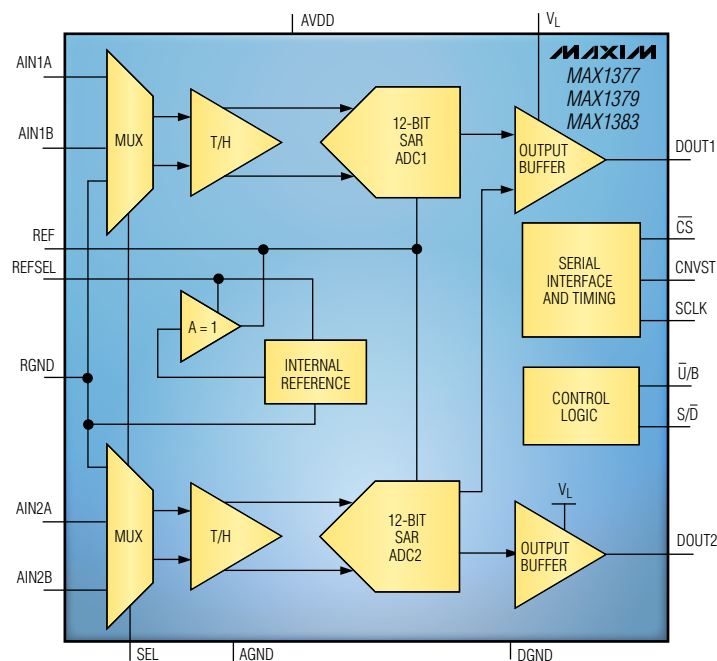
Detect errant motor shifts quickly by sampling at 1.25Msps

MAX1377/MAX1379/MAX1383

The MAX1377/MAX1379/MAX1383 integrate a pair of successive approximation register (SAR) ADCs that simultaneously sample a pair of differential inputs. This design allows a voltage and current pair to be sampled with the phase integrity between the two channels preserved. The MAX1377 (0 to 5V), MAX1379 (0 to 10V), and MAX1383 ($\pm 10V$) sample up to 1.25Msps, allowing constant monitoring of the motor's health at various analog-input ranges. These ADCs communicate over a 4-wire SPI™ serial interface that saves cost and space on the external isolation components compared to similar high-speed ADCs with parallel interfaces.

Benefits

- **Preserve phase integrity, save space**
 - Simultaneous sampling on multiple channels
 - Two differential or four single-ended input channels
- **Simplify data transmission, save cost and space on isolators**
 - 4-wire SPI interface reduces number of isolation components needed compared to ADCs with parallel data interfaces
- **Monitor constantly with a fast sampling speed**
 - Dual integrated ADCs sample at up to 1.25Msps



The MAX1377/MAX1379/MAX1383 integrate two ADCs for true simultaneous sampling.

High-accuracy motor control with encoder data interfaces

Overview

The accuracy with which a motor needs to be controlled depends on the system requirements. In some applications the accuracy requirements are very high, as in industrial robotics or in bottling. A welding robot, for example, is expected to operate with high speed and high precision. Similarly, the motors in a bottling factory must be controlled accurately so that bottles are stopped at the right position for filling, capping, and labeling. To control a motor precisely, the rotor's speed, direction, and position have to be determined. These can be monitored with analog sensors like resolvers, synchros, RVDTs, or rotary potentiometers. High accuracy is obtained with the use of encoders like optical encoders and Hall-effect sensors. Encoders provide the controller with incremental and/or absolute shaft-angle information.

A motor controller, commonly implemented algorithmically by a digital signal processor (DSP), calculates the rotor's present speed and angle. It adjusts the actuating power stages to achieve the desired response efficiently and optimally. This feedback control loop requires robust and reliable information from the sensor, typically communicated over long cables from the encoder to the controller.

Incremental information is typically transmitted to the controller by quadrature signals, i.e., two signals phase shifted by 90°. These signals can be in analog form (sine + cosine) or in binary form. Absolute position information, in contrast, is only communicated by a serialized binary data stream through RS-482 or RS-422.

As the working environments are harsh, the data paths need to be robust and reliable. EMI levels are high, which explains the use of differential



signaling. High temperatures are commonly encountered due to the proximity to the motor.

Maxim's extensive range of RS-485/RS-422 and PROFIBUS interface devices are targeted for these motor-control applications. Interface devices like the [MAX14840E](#) high-speed RS-485 transceiver exhibit the high-signal integrity and robustness expected for stringent safety control and for sustaining the up-time of large capital investments.

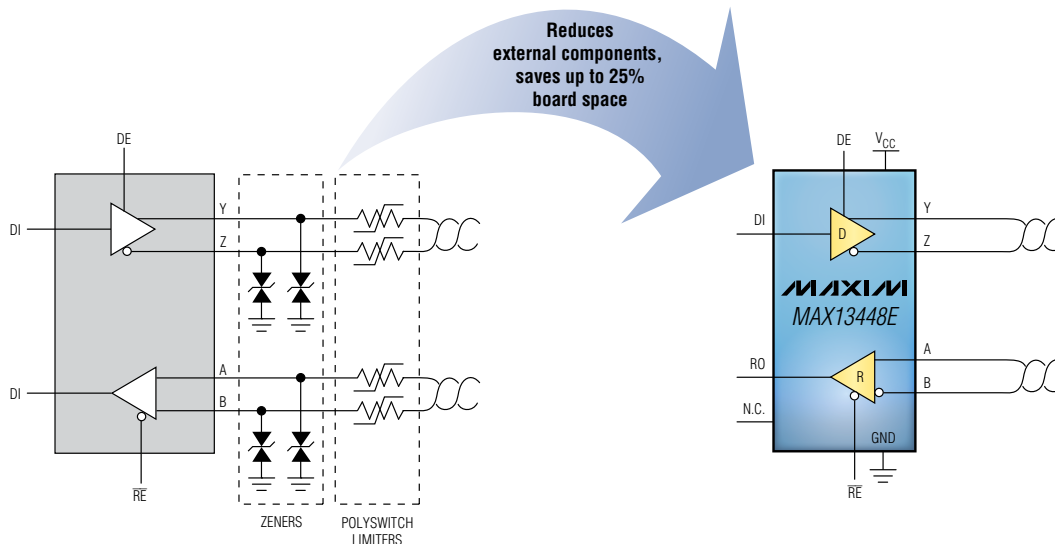
Make equipment more robust with fault-protected RS-485 transceivers

MAX13448E, MAX3440E–MAX3444E, MAX13442E/MAX13443E/MAX13444E, MAX3430

In applications where power and data are distributed over the same cable, there is a potential for miswiring, cable shorts, or surges on the communication bus. Maxim's fault-protected RS-485 MAX13448E, MAX3440E, MAX13442E, and MAX3430 transceiver families offer fault protection up to $\pm 80V_{DC}$.

Benefits

- Integrated fault protection to $\pm 80V_{DC}$ allows smaller encoder designs**
 - Saves board space and cost of discrete protection circuitry
 - High-speed RS-485 requirements are met despite fault protection
 - Reduces field returns due to misconnection
- Multiple configurations increase design flexibility**
 - 3.3V/5V versions allow modern low-voltage supplies
 - Full- and half-duplex operation covers all encoder needs
 - 250kbps and 10Mbps versions support modern encoder speed requirements
- ESD protection up to $\pm 15kV$ (HBM) reduces cost and size**
 - Reduces the need for external ESD protection



Part	V _{CC} Supply (V)	Configuration	Fault Protection (V)
MAX13448E	3.3 to 5	Full	± 80
MAX3440E–MAX3444E	5	Half	± 60
MAX13442E–MAX13444E	5	Half	± 80
MAX3430	3.3	Half	± 80

Maxim's RS-485 family offers high levels of integration which saves board space and cost.

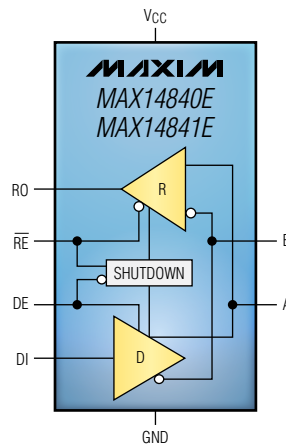
Extend cable lengths in harsh motor-control environments with high-speed RS-485 transceivers

MAX14840E/MAX14841E

The MAX14840E/MAX14841E are 3.3V high-speed (40Mbps), half-duplex RS-485 transceivers ideally suited for industrial applications where extended-cable-length communication is required. The MAX14840E features a symmetrical fail-safe receiver and larger receiver hysteresis. It provides improved noise rejection and improved recovered signals in high-speed and long-cable applications. The MAX14841E has true fail-safe receiver inputs, guaranteeing a logic-high receiver output when inputs are shorted or open. The MAX14840E/MAX14841E are ideal for harsh motor-control environments.

Benefits

- **Improve reliability during handling and installation in environments with high-static charge**
 - Industry's highest ESD protection
 - $\pm 35\text{kV}$ Human Body Model (HBM)
 - $\pm 20\text{kV}$ IEC 61000-4-2 (Air Gap)
 - $\pm 10\text{kV}$ IEC 61000-4-2 (Contact)
- **Rugged performance in housings near motors running at high temperatures and in the harshest environments**
 - Wide -40°C to $+125^{\circ}\text{C}$ operating temperature range
- **Allow smaller encoder enclosures**
 - Space-saving tiny 8-pin (3mm x 3mm) TDFN package



Functional diagram of the MAX14840E/
MAX14841E transceivers.

Transceiver meets PROFIBUS DP standards and protects against $\pm 35\text{kV}$ ESD

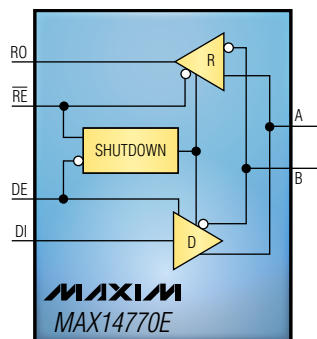


MAX14770E

The MAX14770E PROFIBUS DP transceiver meets strict PROFIBUS standards with a high-output-drive differential (greater than 2.1V) and an 8pF bus capacitance. The high-ESD protection ($\pm 35\text{kV}$, HBM), high-automotive-temperature grade, and space-saving 8-pin TQFN package make the MAX14770E ideal for space-constrained, harsh industrial environments.

Benefits

- **Easy to connect to PROFIBUS networks**
 - Meets EIA 61158-2 Type 3 PROFIBUS DP specifications
 - -40°C to $+125^{\circ}\text{C}$ temperature range for use in extreme conditions
- **Space saving**
 - Tiny 8-pin, 3mm x 3mm TDFN package
- **Industry's highest ESD protection improves reliability**
 - $\pm 35\text{kV}$ Human Body Model (HBM)
 - $\pm 20\text{kV}$ IEC 61000-4-2 (Air Gap)
 - $\pm 10\text{kV}$ IEC 61000-4-2 (Contact)



Block diagram of the MAX14770E.

Recommended solutions

Part	Description	Features	Benefits
ADCs			
MAX11044/45/46 MAX11047/48/49	16-bit, 4-/6-/8-channel, simultaneous-sampling SAR ADCs	93dB SNR; -105dB THD; 0 to 5V or $\pm 5V$ inputs; parallel interface outputs, all eight data results in 250ksps; high-input impedance ($> 1M\Omega$)	High-impedance input saves the cost and space of external amplifier
MAX1377/MAX1379/ MAX1383	12-bit, 1.25Msps, 4-channel, simultaneous-sampling SAR ADCs	0 to 5V, 0 to 10V, or $\pm 10V$ inputs; 70dB SNR; four single-ended or two differential inputs; SPI interface	Serial interface saves cost and space on digital isolators
MAX11040	24-bit, 4-channel, simultaneous-sampling, sigma-delta ADC	117dB SNR; 64ksps; internal reference; SPI interface; 38-pin TSSOP package	Reduces motor-control firmware complexity; captures accurate phase and magnitude information on up to 32 channels
MAX11103*	12-bit, 3Msps, 2-channel SAR ADC	73dB SNR; SPI interface; high 1.7MHz full linear bandwidth; single-channel (SOT23) and 2-channel (μ MAX [®] , TDFN) options	Tiny SOT23, μ MAX, and TDFN packages save space; serial interface simplifies data transmission
Current-sense amplifiers			
MAX9918/19/20	75V precision current sources	-20 to +75V input sensing range	Wide dynamic range supports wide range of motor current-sensing applications
MAX4080/81	75V uni-/bidirectional current sources	High-input voltage; bidirectional current source	Monitor current direction (sink or source) across a wide input-voltage range
MAX4210	Power and current-sense amp with fault detection and alert flag	Continuously monitors power consumption and system current levels with report out	Integrated functionality reduces design time in motor-control applications
Operational amplifiers			
MAX9943/44	High-voltage, precision, low-power op amps	Wide 6V to 38V supply range; 2.4 MHz gain bandwidth (GBW); withstands 40V transient on any pin	Robust performance in harsh environmental conditions
MAX9945	Low-noise, MOS-input, low-power op amp	4.75V to 38V supply voltage range; low input-bias current; low input-current noise; withstands 40V transient on any pin	Robust performance in harsh environmental conditions
MAX9650/51	20V high-output-drive op amps	1.3A output current drive	Reliable and robust design; improve noise immunity in motor-control loop
Variable-reluctance (VR) sensor interface			
MAX9924–MAX9927	Reluctance (VR or magnetic coil) sensor interface devices	Integrated precision amplifier and comparator for small-signal detection; user-enabled, internal adaptive peak threshold or flexible external threshold	Accurately detect position and speed of motors and turning shafts; improve performance and reliability in motor applications
Hall-effect sensor and interface			
MAX9641*	Dual Hall-effect sensor	Three programmable sampling periods (160 μ s, 500 μ s, and 50ms); adjustable threshold levels	Simplifies motor-control designs; provides system flexibility
MAX9621	Dual, 2-wire Hall-effect sensor interface	Monitors the status of Hall-effect sensor either through the analog output or through the filtered digital output	Provides system design flexibility through analog and digital outputs
Thermal management			
DS7505	Low-voltage, precision digital thermometer and thermostat	$\pm 0.5^{\circ}C$ accuracy from $0^{\circ}C$ to $+70^{\circ}C$; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply voltage reduction from LM75
MAX6675	K-type thermocouple-to-digital converter	Built-in cold-junction compensation	Simplest thermocouple interface; no external components needed

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage supervisors			
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; SC70 package saves board space
MAX6495	72V overvoltage protector	Protects against transients up to 72V; small 6-pin TDFN-EP package	Increases system reliability by preventing component damage from high-voltage transients; saves space; easy to use
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable thresholds	Integration shrinks design size and increases reliability compared to multiple components
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing; 3 μ A supply current	Versatile for easy design reuse; SOT23 package saves board space
MAX6816/17/18	Single/dual/octal switch debouncers	\pm 15kV ESD (HBM) protection	High reliability; easy to use; ESD protection makes designs more robust
Interface transceivers			
MAX14840E	High-speed RS-485 transceiver	40Mbps data rates; \pm 35kV (HBM) ESD tolerance; 3.3V; +125°C operating temperature; small 3mm x 3mm TQFN package	High receiver sensitivity and hysteresis extend cable lengths in harsh motor-control environments
MAX13448E	Fault-protected RS-485 transceiver	\pm 80V fault protected; full-duplex operation; 3V to 5.5V operation	Makes equipment more robust and tolerant to misconnection faults
MAX14770E	PROFIBUS transceiver	\pm 35kV (HBM) ESD protection; -40°C to +125°C temperature range; small 3mm x 3mm TQFN package	Industry's highest ESD protection; makes motor control more robust
MAX3535E	Isolated RS-485 transceiver	3V to 5V operation; 2500V _{RMS} isolation; \pm 15kV ESD (HBM) protection	Simple solution for isolating data and power supply
MAX253	Transformer driver for isolated power supply for RS-485/PROFIBUS interfaces	Single 5V or 3.3V supply; 0.4 μ A low-current shutdown mode; pin-selectable 350kHz or 200kHz frequency; μ MAX package	Simple open-loop circuit speeds power-supply design; shortens time to market
DC-DC converters and controllers			
MAX5080/81	Step-down DC-DC converters with integrated switch	4.5V/7.5V to 40V V _{IN} ; 1.23V to 32V V _{OUT} ; switch to pulse-skip mode at light loads; integrated high-side switch	Save cost with integrated DC-DC converters that power directly off an industrial bus
MAX5072	Dual-output buck or boost converter with integrated switch	4.5V to 5.5V or 5.5V to 23V V _{IN} ; 0.8V (buck) to 28V (boost) V _{OUT} ; configure each output as buck or boost	Improves reliability with controlled inrush current, thermal shutdown, short-circuit protection
MAX15023	Wide 4.5V to 28V input, dual-output, synchronous buck controller	4.5V to 28V V _{IN} ; V _{OUT} = 0.6V to 0.85 x V _{IN} ; hiccup mode	Thermal shutdown and short-circuit protection for the system
MAX15034	Single-/dual-output synchronous buck controller for high-current applications	4.75V to 5.5V or 5V to 28V V _{IN} ; V _{OUT} = 0.61V to 5.5V; 25A or 50A output	Thermal shutdown and monotonic start protect devices; improves reliability
MAX15048/49	3-channel DC-DC controllers with tracking/sequencing	4.7V to 23V V _{IN} ; V _{OUT} = 0.6V to 19V; tracking across the three outputs; power sequencing	Saves space and cost by integrating three switching controllers
MOSFET/rectifier drivers			
MAX15024/25	FET drivers	Single/dual operation; 16ns propagation delay; high sink/source current; 1.9W thermally enhanced TDFN package	Simplify design with a very low propagation delay and a thermally enhanced package
MAX5048 MAX5054–MAX5057 MAX5078	FET drivers	4A to 7.6A; 12ns to 20ns; single/dual MOSFET drivers	Increase flexibility with inverting/noninverting inputs to control the MOSFET

For a list of Maxim's recommended motor-drive solutions, please go to: www.maxim-ic.com/motordrive.

Motor Control

Recommended solutions

**Security and
surveillance**

Digital video recorders (DVRs)

Overview

Analog CCTV security systems are moving to digital technology, and video recording is leading this transition. The analog VCR has been replaced by digital video recorders (DVRs) in security systems that require video monitoring and recording. DVRs now offer overwhelming advantages over analog VCRs in security applications. Video footage can be digitally recorded, processed, and streamed over digital networks at virtually any level of image quality, including high definition (HD). Users now make use of digital-only technologies such as real-time analytics, scene search, motion- and activity-detection alarms, and remote access over IP networks. The cost of storage capacity on physical media such as hard disk drives (HDDs), digital versatile discs (DVDs), or network-attached storage (NAS) is a small fraction of analog tape-based recording cost. The use of digital video recording and archiving also

offers permanent storage of video footage with no loss of image quality over time. All of these factors have driven the security industry toward adopting DVR as the standard for video recording.

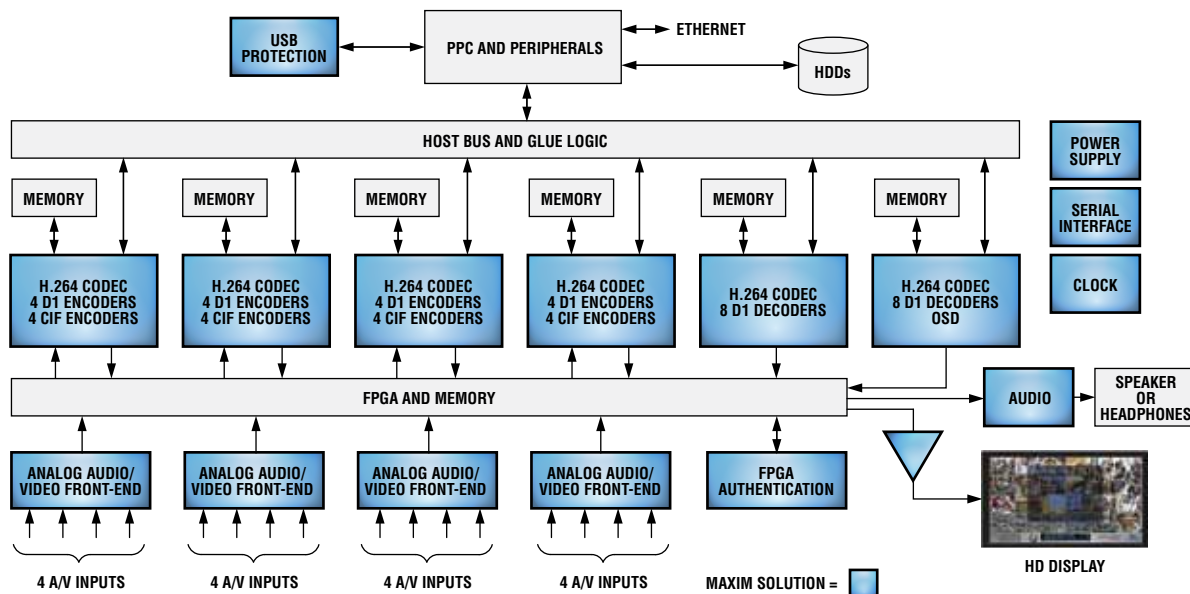
DVR types

The security market has evolved into multiple segments for DVR systems. Embedded, hybrid, and PC-based DVRs all require the essential elements of video and audio capture: analog-to-digital conversion, compression, playback, and network streaming. The embedded DVR is a stand-alone piece of equipment that accepts analog CCTV camera inputs for compression and storage on a local HDD. Hybrid DVRs accept analog CCTV and IP camera inputs as video sources. PC-based DVRs are integrated into surveillance stations with hardware compression add-in cards or software compression running on the PC. The distinguishing features among different models are the number of video input channels;

compression standards supported; video quality of the record, stream, and display modes; storage capacity; and how many functions the system can perform simultaneously.

Video-compression technologies

H.264 is the new industry standard for video compression in security DVRs. Prior generations used MPEG-4 and even MJPEG for video recording. H.264 has the advantage of offering the highest compression ratio, while maintaining excellent video quality for security applications. H.264's higher compression ratio (up to two times better than prior-generation technology) effectively increases storage capacity by 100%, producing smaller file sizes and, therefore, longer recording time on a fixed-capacity storage device. In addition, the use of H.264 allows high-quality images to be transmitted over networks at very low bit rates. Security systems that involve multiple cameras can quickly exceed



Functional block diagram of a security DVR system. For a list of Maxim's recommended solutions for security DVR designs, please go to: www.maxim-ic.com/DVR.

Security and surveillance

Digital video recorders (DVRs)

the available network bandwidth without efficient compression. DVR system designs without H.264 often rely on reduced-frame-rate or lower resolution recording techniques that degrade picture quality in order to increase recording time and reduce video bit rates. Older codec formats (MPEG-4 and MJPEG) are often still required for legacy support, but the industry's trend to adopt H.264 as the primary codec in DVR is well under way. Maxim's family of H.264 processors supports MJPEG recording and playback for backward compatibility with prior-generation equipment.

DVR system requirements

Security video applications are moving to higher recording and display resolutions. CIF resolution recording (NTSC 360 x 240) was used extensively in early generation DVRs to produce digital video quality comparable to the analog VCR that it replaced. Low-resolution CIF was also well suited to first-generation codec technology (MJPEG/MPEG-4)

that cannot produce acceptable compression ratios at higher resolutions. The market requirement today and moving forward is standard-definition (D1 NTSC 720 x 480) or "DVD-quality" video recording. Standard definition (SD) represents a fourfold performance increase in system processing power per channel as compared to CIF. State-of-the-art H.264 codec technology is used at D1 resolution and above to ensure efficient compression ratios. Maxim's family of H.264 processors allows programmable video resolutions for recording at any level of quality required.

Another trend in security and surveillance video is the requirement for full-frame-rate video recording and storage. Full frame rate for an analog CCTV camera is 30 frames-per-second (fps) in NTSC and 25fps in PAL. Real-time video recording represents a twofold to fourfold increase in processing power required per channel versus DVR designs that record at reduced frame rates such as

7.5fps (25% in NTSC) or 15fps (50% in NTSC). A powerful, scalable system architecture is required to meet the processing requirements of new DVR designs.

Many video security systems today are hybrid designs of analog CCTV equipment and digital network technologies that have built up over time. Preexisting digital equipment based on older codec technologies (MJPEG/MPEG-4) creates the need for transcoding between formats in new equipment. For example, the video from an existing IP camera with MJPEG compression must be re-encoded to H.264 in the DVR for efficient storage and network bandwidth usage. DVR designs today must accommodate multiformat digital video input (MJPEG/MPEG-4/H.264) to preserve investments made in earlier generation equipment. Maxim's family of H.264 processors supports video decoding in MJPEG and MPEG2, prior to re-encoding to H.264, for recording and streaming.

H.264 video codec system-on-a-chip (SoC) simplifies multichannel DVR system designs while providing excellent video quality

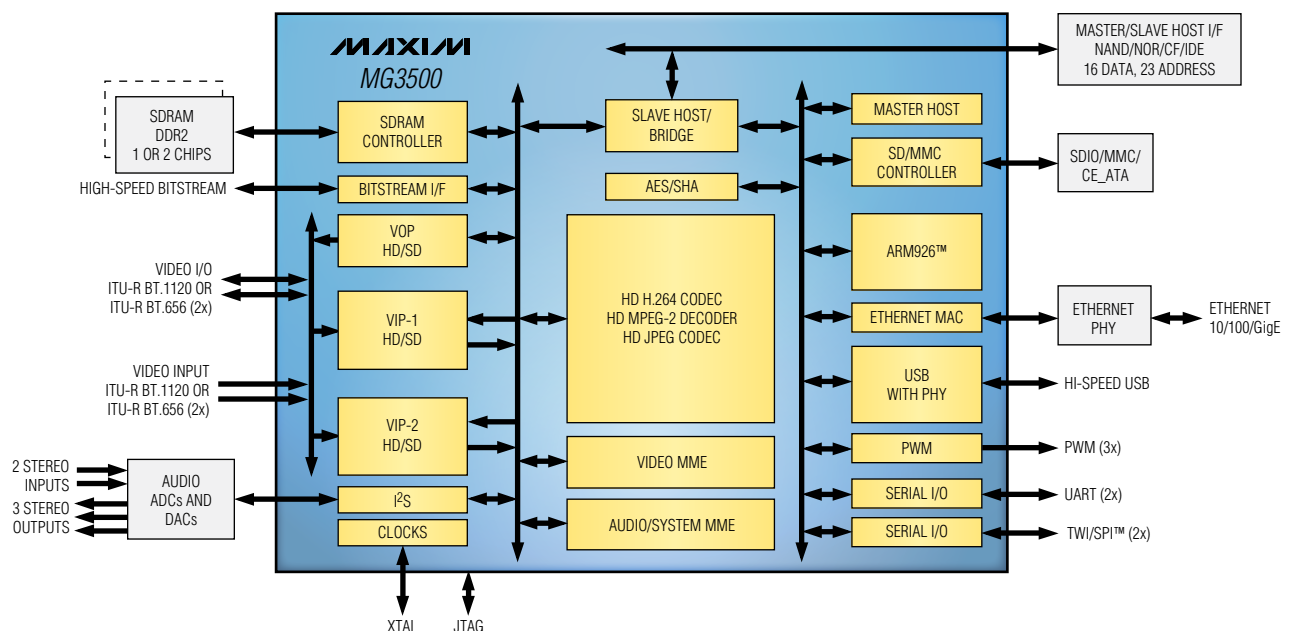
MG3500

The MG3500 is a highly integrated, HD or multichannel SD, H.264 codec SoC ideally suited for the security DVR market. It offers a fully compliant baseline, main, and high-profile HD H.264 codec; MJPEG codec; video preprocessors and postprocessors for scaling and compositing; 240MHz ARM9™ CPU; and a host of peripherals including Gigabit Ethernet MAC, USB OTG, SD™ card, CompactFlash® memory, IDE, CE-ATA, SDIO, and MMC.

Benefits

- **Superb video-quality recordings at any resolution for improved identification**
 - High, main, and baseline profile H.264 video codec
 - Flexible recording resolution up to 1920 x 1080i (p30)
 - Fully programmable video resolutions and frame rates
- **Simplified multichannel system design lowers design cost**
 - 4 D1 + 4 CIF encoders per MG3500 in encoding path
 - Simultaneous primary (recording) and secondary (streaming) channel encoding
 - 8 D1 decoders per MG3500 in playback decoding path
- **Integrated on-chip peripherals reduce board size and manufacturing cost**
 - 10/100/Gigabit Ethernet MAC
 - USB On-The-Go
 - NAND/NOR/SD/SDIO/MMC/CF/CE-ATA/IDE interfaces

(Continued on next page)



MG3500 functional block diagram

H.264 video codec system-on-a-chip (SoC) simplifies multichannel DVR system designs while providing excellent video quality *(continued)*

Benefits *(continued)*

- **Lowest power consumption per video channel in the industry reduces heat buildup and overall operating cost**
 - 500mW total power consumption
- **Complete development environment drastically reduces time to market**
 - Hardware evaluation boards available
 - Includes predeveloped software: Linux® operating system, firmware, drivers

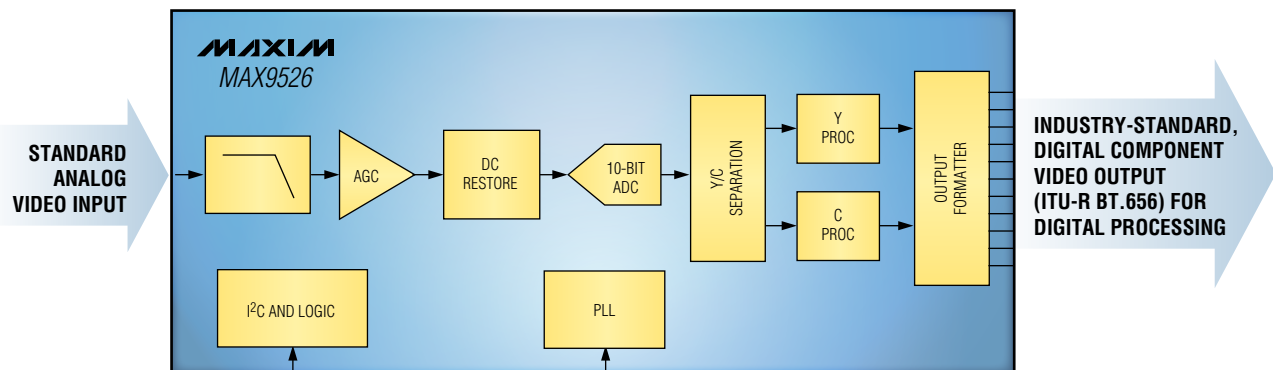
Video decoder provides superior video quality

MAX9526

The MAX9526 low-power video decoder was designed to support multiple video (NTSC/PAL) standards, making it ideal for security and surveillance systems. It integrates true 10-bit processing, 54MHz sampling (4x oversampling), anti-aliasing filtering, DC restoration, automatic gain control (AGC), and 2:1 input multiplexing into a compact, high-performance package capable of operating in a variety of security system environments.

Benefits

- **Provides superior video quality for improved identification**
 - True 10-bit decoding
 - 54MHz sampling (4x oversampling)
- **Low power consumption reduces heat buildup and operating costs for compact designs and portable/battery backup**
- **Programmable configuration eases design and time to market**
 - Only 16 registers required for full configurability and status indicators
- **Flexibility of operation allows one design to serve multiple markets**
 - Widest temperature range (-40°C to +125°C) for the harshest environments
 - 1.8V/3.3V (typ) digital I/O supply voltage
 - Supports multiple analog video standards for compatibility with a variety of video inputs
- **Simple design speeds time to market**
 - 1.8V operation
 - Integrated functionality results in few external components, so physical design is smaller and less prone to error



MAX9526 digital output processing

Security and surveillance

Digital video recorders (DVRs)

Recommended solutions

Part	Description	Features	Benefits
Video codec			
MG3500	H.264 video codec SoC	Video formats: HD 1080p30 H.264 codec, MJPEG codec; audio formats: AAC, AMR, Dolby®, G.7xx, MP1/2/3; HD MPEG-2 decoder, 4 D1 + 4 CIF H.264 encoders or 8 D1 H.264 decoders	Superb video-quality recordings at any resolution for improved identification; complete development environment drastically reduces time to market
Video decoder			
MAX9526	Low-power, high-performance NTSC/PAL video decoder	Supports all NTSC and PAL standards; true 10-bit digital processing; 2:1 video input mux	Superior video quality provides improved identification; configuration method speeds design time
Video amplifiers			
MAX9652–54	3.3V, HD/SD triple-channel filter amplifiers with shutdown	2V/V gain; 42MHz passband for HD with 50dB attenuation at 109MHz	Allow design flexibility where switchable HD/SD operation is required; shutdown mode saves power
MAX9586–89	Single/dual/triple/quad, SD video filter amplifiers with AC-coupled input buffers	Low power; small size; 8.5MHz passband; 55dB attenuation at 27MHz	Integrated solution saves PCB area
MAX9507	1.8V, DirectDrive® video filter amplifier with load detection and dual SPST analog switches	Dual SPST analog switches controlled through I ² C interface; DirectDrive sets video-output level near ground; internal gain of 8V/V; load detection and reporting	Integrated switching functionality simplifies design; DirectDrive eliminates output capacitance, thus reducing cost and saving space
Audio codec/DAC			
MAX9860	16-bit audio voice codec	Ultra-low power, mono codec; programmable digital filter	Complete audio solution saves development time
Power ICs			
MAX8654	Step-down switching regulator	25mΩ R _{ON} ; 8A internal switch; 4.5V to 14V input; 6mm x 6mm, 36-pin TQFN	Reduces space requirements when implementing power supplies requiring a high-current output
MAX15035	Step-down regulator	Fully integrated; 4V to 26V	Compact solution for small form-factor applications
MAX1970	Dual step-down converter	2.6V to 5.5V input; 750mA output current; power-on reset (POR); 180° out-of-phase operation	Saves space by reducing input capacitance
USB ESD-protection IC			
MAX4987	Overvoltage-protection controller with USB ESD protection	Integrated low-R _{ON} (100mΩ) nFET switch; overcurrent protection (auto-retry); 1.5A (min) internal overcurrent protection	Provides ESD protection for Hi-Speed USB I/O, increasing system reliability
USB current-limited switch			
MAX8586	USB current-limit switch	3mm x 3mm; 2.7V to 5.5V; 20ms fault blanking	Protects against power faults, increasing system reliability while saving space
FPGA authenticators			
DS28E01-02	1-Wire® SHA-1 bidirectional authenticator with 1Kb of EEPROM	Single, dedicated contact operation; SHA-1 secure authentication and data protection; 1Kb of EEPROM	Crypto-secure to prevent copying of FPGA design; single FPGA I/O pin for operation
DS28E10*	1-Wire SHA-1 authenticator with 224b of one-time programmable (OTP) EPROM	Single-contact operation; unidirectional SHA-1 authentication	Lowest cost solution for SHA-1 authenticator

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* Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
RTCs			
DS1315	Phantom time chip	Real-time clock (RTC); nonvolatile memory controller	Integrated clock and memory controller save space and provide design flexibility; phantom interface allows communication over parallel bus with no address space requirements
DS1500	Watchdog timekeeper with nonvolatile memory control	Programmable watchdog timer; time-of-day alarm; power-control circuitry	Integrated clock and memory controller save space
DS1685	Multiplexed-interface real-time clock	64-bit unique serial number; 242 bytes of battery-backed NV SRAM	Simplifies adding a unique ID to a design while providing extra battery-backed memory
Supervisory ICs			
MAX6381–90	Single-voltage monitors	Low power; SC70; various reset thresholds and timeouts	Save space, save power, and increase reliability with no external components
MAX6443–52	Voltage monitors with extended setup delay pushbutton	Extended pushbutton setup delay (6 seconds); manual reset	Increases reliability by avoiding accidental resets; increases performance by allowing system to be reset by external pushbutton
MAX16056–59	Ultra-low-power reset + watchdog ICs	125nA supply current; capacitor-adjustable reset; watchdog timeout delays	Save power and battery life; use one IC across multiple applications with adjustable timeouts

For a list of Maxim's recommended solutions for security DVR designs, please go to www.maxim-ic.com/DVR.

Security and surveillance

Digital video recorders (DVRs)

IP cameras

Overview

IP cameras use the Internet protocol (IP) to transmit audio and video data, along with control signals, over Ethernet links in closed-circuit television (CCTV) systems. They offer numerous advantages over traditional analog security cameras, which typically transmit an analog NTSC/PAL signal over coaxial cable. Unlike analog cameras, IP cameras support high-definition (HD) images, intelligent analytics, local video storage, and remote control.

Video compression is performed in the IP camera together with analytic functions, video encryption (to stop hackers), and encapsulation of video data into Ethernet packets. The compressed video stream is usually sent to a hybrid digital video recorder (DVR) or network video recorder (NVR) for storage, playback, and display. The use of an IP network for video monitoring can enable security staff to be located at geographically remote locations, allowing centralized control over security cameras across campuses or multiple sites using pan-tilt-zoom (PTZ) commands sent over the IP network.

Low-power camera designs can be powered over Ethernet (PoE) without additional power sources. By using the same cable to transmit both data and power, PoE installations can substantially reduce cabling costs. In some cases, wireless networks such as Wi-Fi® can be used to replace Ethernet, thus easing camera placement. This is especially true of home security cameras where Ethernet wiring may not be readily available, and where “cloud computing” DVR applications replace physical DVRs.

Multistream H.264 and Motion-JPEG compression

The H.264 video compression standard provides approximately twice the compression of the previous MPEG-4 standard for the same video quality. Within the H.264 standard, the “high” profile defines the highest video quality with the lowest bit rate, making it especially relevant for applications such as video security. Achieving very-low-latency (delay) encoding minimizes the response time from security personnel. Meanwhile, high-definition video encoding enables the IP camera to capture details such



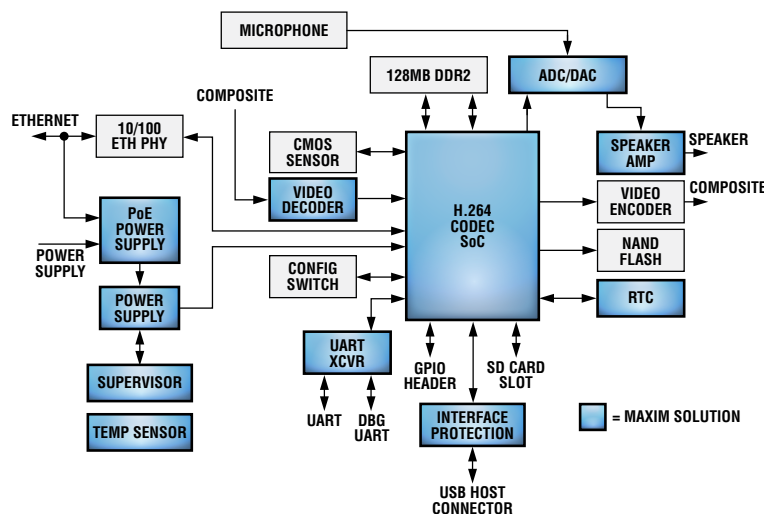
Mobicam3 720p H.264/M-JPEG IP camera reference design

as facial features and license plates for enhanced security imaging. Since network bandwidth may be limited, systems can require the ability to encode/record one HD stream over a local area network (LAN) while simultaneously streaming a lower resolution feed for remote viewing over a wide area network (WAN).

In addition to H.264, many security systems require backward compatibility with existing equipment that does not support H.264. The Motion-JPEG (M-JPEG) standard can provide backward compatibility in such systems, as well as the ability to take high-resolution lossless snapshots. Specifically, it supports simultaneous encoding of H.264 video for uninterrupted video recording while capturing JPEG still images, which may be driven by specific events.

Analytics

Video analytics is the process of analyzing video data and making decisions based upon it. Supporting analytics in software within the camera enables actions to be taken immediately based on specific events and without the need for inputs from security personnel. For example, an alarm may be sounded if the camera detects that a person has crossed into a secure area. Analytic functions include motion detection, trip wire, and image tracking. All of these functions need to be configurable from the PC-based security management software using an intuitive graphical user interface (GUI).



IP camera block diagram. For a list of Maxim's recommended solutions, please visit: www.maxim-ic.com/IPcamera.

Embedded Linux® software and networking

IP cameras need to provide the capability for streaming video to multiple clients. For example, Maxim's IP

camera reference design (Mobicam3) supports up to 16 clients and both the real-time transport protocol (RTP) and the real-time streaming protocol (RTSP). The following Ethernet protocols are also supported: HTTP,

DHCP, SMTP, TCP/IP, UDP, TFTP, FTP, NTP, and UPnP™. Streams can be encrypted using AES or SHA encryption to prevent hacking or tampering.

Mobicam3: IP camera reference design kit

Mobicam3 is a complete, copy-ready, IP camera reference design kit based on Maxim's MG2580 720p H.264/M-JPEG codec system on a chip (SoC). The design kit includes the camera, hardware design files, software development kit (SDK), and demo version of elfochips' video security management software. Maxim's SDK provides a quick start to developing an IP camera. It gives the user low-level firmware, Linux distribution, test applications, example code, and development tools to easily configure and customize a complete product.

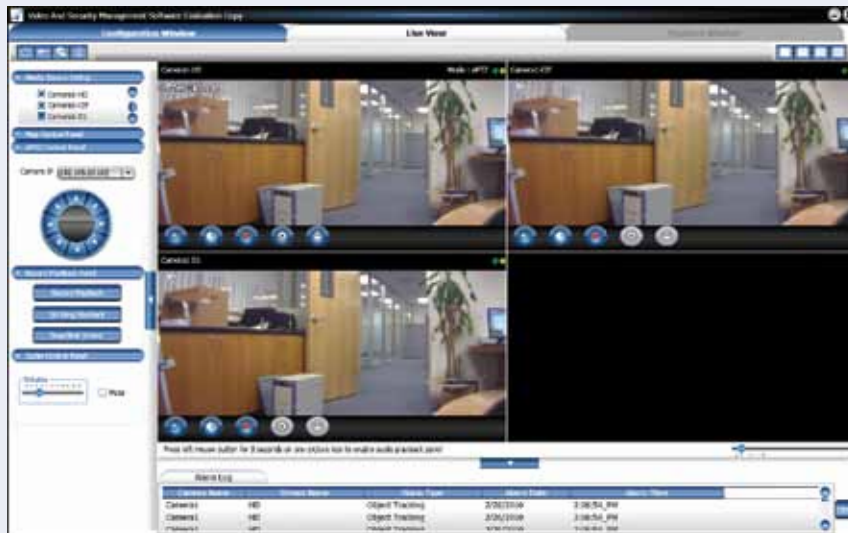
Key camera hardware features

- Small form factor: 44mm x 100mm
- Based on the MG2580 H.264 IP camera SoC
- Power over Ethernet (PoE)
- High-quality C-mount lens
- Local video monitor output
- Bidirectional audio
- USB and microSD™ storage
- Optional I/O board for advanced features
- Embedded analytics
- Remote-firmware upgradeable
- Auto-iris
- Mechanical PTZ (RS-485)

PC-based video security management software

The Mobicam3 reference design is supplied with a complete PC-based video security management demo application for configuring and viewing media streams from the camera. Full binary and source code versions of the software are available for license from elfochips. The application includes the following major functions to enable the rapid development of a complete security system:

- Multicamera control and viewing
- Scheduled recording and playback
- Analytics including trip wire, motion detection, and object tracking
- Event logging
- Snapshots and alarms
- Electronic pan-tilt-zoom (ePTZ) control



Screenshot of the video security management software showing the multicamera decoding and configuration interface.

High-definition H.264 codec SoC supports multistream applications with intelligent analytics

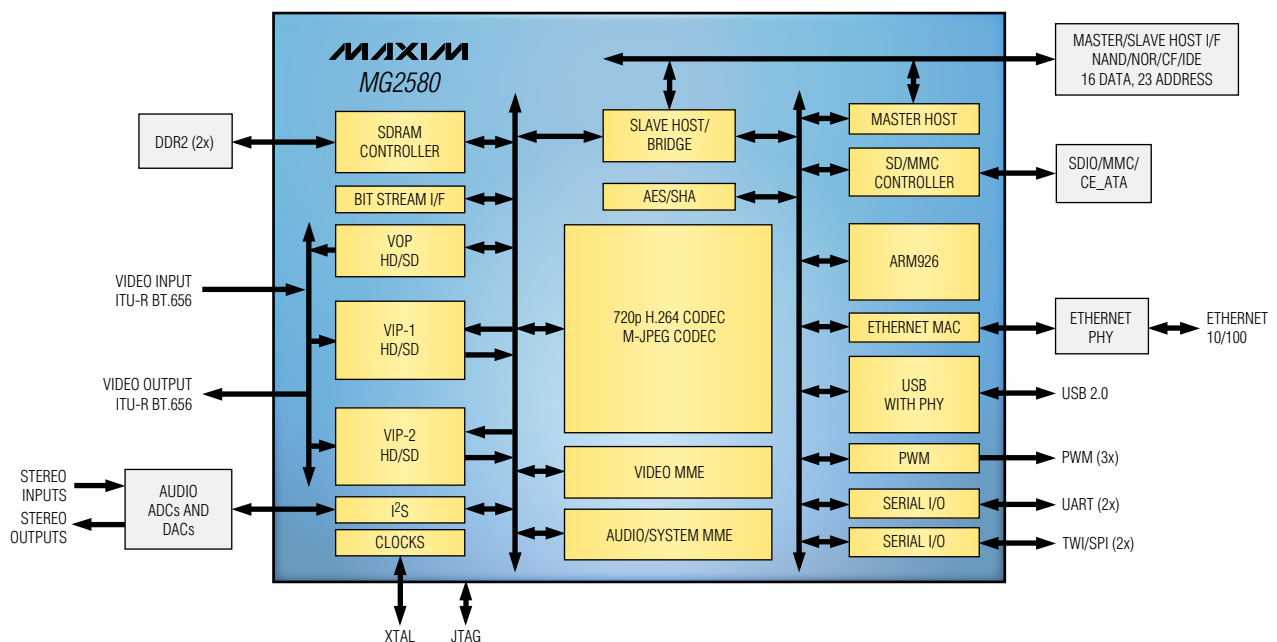
MG2580

Maxim's Mobicam3 IP camera reference design uses the MG2580 codec SoC to perform multistream H.264 compression, M-JPEG compression, analytics, AES/SHA video encryption, and Ethernet communication functions on a single chip. The MG2580 can compress three H.264 streams simultaneously at CIF, D1, and 720p resolutions. Simultaneous M-JPEG video or JPEG still-image capture is also supported.

The MG2580 includes a fully programmable audio processor and offers support for full-duplex G.722/AAC audio with the ability to select both sample and bit rates. The full-duplex operation enables two-way voice communication with people at the camera location. AES and SHA encryption are performed in dedicated hardware for the highest performance. The ARM9™ processor in the MG2580 is not required for audio or video encoding, allowing it to be used solely for networking and applications.

Benefits

- **Highly integrated system reduces part count, simplifies design, and reduces camera size**
 - Integrated ARM9 CPU, Ethernet, and USB
 - Audio codecs: G.722, AMR, AAC, and MP1/2/3
 - ePTZ support
- **Multistream, high-profile video encoding for the highest image quality**
 - High, main, and baseline H.264 1280 x 720p30 codec
 - M-JPEG codec, up to 12MP
 - Triple-stream encoding: 720p plus CIF or D1 H.264, and M-JPEG simultaneous encoding
- **Embedded analytics reduce software development time**
 - Motion detection
 - Trip wire
 - Image tracking



Functional diagram of the MG2580.

Recommended solutions

Part	Description	Features	Benefits
Video codec			
MG2580	H.264 HD codec SoC	H.264 and M-JPEG encoding, ARM9 processor, Ethernet, USB, audio codecs (G.722, AMR, AAC, MP1/2/3)	Highly integrated system reduces part count, simplifies design, and reduces camera size
Video decoder			
MAX9526	Low-power, high-performance NTSC/PAL video decoder	Supports all NTSC and PAL standards, true 10-bit digital processing, 2:1 video input multiplexer	Easy to configure yet flexible for multiple modes of operation
Audio amplifiers			
MAX9860	16-bit mono audio codec	1.8V single-supply operation, mono codec with programmable digital filter	Provides a complete audio solution in a small 4mm x 4mm TQFN package
MAX9718	Low-cost, mono, 1.4W differential audio power amplifier	Class AB gives superior THD+N down to 0.002%	Simple, high-fidelity solution
Interface protection			
ESD protectors			
MAX3203E–MAX3206E	ESD-protection arrays for high-speed data interfaces	Low (5pF) capacitance; 2-, 3-, 4-, and 6-channel options; ±15kV ESD protection	Tiny UCSP™ and WLP packages save space
Current-limited USB switch			
MAX1946	Single USB switch with autoreset and fault blanking	3mm x 3mm package, 2.7V to 5.5V supply	Selectable active-high/active-low control logic and shutdown control provide design flexibility for use in many designs
PoE controllers			
MAX5941/MAX5942	IEEE® 802.3af-compliant PoE interface/PWM controllers for powered devices (PDs)	Single-chip solutions integrate 802.3af PD interface and PWM; adjustable UVLO allows operation with legacy PSE systems; surface-mount, 16-pin SO package	802.3af-compliant PoE power supplies are highly integrated, minimizing required space while reducing build cost
MAX5969A/MAX5969B	IEEE 802.3af/at-compliant PD interface controllers with integrated power MOSFET	IEEE 802.3af/at compliant; 100V absolute maximum rating; simplified wall-adaptor interface; thermally enhanced, 3mm x 3mm, 10-pin TDFN	Simplify design of PDs that draw power from either a PoE cable or a wall adapter
MAX15000/MAX15001	Current-mode PWM controllers with programmable switching frequency	Programmable switching frequency up to 625kHz; digital soft-start eliminates output-voltage overshoot and guarantees monotonic rise during power-up; 10-pin μMAX® package	Enable the implementation of very small power supplies for PoE
Power ICs			
MAX8667	4-channel PMIC with two step-down converters and two low-input LDOs	2.6V to 5.5V supply, 1.2A and 600mA step-down DC-DCs, 3mm x 3mm TQFN, 1.5MHz switching frequency	High frequency allows for tiny external components, thereby reducing overall power-supply size
MAX15022	Dual switching DC-DC converter with dual LDO	500kHz to 4MHz switching frequency, 180° out-of-phase operation, 5mm x 5mm 28-pin TQFN	Simplifies design, saves space, and reduces cost
MAX8635	Dual 300mA LDO	Independent shutdown, low 90mV dropout at 100mA load	Pin-programmable output voltage makes configuration easy while providing flexibility for use across many designs
<i>(Continued on next page)</i>			

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Real-time clocks (RTCs)			
DS1340	I ² C RTC with trickle charger	Automatic backup power switching	Reliable timekeeping during power-supply interruptions
DS1390	Low-voltage SPI™/3-wire RTC with trickle charger	Automatic backup power switching, time-of-day alarm	Reliable timekeeping during power-supply interruptions
DS1318	44-bit binary counter	Resolution of 244µs; counter can be configured as an event counter or RTC	Reliable event tracking during power-supply interruptions
Supervisors			
MAX6736–MAX6745	Dual-/triple-voltage monitors	SC70 package, 6µA supply current	Conserve battery life; save board space compared to using multiple single-voltage monitors
MAX6381–MAX6390	Single-/dual-voltage monitors	1.8V to 5V supply, 3µA (typ) at 1.8V, SC70, various reset thresholds and timeouts	SC70 package saves board space; no external resistors or capacitors required
MAX16056–MAX16059	Ultra-low-power reset + watchdog ICs	125nA supply current, capacitor-adjustable reset and watchdog timeout delays	Save power and battery life; adjustable timeouts allow designers to use one IC across multiple applications
MAX16054	Pushbutton on/off controller	±15kV ESD protection, SOT23 package, 7µA quiescent current	ESD protection increases reliability; SOT23 package saves board space
MAX6443–MAX6452	Voltage monitors with extended-setup-delay pushbutton	Extended pushbutton setup delay (6s), single or dual manual-reset inputs	Increase reliability by avoiding accidental resets
Temperature sensors			
MAX6613	Low-voltage analog temperature sensor	1.8V to 5.5V operation, 13µA (max) supply current, SC70 package	Provides temperature sensing while minimizing power drain
MAX6631	Low-power digital temperature sensor	±1°C accuracy from 0°C to +70°C, 50µA (max) supply current	Minimizes power consumption
DS7505	Low-voltage, ±0.5°C accurate digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C, 1.7V to 3.7V operation, industry-standard pinout and registers	Industry-standard pinout allows easy accuracy upgrade and supply voltage reduction from LM75

For a list of Maxim's recommended solutions, please visit: www.maxim-ic.com/IPcamera.

Security and surveillance

IP cameras

LED lighting

The expanding role for LED lighting

Light-emitting diodes (LEDs) are a rapidly evolving technology and are becoming viable for many general lighting applications, usually referred to as solid-state lighting. The most relevant examples of LED lighting applications are indoor uses in commercial, industrial, and residential environments; outdoor applications like street lights and parking lights; and architectural and decorative lighting where LEDs were initially adopted because of their ability to emit the whole spectrum of colors.

LEDs have been an effective solution for architectural lighting for some time. Today LEDs are penetrating the mainstream general lighting market, thanks to their higher performance compared to other lighting technologies:

- **They have a much longer lifetime than other lighting technologies.** LEDs can operate for 50,000 hours versus 1,000 to 2,000 hours for incandescent lamps and about 5,000 to 10,000 hours for compact fluorescent lights (CFLs). This markedly longer lifetime makes LEDs ideal for many commercial and industrial lighting applications where the labor cost to replace a lamp is high.
- **Their energy efficiency is superior to incandescent and halogen lamps, and often equivalent to fluorescent lamps.** Additionally, the efficacy of LEDs is continuously improving; the efficacy of white LEDs (WLEDs) is now forecasted to improve by about 50% over the next three to four years.

- **They have a small form factor.** LEDs fit in some form factors like MR16 and GU10 lamps where CFLs do not.
- **They can be dimmed with the appropriate driver.** Fluorescent lamps pose technical limitations when the application requires dimming. Although conventional LED designs have encountered similar issues, innovative LED drivers from Maxim are compatible with triac and trailing-edge dimmers.
- **They emit a very directional light.** Unlike other lighting technologies, LEDs are more appropriate for applications like narrow-angle reflector lamps that require a very directional light.
- **Their efficacy improves at lower temperatures.** The efficacy of fluorescent lamps degrades at lower temperatures. In contrast, LEDs are ideal for applications with a low ambient temperature like refrigerator lighting.
- **It is very easy to change the color of their emitted light.** This makes RGB LEDs ideal for applications like architectural and mood lighting where the color of the light must change in real time.

In summary, LEDs offer many advantages over incandescent lamps and fluorescent lamps. Consequently, designers continue to find more applications for LED lighting, but that discussion could consume us for a long while. This review will focus on only two, but quite timely, applications: LED retrofit lamps and remote-controlled LED lighting.

LED retrofit lamps are made to replace incandescent, halogen, or fluorescent lamps in the same socket.

These LED lamps must fit in the existing form factor and be compatible with the existing infrastructure.

LEDs for remote-controlled lighting allow greater flexibility in dimming and changing the color of the light. Moreover, the use of wireless or powerline-communication (PLC) remote controls facilitates even more new LED applications.

LED retrofit lamps

Many would argue that the LED retrofit lamp market is the fastest growing application for LED lighting today. The reason for this fast growth is actually quite straightforward: these lamps do not require a new



PAR20 product photo courtesy of LEDtronics, Inc.



LuxDot is a trademark of LedEngin, Inc. Photo courtesy of LedEngin, Inc.

electrical infrastructure (i.e., cabling, transformers, dimmers, and sockets), a significant advantage for LED technology.

Fitting an LED lamp into the existing infrastructure challenges the designer in two principal ways:

1. **The form factor.** Retrofit lamps must fit in the form factor of the previous light source.
2. **Electrical compatibility.** Retrofit lamps must work correctly and without light flicker in the existing electrical infrastructure.

We shall discuss each challenge in turn.

Fitting the existing form factor

The existing form factor imposes both a physical limitation (i.e., the driver board has to be small enough) and a thermal limitation on a retrofit lamp. These limitations pose challenges for the design of a replacement lamp (e.g., PAR, R, and A form factors), challenges that are particularly hard to overcome for smaller form factors like MR16 and GU10.

While size is important for a retrofit, thermal limitation is often more critical. LEDs emit only visible light; they do not irradiate energy at infrared wavelengths like other technologies. Thus while LEDs are more energy efficient than incandescent or halogen lamps, they dissipate much more heat through thermal conduction in the lamp.

Thermal dissipation is also the main limiting factor for the amount of light that a lamp can produce. Today's LED technology in retrofit lamps can barely achieve a level of brightness that is acceptable for the mainstream market. Pushing the limits of brightness and, consequently, thermal design are essential for designing a commercially successful product.

A corollary issue to the thermal dissipation is the lifetime of the driver board. To emit more light, the lamp must work at a fairly high temperature (+80°C to +100°C). At these temperatures, the lifetime of the driver board can limit the operation of the whole lamp. Electrolytic capacitors are, in particular, the biggest challenge. Since they dry quickly at those temperatures, the operation of those capacitors is limited to no more than a few thousand hours, and this becomes the limiting factor for the whole lamp. Since longevity is a major selling point for LED lamps, managing the relatively short lifetime of electrolytic capacitors is a major issue for the lamp designer.

Maxim has developed unique LED solutions for both 120VAC/230VAC input and 12VAC input retrofit lamps. These LED solutions do not require electrolytic capacitors on the board. This extends the lifetime of the lamp from typically less than 10,000 hours to up to 90,000 hours. Not having electrolytic capacitors also reduces the size of the solution, so the driver board fits the small retrofit form factor.

Matching the electrical infrastructure

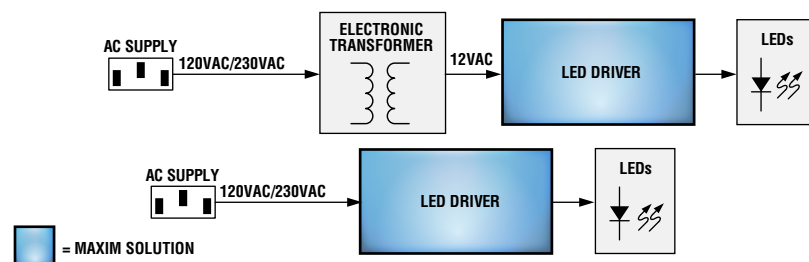
Retrofit LED lamps must work correctly in infrastructures that include cut-angle (triac or trailing-edge) dimmers and electronic transformers.

Working off the 120VAC/230VAC line, the lamp can be preceded by a triac

dimmer. Triac dimmers are designed to work well with incandescent and halogen lamps, which are perfectly resistive loads. With LED retrofit lamps, however, the LED driver is generally a very nonlinear and not purely resistive load; its input bridge rectifier typically draws brief, high-intensity peaks of current when the AC input voltage is at its positive and negative peaks. This LED behavior does not allow the triac dimmer to work properly, because it provides neither the needed start current nor the hold current. As a result, the dimmer does not start properly or turns off while operating, and the LED lamp light flickers in an unacceptable way.

The electrical infrastructure is even more complicated for 12VAC input lamps, because an electronic transformer and trailing-edge dimmer can be connected at the lamp's input. Again, a 12VAC input lamp driver that uses the traditional bridge rectifier and DC-DC converter topology flickers because of incompatibility with the transformer and dimmer.

Maxim's LED solutions for 120VAC/230VAC and 12VAC input lamps use a single-stage conversion. By shaping the input current so that the light does not flicker even when dimmed, these solutions are compatible with triac and trailing-edge dimmers and electronic transformers. No other solutions for MR16 lights offer this feature; few solutions for PAR, R, and A lamps offer it. In addition, these solutions provide better



Block diagram for MR16 (top) and offline (bottom) lamps.

For a list of Maxim's recommended LED-lighting solutions, please go to: www.maxim-ic.com/lighting.

than 0.9 power-factor correction and require a very limited number of external components. No electrolytic capacitors are required, which considerably extends the lifetime of the driver circuit working in a hot environment. Both the 120VAC/230VAC and 12VAC solutions employ the MAX16834 IC, and are available for evaluation and use in mass production. They are both proprietary to Maxim, which is the only supplier to provide this combination of advantages.

Remote-controlled applications in street, parking, and indoor lights



As stated above, LEDs offer more design flexibility for dimming and changing the light color. This versatility makes them ideal for applications like architectural lighting, indoor ambient lighting, and dimmable, energy-efficient street and outdoor lighting. All these applications require a technology to control the LED light remotely. For the application to be successful in the marketplace, the cost of upgrading the lighting infrastructure to new LED technology must be minimized. Not surprising, solutions that can reuse the present infrastructure will likely be the first to penetrate the market.

When converting to remote-controlled LED lighting, the most costly infrastructure upgrade to anticipate is the wiring to control the LED lights. Fortunately, two technologies can negate the need for that costly upgrade: LED lamps can be controlled

with a wireless link, or they can be controlled through existing power lines using PLC technology.

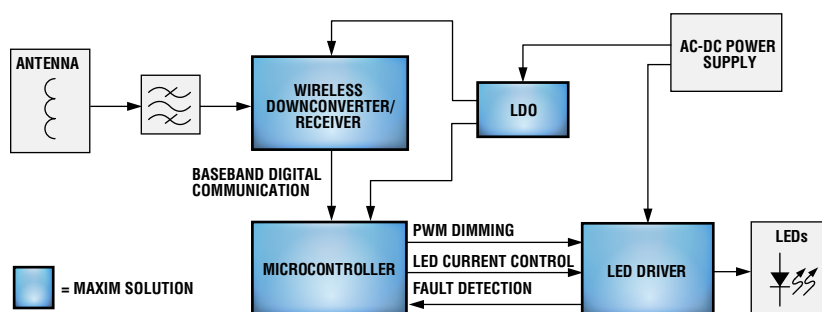
PLC technology allows communication over a long range, but this can be problematic when breakers or transformers on the AC line do not allow the communication to flow freely. While wireless communications do not have this problem, the wireless communication range can be limited if free bands are used. A mix of both technologies can sometimes be the best solution: powerline connections for devices that are not separated by transformers, and wireless connections to bypass transformers.

The main design requirements for remote-controlled LED lighting solutions are:

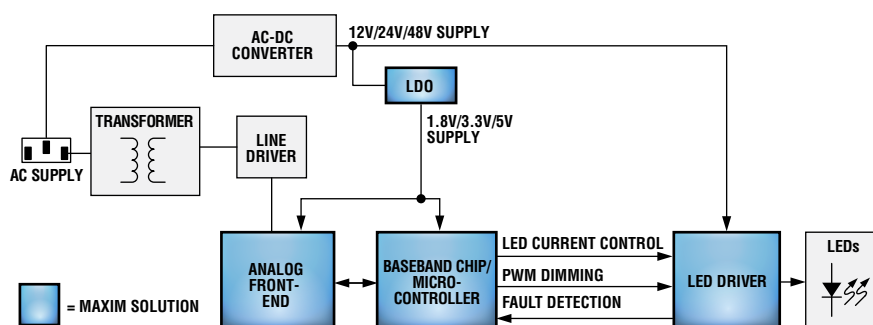
- **The communication range**, which is dictated by the application. For

an indoor residential application, something in the range of 30m is sufficient. Street lighting can require a range of several kilometers.

- **Low power consumption.** An important selling point of LEDs is their high energy efficiency. It is important that an LED lamp consume the least power possible when the light is off and only the communication circuit is active.
- **The communication rate.** Some lighting applications require only a low communication bit rate (i.e., a few kbps) to control light dimming and perhaps read possible faults. Architectural lighting, however, can sometimes require a high data rate, even 100kbps. An example can be a wall-washer application where many lights are controlled through a single bus and the colors change continuously.



Block diagram of a typical wireless-controlled lighting system.



Block diagram of a typical PLC-controlled lighting system.

For a list of Maxim's recommended LED-lighting solutions, please go to: www.maxim-ic.com/lighting.

Lighting

LED lighting

- **Low costs.** This is true for most lighting applications.

A remote-controlled lamp often includes a microcontroller, either as a discrete component or integrated in another IC. Unless a complex communication protocol is adopted with a complex stack (e.g., ZigBee®), a basic microcontroller is typically sufficient. The microcontroller's duties will typically include decoding of the communication protocol, generation of dimming signals for the LED driver, reading faults, and controlling the lighting effects of the lamp (e.g., theater dimming).

For wireless communication in lighting applications, Maxim offers the [MAX1473](#) receiver and the [MAX1472](#) transmitter. These products allow communication in the 300MHz to 450MHz free bands, over a range of 30m to 50m in an indoor environment. The [MAXQ610](#) microcontroller offers all the required features at a low cost.

For PLC, Maxim's solution includes the [MAX2991](#) analog front-end (AFE) and the [MAX2990](#) baseband processor. These devices form a powerline transmitter/receiver chipset that is capable of transmit-

ting data over distances up to 10km and at data rates up to 100kbps. This range makes the parts ideal for street-lighting applications. A microcontroller with PWM outputs to control the PWM dimming input of the LED driver is integrated into the [MAX2990](#). This feature eliminates the need for another circuit to generate this signal.

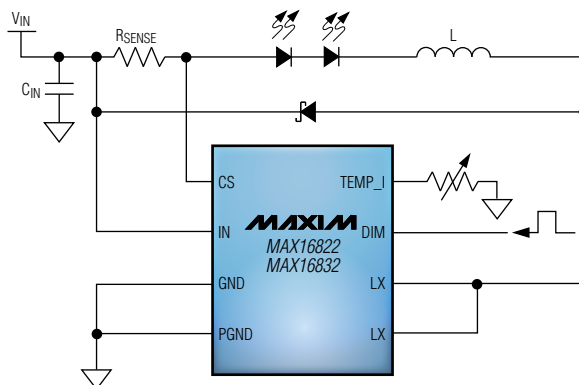
Industrial-grade LED drivers reduce external component count

MAX16822/MAX16832

The MAX16822/MAX16832 are high-input-voltage, buck-mode, high-brightness (HB) LED drivers for up to 1A or 500mA current. With hysteretic control of the LED current, they do not need a compensation circuit. They require very few external components, thus reducing BOM cost and board area substantially compared to other solutions. A switching MOSFET is included, and they feature an analog dimming input with a nonlinear behavior for thermal foldback.

Benefits

- **Low external component count and low BOM cost**
 - Hysteretic current control eliminates the need for external compensation
 - Integrated switching MOSFET: up to 1A (MAX16832) or 500mA (MAX16822) output current
 - Low 1 μ F input capacitor
- **Industrial-grade devices, ideal for rough environments**
 - 6.5V to 65V input range is compatible with 12V/24V/48V inputs, and robust for input voltage spikes
 - -40°C to +125°C operating temperature range
 - High-power-dissipation capability in an 8-pin SO-EP package (MAX16832) for environments with high ambient temperatures
 - Thermal-foldback input protects LEDs in case of overheating



Typical operating circuit for the MAX16822/MAX16832.

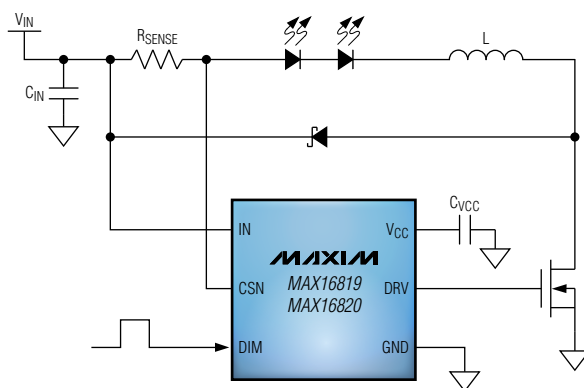
HB LED drivers reduce BOM cost

MAX16819/MAX16820

The MAX16819/MAX16820 are buck-mode HB LED drivers featuring an external switching MOSFET for applications with more than 1A current. They provide hysteretic control of the LED current so that they do not need a compensation circuit. They require very few external components, are low in cost, and are available in a small package size (3mm x 3mm). These are dependable products for the harsh operating environment of industrial applications.

Benefits

- **Low external component count and low BOM cost**
 - Hysteretic current control needs no external compensation
 - Simple, low-cost ICs
- **Ideal for applications with a limited board area**
 - Small, 3mm x 3mm, 6-pin TDFN package
- **Industrial-grade product for harsh operating environments**
 - 4.5V to 28V input voltage range
 - -40°C to +125°C operating temperature range



Typical operating circuit for the MAX16819/MAX16820.

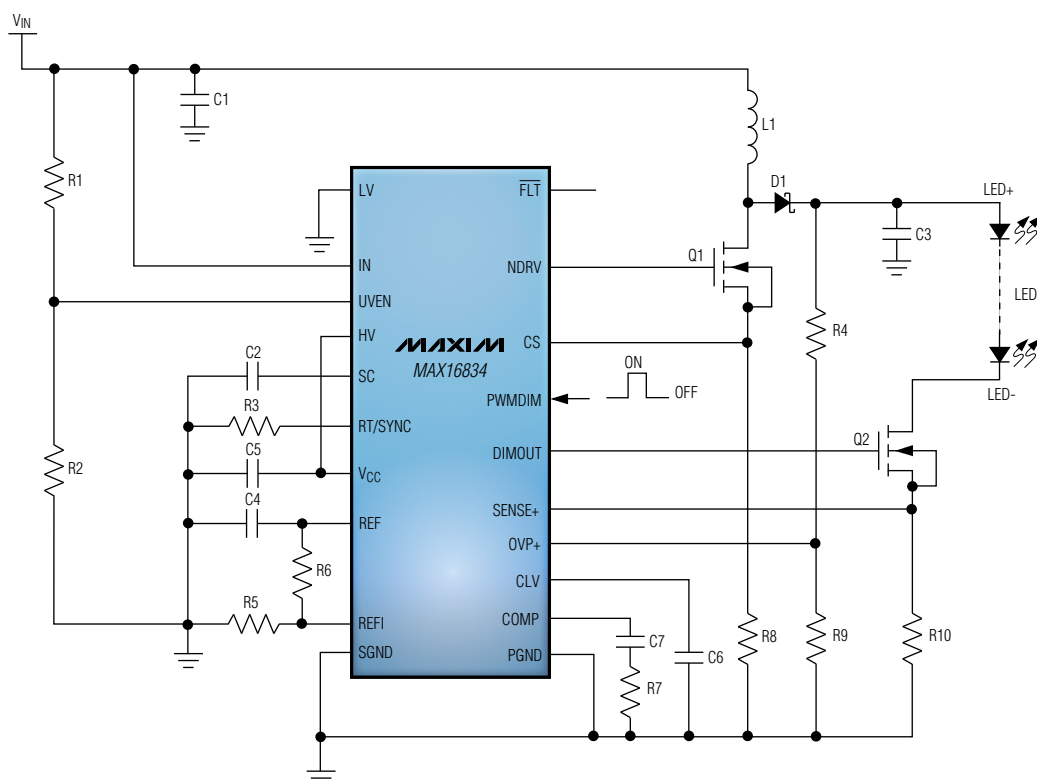
Highly flexible HB LED driver provides ideal light intensity over widely varying ambient-light conditions

MAX16834

The MAX16834 is a highly flexible HB LED driver that can work in buck, buck-boost, boost, SEPIC, and flyback configurations. It uses current-mode control of the LED current. By including a driver for a dimming pass MOSFET, it allows a 3000:1 PWM dimming range. With its unmatched flexibility, this driver is used for Maxim's proprietary solutions for MR16 and offline (PAR, R, A, GU10) retrofit lamps.

Benefits

- **Ideal for environments with widely varying ambient light**
 - Wide PWM dimming ratio: up to 3000:1 ratio at 200Hz dimming frequency
- **Very flexible—a single IC can work for many different applications, thus reducing inventory**
 - For buck-boost, boost, SEPIC, flyback, and high-side buck configurations
 - Analog and PWM dimming inputs
 - Highly flexible, it is used for Maxim's MR16 and offline solutions
- **Industrial-grade product provides a fault-safe solution for rough environments**
 - Shorted- and open-LED protection
 - -40°C to +125°C operating range



Typical operating circuit for the MAX16834.

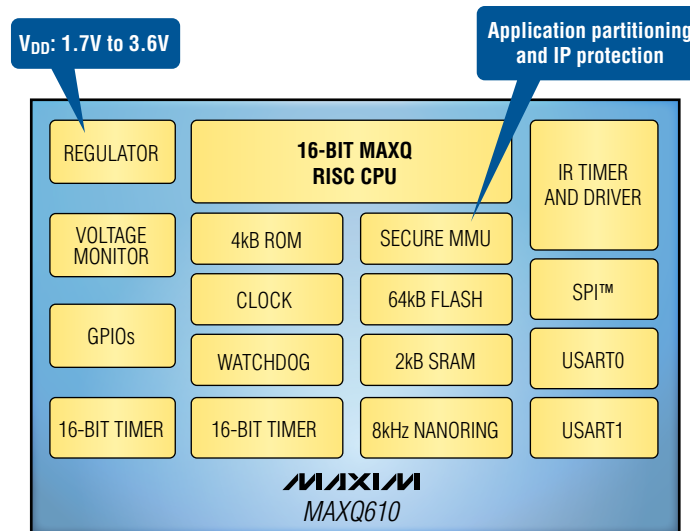
16-bit MAXQ® microcontroller greatly extends battery life in portable equipment

MAXQ610

The MAXQ610 is designed for low-cost, high-performance, battery-powered applications. This 16-bit, RISC-based microcontroller has a wide operating range (down to 1.7V) for long battery life and ultra-low power consumption. Its anticloning features and secure MMU enable you to protect your IP.

Benefits

- **Ultra-low supply current minimizes power consumption**
 - Active mode: 3.75mA at 12MHz
 - Stop mode: 200nA (typ), 2.0µA (max)
- **Secure MMU supports multiple privilege levels, protects code from unauthorized access**



Block diagram for the MAXQ610.

Recommended solutions

Part	Description	Features	Benefits
LED power			
MAX16822	500mA, buck, switch-mode driver with integrated MOSFET	6.5V to 65V input; LED current thermal foldback; few external components	Small board area; low BOM cost
MAX16832	1A, buck, switch-mode driver with integrated MOSFET	6.5V to 65V input; LED current thermal foldback; few external components	Small board area; high-power-dissipation package reduces need for heatsink
MAX16820	Buck, switch-mode driver	External MOSFET; > 1A output; no compensation circuit	Flexible with few external components
MAX16834	Boost and buck-boost driver	Internal driver for PWM dimming MOSFET; analog dimming input	3000:1 dimming range; supports multiple topologies; ideal for triac-dimmable lighting
MAX16826	Programmable, 4-channel HB LED driver with integrated DC-DC controller	4 channels; 4.75V to 24V input voltage; up to 300mA/channel current capability; I ² C interface	Easily controlled by a microcontroller
LDO			
MAX6765–MAX6774	Low-quiescent current, high-voltage linear regulators	Low 31µA quiescent current; wide 4V to 72V input voltage range; active-low RESET with fixed or adjustable thresholds; small, thermally-enhanced 1.9W, 3mm x 3mm TDFN package	Low quiescent current improves energy savings
Microcontroller			
MAXQ610	Low-power, 16-bit microcontroller	1.7V to 3.6V supply range; up to 32 GPIOs; wakeup timer	Extends battery life; low cost
Powerline controllers			
MAX2990	10kHz to 490kHz OFDM-based PLC modem	Combines the physical layer (PHY) and media access controller (MAC) to provide a data rate of 100kbps over the powerline	High-reliability data communications
MAX2991	Integrated AFE receiver for PLC	Optimized to operate with the MAX2990; on-chip band-select filter, VGA, and a 10-bit ADC for the Rx path	High receiver sensitivity for long-range communication
RF ICs			
MAX1472	300MHz to 450MHz, low-power, crystal based, ASK transmitter	Crystal based; low power; 3mm x 3mm package	Superior performance; long battery life; compact
MAX1473	300MHz to 450MHz ASK receiver with automatic gain control (AGC)	High sensitivity and AGC; 5mm x 5mm package; single supply	Long range; low solution cost; compact

For a list of Maxim's recommended LED-lighting solutions, please go to: www.maxim-ic.com/lighting.

Trim, calibrate, and adjust

Making industrial equipment accurate, safe, and affordable with electronic calibration

We demand safety in our factories. Customers expect quality products, which require accurate manufacturing equipment. At the same time, equipment must be affordable. How can manufacturers deliver “perfect” equipment at a reasonable price? In a word, *calibration*. Electronic calibration enables the remote calibration and testing of field devices such as sensors, valves, and actuators. Because field devices and programmable logic controllers (PLCs) are size constrained, they benefit from the small size of electronic calibration devices.

All practical components, both mechanical and electronic, have manufacturing tolerances. The more relaxed the tolerance, the more affordable the component. When components are assembled into a system, the individual tolerances sum to create a total system error tolerance. Through the proper design of trim, adjustment, and calibration circuits, it is possible to correct these system errors, thereby making equipment safe, accurate, and affordable.

Calibration can reduce cost in many areas. It can be used to remove manufacturing tolerances, specify less-expensive components, reduce test time, improve reliability, increase customer satisfaction, reduce customer returns, lower warranty costs, and speed product delivery.

Digitally controlled calibration devices and potentiometers (pots) are replacing mechanical pots in many factory settings. This digital approach results in better reliability and improved employee safety. This

increased dependability can reduce product liability concerns. Another advantage is reduced test time and expense by removing human error. Automatic test equipment (ATE) can perform the test functions quickly and precisely, time after time. In addition, digital devices are insensitive to dust, dirt, and moisture, which can cause failure in mechanical pots.

Testing and calibration fall into three broad areas: production-line final testing, periodic self-testing, and continuous monitoring and readjustment. Practical products may use some or all of the above test methods.

Compensating for component tolerances using final-test calibration

Final-test calibration corrects for errors caused by the combined tolerances of many components. One or more adjustments may be required to calibrate the device under test (DUT) to meet a manufacturer’s specifications.

To provide a simple example, we will say that this equipment uses resistors with five percent tolerance in several circuits. In design, we simulate the circuits and perform Monte Carlo testing. That is, we randomly change the resistor values within the tolerance limits to explore their effects on the output signal. The simulation results in a family of curves that show the worst-case errors that the resistor tolerances cause. With this knowledge, the designer decides to use the circuits as-is and to simply adjust the offset and span (gain) during final test to meet system specifications. So, we make measurements in the final production test and have a human set the span and offset using two

mechanical pots. Calibration is complete, but have we solved the problem, masked the problem, or added a bigger unknown?

Experienced production engineers know human error is a real issue. Unintentional slips can ruin the best of plans. Asking a human to perform a boring, repetitive task is asking for problems. A better way is to automate such a task. Electrically adjustable calibration devices enable quick automatic testing, which improves repeatability, reduces cost, and enhances safety by removing the human-error factor.

Improving reliability and long-term stability by power-on self-test and continuous/periodic calibration

Manufacturing tolerances are compensated for by calibration during the final production test, and that data is utilized when a system is powered up. Environmental parameters in the field also create a need for test and calibration. Such environmental factors include temperature, humidity, and circuit component aging (drift), which result in signal span and offset errors. Some circuits contain control or average information, which can be periodically memorized. These factors are accounted for with a combination of self-test at power-up and periodic or continuous testing. The field testing may be as simple as sensing temperature and compensating accordingly, or it may be more complex.

Many products include an internal microprocessor, which can aid testing. For example, a weight scale can compensate for the weight of the product package, such as a plastic bag or glass jar. Subtracting the weight of the package (tare weight)

Related functions

Trim, calibrate, and adjust

from the gross weight is necessary to accurately measure the net weight of the material on the scale. Because the weight of the package may change over time due to manufacturing variation or a change of vendors, it is desirable to update the tare or container weight from time to time.

Another example is using a switch to short an amplifier input to ground to measure offset voltage. This could be done during power-on self-test to compensate for component aging. Alternatively, it can be performed periodically to compensate for temperature-induced drift. If the temperature drift is predictable and repeatable, a microprocessor can aid testing by measuring temperature and controlling the calibration device in an open-loop manner.

System gain errors can be calibrated by switching a known signal into the equipment at an early stage and measuring the output level. This is done at power-up or periodically during lulls in operation.

Enabling accurate automated adjustments with calibration DACs and pots

Calibration digital-to-analog converters (CDACs) and calibration digital pots (CDPots) share some unique attributes that enable trimming, adjustment, and calibration. The first advantage is internal nonvolatile memory, which automatically restores the calibration setting during power-up. **Figure 1** illustrates a second advantage: the ability to customize the calibration granularity and location for industrial safety.

Ordinary DACs allow a single reference voltage (V_{REF}) to be applied; this reference voltage usually becomes the highest DAC setting. The lowest DAC setting is a fixed voltage, typically ground. For a near-center adjustment, much of this range between V_{REF} and ground must

be ignored and not used, since the available step size is evenly distributed over the range. For example, with V_{REF} set to 4V, a 10-bit DAC yields a step size of 0.0039V per step. It is critical in industrial equipment to remove all safety-related errors. Removing the unused adjustment range eliminates any possibility that the circuit could be grossly misadjusted.

The CDAC and CDPot allow both the top and bottom DAC voltage to be set to arbitrary voltages, thus removing excess adjustment range. In **Figure 1**, a low value of 1V and a high value of 2V are selected as examples. To achieve a 0.0039V step size over the 1V to 2V range, only an 8-bit device is needed, which saves cost. Additionally, this increases safety by removing any possibility that the circuit could be misadjusted. The high and low voltages for the CDAC are arbitrary and, therefore, can be centered wherever the

circuit calibration is required. If the tolerance analysis for the circuit indicates that a range of 1.328V to 1.875V is needed for calibration, it can be accommodated. The 256-step device would yield a granularity of 0.00214V. Thus, the granularity of the adjustment can be optimized for the specific application.

Reducing cost and improving accuracy by replacing mechanical trims with all-electronic equivalents

Digitally controlled adjustable devices offer several advantages over mechanical devices in industrial systems. The largest advantage is lower cost. ATE can perform calibration precisely time after time, thereby eliminating the considerable costs associated with error-prone manual adjustments. Also, digital pots allow periodic testing to occur more

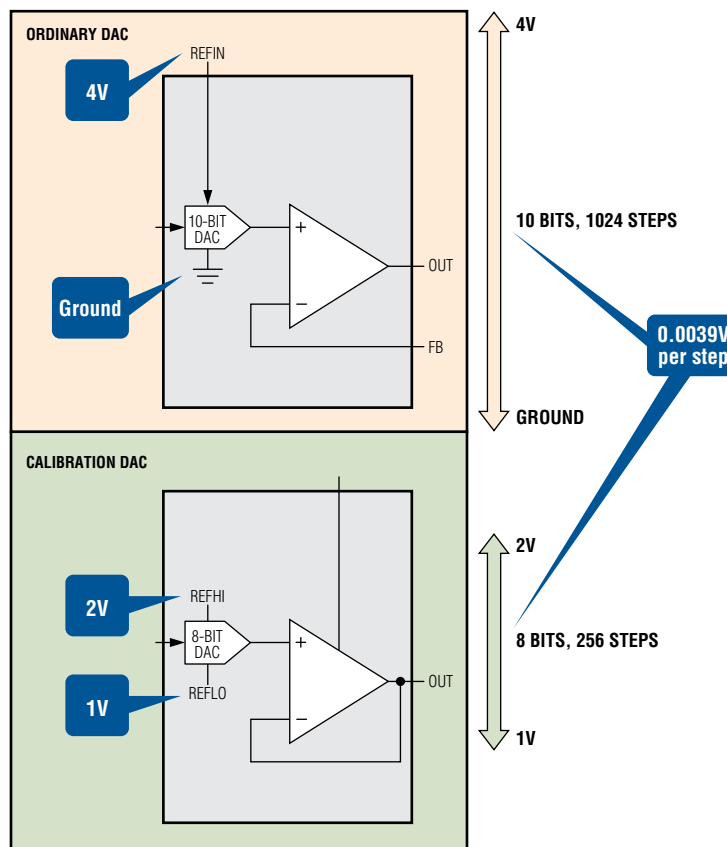


Figure 1. Comparing the calibration range of an ordinary DAC to a CDAC.

frequently or over longer equipment lifespans, since they can guarantee 50,000 writing cycles. The best mechanical pots can support only a few thousand adjustments.

Location flexibility and size are other advantages compared to mechanical pots. Digitally adjustable pots can be mounted on the circuit board directly in the signal path, exactly where they are needed. In contrast, mechanical pots may require human access, which can necessitate long circuit traces or coaxial cables. In sensitive circuits, the capacitance, time delay, or interference pickup of these cables can reduce equipment performance.

Digital pots also maintain their calibration values better over time, whereas mechanical pots can continue to experience small movements even after they are sealed. The wiper will move as the wiper spring relaxes, when the pot is temperature cycled, or when the pot is subjected to shipping vibration. Calibration values stored in digital pots are not affected by these factors.

A one-time programmable (OTP) CDPot can be used for extra safety. It permanently locks in the calibration setting, preventing an operator from making further adjustments. To change the calibration value, one must physically replace the OTP CDPot. A special variant of the OTP CDPot always returns to its stored value upon power-on reset, while allowing operators to make limited adjustments during operation at their discretion.

Leveraging precision voltage references for digital calibration

Sensor and voltage measurements with precision analog-to-digital converters (ADCs) are only as good as the voltage reference used for comparison. Likewise, output control signals are only as accurate as the reference voltage supplied to the DAC, amplifier, or cable driver.

Common power supplies are not adequate to act as precision voltage references. Typical power supplies are only five to ten percent accurate; they change with load and line changes; and they tend to be noisy.

Compact, low-power, low-noise, and low-temperature-coefficient voltage references are affordable and easy to use. In addition, some references have internal temperature sensors to aid in the tracking of environmental variations.

In general, there are three kinds of serial calibration voltage references (CRefs), each of which offers unique advantages for different factory applications. Having a choice of serial voltage references enables the designer to optimize and calibrate his exact circuits.

The first type of reference enables a small trim range, typically three to six percent; this is an advantage for gain trim in industrial imaging systems. For instance, coupling a video DAC with a trimmable CRef allows the overall system gain to be fine-tuned by simply adjusting the CRef voltage.

The second type is an adjustable reference that allows adjustment over a wide range (e.g., 1V to 12V), which is advantageous for field devices that have wide-tolerance sensors and that must operate on unstable power. Portable maintenance devices may need to operate from batteries, automotive power, or emergency power generators.

The third type, called an E²CRef, integrates memory, allowing a single-pin command to copy any voltage between 0.3V and $[V_{IN} - 0.3V]$ and, then, to infinitely hold that level. E²CRefs benefit test and monitoring instruments that need to establish a baseline or warning-alert threshold.

Figure 2 illustrates the production advantages of using an E²CRef. In this example, a power-supply manufacturer uses an E²CRef to create an affordable power supply that stores the setting established during final production test. The manufacturer builds a generic power supply and places it into a holding inventory. When a customer order is received, the output voltage is adjusted by an automated test system before the order is shipped.

The power-supply manufacturer leverages final-test calibration to provide two real benefits. First, he reduces cost by using individual components with relaxed tolerances, as the final-test calibration corrects for cumulative errors. Second, he provides faster delivery to the customer by making custom adjustments to a standard product.

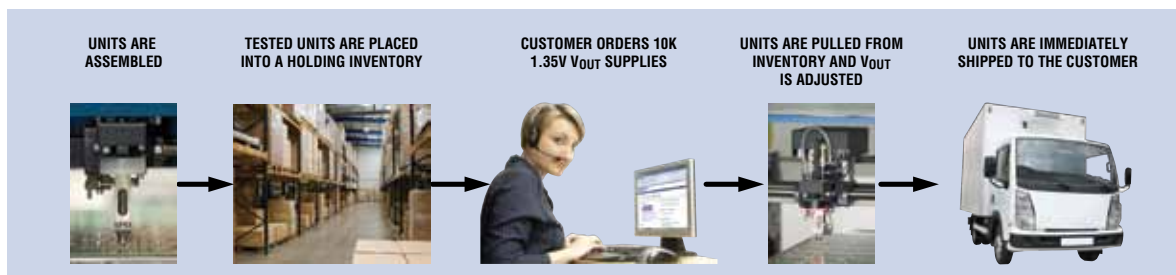


Figure 2. Illustrating the manufacturing benefits of using an E²CRef.

Related functions

Trim, calibrate, and adjust

"Just-in-time" inventory control is more important today than it has ever been because getting the order may hinge on quick delivery time. Winning an order when a competitor fails to deliver can lead to repeat orders. Plus, increasing inventory turns increased profit directly to the bottom line.

Summary

Calibration is a means to an end. Practical devices have manufacturing component tolerances that can be calibrated out during final production test with laboratory-grade external test equipment. Environmental drift due to time, humidity, or temperature requires field calibration. Electronically adjust-

able calibration parts allow quick field calibration including power-on self-test and continuous or periodic calibration. Periodic calibration may also include calibration against laboratory equipment with standards traceable to a recognized standards body. Electronic calibration helps us meet our goal; it allows us to have affordable industrial equipment that is also safe and accurate.

Recommended solutions

Part	Description	Features	Benefits
CDPots			
MAX5481	1024-tap (10-bit) CDPot with SPI™ or up/down interface	1.0μA (max) in standby, 400μA (max) during memory write	Minimal power use for battery-operated portable devices
MAX5477	Dual, 256-step (8-bit) CDPot with I ² C interface	EEPROM write protection, single-supply operation (2.7V to 5.25V)	EEPROM protection retains calibration data for safety
MAX5422	Single, 256-step (8-bit) CDPot with SPI interface	Tiny (3mm x 3mm) TDFN package	Saves PCB space for portable products
MAX5427	32-step (5-bit), OTP CDPot	OTP or OTP plus adjustment	Versatile, reduces component count by performing two functions
DS3502	128-step (7-bit) CDPot with I ² C interface	High output-voltage range (up to 15.5V)	Permits direct calibration of high-voltage circuits
CDACs			
MAX5105/MAX5115	Quad, 8-bit CDACs with independent high and low reference inputs	Rail-to-rail output buffers, choice of I ² C or SPI interface	Selectable voltage range improves granularity and prevents unsafe adjustments
MAX5106	Quad, 8-bit CDAC with independently adjustable voltage ranges	Allows customization of calibration granularity; small 5mm x 6mm package	Saves PCB space for portable products
MAX5116	Quad, 8-bit CDAC with independent high and low reference inputs	Four amplifier circuits are calibrated by one 5mm x 6mm part	Reduces costs with fewer components, saves PCB area, and simplifies control
MAX5109	Dual, 8-bit CDAC with independent high and low reference inputs	Single-supply operation (2.7V to 5.25V), 200μA per DAC, less than 25μA in power-down, rail-to-rail output buffers, I ² C interface	Battery friendly for portable devices; custom range and granularity control
DS1851	Dual temperature-controlled CDAC	Each DAC has EEPROM, which can contain temperature coefficients for temperature-specific calibration	System temperature effects can be corrected without any additional external devices, thus saving space and cost
CRefs and E²CRefs			
MAX6160	Adjustable CRef (1.23V to 12.4V)	Low 200mV dropout; 75μA supply current is virtually independent of input-voltage variations	Longer battery life in portable equipment
MAX6037	Adjustable CRef (1.184V to 5V)	Shutdown mode (500nA, max), low 100mV (max) dropout at 1mA load, 5-pin SOT23 (9mm ²)	Battery friendly and small size for portable applications
MAX6173	Precise voltage reference with temperature sensor	±0.05% (max) initial accuracy, ±3ppm/°C (max) temperature stability	Allows analog system gain trim while maintaining the digital accuracy of ADCs and DACs
MAX6220	Low-noise, precision voltage reference	8V to 40V input-voltage range, ultra-low 1.5μV _{P-P} noise (0.1Hz to 10Hz)	Dependable operation from unstable power (batteries, automotive power, or emergency power generators)
DS4303	Electronically programmable voltage reference	Wide, adjustable output-voltage range can be set within 300mV of the supply rails with ±1mV accuracy	A calibration voltage is memorized forever using one simple GPIO pin

Related functions

Trim, calibrate, and adjust

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