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Medical
Solutions Guide

Edition 1. May 2010

INNOVATION DELIVERED®

A message from the CEO

Dear Customers,

For over 27 years Maxim's mission has been to provide our customers with solutions that add value to their systems.

My desire is that when you start the design of your next medical product, you will think of Maxim first. We want to be the ones that you go to for a value-added solution.

The *Medical: Solutions Guide* discusses 21 specific pieces of medical equipment, and focuses you on the Maxim® products that that will bring the most value to that specific type of equipment.

We reviewed the 6300 products in our catalog, and selected the best ones for each type of 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 *Medical: 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 is focused on being the leading solutions provider for medical equipment. Before long, I am confident that you will agree with me that "Maxim is Medical."

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,

Tunç Doluca

President and Chief Executive Officer

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Disclaimer

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Blood glucose meters

Overview

Blood glucose meters and other home medical devices today are small, portable, and easy to use. The mark of a good meter is one that the patient will use regularly and that returns accurate and precise results. Over the past few years the trend with blood glucose meters has been to maximize patient comfort and convenience by reducing the volume of the blood sample required. The blood sample size is now small enough that alternate-site testing is possible. This eliminates the need to obtain blood from the fingers and greatly reduces the pain associated with daily testing. Accurate and precise results have been increased by using better test strips, electronics, and advanced measurement algorithms. Other conveniences include speedy results, edge fill strips, and illuminated test strip ports, to name just a few.

Meter types

There are continuous and discrete (single-test) meters on the market today, and implantable and non-invasive meters are in development. Continuous meters are by prescription only and use a subcutaneous electrochemical sensor to measure at a programmed interval. Single-test meters use electrochemical or optical reflectometry to measure the glucose level in units of mg/dL or mmol/L.

The majority of blood glucose meters are electrochemical. Electrochemical test strips have electrodes where a precise bias voltage is applied with a digital-to-analog converter (DAC), and a current proportional to the glucose in the blood is measured as a result of the electrochemical reaction on the test strip. There can be one or more channels, and the current is usually converted to a voltage by a transimpedance amplifier (TIA) for measurement with an analog-to-digital converter (ADC). The full-scale current measurement of the test strip is in the range of 10µA to 50µA with a resolution of less than 10nA. Ambient temperature needs to be measured because the test strips are temperature dependent.

Electrochemical blood glucose meter

Optical-reflectometry test strips use color to determine the glucose concentration in the blood. Typically, a calibrated current passes through two light-emitting diodes (LEDs) that alternately flash onto the colored test strip. A photodiode senses the reflected-light intensity, which is dependent on the color of the test strip, which, in turn, is dependent on the amount of glucose in the blood. The photodiode current is usually converted to a voltage by a TIA for measurement with an ADC. The full-scale current from the photodiode ranges from 1µA to 5µA with a resolution of less than 5nA. Ambient temperature is required for this method.

Optical-reflectometry blood glucose meter

Test-strip calibration

The test strips usually need to be calibrated to the meter to account for manufacturing variations in the test strips. Calibration is done by entering a code manually or by inserting a memory device from the package of test strips. An EPROM or EEPROM memory device enables additional information to be transferred, which is a significant advantage over manually entering a code. A 1-Wire® memory device provides an additional benefit, because the unique serial identification number in each 1-Wire device ensures that the proper test strip is used.

Some meters use test strips that do not require any coding by the user. This "self-calibration" can be accomplished three ways: with tight manufacturing controls, built-in calibration on each test strip, or built-in calibration on a pack of test strips loaded into the meter. A pack of test strips inside the meter also facilitates testing because these often small strips do not need to be handled and inserted by the user.

Glucose meter solutions

Accuracy and precision

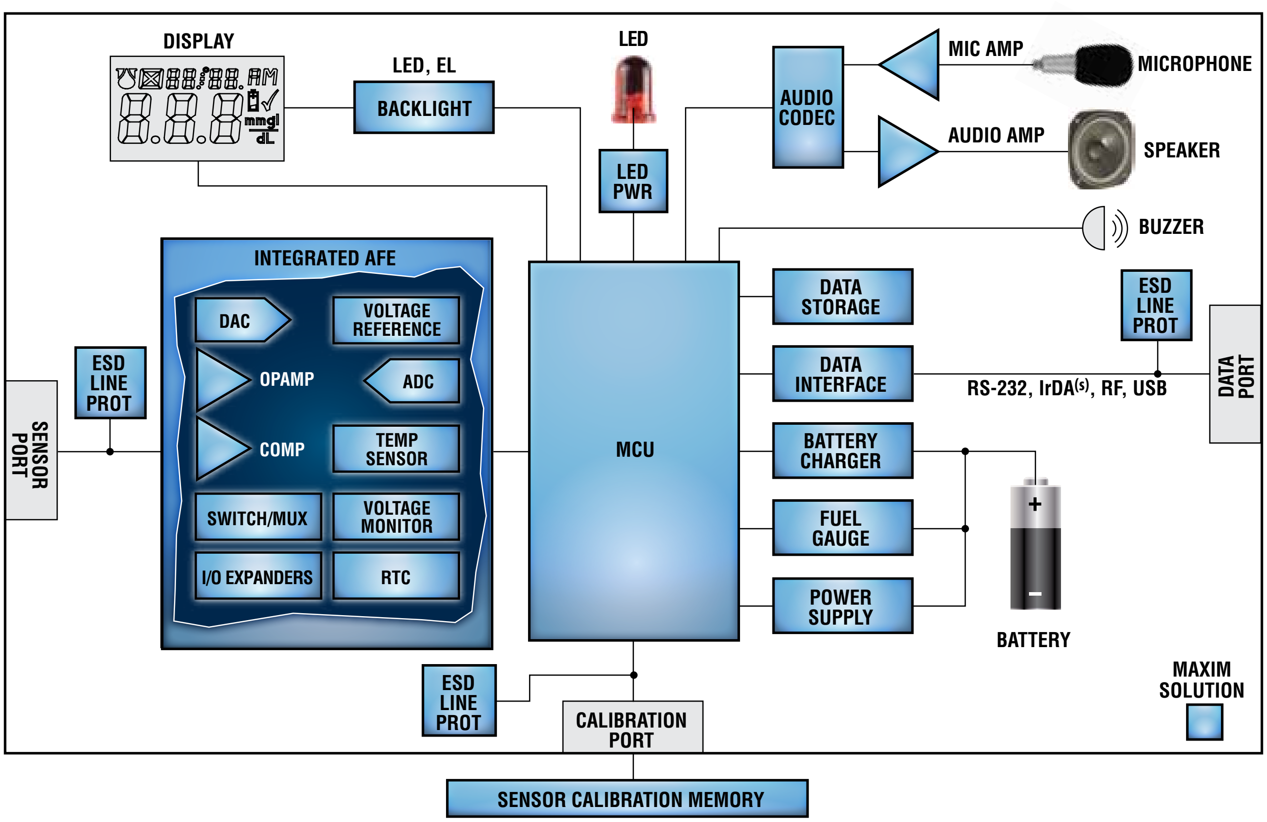
Both optical-reflectometry and electrochemical meters need to resolve currents in the single-digit nano-amp range. To meet the error budget for a meter, components must have extremely low leakage and drift over supply voltage, temperature, and time once the meter has been calibrated during manufacture. An operational amplifier's key specifications are ultra-low input bias current (< 1nA), high linearity, and stability when connected to a capacitive electrochemical test strip. The operational amplifier is typically configured as a TIA for both types of meters. A voltage reference's key specifications include a temperature coefficient less than 50ppm/°C, low drift over time, and good line and load regulation. A 10- or 12-bit DAC is used to set the bias voltage for an electrochemical test strip and to set the LED current for an optical-reflectometry test strip. Sometimes a comparator is employed with electrochemical test strips to detect when blood has been applied to the test strip. This saves power while waiting for blood to be applied to the test strip, and ensures that the reaction site is fully saturated with blood. The ADC requirements vary depending on the type of meter, but most require ≥ 14-bit resolution and low noise for repeatable results. Sometimes 12-bit resolution is used when there is a programmable gain stage before the ADC to extend the dynamic range.

Temperature measurement

Ideally, the temperature of the blood on the test strip should be measured, but usually the ambient temperature near the test strip is measured. Temperature measurement accuracy varies by test-strip type and chemistry, but is typically in the ±1°C to ±2°C range. This measurement can be accomplished with stand-alone temperature-sensor ICs, or with a remote thermistor or PN junction together with an ADC. Using a thermistor in a half-bridge configuration driven by the same reference as the ADC provides more accurate results because this design eliminates any voltage-reference errors. Remote or internal PN junctions can be measured with highly precise integrated analog front-ends (AFEs).

Electrochemical test-strip configurations

Most test strips are proprietary and vary by meter manufacturer. The variations include the reagent formulation, the number of electrodes, the number of channels, and biasing method of the reagent. The simplest configuration is a self-biased test strip (**Figure 1**) which has two electrodes with current measured at the working electrode and the common electrode grounded. There can be



Functional block diagram of a blood glucose meter. For a list of Maxim's recommended glucose-meter solutions, please go to: www.maxim-ic.com/glucose.

multiple channels on a single test strip; the additional channels are used for a reference measurement, initial blood detection, or to ensure that the blood has saturated the reaction site.

An alternate configuration actively drives both electrodes and measures at the common electrode.

Another more advanced design is a counter configuration (**Figure 2**). Here there are three electrodes with current measured at the working electrode and a force-sense circuit drives the common and reference electrodes. There is an important advantage to this configuration: the bias voltage at the reaction site on the test strip is set and maintained more accurately throughout the measurement. The disadvantage of this design is its additional complexity and the larger headroom required to allow the force-sense amplifier to swing negative to maintain the bias voltage during current flow.

Integrated AFE

Maxim's precision AFEs integrate all the functionality discussed in the previous sections, and are designed for the specifications and performance required in blood glucose meters. The AFEs are also suitable for similar applications such as coagulation and cholesterol meters.

Display and backlighting

Most blood glucose meters use a simple liquid-crystal display (LCD) with about 100 segments that can be driven with an LCD driver integrated in the microcontroller. Some meters feature a more complicated dot-matrix LCD which usually requires using a module with the glass, bias voltages, and drivers assembled together. The dot-matrix display also requires additional memory to store the messages to be displayed. There are also color displays that require additional and higher voltages than both the segment or dot-matrix LCDs. Backlighting can be added by using one or two white LEDs (WLEDs) or an electroluminescent source.

Data interface

The ability to upload test results to a computer has existed for many years, but utilization of this data interface has been low. Initially to keep the cost of the meter down, the incremental cost for this functionality was designed into a proprietary cable. Today meters are moving from proprietary data interfaces to industry-standard interfaces such as USB and Bluetooth®. The added cost of these open interfaces is now moving into the meters, a movement driven, in part, by the Continua Health Alliance and the push to conveniently upload patient data to your health-care provider.

Audio

Audible indicators range from simple buzzers to more advanced talking meters for the vision impaired. A simple buzzer can be driven by one or two microcontroller port pins with pulse-width modulation (PWM) capability. More advanced voice indicators and even voice recording for test result notes can be achieved by adding an audio codec along with speaker and microphone amplifiers.

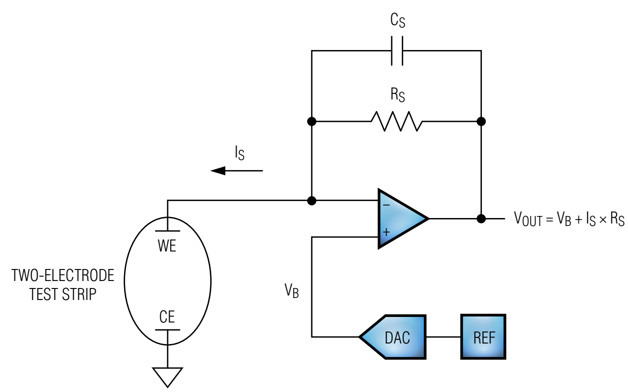


Figure 1. Electrochemical test strip in a self-biased configuration.

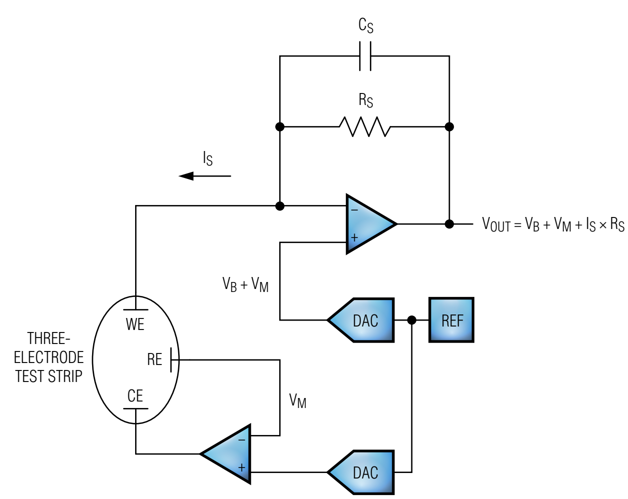


Figure 2. Electrochemical test strip in a counter configuration.

Power and battery management

Meters with simple displays can run directly off of a single lithium coin cell or two alkaline AAA primary batteries. To maximize battery life, this meter requires electronics capable of running from 3.6V down to 2.2V for the lithium coin cell or 1.8V for the alkaline AAAs. If the electronics require a higher or regulated supply voltage, then a step-up switching regulator can be used. Powering down the switching regulator during sleep mode and running directly off the batteries extends battery life, as long as the sleep circuitry can run from the lower battery voltages. Adding a backlit or a more advanced display will require higher and sometimes additional voltages. A more advanced power-management scheme may be required at this point. Rechargeable batteries such as single-cell lithium ion (Li+) can be used by adding a battery charger and fuel-gauge circuitry. Charging with USB is certainly a convenient option for the user, if USB is available in the meter. If the battery is removable, then authentication may be required for safety and aftermarket control.

Electrostatic discharge

All meters must pass 61000-4-2 electrostatic discharge (ESD) requirements. Using electronics with built-in ESD protection or adding ESD line protectors to exposed traces can help meet this requirement.

Functional scalability

Once the core meter design is complete using a precision, integrated AFE, the goal is not to redesign that portion of the meter when another feature is needed later. Instead, standard parts with a singular function targeted for portable medical devices can be used to add a feature with minimal disruption. That minimal disruption translates into lower risk, easier FDA approvals, and faster time to market. It also means that more meters will be available with the features that patients want and need. Blood glucose testing will be more frequent with the predictable result of increased compliance to acceptable glucose levels and better individual health.

www.maxim-ic.com/glucose

Integrated AFEs provide accurate and precise glucose measurements while extending battery life

MAX1358/MAX1359, MAX11359*

The MAX1358/MAX1359 and MAX11359 are low-power, precision integrated AFEs for blood glucose meters and other portable medical devices. The ICs are based on a 16-bit, sigma-delta ADC and system-support functionality for a microcontroller-based system. These devices integrate an ADC, DACs, operational amplifiers, a comparator, a selectable reference, temperature sensors, analog switches, a 32kHz oscillator, a real-time clock (RTC) with alarm, a high-frequency-locked loop (FLL) clock, four user-programmable I/Os, an interrupt generator, and 1.8V and 2.7V voltage monitors in a single chip.

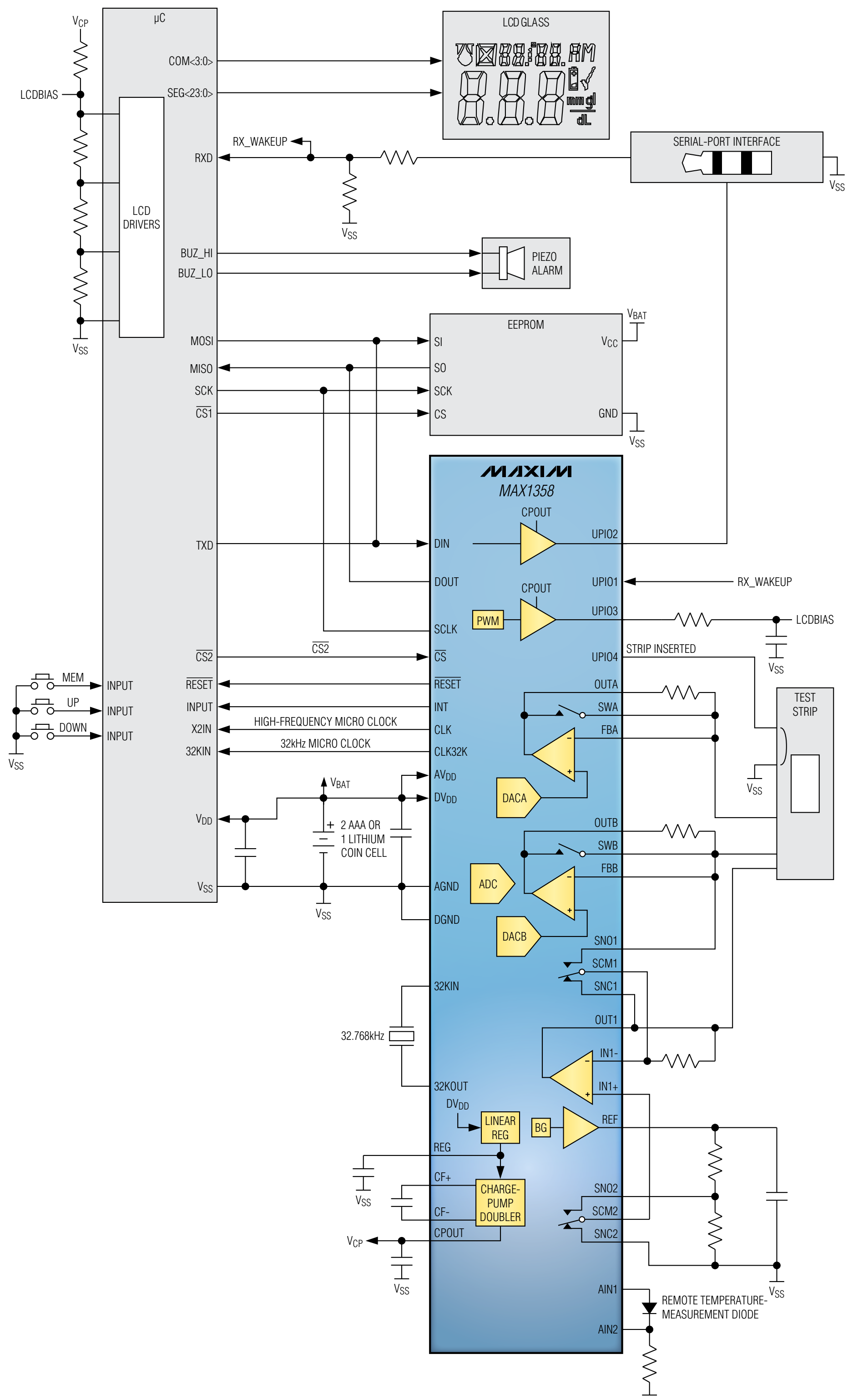
Benefits

- **Accurate and precise test results**
  - 16-bit, 10sps to 500sps, Σ-Δ ADC
  - 15ppm/°C (typ) bandgap reference
  - ±400pA (max) input bias currents
- **Highly configurable AFE for most electrochemical sensors**
  - Programmable elements such as 10-bit force-sense DACs, operational amplifiers, voltage reference, and dual SPDT analog switches
- **Longer battery life**
  - Run directly off battery down to 1.8V
  - 1.7mA (max) run mode with everything turned on
  - 4.4µA (typ) sleep mode with RTC and voltage monitor on
  - Turn microprocessor completely off during sleep mode
- **Integration lowers system cost**
  - Local/remote temperature sensors
  - 32kHz oscillator; RTC; 5MHz FLL clock drives microcontroller
  - +3.3V charge-pump power supply for display, interface, etc.

(Block diagram on next page)

* Future product—contact factory for availability.

Integrated AFEs provide accurate and precise glucose measurements while extending battery life *(continued)*

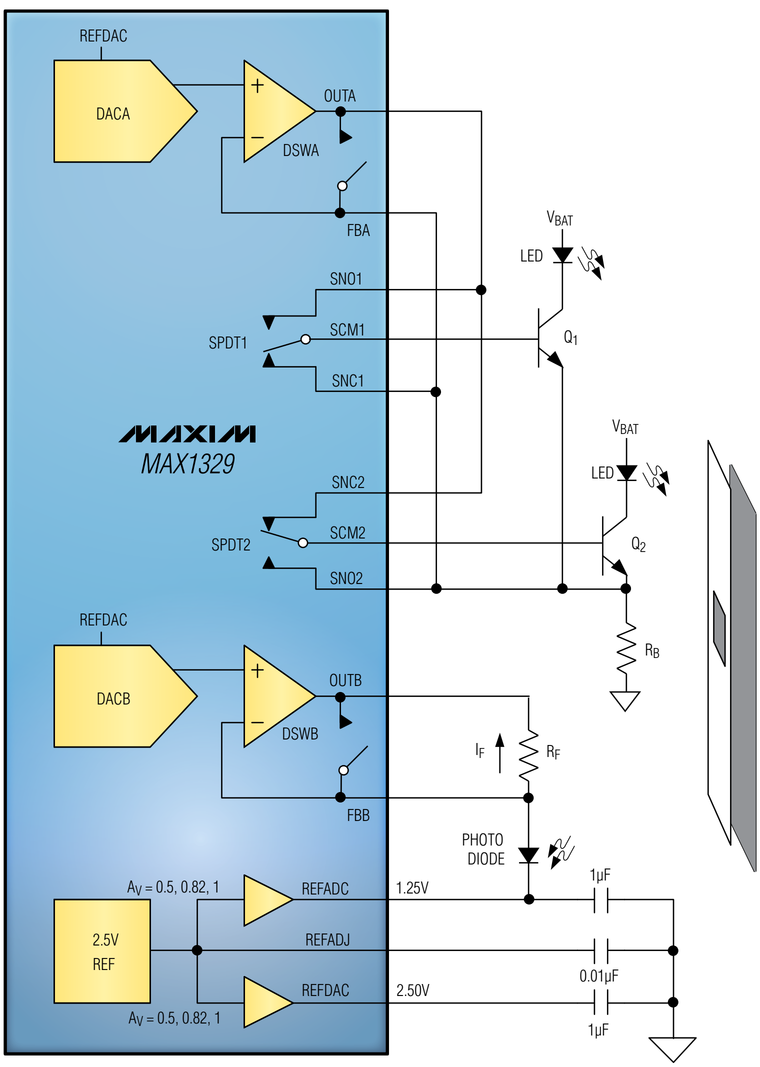


MAX1358 in an electrochemical glucose meter application.

Highly integrated AFE for AC-excitation systems delivers accurate results in a smaller meter

MAX1329

The MAX1329 is a low-power, precision integrated AFE for blood glucose meters and other portable medical devices. It is optimized for optical-reflectometry and electrochemical applications using AC excitation. The MAX1329 integrates a 12-bit SAR ADC, 12-bit DACs, operational amplifiers, voltage references, a temperature sensor, and analog switches. The on-chip programmable gain amplifier (PGA) extends the ADC's dynamic range up to 15 bits. In DSP mode the ADC provides up to 16 bits of resolution at 1ksps. The MAX1329 operates from a 1.8V to 3.6V digital power supply. Under normal operation, an internal charge pump boosts the supply voltage for the analog circuitry when the supply is < 2.7V.



MAX1329 as an analog interface to an optical-reflectometry glucose meter.

Benefits

- **Optimized to simplify design for optical-reflectometry and electrochemical AC-excitation meters**
  - 12-bit SAR ADC with many DSP features to off-load the microcontroller
  - 12-bit force-sense DACs with automated waveform generation
  - Independent programmable voltage references for ADC and DACs
- **Accurate and precise test results**
  - SAR ADC with up to 15-bit dynamic range and up to 16-bit resolution
  - 10ppm/°C (typ) bandgap reference
  - ±1nA (max) input bias current over -40°C to +85°C
- **Longer battery life**
  - Runs off a battery down to 1.8V (2.7V without enabling charge pump)
  - 7.5mA (max) run mode with everything on except charge pump
  - 1µA (typ) sleep mode with voltage monitor on
- **Integration lowers system cost**
  - Local/remote temperature sensors
  - 3.6864MHz internal clock with input/output to/from microcontroller
  - 3V/4V/5V internal power supply for display, backlighting, interface, etc.

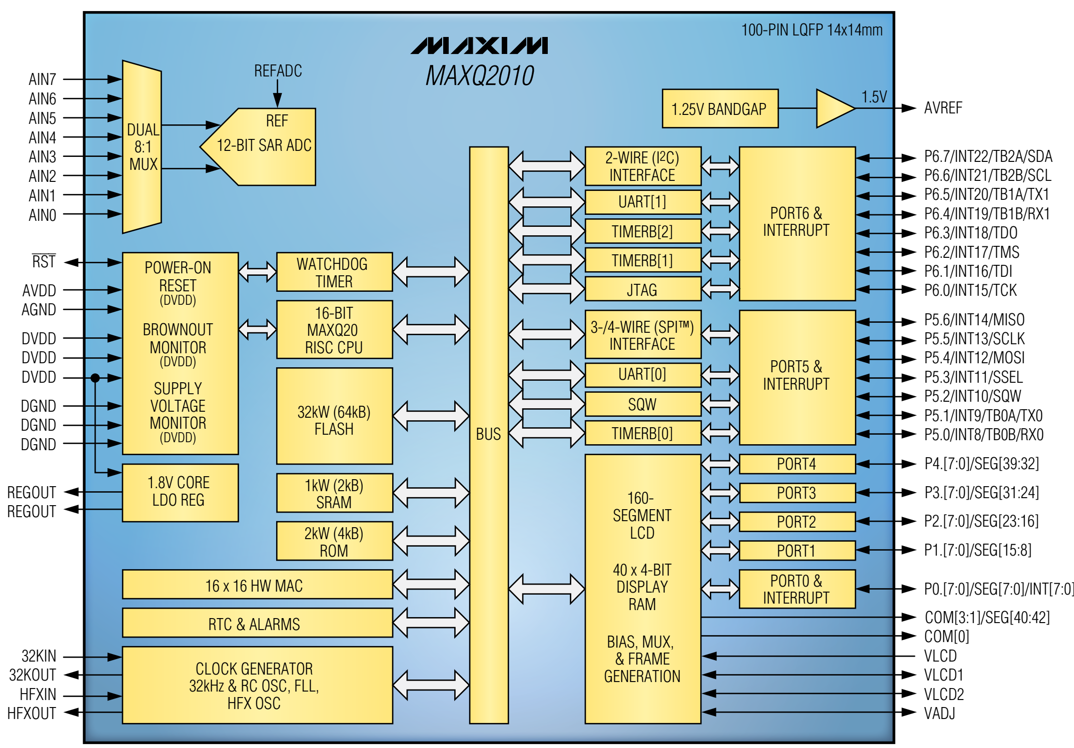
Mixed-signal microcontroller with LCD interface achieves near 1MIPS/MHz performance to extend battery life

MAXQ2010

The MAXQ2010 is a low-power, 16-bit microcontroller that incorporates a high-performance, 12-bit, multichannel ADC and an LCD interface. High performance, low power, and mixed-signal integration make the MAXQ2010 ideal for portable medical devices. The MAXQ2010 has 64KB of flash memory, 2KB of RAM, three 16-bit timers, and two universal USARTs. For the best low-power performance, the MAXQ2010 provides both a low-power sleep mode with the ability to selectively disable peripherals and multiple power-saving operating modes.

Benefits

- **Low power and efficient 16-bit MAXQ® RISC core increases battery life**
  - 1mA (typ) at 1MHz flash operation at 2.7V
  - Low-power modes, 370nA (typ) in stop mode
  - 33 instructions, most single cycle
- **Flexibility and scalability reduces design time**
  - Customer-requested memory size and LCD segments
  - Many peripherals (including timers, serial interfaces, RTC, WDT, HMAC)
- **Fast wake up from sleep and stop modes makes meter more responsive**



MAXQ2010 functional block diagram.

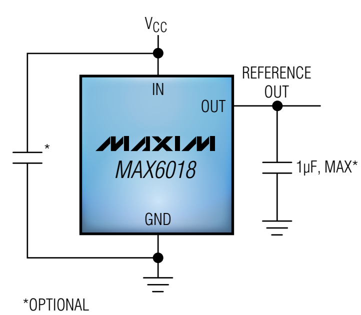
Micropower 1.6V voltage reference operates from a 1.8V supply and increases measurement precision

MAX6018A/MAX6018B

The MAX6018 is a precision, low-voltage, low-dropout, micropower voltage reference in a SOT23 package. This three-terminal reference operates with an input voltage from (V_{OUT} + 200mV) to 5.5V, and is available with output voltage options of 1.2V, 1.6V, 1.8V, and 2.048V. The MAX6018 consumes less than 5µA (max) of supply current and can source and sink up to 1mA of load current. The device has initial accuracies of 0.2% (A grade) and 0.4% (B grade) and temperature drift of 50ppm/°C (max). The low-dropout voltage and the ultra-low supply current make this device ideal for two-cell alkaline, end-of-life, battery-monitoring systems.

Benefits

- **Accurate and precise test results**
  - ±0.2% (max) initial accuracy
  - 50ppm/°C (max) low temperature drift
  - 700µV/mA (max) load regulation (1mA source)
  - 250µV/V (max) line regulation ([V_{OUT} + 200mV] to 5.5V)
- **Eliminates regulated power supply by running directly off of batteries without sacrificing ADC dynamic range**
- **Longer battery life**
  - 5µA (max) ultra-low supply current
  - 1.6V output from 1.8V input
- **Small meter design with ultra-small, 3-pin SOT23 package**



Typical operating circuit for the MAX6018.

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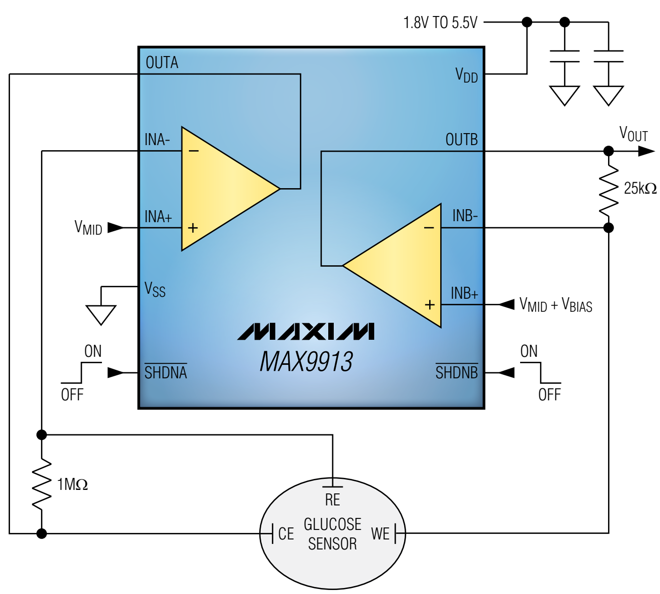
200kHz, 4µA, rail-to-rail I/O op amps with shutdown easily interface to sensors and minimize measurement errors

MAX9910–MAX9913

The MAX9910/MAX9911 (single) and MAX9912/MAX9913 (dual) op amps feature a maximized ratio of gain bandwidth (GBW) to supply current and are ideal for battery-powered applications such as portable instrumentation and portable medical equipment. These CMOS op amps feature an ultra-low input-bias current of 1pA, rail-to-rail inputs and outputs, a low 4µA supply current, and a 1.8V to 5.5V single-supply range. For additional power conservation, the MAX9911/MAX9913 have a low-power shutdown mode that reduces supply current to 1nA and puts the amplifiers' outputs in a high-impedance state. These devices are unity-gain stable with a 200kHz GBW product.

Benefits

- **Fewer sensor-measurement errors**
  - Ultra-low 1pA input bias current
  - Rail-to-rail input and output voltage ranges
  - Low ±200µV input offset voltage
- **High-output impedance during shutdown allows blood to saturate reagent**
- **Power conservation and extended battery life**
  - Ultra-low 4µA supply current and 200kHz GBW
  - 1.8V to 5.5V operation
  - 1pA shutdown current
- **Pin-compatible 1MHz GBW versions provide upgrade path**



MAX9913 in a three-electrode, electrochemical glucose meter application.

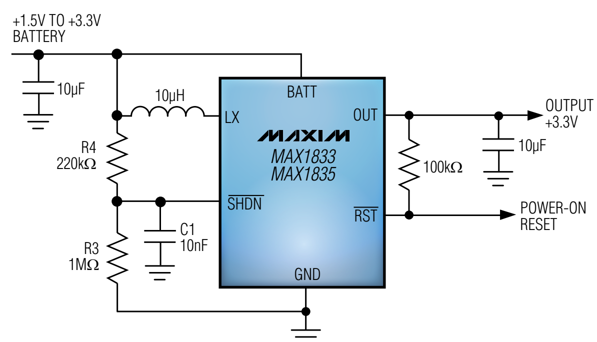
Simplify meter design with reverse-battery protection, and extend battery life by connecting battery to load in shutdown

MAX1832–MAX1835

The MAX1832–MAX1835 are high-efficiency step-up converters with complete reverse-battery protection that protects the device and the load when the battery is reversed. A built-in synchronous rectifier allows for over 90% efficiency and reduces size and cost by eliminating the need for an external Schottky diode. These step-up converters operate from a 1.5V to 5.5V input voltage range and deliver up to 150mA of load current. They are available with a fixed 3.0V/3.3V output voltage or adjustable output from 2V to 5.5V. In shutdown, the battery input is connected to the voltage output, thereby allowing the input battery to be used as a backup or RTC supply.

Benefits

- **Integrated reverse-battery protection simplifies mechanical/electrical design**
- **Longer battery life**
  - < 1µA shutdown supply current
  - BATT connected to OUT in shutdown for backup power
  - Up to 90% efficiency and 4µA quiescent current
- **Family of pin-compatible power supplies simplifies design changes**
  - Fixed 3.3V/3.0V or adjustable output voltage
- **Flexibility to work with a single lithium coin cell or two alkaline batteries**
  - 1.5V to 5.5V input voltage range
  - Accurate active-low SHDN threshold for low-battery cutoff



Typical operating circuit for the MAX1833/MAX1835.

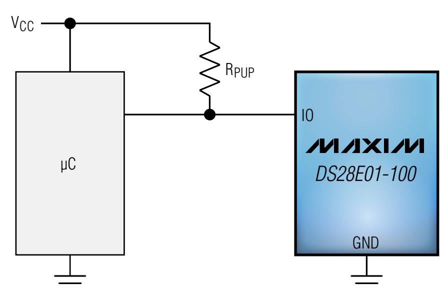
1Kb-protected 1-Wire EEPROM with SHA-1 engine calibrates test strip securely and reliably

DS28E01-100

The DS28E01-100 combines 1024 bits of EEPROM with challenge-and-response authentication security implemented with the ISO/IEC 10118-3 Secure Hash Algorithm (SHA-1). The 1024-bit EEPROM array is configured as four pages of 256 bits with a 64-bit scratch-pad to perform write operations. All memory pages can be write protected, and one page can be put in EPROM-emulation mode, where bits can only be changed from a 1 to a 0 state. Each DS28E01-100 has its own guaranteed, unique 64-bit ROM registration number that is factory lasered into the chip. The DS28E01-100 communicates over the single-contact 1-Wire bus. The communication follows the standard 1-Wire protocol with the registration number acting as the node address in the case of a multidevice 1-Wire network.

Benefits

- **Prevents test-strip cloning**
  - On-chip 512-bit SHA-1 engine
  - Unique, factory-lasered and tested 64-bit registration number assures absolute traceability because no two parts are alike
- **Robust and reliable operation**
  - Single-contact 1-Wire interface
  - Switchpoint hysteresis and filtering optimize performance in the presence of noise
  - High-ESD protection
- **Turnkey solution available**



Typical operating circuit for the DS28E01-100.

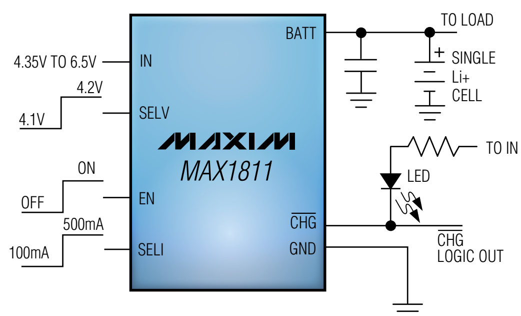
USB-powered Li+ charger safely charges directly from USB port and eliminates the need for an AC-DC adapter

MAX1811

The MAX1811 is a single-cell Li+ battery charger that can be powered directly from a USB port* or from an external supply up to 6.5V. The MAX1811 has a 0.5% overall battery-regulation voltage accuracy to allow maximum utilization of the battery capacity. The charger uses an internal FET to deliver up to 500mA charging current to the battery. The device can be configured for either a 4.1V or 4.2V battery by using the SELV input. The SELI input sets the charge current to either 100mA or 500mA. An open-drain output (active-low CHG) indicates charge status. The MAX1811 has preconditioning that soft starts a near-dead battery cell before charging. Other safety features include continuous monitoring of voltage and current, and initial checking for fault conditions before charging.

Benefits

- **Flexible and convenient use of a single USB connector for data interface and battery charging**
  - Charges single-cell Li+ batteries directly from USB port
- **Safe and easy charging**
  - Automatic IC thermal regulation
  - Preconditions near-depleted cells
- **Low-cost solution**
  - Minimal external components



Typical operating circuit of the MAX1811 charging from a USB port.

*Protected by U.S. Patent #6,507,172.

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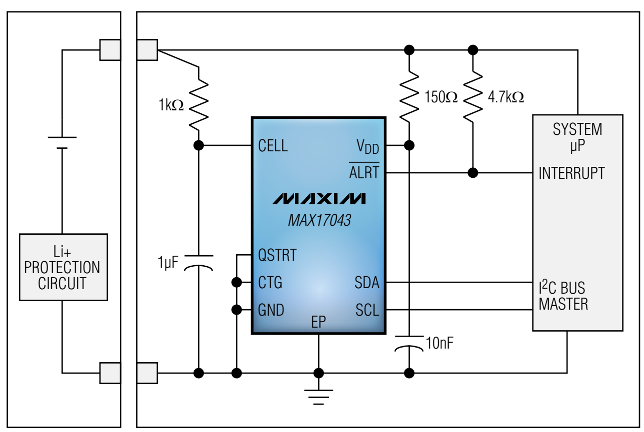
Compact fuel gauges reliably determine remaining battery capacity

MAX17043

The MAX17043 is an ultra-compact, low-cost, 1-cell, host-side fuel-gauge system for Li+ batteries in handheld and portable equipment. A sophisticated Li+ battery-modeling scheme called ModelGauge is used to track the battery's relative state-of-charge/discharge profile. Unlike traditional fuel gauges, the ModelGauge algorithm eliminates the need for battery relearn cycles and an external current-sense resistor. Temperature compensation is possible in the application with minimal interaction between a microcontroller and the device. A quick-start mode provides a good initial estimate of the battery's state of charge (SOC). This feature allows the IC to be located on the system side, thus reducing the cost and supply-chain constraints on the battery.

Benefits

- **Flexible, works with removable and nonremovable batteries**
  - Host-side or battery-side fuel gauging
- **Reliable low-battery indicator for customer**
  - Accurate relative capacity (RSOC) calculated from ModelGauge algorithm
  - No sense resistor required
  - No offset accumulation on measurement
  - No full-to-empty battery relearning necessary
- **Simple and reliable interface to microcontroller**
  - External alarm/interrupt for low-battery warning
  - 2-wire interface



Simplified operating circuit for single-cell Li+ battery using the MAX17043.

Insulin pumps

Overview

Insulin pumps provide a precisely controlled rate of insulin delivery to diabetic patients who would normally need multiple daily injections to regulate blood glucose levels. Insulin pumps improve patient quality of life and reduce the incidence of long-term complications by providing tighter control of blood glucose levels. The firmware allows numerous modifications to the bolus dose and basal rate to enable patients to manage insulin levels in response to (and in anticipation of) events such as eating, sleeping, and exercise.

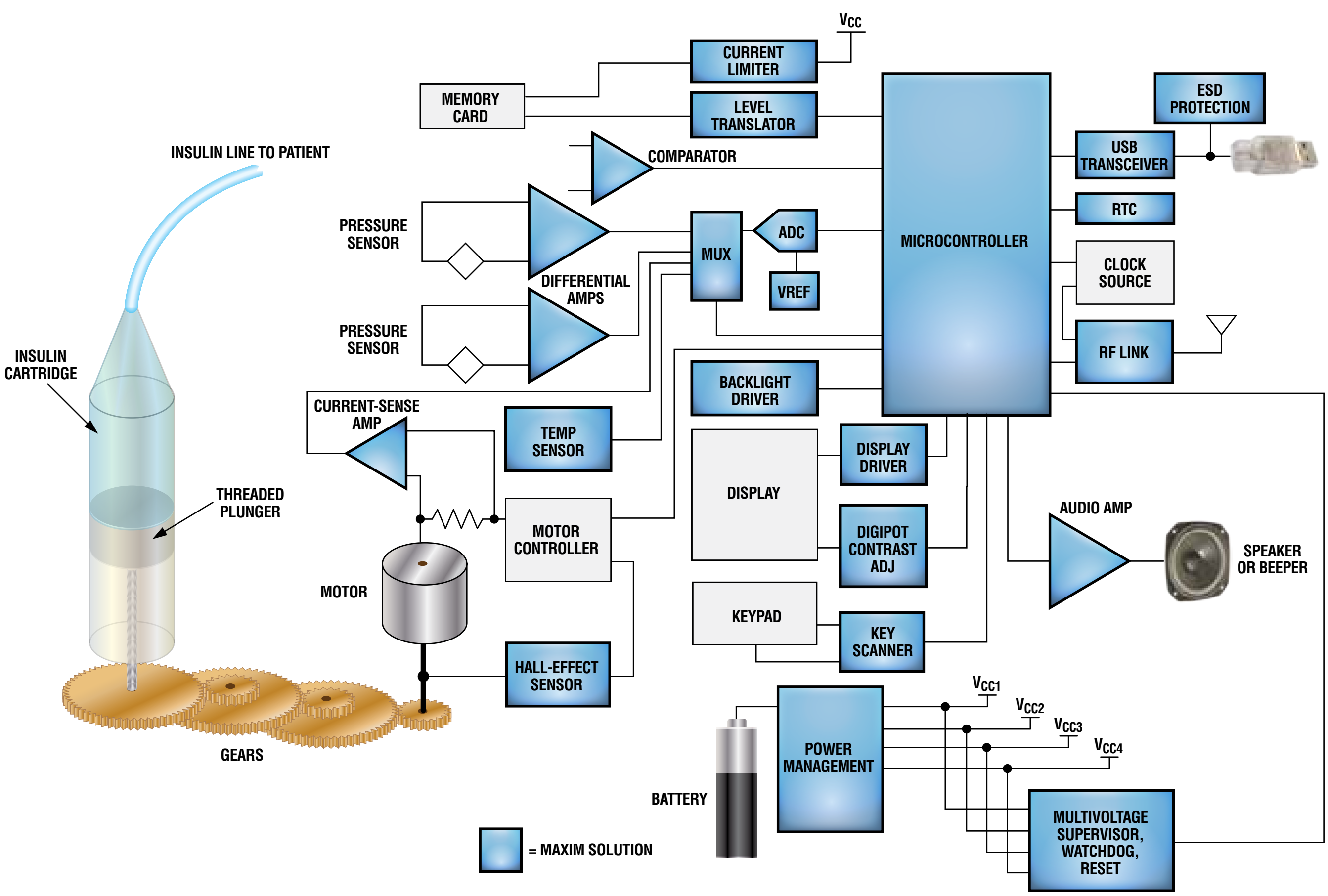
The insulin is contained in a user-replaceable cartridge held inside the pump. This reservoir is effectively a specialized syringe with a piston that is slowly pressed by the pump.

The cartridge output is connected to flexible tubing going to the patient's subcutaneous injection site, usually on the abdomen.

A related product for managing diabetes is a continuous blood glucose monitor. This device provides real-time glucose-level monitoring through a subcutaneous sensor. The sensor can be left in place for several days at a time, which reduces the need for the patient to test multiple individual blood samples. Future developments are expected to close the loop between these two systems by continuously monitoring the glucose level and, in response, automatically adjusting insulin dosage levels.

FDA-regulated medical equipment

Insulin pumps are portable medical equipment whose design and manufacture is regulated by the U.S. Food and Drug Administration (FDA). This means that their design and construction must follow precisely documented processes, and their performance must meet stringent documentation, development testing, production testing, and field maintenance requirements.



Functional block diagram of an insulin pump. For a list of Maxim's recommended solutions for insulin pumps, please visit: www.maxim-ic.com/insulin.

The equipment also must contain comprehensive self-test and fault-indication capabilities, which require additional circuitry and the use of components that include self-test features.

Given the time and expense required to achieve FDA approval, manufacturers must select a supplier with a customer-oriented discontinuance policy to ensure that system components will be available for many years.

Medical customers rely on Maxim products because over the years we have carefully avoided discontinuing parts. We realize how devastating product discontinuance can be to a customer, so we work diligently to transfer some products to newer production lines, create wafer buffers, allow last-time purchases, or develop upgrade devices. Very few Maxim parts have ever been discontinued while demand still existed. Maxim's Discontinuance Policy is one of the most flexible among our peer supplier companies.

Portability

Insulin pumps are wearable devices and, thus, must be very small and lightweight. They typically measure about 2in x 3in x 0.75in, and they weigh in the 2oz to 4oz range. These form-factor requirements lead designers to put size and power consumption as high priorities when selecting components.

To save space, system designers require highly integrated solutions and extremely small packages, such as UCSP™ and wafer-level packaging (WLP). To keep batteries as small as possible, designers must reduce power consumption and improve efficiency wherever possible. If possible, any circuitry that is not in use at any given time is shut down until needed.

Insulin pump solutions

Pump mechanism

Insulin is measured in "units" where there are 100 units per cc (or mL), assuming the standard U-100 concentration. This means that one unit is 10µL. Basal rates are on the order of one unit/hour administered every three to ten minutes, while bolus doses are several units. Typical cartridge volumes are 200 to 300 units.

Due to these ultra-low flow rates, the motor is geared down, and a screw drive is used to advance the cartridge piston very slowly with many revolutions of the motor. Consequently, only coarse angular measurements of the motor are needed. Most major insulin pump manufacturers use optical encoders and DC motors, although stepper motors can also be used. Other possible approaches include the use of MEMS-based pumps to miniaturize the system, or pressure pumps to eliminate motors and piston-based reservoirs.

Flow sensing

Pressure sensors are used to ensure normal operation and detect occlusions. Based on silicon strain gauges, these sensors provide signals in the millivolt range, rather than the microvolt level provided by bonded-wire strain gauges. The strain gauges use a typical bridge configuration, which provides a differential signal at a common-mode voltage that is roughly half of the supply voltage.

Designs will use either analog-to-digital converters (ADCs) with a differential programmable gain amplifier (PGA) input, or ADCs internal to the microcontroller with external differential or instrumentation amplifiers for signal conditioning. Precision pressure measurements are not needed since pressure readings are used for indicating normal operation and not for calculating drug delivery.

Power supplies

Insulin pumps typically use a step-up regulator to boost the low voltage (1.5V, nominal) from a single alkaline cell up to 2V or more. In order to get the most life from the cell, these boost regulators should run down to the lowest input voltage possible. Maxim offers regulators that can run down to 0.6V, with startup-voltage minimums as low as 0.7V, to maximize battery-capacity utilization.

In devices that require tightly regulated power-supply voltages, it may be necessary to regulate down from the boosted supply discussed above. Linear voltage regulators can be more efficient in extremely low-power applications, since they do not suffer from the switching losses of switch-mode power supplies. Buck regulators with skip mode will have good light-load efficiency; however, low-dropout linear regulators (LDOs) yield physically smaller solutions, which is very important in these pumps. LDO efficiency is very close to the ratio V_{OUT}/V_{IN}, so efficiency can be high if V_{IN} is fixed slightly above the LDO dropout-voltage specification.

If voltage regulation is required for the motor, system designers use switch-mode converters. To minimize size and weight, these converters should run as fast as possible. Power-management ICs (PMICs) can also be used to save space when multiple power-supply outputs are needed.

Battery management

Insulin pump manufacturers have made great strides in reducing power consumption to maximize battery life. Today's pumps can operate for three to ten weeks at a time before the batteries need to be replaced or recharged. Many pumps on the market use single AA or AAA alkaline or lithium batteries. Primary (nonrechargeable) cells are common, but secondary (rechargeable) cells can be used to save the patient long-term cost. Since secondary cells have lower capacities than primary cells, they provide reduced runtime between charges.

Given size constraints and the wide usage of primary cells, insulin pumps do not include battery chargers. Since there are not fuel gauges for primary cells, battery-life indicators rely on simple battery-voltage and, sometimes, temperature measurement. These readings of voltage and temperature will be sent to the ADC to be digitized. The microcontroller will process this data and use a lookup table to determine the remaining capacity within three or four bins. It will then drive the display, typically a battery symbol with a number of bars indicating remaining capacity. When down to the last bar, the insulin pump will issue a low-battery warning.

Programmability

As mentioned above, a sophisticated array of options is provided to users to tailor basal and bolus dosages to their needs. This is all done through a fairly simple interface using just a few keys for user inputs. Users can also set reminders to help manage insulin doses.

Displays/keyboards

Monochrome, custom alphanumeric, backlit liquid-crystal displays (LCDs) are commonly used, although some pumps use color screens. The display provides information about insulin dosages and rates, remaining battery life, time and date, reminders, and system alarm conditions (e.g., blockages or low-insulin reserves). Display self-test at power-up is an FDA requirement, so designers require drivers with built-in self-test features. Visible and audible response to user touch inputs is also usually needed.

Newer pumps include continuous monitoring displays. For these

systems, a separate continuous monitor with a radio transmitter measures and reports blood glucose levels to a sensor-enabled pump. The pump, in turn, displays trend information with graphical charting of glucose history to aid insulin dosage calculations.

Self-test

All insulin pumps must perform power-on self-test (POST) to meet FDA requirements. This includes tests of all critical processors, critical circuitry, indicators, displays, and alarm functionality. Some POST operations can require user observations, but additional circuitry is used for self-checking to reduce the risk of undetected failures.

For example, some models use a safety processor to monitor the performance of the main processor and generate an alarm if unexpected behavior is detected. Another example of self-test is the simple monitoring of current through light-emitting diodes (LEDs) as they are turned on and off. If currents fall outside the acceptable range, a fault is indicated. Probably the most common self-test is the watchdog timer (WDT). Microprocessor supervisors with WDT functions are commonly used to ensure that the processor executes within proper code boundaries. In medical devices it is usually not acceptable to have the supervisor on the same IC as the microprocessor, as this approach would subject the supervisor to the same transient errors as the microprocessor.

Supervisory functions are critical for ensuring that the pump is operating properly during patient use. Microcontrollers must be held in reset until all power supplies are within tolerance and stable. Power supplies are monitored with voltage supervisors for undervoltage and overvoltage conditions. Motor loading is monitored and motor-stall detection is needed. (Motor stall is a critical failure causing a top-priority alarm.) ADCs, either internal or external to the microprocessor, are needed to digitize sensor readings such as temperature, motor loading, insulin-line pressure, and battery voltage.

Alarms

Insulin pumps require audible and visible alarms to alert users when a fault is detected, a specific time arrives, or a warning condition is triggered. Individual LEDs can be used as visual indicators in glucose monitor remotes and insulin pumps. A flashing green LED usually indicates normal operation, while a red LED signals an alarm or warning.

The audio beeper must include a self-test feature, which can be implemented either indirectly by monitoring for a speaker impedance within range or directly by incorporating a microphone near the speaker to register the audio output and confirm that it is at the proper level. Designers commonly use a variety of operational amplifiers, comparators, audio amplifiers, microphone amplifiers, and other components to implement the alarm and self-test functions. Audio digital-to-analog converters (DACs) can be used to generate unique alarm outputs.

Newer pumps may also include an eccentric rotating mass (ERM) motor to implement a vibrating alarm. The drive to the ERM motor is not critical, but an amplifier or voltage regulator of some type might be used. The ERM should self-test at battery installation by spinning briefly.

Timekeeping

Due to the criticality of proper insulin dosing, pumps typically log and time stamp all activity and programming changes. A real-time clock (RTC) is required for this and, of course, for timer alarms.

Electrostatic discharge

All insulin pumps must pass IEC 61000-4-2 electrostatic discharge (ESD) requirements by either using electronics with built-in protection or by adding ESD line protectors to exposed traces. Maxim offers many interface parts with this high ESD protection built-in, as well as standalone ESD diode arrays.

Interfaces

Data ports are provided on most insulin pumps to allow data transfer to a computer and to download firmware upgrades. This allows history files to be pulled into application programs and sent to caregivers to aid in insulin therapy. USB interfaces are commonly used. These interfaces should include features such as ESD protection, current limiting, and logic-level translation for memory cards.

RF interface

As mentioned above, some pumps have RF receivers to obtain data from continuous glucose monitors. Most pumps will use either Bluetooth® or unlicensed-ISM-band receivers.

www.maxim-ic.com/insulin

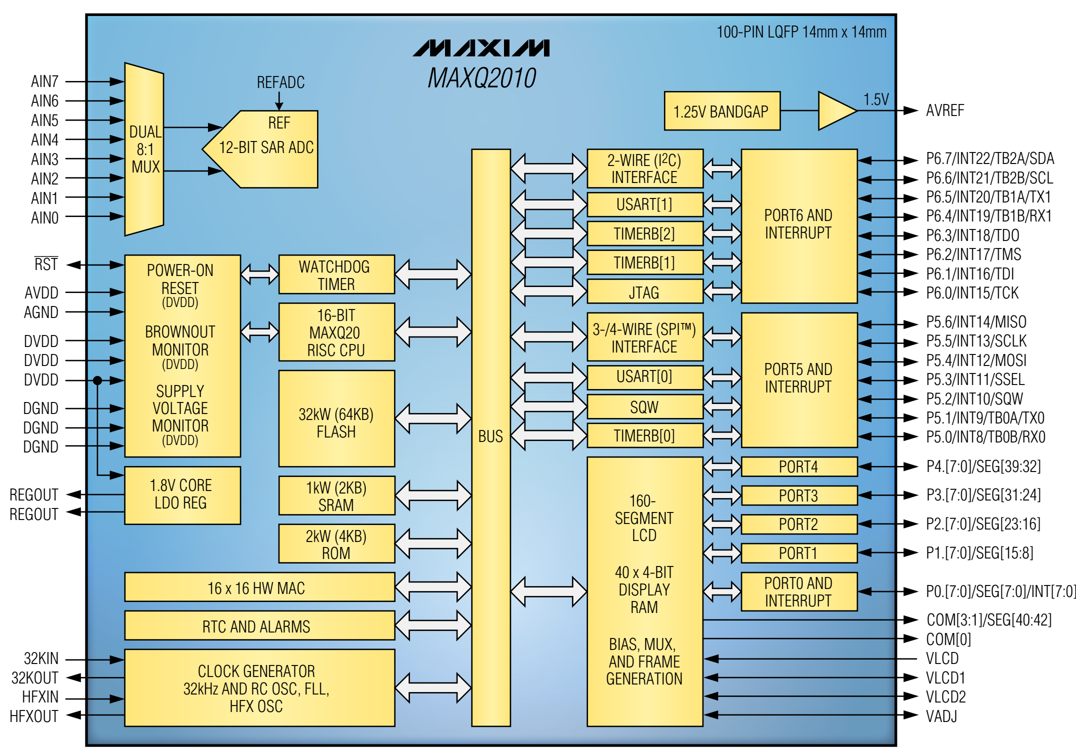
16-bit mixed-signal microcontroller with LCD interface combines low-power operation and an efficient core to achieve near 1MIPS/MHz performance

MAXQ2010

The MAXQ2010 is a low-power, 16-bit microcontroller that incorporates a high-performance, 12-bit, multichannel ADC and an LCD interface. A combination of high performance, low power, and mixed-signal integration makes this microcontroller ideal for portable medical devices. The MAXQ2010 has 64KB of flash memory, 2KB of RAM, three 16-bit timers, and two universal USARTs. For the best low-power performance, it offers a low-power sleep mode, the ability to selectively disable peripherals, and multiple power-saving operating modes.

Benefits

- **Low-power, highly efficient 16-bit MAXQ® RISC core increases battery life**
  - 1mA (typ) at 1MHz flash operation at 2.7V
  - Low-power operating modes: 370nA (typ) in stop mode
  - 33 instructions, most single cycle
- **Flexibility and scalability reduce design time**
  - Customer-requested memory size and LCD segments
  - Many peripherals (timers, serial interfaces, RTC, WDT, HMAC, etc.)
- **Fast wake-up from sleep and stop modes makes pump more responsive**
- **Fast ADC option when mated with high-resolution integrated AFEs for faster response**
  - 312.5ksps, 12-bit SAR ADC with reference and autoscan



Functional block diagram of the MAXQ2010.

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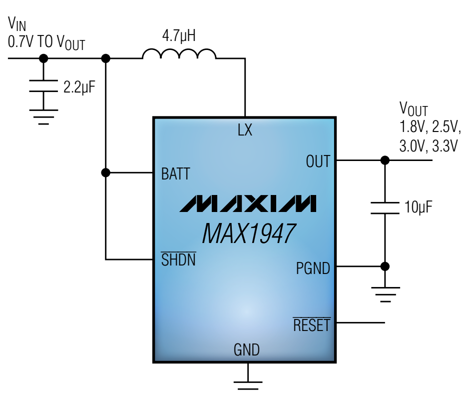
Tiny step-up voltage regulator extracts the most energy from a single alkaline cell

MAX1947

The MAX1947 is a step-up DC-DC converter with a low 0.7V to 3.6V input-voltage range. Its 2MHz switching current-mode control reduces component sizes, achieves over 94% efficiency, and yields fast transient response. It integrates all required switches (power switch, synchronous rectifier, and reverse-current blocker) to minimize solution size. True Shutdown™ circuitry allows the load to be discharged and disconnected from the battery during shutdown to maximize battery life.

Benefits

- **Get more energy from one or two alkaline cells for extended battery runtime**
  - Operation down to 0.7V (typ) input; startup guaranteed down to 0.95V
  - Synchronous switching yields 94% efficiency
  - Lossless cycle-by-cycle current sensing avoids sense resistor that would lower efficiency
  - Pulse-skipping mode increases light-load efficiency
  - True Shutdown circuitry prevents battery drain when in shutdown mode
- **Minimizes solution size**
  - Built-in power switches
  - No external compensation network required
  - Fast 2MHz switching frequency keeps external L's and C's small
  - RESET flag saves additional parts



Typical operating circuit for the MAX1947.

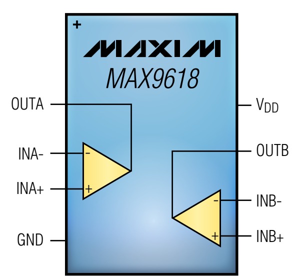
Precision op amps with high bandwidth-to-power ratio minimize power drain

MAX9617–MAX9620

The MAX9617–MAX9620 are zero-drift, rail-to-rail operational amplifiers designed for portable medical devices. These op amps have ultra-low input-offset voltage, input-bias current, and input-voltage noise; very high CMRR; and minimal 1/f noise. They are packaged in a 2mm x 2mm SC70 to save space in portable devices.

Benefits

- **High-efficiency solutions maximize battery life**
  - Low 59µA quiescent current while running on 1.8V supply voltage and delivering 1.5MHz GBW
  - Shutdown pin reduces power further when it is not needed
- **High-accuracy solutions improve system performance**
  - Low 10µV (max) input-offset voltage provides precision response to sensor signals, signal path filtering and gain stages, and ADC input conditioning
  - Ultra-low 10pA input-bias current provides high input impedance for sensors with low drive capability
  - Low input noise of $42nV/\sqrt{Hz}$ at 1kHz and $1\mu V_{P-P}$ from 0.1Hz to 10Hz keeps full signal-to-noise ratio of ADC
- **Ease of use**
  - Rail-to-rail input and output ease design-in for a wide range of signal-processing applications
  - Unity-gain stable expands use to voltage followers



Functional diagram of the MAX9618.

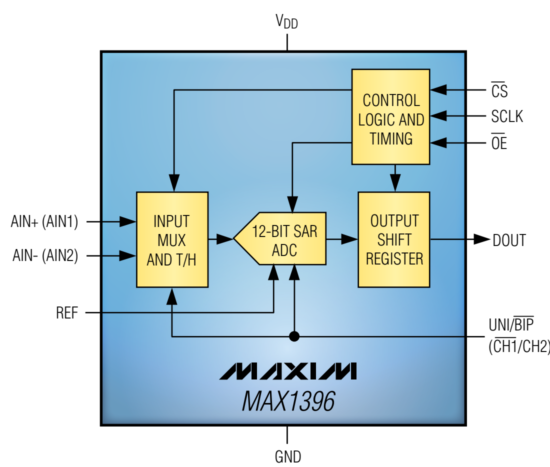
Low-power, dual 12-bit ADC extends battery life

MAX1396

The MAX1396 is a low-power, 2-channel, 12-bit ADC designed to conserve power in small-form-factor applications. An ultra-low supply range (1.5V to 3.6V) and excellent PSRR (±150µV/V, typ) allow operation directly from a battery without the need for a boost regulator. Automatic shutdown between conversions reduces power consumption; lower throughput rates can also be used to extend battery life.

Benefits

- **Low 1.5V to 3.6V supply range allows direct connection to battery power, which can eliminate a boost regulator**
  - Low-power operation saves battery life
  - 305µW at 100ksps
  - 3.1µW at 1ksps
- **Tiny package saves board space**
  - 3mm x 3mm, 10-pin TDFN



Simplified functional block diagram of the MAX1396.

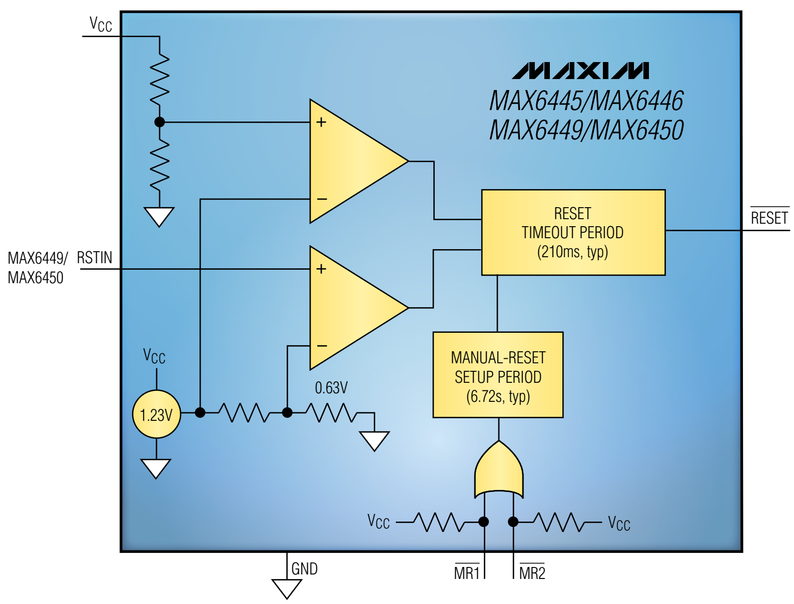
Microprocessor supervisors with dual manual-reset inputs for easy system reset

MAX6445/MAX6446/MAX6449/MAX6450

The MAX6445/MAX6446 (single) and MAX6449/MAX6450 (dual) are microprocessor supervisors with two manual-reset inputs. These supervisors provide an easy way for customers to force a hard reset, even if software is not running. An extended timeout setup period helps avoid accidental resets. All devices offer precision voltage monitoring down to 0.63V, and are immune to short voltage transients.

Benefits

- **Provide a guaranteed way to restart a stuck system without requiring a pinhole in the equipment case**
  - Dual manual-reset inputs with extended setup period (6.72s)
  - Operate even if the key scanner is not operating



Functional diagram of the MAX6445/MAX6446/MAX6449/MAX6450.

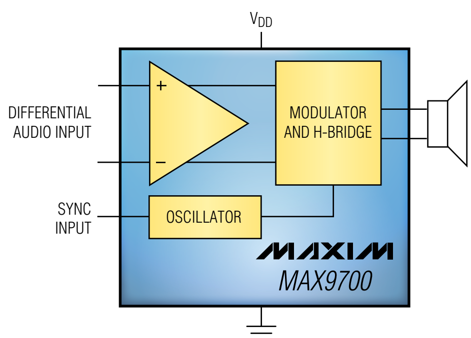
Mono, 1.2W, Class D audio amplifier saves power and space

MAX9700

The MAX9700 is a mono Class D speaker amplifier for portable applications. This device provides Class AB performance with Class D efficiency (up to 94%), and is capable of delivering 1.2W into an 8Ω load. Packaged in a 1.5mm x 2mm UCSP, the MAX9700 saves valuable board space in tight enclosures.

Benefits

- **Smallest available audio solution**
  - 1.5mm x 2mm x 0.6mm UCSP
  - No DC-blocking capacitors needed between IC and speaker
  - Filterless bridge-tied load (BTL) speaker connection reduces external components and overall solution size
- **High-efficiency operation prolongs battery life**
  - Class D architecture offers efficiencies up to 94%



Functional block diagram of the MAX9700.

Recommended solutions

Part	Description	Features	Benefits
ADCs			
MAX1228/MAX1229	12-bit, 12-channel, 300ksps SAR ADCs with serial interface	Internal reference	Save space for compact pump designs
MAX1162	16-bit, 200ksps SAR ADC with serial interface	10-pin µMAX® package, 10µA in shutdown	Saves space and reduces battery drain
MAX11605	8-bit, 12-channel, 188ksps SAR ADC with serial interface	Internal reference	Flexible interface reduces design time and saves space
MAX1396	12-bit, 2-channel, 312.5ksps SAR ADC with serial interface	1.5V to 3.6V supply, 305µW at 100ksps, 3.1µW at 1ksps, 3mm x 3mm package	Supply voltage range minimizes design size; low power consumption extends battery life
MAX1394	8-bit, 2-channel, 400ksps SAR ADC with serial interface	49dB SINAD, ±0.2 LSB (max) INL, 1.5V to 3.6V supply, 3mm x 3mm TDFN	Small package and serial interface reduce solution size; low power consumption extends battery life
MAX1115	8-bit, 100ksps SAR ADC with serial interface	400µW at 100ksps	Serial interface reduces solution size; low power consumption extends battery life
Amplifiers			
Audio amps			
MAX9700	Mono, 1.2W, Class D audio amplifier	Up to 94% efficiency, filterless operation, 1.5mm x 2mm UCSP	Extends battery life; minimizes solution size
MAX9718/MAX9719	Low-cost, mono/stereo, 1.4W differential audio power amplifiers	Differential input and output, fixed or adjustable gain, 2.7V to 5.5V supply, shutdown mode	Minimal external components for small solution; maximum audio output from low supply voltages
Current-sense amps			
MAX9918–MAX9920	Bidirectional current-sense amplifiers with wide -20V to +75V common-mode voltage	-40°C to +125°C temperature range, precision 400µV (max) V_{OS}, ±0.45% gain error, shutdown	High precision and shutdown allow small sense resistors, which reduce power loss and BOM cost; wide input range eliminates protection devices
MAX9928F/MAX9929F	Bidirectional current-sense amplifiers with wide 0 to 28V common-mode voltage	Precision 400µV (max) V_{OS}, ±1% gain error, sign output, current output, 1mm x 1.5mm UCSP	Sign output allows full use of ADC range; precision and small package reduce size and cost of solution
MAX9634	1µA, precision current-sense amplifier	28V (max) common-mode voltage, 250µV (max) V_{OS}, 1µA (max) quiescent current, small UCSP and SOT23 packages	Very low supply current reduces battery drain; tiny package reduces solution size
Instrumentation amps			
MAX4208/MAX4209	Precision instrumentation amplifiers with ultra-low offset/drift and REF buffer	20µV (max) V_{OS} with "zero drift," 1.4µA shutdown current, indirect-current-feedback architecture	Allow near-ground sensing with single supply, thus simplifying design
MAX4194–MAX4197	Micropower, three-op-amp instrumentation amplifiers	450µV (max) V_{OS}, 93µA quiescent current, adjustable and fixed (1, 10, 100V/V) gain versions	Shutdown function and low-current operation save power
Op amps			
MAX9617–MAX9620	High-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs	10µV (max) V_{OS} with "zero drift," 0.42µV_{P-P} noise, 59µA quiescent current, tiny 8-pin SC70	Improve measurement accuracy and reduce calibration requirements
MAX4475–MAX4478	Precision, low-distortion, 4.5nV/$\sqrt{Hz}$ op amps	750µV (max) V_{OS}, 10MHz op amps, 4.5nV/$\sqrt{Hz}$ noise, CMOS inputs, SOT23	Improve measurement accuracy when used for gain, filtering, or driving ADC inputs
Comparators			
MAX9060–MAX9064	Ultra-low-power single comparators	50nA/400nA comparators with and without internal 0.2V reference in space-saving UCSP	Save space and power; ideal for voltage-rail monitoring

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Digital potentiometers			
MAX5160/MAX5161	Low-power digital potentiometers in SOT23/μMAX package	32 tap positions, 2.7V to 5.5V supply	Enable digital calibration at low power to save battery life
Display drivers			
MAX6979	16-port LED driver with fault detection and watchdog	16 constant-current LED outputs, up to 55mA per output, ±3% matching, serial interface, reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
MAX6978	8-port LED driver with fault detection and watchdog	8 constant-current LED outputs, up to 55mA per output, ±3% matching, serial interface, reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
Hall-effect sensor interface			
MAX9921	Dual, 2-wire Hall-effect sensor interface with diagnostics	Withstands 60V voltage transients and ±15kV ESD spikes, built-in diagnostics, controlled ramp for Hall-effect sensor power	Integrated ESD and diagnostics increase product reliability while saving space
Interface ICs			
Current limiters			
MAX4995	50mA to 600mA adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
MAX14523	250mA to 1.5A adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
ESD protectors			
MAX3207E	2-channel, ±15kV HBM ESD protector	2.5pF, ±15kV HBM ESD protection	Increases reliability by protecting high-data-rate interfaces
MAX13204E	4-channel, ±30kV HBM ESD protector	6pF, ±30kV HBM ESD protection	Increases reliability by protecting high-data-rate interfaces
Logic-level translators			
MAX13030E	6-channel, high-speed logic-level translator	100Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 2mm x 2mm UCSP	Translates at high speeds while offering ESD protection; ideal for memory card applications
MAX13101E	16-channel logic-level translator	20Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 3mm x 3mm WLP	Integrates level translation with ESD protection in a space-saving package
Transceivers			
MAX3456E	±15kV ESD protected USB transceiver	Full-/low-speed USB, integrated ESD on D+/D- lines	Increases reliability by protecting high-data-rate interfaces
MAX3349EA	Full-speed USB transceiver with UART multiplexer	Full-/low-speed USB, integrated ESD on D+/D- lines	Increases reliability and reduces size by functionally sharing a USB connector
Keyboard scanners, touch-screen controller			
MAX7359	2-wire-interfaced, low-EMI key-switch controller/GPO	Monitors up to 64 keys, low-voltage design, key debounce, key-release detection	Simplifies software; frees up microcontroller I/O
MAX7349	2-wire-interfaced, low-EMI key-switch and sounder controller	Monitors up to 64 keys, low-voltage design, key debounce, integrated sounder controller	Simplifies software; frees up microcontroller I/O
MAX7347	2-wire-interfaced, low-EMI key-switch controller	Monitors up to 24 keys, low-voltage design, key debounce	Simplifies software; frees up microcontroller I/O

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Keyboard scanners, touch-screen controller (continued)			
MAX11811	4-wire touch-screen controller with integrated haptic motor driver	12-bit ADC, I^2C interface, proximity driver, automatic power down	Reduces processor burden; extends battery life
Microcontrollers			
MAXQ2010	Low-power, 16-bit mixed-signal LCD microcontroller	8-channel, 12-bit SAR ADC; 64KB flash; supply voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current	Powerful, integrated microcontroller saves space in battery-powered applications
MAXQ8913	16-bit mixed-signal microcontroller	7-channel, 12-bit SAR ADC; 64KB flash; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Single chip integrates multiple functions to minimize solution size
MAXQ2000	Low-power, 16-bit LCD microcontroller	20MHz operation, 64KB flash, hardware multiplier, 132-segment LCD controller, 32-bit RTC, 700nA stop-mode current	High integration saves board space; low-power architecture extends battery life
MAXQ610	Low-power, 16-bit IR microcontroller	1.7V to 3.6V supply, up to 32 GPIOs, IR module, ring oscillator, wakeup timer, 200nA stop-mode current	Extends battery life
MAXQ622	Low-power, 16-bit IR microcontroller	1.7V to 3.6V supply, 128KB flash, USB 2.0 transceiver, IR module, up to 52 GPIOs	Extends battery life
Power supplies			
MAX1947	Boost regulator for single alkaline battery input	Low 0.7V input, internal synchronous switches, 2MHz switching, 94% efficiency, True Shutdown, reset flag	Harvests more energy from alkaline cells; high efficiency further extends battery life
MAX8902A	Low-noise, 500mA LDO in 2mm x 2mm TDFN	$16\mu V_{RMS}$; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, and temperature; shutdown mode; soft-start	Low noise and high accuracy enable optimal performance from sensitive analog circuits
MAX1565	Five-output power-supply IC	Five switching regulators at 1MHz; 1µA in shutdown; supplies for motor, main, core, and LCD from supply down to 0.7V	Complete power-management solution in one IC reduces size
Real-time clocks			
DS1394	SPI RTC with trickle charger	Provides hundredths of a second to years information, trickle charger for coin-cell backup, UL® recognized, SPI bus to 4MHz, alarm	Provides accurate time stamps of system usage events
DS1388	I^2C RTC with trickle charger	Provides hundredths of a second to years information, UL recognized, I^2C bus, supervisor with watchdog, 512 bytes of EEPROM	Provides accurate timing while saving space by integrating multiple functions
RF solutions			
Transceivers			
MAX7030	Low-cost, factory-programmed ASK/OOK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm package, no programming interface required	Long battery life; smaller size; faster and simpler product design
MAX7031	Low-cost, factory-programmed FSK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm package, no programming interface required	Long battery life; smaller size; faster and simpler product design
MAX7032	Low-cost, frequency-programmable ASK/FSK/OOK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm package, fully programmable from 300MHz to 450MHz	Long battery life; smaller size; maximum flexibility

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Transmitters			
MAX1472	Low-power, 300MHz to 450MHz, crystal-based ASK transmitter	Wide frequency range, low-current operation, 3mm x 3mm package	Compact ASK transmitter for both North America and Europe offering crystal stability and long battery life
MAX1479	Low-power, 300MHz to 450MHz, crystal-based ASK/FSK transmitter	Wide frequency range, low-current operation	ASK/FSK transmitter for both North America and Europe offering crystal stability and long battery life
MAX7057	300MHz to 450MHz, crystal-based ASK/FSK transmitter	Wide frequency range, programmable synthesizer, antenna-matching network	Efficiently transmits any frequency in the 300MHz to 450MHz band using a single crystal
Receivers			
MAX1471	Programmable 300MHz to 450MHz ASK/FSK receiver	High sensitivity, built-in image rejection, and separate ASK/FSK data paths in a 5mm x 5mm package	Provides extended range while reducing cost
MAX1473	300MHz to 450MHz ASK receiver with AGC	High sensitivity, AGC, and built-in image rejection in a 5mm x 5mm package	Offers a compact, low-cost ASK solution with longer range
MAX7042	300MHz to 450MHz FSK receiver	Best FSK sensitivity and built-in image rejection in a 5mm x 5mm package	Provides a compact, low-cost FSK solution with longer range
Switch/multiplexer			
MAX4781	High-speed, low-voltage, 0.7Ω analog multiplexer	Excellent on/off performance up to 10MHz, 8:1 configuration, 1.6V to 3.6V supply	Wide operating range allows use in many applications
Temperature sensors			
DS600	±0.5°C accurate analog-output temperature sensor	Industry's most accurate analog temperature sensor: ±0.5°C accuracy from -20°C to +100°C	Improves system temperature-monitoring accuracy and is easy to design with
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
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C, 1.7V to 3.7V operation, industry-standard pinout and registers	Industry-standard pinout facilitates migration from LM75 to lower supply voltage
DS18B20	±0.5°C accurate, 1-Wire® digital temperature sensor	±0.5°C accuracy, 1-Wire interface, unique 64-bit serial number	Simplifies interface when deploying multiple distributed precision sensors
MAX6612	Small, low-power, analog temperature sensor	19.5mV/°C slope, ±3°C accuracy from 0°C to +70°C, SC70 package, 35µA (max) quiescent current	Small, low-power solution
Voltage references			
MAX6006	Precision shunt voltage reference in SOT23	Ultra-low operating current (1µA), ±0.2% accuracy, wide operating range (1µA to 2mA)	Ultra-low operating current saves battery life
MAX6018	Precision, micropower, 1.8V supply, low-dropout, series voltage reference in SOT23	1.263V to 2.048V V_{OUT}, ±0.2% to ±0.4% accuracy, 5µA quiescent current	Low operating current extends battery life
MAX6023	Precision, low-power, low-dropout, series voltage reference in ultra-small UCSP	1.25V to 5V V_{OUT}, ±0.2% accuracy, 1mm x 1.5mm x 0.3mm package	Smallest size fits in space-constrained designs
MAX6034	Precision, micropower, series voltage reference in small SC70	±0.2% accuracy, 30ppm/°C, 90µA quiescent current, 2.048V to 4.096V V_{OUT}	Small SC70 package eases layout

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage supervisors			
MAX6381	Single-voltage supervisor	Multiple thresholds and timeout options in tiny µDFN package; only a few external components	Small µDFN and few external components save space
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable threshold, small SOT23 package	Integrates three voltage monitors into one space-saving package
MAX16062	Octal-voltage supervisor	Fixed and adjustable thresholds and timeouts; margin-enable and tolerance-select inputs; watchdog timer	Breadth of features and options provides flexibility to meet many design needs
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing, 3.7µA quiescent current	Easy to adjust timing to system requirements
MAX6816–MAX6818	Single, dual, and octal switch debouncers	±15kV ESD protection	High reliability; easy to use
MAX6445/MAX6446	Single µP reset ICs with two manual-reset inputs	Two manual-reset inputs with extended setup period (6.72s), precision voltage monitoring down to 0.63V	Avoid nuisance resets; eliminate the need for a pinhole in the equipment case
MAX6449/MAX6450	Dual µP reset ICs with two manual-reset inputs	Two manual-reset inputs with extended setup period (6.72s), precision voltage monitoring down to 0.63V	Avoid nuisance resets; eliminate the need for a pinhole in the equipment case

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

Visit digikey.com

Blood pressure monitors

Overview

A blood pressure monitor, or sphygmomanometer, uses an inflatable air-bladder cuff and a listening device or pressure sensor to measure blood pressure in an artery. This monitoring can be performed by using either of two methods: a manually inflated cuff with a stethoscope for listening to arterial wall sounds (the auscultatory method), or a blood pressure monitor that contains a pressure sensor for sensing arterial wall vibrations (the oscillometric method).

Automatic monitor types

The two main types of automatic blood pressure monitors are upper-arm and wrist models. The upper-arm model has a cuff that is placed on the upper arm; the cuff is connected by a tube to the monitor that rests on a surface near the arm. The wrist model is smaller and the entire unit wraps around the wrist—this is a much more space-critical design. Some upper-arm models require manual inflation of the cuff, but most upper-arm and all wrist models have fully automatic inflation.

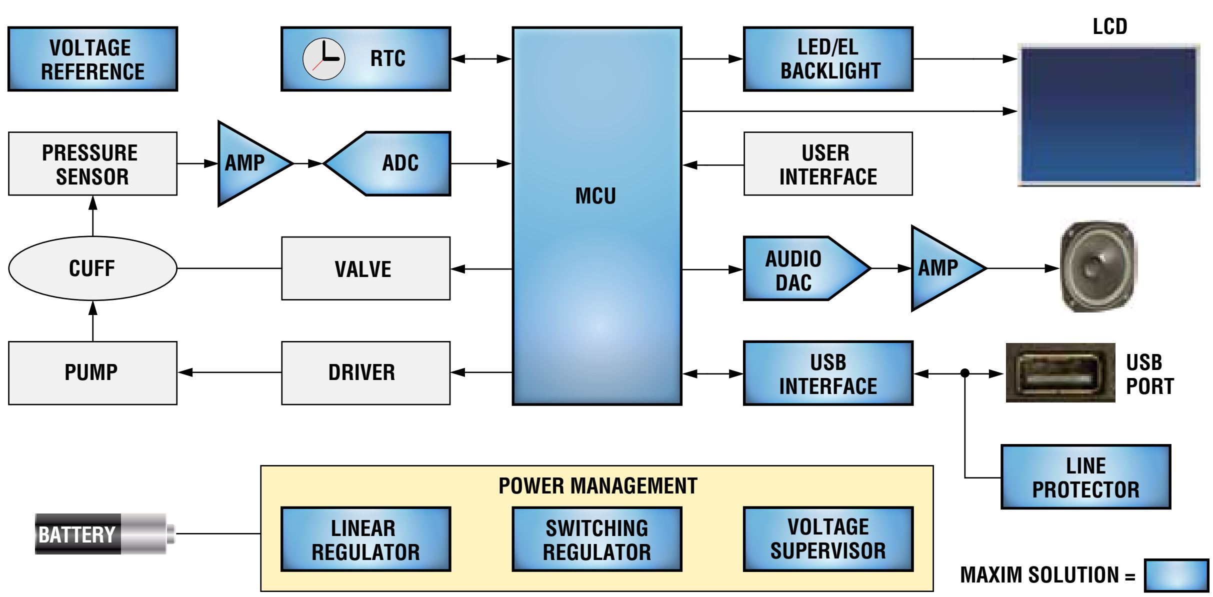
Measurement techniques

An automatic blood pressure monitor inflates a cuff surrounding an arm with sufficient pressure to prevent blood flow in the local main artery. This pressure is gradually released until the moment that the blood begins to flow through the artery, the measurement of which determines the systolic pressure. Pulse rate is also sensed at this time. The measurement taken when the blood flow is no longer restricted determines the diastolic pressure. This complete measurement cycle is performed automatically with a pump, cuff, valve, and pressure sensor.

The signal from the pressure sensor is conditioned with an op-amp circuit or by an instrumentation amplifier before data conversion by an analog-to-digital converter (ADC). The systolic pressure, diastolic pressure, and pulse rate are then calculated in the digital domain using a method

Upper-arm blood pressure monitor

Wrist blood pressure monitor



Functional block diagram of a blood pressure monitor that includes an advanced voice indicator. For a list of Maxim's recommended solutions for blood pressure monitor designs, please go to: www.maxim-ic.com/bloodpressure.

appropriate for the type of monitor and sensor utilized. The resulting systolic, diastolic, and pulse-rate measurements are displayed on a liquid-crystal display (LCD), time/date-stamped, and stored in non-volatile memory.

Data interface

Some blood pressure monitors have the ability to upload data to a computer for further analysis and tracking of measurements over time. This data transfer is usually done through a USB interface. A discrete USB transceiver can provide this functionality, or it can be integrated within the microcontroller.

Audio indicators

Audible indicators in blood pressure monitors range from simple beepers to more advanced audio output. A simple beeper can be driven by one or two microcontroller port pins that have pulse-width modulation (PWM) capability. More advanced voice indicators can be achieved by adding an audio digital-to-analog converter (DAC) and speaker amplifier.

Power management

Upper-arm monitors typically use four AAA (1.5V) alkaline batteries and wrist monitors typically use two AAA alkaline batteries. The monitor's pump and analog circuitry require a 5V or 3.3V supply and the digital circuitry needs a 3.3V or 1.8V supply, depending on the technology used. Consequently, a typical upper-arm monitor would need a buck-boost switching regulator to regulate the pump/analog supply voltage to 5V and a low-dropout linear regulator (LDO) for the 3.3V digital requirement. The typical wrist monitor would use a boost switching regulator to step up the pump/analog supply voltage to 3.3V and an LDO for the 1.8V digital supply.

To extend battery life, powering down the switching regulators may be possible while the monitor is off, as long as the real-time clock (RTC) keeps running and the monitor can easily be turned back on.

Display and backlighting

Blood pressure monitors use a simple LCD with 100 segments or less that can be driven by a driver integrated within the microcontroller. Backlighting can be added by using 1 or 2 white LEDs (WLEDs) or an electroluminescent (EL) source. A discrete WLED driver can easily be added to a monitor design by using a switching topology for wrist monitors and a linear topology for upper-arm monitors.

Electrostatic discharge

All monitors must pass IEC 61000-4-2 electrostatic discharge (ESD) requirements. Using circuitry with built-in ESD protection or adding ESD line protectors to exposed traces can help meet these requirements.

www.maxim-ic.com/bloodpressure

Low-dropout, 150mA linear regulators enable low-cost solutions

MAX8891/MAX8892

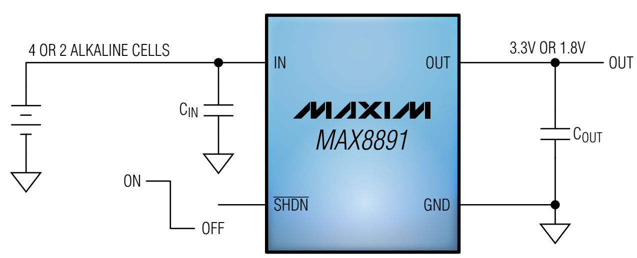
The MAX8891/MAX8892 LDOs are designed to deliver up to 150mA continuous output current, and achieve a low 120mV output dropout for a 120mA load current. Due to an integrated p-channel MOSFET, these regulators maintain a very low, 40µA ground current. Quiescent current is further reduced to less than 1µA in shutdown mode.

The MAX8891 only requires one input and one output capacitor, hence achieving the smallest PCB solution area. Both LDOs are designed and optimized to work with low-value, low-cost ceramic capacitors—they require only 1µF (typ) of output capacitance for stability with any load.

The MAX8891/MAX8892 provide overcurrent and thermal protection, as well as excellent load/line transient response. The MAX8891 is preset to 10 specific voltages in the 1.5V to 4.5V range, while the MAX8892's output voltage can be adjusted with an external divider.

Benefits

- **Reduce system cost**
  - Stable with low-cost, 1µF ceramic capacitor for any load
  - Overcurrent and thermal protection
- **Extend battery life**
  - Low 40µA quiescent ground current
  - Low 1µA (max) shutdown current
- **Save board space**
  - Tiny, 2mm x 2.2mm, 5-pin SC70 package
  - Needs only one input/output capacitor (MAX8891)



Typical application circuit for the MAX8891, showing the voltage regulation provided for the digital circuitry in a blood pressure monitor. Also apparent is the need for only one input capacitor and one output capacitor.

Tiny, 1.7V to 5.5V, 32-bit binary counter watchdog clock saves space and cost in low-power applications

DS1371

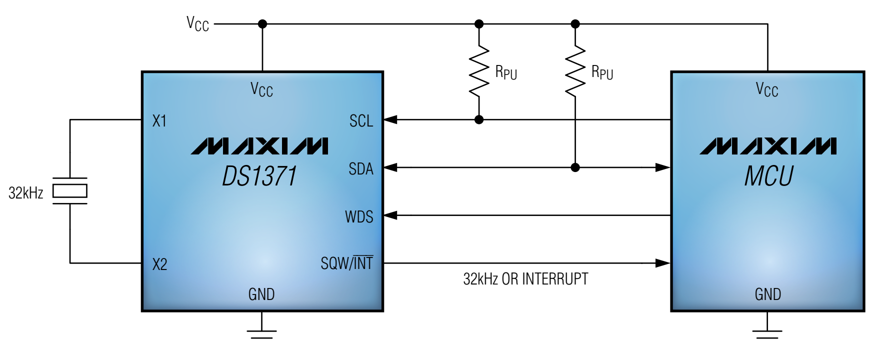
The DS1371 is a tiny, 32-bit binary counter that is designed to continuously count time in seconds. It saves space and cost by sharing a 32kHz crystal with the microcontroller, thus eliminating the need for the microcontroller to have its own crystal.

Though only 14.9mm², the DS1371 includes an additional counter that can generate a periodic alarm, be enabled to serve as a watchdog timer, or be disabled for use as 3 bytes of general-purpose RAM. The DS1371 also integrates a configurable output that can be used as an interrupt or to provide a square wave at one of four selectable frequencies.

The DS1371 is programmed serially or can read data through an I²C bidirectional bus. It typically operates from 1.7V to 5.5V, though the internal oscillator requires as little as 1.3V for timekeeping when it consumes only 800nA.

Benefits

- **Reduces system cost**
  - Programmable square-wave output eliminates need for second crystal
  - Integrated watchdog timer
- **Extends battery life**
  - Operates from 1.7V to 5.5V, and down to 1.3V for timekeeping
  - Ultra-low 800nA timekeeping current
- **Saves board space**
  - Tiny, 3mm x 4.9mm, 8-pin µSOP package
  - Shares 32kHz crystal with microcontroller



Typical application circuit for the DS1371 shows how the device drives the clock signal to the microcontroller through its square-wave output.

Heart-rate/fitness monitors

Overview

Fitness monitors track and record physical activity with the goal of improving a person's physical fitness. This is done by sensing or measuring a number of parameters such as heart rate, temperature, distance, and time. A wristwatch device collects the information to display to the user. A heart-rate chest strap measures pulse and sometimes temperature, provides conditioning of the cardiac signal before data conversion, and wirelessly transmits the data to the wristwatch display. An optional foot-pod shoe insert measures a runner's cadence to determine the distance traveled, and it wirelessly transmits that data to the wristwatch display. Some fitness monitors use GPS to measure the distance traveled, eliminating the need for a foot pod.

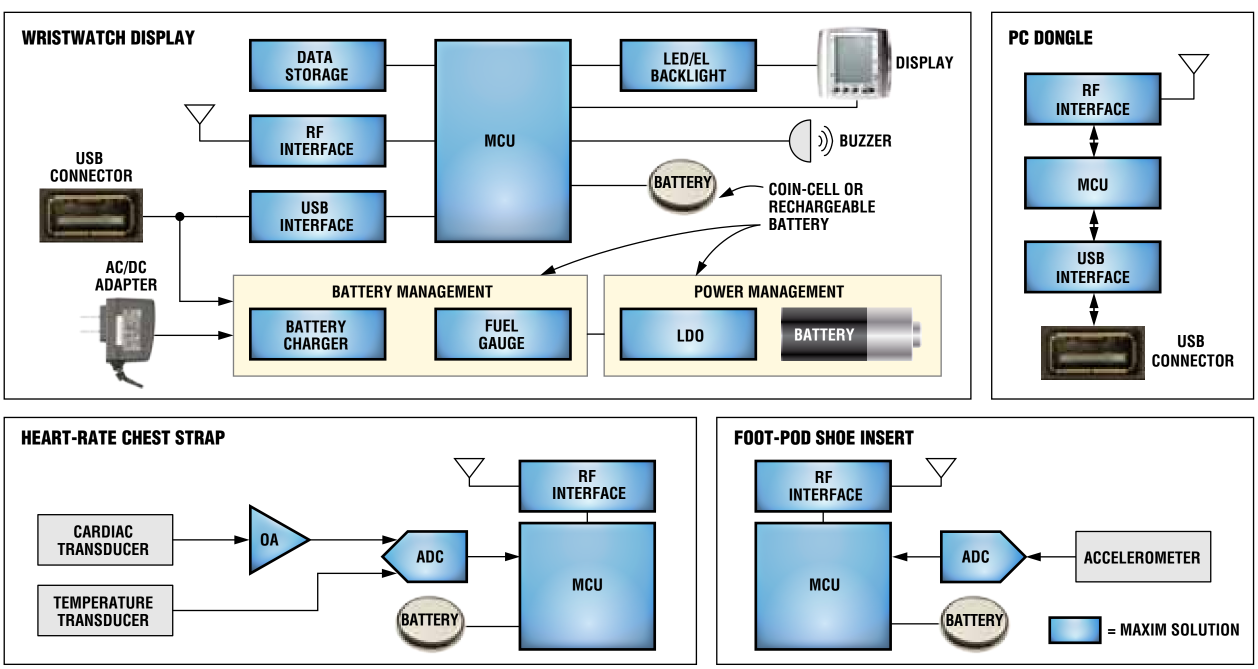
Heart-rate fitness monitor

Design parameters

The wristwatch monitors the workout in real time and records the results in an onboard memory device or within the MCU. It uploads this data to a PC using a USB cable or wirelessly through a dongle plugged into a USB port on the PC.

The RF transmitters need to be low power because they are powered by small batteries and because of FCC regulations. The low transmitter power means that good antenna design is critical for reliable data transfer, even though the transmit distance is typically less than two meters. ASK transmission is recommended for this application because it offers better sensitivity than FSK and, thus, enables lower power transmission. Minimizing the transmit time with a low duty cycle and powering down the transmitter in between each transmission can save additional power.

All the individual elements of the fitness monitor, except for the PC dongle, are worn by the user and are battery powered. Thus, small size and low power are critical design parameters. The heart-rate chest strap and foot-pod shoe insert are usually powered by a primary coin-cell battery. The wristwatch display can be powered either by a primary coin-cell or a rechargeable battery, which is charged through an AC adapter or USB cable. A simple-segment LCD with an optional backlight is used for the wristwatch display.



Functional block diagram of a heart-rate/fitness monitor. For a list of Maxim's recommended solutions for heart-rate/fitness monitors, go to the solutions page below.

www.maxim-ic.com/heartrate

Visit digikey.com

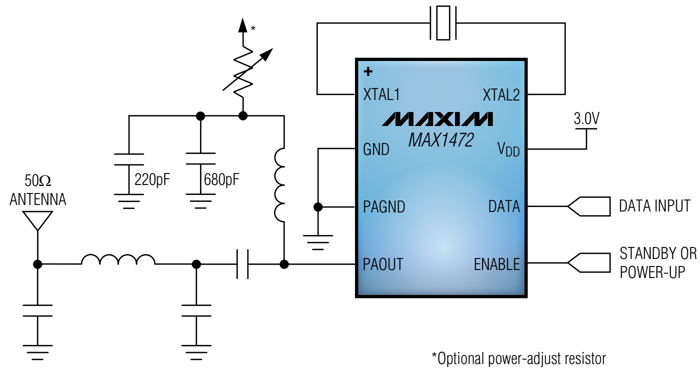
Batteries go the extra mile with the industry's smallest 300MHz to 450MHz transmitter

MAX1472

The MAX1472 is a crystal-referenced phase-locked loop (PLL) VHF/UHF transmitter designed to transmit OOK/ASK data in the 300MHz to 450MHz frequency range. The device supports data rates up to 100kbps, and delivers an adjustable output power of more than +10dBm into a 50Ω load. The crystal-based architecture of the MAX1472 eliminates many of the common problems with SAW transmitters by providing greater modulation depth, faster frequency settling, higher tolerance of the transmit frequency, and reduced temperature dependence. The MAX1472 is available in a 3mm x 3mm 8-pin SOT23 package

Benefits

- **Long battery lifetime**
  - 2.1V to 3.6V operation
  - 5.3mA (typ) operating current at +10dBm
  - Adjustable output power
  - 5nA (typ) standby current
  - Fast 220μs startup time
- **Small and simple to use**
  - 3mm x 3mm 8-pin SOT23 package
  - Few external components
  - No registers to program
- **Provides stable and reliable communication**
  - Crystal-based clock
- **Global application**
  - One product covers Europe, North America, and other countries using the 300MHz to 450MHz band



Typical operating circuit for the MAX1472 in an RF transmitter application.

Digital thermometers

Overview

A medical thermometer measures the temperature of the human body over a small temperature range centered around 37°C. Digital thermometers have been replacing mercury stick thermometers over the past 10 to 15 years due to new technologies that provide faster, more convenient measurements and also the environmental hazard of mercury in legacy thermometers. Probe and ear types are the two main digital thermometers on the market, with temple and forehead types emerging as other alternatives. The probe type is used in the same way as a traditional mercury stick thermometer and measures oral, rectal, or sometimes armpit temperatures. The ear type is a noncontact thermometer and measures the infrared energy radiated from the ear canal. The temple and forehead types are usually contact thermometers and measure the infrared energy radiated from the temple or forehead to determine body temperature.

Probe-type digital thermometer

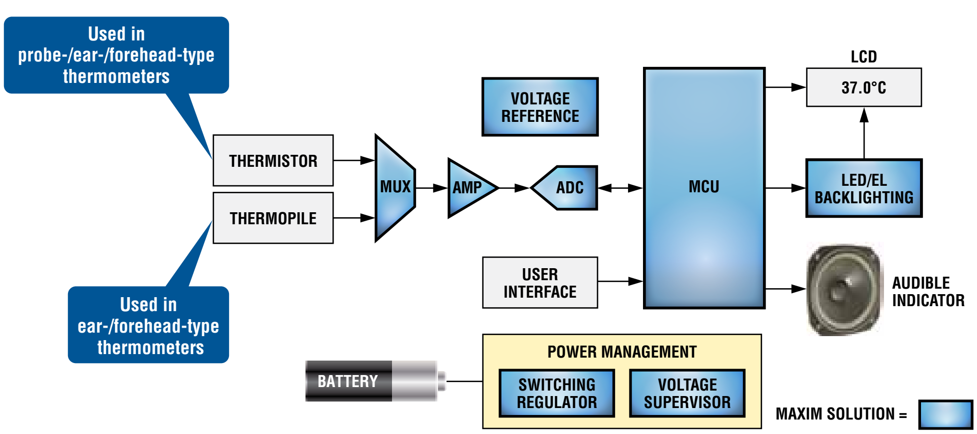
Ear-type digital thermometer

Forehead-type digital thermometer

Measurement

Probe-type thermometers usually use a thermistor in the probe tip to measure the temperature. A thermistor is a resistor whose resistance varies with temperature. A voltage-divider, composed of a thermistor in series with a precision resistor, is driven by a reference voltage and measured either single-ended at the midpoint or differentially across the thermistor. Additional precision resistors are sometimes used along with the same reference voltage in a separate circuit to eliminate errors caused by the reference voltage drifting over time. If the thermistor-divider circuit and the analog-to-digital converter (ADC) use the same reference voltage, then the precision calibration resistors are not needed. In such a case, the reference voltage is eliminated from the temperature calculation, thus easing the reference requirements.

A thermistor requires a calculation involving a natural log, which can consume a lot of computational cycles and code space in the microcontroller. Alternatively, a lookup table can be used to calculate the temperature, an approach that usually results in a faster calculation



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

and more compact code. However, there is a trade-off between the size of the table and the interpolation error between table entries where increasing the number of points in the table will decrease the interpolation error. An ADC with 12 bits or more is sufficient for this measurement, and a gain stage is optional depending on the measurement range and desired accuracy.

Ear-type thermometers use thermopiles and thermistors to measure the temperature. A thermopile is composed of a number of thermocouples connected in series to increase the output voltage. Thermopiles generate an output voltage proportional to the energy absorbed. They use the principle of black body radiation, whereby any object above absolute zero will radiate energy; in this case, the infrared spectrum is being measured. The infrared radiation from the ear canal is focused and directed onto a thermopile, the low-level voltage output of which is amplified and converted by an ADC with 12-bit resolution or more. The thermistor measures the cold-junction temperature of the thermopile, and both the thermopile and thermistor measurements are used to calculate the body temperature.

Temple- and forehead-type thermometers use the same technology to measure infrared radiation as ear-type thermometers—they just measure it from a different location on the body. A specialized forehead thermometer, called a temporal thermometer, measures the temperature of the temporal artery in the forehead and the ambient temperature, and then uses these temperatures to calculate the body temperature.

Digital thermometers are much faster than mercury thermometers. Sometimes, the thermistor is preheated so that it gets to the final temperature faster. Often, predictive algorithms are used to determine the temperature. Instead of waiting for the temperature sensor to settle completely, the algorithm predicts what the final temperature will be based on the response during the beginning of the measurement cycle and the characteristics of the thermistor.

Power management

Probe-type thermometers typically use a coin-cell battery or two button-cell batteries, and ear-type thermometers usually use a coin-cell battery or two AAA alkaline batteries. Both thermometer types can run either directly from the battery or from a step-up switching regulator, depending on the circuitry chosen.

Some forehead-type thermometers use 9V transistor batteries, thus requiring a step-down switching regulator or linear regulator. Low shutdown current and the ability to turn the switching regulator off when not in use are critical to long battery life in this application. A voltage supervisor can monitor the battery and provide a reset to the microcontroller if the battery falls below the microcontroller's safe operating voltage. Additionally, an extra input to the ADC can measure the battery so that the user is given a warning that the battery will soon need to be replaced.

Audible indicators

Audible indicators are used to indicate when the thermometer is ready to be used and/or when the measurement is complete. This is usually a beeper or buzzer driven either single-ended or differentially from a microcontroller's timer outputs.

Display and backlighting

All digital thermometers use a simple LCD display that can be driven by a microcontroller with an integrated driver. Backlighting can be implemented by using either a single white LED (WLED) driven by a discrete LED driver or an electroluminescent (EL) sheet and driver.

www.maxim-ic.com/thermometer

1.5V to 3.6V, 1- or 2-channel, 12-bit ADCs extend battery life, reduce system cost, and save board space

MAX1393/MAX1396

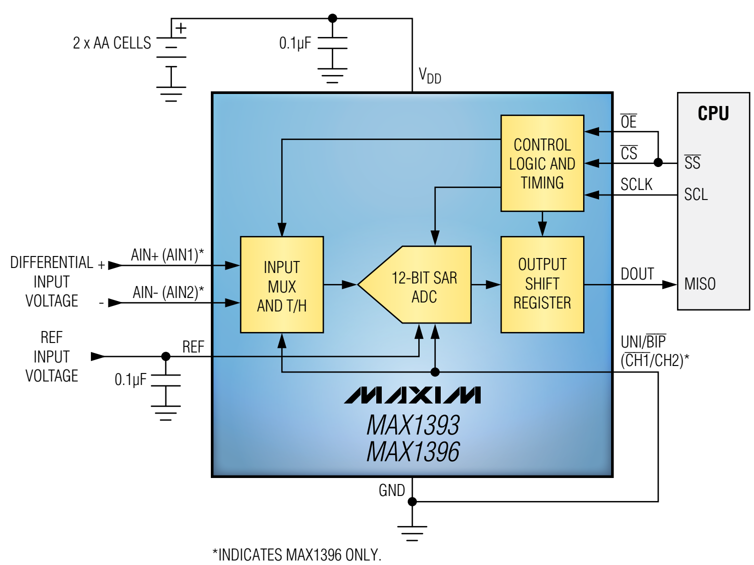
The MAX1393/MAX1396 micropower, serial-output, 12-bit ADCs operate from a single 1.5V to 3.6V power supply. These ADCs feature automatic shutdown, fast wake-up (600ns), and a high-speed (up to 5MHz) 3-wire interface. Power consumption is only 0.734mW (V_{DD} = 1.5V) at the maximum conversion rate of 312.5ksps. AutoShutdown™ between conversions reduces power consumption at slower throughput rates.

Both ADCs require an external reference (V_{REF}) with a wide range from 0.6V to V_{DD}. The MAX1393 provides one true-differential analog input that accepts signals ranging from 0 to V_{REF} (unipolar mode) or $\pm V_{REF}/2$ (bipolar mode). The MAX1396 provides two single-ended inputs that accept signals ranging from 0 to V_{REF}.

Excellent performance, low voltage, low power, flexible interface, and small package size make these converters ideal for portable battery-powered applications, as well as any applications that demand low power consumption and minimal space.

Benefits

- **Extend battery life**
  - 1.5V to 3.6V supply voltage operation
  - 3.1μW at 1ksps and 1.8V supply voltage
  - AutoShutdown between conversions
  - < 1μA shutdown current
- **Reduce system cost**
  - Running directly off battery eliminates need for power supply
  - Flexible interface allows use with any MCU or DSP
- **Save board space**
  - Small, 3mm x 3mm, 10-pin TDFN package
  - Needs only minimal external components (two ceramic capacitors)



MAX1393/MAX1396 typical operating circuit.

Hearing aids

Overview

An electronic hearing aid is a small device placed in or around the ear to improve the hearing of those with hearing loss. The basic components of a hearing aid are a microphone, signal conditioning, a receiver also known as a speaker, and a battery. The microphone converts the sound into an electric signal. The signal then undergoes conditioning that can be as simple as amplifying all of the sound equally, to more advanced equalization involving a digital signal processor (DSP). The receiver converts the electronic signal back to sound, and the battery powers the electronics.

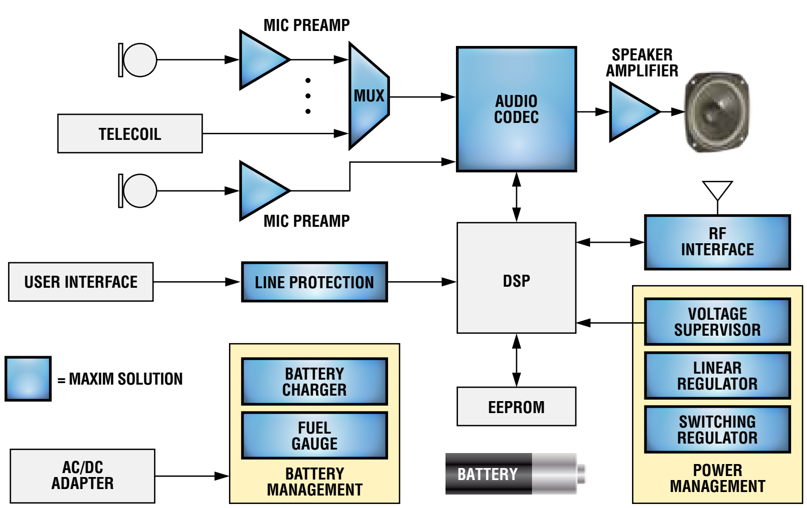
Styles

There are four main styles of hearing aids on the market today. From largest to smallest, they are behind the ear (BTE), in the ear (ITE), in the canal (ITC), and completely in the canal (CIC). The BTE style sits behind the ear with a clear tube going to an earmold in the ear to deliver the sound. A variation on this style is called an open-fit-behind-the-ear (OTE) where the earmold is replaced by a small tip, resulting in a more open feeling. Other variations include replacing the tube with wires and moving the receiver from the behind the ear to inside the ear. The ITE style moves the hearing aid into the outer ear, where it becomes a single unit with the earmold. This style fills up most of the outer ear and appears as a solid mass. The ITC style moves some of the hearing aid into the ear canal and reduces the space taken up in the outer ear, but is still plainly visible. The CIC style is the smallest of them all, as it fits completely inside the ear canal, thus nearly disappearing from view.

Behind the ear (BTE), in the ear (ITE), in the canal (ITC), and completely in the canal (CIC). Photos courtesy of Starkey Laboratories, Inc.

Technology types

The two basic types of technology for hearing aids are analog and digital. The first to exist, analog hearing aids process electrical sound in the analog domain; the more recent digital hearing aids process electrical sound in the digital domain. The earliest analog hearing aids simply amplified both speech and noise, and were ordered after testing to determine the particular frequency response needed by the patient. Newer analog hearing aids can be programmed during the fitting process, and some have multiple listening profiles that the patient can select with a button on the hearing aid. Digital hearing aids are also programmable during the fitting process and have multiple listening profiles that are selectable by the patient. The digitization of sound allows more advanced signal processing such as noise reduction, filtering, and acoustic feedback (ringing) control. The vast majority of hearing aids sold today are digital because of their increased performance and flexibility over the analog versions.



Digital hearing aid functional block diagram. For a list of Maxim's recommended solutions for hearing aid designs, please go to: www.maxim-ic.com/hearing.

Features

There are many features available for today's hearing aids, including volume control, remote control, telecoil, direct audio input, FM reception, Bluetooth® capabilities, directional microphone, compression, clipping, frequency shifting, wind-noise management, data logging, self-learning, moisture resistance, and earmold venting. Some of these features require external area to implement and become more difficult to include as the size of hearing aids shrinks, while other features can be implemented in all hearing aids.

Volume control is performed manually with buttons or a rotary dial on the hearing aid. A remote control eliminates the need for buttons and dials on the hearing aid and can be used to control all the features of the hearing aid. A telecoil is an alternate input other than the microphone. It originally picked up the magnetic signal generated by older telephones with speakers driven by magnetic coils so that listeners could hear better when talking on the telephone. Today's telephones and other alternate listening devices build-in this capability in order to work with a telecoil and specifically indicate that they are hearing aid compatible. Direct audio input and FM reception are other ways to input sound or speech into the hearing aid, the first using a wired connector as an input, and the other an FM radio receiver. An emerging trend is to include Bluetooth capability to receive sound from a cell phone or music player. The Bluetooth device can either be integral to the hearing aid or an add-on device through the telecoil or FM input.

A hearing aid with directional microphones uses two or more microphones to receive sound from multiple directions. This improves the signal-to-noise ratio (SNR) of speech when heard in a noisy environment, and enhances the quality of speech further when used with digital signal processing. Compression and clipping both increase listening comfort by reducing portions of the sound that are too loud but, in some cases, just clip or limit the sound. Frequency shifting uses digital signal processing to shift speech to a lower frequency, which is helpful for people with high-frequency hearing loss. Wind-noise management detects wind and eliminates the feedback that would otherwise cause ringing sounds to be heard by the hearing aid wearer.

Data logging records the listening environment and how the hearing aid is used. A hearing professional can use this information to fine-tune hearing aid performance. Self-learning uses the data logs and fine-tunes the performance on its own over time. Moisture resistance helps reduce repairs due to exposure to moisture, and earmold vents provide additional comfort by reducing the closed-in sensation felt when wearing an earmold type of hearing aid.

General requirements

The critical components of a hearing aid design are in the audio-processing path. The one or more microphones and the receiver are chosen in conjunction with the preamplifiers (if required) and the speaker amplifiers. Class D amplifiers are used in modern hearing aids due to their low-power operation, low distortion, and small size as compared to Class A and B amplifiers. Whether the audio bandwidth is 20kHz or limited to 8kHz, the audio codec should have a high SNR to preserve and reproduce sounds accurately.

The heart of the system is the digital signal processor (DSP), which is where all of the benefits of a digital hearing aid are implemented. The DSP implementation is manufacturer dependent. In general, it performs compression/expansion by band, positive feedback reduction, noise reduction, and speech enhancement. It also processes directional information and can generate its own signals to help improve fitting a hearing aid to a patient.

Power and battery management

Some hearing aids are beginning to use rechargeable single-cell lithium-ion (Li+) batteries, but most hearing aids are still powered by primary zinc-air batteries. There are five main sizes of zinc-air batteries used, depending on the hearing aid style or size, the power consumption of the circuitry, and the battery-life requirements. **Table 1** compares the capacity and size of the five most common zinc-air batteries, and includes their color codes for easy selection and the styles of hearing aid in which they are usually used.

Zinc-air batteries start at 1.4V and are used down to about 1.0V or lower before requiring replacement. When used for 16 hours per day, battery

Type	Capacity (mAh)	Size (d x h, mm)	Color Code	Style Usage
675	540 to 640	11.6 x 5.4	Blue	BTE (high power), cochlear implants
13	230 to 285	7.9 x 5.4	Gold	BTE, ITE
312	120 to 160	7.9 x 3.6	Burgundy	miniBTE, ITE, ITC
10	60 to 90	5.8 x 3.6	Yellow	ITC, CIC
5	30 to 40	5.8 x 2.1	Red	CIC

Zinc-air battery comparison

life ranges from a couple of days to a few weeks, depending on the battery capacity and hearing aid design. The most power-efficient design runs directly off of a single battery, but a switching regulator can be used to boost the voltage to fit design needs, whether 1.8V or 3.0V. The power dissipation is targeted to be 1mW to 10mW when running off of zinc-air batteries. Hearing aids that use rechargeable Li+ batteries may require a linear or switching regulator to step the battery voltage down if the circuitry cannot run directly from the typical 4.2V, single-cell Li+ battery's fully charged voltage. Alternatively, the battery charger can limit the charging to a lower end voltage such as 3.3V, depending on the circuitry requirements. An accurate fuel gauge is critical to provide warning before the battery is depleted so that the patient is not left with a nonfunctioning hearing aid.

Electrostatic discharge

All hearing aids must pass IEC 61000-4-2 electrostatic discharge (ESD) requirements. Using electronics with built-in protection or adding ESD line protectors to exposed traces can help meet these requirements.

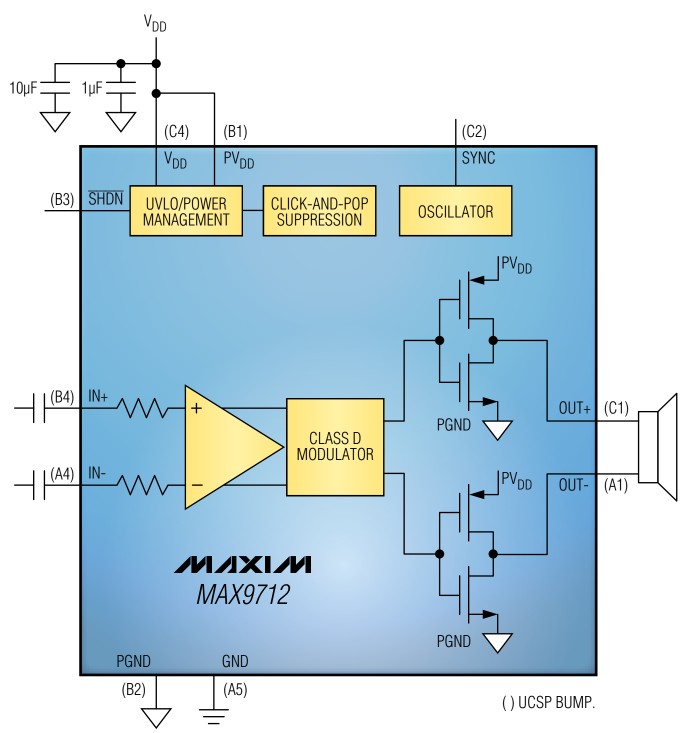
www.maxim-ic.com/hearing

Low-EMI, Class D speaker amplifier delivers high performance in a tiny space

MAX9712

The MAX9712 mono, Class D, audio power amplifier provides Class AB amplifier performance with Class D efficiency, conserving board space and extending battery life. Using the Class D architecture, the MAX9712 delivers up to 500mW into an 8Ω load while providing efficiencies above 85%. The device utilizes a fully differential architecture, full-bridge output, and comprehensive click-and-pop suppression.

The MAX9712 offers two modulation schemes: a fixed-frequency mode, and a patented spread-spectrum mode that reduces EMI-radiated emissions caused by the modulation frequency. This spread-spectrum mode* renders the traditional Class D output filter unnecessary. The external component count is further reduced as the gain is internally set to 4V/V.



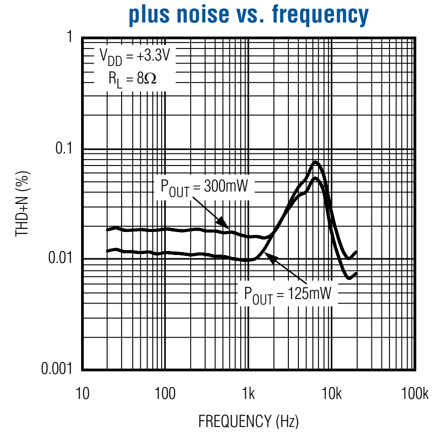
MAX9712 functional diagram

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

Benefits

- **Higher audio fidelity improves quality of hearing**
  - Low 0.01% THD+N
  - SNR > 90dB
  - High PSSR (72dB at 217Hz)
- **Longer battery life reduces cost of operation**
  - 85% efficiency
  - Low quiescent current (4mA)
  - Low-power shutdown mode (0.1µA)
- **Smaller hearing aid design for more convenient, discreet operation**
  - 1.5mm x 2mm x 0.6mm, 12-bump UCSP™
  - No output filter necessary
  - Integrated short-circuit and thermal-overload protection
  - Gain set to 4V/V
- **Low-EMI modulation scheme simplifies design**
  - Unique spread-spectrum mode offers 5dB emissions improvement over conventional methods
  - Filterless amplifier passes FCC radiated-emissions standards with 100mm of unshielded speaker cable

Total harmonic distortion plus noise vs. frequency



High-efficiency, step-up converters boost a zinc-air battery to 3V, yet operate down to 0.8V, thus extending battery operating range

MAX1722/MAX1723/MAX1724

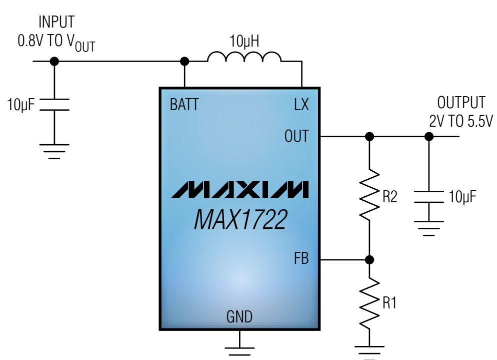
The MAX1722/MAX1723/MAX1724 compact, high-efficiency, step-up DC-DC converters are available in tiny, 5-pin, thin SOT23 packages. They feature an extremely low 1.5µA quiescent supply current to ensure the highest possible light-load efficiency. Optimized for operation from one to two alkaline, zinc-air, or nickel-metal-hydride (NiMH) cells, or a single Li+ cell, these DC-DC converters are ideal for applications where extremely low quiescent current and ultra-small size are critical.

Built-in synchronous rectification significantly improves efficiency and reduces size and cost by eliminating the need for an external Schottky diode. Also, no external FET is required, as all three devices integrate a 0.5Ω n-channel power switch.

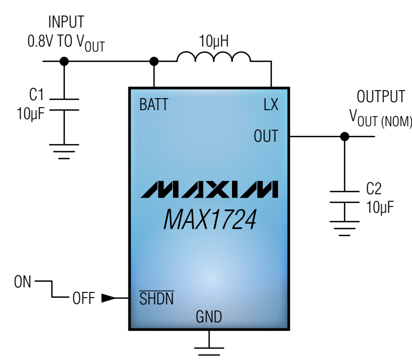
The MAX1722/MAX1724 feature proprietary noise-reduction circuitry, which suppresses EMI caused by the inductor in many step-up applications. These DC-DC converters offer various combinations of fixed or adjustable outputs, shutdown, and EMI reduction.

Benefits

- **High efficiency extends battery life**
  - Up to 90% efficiency
  - 1.5µA quiescent supply current
  - 0.1µA logic-controlled shutdown
- **Compact solution enables small hearing aid design**
  - Thin SOT23-5 package (1.1mm height, max)
  - No external diode or FETs needed
- **Low EMI simplifies design**
  - Internal EMI suppression (MAX1722/MAX1724)



MAX1722 adjustable output voltage circuit



MAX1724 standard application circuit

Recommended solutions

Part	Description	Features	Benefits
1-Wire® products			
1-Wire memory			
DS2502	1-Wire 1024-bit OTP EPROM	Single-dedicated-contact operation, programmable data protection, ±8kV HBM ESD protection	Minimal contact requirement to add nonvolatile memory for ID, calibration, or authentication; simplifies design
DS28E01-100/ DS28E02*	1-Wire 1024-bit EEPROM with SHA-1 authentication	Single-dedicated-contact operation, SHA-1 secure authentication and data protection, 1.8V operation (DS28E02), ±8kV HBM/±15kV IEC ESD protection	Ensure consumables are OEM with crypto-strong SHA-1 authentication; increase performance and reliability
DS2431	1-Wire 1024-bit EEPROM	Single-dedicated-contact operation, programmable data protection, ±8kV HBM/±15kV IEC ESD protection	High ESD performance typically eliminates the need to add protection to sensors, thus saving cost and space
1-Wire masters			
DS2460	SHA-1 coprocessor with EEPROM	Hardware-accelerated SHA-1 computation engine, secure memory to store three 64-bit master secrets for use with authenticating 1-Wire SHA-1 slaves, I^2C interface	Simplifies host system implementation of SHA-1 authenticated sensors and probes
DS2480B	Single-channel 1-Wire master with UART/RS-232 interface	UART/RS-232 to 1-Wire protocol bridging, supports standard and overdrive 1-Wire speeds, low-impedance strong pullup on 1-Wire I/O	Generates 1-Wire waveforms from UART/RS-232 command/communication, greatly simplifying host software development
DS2482-100	Single-channel 1-Wire master with I^2C interface	I^2C to 1-Wire protocol bridging, supports standard and overdrive 1-Wire speeds, low-impedance strong pullup on 1-Wire I/O	Generates 1-Wire waveforms from I^2C interface, greatly simplifying host software development
Analog front-ends (AFEs)			
MAX1329	12-/16-bit data-acquisition system with ADC, DACs, DPIOs, APIOs, reference, voltage monitors, and temp sensor	1.8V to 3.6V digital supply; internal charge pump for analog circuits (2.7V to 5.5V); 12-bit SAR ADC; dual, 12-bit force-sense DAC; integrated voltage references, op amps, analog switches, temp sensor, interrupts, and voltage monitors	Integrated solution and precision measurement simplify design for optical reflectometry and electrochemical AC-excitation meters
MAX1358/MAX1359, MAX11359*	16-bit data-acquisition systems with ADC, DACs, UPIOs, RTC, voltage monitors, and temp sensor	1.8V to 3.6V supply; multichannel, 16-bit sigma-delta ADC; 10-bit force-sense DACs; integrated op amps, analog switches, voltage reference, RTC with alarm, temp sensor, maskable interrupts, and dual V_{DD} monitors	Highly configurable AFEs provide accurate results and are compatible with most electrochemical test strips
MAX1407–MAX1409, MAX1414	Low-power, 16-bit multichannel data-acquisition systems with internal reference, 10-bit force-sense DACs, and RTC	1.15mA during operation; 2.5µA in sleep mode; 18ppm/°C (typ) reference; 2.4576MHz PLL clock output; integrated RTC and alarm, dual voltage monitors, comparator, interrupts, and wake-up circuitry	Very low operating current delivers over 1500 tests and greater than one year of battery life from a single coin-cell battery
Amplifiers			
Current-sense amplifiers			
MAX9634	1µA, precision current-sense amp	28V (max) common-mode voltage, 250µV (max) V_{OS}, 1µA (max) quiescent current, small UCSP™ and SOT23 packages	Very low supply current reduces battery drain; tiny package reduces solution size
MAX9918–MAX9920	Bidirectional current-sense amps with wide -20V to +75V common-mode voltage	-40°C to +125°C temperature range, precision 400µV (max) V_{OS}, ±0.45% gain error, shutdown mode	High precision and shutdown allow small sense resistors, which reduce power loss and BOM cost; wide input range eliminates protection devices

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*Future product—contact factory for availability.

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Current-sense amplifiers (continued)			
MAX9928F/ MAX9929F	Bidirectional current-sense amps with wide 0 to 28V common-mode voltage	Precision 400µV (max) V_{OS}, ±1% gain error, sign output, current output, 1mm x 1.5mm UCSP	Sign output enables full use of ADC range; precision and small package reduce size and cost of solution
Instrumentation amplifiers			
MAX4194–MAX4197	Micropower, three-op-amp instrumentation amps	450µV (max) V_{OS}, 93µA quiescent current, adjustable and fixed (1, 10, 100V/V) gain versions, shutdown mode	Shutdown function and low-current operation save power, thus extending battery runtime
MAX4208/MAX4209	Ultra-low offset/drift, precision instrumentation amps with REF buffer	20µV (max) input V_{OS} with "zero drift," 1pA input-bias current, 1.4µA shutdown current, fixed and programmable gain versions available	Near-ground sensing simplifies design, while zero-drift offset preserves accuracy
Operational amplifiers			
MAX4464, MAX4470–MAX4472, MAX4474	Single/dual/quad, 1.8V/750nA, SC70, rail-to-rail op amps	1.8V to 5.5V supply, 750nA/ch quiescent current, rail-to-rail outputs, ground-sensing inputs	Low voltage, ultra-low current, and rail-to-rail outputs extend battery life
MAX4475–MAX4478	Precision, low-distortion, $4.5nV/\sqrt{Hz}$ op amps	750µV (max) V_{OS}, 10MHz op amps, $4.5nV/\sqrt{Hz}$ noise, CMOS inputs, SOT23	Improve measurement accuracy when used for gain, filtering, or driving ADC inputs
MAX9617–MAX9620	High-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs	10µV (max) V_{OS} with "zero drift," $0.42µV_{P-P}$ noise, 59µA quiescent current, tiny 8-pin SC70	Improve measurement accuracy and reduce calibration requirements
MAX9910–MAX9913	Low-power, high-bandwidth, single/ dual, rail-to-rail I/O op amps with shutdown	4µA quiescent current, 1pA I_{BIAS}, 200kHz GBW, 1.8V to 5.5V supply, MOS inputs, 1mV (max) V_{OS}, SC70 package, independent shutdowns (dual)	4µA quiescent current extends battery life
MAX9914–MAX9917	Low-power, high-bandwidth, single/ dual, rail-to-rail I/O op amps with shutdown	20µA quiescent current, 1pA I_{BIAS}, 1MHz GBW, 1.8V to 5.5V supply, MOS inputs, 1mV (max) V_{OS}, SC70 package, independent shutdowns (dual)	20µA quiescent current extends battery life
Comparators			
MAX9060–MAX9064	Ultra-low-power single comparators	50nA/400nA comparators with and without internal 0.2V reference in space-saving UCSP	$1mm^2$ package saves space, while 400nA current saves power
MAX9065	Ultra-small, low-power window comparator in UCSP/SOT23	1.0V to 5.5V supply, 1µA (max) quiescent current, preset 3V and 4.2V thresholds	Monitoring Li+ battery voltage improves reliability in portable applications
Analog switches and multiplexers			
Analog switches			
MAX4575–MAX4577	±15kV ESD-protected, low-voltage, dual SPST, CMOS analog switches	IEC 1000-4-2 compliant, 0.5nA (max) leakage, 2V to 12V supply	Integrated ESD protection and low leakage improve analog sensor measurement accuracy
MAX4624/MAX4625	1Ω, low-voltage, single-supply, SPDT, CMOS analog switches	1Ω (5V) and 2Ω (3V) max R_{ON}, 1.8V to 5.5V supply, SOT23	Small package enables compact design
MAX4751–MAX4753	0.9Ω, low-voltage, single-supply, quad SPST, CMOS analog switches	0.9Ω (3V) and 2.5Ω (1.8V) max R_{ON}, 1.6V to 5.5V supply, 1µA quiescent current	Wide operating range down to 1.6V simplifies design and extends battery life
MAX4754–MAX4756*	0.85Ω, low-voltage, single-supply, quad SPDT, analog switches in UCSP/TQFN	2mm x 2mm UCSP, 1.8V to 5.5V supply	High integration and small package shrink design
Analog multiplexers			
MAX4558–MAX4560	±15kV ESD-protected, low-voltage, CMOS analog multiplexers/switches	Single 8:1 or dual 4:1 muxes, IEC 1000-4-2 compliant, 1.0nA (max) leakage, single 2V to 12V supply	Integrated ESD protection simplifies design and saves cost

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*Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Analog multiplexers (continued)			
MAX4638/MAX4639	6Ω, low-voltage, analog multiplexers	Single 8:1 or dual 4:1 muxes, single 1.8V to 5.5V supply, -80dB crosstalk, -60dB off-isolation	Guaranteed specs deliver more-reliable measurements, providing higher customer satisfaction
MAX4734	0.8Ω, low-voltage, 4:1 analog multiplexer in TQFN	0.8Ω (3V) and 2Ω (1.8V) max R_{ON}, single 1.6V to 3.6V supply, 3mm x 3mm TQFN	Guaranteed specs deliver more-reliable measurements, providing higher customer satisfaction
MAX4781–MAX4783	0.7Ω, high-speed, low-voltage, CMOS analog switches/multiplexers	Excellent on/off performance up to 10MHz, 8:1 configuration, 1.6V to 3.6V supply	Wide operating range allows use in many applications, increasing design reuse
Audio solutions			
Audio codecs			
MAX9851/MAX9853	Stereo audio codecs with microphone, DirectDrive® headphone amps, speaker amps, or line outputs	1.7V to 3.3V digital supply, 2.6V to 3.3V analog supply, 26mW playback power	Flexible solutions simplify audio design
MAX9856	Low-power audio codec with DirectDrive headphone amps	1.71V to 3.6V supply, 30mW DirectDrive headphone amp, 9mW playback power consumption, low noise, clickless/popless operation, 36mm^2 footprint	Complete audio-path solution improves audio quality and extends battery life; small footprint saves PCB space
MAX9860	16-bit, mono, audio voice codec	1.7V to 1.9V supply, 1.7V to 3.6V digital I/O supply, 30mW BTL headphone amp, dual low-noise microphone inputs, clickless/popless operation, 16mm^2 footprint	Complete audio-path solution improves audio quality; extra-small footprint enables smaller designs
MAX9867	Ultra-low-power stereo audio codec	1.65V to 1.95V supply, 1.65V to 3.6V digital I/O supply, 6.7mW playback power consumption, auxiliary battery-measurement ADC, < 6mm^2 footprint	Complete audio-path solution improves audio quality and provides longest battery life; super-small footprint enables smallest designs
Audio DAC			
MAX9850	Stereo audio DAC with DirectDrive headphone amp	Integrated volume control, 1.8V to 3.6V supply, clickless/popless operation	DirectDrive architecture eliminates DC-blocking capacitors, saving board space
Microphone preamplifiers			
MAX4060–MAX4062	Differential microphone preamplifiers with internal bias and complete shutdown	2.4V to 5.5V supply, adjustable or fixed-gain options, low input noise, 300nA shutdown, 0.04% THD+N, TQFN	Shutdown and low supply voltage extend battery life
MAX9810	Electret condenser-microphone cartridge preamplifier	2.3V to 5.5V supply, 82dB PSRR, three gain options, 1mm x 1mm UCSP	Tiny package shrinks design size
MAX9812/MAX9813	Tiny, low-cost, single-/dual-input, fixed-gain microphone amps with integrated bias	230µA quiescent current, 20dB gain, 0.015% THD+N, 100nA shutdown, SC70 and SOT23	Built-in bias and small package reduce solution size; low noise and low distortion improve listening experience
Headphone amplifiers			
MAX4409–MAX4411	80mW, DirectDrive stereo headphone amps with shutdown	1.8V to 3.6V supply, fixed or external gain options, common-mode sensing option	Elimination of output capacitors improves low-frequency audio response
MAX9720	50mW, DirectDrive stereo headphone amp with SmartSense™ and shutdown	Auto mono/stereo detection, shutdown, fixed-gain options, 0.003% THD+N, 1.8V to 3.6V supply	Integrated features save space and simplify design

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Headphone amplifiers (continued)			
MAX9723	Stereo DirectDrive headphone amp with bass boost, volume control, and I²C interface	1.8V to 3.6V supply, 62mW DirectDrive headphone amp, 32-level volume control, 0.006% THD+N, shutdown, UCSP and TQFN	Elimination of output capacitors improves low-frequency audio response
MAX9724	60mW, fixed-gain, DirectDrive, stereo headphone amp with low RF susceptibility and shutdown	Click-and-pop suppression, 0.003% THD+N, short-circuit and thermal protections, < 100nA shutdown, UCSP and TDFN	DirectDrive architecture eliminates the need for DC-blocking capacitors, saving board space and cost
MAX9820	DirectDrive headphone amp with external gain	95mW output power, high RF noise immunity, clickless/popless operation, 3mm x 3mm TDFN	High RF immunity simplifies design
Speaker amplifiers			
MAX9700	Mono, 1.2W, Class D audio amp	Up to 94% efficiency, filterless operation, 1.5mm x 2mm UCSP	High efficiency extends battery life; small package minimizes solution size
MAX9705	2.3W, ultra-low-EMI, filterless, Class D audio amp	Class D gives better efficiency, yet delivers 0.02% THD+N	Small, efficient solution to drive headphones/ speakers
MAX9718/MAX9719	Low-cost, mono/stereo, 1.4W, differential audio power amps	Class AB with superior THD+N down to 0.002%	Simple, high-fidelity solution reduces cost
MAX98000*	I²S, mono, Class D amp with FLEXSOUND™ advanced audio processing	Low EMI; 5-band parametric EQ; automatic level control; speaker-excursion, power, and distortion limiters	High-efficiency Class D extends battery life
Battery management			
Battery chargers			
MAX1736	Single-cell Li+ battery charger for current-limited supply	Single-cell Li+, pulse topology, 4.7V to 22V input, stand-alone or MCU controlled, 9mm² SOT23	Smallest solution; minimal external components saves board space and cost
MAX1811	USB-powered Li+ charger	Single-cell Li+; linear topology; charges from USB port; 4.35V to 6.5V input	Simplest solution when USB is available
MAX8606	Dual-input (USB/AC adapter), linear Li+ battery charger with integrated 50mΩ battery switch in TDFN	Selectable current limits, overvoltage protection, USB or AC adapter input	Enables charging from USB or AC adapter
MAX8900A/ MAX8900B	1.2A switch-mode Li+ chargers with ±22V input rating and JEITA-compliant battery temperature monitoring	Single-cell Li+, switching topology, 3.4V to 6.3V or 8.7V input, 3.25MHz, small external inductor	Safest solution, less heat, highly reliable
MAX1551/MAX1555	Dual-input (USB/AC adapter), single-cell Li+ battery chargers in SOT23	Linear topology; automatic switchover when AC adapter is plugged in; power-present and charge-status indicators	Simplify design
Fuel gauges			
DS2745	Low-cost, I²C battery monitor	Single-cell Li+; precision voltage, current, and temperature monitor; works with MCU	Precision measurements increase runtime between charges
DS2756	High-accuracy battery fuel gauge with programmable suspend mode	Precision voltage, current, and temperature monitor; 96 bytes of EEPROM	Programmable suspend mode extends battery runtime per charge
DS2780	Stand-alone, 1-Wire fuel-gauge IC	Single-cell Li+; FuelPack™ algorithm with precision voltage, current, and temperature monitor; 1-Wire multidrop interface; EEPROM storage	Stand-alone solution simplifies software development

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*Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Fuel gauges (continued)			
DS2782	Stand-alone fuel-gauge IC	Single-cell Li+; FuelPack algorithm with precision voltage, current, and temperature monitor; I^2C interface; EEPROM storage	Stand-alone solution simplifies software development
MAX17043*	Low-cost, I^2C fuel-gauge IC	ModelGauge™ algorithm, 2mm x 3mm footprint, low-battery alert, no sense resistor	Allows system µC to remain in sleep mode for longer, thus saving power
Data converters			
Analog-to-digital converters (ADCs)			
MAX1162	16-bit, 200ksps SAR ADC with serial interface	10-pin µMAX® package, 10µA in shutdown	Small package saves space, while low-power operation reduces battery drain
MAX1226–MAX1231	12-bit, 12-channel, 300ksps SAR ADCs with serial interface	Internal reference, internal temperature sensor, 5mm x 5mm 28-TQFN	Small package saves space for compact designs
MAX1391–MAX1396	8-/10-/12-bit SAR ADCs with serial interface	1.5V to 3.6V supply, 305µW at 100ksps, 3.1µW at 1ksps, 3mm x 3mm TDFN	Supply voltage range eliminates regulated power supply; low power consumption extends battery life
MAX1415/MAX1416	16-bit, 500sps sigma-delta ADCs with serial interface	16-bit, 2-channel ADCs with PGA gains between 1 and 128; low power (1mW, max); 2µA in shutdown	Low-power operation extends battery life
MAX11600–MAX11605	8-bit, 12-channel, 188ksps SAR ADCs with serial interface	Internal reference	Flexible interface reduces design time and saves space
Digital-to-analog converters (DACs)			
MAX5510–MAX5515	Ultra-low-power, single/dual 8-bit DACs	1.8V to 5.5V operation, 4µA/ch (max), internal or external voltage reference, 30ppm/°C (max) tempco, voltage or force-sense outputs	Complete electrochemical sensor solutions simplify design, increase accuracy, and extend battery life
MAX5520–MAX5525	Ultra-low-power, single/dual 10-bit DACs	1.8V to 5.5V operation, 4µA/ch (max), internal or external voltage reference, 30ppm/°C (max) tempco, voltage or force-sense outputs	Complete electrochemical sensor solutions simplify design, increase accuracy, and extend battery life
MAX5530–MAX5535	Ultra-low-power, single/dual 12-bit DACs	1.8V to 5.5V operation, 4µA/ch (max), internal or external voltage reference, 30ppm/°C (max) tempco, voltage or force-sense outputs	Complete electrochemical sensor solutions simplify design, increase accuracy, and extend battery life
Digital potentiometers			
MAX5160/MAX5161	Low-power digital potentiometers in SOT23/µMAX	32 tap positions, 2.7V to 5.5V supply	Enable digital calibration at low power to save battery life
Display			
LED backlight drivers			
MAX1574	180mA, 1x/2x, white LED charge pump in 3mm x 3mm TDFN	3 LEDs (max), up to 60mA/LED, 5% to 100% dimming via single wire, 100nA in shutdown, soft-start limits inrush current	Integrated dimming saves space
MAX1848	White LED step-up converter in SOT23	2.6V to 5.5V supply, switching topology, constant-current regulation, analog- or logic-controlled intensity, soft-start	Uniform brightness provides better viewing experience in low-light conditions
MAX1916	Low-dropout, constant-current, triple white LED bias supply	3 LEDs (max), up to 60mA/LED, linear topology, 50nA in shutdown, SOT23	Tiny, low-cost, high-efficiency solution saves board space and extends battery life

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*Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
LED backlight drivers (continued)			
MAX1984–MAX1986	Ultra-efficient white LED drivers	1 to 8 LEDs; selectively enable LEDs; switching topology; open-LED detection	Open-LED detection increases reliability
MAX8630	125mA, 1x/1.5x charge pump for 5 white LEDs in 3mm x 3mm TDFN	Up to 93% efficiency; charge-pump topology; PWM dimming; factory-trimmed, full-scale LED current	Integrated derating function protects LEDs from overheating, thus increasing reliability
LED display drivers			
MAX6950/MAX6951	Serially interfaced, 2.7V to 5.5V, 5- and 8-digit LED display drivers	Slew-rate-limited driver ICs include blinking control and PWM dimming with low EMI in a small 16-pin package	Lower system cost by using simpler MCU and offloading display control
MAX6952	4-wire-interfaced, 2.7V to 5.5V, 4-digit, 5 x 7 matrix LED display driver	Slew-rate-limited driver IC for alphanumeric displays includes blinking control and PWM dimming with low EMI	Lowers system cost by using simpler MCU and offloading display control
MAX6954	4-wire-interfaced, 2.7V to 5.5V LED display driver with I/O expander and keyscan	Slew-rate-limited driver IC includes blinking control, PWM dimming, and keyscan	Compact, low-EMI solution for medium-sized displays and switch arrays shortens design time and approvals
MAX6978	8-port LED driver with fault detection and watchdog	8 constant-current LED outputs; up to 55mA per output; ±3% matching; serial interface; reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
MAX6979	16-port LED driver with fault detection and watchdog	16 constant-current LED outputs; up to 55mA per output; ±3% matching; serial interface; reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
Touch-screen controllers			
MAX11800–MAX11803	Low-power, ultra-small, 4-wire resistive touch-screen controllers with I²C/SPI™ interface	12-bit SAR ADC, 1.7V to 3.6V supply, direct and autonomous modes, 1.6mm x 2.1mm WLP	Tiny wafer-level package enables small designs; integration reduces cost
MAX11811	4-wire touch-screen controller with integrated haptic motor driver	12-bit ADC, I²C interface, proximity driver, automatic power-down, direct and autonomous modes	Autonomous mode reduces processor burden; automatic power-down extends battery life
MAX1233/MAX1234	±15kV ESD-protected, 4-wire touch-screen controllers include DAC and keypad controller	12-bit SAR ADC, SPI interface, keypad controller, low power	Combine touch-screen and keypad controller, which simplifies design and saves board space; low power extends battery life
Interface			
Current limiters			
MAX4995	50mA to 600mA adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
MAX14523	250mA to 1.5A adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
I/O expanders			
MAX7310	2-wire-interfaced, 8-bit I/O port expander with reset	Bus timeout, 2.0V to 5.5V supply	Lockup-free operation increases reliability; low supply voltage simplifies design
MAX7315	8-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V supply, 50mA output drive, global and individual PWM intensity control with blinking	Ability to drive heavier loads makes designs more robust

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
I/O expanders (continued)			
MAX7318	2-wire-interfaced, 16-bit, I/O port expander with interrupt and hot-insertion protection	Bus timeout, 2.0V to 5.5V supply	Lockup-free operation improves reliability; lower supply voltage simplifies design
MAX7323	I^2C port expander with four push-pull outputs and four open-drain I/Os	1.71V to 5.5V supply, I^2C interface, 20mA sink, 10mA source	Low-voltage operation and I/O flexibility make design easier
MAX7328–MAX7329	I^2C port expanders with eight I/O ports	2.5V to 5.5V supply; address up to 16 devices with 100kHz I^2C interface; 10µA quiescent current	Expand port pins without having to switch to a more costly microcontroller
Logic-level translators			
MAX13030E	6-channel, high-speed logic-level translator	100Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 2mm x 2mm UCSP	ESD protection with low capacitance enables high data rates
MAX13101E	16-channel logic-level translator	20Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 3mm x 3mm WLP	Integrates level translation with ESD protection in a space-saving package
USB transceivers			
MAX3349E	Full-speed USB transceiver with UART multiplexer	Full-/low-speed USB, ±15kV ESD protection on D+/D- lines	Increases reliability and reduces size by functionally sharing a USB connector
MAX3453E–MAX3456E	±15kV ESD-protected USB transceivers	Full-/low-speed USB, ±15kV ESD protection on D+/D- lines, 1.65V to 3.6V logic supply	Increase reliability by protecting high-data-rate interfaces
MAX13481E–MAX13483E	±15kV ESD-protected USB transceivers with external/internal pullup resistors	Full-speed USB, ±15kV ESD protection on D+/D- lines, 1.6V to 3.6V logic supply	Compatible with low-voltage ASICs and ASSPs, thus eliminating the need to add an interface chip
IrDA℠ product			
MAX3120	Low-profile, 3V, 120µA, IrDA infrared transceiver	IrDA 1.2 compatible, 115.2kbps (max), 120µA (typ) supply current, 10nA (typ) shutdown current	Infrared transceiver allows for optimal placement of optical components
RS-232 drivers/receivers			
MAX3221E/ MAX3223E/ MAX3243E	±15kV ESD-protected RS-232 transceivers	1/1, 2/2, and 3/5 driver/receiver options	AutoShutdown™ extends battery life
MAX3224E–MAX3227E, MAX3244E/ MAX3245E	±15kV ESD-protected, 1µA, 1Mbps RS-232 transceivers with AutoShutdown Plus™	1/1, 2/2, and 3/5 driver/receiver options; UCSP option; 2.35V, 2.5V, or 3.0V to 5.5V supply options	Increased reliability; small solution size can be located on main board or in cable
ESD/line protection			
MAX3202E–MAX3204E, MAX3206E	Low-capacitance, 2-/3-/4-/6-channel, ±15kV ESD protection arrays	5pF input capacitance, 1nA input-leakage current, 1nA supply current, tiny footprint	Easily comply with IEC 61000-4-2 ESD protection
MAX3205E/ MAX3207E/ MAX3208E	Low-capacitance, 2-/4-/6-channel, ±15kV ESD protection arrays with TVS	2pF input capacitance, integrated transient-voltage suppressor	Increase reliability by protecting high-data-rate interfaces
MAX9940	Signal-line overvoltage protector	Small SC70, low supply current, ±4kV IEC Contact protection	Protects low-voltage circuitry from high-voltage faults, thus improving reliability

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
ESD/line protection (continued)			
MAX13202E/ MAX13204E/ MAX13206E/ MAX13208E	Low-capacitance, 2-/4-/6-/8-channel, ±30kV ESD protection arrays	6pF input capacitance, 1nA input-leakage current, ±30kV ESD protection	Increase reliability by protecting high-data-rate interfaces
Keyboard scanners			
MAX7347–MAX7349	2-wire-interfaced, low-EMI key-switch controllers	Monitor up to 24, 40, or 64 keys; low-voltage design; key debounce	Independent key controllers free up microcontroller I/O and reduce software complexity
MAX7359	2-wire-interfaced, low-EMI key-switch controller/GPO	Monitors up to 64 keys, low-voltage design, key debounce, key-release detection	Independent key controller frees up microcontroller I/O and reduces software complexity
Switch debouncers			
MAX6816–MAX6818	Single, dual, and octal switch debouncers	±15kV ESD protection	Improve reliability; ease of use simplifies design
MAX16054	Pushbutton on/off controller	±15kV ESD protection	Improves reliability; small size saves space
Microcontrollers			
MAXQ610	Low-power, 16-bit microcontroller with IR module	1.7V to 3.6V supply, up to 32 GPIOs, IR module, ring oscillator, wakeup timer, 200nA stop-mode current	Low operating voltage for longer battery life
MAXQ612/MAXQ622	Low-power, 16-bit microcontrollers with IR module and optional USB	1.7V to 3.6V supply, 128KB flash, USB 2.0 transceiver, IR module, up to 52 GPIOs	Extended battery life and easier data transfer from portable device
MAXQ2000	Low-power, 16-bit LCD microcontroller	20MHz operation, 64KB flash, hardware multiplier, 132-segment LCD controller, 32-bit RTC, 700nA stop-mode current	High integration saves board space; low-power architecture extends battery life
MAXQ2010	Low-power, 16-bit mixed-signal LCD microcontroller	8-channel, 12-bit SAR ADC; 64KB flash; supply voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current	Powerful, integrated microcontroller saves space in battery-powered applications
MAXQ8913	16-bit mixed-signal microcontroller	7-channel, 12-bit SAR ADC; 64KB flash; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Single chip integrates multiple functions to minimize solution size
Power management			
Switching regulators			
MAX1722–MAX1724	1.5µA I_Q, step-up DC-DC converters in thin 5-SOT23	0.91V startup, 150mA output current, 90% efficiency, internal EMI suppression, 100nA in shutdown	0.91V startup enables single-cell operation, saving space, weight, and cost
MAX1832–MAX1835	High-efficiency step-up converters with reverse-battery protection	4µA quiescent current, 1.5V startup, 150mA output current, 90% efficiency, < 100nA in shutdown, battery connected to OUT in shutdown	Simplify electromechanical design with integrated reverse-battery protection; turn off power supply when not in use to save power
MAX1947	Boost regulator for single alkaline-battery input	Low 0.7V input, internal synchronous switches, 2MHz switching, 94% efficiency, True Shutdown™, reset flag	Harvests more energy from alkaline cells to extend battery life; high switching frequency reduces external component size
MAX8569	200mA step-up converter in 6-pin SOT23 and TDFN	1.5V startup, 200mA output current, 95% efficiency, < 100nA in shutdown, battery connected to OUT in shutdown	Turns off power supply when not in use to save power; increases efficiency by running directly off of batteries
MAX8625	High-efficiency, seamless-transition, step-up/down DC-DC converter	2.5V to 5.5V supply, glitch-free buck-boost transitions, 92% efficiency, PWM or skip modes, output overload protection	Wide input range maximizes battery life from single-cell Li+

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Linear regulators			
MAX6469–MAX6484	300mA LDO linear regulators with internal microprocessor-reset circuit	114mV dropout at 300mA, preset 1.5V to 3.3V in 100mV steps, 82µA supply current, 100nA shutdown current	Integrated reset saves cost and space by eliminating need for a separate voltage supervisor
MAX8860	300mA LDO linear regulator in µMAX®	60µV_{RMS} output noise, 105mV dropout at 200mA, 120µA quiescent current, reverse-battery protection, small 2.2µF I/O capacitor	Reverse-battery protection simplifies design; small input and output capacitors save board space
MAX8902A/ MAX8902B	Low-noise, 500mA LDO linear regulators in a 2mm x 2mm TDFN	16µV_{RMS}; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, and temperature; shutdown mode; soft-start	Low noise and high accuracy enable optimal performance from sensitive analog circuits
Power-management IC (PMIC)			
MAX1565	Five-output power-supply IC	Five switching regulators at 1MHz; 1µA in shutdown; supplies for motor, main, core, and LCD from supply down to 0.7V	Complete power-management solution in one IC saves board space
Voltage references			
MAX6006–MAX6009	Precision shunt voltage references in SOT23	1µA operating current, ±0.2% accuracy, wide operating range (1µA to 2mA)	Ultra-low operating current saves battery life
MAX6018	Precision, micropower, low-dropout, series voltage reference in SOT23	1.263V to 2.048V V_{OUT}, ±0.2% to ±0.4% accuracy, 1.8V supply, 5µA quiescent current	Low operating current extends battery life
MAX6023	Precision, low-power, low-dropout voltage reference in UCSP	1.25V to 5V V_{OUT}, ±0.2% initial accuracy, 30ppm/°C tempco, 1mm x 1.5mm x 0.3mm package	Small package fits in space-constrained designs
MAX6029	Ultra-low-power, precision series voltage reference	5.25µA quiescent current, 30ppm/°C tempco, no external capacitors needed	Ultra-low operating current saves power; stability over temperature increases reliability
MAX6034	Precision, micropower, series voltage reference in small SC70	2.048V to 4.096V V_{OUT}, ±0.2% accuracy, 30ppm/°C tempco, 90µA quiescent current	Small SC70 package eases layout and saves board space
Voltage supervisors			
MAX6381–MAX6390	Single/dual, low-power µP reset circuits in SC70/µDFN	Multiple thresholds and timeout options; only a few external components	Versatility eases design reuse; small package saves space in small systems
MAX6443–MAX6452	Single/dual µP reset circuits with manual-reset inputs	Two manual-reset inputs with extended setup period (6.72s), precision voltage monitoring down to 0.63V	Avoid nuisance resets; eliminate the need for a pinhole in the equipment case
MAX16056–MAX16059	Ultra-low-power supervisory ICs with watchdog timer	125nA supply current, capacitor-adjustable timing	Save power and battery life; adjustable timeouts allow one IC to be used across multiple applications
MAX16060–MAX16062	Quad-/hex-/octal-voltage µP supervisors	Fixed and adjustable thresholds and timeouts, margin-enable and tolerance-select inputs, watchdog timer	Breadth of features and options provides flexibility to meet many design needs, increasing design reuse
MAX16072–MAX16074	µP supervisory circuits in chip-scale package	1mm x 1mm UCSP, 0.7µA supply current	Small package saves space, while low-power operation extends battery life
RF solutions			
ISM transceivers			
MAX2830	2.4GHz to 2.5GHz RF transceiver with power amplifier	2.4GHz to 2.5GHz ISM band operation; IEEE® 802.11g/b compatible; complete RF transceiver, PA, and crystal oscillator	Saves space by eliminating the need for an external SAW filter
MAX7030	Low-cost, 315MHz, 345MHz, and 433.92MHz ASK/OOK transceiver with fractional-N PLL	2.1V to 3.6V or 4.5V to 5.5V supply, no programming required, low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm TQFN	Factory programmed for faster and simpler product design; low-voltage operation and low current for long battery life

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
ISM transceivers (continued)			
MAX7031	Low-cost, 308MHz, 315MHz, and 433.92MHz FSK transceiver with fractional-N PLL	2.1V to 3.6V or 4.5V to 5.5V supply, no programming required, low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm TQFN	Factory programmed for faster and simpler product design; 5mm x 5mm package enables small form factor
MAX7032	Low-cost, crystal-based, programmable ASK/FSK/OOK transceiver with fractional-N PLL	2.1V to 3.6V or 4.5V to 5.5V supply, no programming required, low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm TQFN	Factory programmed for faster and simpler product design; low-voltage operation and low current for long battery life
ISM transmitters			
MAX2900–MAX2904	200mW single-chip transmitter ICs for 868MHz and 915MHz ISM bands	Compliant with FCC CFR 47 Part 15.247 for the 902MHz to 928MHz ISM band and/or ETSI EN330-220 for the European 868MHz ISM band	High level of integration minimizes the number of external components, thus saving board space and simplifying design
MAX1472	Low-power, 300MHz to 450MHz, crystal-based ASK transmitter	Wide frequency range, low-current operation (5.3mA, operating), 3mm x 3mm package	Crystal stability increases performance, while low power consumption increases battery life
MAX1479	Low-power, 300MHz to 450MHz, crystal-based ASK/FSK transmitter	Wide frequency range, low-current operation (6.7mA in ASK mode, 10.5mA in FSK mode)	Crystal stability increases performance, while low power consumption increases battery life
MAX7057	300MHz to 450MHz, crystal-based ASK/FSK transmitter	Wide frequency range, programmable synthesizer, antenna-matching network	High efficiency in the 300MHz to 450MHz band reduces transmit time, saving power and extending battery life
ISM receivers			
MAX1471	Programmable, 300MHz to 450MHz ASK/FSK receiver	High sensitivity, built-in image rejection, and separate ASK/FSK data paths in a 5mm x 5mm package	High sensitivity simplifies design while keeping power low
MAX1473	300MHz to 450MHz ASK receiver with AGC	High sensitivity, AGC, and built-in image rejection in a 5mm x 5mm package	Built-in image rejection provides a more-reliable wireless link
MAX7042	300MHz to 450MHz FSK receiver	Best FSK sensitivity and built-in image rejection in a 5mm x 5mm package	FSK sensitivity improves wireless reception; saves board space
Real-time clocks (RTCs)			
DS1337	I²C RTC with time-of-day alarm and trickle charger	Single 1.8V to 5.5V supply, 1.3V timekeeping voltage, two time-of-day alarms, leap-year compensation, 32kHz square-wave output, integrated-crystal option	Single supply reduces pin count where small packages and simple routing are the primary concerns
DS1341	Low-current, I²C RTC for high-ESR crystals	Compatible with crystal ESR up to 100kΩ; low timekeeping current of 250nA (typ)	Ability to drive high-ESR crystals allows use of any commercially available crystal including smallest surface-mount form factors, thus reducing cost and board space
DS1372	I²C, 32-bit binary counter clock with 64-bit ID	Unique 64-bit serial number and a programmable alarm	Serial number provides a method of identifying systems without adding an extra component or programming step, thus reducing board size and simplifying design
DS1388	I²C RTC/supervisor with trickle charger and 512 bytes of EEPROM	High level of integration (RTC, supervisor, watchdog timer), 512 bytes of EEPROM, backup supply voltage, trickle-charge capability	High level of integration saves board space and cost
DS1390–DS1394	Low-voltage, SPI/3-wire RTCs with trickle charger	Separate SQW and INT outputs, trickle-charge capability, UL® recognized, time-of-day alarm, automatic backup power switching	Automatic backup power switching ensures reliable timekeeping when main power fails

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Sensors			
Temperature sensors			
DS18B20	±0.5°C accurate, 1-Wire digital temperature sensor	±0.5°C accuracy, 1-Wire interface, unique 64-bit serial number	Simplifies interface when deploying multiple distributed precision sensors
DS600	±0.5°C accurate analog-output temperature sensor	Industry's most accurate analog temperature sensor: ±0.5°C accuracy from -20°C to +100°C	Improves system temperature-monitoring accuracy and is easy to design with
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C, 1.7V to 3.7V operation, industry-standard pinout and registers	Industry-standard pinout facilitates migration from LM75 to lower supply voltage
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
MAX6612	Small, low-power analog temperature sensor	19.5mV/°C slope, ±3°C accuracy from 0°C to +70°C, SC70, 35µA (max) quiescent current	Small, low-power solution saves board space and extends battery life
Hall-effect sensor interface			
MAX9921	Dual, 2-wire Hall-effect sensor interface with diagnostics	Withstands 60V voltage transients and ±15kV ESD spikes; built-in diagnostics; controlled ramp for Hall-effect sensor power	Integrated ESD and diagnostics increase product reliability while saving space

Ultrasound imaging systems

Overview

By transmitting acoustic energy into the body and receiving and processing the returning reflections, phased-array ultrasound systems can generate images of internal organs and structures, map blood flow and tissue motion, and provide highly accurate blood velocity information. Historically, the large number of high-performance phased-array transmitters and receivers required to implement these imaging systems resulted in large and expensive cart-based implementations. Recently, advances in integration have allowed system designers to migrate to smaller, lower cost, and more portable imaging solutions with performance approaching these larger systems. The challenge moving forward is to continue to drive the integration of these solutions, while increasing their performance and diagnostic capabilities.

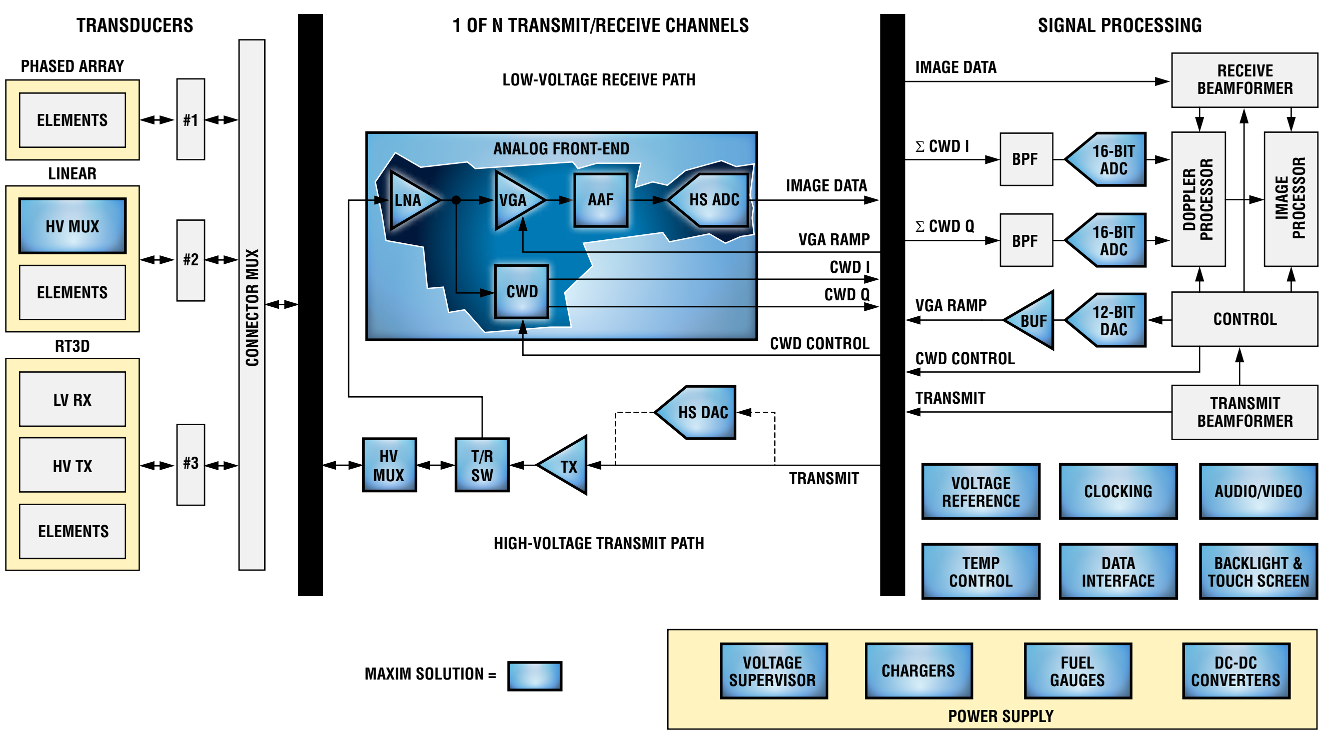
Transducers

A critical component of this system is the ultrasound transducer. A typical ultrasound imaging system uses a wide variety of transducers optimized for specific diagnostic applications. Each transducer is comprised of an array of piezoelectric transducer elements that transmit focused energy into the body and receive the resulting reflections. Each element is connected to the ultrasound system with fine coaxial cables. Typical transducers have 32 to as many as 512 elements and operate at frequencies from 1MHz to 15MHz. Most ultrasound systems provide two to as many as four switchable transducer connectors to allow the clinician to easily switch among the various transducers for each exam type.

High-voltage multiplexing

A typical phased-array ultrasound system will have from 32 to as many as 256 transmitters and receivers. In many cases, the system will have fewer transmitters and receivers than the number of available transducer elements. In these cases, high-voltage switches located in the transducer or system are used as multiplexers to connect a specific transducer element to a specific transmitter/receiver (Tx/Rx) pair. In this way, the system can dynamically change the active transducer aperture over the available transducer element array.

The requirements for these switches are severe. They must handle transmit pulses with voltage swings as large as $200V_{P-P}$ and with peak currents up to 2A. They must switch rapidly to quickly modify the configuration of the active aperture and maximize image frame rate. Finally, they must have minimal charge injection to avoid spurious transmissions and associated image artifacts.



Functional block diagram of an ultrasound imaging system. For a list of Maxim's recommended ultrasound solutions, please go to: www.maxim-ic.com/ultrasound.

High-voltage transmitters

A digital transmit beamformer typically generates the necessary digital transmit signals with the proper timing and phase to produce a focused transmit signal. High-performance ultrasound systems will generate complex transmit waveforms using an arbitrary waveform generator to optimize image quality. In these cases, the transmit beamformer generates digital 8-bit to 10-bit words at rates of approximately 40MHz to produce the required transmit waveform. Digital-to-analog converters (DACs) are used to translate the digital waveform to an analog signal, which is then amplified by a linear high-voltage amplifier to drive the transducer elements. This transmit technique is generally reserved for more expensive and less portable systems, as it can be very large, costly, and power hungry. As a result, the majority of ultrasound systems do not use this transmit-beamformer technique, but instead use multilevel high-voltage pulsers to generate the necessary transmit signals.

In this alternate implementation highly-integrated, high-voltage pulsers quickly switch the transducer element to the appropriate programmable high-voltage supplies to generate the transmit waveform. To generate a simple bipolar transmit waveform, a transmit pulser alternately connects the element to a positive and negative transmit supply voltage controlled by the digital beamformer. More complex realizations allow connections to multiple supplies and ground in order to generate more complex multilevel waveforms with better characteristics.

The slew rate and symmetry requirements for high-voltage pulsers have increased in recent years due to the popularity of second-harmonic imaging. Second-harmonic imaging takes advantage of the nonlinear acoustic properties of the human

body. These nonlinearities tend to translate acoustic energy at f_o to energy at $2f_o$. Reception of these second-harmonic signals has, for a variety of reasons, produced better image quality and is now widely used.

There are two basic methods used to implement second-harmonic imaging. In one method called standard-harmonic imaging, the second-harmonic of the transmit signal is suppressed as much as possible. As a result, the received second-harmonic derives solely from the nonlinear behavior of the body. This mode of operation requires that second-harmonic content of the transmit energy be at least 50dB below the fundamental. To achieve this, the duty cycle of the transmit pulse must be less than ±0.2% of a perfect 50% duty cycle. The other method, called pulse inversion, uses inverted transmit pulses to generate two phase-inverted receive signals along the same image line. Summation of these two phase-inverted receive signals in the receiver recovers harmonic signals generated by nonlinear processes in the body. In this pulse-inversion method, the summed phase-inverted transmit pulses must cancel as much as possible. To do this, the rise and fall times of the high-voltage pulsers must match very closely.

Image-path receivers

The ultrasound image-path receivers are used to detect 2D as well as pulsed-wave Doppler (PWD) signals necessary for color-flow imaging and spectral PWD. The receivers include a Tx/Rx switch; a low-noise amplifier (LNA); a variable-gain amplifier (VGA); an anti-alias filter (AAF); and an analog-to-digital converter (ADC).

Tx/Rx switch

A Tx/Rx switch protects the LNA from the high-voltage transmit pulse and isolates the LNA's input from the transmitter during the receive interval. The switch is usually implemented using an array of properly biased diodes which automatically turn on and off when presented with a high-voltage transmit pulse. The Tx/Rx switch must have fast recovery times to ensure that the receiver is on immediately after a transmit pulse. These fast recovery times are critical for imaging at shallow depths and for providing a low on-impedance to ensure that receiver noise sensitivity is maintained.

Low-noise amplifier (LNA)

The LNA in the receiver must have excellent noise performance and sufficient gain. In a properly designed receiver the LNA will generally determine the noise performance of the full receiver. The transducer element is connected to the LNA through a relatively long coaxial transducer cable terminated into relatively low impedance at the LNA's input. Without proper termination the cable capacitance, combined with the transducer element's source impedence, can significantly limit the bandwidth of the received signal from a broadband transducer. Termination of the transducer cable into a low impedance reduces this filtering effect and significantly improves image quality. Unfortunately, this termination also reduces the signal level at the input

to the LNA and, therefore, tends to reduce the receiver's sensitivity. Consequently, it is important for the LNA to have active-input-termination capability to provide the requisite low-input impedance termination and excellent noise performance required under these conditions.

Variable-gain amplifier (VGA)

The VGA, sometimes called a time gain control (TGC) amplifier, provides the receiver with sufficient dynamic range over the full receive cycle. Ultrasound signals propagate in the body at approximately 1540 meters per second and attenuate at a rate of about 1.4dB/cm-MHz round-trip. Immediately after an acoustic transmit pulse, the received "echo" signal at the LNA's input can be as large as $0.5V_{P-P}$. This signal quickly decays to the thermal noise floor of the transducer element. The dynamic range required to receive this signal is approximately 100dB to 110dB, and is well beyond the range of a realistic ADC. As a result, a VGA is used to map this signal into the ADC. A VGA with approximately 30dB to 40dB of gain is necessary to map the received signal into a typical 12-bit ADC used in this application. The gain is ramped as a function of time (i.e., "time gain control") to accomplish this dynamic range mapping.

The instantaneous dynamic range of an ultrasound receiver is also very important; it affects 2D image quality and the system's ability to detect Doppler shifts and thus blood or tissue motion. This is especially true in second-harmonic imaging where the second-harmonic signals of interest can be significantly less than signals at the transmit fundamental. It is also the case in Doppler modes where small Doppler signals can be located within 1kHz or less of very large signals from tissue or vessel walls. As a result, both the broadband and near-carrier SNR is of prime interest, and is often limited by this stage of the receiver.

Anti-alias filter (AAF) and ADC

The AAF in the receive chain keeps high-frequency noise and extraneous signals that are beyond the normal maximum imaging frequencies from being aliased back to baseband by the ADC. Many times an adjustable AAF is provided in the design. To avoid aliasing and to preserve the time-domain response of the signal, the filter itself needs to attenuate signals beyond the first Nyquist zone. For this reason Butterworth or higher-order Bessel filters are used.

The ADC used in this application is typically a 12-bit device running from 40Msps to 60Msps. This converter provides the necessary instantaneous dynamic range at acceptable cost and power levels. In a properly designed receiver, this ADC should limit the instantaneous SNR of the receiver. As previously mentioned, however, limitations in the poor-performing VGAs many times limit receiver SNR performance.

Digital beamformers

The ADC's output signals are typically routed to digital-receive beamformers through a high-speed LVDS serial interface. This approach reduces PC-board (PCB) complexity and the number of interface pins. The beamformer contains upconverting lowpass or bandpass digital filters which increase the effective sample rate by as much as 4x to improve the system's beamforming resolution. These upconverted signals are stored in memory and appropriately delayed, and then summed by a delay-coefficient calculator to yield the appropriate focus. The signals are also appropriately weighted, or "apodized," using an apodization calculator before summing. This step appropriately windows the receive aperture to lower the side-lobe interference of the receive beam and improve image quality.

Beamformed digital-signal processing

Received, beamformed, digital ultrasound signals are processed for visual and audio output using a wide variety of DSP and off-the-shelf PC-based computer solutions. This process can generally be separated into B-mode or 2D image processing, and Doppler processing associated with color-flow image generation and both PWD and continuous-wave Doppler (CWD) spectral processing.

B-mode processing

In B-mode processing, the RF beamformed digital signal is properly filtered and detected. The detected signal has an extremely wide dynamic range, which the B-mode processor must digitally compress into the visible dynamic range available for the display.

Color-flow processing

In color-flow processing, the RF digital beamformed data is digitally mixed by using quadrature local oscillators (LOs) at the transmit frequency to do the complex mixing into I and Q baseband signals. As a result, each sample of the acoustic receive line has associated magnitude and phase values assigned. In color-flow processing, 8 to 16 acoustic lines are typically collected along the same image path line in order to measure Doppler shifts. Reflections from moving blood flow or from moving tissue along that image path will create a

Doppler shift and, therefore, change the phase of the baseband I/Q samples where that shift occurred. The color processor determines the average phase shift versus time for each point along that image path over the 8 to 16 lines; the processor also assigns a color to represent that average velocity. In this way, a two-dimensional color representation of blood or tissue motion can be made.

Spectral Doppler

In spectral processing, the beam-formed digital signals are digitally filtered, mixed to baseband by using quadrature local oscillators (LOs) at the transmit frequency, and then sampled at the transmit pulse repetition frequency (PRF). A complex, fast Fourier transform (FFT) is used to generate an output spectrum representing the velocity content of the signal. The signal magnitude for each bin of the FFT output is calculated and compressed to optimize the available, visible display dynamic range. The signal magnitude is finally displayed versus time on the ultrasound display.

With CWD the signal is processed in much the same way. In addition to processing these signals for display, the spectral processor also generates left and right stereo audio signals that represent positive and negative velocities. An ADC converts these signals which are used to drive external speakers and headphones.

Display processing

The display processor performs the computations necessary to map the polar-coordinate, acoustic image data from the B-mode or color-flow processor into the rectangular-coordinate bitmap image to avoid image artifacts. This processing is generally referred to as R-θ conversion. The display processor also performs other spatial-image-enhancement filtering functions.

Continuous wave Doppler (CWD)

CWD is a modality available in most cardiac and general-purpose ultrasound imaging systems, and it is used to accurately measure the higher-velocity blood flows typically found in the heart. In CWD mode, the available ultrasound transducer elements are split into equal halves about the center of the transducer aperture. Half of the elements are used as transmitters to produce a focused acoustic CWD transmit beam; the other half of the elements serve as receivers to produce a focused receive beam. The signals applied to the transmit elements are square waves at the Doppler frequency of interest, typically 1MHz to 7.5MHz. Transmit jitter needs to be minimized to avoid phase-noise generation that can adversely affect Doppler phase-shift detection. The transmit beam is focused by properly phasing the signals applied to the transmit elements. In a similar way, the CWD received signals are focused by phasing and summing the signals from each receive element. Because the transmitters are on simultaneously with the receivers in this mode, the Doppler signals of interest are typically within a few kilohertz of a very large receive signal that is generated by reflections from stationary tissue at the transmit fundamental. The dynamic range necessary to handle this large signal is well beyond the range of the VGA, AAF, and 12-bit ADC in the image-receive path. As a result, an alternative high-dynamic receive solution for CWD is necessary.

CWD receivers are typically implemented in one of two ways. In one method high-performance ultrasound systems typically extract a received CWD signal at the LNA output. Complex mixers at an LO frequency equal to the transmit frequency are then used to beamform the signals and mix them to baseband for processing. The phase of the I/Q LOs can be adjusted on a channel-by-channel basis to shift the phase of the received CWD signal. The output of these mixers is summed, bandpass filtered, and converted by an ADC. The resulting baseband beamformed signal is in the audio range (100Hz to 50kHz). Audio-frequency ADCs are used to digitize the I and Q CWD signals. These ADCs need significant dynamic range to handle both the large low-frequency Doppler signals from moving tissue and the smaller signals from blood.

The other method to receive a CWD signal uses delay lines and is usually employed in low-cost systems. In this implementation signals are again extracted at the LNA's output and converted into current signals. A crosspoint switch sums channels with similar phases into 8 to 16 separate output signals, as determined by the receive beamformer. Delay lines are used to delay and sum these signals into a single beamformed signal at the RF frequency. This signal is then mixed to baseband using an I/Q mixer with an LO at the transmit frequency. The resulting baseband audio signal is filtered and converted to a digital representation.

www.maxim-ic.com/ultrasound

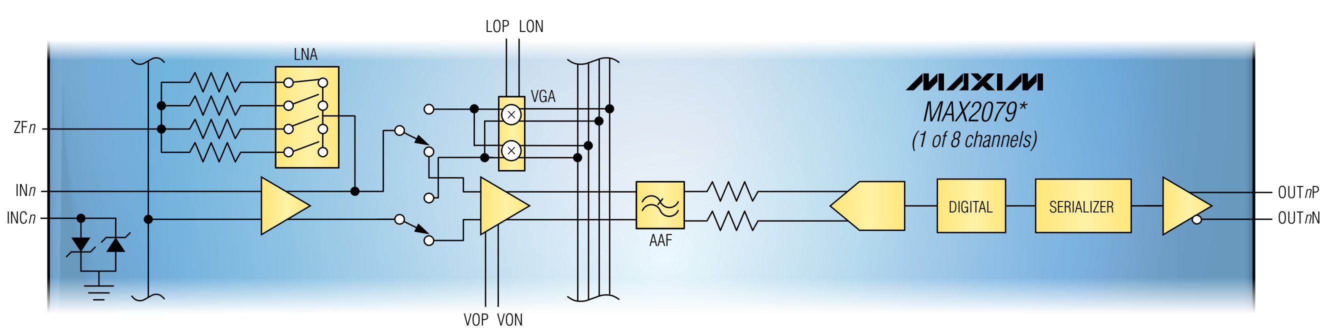
Fully integrated, ultra-low-power, 8-channel front-end provides superior image quality and sensitivity for difficult imaging

MAX2079*

Optimized for low-cost, high-channel-count, high-performance portable and cart-based ultrasound systems, the MAX2079 is a fully integrated, 8-channel ultrasound front-end with a 12-bit ADC. The highly compact and low-power imaging receiver lineup has the lowest noise and highest dynamic range of any competitive, fully integrated product. The receiver lineup achieves an ultra-low 2.4dB noise figure at $R_S = R_{IN} = 200\Omega$, and a full-scale output SNR of 67dBFS with a very low 115mW-per-channel power dissipation. A fully integrated, high-performance, mixer-based programmable CWD beamformer is also included. The MAX2079 gives superior image quality and sensitivity under the most difficult imaging conditions.

Benefits

- **High integration for high-channel-count, small portable or cart-based systems**
  - Octal BiCMOS LNA, VGA, AAF, mixer-based CWD beamformer, and 12-bit CMOS ADC
  - Small, 10mm x 10mm, 144-ball multichip module (MCM) BGA package (0.8 mm pitch)
- **Low power for longer battery life and reduced heat dissipation**
  - 115mW/channel in imaging modes
- **High performance**
  - 2.4dB receiver NF at $R_S = R_{IN} = 200\Omega$ for improved sensitivity and penetration
  - 67dB broadband SNR at gain = 30dB for improved second-harmonic imaging
  - 140dBc narrowband SNR at 1kHz offset from $V_{OUT} = 1\ V_{P-P}$, 5MHz carrier for superior PWD and color flow
  - 155dBc narrowband CWD path SNR at 1kHz offset from $V_{IN} = 200mV_{P-P}$, 1.25MHz carrier for improved CWD sensitivity to low-velocity flow
- **Unique features that reduce board space**
  - Programmable impedance, active-input-termination LNA (50, 100, 200, and 1kΩ)
  - Integrated input-protection diodes



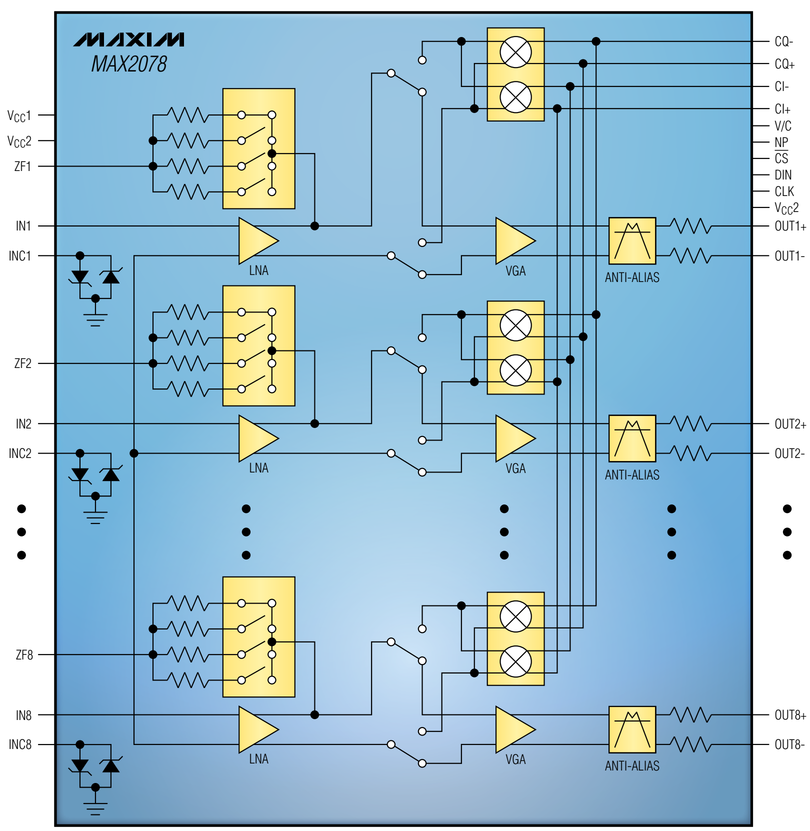
Simplified block diagram of internal schematics for the MAX2079.

*Future product—contact factory for availability.

Integrated 8-channel front-end provides unmatched performance with less space and power

MAX2078/MAX2077

The MAX2078/MAX2077 are 8-channel ultrasound front-ends optimized for high-channel-count, high-performance, cart-based ultrasound systems. The easy-to-use ICs deliver high-end, 2D PWD and CWD imaging capability using substantially less space and power. The highly compact imaging receiver lineup achieves an ultra-low 2.4dB NF at $R_S = R_{IN} = 200\Omega$ at a very low 64.8mW-per-channel power dissipation. When coupled with the MAX1437B octal ADC, the receiver lineup achieves 4dB greater SNR than its nearest competitor and yields superior second-harmonic imaging and color Doppler sensitivity. The MAX2078 also integrates a high-performance mixer-based, programmable CWD beamformer. The device can be combined with the MAX1437B/MAX1438B ADCs for ultra-high performance at only 161mW per channel, or with the MAX19527 for an excellent high-performance, low-power solution for only 123mW per channel.



Typical operating circuit for the MAX2078.

Benefits

- **High integration for high-channel-count, cart-based systems**
  - Octal LNA, VGA, AAF, and mixer-based CWD beamformer
  - Small, 10mm x 10mm TQFN package
- **Low power for reduced heat dissipation and to facilitate designs with fewer PCBs**
  - 65mW/channel in imaging mode
- **High performance**
  - 2.4dB receiver NF at $R_S = R_{IN} = 200\Omega$ for improved sensitivity and penetration
  - $23nV/\sqrt{Hz}$ output referred noise (68dB SNR at gain = 30dB with the MAX1437B 12-bit ADC) for excellent second-harmonic imaging
  - 140dBc narrowband image path SNR at 1kHz offset from $V_{OUT} = 1\ V_{P-P}$, 5MHz carrier for superior PWD and color flow
  - 155dBc narrowband CWD path SNR at 1kHz offset from $V_{IN} = 200mV_{P-P}$, 1.25MHz carrier for improved CWD sensitivity to low-velocity flow
- **Unique features that reduce board space**
  - Programmable active-input-termination impedance LNA (50, 100, 200, and 1kΩ)
  - Integrated input-protection diodes

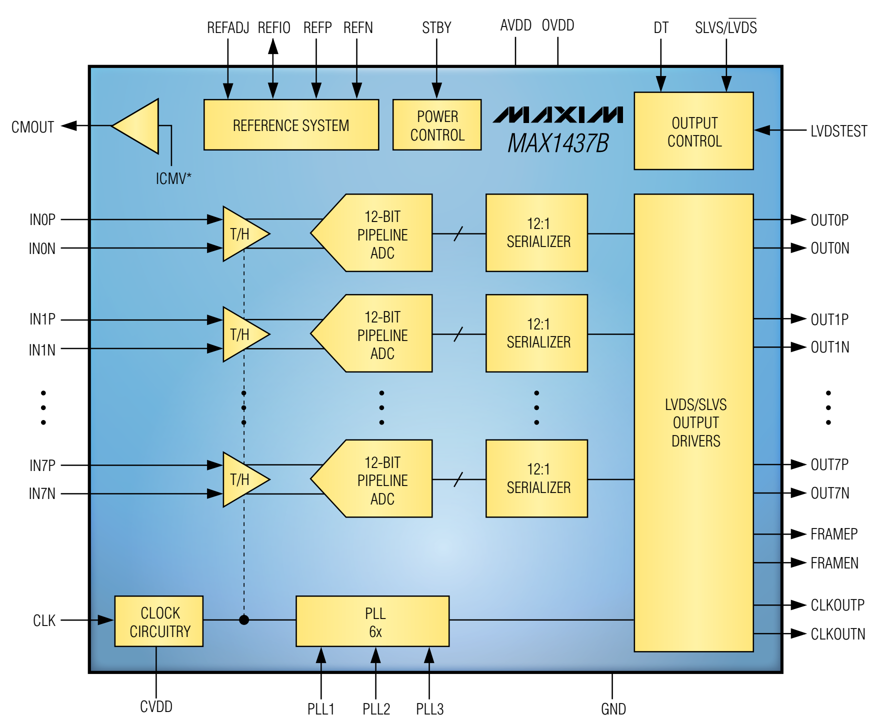
8-channel, 12-bit ADC for superior second-harmonic imaging and color flow

MAX1437B/MAX1438B

The MAX1437B/MAX1438B are high-performance 50Msps/64Msps (respectively) octal ADCs for high-performance ultrasound applications. Serial LVDS outputs reduce interface complexity and beamformer pin count. Optimized for rapid overload recovery, both devices will recover from a 6dB overload within 1 clock cycle. The MAX1437B provides an impressive broadband SNR performance of 70.7dBFS for superior second-harmonic imaging, and a narrowband SNR of 140dBc/Hz at 1kHz offset for superior color flow and PWD sensitivity.

Benefits

- **High integration for high-channel-count, cart-based systems**
  - 8 channels per package
  - Serial LVDS outputs
  - Compact 68-pin, 10mm x 10mm TQFN package
- **Low power for reduced heat dissipation and to facilitate designs with fewer PCBs**
  - 96mW per channel at 50Msps
- **High performance**
  - 70.3dBc broadband SNR for excellent second-harmonic imaging
  - 140dBc/Hz narrowband SNR at 1kHz offset from 5MHz FS tone for PWD and color flow
- **Feature rich for debugging and ease of design**
  - Test mode for digital signal integrity



*ICMV = INPUT COMMON-MODE VOLTAGE (INTERNALLY GENERATED).

Typical operating circuit for the MAX1437B.

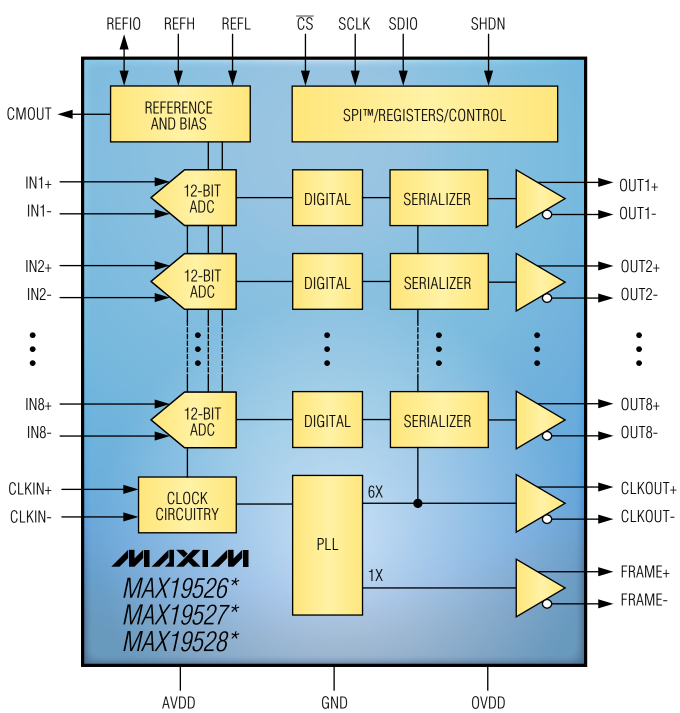
Ultra-low-power, 8-channel, 12-bit ADCs for portable and cart-based ultrasound imaging

MAX19526*/MAX19527/MAX19528*

The MAX19526/MAX19527/MAX19528 are ultra-low-power (52mW per channel at 40Msps), 40Msps to 64Msps, octal ADCs optimized for portable and price-sensitive, high-channel-count, cart-based ultrasound imaging applications. The ADCs achieve an impressive broadband SNR performance of 69dBFS for superior second-harmonic imaging, and a narrowband SNR of 140dBc/Hz at 1kHz offset. This performance provides superior color flow and PWD sensitivity. Further power savings can be achieved by proper utilization of the programmable LVDS output-current feature and the flexible nap and sleep modes. The devices also support differential clock inputs to reduce sensitivity to common-mode clock noise.

Benefits

- **High integration for high-channel-count, cart-based systems**
  - 8 channels per package
  - Serial LVDS outputs
  - Compact 68-pin, 10 mm x 10 mm BGA package
- **Ultra-low power improves reliability and reduces system costs**
  - 52mW per channel at 40Msps
- **High performance**
  - 69dBc broadband SNR for excellent second-harmonic imaging
  - 140dBc/Hz narrowband SNR at 1kHz offset from 5MHz FS tone for PWD and color flow
- **Flexible power-saving features**
  - Programmable LVDS output current
  - Sleep and fast-wake-up nap mode



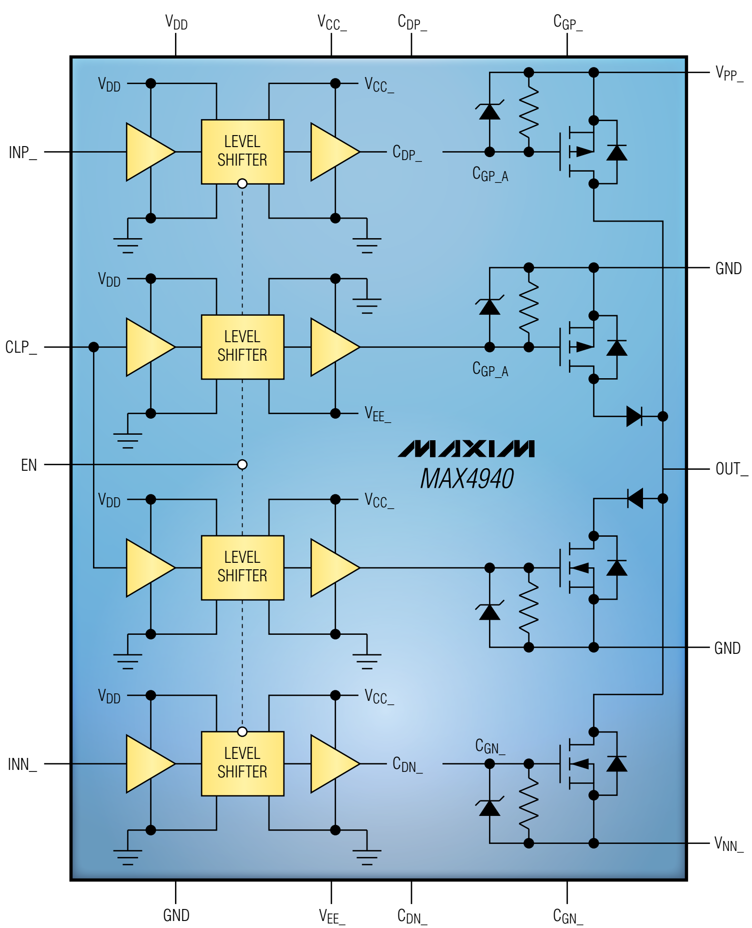
Typical operating circuit for the MAX19526/MAX19527/MAX19528.

*Future part—contact factory for availability.

Highly integrated digital pulsers use active clamping to enhance ultrasound imaging

MAX4940/MAX4940A

The MAX4940/MAX4940A dual/quad pulsers generate high-voltage, high-frequency, unipolar or bipolar (respectively) pulses from low-voltage logic inputs. The ICs feature independent logic inputs, independent high-voltage outputs with active clamps, and independent high-voltage supply inputs. These high-voltage pulsers provide 8.5Ω output impedance for the high-voltage outputs and a 21Ω impedance for the active clamp. The high-voltage outputs can provide 2.0A (typ) output current.



Typical operating circuit for the MAX4940.

Benefits

- **High density in smaller packages for high-channel-count, portable or cart-based systems**
  - Quad design (MAX4940A) with integrated active return to zero (RTZ)
  - TQFN (8mm x 8mm) package
- **High levels of integration**
  - Automatic, DC-coupled, 0.75A (typ) clamp feature improves 2D image quality
  - AC-coupled pulser (2A, typ) supports high-current output
- **Higher performance with lower power**
  - 15ns matched propagation delays for improved transmit focus
  - Matched rise/fall times and low second-harmonic distortion for improved second-harmonic imaging
  - -156dBc/$\sqrt{Hz}$ phase noise at 1kHz offset from a 1.25MHz transmit signal for improved low-velocity PWD and CWD sensitivity
  - Zero quiescent power consumption for longer battery life in portable imaging applications

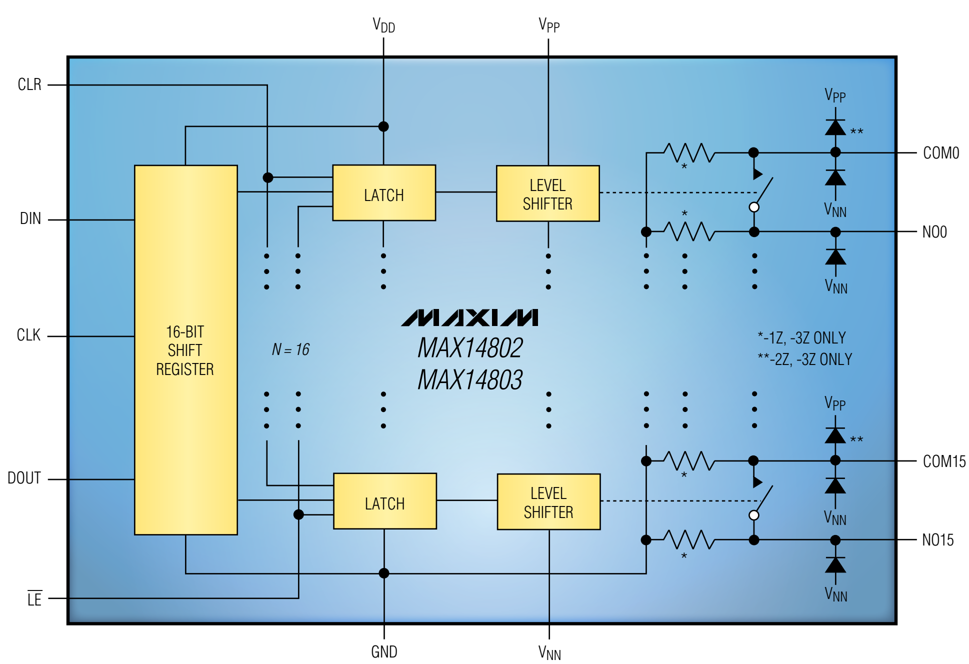
High-density, 16 channel, high-voltage switches allow design flexibility

MAX14802/MAX14803

The MAX14802/MAX14803 provide high-voltage switching on 16 channels for ultrasonic imaging. The devices utilize HVCMOS process technology to provide 16 high-voltage, low-charge-injection SPST switches, controlled by a digital interface. Data is clocked into an internal 16-bit shift register and retained by a programmable latch with enable and clear inputs. A power-on reset ensures that all switches are open on power-up

Benefits

- **High density in smaller packages facilitates smaller transducers**
  - 16 individually programmable high-voltage analog switches
  - 7mm x 7mm TQFP package; CSBGA available
- **Higher performance with lower power**
  - 20MHz serial interface (5V) facilitates higher frame rates
  - 0µA (typ) quiescent current for reduced power dissipation and heat
- **Integrated flexibility and system protection**
  - Integrated overvoltage protection (OVP) for improved reliability
  - Low-charge-injection, low-capacitance RL switches for reduced image artifacts
  - Daisy-chainable serial interface for efficient PCB layout
  - Flexible high-voltage supplies (V_{P-P}- V_{NN} = 250V) accommodate higher supply voltages

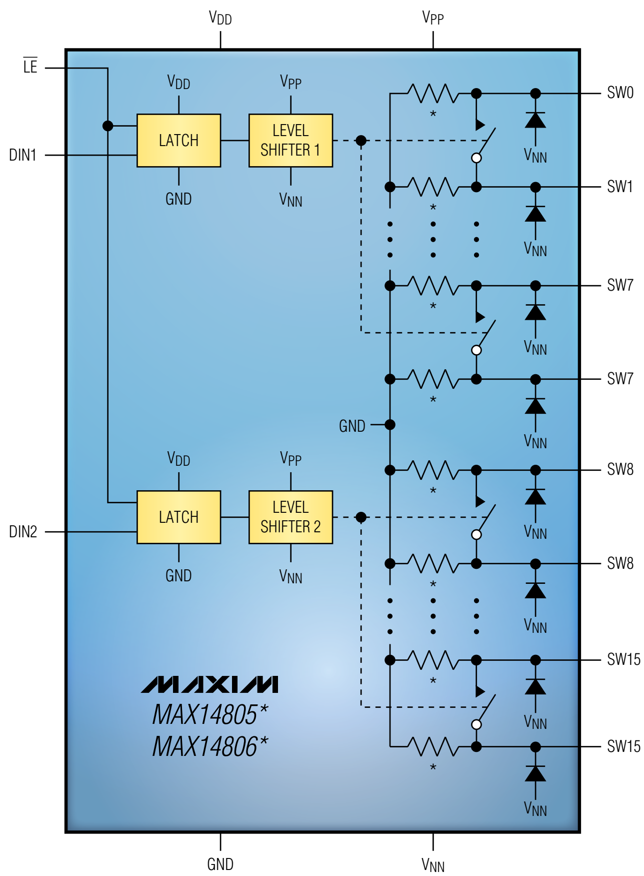


Typical operating circuit for the MAX14802/MAX14803.

Dual, 8-channel, high-voltage switches need no programming

MAX14805*/MAX14806*

The MAX14805/MAX14806 use 250V process technology to provide high-voltage switching on 16 channels configured as two sets of eight SPST switches for ultrasonic imaging. All switches are controlled by a digital interface. This design is optimized for banks selection in biplane or triplane ultrasound probes and relays replacement in medical ultrasound systems.



* BLEED RESISTORS AVAILABLE ON THE MAX14806 ONLY.

Typical operating circuit for the MAX14805/MAX14806.

Benefits

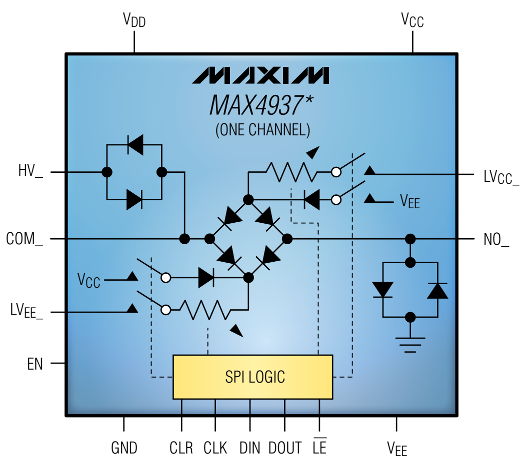
- **High density in smaller packages facilitates smaller transducers**
  - Two sets of eight high-voltage SPST analog switches
- **Higher performance with lower power**
  - DC to 20MHz low-voltage, analog signal-frequency range facilitates higher-frequency imaging
  - Very low quiescent current for reduced power dissipation and heat
  - -77dB (typ) off-isolation at 5MHz (50Ω) for improved 2D image quality
- **Integrated application flexibility**
  - Flexible high-voltage supplies accommodate higher supply voltages
  - 2.7V to 5.5V logic supply voltage for improved ease of use
  - Low-capacitance 20Ω switches for reduced image artifacts
  - Version with bleed resistor available

*Future part—contact factory for availability.

Octal, high-voltage Tx/Rx switches replace discrete components and reduce board space by half

MAX4936*–MAX4939*

The MAX4936–MAX4939 are highly integrated octal, high-voltage Tx/Rx switches. A latch-clear input asynchronously turns off all Tx/Rx switches and puts the devices into a low-power shutdown mode. Each Tx/Rx switch is based on a diode-bridge topology. The amount of current in all the bridges can be programmed with the SPI interface. The switches can be individually turned on and off with SPI for receiver-path multiplexing applications.



Typical operating circuit for the MAX4937.

Benefits

- **High density in smaller packages for high-channel-count, portable or cart-based systems**
  - Octal Tx/Rx switches
  - SPI-programmable switches for reduced pin count and smaller size
  - Low-voltage receive path with high-voltage protection (±110V)
  - Versions available with high-voltage transmit path and low-voltage isolation (grass-clipping diodes)
- **Higher performance with lower power**
  - Individually programmable, 4-bit binary bias resistors (from 187Ω to 2800Ω) for optimized power and performance
  - Low output noise for improved sensitivity
  - Wide -3dB bandwidth at 80MHz facilitates wideband, high-frequency imaging
  - Low 8Ω at 10mA on-impedance for reduced noise and improved sensitivity
  - Dedicated voltage supply allows use of external inductors for better SNR, crosstalk, and power-supply rejection ratio (PSRR)
- **Feature rich for design flexibility**
  - Flexible power supplies (V_{CC}, V_{EE} = +2.7V to +5.5V, V_{DD} = +1.8V to +5.5V) for ease of design

*Future part—contact factory for availability.

Recommended solutions

Part	Description	Features	Benefits
AFEs			
MAX2034	Quad ultrasound LNA	Ultra-low noise; programmable active-input termination; integrated input-protection diodes	Quad ultrasound-specific LNA allows flexible partitioning
MAX2035	Octal ultrasound VGA	High dynamic range; compatible with 10-bit ADCs	Performance optimized for economical 10-bit ADC imaging architectures
MAX2036	Octal ultrasound VGA with CW octal mixers	Compatible with 10-bit ADCs; low noise; high dynamic range; fully integrated mixer-based CWD beamformer	Performance optimized for economical 10-bit ADC imaging architectures; integrated CWD beamformer
MAX2037	Octal ultrasound VGA	Low noise; high dynamic range; compatible with 12-bit ADCs	Best performance for 12-bit ADC imaging architectures
MAX2038	Octal ultrasound VGA with integrated CW octal mixers	High dynamic range; compatible with 12-bit ADCs; fully integrated mixer-based CWD beamformer	Best performance for 12-bit ADC imaging architectures; integrated CWD beamformer
MAX2077	Octal ultrasound front-end with LNA, VGA, and lowpass AAF	Programmable active-input termination LNA; low noise; high dynamic range; 65mW per channel	High integration and high-sensitivity 2D and PWD for high-channel-count, cart-based systems
MAX2078	Octal ultrasound front-end with LNA, VGA, lowpass AAF, and CWD mixers	Programmable active-input termination LNA; low noise; high dynamic range; 65mW per channel; fully integrated mixer-based CWD beamformer	Saves space and power in high-channel-count systems; high-sensitivity 2D, PWD, and CWD for high-channel-count, cart-based systems
MAX2079*	Octal, ultrasound front-end with LNA, VGA, lowpass AAF, CWD mixers, 12-bit, 50Msps ADC	Programmable active-input termination LNA; low noise; high dynamic range; 12-bit ADC; 115mW per channel; fully integrated mixer-based CWD beamformer	Saves space and power in portable imaging applications, high-sensitivity 2D, PWD, and CWD, improved image quality
High-speed ADCs			
MAX1193	Dual, 8-bit, 45Msps ADC	Ultra-low power	Extends battery life for portable ultrasound
MAX1434	Octal, 10-bit, 50Msps ADC	Space-saving serial LVDS interface; compact TQFP package	Ideal for low-cost systems
MAX1436/37/38	Octal, 12-bit, 40/50/65Msps ADCs	High-broadband and narrowband SNR; low-power; space-saving serial LVDS interface	High-performance 2D and PWD image quality
MAX1437B/38B	Octal, 12-bit, 50/64Msps ADCs, 10mm x 10mm package	High density, high-broadband and narrowband SNR; low power; serial LVDS interface	High-integration and compact design for high-channel-count, cart-based systems
MAX19526*/27*/28*	Octal, 12-bit, 40/50/64Msps ADCs, 10mm x 10mm package	High density, high-broadband and narrowband SNR; ultra-low power, serial LVDS interface; 53mW per channel at 40Msps	Uncompromised 2D and Doppler sensitivity; ultra-low power; ultra-small package
High-speed DACs			
MAX5180	Dual, 10-bit, 40MHz, current-output simultaneous-update DAC, 6mm x 10mm package	Fully differential output; interleaved data bus; 11mW per channel at 40Msps	Space-saving solution for generating high-performance transmit arbitrary waveforms
MAX5183	Dual, 10-bit, 40MHz, voltage-output simultaneous-update DAC	Dual channels; interleaved data bus; 11mW per channel at 40Msps; 6mm x10mm package	Ultra-low power; compact solution for generating high-performance transmit arbitrary waveforms
MAX5853	Dual, 10-bit, 80Msps, current-output DAC	Interleaved data bus option; 29mW per channel at 80Msps; 6mm x 6mm package	Space-saving solution for generating high-performance transmit arbitrary waveforms
High-voltage muxes			
MAX4800/02	8-channel, high-voltage analog switches	Low charge injection; low capacitance; low R_{ON}	Reduce associated image artifacts
MAX4800A/02A	8-channel, high-voltage analog switches with 20MHz serial interface	Low charge injection; low capacitance; low R_{ON}; fast SPI interface	Low charge injection reduces image artifacts; fast SPI interface improves frame rate
MAX14802/03	16-channel, high-voltage analog switches with SPI interface	Low charge injection; integrated OVP; low capacitance; fast turn-on/off times	Reduce system and/or transducer size; ideal for space-constrained solution

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
High-voltage muxes (continued)			
MAX14805*/06*	Dual, 8-channel, high-voltage analog switches with low charge injection	Integrated OVP; low capacitance; switchable banks; fast turn-on/off times	Faster frame rates; low spurious transmissions; fewer associated artifacts
High-voltage pulsers			
MAX4806/07	Dual, 2A (min), unipolar/bipolar, high-voltage digital pulsers	Active-clamp circuitry for reduced second-harmonic output; low jitter; low power; 7mm x 7mm TQFN package	Improve Doppler sensitivity to low-velocity flow; improve second-harmonic imaging
MAX4810/11	Dual, 1.3A (min), unipolar/bipolar, high-voltage digital pulsers	Reduced second-harmonic output; low jitter; low power; 7mm x 7mm TQFN package	Improve second-harmonic imaging; improve Doppler sensitivity to low-velocity flow
MAX4940/ MAX4940A	Quad, 2.1A (typ), unipolar/bipolar, high-voltage digital pulsers	Active-clamp circuitry for reduced second-harmonic output; low jitter; matched rise/fall times; matched propagation delays	Improve second-harmonic distortion; enhance image quality
High-voltage Tx/Rx switches			
MAX4936*–MAX4939*	Octal, integrated, high-voltage Tx/Rx switches, 5mm x 11mm package	SPI-programmable bias resistors; low on-impedance; versions with high-voltage transmit-path protection and low-voltage isolation	Save space and power in high-channel-count and portable ultrasound systems
Audio headphone drivers			
MAX4230–MAX4234	Single/dual/quad, 10MHz, low-noise op amps	$10nV/\sqrt{Hz}$, excellent RF immunity; shutdown; small SC70 package	Smallest footprint for portable systems
MAX9724	60mW, fixed-gain, DirectDrive®, stereo headphone amplifier with low RF susceptibility and shutdown	Click-pop suppression; small package; low 0.003% THD+N; excellent RF immunity	Eliminates need for DC-blocking capacitors; reduces size and cost
MAX9705	2.3W, ultra-low-EMI, filterless, Class D audio amplifier	Class D efficiency and 0.02% THD+N	Efficient solution and ultra-low EMI; speeds time to market
MAX9718/19	Low-cost, mono/stereo, 1.4W differential, audio power amplifiers	Class AB with superior THD+N down to 0.002%	Simple, high-fidelity solution
Fan controller			
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
Fuel gauges			
DS2782	I^2C fuel gauge	FuelPack™ algorithm with precision voltage, current, temperature monitor; EEPROM	Improves battery-status reporting
DS2776/78	1-Wire®/I^2C, 2-cell stand-alone fuel gauges with Li+ protector and SHA-1 authentication	FuelPack algorithm with precision voltage, current, and temperature monitor; programmable protector; SHA-1 authentication	Save space and simplify design
DS2788	Stand-alone fuel gauge with LED drivers for multiple cells	FuelPack algorithm with precision voltage, current, and temperature monitor; programmable resistive-divider switch; LED drivers	Simplifies high-cell-count designs
MAX1789	2-/3-/4-cell battery fuel gauge and protector	Accurate fuel gauge; 8-bit RISC microcontroller core; integrated primary-protection IC	High accuracy; maximizes battery utilization
LED drivers			
MAX7313	16-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V; global and individual PWM intensity control with blinking	Tolerates lower supply voltage; simplifies driving LED indicators and backlights
MAX7315	8-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V; 50mA output drive; global and individual PWM intensity control with blinking	Tolerates lower supply voltage; drives heavier loads; simplifies driving LED indicators and backlights

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
LED drivers (continued)			
MAX7323	I²C port expander with four push-pull outputs and four open-drain I/Os	1.71V to 5.5V; I²C; 20mA	Operates from low supply voltage while I/O operates at 6V, thus simplifying power design
Low-speed ADCs			
MAX1162	SAR ADC, serial	16-bit; 200ksps; 10µA shutdown; low 12.5mW power dissipation; 10-pin µMAX® package	Preserves battery life; saves space for portable systems
MAX1132	SAR ADC, serial	16-bit with no missing codes; 200ksps; single channel; 0 to 12V or ±12V input, integrated reference	High precision for wide input-voltage ranges; integration saves space and cost
Low-speed DACs			
MAX5580	Buffered, fast-settling, 12-bit DAC	3µs (max) settling time to 0.5 LSB; internal buffer; glitch-free buffered output	Saves board space with no need for an external buffer
MAX5661	Single-channel, 16-bit DAC with serial interface	Current- or voltage-buffered output	Saves space
Op amps			
MAX4475–MAX4478 MAX4488/89	Low-noise, low-distortion, CMOS-input op amps in a SOT23 package	4.5nV/$\sqrt{Hz}$ input noise; excellent distortion characteristics; 750µV (max) V_{OS}; tiny package	Save board space; excellent SNR for improved CWD sensitivity; RF immunity makes them ideal for use in sensitive environments
MAX410/12/14	Single/dual/quad, 28MHz, low-noise, low-voltage, precision op amps	1.5nV/$\sqrt{Hz}$ low-input noise, precision 250µV (max) V_{OS} and large 28MHz bandwidth; single 5V and dual ±5V rails; small TDFN package	Save board space; excellent SNR for improved CWD sensitivity
MAX9632*	36V precision, low-noise, wideband op amp	1.1nV/$\sqrt{Hz}$; 55MHz; 30V/µs; 125µV (max) V_{OS}; rail-to-rail output; fast 700ns settling to 16-bit accuracy; 3mm x 3mm small TDFN package	High-performance ADC driver for 24-bit delta-sigma converter-based systems; improves system resolution and performance
MAX9633*	36V dual op amp for 16-bit SAR ADC front-ends	2.8nV/$\sqrt{Hz}$; 36MHz; 18V/µs; 100µV (max) V_{OS}; fast 600ns settling to 16-bit accuracy; 3mm x 3mm small TDFN package	High-performance ADC driver for 16-bit SAR ADC converters improves CWD system resolution and performance
Power			
MAX5072	Dual-output buck or boost converter	2.2 MHz; dual outputs with POR and PFO	High frequency and internal FETs reduce total solution size
MAX1951	1MHz, all-ceramic, 2.6V to 5.5V input, DC-DC regulator	2.6V to 5.5V input; 2A; internal FET	Internal FET reduces complexity
MAX8556	Ultra-low-input-voltage LDO regulator	1.425V to 3.6V input voltage range; 4A output current	High current; fully protected from an output short circuit; provides robust design
References			
MAX6034_25	Precision, micropower, low-dropout, series voltage reference in SC70 package	25ppm/°C (max) temperature coefficient (-40°C to +85°C); ±0.2% (max) initial accuracy	More stability versus ambient temperature variations improves measurement repeatability
MAX6033	Ultra-high-precision, series voltage reference in SOT23 package	Ultra-low 7ppm/°C (max) temperature drift; low 16µV_{P-P} noise (0.1Hz to 10Hz) (2.5V output)	Reduces integrated systems noise
MAX6029	Ultra-low-power, precision series voltage reference	Ultra-low 5.25µA (max) supply current; 30ppm/°C (max) temperature coefficient	Saves power in handheld applications; increases stability over temperature
MAX6173	High-precision voltage reference with temperature sensor	Wide (V_{OUT} + 2V) to +40V supply voltage range; excellent 3ppm/°C (max) temperature stability; low 3.8µV_{P-P} noise	Wide operating voltage levels; improved performance over temperature; better systems-noise budget

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*Future part—contact factory for availability.

Visit digikey.com

Recommended solutions *(continued)*

Part	Description	Features	Benefits
RF ICs			
MAX2830	2.4GHz to 2.5GHz RF transceiver with power amplifier	ISM band operation; integrates all circuitry required to implement the RF transceiver function	Saves space by eliminating the need for an external SAW filter
MAX2900–MAX2904	200mW single-chip transmitters for 868MHz/915MHz ISM bands	Comply with the FCC CFR47 part 15.247 902MHz to 928MHz ISM band specifications	High integration with minimal external components
MAX7030	Low-cost, factory-programmed ASK/OOK transceiver	Low current; compact package; no programming interface required	Long battery life; smaller size; faster and simpler product design
MAX7031	Low-cost, factory-programmed FSK transceiver	Low current; compact package; no programming interface required	Smaller size; faster and simpler product design
Supervisors			
MAX6720	Triple-voltage supervisor	Two fixed, one adjustable thresholds	Versatile for easy design reuse; saves space in small modules
MAX6746	Capacitor-adjustable watchdog and reset IC	Capacitor-adjustable timing; low power	Complete system management in easy-to-use, integrated solution
MAX16033	Battery-backup switchover	Battery backup; reset, chip-enable gating; PFI/PFO	Versatile for easy design reuse; saves space in small modules
MAX16054	Pushbutton on/off controller	±15kV ESD protection	Saves space and increases reliability by combining multiple functions in one IC
MAX6495	72V overvoltage protector	Easy to use; highly integrated	Increases system reliability by preventing component damage from high-voltage transients; saves space; easy to use
Temperature sensors			
DS600	Precision, analog-output temperature sensor	Industry's highest accuracy: ±0.5°C from -20°C to +100°C	Improved system temperature-monitoring accuracy
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 and registers	Industry-standard pinout allows easy upgrade
DS75LV	Low-voltage digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C; 1.7V to 3.7V operation; industry-standard pinout and registers	Industry-standard pinout allows easy conversion from LM75 to lower supply voltage
Video filters			
MAX9502G/M	2.5V video amplifiers with reconstruction filter	6-pin µDFN and 5-pin SC70 packages; low cost; DC-coupled input and output; low-current shutdown; fixed 6dB/12dB gain	Small size for portable applications; reduce component count, low-power shutdown mode
MAX9652/53/54	3.3V, HD/SD triple-channel filter amplifiers with shutdown	2V/V gain; 42MHz passband for high definition (HD) with 50dB attenuation at 109MHz	Selectable lowpass filter (MAX9654) allows for HD/SD switchable operation
MAX9586–MAX9589	Single/dual/triple/quad, standard-definition (SD) video filter amplifiers with AC-coupled input buffers	Low power; small size; 8.5MHz passband; 55dB attenuation at 27MHz	Multiple video input streams with combination of sync-tip clamp or bias clamp provide flexibility
MAX9507	1.8V DirectDrive video filter amplifier with load detection	Dual SPST analog switches controlled through I^2C; internal gain of 8V/V	DirectDrive sets black-level output to ground, reduces number of passive components required
MAX7450/51/52	Video signal conditioners with AGC and back-porch clamp	Back-porch clamp-to-GND (adj); fault detection with loss-of-signal (LOS) output; settable 0dB/6dB gain	Automatic gain control (AGC) and output clamp control improve signal quality

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

Positron emission tomography (PET) imaging

Overview

Positron emission tomography (PET) imaging systems construct 3-D medical images by detecting gamma rays emitted when certain radioactively doped sugars are injected into a patient. Once ingested, these doped sugars are absorbed by tissues with higher levels of activity/metabolism (e.g., active tumors) than the rest of the body.

Gamma rays are generated when a positron emitted from the radioactive material collides with an electron in tissue. The resulting collision produces a pair of gamma-ray photons that emanate from the collision site in opposite directions and are detected by gamma-ray detectors arranged around the patient. Unlike anatomical imaging techniques like computed tomography (CT), X-ray, and ultrasound, PET imaging provides "functional" information about the human body.

Photo by Jens Langner

CT and PET systems can be combined to provide both excellent anatomical detail and functional information.

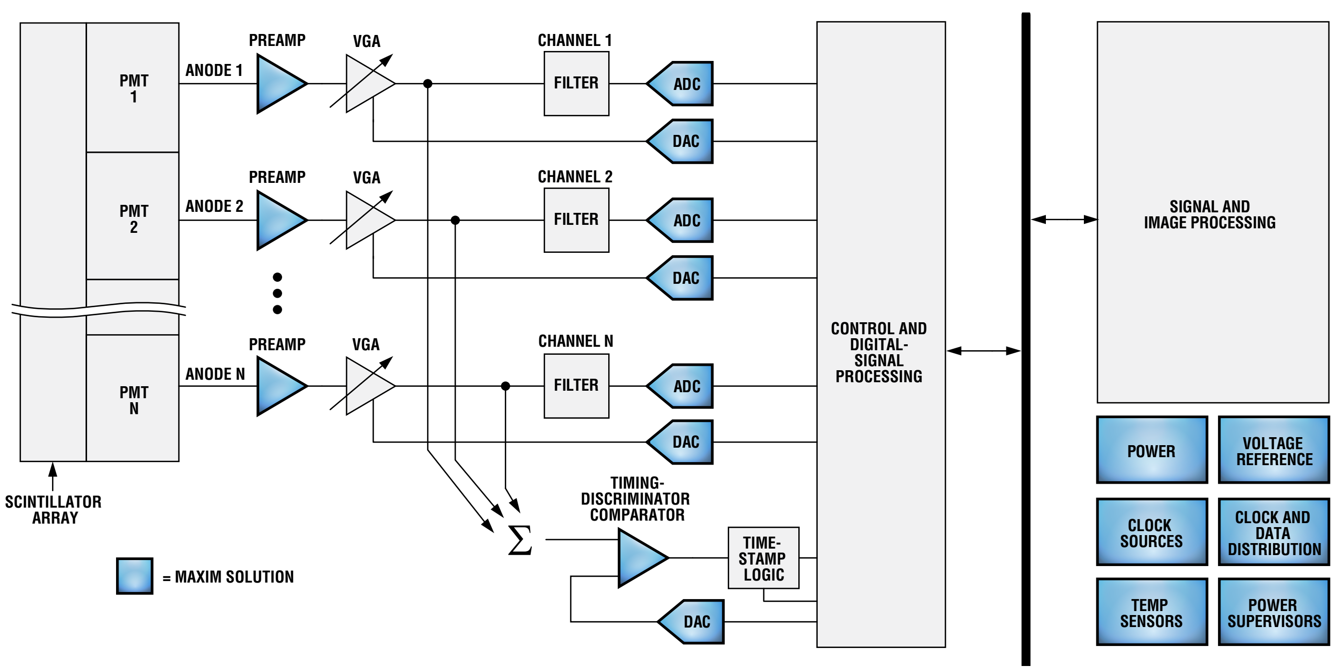
Detecting a photon

The PET detector is comprised of an array of thousands of scintillation crystals and hundreds of photomultiplier tubes (PMTs) arranged in a circular pattern around the patient. The scintillation crystals convert the gamma radiation into light that is detected and amplified by the PMTs.

Signal versus random photon "noise"

The manufacturers of PET imaging equipment continue to improve the diagnostic performance of these systems. Their focus has been on increasing the timing accuracy and the localization of gamma-ray photon detection.

Random gamma rays exist in the environment and the PET imaging system must differentiate a random photon from photon pairs generated within the body. To do this, the system must detect a time-correlated photon pair or, more simply stated, the presence of two photons generated at the same time and traveling in opposite directions. The system accomplishes this by analyzing the location of the photon pairs striking the circular detector



Block diagram of a PET system. This diagram shows one of multiple receiver groups that share a common time discriminator.
For a list of Maxim's recommended PET solutions, please go to: www.maxim-ic.com/pet.

array to ensure that they are traveling in opposite directions. The system must also accurately measure when the photon pair strike the detector to ensure that they were generated at approximately the same time. Using this information, the PET system can discriminate random photon noise from the desired signal.

Detecting photon signal strength for event localization

To reduce cost and complexity, most modern PET systems have many more scintillating crystals than PMTs. Given the disparity between the number of crystals and PMTs, the system must determine which of the many scintillating crystals was struck by a photon. It does this by analyzing the signal strength from the output of the PMTs in the vicinity of the crystal of interest.

The current signal from each PMT output is converted to a voltage and amplified by a low-noise amplifier (LNA). The signal generated by the PMT is a pulse with a fast attack and slow decay. The signal strength from each PMT is determined by digitally integrating the area under this time-domain pulse. The system uses a variable-gain amplifier (VGA) after the LNA to compensate for variability in the sensitivity of the PMTs.

The combined LNA and VGA gain is approximately 40dB with a gain range of about 20dB. The amplifiers used typically have noise of a few $nV/\sqrt{Hz}$ or less, with bandwidths in the 100kHz to 1GHz range. Current-feedback amplifiers are sometimes used to provide high speed while minimizing power. High-density digital-to-analog converters (DACs) with 10-bit to 12-bit resolution are use to control the gain of the VGAs.

The VGA's output is passed through a lowpass filter, offset compensated, and then converted to a digital signal by a 10-bit to 12-bit analog-to-digital converter (ADC) sampling at a 50Msps to 100Msps rate.

The ADC samples are typically processed by a field-programmable gate array (FPGA) discriminator that can process multiple ADC outputs. As such, ADCs with serial LVDS outputs or dual ADCs with multiplexed CMOS output buses can be useful in some cases to reduce both interconnect complexity and digital noise. As noted above, the digital-signal information from multiple PMTs is used to calculate the location of a particular photon strike.

Detecting the timing of a photon strike

The timing resolution of the digitized receiver output is, unfortunately, not adequate enough to determine precise time-of-flight information for enhanced imaging or even the approximate coincidence of two photon strikes. For this reason, the PET system utilizes ultra-high-speed comparators.

The signals from a number (typically four or more) of physically close PMTs are summed, and this combined signal drives the input of an ultra-high-speed comparator. A DAC generates the comparator's reference voltage to compensate for DC offsets. Extremely high accuracy is required to calculate time of flight, so a digital timestamp is generated using the comparator's output signal and an ultra-high-speed clock. In this way, timing information can be compared for multiple PMTs that are physically separated by a significant distance.

Generating an image

The photon pair defines a line on which the collision took place. This is called the line of response (LOR). By analyzing tens of thousands of LORs, the backend image signal processor can display the collision activity as a 3-D image. In some PET systems, the timestamp of two photon-strike events is used solely to determine if two strikes were close enough in time to be counted by the system as a valid signal. Verifying this LOR is challenging and requires a timing accuracy of a few nano-seconds.

Newer, higher performance PET systems are now using the time-stamps of the two photon-strike events to determine the approximate location of the collision site on the LOR. This technique improves image quality. These PET systems calculate the location of the collision to within ~10cm by computing the time of flight for each photon to within 100ps. This calculation places significantly greater demand on the timing accuracy of the system.

Power and integration density considerations

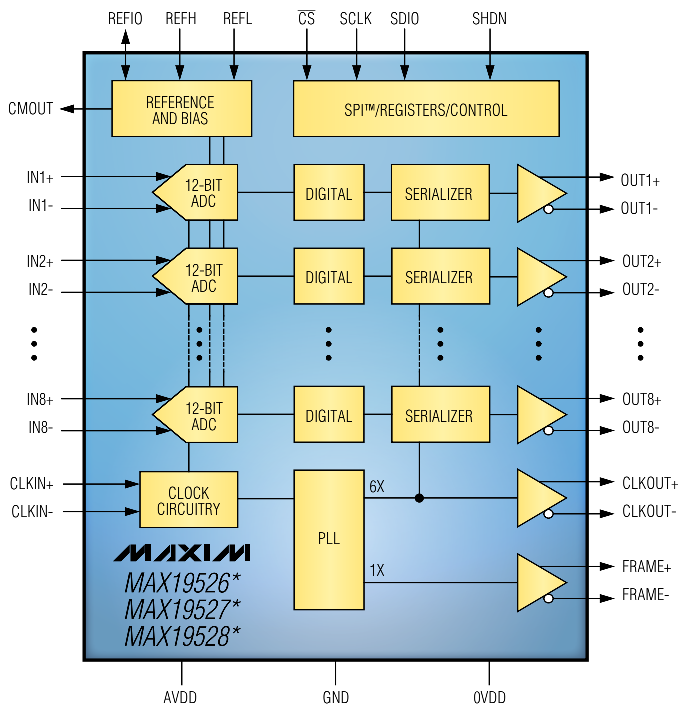
Power dissipation is a significant issue in a PET system, given the large number of system channels and signal-processing speeds. Consequently, manufacturers want lower power and more highly integrated solutions. In the future, PET systems will evolve away from PMTs and begin to utilize solid-state photo-detectors with much higher channel counts. When this happens, channel counts could increase from hundreds to tens of thousands of channels. This evolution will put significant pressure on IC solution providers to reduce power and increase integration density even further.

www.maxim-ic.com/pet

Ultra-low-power, 8-channel, 12-bit ADCs improve pulse-location accuracy

MAX19526*/MAX19527*/MAX19528*

The MAX19526/MAX19527/MAX19528 are ultra-low-power, 40Msps to 64Msps, octal ADCs ideal for PET receiver applications. The MAX19526 offers an impressive ENOB of 11.0 at 50Msps for only 59mW per channel. The ADCs' 12-bit resolution reduces the necessary VGA gain range and improves pulse-location accuracy. Serial LVDS outputs reduce FPGA interface pin count, simplify PC-board (PCB) complexity, and lower noise.



Typical operating circuit for the MAX19526/MAX19527/MAX19528, which are used to improve pulse-location accuracy.

Benefits

- **Better pulse-location accuracy**
  - 12-bit (11.0 ENOB) ADCs for high-dynamic-range pulse detection; fulfills the requirements for reduced VGA gain range and improved pulse-location accuracy
  - 8 channels in a small 10mm x 10mm package for high-channel-count systems with limited space
- **Reduced heat dissipation and improved reliability**
  - Ultra-low power per channel makes them ideal for multichannel ultrasound applications
- **Reduced digital radiated RF emission**
  - Low-noise, LVDS digital interface
- **Ease of design and test**
  - Programmable serial test patterns
  - Serial LVDS outputs reduce FPGA interface pin count and PCB layout complexity

* Future product—contact factory for availability.

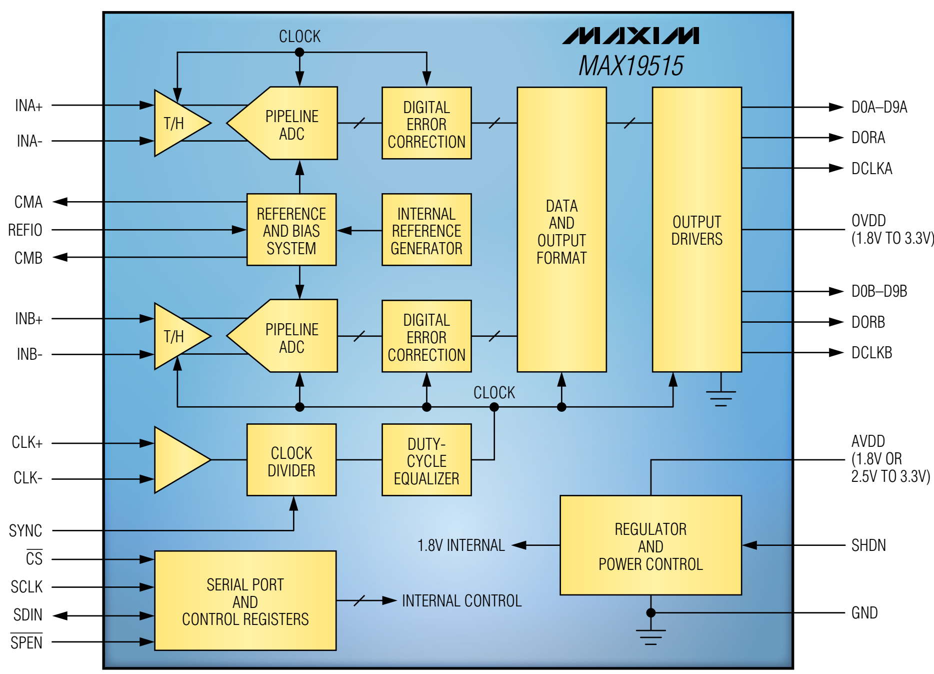
Ultra-low-power, high sample rate, 10-bit ADCs aid high-speed pulse discrimination

MAX19515/ MAX19516/MAX19517

The MAX19515/MAX19516/MAX19517 are ultra-low-power, 65Msps to 130Msps, dual, 10-bit ADCs ideal for high-sample-rate PET receiver applications. The MAX19516 offers an impressive ENOB of 9.6 at 100Msps for only 57mW per channel. A multiplexed, CMOS-output bus capability reduces FPGA interface pin count and PCB complexity.

Benefits

- **Better pulse-location accuracy**
  - 10-bit (9.6 ENOB) ADCs for high dynamic range
- **Ideal for a space-constrained application**
  - 2 channels in a small 7mm x 7mm package for high-channel-count systems
- **Simpler PCB layout**
  - Multiplexed CMOS-output bus for reduced pin count for FPGA interface
- **Reduced heat dissipation and improved reliability**
  - Ultra-low, 57mW per channel at 100Msps



Typical operating circuit for the MAX19515, which detects high-speed pulse signals.

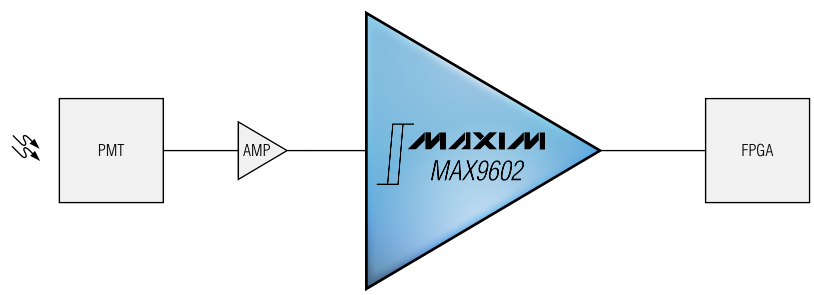
Ultra-high-speed comparators allow high-speed pulse discrimination and improve image quality for accurate diagnosis

MAX9600/MAX9601/MAX9602

The MAX9600/MAX9601 (dual) and MAX9602 (quad) ultra-high-speed comparators feature an extremely low 500ps propagation delay. The low-propagation-delay skew (only 10ps) and dispersion (only 30ps) allow accurate discrimination of the short pulses found in the front-end circuits of PET equipment. Latch enable and adjustable hysteresis add flexibility so the parts can be tailored to the signal variations. These comparators are available in 20-pin and 24-pin TSSOP packages.

Benefits

- **Improved image quality from accurate pulse discrimination**
  - Low 500ps propagation delay
  - Low-propagation-delay skew and dispersion
- **Compact size**
  - Small 20-/24-pin TSSOP packages



An ultra-high-speed MAX9602 comparator is used in a basic PET system to detect precise time-of-flight information.

Low-noise, ultra-high-speed amplifiers allow photon speed and energy information to be captured accurately for diagnosis

MAX4223–MAX4228, MAX4104

The MAX4223–MAX4228 and MAX4104 current-feedback op amps combine ultra-high-speed performance with low-distortion performance, so they are ideal for PET front-end signal-processing circuitry. An ultra-high slew-rate capability buffers the fast current pulses from a PMT, while the low-distortion performance ensures that the amplifier retains each pulse's shape characteristics. A low-power mode reduces the supply current, and the small, space-efficient SOT23 package allows these parts to be placed close to the input connector.

Benefits

- **Improved image quality from accurate pulse discrimination**
  - 1GHz small-signal bandwidth
  - 1100V/µs slew rate
  - 2nV/$\sqrt{Hz}$ input voltage noise
- **Compact size**
  - Small SOT23 package

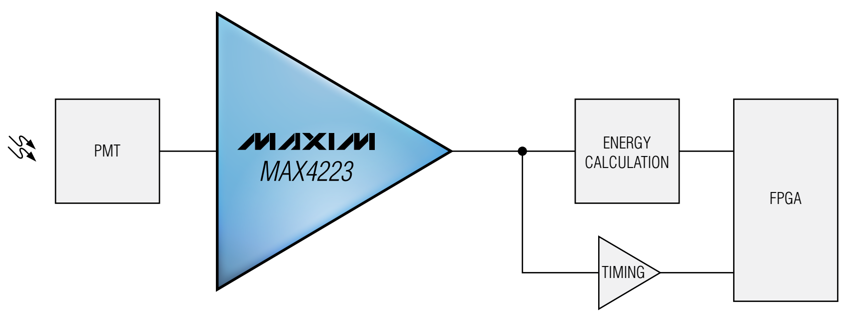


Diagram of a basic PET system using the ultra-high-speed MAX4223 preamplifier.

Recommended solutions

Part	Description	Features	Benefits
ADCs, high speed			
MAX1434	Octal, 10-bit, 50Msps ADC	Space-saving serial LVDS interface	Low cost, reduced digital-interface complexity
MAX1436/37/38	Octal, 12-bit, 40/50/65Msps ADCs	High SNR, space-saving serial LVDS interface	Reduced digital-interface complexity; high dynamic range simplifies pulse-receiver design
MAX1437B/MAX1438B	Octal, 12-bit, 50, 64Msps ADCs	High SNR, space-saving serial LVDS interface, small 10 mm x 10 mm package	Small size, reduced digital-interface complexity, high dynamic range simplifies pulse-receiver design
MAX19526*/27*/28*	Octal, 12-bit, 40/50/64Msps ADCs	High SNR, ultra-low-power, space-saving serial LVDS interface, small 10mm x 10mm package	Reduced digital-interface complexity; high dynamic range simplifies pulse-receiver design
MAX19515/16/17	Dual, 10-bit, 65/100/130Msps, 1.8V ADCs with muxed CMOS outputs	High sample rate, ultra-low power	Ultra-low power for improved reliability, higher sample rate for short pulse detection and improved image quality
MAX1122/23/24	10-bit, 170/210/250Msps, 1.8V ADCs	High sample rate, parallel LVDS outputs	High sample rate for short pulse detection and improved image quality, low-RF-emission digital interface
Comparator, high speed			
MAX9600	Quad, PECL high-speed comparator	Low 500ps propagation delay, differential ECL outputs, adjustable hysteresis	High-accuracy event timing for improved image quality
Amplifiers			
MAX4223	$2nV/\sqrt{Hz}$, 1GHz current-feedback op amps	Small SOT23 package, low 6mA supply current, 80mA output drive, shutdown	Buffers high-speed pulses from PET front-ends, thus allowing both speed and energy information to be captured for accurate diagnosis
MAX4104	$2nV/\sqrt{Hz}$ voltage-feedback op amp	Small SOT23 package, 70mA output drive, high slew-rate, decompensated versions available	Low noise for improved detection sensitivity and image quality
DACs, low speed			
MAX5500B	Low-power, quad, 12-bit, voltage-output DAC with serial interface	Power-on reset, recalls last state prior to shutdown	Power-on reset clears all registers, upon power-up goes to known preset state before shutdown
MAX5661	Single-channel, 16-bit DAC with serial interface	Current- or voltage-buffered outputs	Reduces external component count and saves cost
Power converters			
MAX15037	2.2MHz, 3A, buck or boost converter	Integrated high-side FET	Small magnetics save space
MAX15041	DC-DC regulator	Internal switch for low-current power rails	93% efficiency; stable with low-ESR capacitor; provides robust design
MAX15022	Dual DC-DC converter with dual linear controllers	2.5V to 5.5V, 500kHz to 4MHz switching frequency	Simplifies design, saves space
MAX5072	DC-DC converter	2.2MHz, dual-output, buck/boost, POR and PFO	High frequency and internal FETs reduce complexity
MAX8556	Ultra-low-input-voltage LDO	1.425V to 3.6V, 4A output current	High current; fully protected from an output short circuit; provides robust design

(Continued on next page)

*Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
References			
MAX6043	Precision, high-voltage reference in a SOT23 package	Ultra-small 3-pin SC70 package, 30ppm/°C (max) temperature coefficient, 90µA supply current	Saves PCB space, adds stability over temperature variations, reduces power consumption
MAX6034_25	Precision, micropower, low-dropout series voltage reference in an SC70 package	25ppm/°C (max) temperature coefficient (-40°C to +85°C), ±0.2% (max) initial accuracy, 95µA (max) quiescent supply current, 10mA source current, 2mA sink current	More stability versus ambient temperature variations; saves power with low quiescent current
MAX6025/MAX6033	Precision, low-power, low-dropout voltage references in a 3-pin SOT23 package	Ultra-low 7ppm/°C (max) temperature drift, low 16µV_{P-P} noise (0.1Hz to 10Hz) (2.5V output)	Enhance stability over temperature variations, reduce integrated systems noise
MAX6029	Ultra-low-power, precision series voltage reference	Ultra-low 5.25µA (max) supply current, 30ppm/°C (max) temperature coefficient	Saves power, increases stability over temperature
MAX6173	High-precision voltage reference with temperature sensor	Wide (V_{OUT} + 2V) to +40V supply voltage range, excellent 3ppm/°C (max) temperature stability, low 3.8µV_{P-P} noise	Wide operating voltage levels; improves performance over temperature; better systems noise budget
Supervisors			
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; saves space in small systems
MAX16065	12-channel voltage monitor/sequencer	GUI-programmable, current sense, nonvolatile (NV) fault registers	Complete system management simplifies design
MAX6746	Capacitor-adjustable watchdog and reset IC	Capacitor-adjustable timing, low power	Provides complete system management in an easy-to-use, integrated solution
MAX6495	72V overvoltage protector	Wide 5.5V to 72V supply range, adjustable voltage threshold	Protects against high-voltage transients
Temperature sensor			
MAX6630	12-bit + sign digital temperature sensor with serial interface	200µA (typ) power consumption	High accuracy and extended temperature range

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

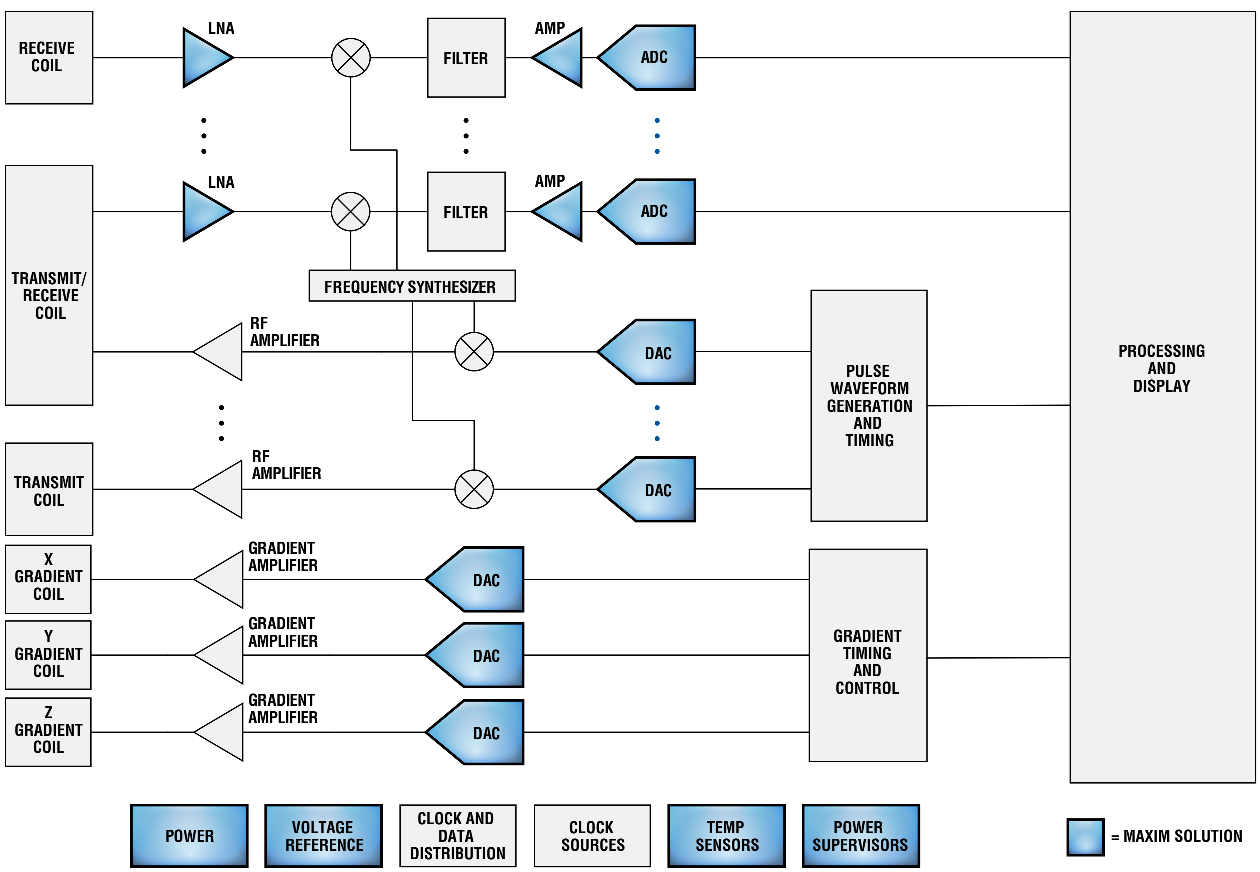
Magnetic resonance imaging (MRI)

Overview

Magnetic resonance imaging (MRI) systems provide highly detailed images of tissue in the body. The systems detect and process the signals generated when hydrogen atoms, which are abundant in tissue, are placed in a strong magnetic field and excited by a resonant magnetic excitation pulse.

Hydrogen atoms have an inherent magnetic moment as a result of their nuclear spin. When placed in a strong magnetic field, the magnetic moments of these hydrogen nuclei tend to align. Simplistically, one can think of the hydrogen nuclei in a static magnetic field as a string under tension. The nuclei have a resonant, or "Larmor," frequency determined by their localized magnetic field strength, just as a string has a resonant frequency determined by the tension on it. For hydrogen nuclei in a typical 1.5T MRI field, the resonant frequency is approximately 64MHz.

Proper stimulation by a resonant magnetic or RF field at the resonant frequency of the hydrogen nuclei can force the magnetic moments of the nuclei to partially, or completely, tip into a plane perpendicular to the applied field. When the applied RF-excitation field is removed, the magnetic moments of the nuclei precess in the static field as they realign. This realignment generates an RF signal at a resonant frequency determined by the magnitude of the applied field. This signal is detected by the MRI imaging system and used to generate an image.



Block diagram of an MRI imaging system. For a list of Maxim's recommended MRI solutions, please go to: www.maxim-ic.com/mri.

Static magnetic field

MRI imaging requires the patient to be placed in a strong magnetic field in order to align the hydrogen nuclei. There are typically three methods to generate this field: fixed magnets, resistive magnets (current passing through a traditional coil of wire), and super-conducting magnets. Fixed magnets and resistive magnets are generally restricted to field strengths below 0.4T and cannot generate the higher field strengths typically necessary for high-resolution imaging. As a result, most high-resolution imaging systems use super-conducting magnets. The super-conducting magnets are large and complex; they need the coils to be soaked in liquid helium to reduce their temperature to a value close to absolute zero.

The magnetic fields generated by these methods must not only be strong, but also highly uniform in space and stable in time. A typical system must have less than 10ppm variation over the imaging area. To achieve this accuracy, most systems generate weaker static magnetic fields using specialized shim coils to “shim” or “tweak” the static field from the super conductor and thereby correct for field inaccuracies.

Gradient coils

To produce an image, the MRI system must first stimulate hydrogen nuclei in a specific 2D image plane in the body, and then determine the location of those nuclei within that plane as they precess back to their static state. These two tasks are accomplished using gradient coils which cause the magnetic field within a localized area to vary linearly as a function of spatial location. As a result, the resonant frequencies of the hydrogen nuclei are spatially dependent within the gradient. Varying the frequency of the excitation pulses controls the area in the body that is to be stimulated. The location of the stimulated nuclei as they precess back to their static state can also be determined by using the emitted resonant RF-frequency and phase information.

An MRI system must have x, y, and z gradient coils to produce gradients in three dimensions and thereby create an image slice over any plane within the patient’s body. The application of each gradient field and the excitation pulses must be properly sequenced, or timed, to allow the collection of an image data set. By applying a gradient in the z direction, for example, one can change the resonant frequency required to excite a 2D slice in that plane. Therefore, the spatial location of the 2D plane to be imaged is controlled by changing the excitation frequency. After the excitation sequence is complete, another properly applied gradient in the x direction can be used to spatially change the resonant frequency of the nuclei as they return to their static position. The frequency information of this signal can then be used to locate the position of the nuclei in the x direction. Similarly, a gradient field properly applied in the y direction can be used to spatially change the phase of the resonant signals and, hence, be used to detect the location of the nuclei in the y direction. By properly applying gradient and RF-excitation signals in the proper sequence and at the proper frequency, the MRI system maps out a 3-D section of the body.

To achieve adequate image quality and frame rates, the gradient coils in the MRI imaging system must rapidly change the strong static magnetic field by approximately 5% in the area of interest. High-voltage (operating at a few kilovolts) and high-current (100s of amps) power electronics are required to drive these gradient coils. Notwithstanding the large power requirements, low noise and stability are key performance metrics, since any ripple in the coil current causes noise in the subsequent RF pickup. That noise directly affects the integrity of the images.

To differentiate tissue types, the MRI systems analyze the magnitude of the received signals. Excited nuclei continue to radiate a signal until the energy absorbed during the excitation phase has been released. The time constant of these exponentially decaying signals ranges from tens of milliseconds to over a second; the recovery time is a function of field strength and the type of tissue. It is the variations in this time constant that allow different tissue types to be identified.

Transmit/receive coils

Transmit and receive coils are used both to stimulate the hydrogen nuclei and to receive the signals generated as the nuclei recover. These coils must be optimized for the particular body area to be imaged, so they are available in a wide variety of configurations. Depending on the area of the body to be imaged, either separate transmit and receive coils or combined transmit/receive coils are used. In addition, to improve image acquisition times, MRI systems use multiple transmit/receive coils to recover more information in parallel, thus utilizing the spatial information associated with the location of the coils.

RF receiver

An RF receiver is used to process the signals from the receiver coils. Most modern MRI systems have six or more receivers to process the signals from multiple coils. The signals range from approximately 1MHz to 300MHz, with the frequency range highly dependent on applied-static magnetic field strength. The bandwidth of the received signal is small, typically less than 20kHz, and dependent on the magnitude of the gradient field.

A traditional MRI receiver configuration has a low-noise amplifier (LNA) followed by a mixer. The mixer mixes the signal of interest to a low-frequency IF frequency for conversion by a high-resolution, low-speed, 12-bit to 16-bit analog-to-digital converter (ADC). In this receive architecture, the ADCs used have relatively low sample rates below 1MHz. Because of the low-bandwidth requirements, ADCs with higher 1MHz to 5MHz sample rates can be used to convert multiple channels by time-multiplexing the receive channels through an analog multiplexer into a single ADC.

With the advent of higher-performance ADCs, newer receiver architectures are now possible. High-input-bandwidth, high-resolution, 12-bit to 16-bit ADCs with sample rates up to 100MHz can also be used to directly sample the signals, thereby eliminating the need for analog mixers in the receive chain.

Transmitter

The MRI transmitter generates the RF pulses necessary to resonate the hydrogen nuclei. The range of frequencies in the transmit excitation pulse and the magnitude of the gradient field determine the width of the image slice. A typical transmit pulse will produce an output signal with a relatively narrow ±1kHz bandwidth. The time-domain waveform required to produce this narrow frequency band typically resembles a traditional sync function. This waveform is usually generated digitally at baseband and then upconverted by a mixer to the appropriate center frequency. Traditional transmit implementations require relatively low-speed, digital-to-analog converters (DACs) to generate the baseband waveform, as the bandwidth of this signal is relatively small.

Again, with recent advances in DAC technology other potential transmit architectures are achievable. Very-high-speed, high-resolution DACs can be utilized for direct RF generation of transmit pulses up to 300MHz. Waveform generation and upconversion over a broad band of frequencies can, therefore, now be accomplished in the digital domain.

Image signal processing

Both frequency and phase data are collected in what is commonly referred to as the k-space. A two-dimensional Fourier transform of this k-space is computed by a display processor/computer to produce a gray-scale image.

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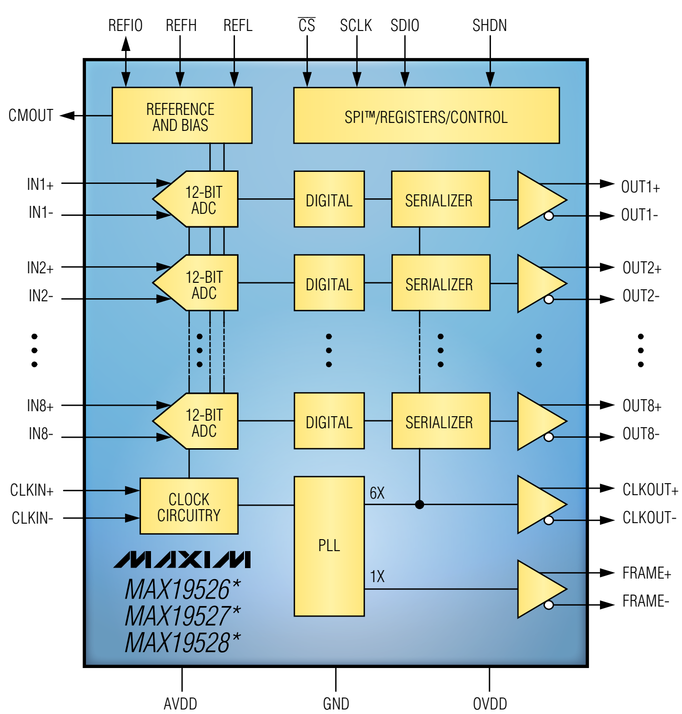
Save space and improve reliability in MRI multichannel receiver architectures with ultra-low-power 12-bit ADCs

MAX19526*/MAX19527*/MAX19528*

The MAX19526/MAX19527/MAX19528 are ultra-low-power, 40Msps to 64Msps, octal ADCs ideal for multichannel MRI receiver architectures. Serial LVDS outputs reduce the interface pin count for the field-programmable gate array (FPGA), thus reducing design complexity and noise. The MAX19527 provides an impressive 69dB signal-to-noise ratio (SNR) for superior image quality.

Benefits

- **Provide superior image quality**
  - 69dB SNR for excellent receiver sensitivity and image resolution
- **Improve equipment reliability**
  - Ultra-low power reduces heat dissipation and improves reliability
- **Simplify design and saves space**
  - Serial LVDS outputs reduce FPGA interface pin count, simplify PCB layout, and reduce digital-interface radiated RF emissions
  - Programmable serial test patterns improve ease of design and test
  - 8 channels in a small 10mm x 10 mm package facilitate multichannel receiver architectures



Block diagram of the MAX19526/MAX19527/MAX19528.

* Future product—contact factory for availability.

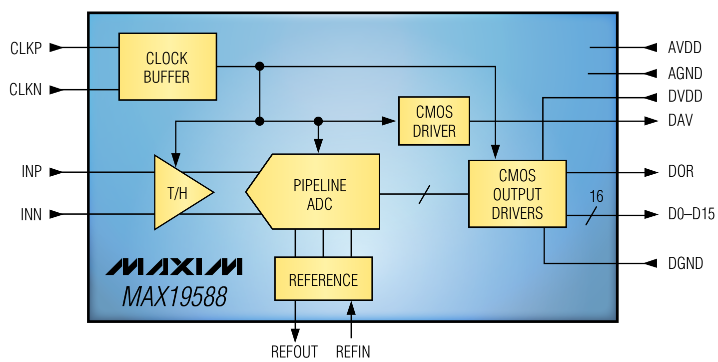
Achieve superior MRI receiver sensitivity and resolution with high-dynamic-range, 100Msps, 16-bit ADC

MAX19588

The MAX19588 16-bit ADC is an excellent choice for high-dynamic-range MRI receiver applications. The ADC achieves an exceptional 79dB SNR at F_{IN} = 70MHz (second Nyquist zone) for the best image quality. The MAX19588 is an excellent choice for IF-sampled MRI receiver designs.

Benefits

- **Ensures exceptional image quality**
  - 79dB SNR in the second Nyquist zone for excellent receiver sensitivity and image resolution
  - High dynamic range, high-IF sampling capability for low-complexity, direct-sampled receiver designs
- **Space savings**
  - Small 8mm x 8mm package saves space in multichannel receiver architectures
- **Improves equipment reliability**
  - 1.275W power dissipation reduces heat dissipation requirements and improves reliability



Block diagram of the MAX19588.

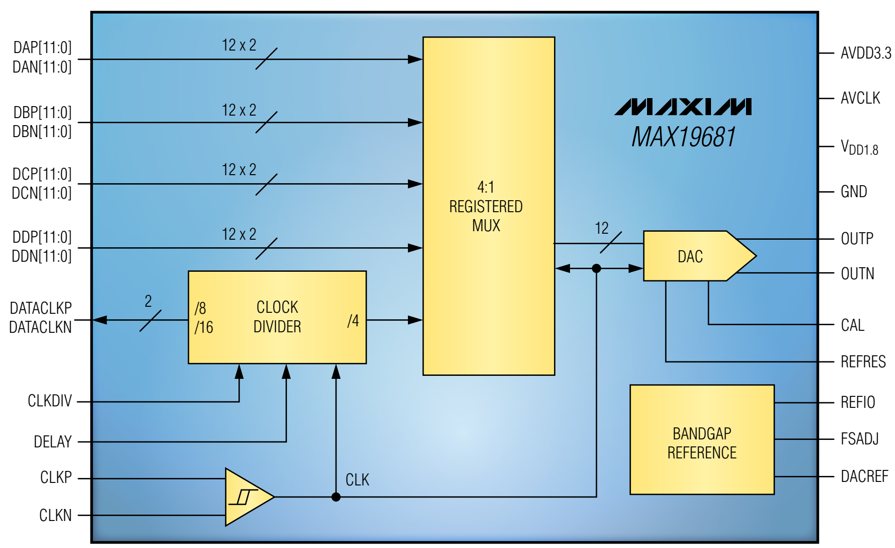
Flexible, direct-RF excitation pulse generation with 12-bit, 1.5Gsps DAC

MAX19681

The MAX19681 12 bit, 1.5Gsps DAC is an excellent choice for direct-RF MRI transmit applications. The high sample rate and low -162dBm/Hz output noise density allow generation of high-accuracy transmit excitation pulses over a wide frequency range.

Benefits

- **Provides superior image quality**
  - High 1.5Gsps sample rate allows flexible direct-RF pulse generation over a wide frequency band
  - -162dBm/Hz noise density at 200MHz allows a high-SNR transmit pulse and improves image quality
- **Simplifies design**
  - 4:1 multiplexed LVDS inputs at 375MHz simplify the interface to the FPGA pulse generator
- **Reduces system heat dissipation**
  - 760mW power dissipation reduces heat-dissipation requirements and improves reliability



Block diagram of the MAX19681.

Recommended solutions

Part	Description	Features	Benefits
High-speed ADCs			
MAX19526*/27*/28*	Octal, 12-bit, 40/50/64Msps ADCs	High density; high SNR; ultra-low-power 53mW per channel; small 10mm x 10mm package	Save space; serial LVDS outputs reduce interface pins and cost
MAX19588	16-bit, 100Msps ADC	Wideband track and hold; high SNR; 1.275W power dissipation; small 56-pin, 8mm x 8mm TQFN-EP package	High dynamic range improves image quality; supports low-cost direct-conversion receiver architectures
MAX12559	Dual, 14-bit, 96Msps ADC	IF sampling up to 350MHz; high SNR; small 68-pin, 10mm x 10mm TQFN package; dual configuration	Dual configuration reduces PCB space
High-speed DACs			
MAX19681	12-bit, 1500Msps DAC	High update rate; low noise density; 4:1 multiplexed LVDS inputs at 375MHz each; low 760mW power dissipation	High update sample rate for flexible direct-RF excitation pulse generation
MAX5898	16-bit, 500Msps, interpolating and modulating dual DAC with interleaved LVDS inputs	Low spectral noise density; built-in interpolator and modulator; dual configuration; interleaved LVDS inputs; low 831mW power dissipation	Integrated upconverter reduces costs
MAX5891	16-bit, 600Msps DAC with LVDS inputs	Low spectral noise density; low-power dissipation; compact 10mm x 10mm QFN-EP package	High sample rate and resolution for high performance and flexible direct-RF excitation; low power
MAX5878	Dual, 16-bit, 250Msps DAC with LVDS inputs	Dual configuration; low spectral noise density; low-power dissipation; compact 10mm x 10mm QFN-EP package	Saves space and power without sacrificing performance
ADCs, low speed			
MAX11044/45/46	16-bit, 250ksps ADCs	4/6/8 simultaneously sampled channels per package; single analog and digital supply; multiplexed CMOS output bus; small 56-pin, 8mm x 8mm TQFN package	Multichannel configuration saves space; high dynamic range improves image quality
Amplifiers			
MAX4104	2nV/$\sqrt{Hz}$, 625MHz op amp in SOT23 package	Small SOT23 package; 70mA output drive; high-slew-rate decompensated versions also available	Improves image quality by reducing distortion, leading to better diagnosis of patient images
MAX9626*/27*/28*	Low-noise, low-distortion, differential-in, differential-out, fixed-gain amplifiers	Internal matched resistors with gain of 1/2/4; 5nV/$\sqrt{Hz}$; -95dBc THD at 50MHz; 6500V/s slew rate; 3mm x 3mm small TDFN package	High-performance ADC driver for 16-bit pipelined differential-input ADCs; detect small signals; improve system resolution and acquisition speeds
MAX9632*	36V precision, low-noise, wide-bandwidth op amp	1.1nV/$\sqrt{Hz}$; 55MHz; 30V/µs; 125µV (max) V_{OS}; rail-to-rail output; fast 700ns settling to 16-bit accuracy; 3mm x 3mm small TDFN package	High-performance ADC driver for 24-bit delta-sigma converter-based systems; improves system resolution and performance
Power			
MAX8655	Step-down DC-DC converter with 4.5V to 28V input voltage range	Up to 1.2MHz programmable switching frequencies; 8mm x 8mm TDFN package	Integrated power MOSFETS reduce board trace inductance, ensuring highest efficiency at high frequencies
MAX8576	Step-down controller with 3V to 28V input	200kHz to 500kHz switching frequency; hysteretic voltage-mode-control algorithm	Fast transient response; no-loop compensation simplifies design

(Continued on next page)

* Future product—contact factory for availability.

Visit digikey.com

Recommended solutions *(continued)*

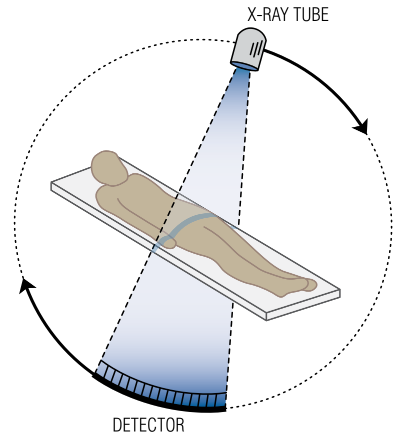
Part	Description	Features	Benefits
Power (continued)			
MAX8902A	Low-noise, 500mA LDO regulator in 2mm x 2mm TDFN package	16µV_{RMS}; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, temp; shutdown; soft-start, preset or adjustable	Low noise and high accuracy enable sensitive analog circuits to optimize image quality
MAX8556	Ultra-low-input-voltage LDO regulator	1.425V to 3.6V; 4A output current	High current; fully protected from an output short circuit, thus provides robust design
References			
MAX6043	Precision, high-voltage reference in SOT23 package	Ultra-small, 3-pin SC70 package; 30ppm/°C (max) temperature coefficient; 90µA supply current	Saves PCB space; adds stability over temp variations; uses less power
MAX6034	Precision, micropower, low-dropout, SC70 series voltage reference	25ppm/°C (max) temperature coefficient (-40°C to +85°C); ±0.2% (max) initial accuracy; 95µA (max) quiescent supply current; 10mA source current; 2mA sink current	Saves power with low quiescent current
MAX6033	Ultra-high-precision SOT23 series voltage reference	Ultra-low 7ppm/°C (max) temperature drift; low 16µV_{P-P} noise (0.1Hz to 10Hz) (2.5V output)	Reduces integrated systems noise
MAX6173	High-precision voltage reference with temperature sensor	Wide (V_{OUT} + 2V) to +40V supply voltage range; excellent temperature stability: 3ppm/°C (max); low 3.8µV_{P-P} noise	Improves performance over temp; provides better systems noise budget
Supervisors			
MAX6720	Triple-voltage supervisor	Two fixed, one adjustable thresholds	Versatile for easy design reuse; saves space in small modules
MAX6746	Capacitor-adjustable watchdog and reset IC	Capacitor-adjustable timing; low power	Provides complete system management in easy-to-use, integrated solution
MAX16033	Battery-backup switchover	Battery-backup; reset; chip-enable gating; PFI/PFO	Versatile for easy design reuse; saves space in small modules
MAX16054	Pushbutton on/off controller	±15kV ESD protection	Saves space and increases reliability by combining multiple functions
MAX6495	72V overvoltage protector	Easy to use; highly integrated	Increases system reliability by preventing component damage from high-voltage transients; saves space; easy to use

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

Computed tomography (CT) imaging

Overview

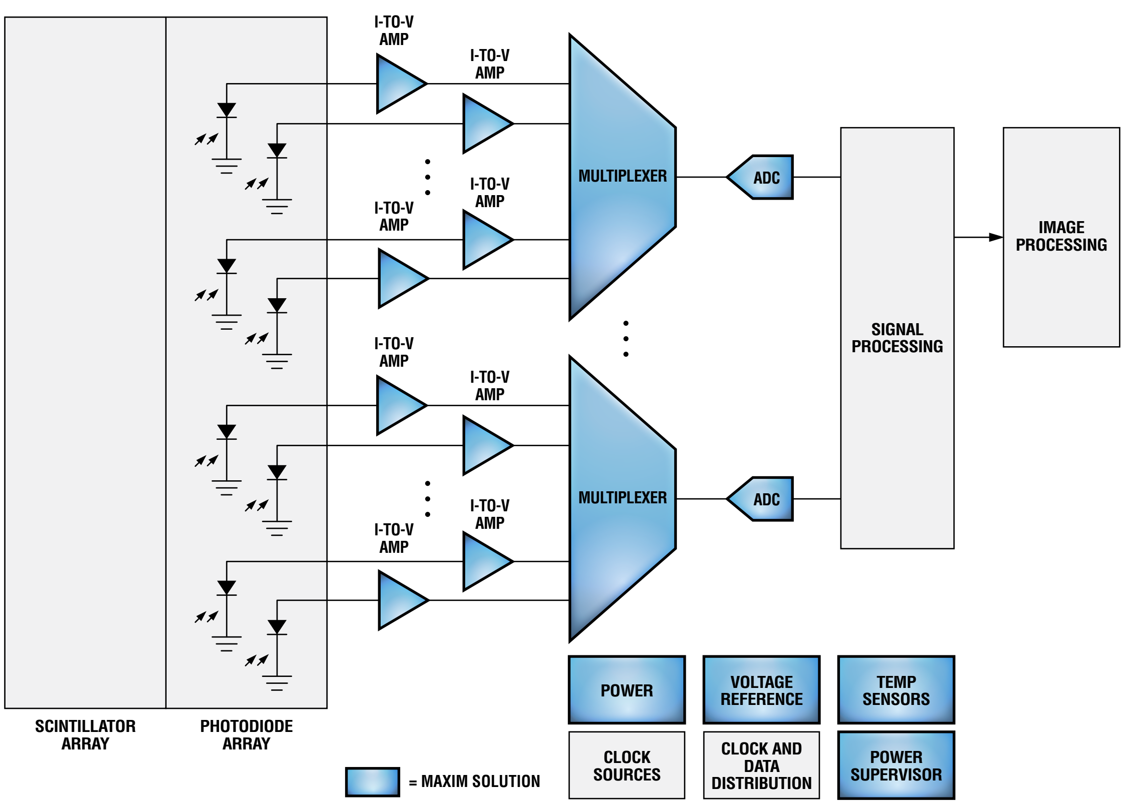
Computed tomography (CT) medical-imaging systems generate three-dimensional (3-D) images of internal body structures using complex x-ray and computer-aided tomographic imaging techniques.



The patient is exposed to a fan-shaped x-ray beam, and the projected image is detected on a thin, semicircular digital x-ray detector.

The x-ray images used to generate the tomographic images are generated first by exposing the patient to a fan-shaped x-ray beam, and then detecting the projected image on a thin semicircular, digital x-ray detector. The patient is placed between the source and detector, and the detector is configured with its geometric center located at the x-ray source. Each image is an x-ray projection of a very thin transverse slice of the body. To collect the multitude of x-ray projections necessary to generate a tomographic CT image, both the x-ray source and detector are rotated about a patient within a supporting gantry. While the source and detector rotate, images are collected and stored. As in a traditional x-ray, the signal levels in the image slice represent the relative radio density of the patient along a line from the x-ray source to the corresponding pixel location.

To improve image-capture times and resolution, manufacturers utilize multislice CT imaging techniques. Instead of a single 2D detector



Block diagram of a CT imaging system. For a list of Maxim's recommended CT imaging solutions, please go to: www.maxim-ic.com/ct.

array which provides only a single image slice, multislice imaging uses a 3-D array. The added imaging dimension allows the system to generate multiple slices in parallel. Photodetector arrays used in CT imaging have as many as 1000 detectors in the long dimension along the semicircular detector arch; 16 or more detectors are positioned in the shorter dimension tangential to the arch. The number of detectors in the short dimension determines the number of available image slices.

Modern CT imaging systems can also generate images in any plane within the body by using a technique called spiral CT. In a spiral-CT system the patient is slowly moved into the center of the gantry while the x-ray source and detector rotate about the patient. Very-high-speed computers are necessary to process the images collected in this manner. Sophisticated tomographic imaging techniques are used to produce the required image.

X-ray detection

Early CT imaging systems accomplished x-ray detection using both scintillation crystals and photomultiplier tubes. The scintillation crystals converted x-rays to light, and the photomultiplier tubes converted these light signals to a usable electrical signal. Modern CT systems now employ more sophisticated scintillation crystal materials and solid-state photodetector diodes for this purpose.

The output from each photodiode is a current proportional to the light striking the diode. These currents can be directly converted to a voltage by a low-noise transimpedance amplifier (TIA), or integrated over time using a capacitor or active integrator op-amp circuit to produce a voltage output. Integration of the current from each diode can be accomplished in multiple ways. Capacitance in the photodiode detector array itself can be used for this purpose. The signals from these capacitors are multiplexed using FET switches in the diode-array detector. The signals are then routed to the digital acquisition system (DAS), which amplifies and converts the signals to a digital format using high-resolution analog-to-digital converters (ADCs). An alternative method routes the signals from every photodiode to an integrator in the DAS. In these implementations, the integrated current signals are converted to a voltage, sampled at the same time, and multiplexed into the input of an ADC.

The time required to capture a single x-ray image varies widely, but can be as short as 100µs. The sampling speed of the ADCs used in the DAS to convert these signals largely determines the amount of multiplexing and, hence, the number of converters and amplifiers in the system. The ADCs' dynamic range must be large to preserve the large dynamic range of the x-ray image. Converters with 16-bit resolution or greater are common. The outputs of the ADCs are routed to an image signal processor over a high-speed bus for further signal processing and image reconstruction. In some implementations, the digital processing can be physically separated from the ADCs by a reasonable distance. In these cases, high-speed line drivers are used to route the signals.

Tomographic imaging

The resulting x-ray image data set is converted to an image by the image processor. The image processor is typically a very-high-speed computer which performs the massive calculations required for the tomographic image reconstruction. The resulting image will commonly have a very large dynamic range (i.e., 16-bit grayscale images). Further image processing is necessary to map this large dynamic range most effectively into the limited visible display range.

www.maxim-ic.com/ct

Improve CT x-ray imaging granularity with a wide-dynamic-range, 16-bit, 8-channel ADC

MAX11049

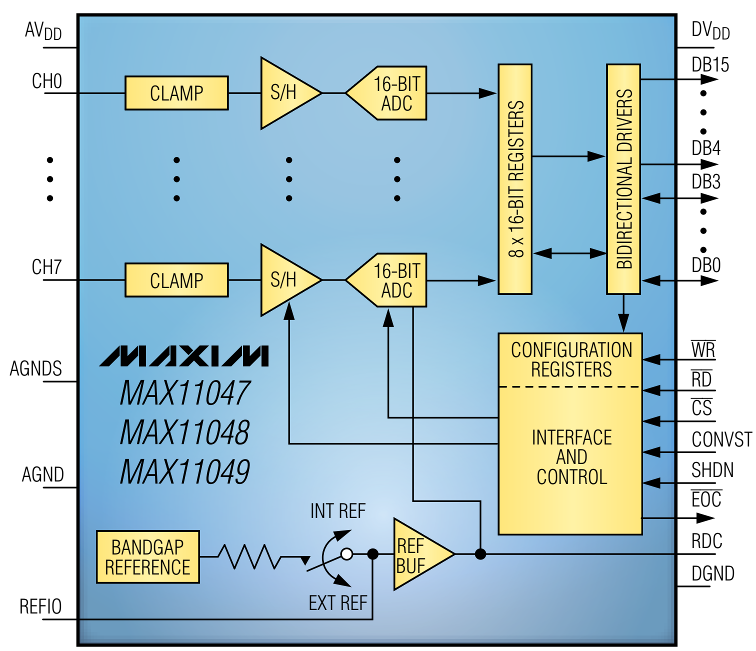
The MAX11049 ADC offers > 92dB signal-to-noise ratio (SNR), making it an ideal solution for CT x-ray imaging applications which require a wide dynamic range. The MAX11049 simultaneously samples up to eight analog inputs. This eliminates the cost and space of an external multiplexer and allows direct connection to the TIAs. A parallel interface reads out all eight measurements within 4ms (250ksps).

The MAX11049 is part of a family of simultaneous-sampling ADCs that convert 8, 6 (MAX11048), or 4 (MAX11047) input channels.

Operating from a single 5V supply, the MAX11047/MAX11048/MAX11049 ADCs measure 0 to 5V analog inputs. The MAX11044/MAX11045/MAX11046 companion 16-bit simultaneous-sampling ADCs measure ±5V.

Benefits

- **Industry-leading dynamic range provides excellent x-ray granularity**
  – 92.3dB SNR and -105dB THD
- **Simultaneous sampling eliminates phase-adjust firmware requirements**
  – 8-, 6-, or 4-channel ADC options
- **Lower system cost compared to competing ADCs**
  – Bipolar input eliminates level shifter (MAX11044/MAX11045/MAX11046)
  – Single voltage supply (MAX11047/MAX11048/MAX11049)
  – 20mA surge protection
- **Eliminate external protection components, saving space and cost**
  – Integrated analog-input clamps
  – Small 8mm x 8mm TQFN/TQFP packages offer the highest density per channel



Block diagram of the MAX11047/MAX11048/MAX11049 ADCs.

Recommended solutions

Part	Description	Features	Benefits
Amplifiers			
MAX9617/18	Single/dual, zero-drift 1.5MHz op amps	Rail-to-rail input/output; extremely low 120nV/°C offset voltage (V_{OS}) drift; small SC70 package	Low V_{OS} is ideal for buffering low ppm precision references; excellent precision over temperature enables precise measurements over longer scan periods; speed patient diagnosis
MAX4238	Single 2µV (max), zero-drift 1MHz op amp	Low 15nV/°C (max) V_{OS} drift; low charge injection; self-correcting V_{OS} circuitry	Low V_{OS} drift over temperature causes low dark current in photodiode interface, leading to better image quality and clearer diagnosis
Data converters			
MAX11044/45/46 MAX11047/48/49	16-bit, 4-/6-/8-channel, simultaneous-sampling ADCs	92.3dB SNR; -105dB THD; 0 to 5V or ±5V input ranges; 250ksps for all 8 channels; 8mm x 8mm TQFN package	Multiple integrated ADCs eliminate external mux; save cost and space
MAX1300*/01 MAX1302*/03	16-bit, 8-channel, 115ksps serial SAR ADCs	115ksps; up to ±12V bipolar input range, or down to 0 to 2.048V unipolar range; ±16.5V overvoltage protection (OVP)	Software-programmable input ranges save design time and reduce external circuitry
MAX11040	24-bit, 4-channel, simultaneous-sampling, serial, delta-sigma ADC	64ksps; 117dB SNR; internal reference; 38-pin TSSOP package	Reduces firmware complexity by capturing accurate phase and magnitude information on up to 32 channels
Power			
MAX15037	2.2MHz, 3A, buck or boost converter	Integrated high-side FET	Small magnetics save space
MAX15041	3A, 4.5V to 28V input, DC-DC regulator	Internal switch for low-current power rails	Internal switch minimizes EMI, reduces board space, and provides higher reliability by minimizing external components
MAX15022	Dual DC-DC converter with dual linear controllers	2.5V to 5.5V input voltage range; 500kHz to 4MHz switching frequency	Simplifies design; saves space
MAX5072	DC-DC converter	2.2MHz; dual-output; buck/boost; POR and PFO	High switching frequency and internal FETs reduce complexity
MAX8556	Ultra-low-input-voltage LDO	1.425V to 3.6V input voltage range; 4A output current, internal p-channel MOSFET pass transistor	P-channel MOSFET eliminates the need for an additional external supply or a noisy internal charge pump; simplifies the design
Supervisors			
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options	Versatile for easy design reuse; SC70 package saves space in small systems
MAX16065	12-channel voltage monitor/ sequencer	GUI programmable; current sensing; nonvolatile (NV) fault registers	Complete system management simplifies design
MAX6746	Capacitor-adjustable watchdog and reset IC	Capacitor-adjustable timing; low 3.7µA supply current	Provides complete system management in an easy to use, integrated solution
MAX6495	72V overvoltage protector	Wide 5.5V to 72V supply range; adjustable voltage threshold	Increases system reliability; prevents component damage due to high-voltage transients
References			
MAX6043	Precision, high-voltage reference in SOT23 package	Small 6-pin SOT23 package; 30ppm/°C (max) temperature coefficient; 90µA supply current	Saves PCB space; adds stability over temp variations; reduces power consumption

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
References (continued)			
MAX6034	Precision micropower, low-dropout, SC70 series voltage reference	25ppm/°C (max) temperature coefficient (-40°C to +85°C); ±0.2% (max) initial accuracy; 95µA (max) quiescent supply current; 10mA source current; 2mA sink current	Saves power with low quiescent current
MAX6033	Ultra-high-precision, SOT23 series voltage reference	Ultra-low 7ppm/°C (max) temperature drift; low 16µV_{P-P} noise (0.1Hz to 10Hz) (2.5V output)	Reduces integrated systems noise
MAX6173	High-precision voltage reference with temperature sensor	Wide (V_{OUT} + 2V) to 40V supply voltage range; excellent temperature stability: 3ppm/°C (max); low 3.8µV_{P-P} noise	Improves performance over temperature; provides better systems noise budget
Multiplexer			
MAX4756*	Quad SPDT switch in UCSP™/QFN packages	0.5Ω on-resistance (R_{ON}); 0.1Ω (typ) channel-to-channel matching	Low R_{ON} minimizes signal loss

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

*Future part—contact factory for availability.

Pulse oximeters

Overview

Pulse oximeters noninvasively measure or continuously monitor oxygen saturation in arterial blood to ensure that there is sufficient oxygenation. Typical applications include people with respiratory problems who are under anesthesia, neonates, and critically ill patients.

In a pulse oximetry system, a clip with optical electronics is usually attached to a finger, toe, or ear so that light can be transmitted through the skin from one side of the clip and received on the other side with a photodiode. Good arterial blood flow is required to measure oxygen saturation. Most applications use transmissive optical techniques, but there are some applications that use reflective techniques.

Oximeter types

Available in different shapes and sizes, pulse oximeters fall within three main categories.

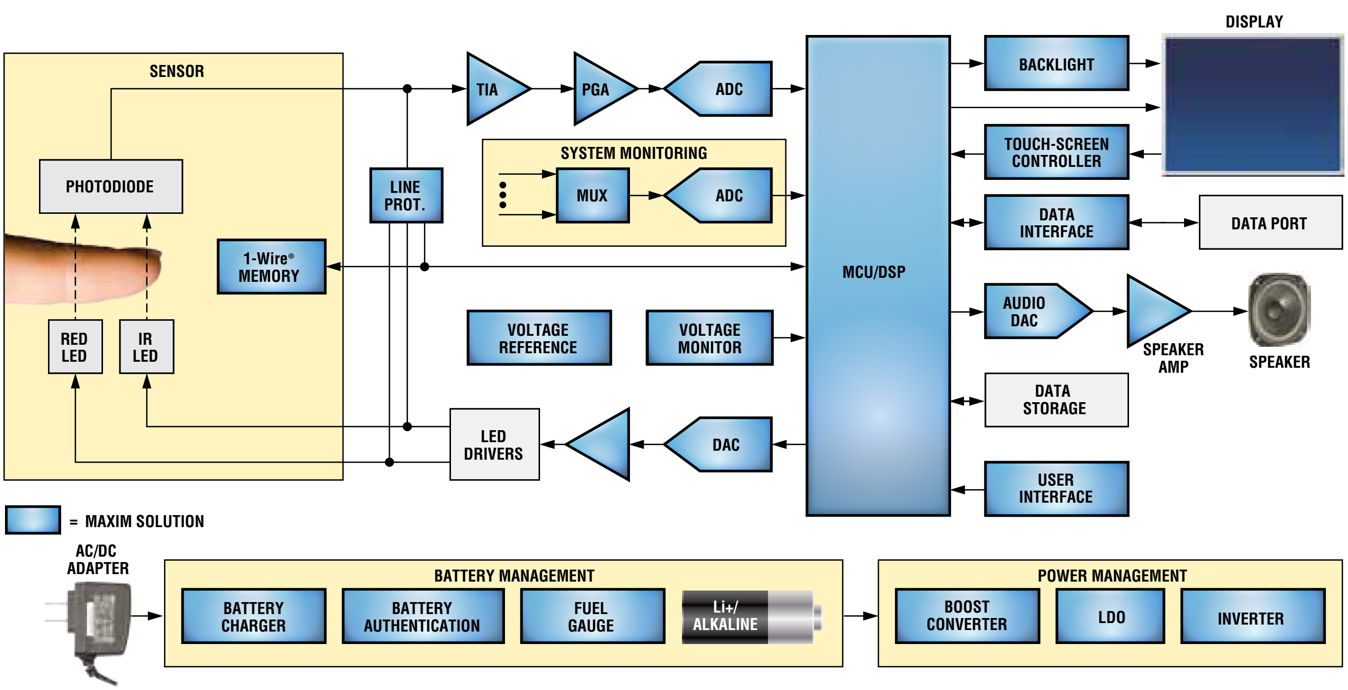
At the high end are portable bedside patient monitors, which have a removable cable that includes a clip containing the optics used to measure oxygen saturation. These models are either dedicated to pulse oximetry or they monitor multiple vital parameters such as pulse, blood pressure, respiratory rate, and temperature. These high-end models demand high performance, with a low-noise signal path being the most important design parameter. Power is a secondary consideration, since the monitor is line powered most of the time and only runs off of battery power when the patient is mobile. Size is not a driving factor in these designs.

Mid-range models are typically battery-powered handheld units with a removable cable. Performance is still important, but it needs to be balanced with size and power constraints. While handheld units run off of batteries all of the time, they have the space to include decently sized batteries.

Mid-range handheld pulse oximeter

Low-end fingertip pulse oximeter

At the low end are fingertip models, which combine the base unit and cable into a clip that is large enough to cover a finger and house the electronics and batteries. The small size means that performance may need



Functional block diagram of a pulse oximeter. For a list of Maxim's recommended solutions for pulse oximeters, please go to: www.maxim-ic.com/pulseox.

to be sacrificed to preserve the small form factor and achieve the desired battery life.

Principle of operation

Operation is based on the light-absorption characteristics of hemoglobin in the blood. Oxygenated hemoglobin absorbs more infrared light than red light, and deoxygenated hemoglobin absorbs more red light than infrared light. Thus, red and infrared LEDs in the oximeter alternately transmit light, and a photodiode receives the light that is not absorbed. The ratio of the red and infrared light received by the photodiode is used to calculate the percentage of oxygen in the blood. Based on the pulsatile nature of arterial blood flow, the pulse rate and strength are also determined and displayed during the measurement cycle.

Sensor cable calibration

Pulse oximeter sensor cables are removable and often disposable. The performance of the LEDs and the photodiode in the cable can vary due to either manufacturing tolerances or alternate versions of the sensor. The performance of the pulse oximeter can be improved by incorporating nonvolatile memory such as EPROM or EEPROM into the sensor cable to store calibration coefficients. This calibration data is used by the base unit to optimize the performance of the particular optical components in the sensor.

Because the electromechanical connector for the sensor cable typically has limited pins, system designers must add this calibration functionality with minimal interconnect. The simplest and most robust method to do this is to add a 1-Wire memory device to the cable connector. The 1-Wire protocol is a proven serial interface that uses only one connector pin to add calibration and other functionality to pin-limited designs. Additionally, since each 1-Wire product is designed with high ESD protection built in, designers do not need to use external protection diodes.

An added benefit of 1-Wire memory devices is that they can be used to pass updates or new algorithms to the base unit, thereby providing a vehicle for in-field upgrades. They can also enable aftermarket control by allowing only approved sensor cables to be used. A unique 64-bit serial identification number is inscribed in each 1-Wire device. By writing to a lockout bit in the memory device, manufacturers are able to control how many times the sensor can be used before replacement is required. Replacement is driven by safety concerns and, more specifically, by patient contamination issues.

Pulse oximeter solutions

Transmit path: driving the LEDs

The red and infrared LEDs are driven alternately with a precise current; a quiet time occupies the interval between each alternating pulse. The repetition rate is not fast, usually well under 10kHz. The duty cycle is also low to keep overall power down and to allow ambient-light measurement while both LEDs are off. Most of the time the LEDs are at the end of a cable, so system designers prefer to drive the LEDs with current from the base unit. This approach reduces current errors and requires fewer lines in the cable, which, in turn, reduces cost and weight. The current used to drive the LEDs must have minimal noise because any noise in the bandwidth of interest will degrade the signal-to-noise ratio (SNR) of the system and decrease its ability to measure low oxygen-saturation levels in critically ill patients.

Off-the-shelf LED drivers are not typically used in this application for several reasons. It is difficult to accurately and precisely program the LED current with the required resolution, since the backlighting applications for which they are designed do not require high resolution. Also, if a switching topology is used for the LED driver, then the current noise will be too high. It is possible that an LED driver with a linear topology could

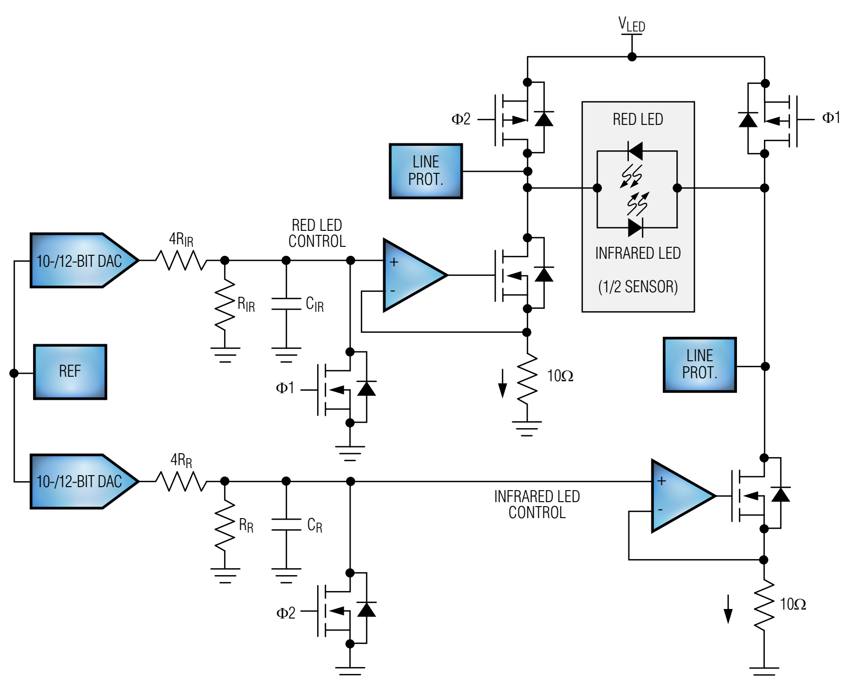


Figure 1. Simplified red and infrared LED bias and control circuit.

be used, but this approach is not ideal due to the lack of resolution in programming the current.

The LEDs can be driven independently with a line from the base unit for each LED along with a shared ground. Alternatively, to save connector pins and lines, the LEDs can be driven in a back-to-back or antiparallel configuration. **Figure 1** shows a method for driving the two LEDs in the cable using two digital-to-analog converters (DACs) to independently set the currents in the LEDs. The advantage of using two DACs is that they can be heavily filtered to reduce the noise because their output is relatively static. LED modulation is performed after the filtering of the DACs in this topology.

In all topologies, the operational amplifier used in the force-sense (FS) configuration needs to have low voltage noise and high enough bandwidth to modulate the LEDs. A single DAC can be used to reduce cost, but the performance may suffer if the noise increases. The peak current through each LED varies according to the characteristics of each LED and photodiode, and with the duration of each pulse. In practice, the peak current ranges from tens of mA to hundreds of mA across all oximeters, though individual meters will use a narrower range of currents.

Receive path: photodiode interface, signal conditioning, and data conversion

A photodiode receives both ambient and modulated light from the red and infrared LEDs, and then generates a current that will be measured over time to determine oxygen saturation. The photodiode current is most often converted to a voltage using an operational amplifier in a transimpedance configuration, also called a transimpedance amplifier (TIA). The light received by the photodiode largely comprises ambient light that is not useful for determining oxygen saturation or pulse. The small amount of red or infrared light not absorbed by the tissue, venous blood, or arterial blood is the signal of interest and is buried in the ambient light.

Figure 2 presents a simplified circuit for converting the photodiode current to a voltage, for signal conditioning, and for analog-to-digital conversion. This circuit converts both the red and infrared signals together and then processes them in the digital domain. Alternate topologies exist where the red and infrared light are separated in the analog domain using synchronous demodulation. This technique allows the use of slow but high-resolution analog-to-digital converters (ADCs); however, it is poor at detecting motion artifacts.

The key specifications for the TIA are extremely low input current, input-current noise, and input-voltage noise, as well as high-voltage operation. These characteristics are necessary to maximize the SNR so that the small currents of interest can be measured amid the large ambient currents. High-voltage operation means that a larger feedback resistor can be used to easily amplify the ambient and received LED current before removing the ambient portion with a highpass filter. The remaining small signal of interest is then amplified to maximize the ADC's dynamic range. This gain stage should be programmable to compensate for changing environmental factors and the aging of optical components.

The key specifications for the ADC are high SNR and sample rate. The sample rate should be fast enough to capture the modulated signal and perform the required digital processing, which is different for each manufacturer.

Display and backlighting

If a bedside pulse oximeter is part of a multiparameter patient monitor, it does not require its own display because it uses the large color display incorporated in the patient monitor. Bedside monitors dedicated to pulse oximetry will usually have a medium-sized color display, or they can incorporate a touch-sensitive display to enhance the user interface and reduce the number of dedicated buttons. Handheld models have either a simple LED or LCD segment display or a more advanced dot-matrix LCD display. Fingertip units have the space and power only for a small and simple LED or LCD display. Simple displays can be driven by the display drivers found in many microcontrollers; dot-matrix or more advanced displays will require dedicated circuitry or a turnkey display solution. Backlighting is not required for LED displays; a few white LEDs can be used to backlight small LCD displays.

Data interface

Most handheld and bedside models have the ability to interface with a

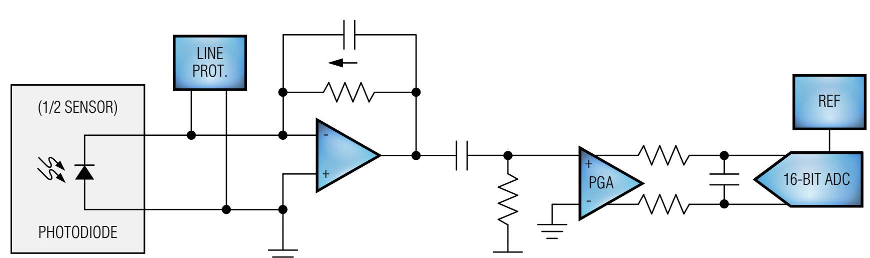


Figure 2. Simplified photodiode receive path circuit.

computer. This data transfer is usually performed by a health-care provider or technician and not by the patient. Traditionally, the data interface has used RS-232, and the format has been proprietary to the manufacturer. Pulse oximeters are now migrating toward USB or wireless (Bluetooth®, Wi-Fi®) interfaces, and in the future oximeters will be able to securely transfer data to any device with these standard interfaces.

Audible alarms

Audible alarms range from simple buzzers to speakers outputting multiple tones, levels, and patterns. A simple buzzer can be driven by one or two microcontroller port pins with pulse-width modulation (PWM) capability. More advanced audible alarms can be achieved by adding an audio DAC along with a speaker amplifier.

Power and battery management

A pulse oximeter needs to generate multiple power-supply rails. Separate analog (3V) and often multiple digital (3V, 1.8V) supplies are required if there are low-voltage cores requiring their own supply. A separate clean supply for powering the LEDs (5V) is usually required due to the power, headroom, and noise considerations. A high voltage (+30V or -30V) is sometimes required for the TIA connected to the photodiode to increase the SNR and, in some cases, for the display.

Fingertip models use two primary alkaline batteries in the AAA form factor while handheld models use either two primary AA alkaline or rechargeable batteries. Both models require a combination of step-up switching regulators, low-dropout linear regulators (LDOs), and sometimes an inverting switching regulator. Bedside monitors are mainly line powered but will use lithium-ion (Li+) or nickel-metal-hydride (NiMH) rechargeable backup batteries. A regulated 5V DC voltage is usually supplied, so the power-supply design is different than the fingertip and handheld models. Battery charging and fuel gauges are needed for the models with rechargeable batteries, as well as authentication for safety and after-market control if the batteries are removable.

Electrostatic discharge

Electrostatic discharge (ESD) is a concern where the sensor cable plugs in. This potential problem can be addressed with dedicated ESD line protectors, as well as careful design and layout of the board. The use of ESD-protected interfaces allows designers to avoid the space and cost associated with discrete protection components. ESD is also possible at the data port and printer port, if the oximeter is equipped with one. Air discharge may also need to be addressed for the buttons and display through small openings in the casing, but this depends on the individual oximeter design.

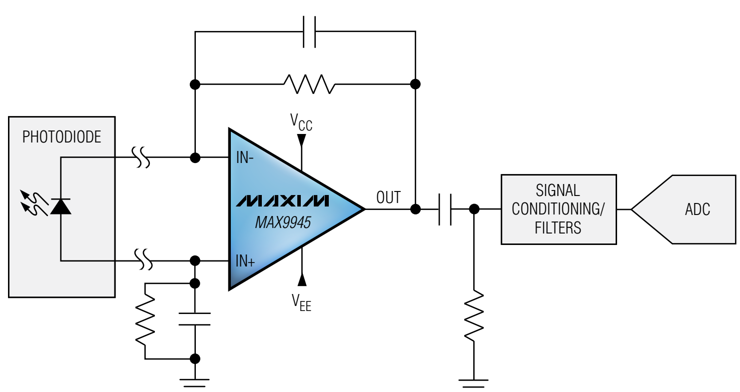
Ultra-low-noise, high-voltage operational amplifier measures lower oxygen-saturation levels

MAX9945

The MAX9945 operational amplifier features an excellent combination of low operating power and high-voltage operation. The device draws a low 400µA quiescent current to conserve battery life, and accepts a wide 4.75V to 38V supply voltage range. In addition, MOS inputs enable the MAX9945 to achieve low input-bias currents and low input-current noise. This op amp is unity-gain stable and capable of rail-to-rail output-voltage swing. The MAX9945 is ideal for low-noise analog front-ends (AFEs) in performance applications such as photodiode transimpedance and chemical sensor interface circuits. The MAX9945 is available in a space-saving, 6-pin TDFN and an 8-pin µMAX® package.

Benefits

- **Low-noise front-end extends oxygen-saturation measurement range**
  - Up to 38V supply voltage
  - Low 1fA/$\sqrt{Hz}$ input-current noise
  - Low 15nV/$\sqrt{Hz}$ input-voltage noise
- **Increases saturation measurement accuracy**
  - Low 50fA input-bias current
  - 3MHz unity-gain bandwidth
  - Rail-to-rail output-voltage swing
- **Enables smaller, lower power pulse oximeters**
  - 400µA quiescent current increases battery life
  - 3mm x 3mm, 6-pin TDFN package saves board space



Typical operating circuit for the MAX9945 in a photodiode application.

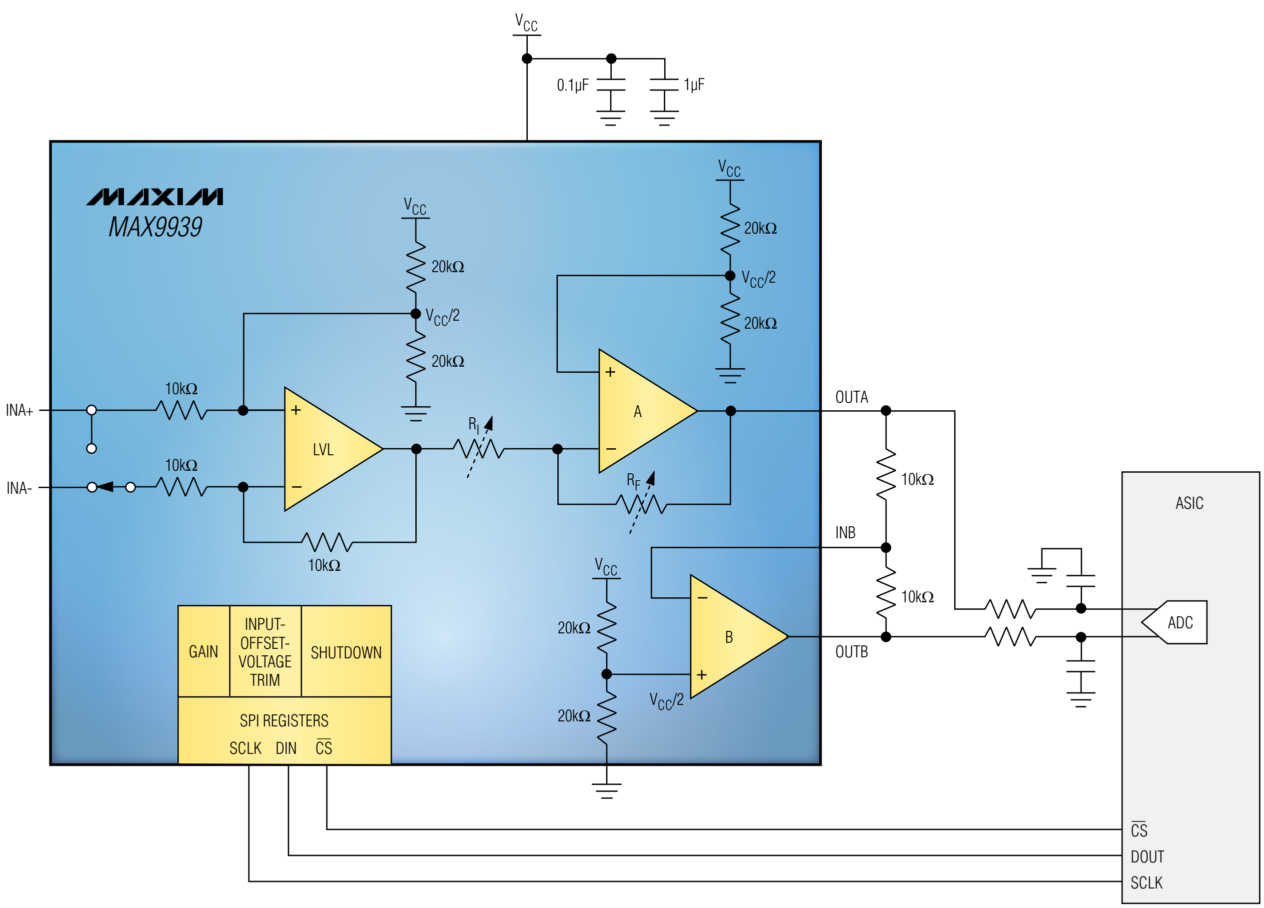
Flexible programmable gain amplifier extends range and increases accuracy

MAX9939

The MAX9939 is a flexible, differential-input PGA that is ideal for conditioning wide-dynamic-range signals such as those found in medical instrumentation. It features SPI™-programmable differential gains from 0.2V/V to 157V/V, input-offset-voltage compensation, and an output amplifier that can be configured either as a high-order active filter or to provide a differential output. Precision resistor matching provides extremely low gain tempco and high CMRR. The inputs are protected to ±16V, allowing it to withstand fault conditions and signal overranges. The MAX9939 draws 3.4mA of quiescent supply current at 5V, and includes a software-programmable shutdown mode that reduces its supply current to only 13µA.

Benefits

- **Improves oximeter measurement range by maximizing the ADC's dynamic range**
  - 0.2V/V to 157V/V gain range
  - Input-offset-voltage compensation
  - Ultra-low gain temperature coefficient
- **Flexibility and ease of use decrease design time**
  - SPI-programmable gain and offset
  - Integrated uncommitted amplifier
  - Input protection up to ±16V
- **Extends battery life with software shutdown mode**



Typical operating circuit for the MAX9939 driving an ADC with a differential input.

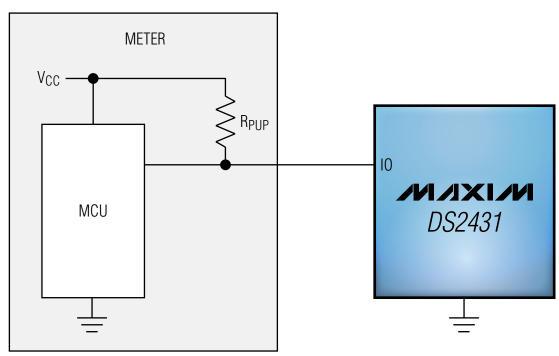
Calibrate, authenticate, and securely control sensors using just a single wire to save space and cost

DS2431

The DS2431 is a 1024-bit, 1-Wire EEPROM chip organized as four memory pages of 256 bits each. As a special feature, the four memory pages can either be individually write protected or put in EPROM-emulation mode, where bits can only be changed from a 1 to a 0 state. The DS2431 communicates over the single-conductor 1-Wire bus and follows the standard 1-Wire protocol. Each device has its own unalterable and unique 64-bit ROM registration number that is factory lasered into the chip to facilitate identification, authentication, and usage monitoring.

Benefits

- **Enables the use of smaller, lighter, lower cost sensor connectors and wires**
  - Single wire or pin for communication and power
- **Provides individual sensor calibration to the meter for higher accuracy**
  - 1024 bits of nonvolatile EEPROM
- **Integrated functionality meets safety and security requirements in minimal space**
  - Unique 64-bit laser-trimmed ROM identification number
  - Allows the sensor to be disabled at end of life
- **Reduces board space with integrated ESD protection**
  - IEC 1000-4-2 Level 4 (±15kV Air, ±8kV Contact)

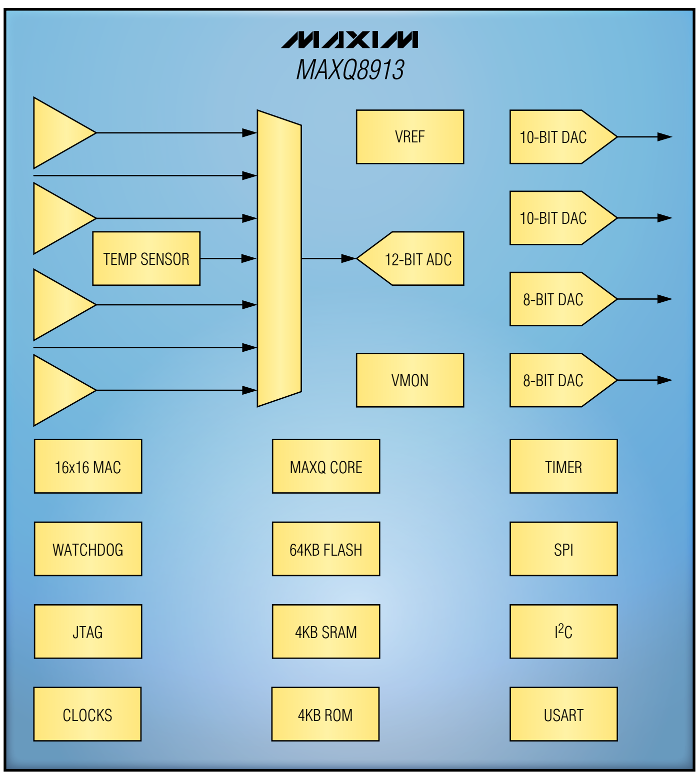


Typical operating circuit for the DS2431.

Mixed-signal microcontroller enables small, low-power fingertip pulse oximeters

MAXQ8913

The MAXQ8913 incorporates all the necessary elements for a low-end pulse oximeter, including driving the sensor LEDs, conditioning of the photodiode signal, analog-to-digital conversion, and digital processing using a 16-bit RISC microcontroller core. The MAXQ8913 includes four op amps; a 7-channel, 12-bit ADC; dual 10-bit differential DACs; dual 8-bit single-ended DACs; and dual 8-bit current DACs. It also contains 64KB of flash memory, 4KB of RAM, 4KB of ROM, a 16-bit timer/counter, a USART, an I^2C port, and an SPI master/slave port. For the ultimate in low-power performance, this microcontroller includes a low-power sleep mode, the ability to selectively disable peripherals, and multiple power-saving modes.



Simplified functional block diagram of the MAXQ8913.

Benefits

- **High level of integration reduces meter size**
  - Tiny 58-pin wafer-level package (WLP)
  - Op amps, DACs, reference, ADCs, and temperature sensor in a single IC
- **Low-power operation extends battery life**
  - 3mA (max) at 10MHz flash operation at 3.3V
  - 4.5µA (max) in stop mode
  - Low-power power-management mode (PMM)
- **High-end performance with reduced BOM cost**
  - 16-bit MAXQ® RISC core, 64KB flash, 4KB SRAM, JTAG
  - 16x16 hardware multiplier and accumulator (MAC) with 48-bit accumulator
  - 16-bit timer/counter, USART, I^2C, SPI, watchdog timer (WDT)

Recommended solutions

Part	Description	Features	Benefits
1-Wire products			
DS2502	1-Wire 1024-bit OTP EPROM	Single dedicated contact, 128-byte OTP, programmable data protection, ±8kV HBM ESD protection	Minimal contact requirement to add NV memory for ID, calibration data, etc., to sensors or probes
DS2431	1-Wire 1024-bit EEPROM	Single dedicated contact, 128-byte EEPROM, programmable data protection, ±8kV HBM and ±15kV IEC ESD protection	High ESD performance typically eliminates the need to add protection to sensor
DS28E01-100, DS28E02*	1-Wire 1024-bit EEPROM with SHA-1 authentication	Single dedicated contact, 128-byte EEPROM, SHA-1 secure authentication and data protection, 1.8V operation (DS28E02), ±8kV HBM and ±15kV IEC ESD protection	Ensure consumables are OEM with crypto-strong SHA-1 authentication; high ESD performance typically eliminates the need to add protection to sensor
DS2482-100	Single-channel 1-Wire master	I^2C to 1-Wire protocol bridging, supports standard and overdrive 1-Wire speeds, low-impedance strong pullup on 1-Wire I/O	Generates 1-Wire waveforms from I^2C command/communication, greatly simplifying host software development
DS2480B	Single-channel 1-Wire master	UART/RS-232 to 1-Wire protocol bridging, supports standard and overdrive 1-Wire speeds, low-impedance strong pull-up on 1-Wire I/O	Generates 1-Wire waveforms from UART/RS-232 command/communication, greatly simplifying host software development
DS2460	SHA-1 coprocessor with EEPROM	Hardware-accelerated SHA-1 computation engine, 112-byte EEPROM, I^2C interface	Simplifies host system implementation of SHA-1-authenticated sensors and probes
ADCs			
MAX1162	SAR ADC with serial interface	16-bit, 200ksps ADC in 10-pin µMAX package, 10µA in shutdown	Saves space
MAX1168	SAR ADC with serial interface	16-bit, 8-channel 200ksps ADC	Provides extended measuring capability
MAX1167	SAR ADC with serial interface	16-bit, 4-channel 200ksps ADC	Provides extended measuring capability
MAX1396	SAR ADC	1.5V to 3.6V supply, 312.5ksps, 12-bit SAR ADC	Low power and longer battery life due to automatic shutdown; fast wakeup
MAX1393	SAR ADC	1.5V to 3.6V supply, 312ksps, 12-bit SAR ADC with 70dB SINAD and ±1 LSB (max) INL	Saves space
Amplifiers			
MAX9945	High-voltage, MOS-input op amp	4.75V to 38V supply, $1fA/\sqrt{Hz}$ input-current noise, $15nV/\sqrt{Hz}$ input-voltage noise, 3MHz BW, 3mm x 3mm TDFN	Better SNR for photodiode front-end design; saves space in portable applications
MAX9618	High-efficiency, 1.5MHz dual op amp with rail-to-rail inputs and outputs	10µV (max) V_{OS} with "zero drift," $0.42µV_{P-P}$ noise, 59µA quiescent current, tiny 8-pin SC70	Increases measurement accuracy; saves power and board space
MAX4252	Low-noise, low-distortion dual op amp	$7.9nV/\sqrt{Hz}$ noise, 0.0002% THD, 70µV V_{OS}, 400µA quiescent current, UCSP™ package	Extends measurement range; reduces board space
MAX9939	PGA with SPI interface	0.2V/V to 157V/V gain range, input common-mode voltage range extends below GND, includes internal op amp, 13µA shutdown mode	Extends measurement dynamic range; reduces board space
Audio amplifiers			
MAX9705	2.3W, ultra-low-EMI, filterless, Class D audio amplifier	Class D gives better efficiency (90%), yet delivers 0.02% THD+N; 1.5mm x 2mm UCSP	Small, efficient solution increases battery life
MAX9718	Low-cost, mono, 1.4W differential audio power amplifier	Class AB yields superior THD+N down to 0.002%	Excellent fidelity for speakers

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* Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Audio DACs			
MAX9850	1.8V stereo audio DAC with built-in DirectDrive® headphone amplifier	Delivers up to 30mW from 1.8V; DirectDrive technology eliminates DC-blocking capacitors and suppresses clicks and pops	Meets the board space and performance requirements of portable devices
DACs			
MAX5137	Dual, 12-bit, buffered voltage-output DAC with fast settling time	2.7V to 5.25V, 3µs (max) 12-bit settling time to ±0.5 LSB	Save power; improve system performance
MAX5535	Dual, 12-bit, force-sense voltage-output DAC with an internal reference	1.8V to 5.5V, 8µA (max) supply current, 30ppm/°C (max) reference tempco	Long battery life; precision output voltage
MAX5812	Low-power, voltage-output 12-bit DAC with a 2-wire serial interface	100µA supply current, SOT23 package, 2.7V to 5.5V supply voltage	Saves power; extends battery life
I/O expanders			
MAX7310	Serially interfaced, 8-bit I/O port expander with reset	Bus timeout, 2.3V to 5.5V	Lockup-free operation; tolerates lower supply voltage
LED backlight drivers			
MAX1916	1- to 3-channel white-LED driver with linear regulator	0.05µA shutdown current, 40µA quiescent current, 200mV dropout voltage	Provides more uniform backlighting
MAX16814/ MAX16838	2- and 4-channel HB LED drivers with integrated DC-DC controller	Integrated switching converter and fault protection, 150mA/channel, 4.75V to 40V input voltage	Minimize solution size and BOM cost
MAX16826	Programmable, 4-channel HB LED driver with integrated DC-DC controller	I^2C interface for programming LED current and output voltage, 4.75V to 24V input voltage, up to 300mA/channel	Easily controllable from MCU, thus saving design time
MAX16809	16-channel LED driver with integrated DC-DC controller	8V to 26.5V input voltage, 55mA/channel	Saves space and simplifies design by driving 16 LED strings with a single device
LED display drivers			
MAX6950	Serially interfaced, 2.7V to 5.5V, 5-digit LED driver	Slew-rate-limited driver IC includes blinking control and PWM dimming in a small 16-pin package	Low EMI simplifies design
Line protectors			
MAX3207E	2-channel ESD-protection IC	±15kV Air-Gap and ±8kV Contact IEC 61000-4-2 ESD protection, 2.5pF, 6-pin SOT23	Hi-Speed USB compatible; small size
MAX3208E	4-channel ESD-protection IC	±15kV Air-Gap and ±8kV Contact IEC 61000-4-2 ESD protection, 2.5pF, 10-pin µMAX	Hi-Speed USB compatible; small size
MAX9940	Digital port protector withstands DC faults and ESD strikes	28V fault protection, 60ns fault reaction time, ±4kV Contact IEC 61000-4-2 ESD protection, small SC70 package	Enables more robust medical equipment
MAX6495	72V overvoltage protector	Adjustable overvoltage thresholds, highly integrated protection circuit	Protects meter against high-voltage transients
Microcontrollers			
MAXQ2010	Low-power, 16-bit mixed-signal LCD microcontroller	8-channel 12-bit SAR ADC, 64KB flash, supply voltage monitor, hardware multiplier, 160-segment LCD controller, 370nA stop-mode current	Saves space and power, resulting in smaller design

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Microcontrollers (continued)			
MAXQ8913	16-bit mixed-signal microcontroller	7-channel 12-bit SAR ADC, 64KB flash, two 10-bit DACs, two 8-bit DACs, four op amps, temp sensor, two current sinks	Single chip implements multiple functions to save space and design time
MAXQ2000	Low-power, 16-bit LCD microcontroller	20MHz operation, 64KB flash, 132-segment LCD controller, hardware multiplier, 32-bit RTC, 700nA stop-mode current	Ultra-low power consumption increases battery life
MAXQ610	Low-power, 16-bit IR microcontroller	1.7V to 3.6V supply, up to 32 GPIOs, IR module, ring oscillator, wakeup timer, 200nA stop-mode current	Extends battery life
MAXQ622	Low-power, 16-bit IR microcontroller	1.7V to 3.6V supply, 128KB flash, USB 2.0 transceiver, IR module, up to 52 GPIOs	Integrated transceiver for easy USB design
Power ICs			
Battery chargers			
MAX8808X	Li+ charger in 4mm^2 TDFN	15V adapter input, CCCV temperature-regulated control	Saves space by integrating FET, diode, and current-sense resistor
MAX8814	Li+ charger in 4mm^2 TDFN	28V adapter input, soft-start	Thermal regulation results in safest and fastest charging
Fuel gauges			
MAX17043	Low-cost, I^{2}C fuel-gauge IC	ModelGauge™ algorithm, 2mm x 3mm footprint, low-battery alert	Reports SOC without sense resistor; saves space
DS2756	High-accuracy battery fuel gauge with programmable suspend mode	Precision voltage, current, and temperature monitor; 96 bytes of EEPROM	Reports accurate battery measurements to calculate state of charge (SOC) in % and mAh
DS2780	Stand-alone fuel-gauge IC with 1-Wire interface	FuelPack™ algorithm with precision voltage, current, and temperature monitor; automatic backup of critical information in EEPROM	Increases system reliability and saves design time
DS2784	1-cell stand-alone fuel-gauge IC with Li+ protector and SHA-1 authentication	FuelPack algorithm with precision voltage, current, and temperature monitor; programmable protector; SHA-1 authentication	Integrated protector and SHA-1 authentication allows small, low-profile battery packs
Linear regulators			
MAX15029	LDO	1.425V to 3.6V supply, 500mA output current	Low 40mV dropout voltage simplifies design
MAX8530	Dual LDO	200mA and 150mA outputs, UCSP package	Saves space for applications that require two LDOs
Power-management ICs			
MAX8667	Highly integrated power-management IC (PMIC)	4-channel PMIC integrates two step-down converters and two low-input LDOs	80% less power loss; 75% smaller than discrete solutions
Switching regulators			
MAX8569	Step-up converter in 6-pin SOT23 and TDFN packages	200mA, 95% efficiency, internal synchronous rectification	Eliminates the need for a Schottky diode
MAX8570	High-efficiency, high-voltage boost with true shutdown	Adjustable output up to 28V, output protection, 87% efficiency	Easily generate a high-voltage supply
RF ICs			
MAX2830	2.4GHz to 2.5GHz RF transceiver with power amplifier (PA)	IEEE 802.11g/b compatible; complete RF transceiver, PA, and crystal oscillator	Saves space and cost by eliminating the need for an external SAW filter
MAX2831	2.4GHz to 2.5GHz, 802.11g RF transceiver with PA	IEEE 802.11g/b compatible; complete RF transceiver, PA, and crystal oscillator	Completely integrated RF transceiver reduces design time, saves space, and lowers cost

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
RF ICs (continued)			
MAX2829	Dual-band 802.11a/b/g transceiver	Single-chip RF transceiver optimized for OFDM 802.11 WLAN applications	Dual-band 802.11a/g provides flexibility for designs intended for worldwide distribution
MAX7032	Low-cost, frequency-programmable ASK/FSK/OOK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm TQFN, fully programmable from 300MHz to 450MHz	Longer battery life; smaller size; maximum flexibility
MAX2821	2.4GHz, 802.11b zero-IF transceiver	Integrates all circuitry required to implement an 802.11b RF-to-baseband transceiver solution	Eliminates external IF and baseband filters to enable smaller, simpler designs
Touch-screen controller			
MAX11800	Smallest, smartest resistive touch-screen controller	4-wire touch-screen interface, 12-bit SAR ADC, 1.7V to 3.6V supply, autonomous mode	Saves power and frees up the MCU
Voltage references			
MAX6033	Ultra-precise series voltage reference in SOT23 package	Ultra-low 7ppm/°C (max) temperature drift, low $16\mu V_{P-P}$ noise (0.1Hz to 10Hz, 2.5V output)	Accurate and precise results over time and temperature
MAX6029	Ultra-low-power, precision voltage reference	5.25µA (max) supply current, 30ppm/°C (max) tempco, ±0.15% initial accuracy, SOT23	Longer battery life
MAX6173	High-precision voltage reference with temperature sensor	(V_{OUT} + 2V) to 40V supply range, excellent temperature stability (3ppm/°C, max), low noise ($3.8\mu V_{P-P}$)	Accurate and precise results over time and temperature
Voltage supervisors			
MAX6381	Single-voltage supervisor	Multiple threshold and timeout options, SC70 and µDFN packages	Versatile; saves space
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable threshold	Integrated circuit saves space and increases flexibility
MAX6746	Capacitor-adjustable watchdog and reset IC	Capacitor-adjustable timing, 3.7µA quiescent current, 8-pin SOT23	Increases design flexibility and saves space
MAX16033	Battery-backup switchover	Battery backup, reset, chip-enable gating, power-fail warning	Simplifies battery-management design
MAX16054	Pushbutton on/off controller	±15kV HBM ESD protection, 6-pin thin SOT23	Integrated ESD protection enables simpler, lower cost switches; small size

For a list of Maxim's recommended solutions for pulse oximeters, please go to: www.maxim-ic.com/pulseox.

Infusion pumps

Overview

Computer-controlled infusion pumps represent a vast improvement in accuracy and safety over old-fashioned drip-chamber and roller-clamp systems. Modern infusion pumps provide a precisely controlled rate of fluid delivery to the patient through an intravenous (IV) line. They also include state-of-the-art safety features to ensure that any single failure of any significance is detected and reported immediately.

There are two classes of infusion pumps: large-volume pumps (LVPs) and small-volume pumps (SVPs, or syringe pumps). In an LVP, the fluids are usually contained in an IV bag or bottle, and the pump manipulates a special section of tubing between it and the patient's IV site. Some infusion pumps have the ability to control up to four IV lines to the patient, although one- and two-line versions are the most common.

Closely related to the LVP is the syringe pump. This device presses the plunger of a large syringe at a precisely controlled rate. The infusion rate of these syringe pumps is generally orders of magnitude lower than that of LVPs. Aside from the pumping mechanism, almost all other aspects of syringe pumps are similar to LVPs.

FDA-regulated medical equipment

Infusion pumps are portable medical equipment whose design and manufacture is regulated by the Food and Drug Administration (FDA). This means that their design and construction must follow precisely documented processes, and their performance must meet stringent documentation, development testing, production testing, and field maintenance requirements. The equipment also must contain comprehensive self-test and fault-indication capabilities, which require additional circuitry and the use of components that include self-test features.

Large-volume infusion pump

Syringe pump

Electrical leakage to the patient is a significant concern. Medical device developers must meet the requirements of the IEC 60601-1 product safety standard for electrical medical equipment. Even though the pump is a patient-connected device, the connection is nonconductive, so it falls in the least-stringent category (type B).

Given the time and expense required to achieve FDA approval, manufacturers must select a supplier with a customer-oriented discontinuance policy to ensure that system components will be available for many years.

Medical customers rely on Maxim products because over the years we have carefully avoided discontinuing parts. We realize how devastating product discontinuance can be to a customer, so we work diligently to transfer some products to newer production lines, create wafer buffers, allow last-time purchases, or develop upgrade devices. Very few Maxim parts have ever been discontinued while demand still existed. Maxim's Discontinuance Policy is one of the most flexible among our peer supplier companies.

Portability

Infusion pumps must be portable, since patients need to be mobile both within the hospital and at home. The devices must be battery powered, relatively small, and relatively lightweight. Designers, therefore, require solutions that minimize size and power consumption. Examples include the use of switching voltage regulators instead of linear regulators, even in low-energy power supplies, and the use of higher frequency switching supplies to minimize the size of external components.

Infusion pump solutions

Pump mechanism

Traditionally, stepper motors have been used in the pump mechanism to provide a precise flow rate. With angular-position sensors or Hall-effect sensors, it is possible to use DC motors instead. In these designs, the motors drive actuators (cams and fingers) to milk the tubing in precisely known fluid volumes per revolution of the mechanism.

Motor loading varies as the mechanism rotates. Motor load is affected by the position of the pump mechanism, fluid viscosity, and flow rate. To reduce power consumption, motor drive circuits can include motor-load sensor signals that feed into a closed-loop control system to adjust the motor drive voltage. A variety of current-sense amplifiers, operational amplifiers, comparators, and filters are used to implement these closed-loop control systems.

Power supplies

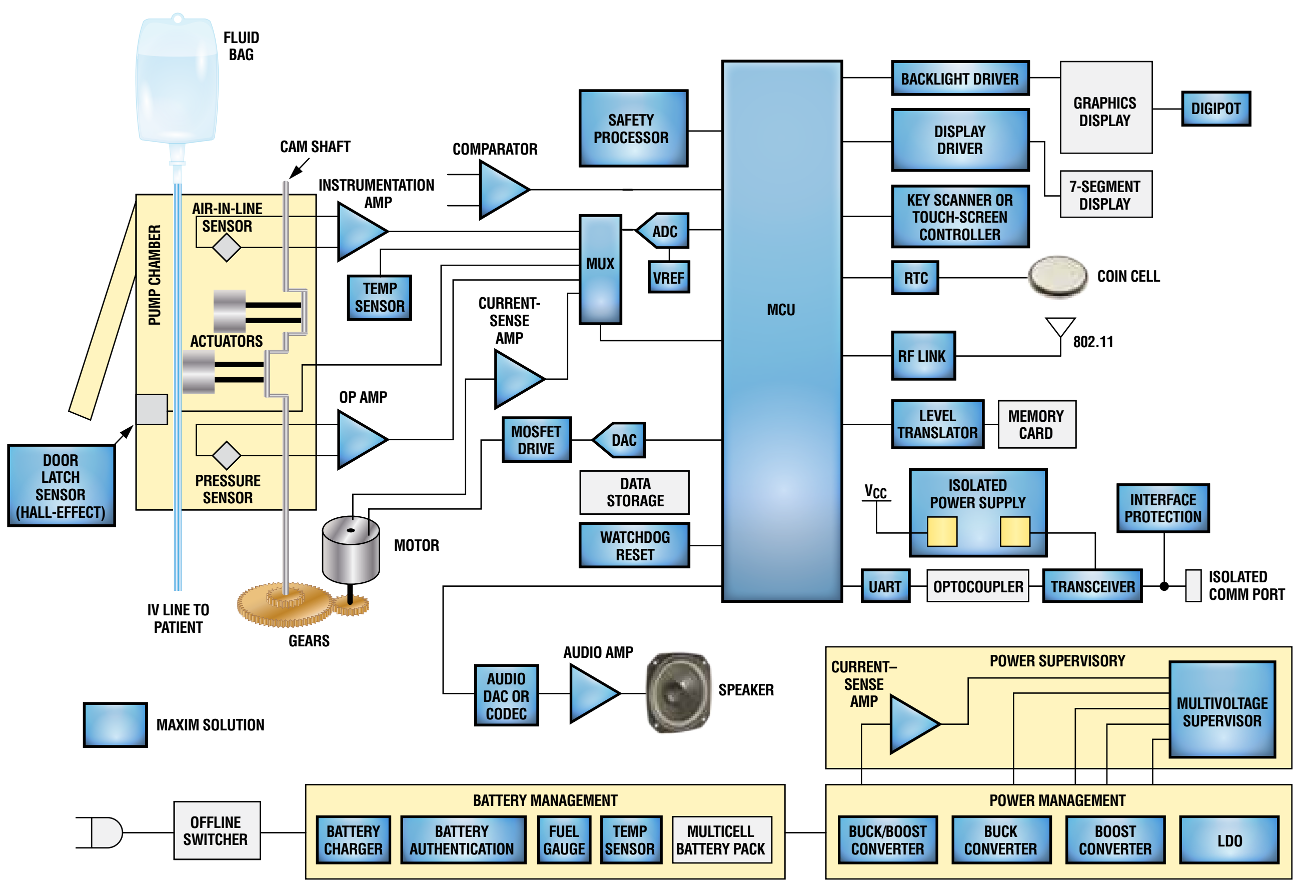
To maximize battery life, system designers use switch-mode voltage regulators for any significant power level. Switch-mode converters should run as fast as possible to minimize size and weight. Low-dropout linear regulators (LDOs) are used only in the very lowest power circuitry where their low efficiency can be tolerated, or where the output voltage of the LDO is not much lower than the input voltage, which keeps the efficiency high.

The use of fairly sophisticated processors places requirements on power supplies that can include voltage identification digital (VID) control from the central processing unit (CPU), fast load-step response, and precision low-voltage/high-current outputs. Digital-to-analog converters (DACs) and digital potentiometers are used in these power supplies when on-the-fly programmability is needed but VID control is not built into the regulator controller.

Because these are patient-connected devices and AC-line powered, they must meet UL® and IEC safety requirements. This means that the offline switching power supply must be designed and certified by these organizations for medical applications with patient connection.

Battery management

Caregivers often need to transport patients while they remain on the IV,



Functional block diagram of an infusion pump. For a list of Maxim's recommended solutions for infusion pumps, please visit: www.maxim-ic.com/infusion.

so the infusion pump must be able to operate from battery power alone for several hours. The use of rechargeable battery packs is mandatory.

The infusion pump absolutely must not run out of battery power; otherwise, it would stop pumping. Because of this, an accurate battery fuel gauge is required. Coulomb counting is the accepted method today, as voltage-sensing fuel gauges are not nearly accurate enough for this type of patient-connected equipment.

User interface

The user interface is used to program the flow rate and provides a wealth of information. In addition to the infusion rate, hospital units display parameters such as the fluid being infused, patient information, the health of the pumping system, the amount of battery life remaining, and alarm conditions.

On some wearable models intended for home use, the patient is expected to do the programming. These devices benefit from intuitive graphical user interfaces (GUIs) that guide patients through the programming process. These infusion pumps frequently have color displays and touch screens for user inputs. Visible, audible, and haptic responses to user touch inputs help designers improve the user experience. Advanced touch-screen controllers like the MAX11811 offer haptic feedback, touch processing to reduce bus traffic, and autonomous modes for precision gesture detection.

Flow rates can be programmed over a very wide range: 0.01mL/hr to 999mL/hr is typical. Due to a history of medication errors caused by pump programming errors, sophisticated software routines have been implemented in infusion pumps to warn users when unusual or dangerous infusion rates are selected.

Displays/keyboards

Full-color, high-resolution, backlit liquid-crystal displays (LCDs) are the most common. Some pumps also incorporate auxiliary alphanumeric displays. Display self-test at power-up is an FDA requirement, so designers require drivers with built-in self-test features.

Self-test and system monitoring

All infusion pumps must perform power-on self-test (POST) to meet FDA requirements. This includes tests of all critical processors, critical circuitry, indicators, displays, and alarm functionality. Some POST operations can require user observations, but additional circuitry is used for self-checking to reduce the risk of undetected failures.

For example, some models use a safety processor to monitor the performance of the main processor and to generate an alarm if unexpected behavior is detected. Another example of self-test is the simple monitoring of current through light-emitting diodes (LEDs) as they are turned on and off. If currents fall outside the acceptable range, a fault is indicated. Probably the most common self-test is the watchdog timer (WDT). Microprocessor supervisors with WDT functions are commonly used to ensure that the processor executes within proper code boundaries. In medical devices, it is usually not acceptable to have the supervisor on the same IC as the microprocessor, as this approach would subject the supervisor to the same transient errors as the microprocessor.

Supervisory functions are critical for ensuring that the pump is operating properly during patient use. Microcontrollers (of which there are often several in a single pump) must be held in reset until all power supplies are within tolerance and stable. All power supplies are monitored with voltage supervisors for undervoltage and overvoltage conditions. Motor loading is monitored and motor-stall detection is provided. (Motor stall is a critical failure causing a top-priority alarm.) Because of the criticality of the system, often power-supply voltages are monitored with ADCs so that their exact value can be recorded periodically. ADCs are also needed for sensor readings, such as temperature, motor loading, IV line pressure, and battery voltage.

Temperature sensing is implemented in the battery pack, the power supply, the motor, and the display. Due to the high efficiency of these designs, fans are usually not needed. These pumps must be splash-proof, so it is difficult to put in openings for airflow.

Alarms

Infusion pumps require audible and visible alarms to alert users to faults or potentially dangerous conditions. Bicolor or tricolor (red/orange/green) LEDs are typically used as visual indicators. Audible alarms vary from simple beepers driven by the microcontroller's pulse-width modulation (PWM) output to more sophisticated alarms (such as voice synthesis) created with an audio DAC.

Even simple audio beepers should include a self-test feature. This function can be implemented either indirectly by monitoring for a speaker impedance within range or directly by incorporating a mic near the speaker to register the audio output and confirm that it is at the proper level.

Timekeeping

Due to the criticality of patient care, every event needs to be logged and time stamped. Every key press, every start and end of an infusion, every change of configuration (pump door opening/closing, AC power disconnect, etc.), and every reported fault condition needs to be logged and time stamped for later review in case of lawsuits or instrument malfunction.

A real-time clock (RTC) is required. Since other clock sources for microprocessors and digital circuitry are not especially critical, standard crystals can be used. If extreme accuracy is needed for the RTC, Maxim has RTCs with built-in temperature-compensated crystal oscillators (TCXOs) that achieve an accuracy of ±2ppm (0°C to +40°C), which is about two orders of magnitude more accurate than a standard crystal.

Electrostatic discharge

All infusion pumps must pass IEC 61000-4-2 electrostatic discharge (ESD) requirements by either using electronics with built-in protection or by adding ESD line protectors to exposed traces. Maxim offers many interface parts with this high ESD protection built-in, as well as standalone ESD diode arrays.

Interfaces

Modern infusion pumps include interfaces to connect to hospital information systems. These are variously hardwired (RS-232, RS-485, USB, and Ethernet) and/or wireless interfaces (Bluetooth® and Wi-Fi®).

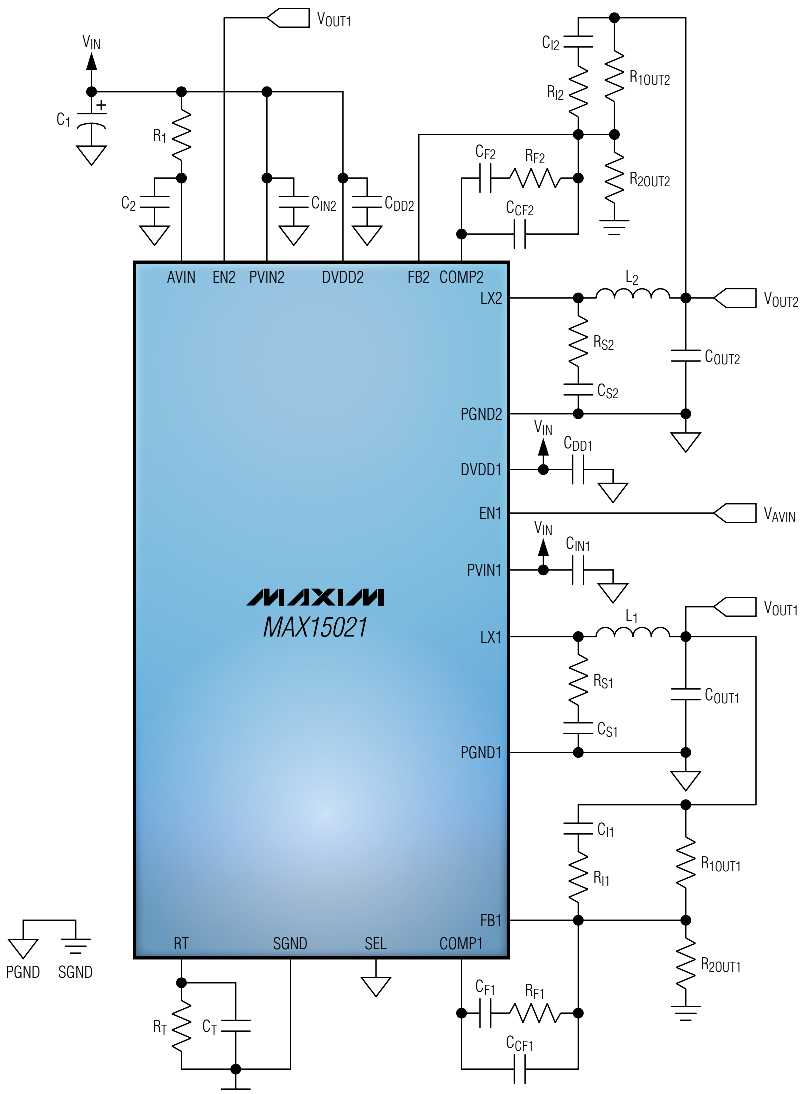
For wired interfaces, galvanic isolation is critical to meet the patient safety requirements of IEC 60601-1. Interfaces with unidirectional lines (such as RS-232, RS-485, RS-422) are not difficult to isolate. The only challenge is to create an isolated supply for them residing on the isolated side. An integrated device such as the MAX256 can solve this challenge by providing up to 3W of isolated power for isolated interfaces from a compact SO package.

www.maxim-ic.com/infusion

Voltage regulator reduces solution size while offering high efficiency and safety for modern processor power

MAX15021

The MAX15021 is a dual 4A/2A step-down regulator that has integrated switches and runs at up to 4MHz. Tracking/sequencing features and digital soft-start/stop provide the protection needed to bring up modern processors and ASICs with restrictive voltage-rail relationships.



Typical operating circuit for the MAX15021 used in a sequencing configuration.

Benefits

- **Minimizes solution size**
  - Onboard power FETs eliminate external components
  - 4MHz switching reduces L and C sizes
  - 180° out-of-phase operation reduces size of input capacitor
- **High-efficiency solution (over 90% at optimum conditions)**
  - Integrated synchronous switches reduce loss vs. low-side catch diode
  - Lossless cycle-by-cycle current sensing uses $R_{DS(ON)}$ of integrated MOSFET—no extra parts are needed that would dissipate additional power
- **Safety features**
  - Cycle-by-cycle current limit prevents inductor saturation
  - Hiccup-mode short-circuit protection
  - Input undervoltage lockout (UVLO)
- **Flexible features for modern processors**
  - Tracking/sequencing capability
  - Digital soft-start/stop for tracking applications
  - Low output voltage down to 0.6V

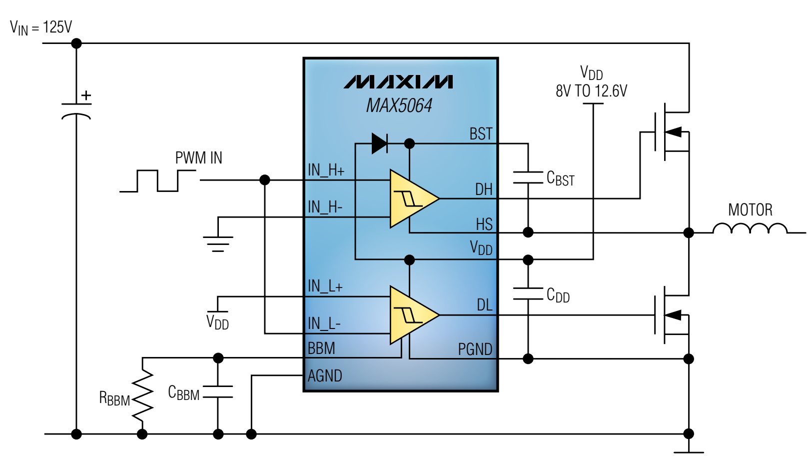
MOSFET driver for motor H-bridges is second-sourced and comes in small package

MAX5064

The MAX5064 is a half-bridge MOSFET driver that comes in a 4mm x 4mm, 12-pin TQFN package. This driver features 125V input operation, 2A peak source/sink current drive capability, and a 35ns (typ) propagation delay.

Benefits

- **Smaller solution size**
  - High- and low-side drivers in single TQFN package
- **Higher efficiency solution**
  - Programmable break-before-make timing guarantees optimum system performance
  - 2A peak source/sink capability ensures fast switching to minimize power dissipation
  - Charge pump allows high-side n-channel MOSFET switching for improved efficiency
  - Low 200µA supply current keeps efficiency high
- **Minimal redesign issues**
  - Some versions are pin-for-pin compatible with alternate source
  - Maxim has a strong minimal-obsolescence policy to keep parts in production as long as possible
- **Safety features**
  - Instant turn-off of drivers during fault
  - UVLO prevents overheating of MOSFETs
  - Tight propagation-delay matching ensures no shoot-through



Typical operating circuit for the MAX5064 in a motor driver application.

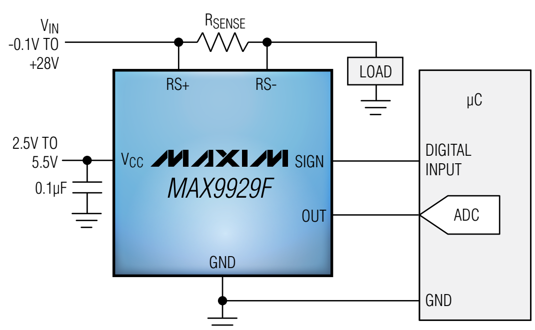
Current-sense amp sits on the high side, won't disrupt ground, and is easy to design in

MAX9929F

The MAX9929F is a current-sense amplifier with a wide -0.1V to +28V input common-mode range. Its unique architecture offers true ground sensing and high-side current sensing, as well as unidirectional or bidirectional current-monitoring capability. Capable of giving a proper reading even if the current-sense rail is shorted to ground, the MAX9929F is ideal for monitoring motor loads, battery current, and power-supply rails.

Benefits

- **Easy to design in**
  - Input common-mode range is independent of supply voltage
  - SIGN output indicates current polarity, allowing use of the ADC's full input range in both directions
- **Small solution size**
  - Available in a 6-bump UCSP™ (1mm x 1.5mm)
  - High gain accuracy (±1%) and low input V_{OS} (0.4mV, max) allow use of low-value, low-power current-sense resistor
- **Accurate readings**
  - High gain accuracy (±1%) and low input V_{OS} (0.4mV, max)
  - Provides upgrade path from earlier MAX4372_EBT, so users can quickly improve accuracy of legacy systems
- **Low power consumption**
  - Low 20µA quiescent current reduces power consumption



Typical operating circuit for the MAX9929F.

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Unique fuel-gauge IC provides accurate remaining-capacity information

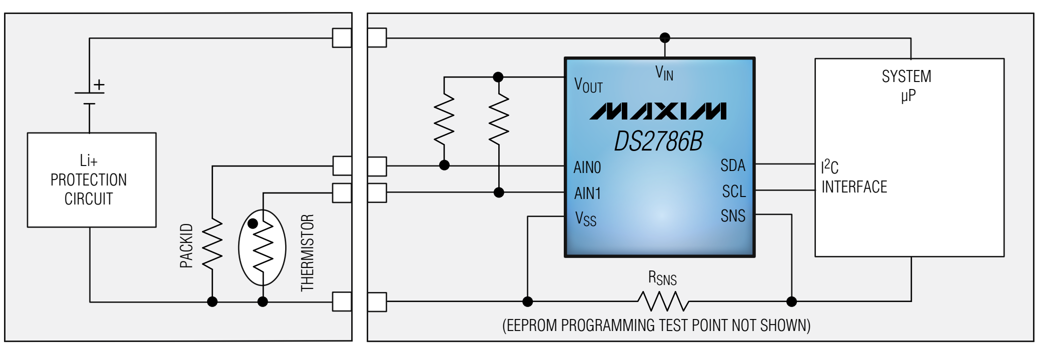
DS2786B

The DS2786B is a 1- to 4-cell battery fuel-gauge IC that uses two complementary methods to achieve an accurate remaining-capacity estimate. An open-circuit voltage (OCV) method corrects for coulomb counter wander, while coulomb counting (CC) corrects for OCV delay. Coulomb counting is known to be very accurate, but it suffers from wander after repeated partial charge and discharge cycles, which typically prevent the gauge from finding full or empty states. Meanwhile, OCV requires a long, no-load battery rest period to provide a good estimate of remaining capacity.

The DS2786B uses both methods to provide a more accurate result than could be achieved with either method on its own. Its 12-bit battery-voltage measurement yields ±10mV accuracy for OCV measurements, while an 11-bit, bidirectional current measurement yields a 1 LSB resolution of 1.67mA for accurate CC even at low loads and over a wide dynamic range.

Benefits

- **Get the best accuracy using OCV and CC in a single IC**
  - CC for accurate charge and discharge tracking
  - OCV measurement corrects for wander in CC
  - Autocalibration cycle minimizes current-measurement offset errors
  - On-chip EEPROM stores cell parameters to tailor results to specific cell characteristics
- **Low power saves battery life**
  - Active current: 50µA (typ), 80µA (max)
  - Sleep current: 1µA (typ), 3µA (max)
- **Small enough to be placed on battery pack side**
  - 3mm x 3mm 10-pin TDFN package
  - Serial I²C interface keeps pin count low



Typical operating circuit for the DS2786B.

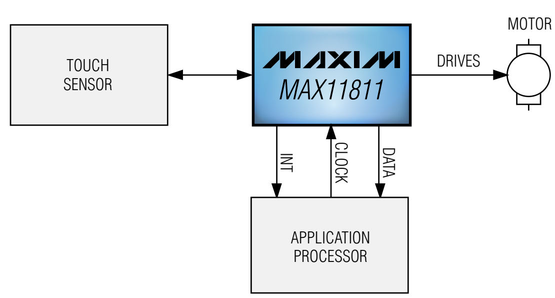
Smart touch-screen controller reduces processor burden while directly driving vibration motor

MAX11811

The MAX11811 is a touch-screen controller for 4-wire touch screens. This controller integrates a haptic motor driver and advanced features such as spatial filtering, an autonomous mode, and data tagging to significantly reduce the number of processor interrupts and processing burden. It also includes a 12-bit ADC, I^2C interface, IR proximity sensor driver, and automatic power-down.

Benefits

- **Smarter solution reduces processor burden**
  - Aperture mode provides spatial filtering to reduce processor interrupts
  - Data tagging provides touch-event information—initial touch, continuing touch, and touch release
  - On-chip FIFO stores events in autonomous mode to capture gestures with more detail
  - Built-in vibration motor driver relieves processor from this time-critical task
  - Built-in haptic waveforms reduce processor burden
- **Low-power operation saves battery life**
  - Automatic power-down saves power whenever it can with no command from the µC
  - Low-power operation of 250µW (at V_{DD} = 1.7V, 34.4ksps)
  - Fewer interrupts in autonomous mode allow processor to sleep longer
  - IR proximity sensor driver can power down display when user walks away



Block diagram for the MAX11811 in a haptic touch-screen application.

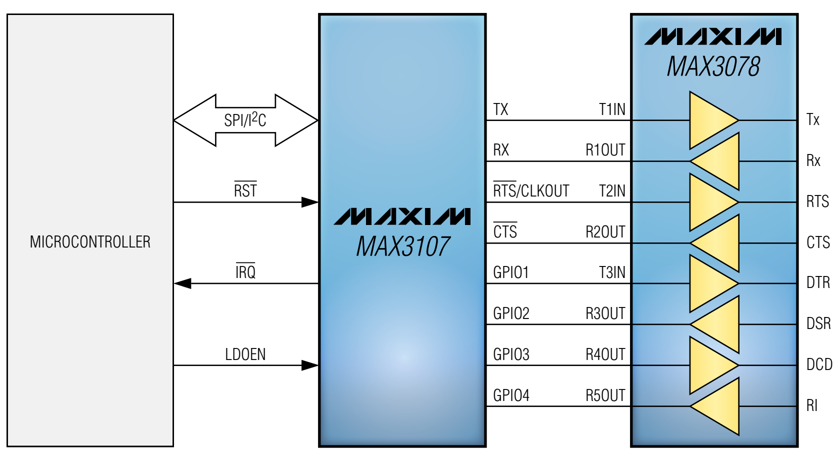
Serial UART eases connection of new microprocessor-based equipment to older hospital information systems

MAX3107

The MAX3107 is a full-featured serial UART for interfacing an RS-485/RS-232 bus with an SPI/I²C microprocessor. It integrates 128-word FIFOs on both the Rx and Tx to provide buffering to offload the microprocessor. Logic-level translation (down to 1.7V) on both the synchronous and asynchronous sides enables use with a wide selection of RS-232/RS-485 transceivers. An onboard fractional baud-rate generator maximizes flexibility in baud-rate selection. The MAX3107 supports a 24Mbps (max) data rate.

Benefits

- **Easy solution for interfacing new microprocessors to traditional hospital information systems**
  - SPI™ or I²C interface to microprocessor eases solution implementation
  - Level translation on both sides eases logic-level issues
  - Additional GPIOs allow full handshaking if needed
- **Small solution reduces size of isolated interface**
  - 3.5mm x 3.5mm TQFN package
  - Integrated oscillator eliminates external parts



Typical operating circuit for the MAX3107 in an RS-232 application.

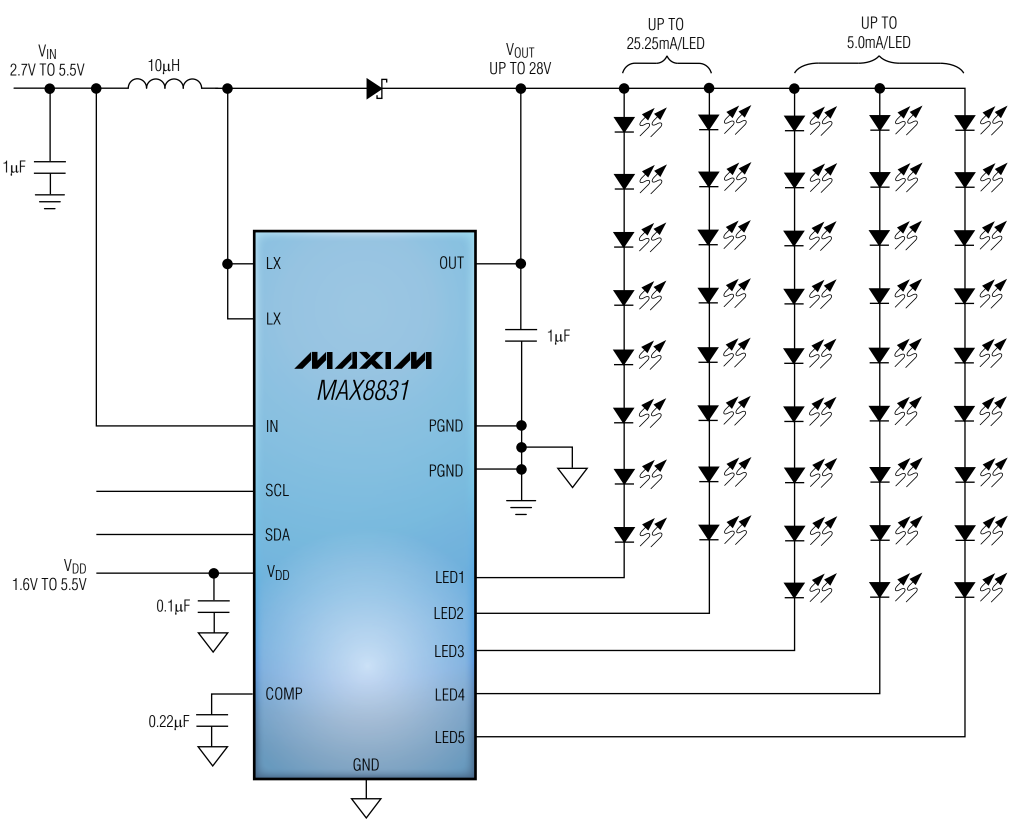
LED backlight driver offers high efficiency to save battery life and fault detection to improve failure response—all in a very small package

MAX8831

The MAX8831 is a white-LED driver with five low-dropout current regulators for display and keypad backlighting. This device integrates an inductor-based boost converter that automatically determines the voltage needed to drive LEDs at the programmed current. It also features an I²C interface to allow full programmability. A 2mm x 2mm wafer-level package (WLP) makes the MAX8831 well suited for space-constrained designs.

Benefits

- **Reduces size and complexity by combining two functions in a single IC**
  - Drives two strings at 25mA for display backlighting and three strings at 5mA for keypad backlighting
  - Tiny 2mm x 2mm WLP
- **Increases battery life**
  - Boosts voltage to LEDs only as much as needed for programmed current, thus keeping efficiency high
  - Switcher enters skip mode for light-load efficiency
  - Ultra-low 0.1µA shutdown current
- **Increases safety**
  - Open/short LED fault detection
  - Output overvoltage protection (OVP)
  - Open-circuit Schottky diode detection



Typical operating circuit for the MAX8831.

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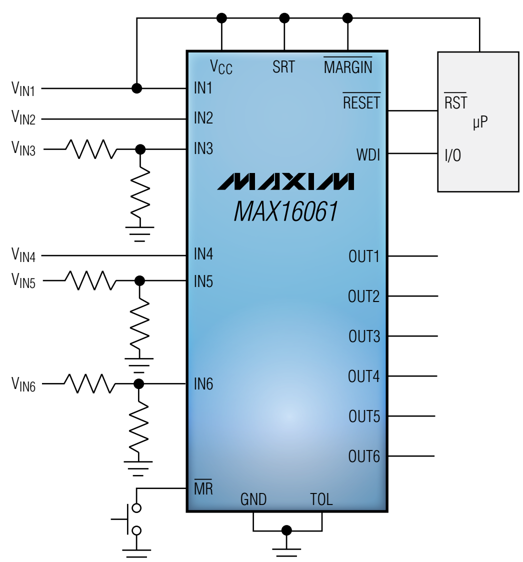
Multivoltage supervisor with watchdog detects voltage faults and processor errors

MAX16061

The MAX16061 is a hex voltage monitor that integrates a watchdog timer and reset to enhance system reliability. (Quad and octal versions are also available.) This exceptionally accurate (±1%) supervisor includes a bandgap reference to enable highly precise trimming of the voltage thresholds. The MAX16061 is well suited for multivoltage systems that require precision voltage monitoring and other supervisory functions.

Benefits

- **Enhances system reliability**
  - ±1% accuracy over wide temperature range keeps detection thresholds valid
  - Includes watchdog timer to ensure that the processor is functioning properly
  - Keeps processor in reset until all voltages are up and stable
- **Reduces size and complexity by combining multiple functions in a single IC**
  - Monitors multiple voltages with individual outputs to allow unique responses to each input
  - Minimizes external parts with some fixed thresholds and with internal pullups on open-drain outputs
  - Combines watchdog function with reset function to simplify system design
- **Eases system integration**
  - Provides extra-long watchdog timeout period at system startup to allow system configuration software to finish
  - Fixed- or capacitor-adjustable timeout enables users to tailor response to system needs



Typical operating circuit for the MAX16061.

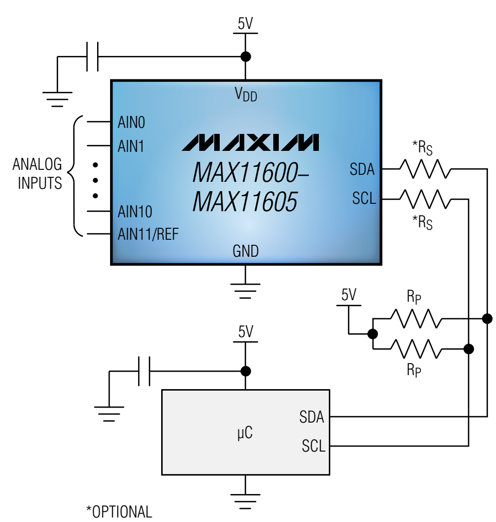
ADC with multiplexer gathers data from 12 sources for self-monitoring needs

MAX11605

The MAX11605 is a 12-channel, 8-bit ADC with an analog input multiplexer for monitoring and digitizing multiple system inputs. This device provides exceptional low-power operation, consuming as little as 350µA at 188ksps or 8µA at data rates of 10ksps or less. The analog inputs are software configurable to support either unipolar or bipolar inputs, as well as single-ended or differential operation.

Benefits

- **Conserves battery life**
  - Runs on supply as low as 2.7V to minimize power consumption
  - Consumes 350µA (typ) at full speed; much less if slowed down
  - Power-down mode uses only 1µA
  - Auto shutdown between conversions reduces supply current to 1µA
- **Fast data gathering for improved response time to fault conditions**
  - I^2C interface can run at 1.7MHz in high-speed mode
  - Up to 188ksps sampling rate
- **Easy to implement with flexible features and a variety of choices**
  - 4-, 8-, and 12-channel versions (MAX11600–MAX11605)
  - Inputs configurable to unipolar or bipolar
  - Supply voltages from 2.7V to 3.6V or 5V
  - Internal or external reference (1V to V_{DD})



Typical operating circuit for the MAX11600–MAX11605.

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Recommended solutions

Part	Description	Features	Benefits
ADCs			
MAX11200*	24-bit, 120sps/480sps sigma-delta ADC with serial interface	50Hz/60Hz noise rejection	Industry's best noise-free resolution per unit of power increases accuracy
MAX1228/MAX1229	12-bit, 12-channel, 300ksps ADCs with serial interface	3V/3.3V/5V supply, internal temperature sensor and voltage reference, unipolar or bipolar inputs	Highly integrated 12-channel ADCs save space for compact pump designs
MAX1162	16-bit, 200ksps SAR ADC with serial interface	10µA in shutdown, 10-µMAX® package	Saves space and reduces battery drain
MAX11605	8-bit, 12-channel, 188ksps ADC with serial interface	Easy system integration, FIFO eases burden on microprocessor, unipolar or bipolar inputs for unique sensing needs	Flexible interface reduces design time and saves space
Amplifiers			
Audio amps			
MAX9812	Low-power microphone amplifier	Low noise, integrated bias, 500kHz bandwidth, rail-to-rail output, SC70, 2.7V operation, shutdown, fixed gain	Built-in bias and small package reduce solution size, while shutdown and low-voltage operation save battery life
MAX9710	Audio power amplifier	3W stereo amplifier with shutdown feature, 100dB PSRR	Provides good audio quality in harsh environments
MAX98000*	Audio DAC	I^2S input, Class D amplifier, mono, low EMI, 2W	High-efficiency Class D extends battery life
MAX9860	Audio codec	Ultra-low power (9mW), mono codec with programmable digital filter	Provides a complete audio solution that minimizes battery drain
MAX9718/MAX9719	Low-cost, mono/stereo, 1.4W differential audio power amplifiers	Differential input and output, fixed or adjustable gain, 2.7V to 5.5V supply, shutdown mode	Minimal external components for small solution; maximum audio output from low supply voltages
Current-sense amps			
MAX9918–MAX9920	Bidirectional current-sense amplifiers with wide -20V to +75V common-mode voltage	-40°C to +125°C temperature range, precision 400µV (max) V_{OS}, ±0.45% gain error	Enable very accurate motor control for improved infusion pump control
MAX9928F/ MAX9929F	Bidirectional current-sense amplifiers with wide 0 to 28V common-mode voltage	-0.1V to +28V common-mode voltage, precision 400µV (max) V_{OS}, ±1% gain error, sign output, current output	Improve motor control for more accurate fluid delivery
MAX9634	1µA, precision current-sense amplifier	28V (max) common-mode voltage, 250µV (max) V_{OS}, 1µA (max) quiescent current, small UCSP and SOT23 packages	1µA supply current is less than the self-leakage current of batteries
Instrumentation amps			
MAX4208/MAX4209	Ultra-low offset/drift, precision instrumentation amplifiers with REF buffer	20µV (max) V_{OS} with "zero drift," 1.4µA shutdown current, indirect-current-feedback architecture	Allow near-ground sensing with single supply, thus simplifying design
MAX4194–MAX4197	Micropower, three-op-amp instrumentation amplifiers	450µV (max) V_{OS}, 93µA quiescent current, adjustable and fixed (1, 10, 100V/V) gain versions	Shutdown function and low-current operation save power
Op amps			
MAX9617–MAX9619	High-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs	10µV (max) V_{OS} with "zero drift," 0.42µV_{P-P} noise, 59µA quiescent current, tiny 8-pin SC70	Improve measurement accuracy and reduces calibration requirements
MAX4475–MAX4478	Precision, low-distortion, 4.5nV/$\sqrt{Hz}$ op amps	750µV (max) V_{OS}, 10MHz op amp, 4.5nV/$\sqrt{Hz}$ noise, CMOS inputs, SOT23	Improve measurement accuracy when used for gain, filtering, or driving ADC inputs

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Battery management			
Fuel gauges			
DS2786B	Battery fuel gauge uses both coulomb counting and OCV	EEPROM included to store unique battery characteristics, low power (50µA active, 1µA sleep), 3mm x 3mm 10-TDFN	Provides accurate estimation of remaining battery capacity while extending battery life
MAX17043*	Low-cost I^2C fuel-gauge IC	ModelGauge™ algorithm, 2mm x 3mm footprint, low-battery alert, no sense resistor	Allows system µC to remain in sleep mode for longer, thus saving power
MAX17041*	Low-cost I^2C fuel-gauge IC for 2S Li+ cells	ModelGauge algorithm, 2mm x 3mm footprint	Reports SOC without sense resistor; reduces design size and cost
DS2776/DS2778	1-Wire®/I^2C, 2-cell stand-alone fuel-gauge ICs with Li+ protector and SHA-1 authentication	FuelPack™ algorithm with precision voltage, current, and temperature monitor; programmable protector	Save space, prevent cloning, and simplify design
MAX1789	2-/3-/4-cell battery fuel gauge and protector	Accurate fuel gauge, 8-bit RISC microcontroller core, integrated primary-protection IC	Provides high accuracy and increases battery safety
Single-input battery chargers			
MAX17435/ MAX17535*	SMBus™ battery charger for 3 or 4 series Li+ cells	Internal switch-mode FETs, 8V to 26V supply, up to 850kHz operation, 11-bit voltage setting	Fixed inductor ripple design reduces component size and cost
DS2715	Multicell NiMH pack charger	dT/dt termination, secondary protection through thermistor and timer, charges 1 to 10 NiMH cells in series	Economically improves safety and reliability in designs using NiMH cells
Comparators			
MAX9060–MAX9064	Ultra-low-power single comparators	50nA/400nA comparators with and without internal 0.2V reference in space-saving UCSP	Save space and power; ideal for jack-insertion detection and voltage-rail monitoring
DACs			
MAX5360	6-bit I^2C DAC for interfacing with LED drivers	230µA supply current, internal reference, buffered output	Saves board space and cost with internal reference and buffers
MAX5363	6-bit SPI DAC for interfacing with LED drivers	230µA supply current, internal reference, buffered output	Saves board space and cost with internal reference and buffers
DS4422	Dual 7-bit I^2C sink/source current DAC	Up to 200µA sink/source current to adjust power supplies	Easily modify power-supply output voltages to save battery life
Digital potentiometers			
MAX5160/MAX5161	Low-power digital potentiometers in SOT23/µMAX package	32 tap positions, 2.7V to 5.5V supply	Low-power solutions save battery life
Display drivers			
MAX6979	16-port LED driver with fault detection and watchdog	16 constant-current LED outputs, up to 55mA per output, ±3% matching, serial interface, reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
MAX6978	8-port LED driver with fault detection and watchdog	8 constant-current LED outputs, up to 55mA per output, ±3% matching, serial interface, reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval

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*Future part—contact factory for availability.

Visit digikey.com

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Hall-effect sensor interface			
MAX9921	Dual, 2-wire Hall-effect sensor interface with diagnostics	Withstands 60V voltage transients and ±15kV ESD spikes, built-in diagnostics, controlled ramp for Hall-effect sensor power	Integrated ESD and diagnostics increase product reliability while saving space
Interface ICs			
Current limiters			
MAX4995	50mA to 600mA adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
MAX14523	250mA to 1.5A adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
ESD protectors			
MAX3207E	2-channel, ±15kV HBM ESD protector	2.5pF, ±15kV HBM ESD protection	Increases reliability by protecting high-data-rate interfaces
MAX13204E	4-channel, ±30kV HBM ESD protector	6pF, ±30kV HBM ESD protection	Increases reliability by protecting high-data-rate interfaces
Logic-level translators			
MAX13030E	6-channel, high-speed logic-level translator	100Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 2mm x 2mm UCSP	High data rate, suitable number of channels, and high ESD protection make this part ideal for memory card level translation
MAX13101E	16-channel logic-level translator	20Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 3mm x 3mm WLP	Integrates level translation with ESD protection in a space-saving package
Transceivers			
MAX3349EA	Full-speed USB transceiver with UART multiplexer	Full-/low-speed USB, integrated ESD on D+/D- lines	Increases reliability and reduces size by functionally sharing a USB connector
MAX13223E	Fault-protected RS-232 transceiver	3.3V to 5V supply, ±70V fault protection	Simplifies design by eliminating external protection components
MAX3535E	Isolated RS-485 transceiver	3V to 5V supply, 2500V_{RMS} isolation, ±15kV HBM ESD protection	Eliminates external isolation components, reducing pump size and cost
MAX13442E–MAX13444E	Fault-protected RS-485 transceivers	±80V fault protection, half duplex, 5V supply	Simplify design by eliminating external components
MAX13430E	RS-485 transceiver with V_L pin in TDFN	3.3V to 5V supply, integrated V_L pin (down to 1.6V), 10-µMAX/TDFN	Integrated V_L pin enables logic-level translation to FPGAs/microcontrollers with no additional parts
UARTs			
MAX3107	SPI/I²C UART with integrated oscillator	24Mbps (max) data rate, 128-word FIFO, RS-485/RS-232 control, four GPIOs, 24-SSOP or 24-TQFN (3.5mm x 3.5mm)	Integration reduces burden on microcontroller; tiny package fits isolated interfaces
MAX14830*	Quad SPI/I²C UART	Integrated oscillator, 24Mbps (max) data rate, power-save features, RS-485 control, four GPIOs, 48-TQFN (7mm x 7mm)	Four high-performance UARTs save space and provide extra flexibility

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Keyboard scanners, touch-screen controller			
MAX11811	4-wire touch-screen controller with integrated haptic motor driver	12-bit ADC, I^2C interface, proximity driver, automatic power-down	Reduces processor burden and extends battery life
MAX7359	2-wire-interfaced, low-EMI key-switch controller/GPO	Monitors up to 64 keys, low-voltage design, key debounce, key-release detection	Simplifies software and frees up microcontroller I/O
MAX7349	2-wire-interfaced, low-EMI key-switch and sounder controller	Monitors up to 64 keys, low-voltage design, key debounce, integrated sounder controller	Simplifies software and frees up microcontroller I/O
Microcontrollers			
MAXQ2010	Low-power, 16-bit mixed-signal LCD microcontroller	8-channel, 12-bit SAR ADC; 64KB flash; supply voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current	Saves space and extends battery life
MAXQ8913	16-bit mixed-signal microcontroller	7-channel, 12-bit SAR ADC; 64KB flash; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Single chip integrates multiple functions to minimize solution size
DS89C450	Highest performance 8051-compatible microcontroller	33MIPS at 33MHz, integrated supervisory functions	Improves device safety by managing safety functions
Power supplies			
MAX15021	Dual 4A/2A step-down regulator	4MHz, 180° out-of-phase switching, tracking/sequencing, built-in synchronous FETs, V_{OUT} down to 0.6V	Integrated safety features and small external components enable smaller solutions
MAX15036	Boost or buck converter capable of 3A	2.2MHz nonsynchronous, 4.5V to 23V V_{IN}, 0.6V to 28V V_{OUT}, clock output for driving second converter out of phase, reset output	One converter with the flexibility to serve many different pump designs
MAX8831	White-LED driver with inductor-based boost for five strings of LEDs	Auto-adjusts V_{OUT} as needed, automatic skip mode, 2mm x 2mm WLP, built-in safety features	Single IC drives display and keypad backlights; detects LED faults to meet medical self-test requirements
MAX8902A	Low-noise, 500mA LDO in 2mm x 2mm TDFN	16µV_{RMS}; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, and temperature	Low noise and high accuracy enable optimal performance from sensitive analog circuits
MAX5064	125V/2A, high-speed, half-bridge MOSFET driver for high- and low-side MOSFETs	High-side driver operates up to 125V, 2A gate drivers, balanced propagation delay, second sourced, UVLO	Reduces heat buildup and improves reliability in motor control applications
Real-time clocks (RTCs)			
DS1394	SPI RTC with trickle charger	Provides hundredths of a second to years information, trickle charger for coin-cell backup, UL® recognized, SPI bus to 4MHz, alarm	Provides accurate time stamps of system usage events
DS1388	I^2C RTC with trickle charger	Provides hundredths of a second to years information, UL recognized, I^2C bus, supervisor with watchdog, 512 bytes of EEPROM	Provides accurate timing while saving space by integrating multiple functions
RF ICs			
RF transceivers			
MAX7030	Low-cost, factory-programmed ASK/OOK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm package, no programming interface required	Long battery life; small size; faster and simpler product design

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
RF transceivers (continued)			
MAX7031	Low-cost, factory-programmed FSK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm package, no programming interface required	Long battery life; small size; faster and simpler product design
MAX7032	Low-cost, frequency-programmable ASK/FSK/OOK transceiver	Low current (< 6.7mA Rx, < 12.5mA Tx), 5mm x 5mm package, fully programmable from 300MHz to 450MHz	Long battery life; small size; maximum flexibility
RF transmitters			
MAX1472	Low-power, 300MHz to 450MHz, crystal-based ASK transmitter	Wide frequency range, low-current operation, 3mm x 3mm package	Compact ASK transmitter for both North America and Europe offering crystal stability and long battery life
MAX1479	Low-power, 300MHz to 450MHz, crystal-based ASK/FSK transmitter	Wide frequency range, low-current operation	ASK/FSK transmitter for both North America and Europe offering crystal stability and long battery life
MAX7057	300MHz to 450MHz, crystal-based ASK/FSK transmitter	Wide frequency range, programmable synthesizer, and antenna-matching network	Efficiently transmits any frequency in the 300MHz to 450MHz band using a single crystal
RF receivers			
MAX1471	Programmable 300MHz to 450MHz ASK/FSK receiver	High sensitivity, built-in image rejection, and separate ASK/FSK data paths in a 5mm x 5mm package	Provides extended range while reducing cost
MAX1473	300MHz to 450MHz ASK receiver with AGC	High sensitivity, AGC, and built-in image rejection in a 5mm x 5mm package	Offers a compact, low-cost ASK solution with longer range
MAX7042	300MHz to 450MHz FSK receiver	Best FSK sensitivity and built-in image rejection in a 5mm x 5mm package	Provides a compact, low-cost FSK solution with longer range
Switch/multiplexer			
MAX4781	High-speed, low-voltage, 0.7Ω analog multiplexer	Excellent on/off performance up to 10MHz, 8:1 configuration, 1.6V to 3.6V supply	Wide operating range allows use in many applications
Temperature sensors			
DS600	±0.5°C accurate analog-output temperature sensor	Industry's most accurate analog temperature sensor: ±0.5°C accuracy from -20°C to +100°C	Improves system temperature-monitoring accuracy
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 enables easy accuracy upgrade and supply voltage reduction from LM75
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C, 1.7V to 3.7V operation, industry-standard pinout and registers	Industry-standard pinout facilitates migration from LM75 to lower supply voltage
DS18B20	±0.5°C accurate, 1-Wire digital temperature sensor	±0.5°C accuracy, 1-Wire interface, unique 64-bit serial number	Simplifies interface when deploying multiple distributed precision sensors
Voltage references			
Series			
MAX6018	Precision, micropower, 1.8V supply, low-dropout, series voltage reference in SOT23	1.263V to 2.048V V_{OUT}, ±0.2% to ±0.4% accuracy, 5µA quiescent current	Low operating current extends battery life
MAX6023	Precision, low-power, low-dropout, series voltage reference in ultra-small UCSP	1.25V to 5V V_{OUT}, ±0.2% accuracy, 1mm x 1.5mm x 0.3mm package	Smallest size fits in space-constrained designs

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Series (continued)			
MAX6034	Precision, micropower, series voltage reference in small SC70	±0.2% accuracy, 30ppm/°C, 90µA quiescent current, 2.048V to 4.096V V_{OUT}	Small SC70 package eases layout
Shunt			
MAX6006	Precision shunt voltage reference in SOT23	Ultra-low operating current (1µA), ±0.2% accuracy, wide operating range (1µA to 2mA)	Ultra-low operating current saves battery life
Voltage supervisors			
MAX6381	Single-voltage supervisor	Multiple thresholds and timeout options in tiny µDFN package; only a few external components	Versatile; saves space
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable threshold	Integrated circuit saves space and increases flexibility
MAX16062	Octal-voltage supervisor	Fixed and adjustable thresholds and timeouts; margin-enable and tolerance-select inputs; watchdog timer	Breadth of features and options provides flexibility to meet many design needs
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing, 3.7µA quiescent current	Increases design flexibility
MAX6816–MAX6818	Single, dual, and octal switch debouncers	±15kV ESD protection	High reliability; easy to use

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

Dialysis machines

Overview

Dialysis machines are artificial kidneys that perform most, but not all, kidney functions for patients who have permanent or temporary renal failure. The machines use hemodialysis to cleanse the blood and balance its constituents. With this process, the patient's blood is circulated through the machine where it is filtered and balanced for electrolytes, pH, and fluid concentration before being returned to the patient. One common problem with renal failure is water retention, so it is common for the process to remove several pints of fluid from the patient's blood.

There are two basic classes of dialysis machines: clinical units, which are commonly cabinet-size machines operated by trained technicians; and home-use dialysis machines, which are smaller and sometimes portable.

Normally, patients with complete loss of kidney function would need to visit the clinic at least three times per week and spend about four hours connected to the machine. With home-use machines, patients have more flexibility in scheduling dialysis, and they can dialyze for longer periods and more frequently. Thus, home-use machines are growing in popularity because they offer greater convenience and better clinical outcomes.

FDA-regulated medical equipment

Dialysis machines are medical equipment whose design and manufacture is regulated by the Food and Drug Administration (FDA). This means that their design and construction must follow precisely documented processes, and their performance must meet stringent documentation, development testing, production testing, and field maintenance requirements.

The equipment also must contain comprehensive self-test and fault-indication capabilities, which require additional circuitry and the use of components that include self-test features.

Electrical leakage to the patient is a significant concern. Medical device developers must meet the requirements of the IEC 60601-1 product safety standard for electrical medical equipment. Even though the dialysis machine is a patient-connected device, the connection is nonconductive so it falls in the least-stringent category (type B).

Given the time and expense required to achieve FDA approval, manufacturers must ensure the long-term availability of system components. Thus, it is important to select a supplier with a customer-oriented discontinuance policy to ensure that system components will be available for many years.

Medical customers rely on Maxim products because over the years we have carefully avoided discontinuing parts. We realize how devastating product discontinuance can be to a customer, so we work diligently to transfer some products to newer production lines, create wafer buffers, allow last-time purchases, or develop upgrade devices. Very few Maxim parts have ever been discontinued while demand still existed. Maxim's Discontinuance Policy is one of the most flexible among our peer supplier companies.

General operation

Extracorporeal circuit

The patient's blood is continuously pumped from an artery, a large vein, or a surgically modified vein to allow high blood flow rates. Its pressure is monitored both upstream and down-

Clinical dialysis machine

stream from the peristaltic blood pump. Before the blood enters the dialyzer, heparin is added to prevent clotting. A syringe pump is used to deliver the heparin at a precisely controlled rate.

The blood then enters the dialyzer where it passes across a large-surface-area, semipermeable membrane with a dialysate solution on the other side. A pressure gradient is maintained across the membrane to ensure the proper flow of compounds out of and into the blood. After cleansing and balancing within the dialyzer, the blood is passed through an air trap to remove any air bubbles before it is returned to the patient. An air bubble sensor ensures that no air bubbles remain.

Blood-pressure, oxygen-saturation, and sometimes hematocrit levels (blood cell concentration) are monitored for proper operation of the machine and to ensure patient safety. For maximum effectiveness, fresh dialysate is continually pumped through the dialyzer during operation.

Dialysate circuit

In clinical settings, dialysate is usually premixed to the proper concentration for direct use. In home units, to keep container size down, concentrated forms of dialysate are often used and diluted with sterilized water in the machine. Thus, home units must include water heaters, valves, pumps, and a variety of sensors to perform these extra steps. To lower power consumption in home units, the dialysate preparation process is often performed ahead of time, separately from dialysis.

Both types of machines include capabilities to add a bicarbonate buffer solution to the dialysate. This subcircuit comprises additional pumps, valves, and sensors.

Disinfection circuit

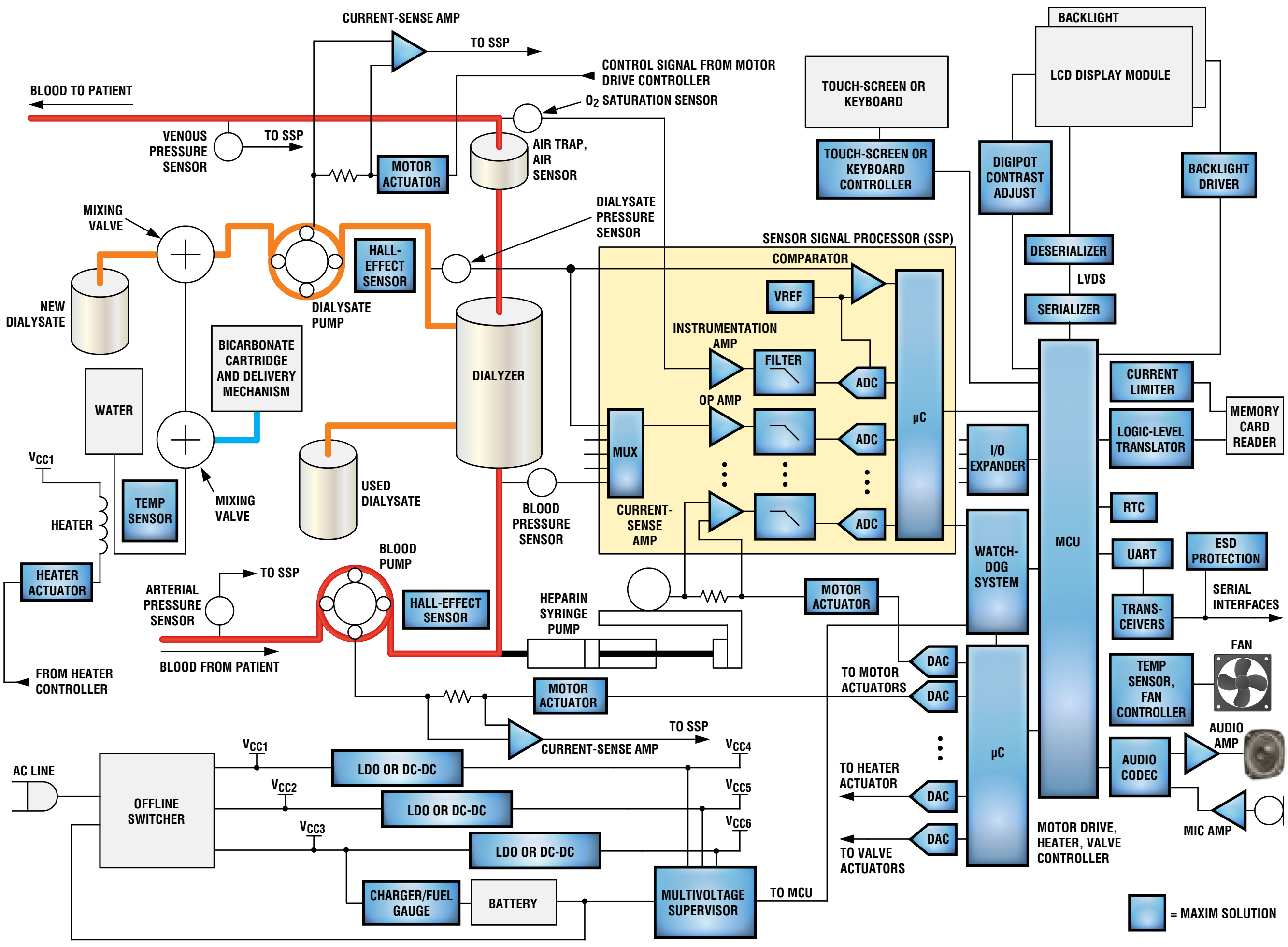
After the dialysis procedure, the machine must be cleansed and sterilized. Provisions are made in the plumbing to close the circuit into a loop and run saline and/or sterilized water through the system to flush away all impurities.

Special requirements of home units

For general convenience, home systems are smaller and sometimes portable. Since they require the additional function of dialysate preparation, the need for small, compact design is increased over clinical machines.

Low power draw is also important in home dialysis units. Earlier systems often required home rewiring to allow more than the typical 15A capability of a 110V AC branch circuit. Today, low-power design can eliminate the need for these costly modifications.

The disinfection cycle at the end of therapy is also a power-hungry process. To accomplish the heating required in a reasonable amount of time, batteries or ultracapacitors are included to provide short-term high-power capability to supplement line power as needed. When line-power usage drops below the 15A limit, the batteries or ultracapacitors are recharged.



Block diagram of a home-use dialysis machine. For a list of Maxim's recommended solutions for dialysis machines, please visit: www.maxim-ic.com/dialysis.

Machine features

Operator controls

Display and backlight. Clinical dialysis machines commonly have relatively large displays (approximately the size of a computer screen), while home units have much smaller displays. Modern machines normally employ a graphical user interface (GUI) for ease of use. They use liquid-crystal displays (LCDs), instead of cathode ray tube (CRT) monitors, to reduce weight and power consumption.

Maxim supplies LVDS serializers and deserializers uniquely suited for LCD panels. These solutions cover a wide range of bit widths (from 1 to 27) and speeds up to 2.5Gbps. They can translate between different logic levels (e.g., from LVCMOS to LVDS) to ensure compatibility between the processor video interface and the display module.

A complete portfolio of products is available to equalize, multiplex, buffer, and level translate these interfaces as needed to ensure signal integrity. For example, the MAX3803 can equalize LVDS, PECL, or CML signals up to 3.2Gbps to compensate for as much as 40in of FR4 board material, thus ensuring the proper display of data in systems where the display is located far from the graphics processor.

Backlighting is required using either cold-cathode fluorescent lamps (CCFLs) or high-brightness white LEDs. Maxim provides drivers for both types of backlights. Available features include spread-spectrum clocking to reduce electromagnetic interference (EMI) and wide dimming ratios to support a range of configurations.

Touch screens and keyboards. Maxim offers a variety of keyboard scanners, including devices that allow multiple simultaneous key presses. In many applications, keyboards are being displaced by touch screens, which can improve the user experience when paired with an intuitive GUI.

In touch-screen applications, designers must consider the tradeoffs of using resistive vs. capacitive touch screens. If multiple touches are to be allowed, then capacitive touch screens are needed. If only single-touch inputs are required, the resistive approach has several advantages. For example, resistive touch screens are compelling for cost reasons in displays that are larger than a few inches. Maxim has several newer and smarter touch-screen controllers for both resistive and capacitive types that perform touch-management functions to reduce the burden on the processor managing this interface.

Patient connections

For basic dialysis, there are no electrical connections to the patient. However, some dialysis machines monitor vital signs such as heart rate, temperature, and respiration rate, in addition to the patient's blood pressure. Since these functions are not specific to the dialysis process, they will not be discussed further in this chapter. See the other chapters in this solutions guide for details on these systems.

Data interfaces

A running record of the dialysis process for each patient session is kept electronically and made available in a number of ways. Dialysis machines can include USB, Ethernet, and a variety of serial (RS-232, RS-485, RS-422, etc.) interfaces to legacy hospital information systems.

Data card slots are also available on some designs. This allows patients to carry an ID card with personal medical information stored on it to enable automatic setup of many of the machine parameters. Wireless interfaces (such as Wi-Fi®) may also be included for direct connection to hospital wireless networks.

Mechanism

Pumps. Peristaltic pumps are commonly used for driving the various higher volume fluids in the machine: blood, dialysate, water, and saline. This type of pump is very convenient because it does not touch the fluids directly. Instead, a section of flexible tubing runs through the pump mechanism where it is compressed by rollers to push the fluid forward. These pumps require a significant amount of power and are driven by either DC or AC motors with variable speed control. Electronic means must be provided to ensure that the motor is turning at the desired rate. Maxim has Hall-effect sensors that give a fully independent signal picked up from actual shaft rotation, which can be used for redundancy if the motors already have Hall-effect sensors built in.

Valves. Several valves with electronic actuation are needed in the machine to allow variable mixing ratios. Various implementations are possible from simple opened/closed valves driven by solenoids to precision variable-position valves driven by stepper motors or other means.

Sensors. Dialysis machines require many different types of sensors to monitor various parameters. Blood pressure at various points in the extracorporeal circuit, dialysate pressure, temperature, O_2 saturation, motor speed, dialyzer membrane pressure gradient, and air are all monitored for proper values during dialysis. Unless they have digital outputs, the sensors' analog signals must be amplified, filtered, and digitized before being sent to the controller. The sensors require a range of ADC resolutions depending on the criticality of their accuracy, and a range of sampling speeds depending on the response times required.

Cleaning system. Between patient sessions, any reused components must be sterilized. One approach is to heat water or saline to a high sterilizing temperature and then run it through the machine, both through the extracorporeal circuit and through the dialysate circuit. Whatever cleaning mode is used, the machine may require additional driving and monitoring for proper operation.

Processing

Microcontrollers. Because of the large number of input signals to be monitored and the large number of pumps and other mechanisms to be controlled, many of these functions are performed with dedicated microcontrollers for that portion of the system. Controlling the overall system will be a main processor capable of running a full operating system and GUI. Communication between the controllers is required to send data, commands, and alerts.

Fail-safe circuitry. ICs with self-test and fault-reporting capabilities are very useful for maintaining patient safety under single-fault conditions. Additional monitoring circuitry is commonly used to monitor power-supply voltages, while watchdog circuits are used to ensure that microprocessor operation remains within bounds. Both audible and visible alarms are provided to alert users when a warning is needed or a fault condition has occurred.

Power supply

Due to the long duration of the dialysis process, all dialysis equipment is AC-line powered. Standard AC-DC converters meeting medical safety standards are employed. Due to the variety of components requiring power, a variety of voltage rails are needed at different power levels. A power system with multiple-output switching regulators is needed with a significant amount of linear regulation at the load for noise-sensitive precision circuits.

Safety regulations require power-supply self-monitoring for voltage, temperature, and current flow. Overvoltage and undervoltage detectors are common. Due to the higher power levels, active cooling is required using fans and temperature sensors in a variety of locations.

Home-use machines include water sterilization capabilities, which can require more power than is available from a standard wall outlet at 15A. Therefore, the power supply must be capable of limiting the current drawn from the AC line and adding in parallel power from a battery (or ultracapacitor).

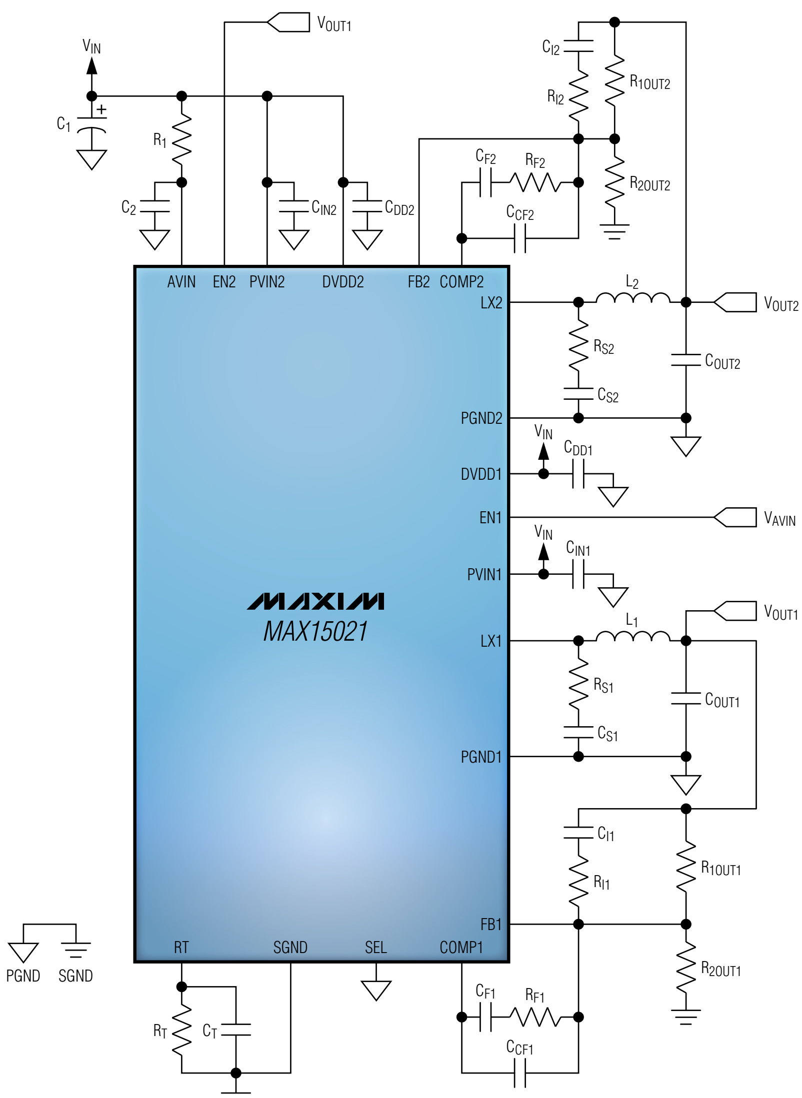
Battery management

As discussed above, home-use dialysis machines need to include batteries (or ultracapacitors) to supplement the power supply's output power when heating water for sterilization. These must be charged whenever possible and fuel gauged to indicate when enough capacity is available to proceed with the water sterilization process.

Voltage regulator reduces solution size while offering high efficiency and safety for modern processor power

MAX15021

The MAX15021 is a dual 4A/2A step-down regulator that has integrated switches and runs at up to 4MHz. Tracking/sequencing features and digital soft-start/stop provide the protection needed to bring up modern processors and ASICs with restrictive voltage-rail relationships.



Typical operating circuit for the MAX15021 used in a sequencing configuration.

Benefits

- **Minimizes system size**
  - Onboard power FETs eliminate external components
  - 4MHz switching reduces L and C sizes
  - 180° out-of-phase operation reduces size of input capacitor
- **Provides a high-efficiency solution (over 90% at optimum conditions)**
  - Integrated synchronous switches reduce loss vs. low-side catch diode
  - Lossless cycle-by-cycle current sensing uses $R_{DS(ON)}$ of integrated MOSFET—no extra parts are needed that would dissipate additional power
- **Integrates safety features**
  - Cycle-by-cycle current limit prevents inductor saturation
  - Hiccup-mode short-circuit protection
  - Input undervoltage lockout (UVLO)
- **Flexible features reduce design time in processor-based systems**
  - Tracking/sequencing capability
  - Digital soft-start/stop for tracking applications
  - Low output voltage down to 0.6V

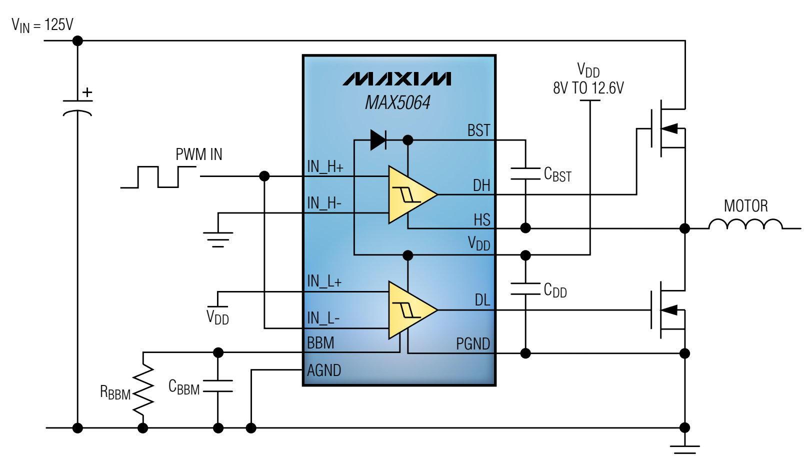
MOSFET driver for motor H-bridges provides enhanced feature set in small package

MAX5064

The MAX5064 is a half-bridge MOSFET driver that comes in a 4mm x 4mm, 12-pin TQFN package. This driver features 125V input operation, 2A peak source/sink current drive capability, and a 35ns (typ) propagation delay. The tight propagation-delay matching prevents cross-conduction by ensuring that the high-side and low-side MOSFETs are never on at the same time.

Benefits

- **Smaller solution size**
  - High- and low-side drivers in single TQFN package
- **Higher efficiency solution conserves power budget**
  - Programmable break-before-make timing guarantees optimum system performance
  - 2A peak source/sink capability ensures fast switching to minimize power dissipation
  - Charge pump allows high-side n-channel MOSFET switching for improved efficiency
  - Low 200µA supply current keeps efficiency high
- **Safety features ensure reliable system operation**
  - Instant turn-off of drivers during fault
  - UVLO prevents overheating by stopping operation when not enough voltage exists to fully enhance the external MOSFETs
  - Tight propagation-delay matching ensures no shoot-through



Typical operating circuit for the MAX5064 in a motor driver application.

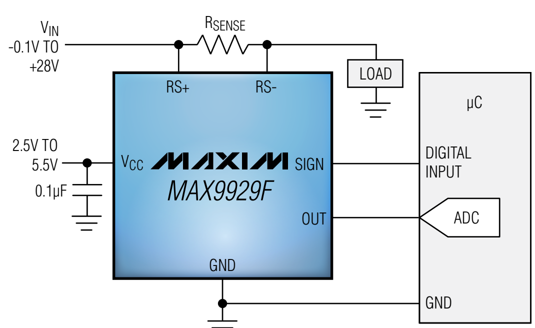
Current-sense amp sits on the high side, won't disrupt ground, and is easy to design in

MAX9929F

The MAX9929F is a current-sense amplifier with a wide -0.1V to +28V input common-mode range. Its unique architecture offers true ground sensing and high-side current-sensing in the same IC. Because it does not add resistance to the ground path—which would cause unwanted voltage shifts between different parts of the ground plane—this architecture ensures proper current reading even if the sensed line is shorted to ground. The MAX9929F is ideal for monitoring motor-winding currents, battery current, and power-supply rails.

Benefits

- **Easy to design in**
  - Input common-mode range is independent of supply voltage
  - SIGN output indicates current polarity, allowing use of the ADC's full input range in both directions
  - Current-output version (MAX9928F) can drive unlimited capacitance for easy filtering and integration solutions
- **Small solution size**
  - Available in a tiny 6-bump UCSP™ (1mm x 1.5mm)
  - High gain accuracy (±1%) and low input V_{OS} (0.4mV, max) allow use of low-value, low-power current-sense resistor
- **Accurate readings increase safety and effectiveness**
  - High gain accuracy (±1%) and low input V_{OS} (0.4mV, max)
  - Provides upgrade path from earlier MAX4372_EBT, so users can quickly improve accuracy of legacy systems
- **Low power consumption**
  - Low 20µA quiescent current reduces power consumption



Typical operating circuit for the MAX9928F/MAX9929F.

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Unique fuel-gauge IC provides accurate battery capacity information to ensure complete sterilization and disinfection cycles

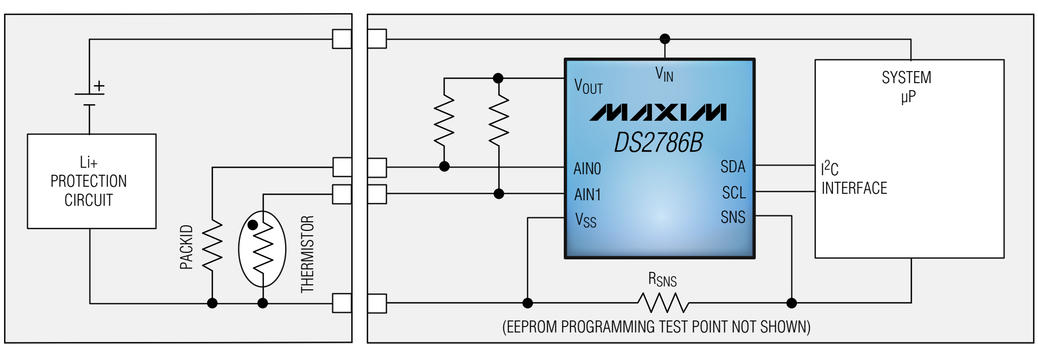
DS2786B

The DS2786B is a 1- to 4-cell battery fuel-gauge IC that uses two complementary methods to achieve an accurate remaining-capacity estimate. An open-circuit voltage (OCV) method corrects for coulomb counter wander, while coulomb counting (CC) corrects for OCV delay. Coulomb counting is known to be very accurate, but it suffers from wander after repeated partial charge and discharge cycles, which typically prevent the gauge from finding full or empty states. Meanwhile, OCV requires a long, no-load battery rest period to provide a good estimate of remaining capacity.

The DS2786B uses both methods to provide a more accurate result than could be achieved with either method on its own. Its 12-bit battery-voltage measurement yields ±10mV accuracy for OCV measurements, while an 11-bit bidirectional current measurement yields a 1 LSB resolution of 1.67mA for accurate CC even at low loads and over a wide dynamic range.

Benefits

- **Get the best accuracy using OCV and CC in a single IC—allows earlier start of sterilization or disinfection cycles**
  - CC for accurate charge and discharge tracking
  - OCV measurement corrects for wander in CC
  - Autocalibration cycle minimizes current-measurement offset errors
  - On-chip EEPROM stores cell parameters to tailor results to specific cell characteristics
- **Low power reduces required battery capacity**
  - Active current: 50µA (typ), 80µA (max)
  - Sleep current: 1µA (typ), 3µA (max)
- **Small enough to be placed on battery pack side for extra convenience**
  - 3mm x 3mm 10-pin TDFN package
  - Serial I²C interface keeps pin count low



Typical operating circuit for the DS2786B.

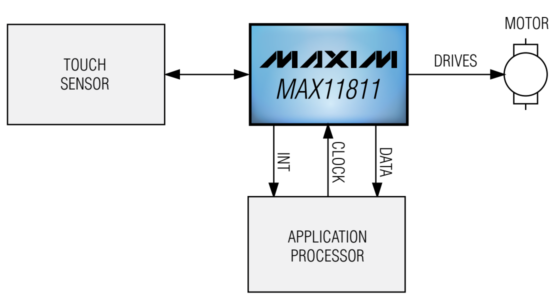
Smart touch-screen controller reduces processor burden while directly driving vibration motor

MAX11811

The MAX11811 is a touch-screen controller for 4-wire touch screens. This controller integrates a haptics motor driver and advanced features such as spatial filtering, an autonomous mode, and data tagging to significantly reduce processor interrupts and processing burden. It also includes a 12-bit ADC, I^2C interface, IR proximity sensor driver, and automatic power-down.

Benefits

- **Smarter solution reduces processor burden and speeds design time**
  - Aperture mode provides spatial filtering to reduce processor interrupts
  - Data tagging provides touch-event information—initial touch, continuing touch, and touch release
  - On-chip FIFO stores events in autonomous mode to capture gestures with more detail
  - Built-in vibration motor driver relieves processor from this time-critical task
  - Built-in haptic waveforms reduce processor burden
- **Low-power operation decreases power-supply and battery-capacity requirements**
  - Automatic power-down saves power whenever it can with no command from the µC
  - Low-power operation of 250µW (at V_{DD} = 1.7V, 34.4ksps)
  - Fewer interrupts in autonomous mode allow processor to sleep longer
  - IR proximity sensor driver can power down display when user walks away



Block diagram for the MAX11811 in a haptic touch-screen application.

Visit digikey.com

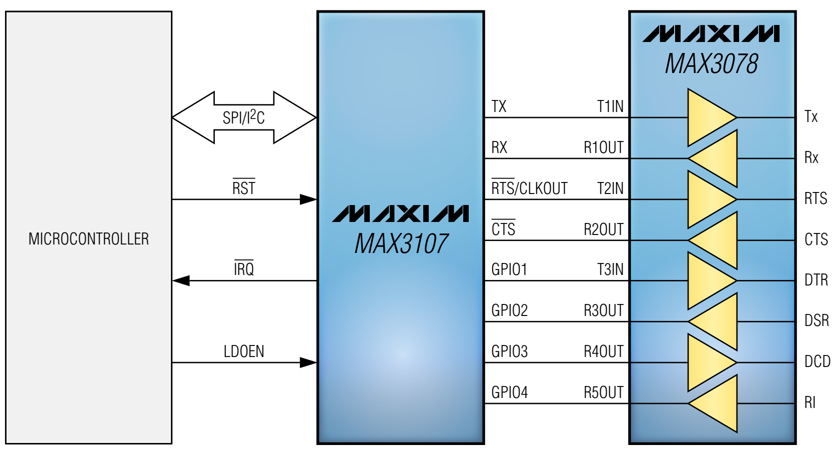
Serial UART eases connection of new microprocessor-based equipment to older hospital information systems

MAX3107

The MAX3107 is a full-featured serial UART for interfacing an RS-485/RS-232 bus with an SPI™/I²C microprocessor. It integrates 128-word FIFOs on both the Rx and Tx to provide buffering to offload the microprocessor. Logic-level translation (down to 1.7V) on both the synchronous and asynchronous sides enables use with a wide selection of RS-232/RS-485 transceivers. An onboard fractional baud-rate generator maximizes flexibility in baud-rate selection. The MAX3107 supports a 24Mbps (max) data rate.

Benefits

- **Easy solution for interfacing new microprocessors to traditional hospital information systems**
  - SPI or I²C interface to microprocessor eases solution implementation
  - Level translation on both sides eases logic-level issues
  - Additional GPIOs allow full handshaking if needed
- **Small solution reduces size of isolated interface**
  - 3.5mm x 3.5mm TQFN package
  - Integrated oscillator eliminates external parts



Typical operating circuit for the MAX3107 in an RS-232 application.

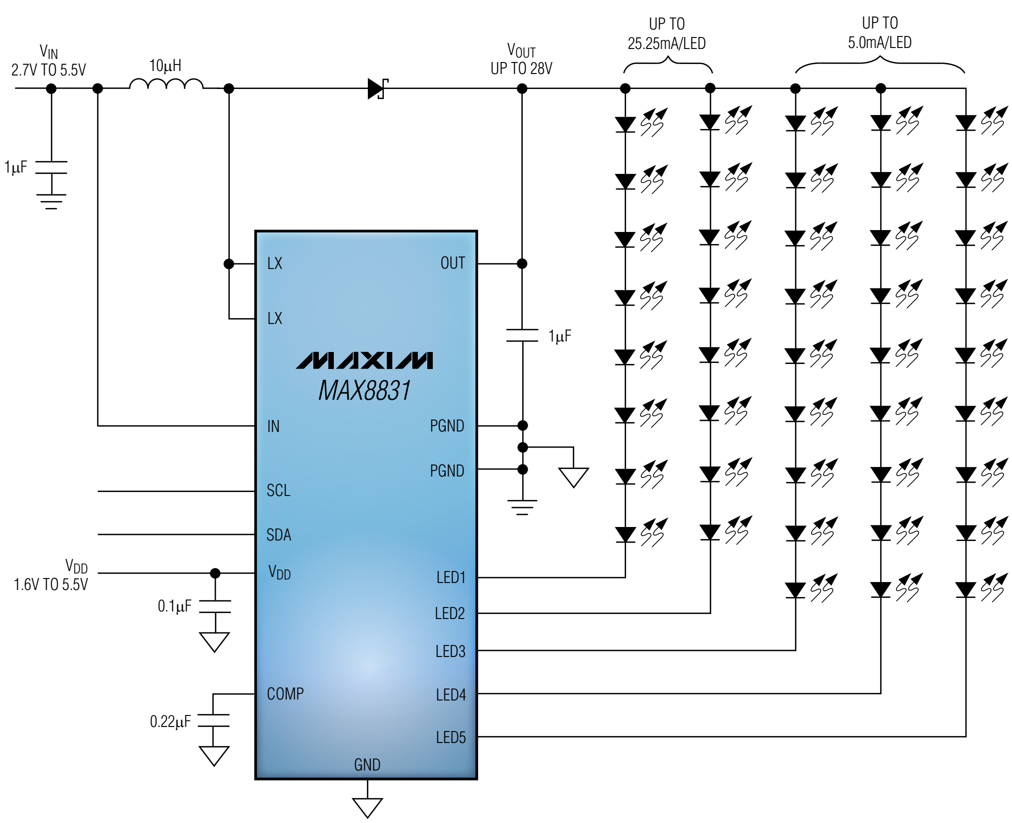
LED backlight driver offers high efficiency to save battery life and fault detection to improve failure response—all in a very small package

MAX8831

The MAX8831 is a white-LED driver with five low-dropout current regulators for display and keypad backlighting. This device integrates an inductor-based boost converter to automatically determine the voltage needed to drive LEDs at the programmed current. It also features an I²C interface to allow full programmability. A 2mm x 2mm wafer-level package (WLP) makes the MAX8831 well suited for space-constrained designs.

Benefits

- **Reduces size and complexity by combining two functions in a single IC**
  - Drives two strings at 25mA for display backlighting and three strings at 5mA for keypad backlighting
  - Tiny 2mm x 2mm WLP
- **Decreases power-supply and battery-capacity requirements**
  - Boosts voltage to LEDs only as much as needed for programmed current, thus keeping efficiency high
  - Switcher enters skip mode for light-load efficiency
  - Ultra-low 0.1µA shutdown current
- **Increases safety**
  - Open/short LED fault detection
  - Output overvoltage protection (OVP)
  - Open-circuit Schottky diode detection



Typical operating circuit for the MAX8831.

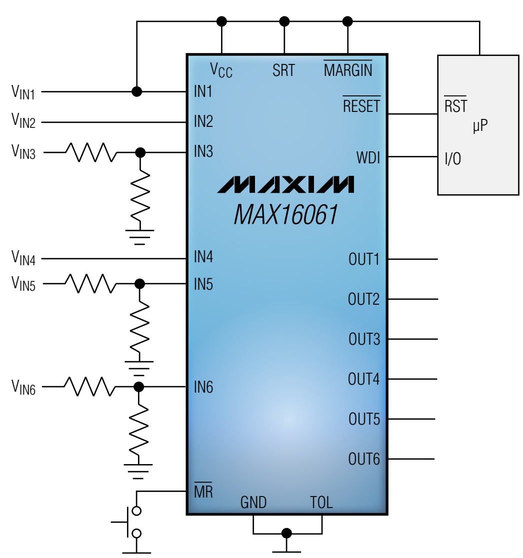
Multivoltage supervisor with watchdog detects voltage faults and processor errors to ensure reliable operation

MAX16061

The MAX16061 is a hex voltage monitor that integrates a watchdog timer and reset to enhance system reliability. (Quad and octal versions are also available.) This exceptionally accurate (±1%) supervisor includes a bandgap reference to allow highly precise trimming of the voltage thresholds. The MAX16061 is well suited for multivoltage systems that require precision voltage monitoring and other supervisory functions.

Benefits

- **Enhances system reliability**
  - ±1% accuracy over wide temperature range keeps detection thresholds valid
  - Includes watchdog timer to ensure that the processor is functioning properly
  - Keeps processor in reset until all voltages are up and stable
- **Reduces size and complexity by combining multiple functions in a single IC**
  - Monitors multiple voltages with individual outputs to allow unique responses to each input
  - Minimizes external parts with some fixed thresholds and with internal pullups on open-drain outputs
  - Combines watchdog function with reset function to simplify system design
- **Eases system integration and reduces design time**
  - Provides extra-long watchdog timeout period at system startup to allow system configuration firmware to finish
  - Fixed- or capacitor-adjustable timeout allows users to tailor response to system needs



Typical operating circuit for the MAX16061.

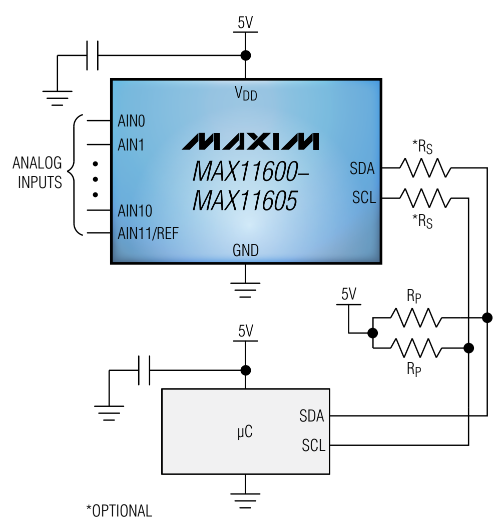
ADC with multiplexer gathers data from 12 sources to simplify self-monitoring

MAX11605

The MAX11605 is a 12-channel, 8-bit ADC with an analog input multiplexer for monitoring and digitizing multiple system inputs. This device provides exceptional low-power operation, consuming as little as 350µA at 188ksps or 8µA at data rates of 10ksps or less. The analog inputs are software configurable to support either unipolar or bipolar inputs, as well as single-ended or differential operation.

Benefits

- **Operates at low power levels to reduce power-supply and battery-capacity requirements**
  - Runs on supply as low as 2.7V to minimize power consumption
  - Consumes 350µA (typ) at full speed; much less if slowed down
  - Power-down mode uses only 1µA
  - Auto shutdown between conversions reduces supply current to 1µA
- **Increased response time to fault conditions improves safety**
  - I^2C interface can run at 1.7MHz in high-speed mode
  - Up to 188ksps sampling rate
- **Flexible features and a variety of choices reduce design time and increase adaptability**
  - 4-, 8-, and 12-channel versions (MAX11600–MAX11605)
  - Inputs configurable to unipolar or bipolar
  - Supply voltages from 2.7V to 3.6V or 5V
  - Internal or external reference from 1V to V_{DD}



Typical operating circuit for the MAX11600–MAX11605.

Recommended solutions

Part	Description	Features	Benefits
Microcontrollers			
MAXQ2010	Low-power, 16-bit mixed-signal LCD microcontroller	8-channel, 12-bit SAR ADC; 64KB flash; supply voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current	Saves space by including LCD controller; reduces battery size by lowering power draw
MAXQ8913	16-bit mixed-signal microcontroller	7-channel, 12-bit SAR ADC; 64KB flash; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Single chip integrates multiple functions to minimize solution size
DS89C450	Highest performance 8051-compatible microcontroller	33MIPS at 33MHz, integrated supervisory functions	Improves device safety by managing safety functions
ADCs			
MAX11200*	24-bit, 120sps/480sps, sigma-delta ADC with serial interface	50Hz/60Hz noise rejection; industry's best noise-free resolution per unit of power consumption	Increases system safety and effectiveness while reducing power consumption
MAX1228/MAX1229	12-bit, 12-channel, 300ksps ADCs with serial interface	3V/3.3V/5V supply, internal temp sensor and voltage reference, unipolar or bipolar inputs	Highly integrated 12-channel ADCs save space for compact dialysis designs
MAX1162	16-bit, 200ksps SAR ADC with serial interface	10µA in shutdown, 10-pin µMAX® package	Saves space and reduces battery drain
MAX11605	8-bit, 12-channel, 188ksps ADC with serial interface	Easy system integration, FIFO eases burden on microprocessor, unipolar or bipolar inputs for unique sensing needs	Flexible interface reduces design time and saves space
Amplifiers			
Audio amps			
MAX9812	Low-power microphone amp	Low noise, integrated bias, 500kHz bandwidth, rail-to-rail output, 2.4mm x 2.2mm SC70, 2.7V operation, shutdown, fixed gain	Built-in bias and small package reduce solution size; shutdown and low-voltage operation save battery life
MAX9711	Audio power amp	3W mono amplifier with shutdown feature, 100dB PSRR	Provides good audio quality, so voice-synthesis instructions are comprehensible even in noisy environments
MAX98000*	Audio DAC	I^2S input, Class D amplifier, mono, low EMI, 2W	High-efficiency Class D extends battery life
MAX9860	Audio codec	Ultra-low power (9mW), mono codec with programmable digital filter	Provides a complete audio voice-command/ response solution that minimizes power consumption
MAX9718/MAX9719	Low-cost, mono/stereo, 1.4W differential audio power amps	Differential input and output, fixed or adjustable gain, 2.7V to 5.5V supply, shutdown mode	Minimal external components for small solution; maximum audio output from low supply voltages
Current-sense amps			
MAX9928F/ MAX9929F	Bidirectional current-sense amps with wide 0 to 28V common-mode voltage	-0.1V to +28V common-mode voltage, precision 400µV (max) V_{OS}, ±1% gain error, sign output, current output	Enable accurate motor control for precise pumping rates
MAX9634	1µA, precision current-sense amp	28V (max) common-mode voltage, 250µV (max) V_{OS}, 1µA (max) quiescent current, small UCSP and SOT23 packages	1µA supply current is less than the self-leakage current of batteries, thereby helping to reduce battery drain
Instrumentation amps			
MAX4208/MAX4209	Ultra-low offset/drift, precision instrumentation amps with REF buffer	20µV (max) input V_{OS} with "zero drift," 1.4µA shutdown current, indirect-current-feedback architecture	Allow near-ground sensing with single supply, thus simplifying design

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Instrumentation amps (continued)			
MAX4194–MAX4197	Micropower, three-op-amp instrumentation amps	450µV (max) V_{OS}, 93µA quiescent current, adjustable and fixed (1, 10, 100V/V) gain versions	Shutdown function and low-current operation save power to extend battery life and reduce power-supply size
Op amps			
MAX9617–MAX9619	High-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs	10µV (max) V_{OS} with "zero drift," 0.42µV_{P-P} noise, 59µA quiescent current, tiny 8-pin SC70	Increase measurement accuracy to improve machine performance; reduce calibration requirements to lower production costs
MAX4475–MAX4478	Precision, low-distortion, 4.5nV/$\sqrt{Hz}$ op amps	750µV (max) V_{OS}, 10MHz op amp, 4.5nV/$\sqrt{Hz}$ noise, CMOS inputs, SOT23	Improve measurement accuracy when used for sensor gain, filtering, or driving ADC inputs, thus increasing safety and effectiveness
Battery-management ICs			
Fuel gauges			
DS2786B	Battery fuel gauge uses both coulomb counting and OCV	EEPROM included to store unique battery characteristics; low power (50µA active, 1µA sleep); 3mm x 3mm 10-TDFN	Provides accurate estimation of remaining battery capacity while extending battery life
MAX17043*	Low-cost I²C fuel-gauge IC	ModelGauge™ algorithm, 2mm x 3mm footprint, low-battery alert, no sense resistor	Allows system µC to remain in sleep mode for longer, thus saving power
MAX17041*	Low-cost I²C fuel-gauge IC for 2 series Li+ cells	ModelGauge algorithm, 2mm x 3mm footprint	Reports state of charge without sense resistor; reduces design size and cost
DS2776/DS2778	1-Wire®/I²C, 2-cell stand-alone fuel-gauge ICs with Li+ protector and SHA-1 authentication	FuelPack™ algorithm with precision voltage, current, and temperature monitor; programmable protector	Save space, prevent cloning, and simplify design
MAX1789	2-/3-/4-cell battery fuel gauge and protector	Accurate fuel gauge, 8-bit RISC microcontroller core, integrated primary-protection IC	Provides high accuracy and increases battery safety
Single-input battery chargers			
MAX17435/ MAX17535*	SMBus™ battery charger for 3 or 4 series Li+ cells	Internal switch-mode FETs, 8V to 26V supply, up to 850kHz operation, 11-bit voltage setting	Fixed inductor ripple design reduces function size and cost
DS2715	Multicell NiMH pack charger	Charges 1 to 10 NiMH cells in series; dT/dt termination; secondary protection through thermistor and timer	Economically improves safety and reliability in designs using NiMH cells
Comparators			
MAX9060–MAX9064	Ultra-low-power single comparators	50nA/400nA comparators with and without internal 0.2V reference in space-saving UCSP	Save space and power; ideal for jack-insertion detection and voltage-rail monitoring
Digital-to-analog converters (DACs)			
MAX5360	6-bit I²C DAC for interfacing with LED drivers	230µA supply current, internal reference, buffered output	Integration of reference and buffers saves board space and cost
MAX5363	6-bit SPI DAC for interfacing with LED drivers	230µA supply current, internal reference, buffered output	Integration of reference and buffers saves board space and cost
DS4422	Dual 7-bit I²C sink/source current DAC	Up to 200µA sink/source current to adjust power supplies	Easily modify power-supply output voltages to extend battery life

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Digital potentiometers			
MAX5160/MAX5161	Low-power digital potentiometers in SOT23/µMAX package	32 tap positions, 2.7V to 5.5V supply	Low-power solutions extend battery life
Display drivers			
MAX6979	16-port LED driver with fault detection and watchdog	16 constant-current LED outputs, up to 55mA per output, ±3% matching, serial interface, reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
MAX6978	8-port LED driver with fault detection and watchdog	8 constant-current LED outputs, up to 55mA per output, ±3% matching, serial interface, reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, speeding design approval
Hall-effect sensor interface			
MAX9921	Dual, 2-wire Hall-effect sensor interface with diagnostics	Withstands 60V voltage transients and ±15kV ESD spikes; built-in diagnostics; controlled ramp for Hall-effect sensor power	Integrated ESD and diagnostics increase product reliability while saving space
Interface ICs			
Current limiters			
MAX4995	50mA to 600mA adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
MAX14523	250mA to 1.5A adjustable current limiter	Adjustable current limit, up to +125°C operation	Adjustability allows precision current limits, thus enabling smaller power-supply solutions
ESD protectors			
MAX3207E	2-channel, ±15kV HBM ESD protector	2.5pF, ±15kV HBM ESD protection	Increases reliability by protecting high-data-rate interfaces
MAX13204E	4-channel, ±30kV HBM ESD protector	6pF, ±30kV HBM ESD protection	Increases reliability by protecting high-data-rate interfaces
Logic-level translators			
MAX13030E	6-channel, high-speed logic-level translator	100Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 2mm x 2mm UCSP	High data rate, suitable number of channels, and high ESD protection make this part ideal for memory card level translation
MAX13101E	16-channel logic-level translator	20Mbps (max) data rate, bidirectional, ±15kV HBM ESD protection on I/O V_{CC} lines, 3mm x 3mm WLP	Integrates level translation with ESD protection in a space-saving package
Transceivers			
MAX3349EA	Full-speed USB transceiver with UART multiplexer	Full-/low-speed USB, integrated ESD on D+/D- lines	Increases reliability and reduces size by functionally sharing a USB connector
MAX13223E	Fault-protected RS-232 transceiver	3.3V to 5V supply, ±70V fault protection	Simplifies design by eliminating external protection components
MAX3535E	Isolated RS-485 transceiver	3V to 5V supply, 2500V_{RMS} isolation, ±15kV HBM ESD protection	Eliminates external isolation components to reduce board space requirements and cost
MAX13442E–MAX13444E	Fault-protected RS-485 transceivers	±80V fault protection, half duplex, 5V supply	Simplify design by eliminating external components
MAX13430E	RS-485 transceiver with V_L pin in TDFN	3.3V to 5V supply, integrated V_L pin (down to 1.6V), 10-pin µMAX or TDFN (3mm x 3mm)	Integrated V_L pin enables logic-level translation to FPGAs/microcontrollers with no additional parts, thus reducing complexity, cost, and solution size

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
UART			
MAX3107	SPI/I²C UART with integrated oscillator	24Mbps (max) data rate, 128-word FIFO, RS-485 control, four GPIOs, 24-SSOP or 24-TQFN (3.5mm x 3.5mm)	Integration reduces burden on microcontroller, allowing slower, lower power operation; tiny package fits isolated interfaces
I/O expanders and LED drivers			
MAX7310	2-wire-interfaced, 8-bit I/O port expander with reset	Bus timeout, 2.0V to 5.5V supply	Lockup-free operation increases reliability while operating at low voltage levels
MAX7313	16-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V supply, global and individual PWM intensity control with blinking	Highly integrated display driver speeds design of low-voltage LED indicators and backlights
MAX7315	8-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V supply, 50mA output drive, global and individual PWM intensity control with blinking	Highly integrated display driver speeds design of low-voltage LED indicators and backlights
Keyboard scanners, touch-screen controller			
MAX11811	4-wire resistive touch-screen controller with integrated haptic motor driver	12-bit ADC, I²C interface, proximity driver, automatic power-down, touch processing	Stand-alone functionality reduces processor burden
MAX7359	2-wire-interfaced, low-EMI key-switch controller/GPO	Monitors up to 64 keys, low-voltage design, key debounce, key-release detection	Stand-alone functionality simplifies software design and frees up microcontroller I/O while allowing multiple key presses
MAX7349	2-wire-interfaced, low-EMI key-switch and sounder controller	Monitors up to 64 keys, low-voltage design, key debounce, integrated sounder controller	Stand-alone functionality simplifies software design and frees up microcontroller I/O
Power supplies			
MAX15021	Dual 4A/2A step-down regulator	4MHz, 180° out-of-phase switching, UVLO, cycle-by-cycle current limit, short-circuit protection, tracking/sequencing, built-in synchronous FETs, V_{OUT} down to 0.6V	Integrated safety features increase reliability and patient safety; 4MHz switching allows small external components
MAX15036	Boost or buck converter capable of 3A	2.2MHz nonsynchronous, 4.5V to 23V V_{IN}, 0.6V to 28V V_{OUT}, clock output for driving second converter out of phase, reset output	One converter with the flexibility to serve many different uses in dialysis machine designs
MAX8831	White-LED driver with inductor-based boost for five strings of LEDs	Auto-adjusts V_{OUT} as needed, automatic skip mode, 2mm x 2mm WLP, built-in safety features	Meets medical self-test requirements to speed certification
MAX8902A	Low-noise, 500mA LDO in 2mm x 2mm TDFN	16µV_{RMS}; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, and temperature	Low noise and high accuracy enable optimal performance from sensitive analog circuits without requiring extra parts to filter out noise
MAX5064	125V/2A, high-speed half-bridge MOSFET driver for high- and low-side MOSFETs	High-side driver operates up to 125V, 2A gate drivers, balanced propagation delay, UVLO	Reduces heat buildup and improves reliability in motor control applications by eliminating cross-conduction
Real-time clocks (RTCs)			
DS1394	SPI RTC with trickle charger	Provides hundredths of a second to years information, trickle charger for coin-cell backup, UL® recognized, SPI bus to 4MHz, alarm	Provides accurate time-stamp resolution of rapidly occurring system events
DS1388	I²C RTC with trickle charger	Provides hundredths of a second to years information, UL recognized, I²C bus, supervisor with watchdog, 512 bytes of EEPROM	Provides accurate timing while saving space by integrating multiple functions

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Switch/multiplexer			
MAX4781	High-speed, low-voltage, 0.7Ω analog multiplexer	Excellent on/off performance up to 10MHz, 8:1 configuration, 1.6V to 3.6V supply	Wide operating range is easily adaptable to multiple designs
Thermal management			
Fan controller			
MAX6639	2-channel temperature monitor and PWM fan controller	Internal and external temperature measurement, closed-loop RPM control, 2-wire interface	Autonomous fan-speed control frees processor for other tasks, increasing system safety
Temperature sensors			
DS600	±0.5°C accurate analog-output temperature sensor	Industry's most accurate analog temperature sensor: ±0.5°C accuracy from -20°C to +100°C	Improves temperature-monitoring accuracy to reduce excess heating, which speeds operation and reduces power-supply and battery size
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
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C, 1.7V to 3.7V operation, industry-standard pinout and registers	Industry-standard pinout facilitates migration from LM75 to lower supply voltage
DS18B20	±0.5°C accurate 1-Wire digital temperature sensor	±0.5°C accuracy, 1-Wire interface, unique 64-bit serial number	Simplifies interface when deploying multiple distributed precision sensors
Voltage references			
Series			
MAX6018	Precision, micropower, 1.8V supply, low-dropout, series voltage reference in SOT23	1.263V to 2.048V V_{OUT}, ±0.2% to ±0.4% accuracy, 5µA quiescent current	Low operating current extends battery life
MAX6023	Precision, low-power, low-dropout, series voltage reference in ultra-small UCSP	1.25V to 5V V_{OUT}, ±0.2% accuracy, 1mm x 1.5mm x 0.3mm package	Small size fits in space-constrained designs
MAX6034	Precision, micropower, series voltage reference in small SC70	±0.2% accuracy, 30ppm/°C, 90µA quiescent current, 2.048V to 4.096V V_{OUT}	Small SC70 package eases layout
Shunt			
MAX6006	Precision shunt voltage reference in SOT23	Ultra-low operating current (1µA), ±0.2% accuracy, wide operating range (1µA to 2mA)	Ultra-low operating current extends battery life
Voltage supervisors			
MAX6381	Single-voltage supervisor	Multiple thresholds and timeout options in tiny µDFN package; only a few external components	Provides flexibility and eases system design
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable threshold	Integrated functions save space and increase flexibility
MAX16061	Hex-voltage supervisor	Fixed and adjustable thresholds and timeouts; margin-enable and tolerance-select inputs; watchdog timer	Breadth of features and options provides flexibility to meet many system needs, thus easing system design and reducing complexity
MAX6746	Capacitor-adjustable watchdog timer and reset IC	Capacitor-adjustable timing, 3.7µA quiescent current	Increases design flexibility while reducing power requirements
MAX6495	72V overvoltage protector	Easy-to-use, highly integrated protection circuit	Increases reliability by protecting against high-voltage transients

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

Digital stethoscopes

Overview

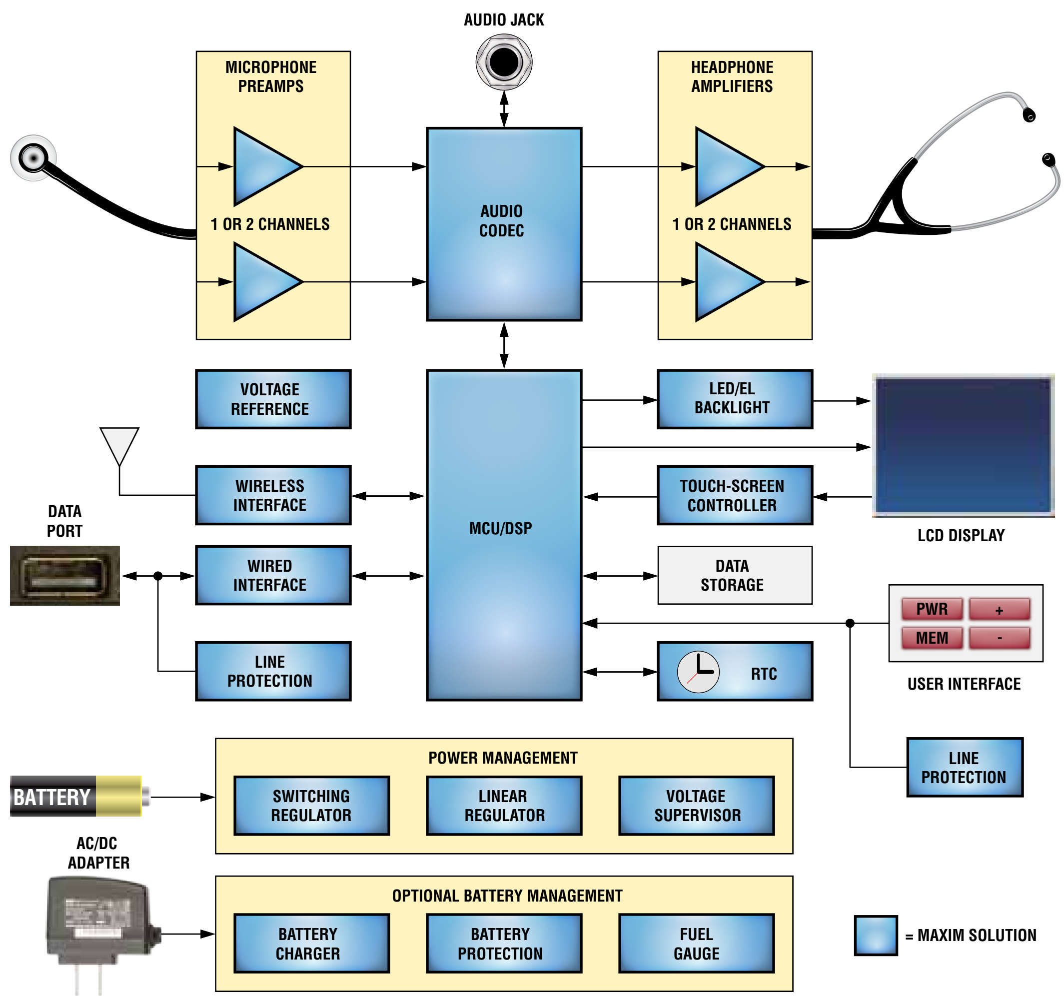
A stethoscope, whether acoustic or digital, is used mainly to listen to heart and lung sounds in the body as an aid to diagnosis. Listening, or auscultation, has been done with acoustic stethoscopes for almost two hundred years; recently, electronic digital stethoscopes have been developed.

The goal of a basic digital stethoscope is to have it retain the look and feel of an acoustic stethoscope but to improve listening performance. In addition, high-end digital stethoscopes offer sophisticated capabilities such as audio recording and playback. They also provide data to visually chart results by connecting to an off-instrument display such as a computer monitor. This advanced functionality increases the physician's diagnostic capability. Maintaining the existing acoustic stethoscope form (i.e., that "look and feel") while improving the performance digitally requires the use of small, low-power solutions.

Audio signal path

The essential elements of a digital stethoscope are the sound transducer, the audio codec electronics, and the speakers. The sound transducer, which converts sound into an analog voltage, is the most critical piece in the chain. It determines the diagnostic quality of the digital stethoscope and ensures a familiar user experience to those accustomed to acoustic stethoscopes.

The analog voltage needs to be conditioned and then converted into a digital signal using an audio analog-to-digital converter (ADC) or audio codec. Some digital stethoscopes have noise cancellation that requires a secondary sound transducer or microphone to record the ambient noise so that it can be removed digitally. In this approach, two audio ADCs are required.



Functional block diagram of a digital stethoscope. For a list of Maxim's recommended digital-stethoscope solutions, please go to: www.maxim-ic.com/stethoscope.

Once in the digital domain, a microcontroller unit (MCU) or digital signal processor (DSP) performs signal processing, including ambient noise reduction and filtering, to limit the bandwidth to the range for cardiac or pulmonary listening. The processed digital signal is then converted back to analog by an audio digital-to-analog converter (DAC) or audio codec.

A headphone or speaker amplifier conditions the audio signal before outputting to a speaker. A single speaker can be used below where the stethoscope tube bifurcates, with the amplified sound traveling through the binaural tubes to the ears. Alternatively, two speakers can be used, with one speaker at the end of each earpiece. The frequency response of the speaker is similar to that of a bass speaker because of the low-frequency sound production needed. Depending on the implementation, one or two speaker amplifiers are used.

A stethoscope must be most sensitive to cardiac sound in the 20Hz to 400Hz range and to pulmonary sound in the 100Hz to 1200Hz range. Note that the frequency ranges vary by manufacturer and that the DSP algorithms filter out sound beyond these optimal ranges.

Data storage and transfer

Once the captured sound is converted to an analog voltage, it can be sent out through an audio jack and played back on either a computer or through the digital stethoscope. The captured sound can also be manipulated digitally. It can be stored in the stethoscope using internal or removable nonvolatile (NV) memory like EEPROM or flash, and then played back through the stethoscope's speakers; or it can be transferred to a computer for further analysis. Adding a real-time clock (RTC) facilitates tagging the recording with time and date. The sound is commonly transferred with a wired interface, such as USB, or with a wireless interface like Bluetooth® or another proprietary wireless interface.

Display and backlighting

Some digital stethoscopes have a small, simple display due to the limited space available; others have only buttons and LED indicators. Backlighting for the display is required because the ambient lighting during the procedure is often at a low level. The small display requires just one or two white light-emitting diodes (WLEDs) controlled by an LED driver or an electroluminescent (EL) panel controlled by an EL driver. Most of the user-interface buttons can be eliminated by adding a touch-screen display and controller.

Power management

Most digital stethoscopes use either one or two AAA 1.5V primary batteries. This design requires a step-up, or boost, switching regulator to increase the voltage to 3.0V or 5.0V, depending on the circuitry utilized.

If a single 1.5V battery is installed, the switching regulator will probably be on all the time, making low quiescent current a critical factor for long battery life. The longer the battery life, the more convenient the digital stethoscope is to use and the closer the experience will be to an acoustic stethoscope.

When using two 1.5V batteries in series, the switching regulator can be left on all the time or shut down when not in use. If the circuit operates from 3.6V down to 1.8V, then a switching regulator may not be needed. Cost will be reduced and space saved. A low-battery warning is required so that a patient's examination need not be interrupted to replace the battery.

Battery management

Rechargeable batteries can be used; the best choice is a single-cell Li+ battery. If a rechargeable battery is used, a battery charger is required either in the digital stethoscope or in a charging cradle. A fuel gauge is the best solution to accurately determine the remaining battery life. If the battery is removable, then authentication is also required for safety and aftermarket management.

www.maxim-ic.com/stethoscope

Miniaturize the design and extend battery life with a complete high-performance audio solution

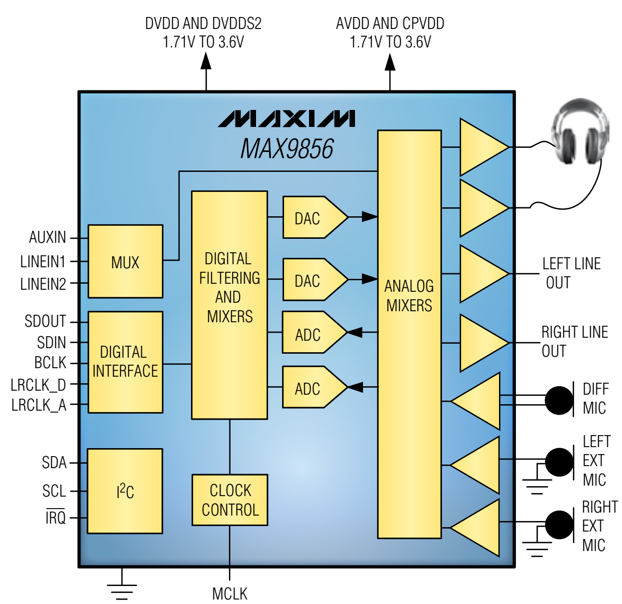
MAX9856

The MAX9856 is a high-performance, low-power, stereo audio codec for portable multimedia devices. Using integrated stereo DirectDrive® headphone amplifiers, this codec outputs 30mW into two 32Ω speakers while operating from a single 1.8V power supply. Very low, 9mW playback power consumption makes it an ideal choice for battery-powered applications.

The MAX9856 provides microphone input amplifiers, flexible input selection, signal mixing, and automatic gain control (AGC). Comprehensive load-impedance sensing enables the MAX9856 to autodetect most common audio headset and jack plug types. Outputs include stereo DirectDrive line outputs and DirectDrive headphone amplifiers. Line inputs can be configured as stereo, differential, or mono and fed through one channel of the microphone path. The ADC path also features programmable, digital highpass filters to remove DC offset voltages (V_{OS}) and noise. The MAX9856 supports all common sample rates from 8kHz to 48kHz in both master and slave modes. The serial, digital audio interfaces support a variety of formats including I^2S, left-justified, and PCM modes.

Benefits

- **Easier auscultation from excellent audio fidelity**
  - 85dB, 48kHz 18-bit ADC
  - 91dB, 96kHz 18-bit DAC
  - Clickless/popless operation
  - Low-noise microphone inputs with noise quieting
- **Increases time with patients by extending battery life and thus reducing interruptions**
  - 9mW playback power consumption
  - 1.71V to 3.6V single-supply operation
- **Enables a more comfortable stethoscope design**
  - Highly integrated audio solution
  - Small, 40-pin, 6mm x 6mm TQFN package



Simplified block diagram of the MAX9856 stereo audio codec.

Recommended solutions

Part	Description	Features	Benefits
Audio			
Audio codecs			
MAX9856	Low-power audio codec with DirectDrive headphone amplifiers	1.71V to 3.6V supply voltage; 9mW playback; 30mW DirectDrive headphone amplifier; low noise; clickless/popless operation	Complete audio path solution simplifies design; high fidelity improves auscultations
MAX9860	16-bit, mono audio voice codec	1.7V to 1.9V supply voltage; 30mW bridge-tied-load headphone amplifier; dual low-noise microphone inputs; clickless/popless operation; 4mm x 4mm footprint	High fidelity improves auscultations; low power extends battery life
MAX9867	Ultra-low-power, stereo audio codec	1.65V to 1.95V supply voltage; 6.7mW playback; battery-measurement auxiliary ADC; 2.2mm x 2.7mm footprint	Lowest power for longest battery life; $6mm^2$ footprint enables smallest design
Microphone preamplifiers			
MAX4060/61/62	Differential microphone preamplifiers with internal bias and complete shutdown	2.4V to 5.5V supply voltage; adjustable or fixed-gain options; low input noise; 300nA shutdown; 0.04% THD+N; TQFN package	Shutdown and low supply-voltage operation extend battery life
MAX9812/13	Tiny, low-cost, single-/dual-input, fixed-gain microphone preamplifiers with integrated bias	230µA supply current; 20dB gain; low 0.015% THD+N; 100nA shutdown; SC70 and SOT23 packages	Built-in bias and small package reduce solution size; low noise and low distortion improve listening
Headphone amplifiers			
MAX9723	Stereo DirectDrive headphone amplifier with BassMax, volume control, and I²C interface	1.8V to 3.6V supply voltage; 62mW DirectDrive headphone amplifier; 32-level volume control; 0.006% THD+N; shutdown; UCSP™ and TQFN package	Improved low-frequency listening response
MAX9724A/24B	60mW, fixed-gain, DirectDrive, stereo headphone amplifiers with low-RF susceptibility and shutdown	Click-and-pop suppression; low 0.003% THD+N; internal short-circuit and thermal protection; < 100nA shutdown; small TQFN and UCSP packages	DirectDrive technology reduces component count, thus saving space
MAX9820	DirectDrive headphone amplifier with external gain	95mW output power; high-RF noise immunity; clickless/popless operation; 3mm x 3mm TDFN package	High-RF immunity simplifies design
Line protectors			
MAX3202E/03E/04E/06E	Low-capacitance, 2-/3-/4-/6-channel, ±15kV ESD protection arrays	5pF input capacitance; 1nA input leakage current; 1nA supply current; tiny footprint with TDFN and UCSP packages	Easily add ESD protection; comply with IEC 61000-4-2 ESD protection for more reliable operation
MAX13202E/04E/06E/08E	Low-capacitance, 2-/4-/6-/8-channel, ±30kV ESD protection arrays	6pF input capacitance; 1nA input leakage current; ±30kV ESD protection	Surpass IEC 61000-4-2 ESD requirements for increased reliability
MAX3205E/07E/08E	Low-capacitance, 2-/4-/6-channel, ±15kV ESD protection arrays with transient voltage suppressor (TVS)	2pF input capacitance; integrated TVS	Increase reliability by protecting high-data-rate interfaces
Voltage references			
MAX6023	Precision, low-power, low-dropout voltage reference in UCSP package	1.25V to 5V V_{OUT}; ±0.2% initial accuracy; 30ppm/°C temperature coefficient; 1mm x 1.5mm x 0.3mm package	Smallest size fits in space-constrained designs
MAX6029	Ultra-low-power precision series voltage reference	Ultra-low 5.25µA supply current; 30ppm/°C temperature coefficient; no external capacitors needed	Saves power in handheld applications, thereby improving battery life

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage references (continued)			
MAX6129	Ultra-low-power series voltage reference	Ultra-low 5.25µA supply current; wide supply voltage range; no external capacitors needed	Saves power in handheld applications, thereby improving battery life
Power management			
Switching regulators			
MAX1722/23/24	1.5µA quiescent current (I_Q), step-up DC-DC converters in thin 5-pin SOT23 package	0.91V startup; 150mA output current; 90% efficiency; internal EMI suppression; 100nA shutdown	Enable single-cell operation, thus saving space and reducing weight and cost
MAX1832–MAX1835	High-efficiency step-up converters with reverse-battery protection	4µA I_Q; 1.5V startup; 150mA output current; < 100nA shutdown current; battery connected to OUT in shutdown	Simplify electromechanical design with integrated reverse-battery protection; save power by turning off power supply when not in use
MAX1947	Low-input-/output-voltage step-up DC-DC converter with active-low RESET	Low 0.7V startup; internal synchronous switches; 2MHz switching; 94% efficiency; true shutdown; reset flag	Harvests more energy from alkaline cells; high-switching frequency reduces external component size
MAX8569	200mA step-up converter in 6-pin SOT23 and TDFN packages	1.5V startup; 200mA output current; 95% efficiency; < 100nA shutdown current; battery connected to OUT in shutdown	Turn off power supply when not in use to save power and runs directly off batteries
MAX8625A	High-efficiency, seamless transition, step-up/-down DC-DC converter	2.5V to 5.5V input range; glitch-free buck-boost transitions; 92% efficiency; pulse-width modulation (PWM) or skip mode; output overload protection	Maximizes battery life from single-cell Li+ battery
Linear regulators			
MAX8860	Low-dropout, 300mA linear regulator in µMAX®	60µV_{RMS} output noise; 105mV dropout at 200mA; 120µA quiescent current; reverse-battery protection; small 2.2µF input/output (I/O) capacitor	Reverse battery protection simplifies design; small input and output capacitors save board space
MAX8902A/02B	Low-noise 500mA LDO regulators in a 2mm x 2mm TDFN package	16µV_{RMS} output noise; 100mV (max) dropout at 500mA; 80µA I_Q; ±1.5% accuracy over load, line, and temperature	Low noise results in better sound quality for more accurate diagnosis
Voltage supervisors			
MAX6375–MAX6380	3-pin, ultra-low-power voltage detectors in SC70/SOT23 packages	500nA supply current; thresholds from 2.20V to 4.63V in 100mV increments; ±2.5% threshold accuracy over temperature	Precise voltage monitoring increases safety and ensures accurate readings
MAX6854/55/56 MAX6858 MAX6860–MAX6869	Nano-power µP supervisory circuits with manual reset and watchdog timer	170nA supply current; thresholds from 1.575V to 4.625V in 100mV increments; manual reset option; watchdog timer option	Extend battery life; provide flexible design options
Display backlighting			
LED backlight drivers			
MAX1574	180mA, 1x/2x, WLED charge pump in 3mm x 3mm TDFN package	Up to 3 LEDs; up to 60mA/LED; 5% to 100% dimming with a single wire; 100nA shutdown current; soft-start limits inrush current	Integrated dimming saves space and reduces design time
MAX1916	Low-dropout, constant-current, triple WLED bias supply	Up to 3 LEDs; up to 60mA/LED; SOT23 package; linear topology; 50nA shutdown current	Tiny, low-cost, high-efficiency solution saves space and extends battery life
MAX1984–MAX1986	Ultra-efficient WLED drivers	1 to 8 LEDs; selectively enable LEDs; switching topology; open LED detection	High efficiency extends battery life

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Battery management			
Battery chargers			
MAX8900A/ MAX8900B	1.2A, switch-mode Li+ chargers with ±22V input rating and JEITA battery temperature monitoring	Single-cell Li+, switching topology; 3.4V to 6.3V (MAX8900A) or 3.4V to 8.7V (MAX8900B) input; 3.25MHz, small external inductor	Safest solutions; less heat; highly reliable
MAX1811	USB-powered Li+ charger	Single-cell Li+; linear topology; charges from USB port; 4.35V to 6.5V input	Simplest solution when USB is available
MAX1736	Single-cell Li+ battery charger for current-limited supply in a SOT23 package	Single-cell Li+; pulse topology; 4.7V to 22V input; stand-alone or microcontroller controlled	Smallest solution; requires minimal external components
Fuel gauges			
DS2745	Low-cost I^2C battery monitor	Single-cell Li+; precision voltage, current, and temperature monitor; works with microcontroller	Reports accurate battery measurements to reduce interruptions
DS2780	Stand-alone, 1-Wire® fuel gauge	Single-cell Li+; FuelPack™ algorithm with precision voltage, current, and temperature monitor; 1-Wire multidrop interface; EEPROM storage	Reports accurate battery measurements to reduce interruptions
DS2782	Stand-alone fuel gauge	Single-cell Li+; FuelPack algorithm with precision voltage, current, and temperature monitor; I^2C interface; EEPROM storage	Provides improved battery status reporting by storing custom cell parameters
MAX17043*	Compact, low-cost 1S fuel gauge with low-battery alert	Single-cell Li+; ModelGauge algorithm; 2-wire interface; small footprint; low-battery alert	Designed to save space and lengthen battery life; eliminates need for sense resistor
Battery protectors			
DS2762	High-precision Li+ battery monitor with alerts	Single-cell Li+ fuel gauge; overvoltage, overcurrent, short-circuit, and undervoltage protection; 0V battery recovery	Fuel gauge and protection in single space-saving solution
DS2784	1-cell stand-alone fuel gauge with Li+ protector and SHA-1 authentication	Single-cell Li+ fuel gauge; overvoltage, overcurrent, short-circuit, and undervoltage protection; 0V battery recovery	SHA-1 algorithm provides additional security
Microcontrollers			
MAXQ610	16-bit microcontroller with infrared module	1.7V to 3.6V supply voltage; up to 32 general-purpose inputs/outputs (GPIOs); IR module; ring oscillator; wake-up timer; 200nA stop-mode current	Low-operating-voltage range for longer battery life
MAXQ612/ MAXQ622	16-bit microcontrollers with infrared module and optional USB	1.7 to 3.6V supply range; 128kB flash; Original (full-speed) USB with built-in transceiver; IR; two SPI™ connections, two USARTs, I^2C; up to 52 GPIOs	Extend battery life and enable easy data transfer from portable device
MAXQ2000	Low-power, 16-bit LCD microcontroller	20MHz operation; 64kB flash; up to 132-segment LCD; 32-bit RTC; 16 x 16 hardware multiplier; SPI, two USARTs, 1-Wire; 700nA stop-mode current	Provides low-cost way to integrate a display into a digital stethoscope
MAXQ2010	16-bit, mixed-signal microcontroller with LCD interface	8 channels; 12-bit successive approximation register (SAR) ADC; 64kB flash; supply voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current	Powerful, integrated microcontroller saves space in battery-powered applications

(Continued on next page)

* Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Wired interfaces			
USB			
MAX3453E–MAX3456E	±15kV ESD-protected USB transceivers	Full-/low-speed USB; integrated ESD on D+ and D- lines; 1.65V to 3.6V logic supply voltage	Increase reliability by protecting high-data-rate interfaces
MAX13481E/82E/83E	±15kV ESD-protected USB transceivers with external/internal pullup resistors	Full-speed USB; integrated ESD on D+ and D- lines; 1.6V to 3.6V logic supply voltage	Increase reliability by protecting high-data-rate interfaces
RS-232			
MAX3224E–MAX3227E MAX3244E/45E	±15kV ESD-protected, 1µA, 1Mbps, 3.0V to 5.5V, RS-232 transceivers with AutoShutdown Plus™	1/1, 2/2, and 3/5 driver/receiver options; UCSP package option; can be located on main board or in cable	Increase reliability; small solution size can be located in the scope or in a cable
Wireless interfaces			
ISM transceivers			
MAX7030	Low-cost, 315MHz, 345MHz, and 433.92MHz ASK transceiver with fractional-N PLL	2.1V to 3.6V or 4.5V to 5.5V supply voltage; ASK/OOK modulation; no programming required; low current; 5mm x 5mm TQFN package	Extends battery life; small package saves space; enables faster and simpler product design
MAX7031	Low-cost, 308MHz, 315MHz, and 433.92MHz FSK transceiver with fractional-N PLL	2.1V to 3.6V or 4.5V to 5.5V supply voltage; FSK modulation; no programming required; low current; 5mm x 5mm TQFN package	Extends battery life; small size saves space; enables faster and simpler product design
MAX7032	Low-cost, crystal-based, programmable, ASK/FSK transceiver with fractional-N PLL	2.1V to 3.6V or 4.5V to 5.5V supply voltage; ASK/OOK/FSK modulation; no programming required; low current; 5mm x 5mm TQFN package	Extends battery life; smaller size saves space; provides maximum design flexibility
Real-time clocks (RTCs)			
DS1337	I^2C serial RTC	Leap-year compensation; two time-of-day alarms; integrated crystal option; 32kHz square-wave output	Single supply reduces pin count and complexity; enables smaller designs
DS1390–DS1394	Low-voltage SPI/3-wire RTCs with trickle charger	Trickle charge capability; UL® recognized; automatic backup power switching; time-of-day alarm	The backup supply can be either a primary battery or a capacitor; no additional components are required
Touch-screen controllers			
MAX11800–MAX11803	Low-power, ultra-small, resistive touch-screen controllers with I^2C/SPI interface	4-wire; 12-bit SAR ADC; 1.7V to 3.6V supply voltage; direct and autonomous modes; I^2C or SPI interface options; 1.6mm x 2.1mm WLP package	Small footprint enables smaller, lighter digital stethoscope
MAX1233/34	±15kV ESD-protected touch-screen controllers with DAC and keypad controller	4-wire; 12-bit SAR ADC; SPI interface; keypad controller; low power	Combine touch-screen and keypad controller for a smaller, lighter digital stethoscope

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

Electrocardiographs

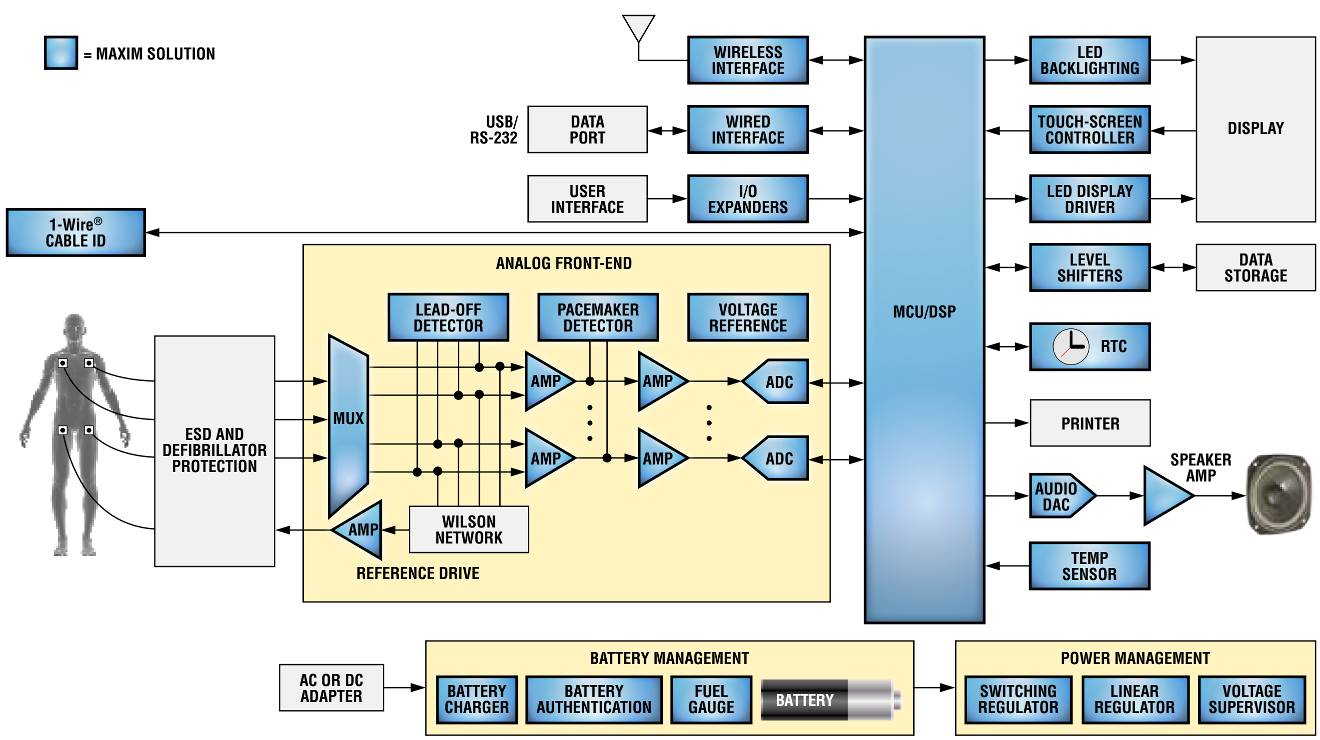
Overview

An electrocardiogram (ECG or EKG) is the measurement and graphic representation, with respect to time, of the electrical signals associated with the heart muscles. Applications of an ECG range from monitoring heart rate to the diagnosis of specific heart conditions. The basics of ECG measurement are the same for all applications, but the details and requirements for electrical components vary greatly. Electrocardiographs, or ECG devices, range from portable handheld units costing less than $200, to units that cost over $5,000 and are the size of facsimile machines. An ECG may even be embedded in a separate piece of equipment, such as a patient monitor or an automatic external defibrillator (AED).

All ECGs pick up heart signals through electrodes connected externally to specific locations on the body. The heart signals are generated by the body and have amplitudes of a few millivolts. The specific locations of the electrodes allow the heart's electrical activity to be viewed from different angles, each of which is displayed as a channel on the ECG printout. Each channel represents the differential voltage between two of the electrodes, or the differential voltage between one electrode and the average voltage from several electrodes. The different combinations of electrodes allow more channels to be displayed than there are electrodes. The channels are commonly referred to as "leads," so a 12-lead ECG device has 12 separate channels displayed graphically. The number of leads varies from 1 to 12 depending on the application. Unfortunately, the wires running to the electrodes are occasionally referred to as leads as well. This can create confusion, as a 12-lead (12-channel) ECG device only requires 10 electrodes (10 wires), so be careful of the context in which "lead" is used.

Patient monitor showing ECG and pulse oximetry readings.

In addition to the biological signals, most ECGs also detect two manmade signals. The most important of these signals comes from implanted pacemakers and is referred to simply as "pace." The pace signal is relatively short, tens of microseconds to a couple of milliseconds, with an amplitude ranging from a few



Full-featured ECG functional block diagram. For a list of Maxim's recommended solutions for an ECG design, please go to: www.maxim-ic.com/ECG.

millivolts to nearly a volt. Often, the ECG must detect the presence of a pace signal while simultaneously preventing it from distorting the signals from the heart.

The second manmade signal is for detecting "lead-off," which is when an electrode is making poor electrical contact. Many ECG devices must provide an alert when this poor contact occurs. Therefore, the ECG device generates a signal to measure the impedance between the electrode and the body for detecting a lead-off occurrence. The measurement may be AC, DC, or both. In some ECG devices, respiration rate is also detected by analyzing the impedance from the lead-off measurement. Lead-off detection is continuous and should not interfere with accurate measurement of the heart signals.

Features

Understanding the required electronic components for an ECG is easier if it is separated into the analog front-end (AFE), which digitizes these signals, and "the rest of the system," which analyzes, displays, stores, and transmits the data. AFEs share the same basic requirements, but differ in the number of leads, fidelity of signal, interference that must be rejected, and so on. The rest of the system differs more radically according to whether features are or are not present. Typical features include a built-in display, the ability to print a hard copy, a radio-frequency (RF) link, and rechargeable batteries.

Number of leads

One of the most obvious features is the number of leads. Some ECGs have only one lead; the maximum number of leads is usually 12. The most common 12-lead ECGs require 10 electrodes. Nine of the electrodes pick up electrical signals and the tenth electrode, on the right leg (RL), is electrically driven by the ECG circuit to reduce the common-mode voltage. The nine input electrodes are: left arm (LA), right arm (RA), left leg (LL), and six precordial (chest) electrodes (V1 through V6). Each lead, or view of the heart, is the differential voltage between one electrode and another electrode or group of electrodes. When electrodes are grouped, their voltage is averaged. RA, LA, and LL are averaged for six of the leads (views) and become one side of the differential pair, while V1 to V6 are individually used for the other side of the differential pair. Three of the leads measure RA, LA, and LL against the average of the other two electrodes. The remaining three leads come from RA, LA, and LL measured as individual pairs. The six leads based on RA, LA, and LL contain duplicate information, but display it in different ways. Because the information is redundant, it is not necessary to measure all six leads. Some of the channels can be calculated by a DSP as it analyzes data from the measured channels.

While the 12-lead system described here is the most common, it is not the only one. In addition, 12-lead ECGs are capable of operating as 5-, 3-, or 1-lead systems. The key point here is the need for a switch matrix and averaging circuits when more than one lead is required.

Analog front-end (AFE)

The primary function of the AFE is to digitize the heart signals. This process is complicated by the need to reject interference from strong RF sources, pace signals, lead-off signals, common-mode line frequency, signals from other muscles, and electrical noise. In addition, the millivolt-level ECG signal can be sitting atop a DC offset that is hundreds of millivolts, with channel-to-channel common-mode voltages differing by over a volt. The electrical connections to the patient must not create a shock hazard or interfere with other medical equipment that may be connected to the patient. The frequency range of interest for the ECG varies somewhat with the application, but is usually around 0.05Hz to 100Hz.

AFE capabilities of various ECG applications

Capabilities	Patient Monitor	Diagnostic	Telemetry	Holter	AED	Consumer
High RF immunity	U	U	S	S	S	N
Minimum frequency (Hz)	0.05	0.05	0.1	0.1	0.5	0.5
Maximum frequency (Hz)	500	500	50	150	40	40
ADC sample rate (sps)	1k to 100k	1k to 100k	1024	1024	250+	250+
ADC resolution (bits)	12 to 20	12 to 20	12 to 20	12 to 20	12	10 to 12
Right leg drive	A	A	S	S	N	S
Pace	A	A	U	U	U	S
Lead-off detection	A	A	U	U	A	S
Respiration	U	S	S	S	S	N
Impedance	S	S	S	S	U	N
Defibrillation	A	U	A	U	A	S

A = always, U = usually, S = sometimes, N = never

Secondary functions of the AFE are the detection of pace signals, lead-off detections, respiration rate, and patient impedance. All of this is done on several channels simultaneously or near simultaneously. In addition, most ECG devices are required to recover quickly from a defibrillation event, which can saturate the front-end and charge capacitors. This creates a long recovery time for capacitively coupled circuits.

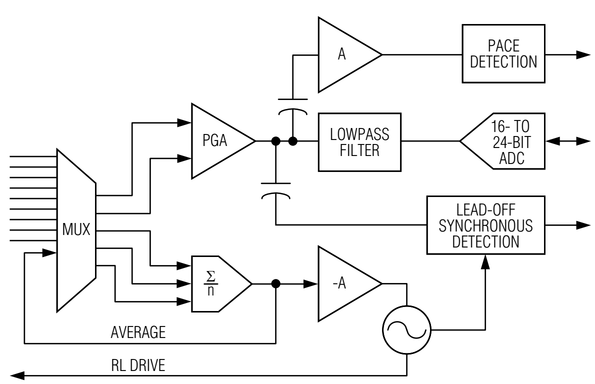
AFE architectures

The AFE architecture has a large impact on the features. The brute force architecture described below provides high fidelity over a wide frequency range due to its high-resolution, high-conversion-rate ADC. The lack of capacitive coupling and the use of a DAC for RL drive enable it to recover very quickly from a defibrillation or RF event. Digitizing the pace signal allows pace analysis that reduces the number of false pace indications and may even detect faults in the pacemaker or its connections. On the downside, the brute force system requires expensive components and uses a great deal of power. In contrast, the minimal AFE features low cost and long battery life, but little else.

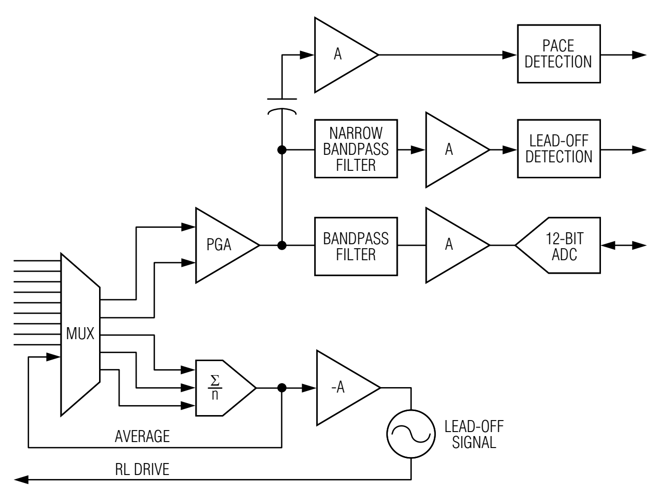
Brute force and DSP AFEs. The measurement requirements of an ECG can be met by using the brute force of powerful ADCs to simultaneously digitize the signals on all nine electrodes to a noise-free resolution of about 20 bits at a rate of 200ksps. A digital signal processor (DSP) can then be used to calculate the signal for each lead, isolate the pace signal, isolate the lead-off/respiration signals, and filter out unwanted frequencies. The DSP also calculates values for a digital-to-analog converter (DAC) driving the RL electrode. This AFE method requires the analog-to-digital (ADC) channels to be tightly matched and may require buffering to isolate the ADC sampling capacitance from the relatively high-impedance electrodes. While this approach may meet the measurement requirement, it will not meet the cost or power consumption requirements of most applications.

Minimal AFEs. At the other end of the AFE features spectrum is the 1-lead, consumer-grade ECG. The AFE circuit of this device capacitively couples the input signals to a lowpass differential amplifier that is followed by a 10-bit, 120sps ADC. Capacitively coupling the inputs eliminates DC-offset issues, and lowpass filtering removes the pace signal. There is no common-mode voltage, because the device is battery powered and has only one channel.

Typical ECG AFEs. The circuits in most ECG devices lie between the above two extremes. Instrumentation amplifiers (IAs) are used to reduce the common-mode voltage, eliminate common-mode noise such as line frequency, and provide a buffer for the ADC's sampling capacitance. Filters after the IA remove the pace and lead-off signals before the heart signals are digitized by the ADC. In some cases, the heart signal and its DC offset are directly digitized by a high-resolution ADC. In other cases, highpass filtering or DACs are used to remove the DC offset so that the heart signal can be amplified and digitized by a lower resolution ADC, typically 12 bits. A separate ADC can be used for each lead, or one ADC can be multiplexed to digitize multiple leads. Multiplexing the ADC can cause a slight time skew between channels. How objectionable this skew is depends on the application. If pace detection is needed, the pace signal is picked off by a highpass filter, amplified, and detected by a comparator circuit.



DC-coupled, high-resolution ADC



AC-coupled ADC

Types of ECG equipment

Telemetry devices

ECG telemetry systems are used to continuously monitor ambulatory patients in a clinical setting. They consist of an RF-equipped ECG measurement unit worn by the patient and a central RF receiving station that collects and analyzes the data from many patients. Some telemetry systems provide additional data such as blood-oxygen levels. The data is used to verify or alter the effectiveness of treatments and to warn of impending problems.

Many telemetry systems are limited to 5 leads, as full 12-lead ECGs make it difficult for patients to be ambulatory. Patients typically use the device continually for a couple of days. Disposable batteries are frequently used in these devices. Other ECGs are also capable of telemetry, but the term "ECG telemetry" refers specifically to the mobile units worn in a hospital that transmit data to a local receiving station. Key considerations for telemetry system designs are low power, low noise, and small size.

Holter monitors

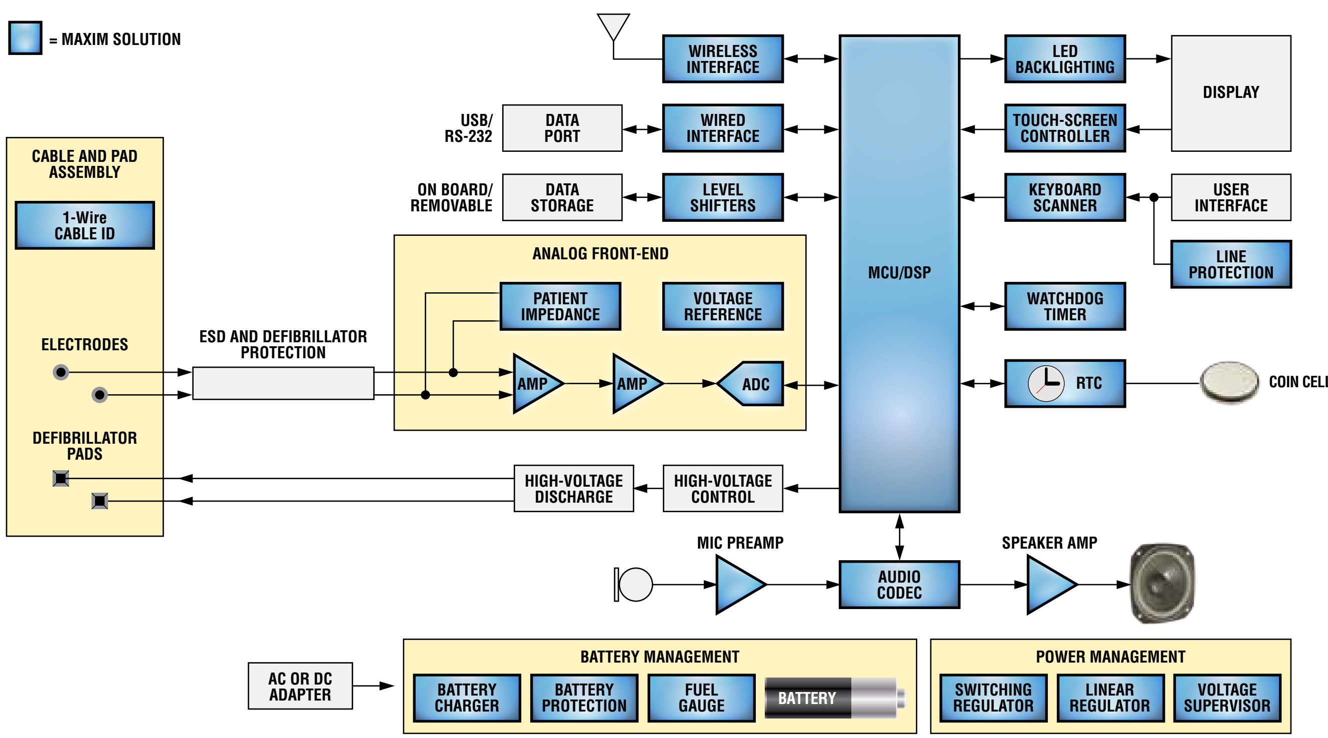
The name Holter comes from Dr. Norman Holter who invented mobile monitors for collecting data that is later uploaded to another system for analysis. Unlike a telemetry unit, these monitors do not require a central receiving station and can be used at home, outdoors, or just about anywhere. Five leads are frequently the maximum for a Holter ECG monitor, since being ambulatory is difficult with a full 12-lead ECG. Data is most commonly retrieved from the monitor by removing the memory card; however, USB and other methods are also used. Most patients need only to be monitored for a day or two. Special long-term monitors are used for patients involved in drug studies—they are used by a single patient for a year or more. Principal concerns for Holter ECG monitor designs are low power, low noise, and small size.

Consumer ECGs

These low-end ECGs easily fit in a hand and are used by people to take their own ECG test at home. The device stores the data, and also displays it on a built-in screen. This data can be transferred to a computer or sent through phone lines to a healthcare provider. Some units have multiple electrodes on wires, while others have two electrodes built into the case. Electrodes in the case can be pressed against the chest, or one hand can be placed on each electrode. The resulting ECG may not be the best quality, but it is a way for people to monitor themselves and to capture data about their heart while they are experiencing an abnormal event. Focal issues for consumer ECG designs are low cost and small size.

Automatic external defibrillators (AEDs)

Intended for emergency use by the untrained public, these devices are frequently seen in public places such as shopping malls, gyms, and offices.



Functional block diagram for an AED device. For a list of Maxim's recommended solutions for an AED design, please go to: www.maxim-ic.com/ECG.

They are used immediately after, or during, a heart attack to jump-start the heart and restore its natural rhythm by delivering a high-energy electric pulse to the chest. This pulse can also kill if delivered at the wrong time; ECG functionality is needed to ensure that this does not happen. AEDs typically have one lead and pick up the heart signal through the same pair of electrodes that deliver the high-energy pulse to the chest.

An AED could sit for months or years without use, and then be used by untrained personnel who are not likely to recognize a problem if one existed. When the system is needed, it must turn on, do a thorough self-check to verify that everything is working perfectly, and then operate for a relatively short period of time. All of the ECG data, as well as the defibrillation information, must be recorded for later analysis. Using a defective AED could do more harm than good. Therefore, reliability and self-diagnostics are essential considerations for AED designs.

Diagnostic ECGs

These machines are used in hospitals and doctors' offices to perform high-quality ECG tests. They are capable of performing a full 12-lead ECG test and creating a hard-copy printout. These units use a high-performance AFE that typically has options for gain adjustment and selection of various filters to improve the quality of the ECG measurements. Being larger and less portable, these machines have room for more features, such as built-in printers, multiple communication ports, and large display screens. These devices are line powered, but usually include a rechargeable backup battery. Key considerations for diagnostic ECG designers are low noise, interference rejection, and flexibility.

Patient monitors

These machines monitor vital signs (pulse rate, respiration rate, blood pressure, and temperature). In addition, they may include ECG functionality, as well as monitor blood oxygen and carbon dioxide levels. Integrating all of these functions into one unit helps unclutter the operating room and simplifies the process of moving the patient from room to room without disconnecting the monitoring equipment.

The AFE used for patient monitors is similar to the AFE used in a diagnostic ECG, but must meet RF-rejection requirements—these machines are used during surgery and can receive strong RF signals from electrocautery knives and argon plasma coagulation (APC) equipment. Rapid recovery from a defibrillation event is also essential.

Patient monitors are line powered but have battery backup, which makes power consumption an important issue. The cases must be splash proof and easily cleanable. This precludes cooling vents, thereby making power dissipation a consideration. Along with power consumption and dissipation, key considerations for patient monitor designs are RF immunity and low noise.

Common features of various ECG applications

Features	Telemetry	Holter	Consumer	AED	Diagnostic	Patient Monitor
Power						
Line	N	N	N	N	A	A
Rechargeable	S	S	S	S	U	A
Disposable	U	U	U	U	S	S
Communication						
RF	A	S	S	S	S	S
RS-232/RS-485	N	S	S	S	S	S
Ethernet	S	S	S	S	S	S
USB	N	S	S	S	S	S
Modem	N	S	S	S	S	S
Data card	N	U	S	S	S	S
Graphic display	S	U	A	S	S	A
Printer	N	N	N	N	A	S

A = always, U = usually, S = sometimes, N = never

www.maxim-ic.com/ECG

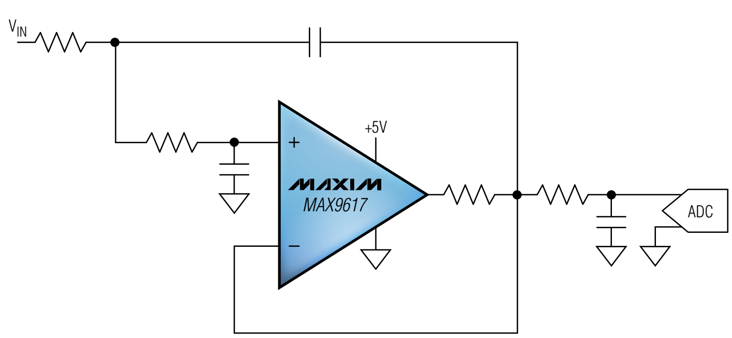
Accurate op amps in SC70 packages save space to accommodate more channels in compact ECG equipment

MAX9617–MAX9620

The MAX9617–MAX9620 are precision op amps with rail-to-rail inputs and outputs. These devices have a low 10µV (max) input offset voltage that hardly drifts over temperature and time due to the self-correcting nature of the on-chip, input offset-voltage-correcting autozero circuitry. The MAX9617–MAX9620 have a large 1.5MHz gain bandwidth (GBW) for good stopband attenuation, while consuming just 59µA of supply current. They operate over a wide 1.6V to 5.5V operating voltage and are available in tiny 2mm x 2.1mm, 6-pin and 8-pin SC70 packages. All devices are specified over the -40°C to +125°C operating temperature range.

Benefits

- **Precision signal processing for high performance**
  - Ultra-low, 10µV (max) input offset voltage
  - Autozero circuitry reduces 1/f noise and temperature drift
  - Low, 10pA input bias current due to CMOS input
  - Large 1.5MHz bandwidth provides good stopband attenuation
- **Extend battery life by reducing power consumption**
  - Consume just 59µA of supply current
  - Shutdown pin available
  - Able to operate from a low 1.6V voltage rail
- **Save space in multichannel designs**
  - Single- and dual-channel versions available in 2mm x 2.1mm SC70



Typical application circuit: Sallen-Key active lowpass filter

Zero-drift, low input offset-voltage instrumentation amplifiers save space and cost

MAX4208/MAX4209

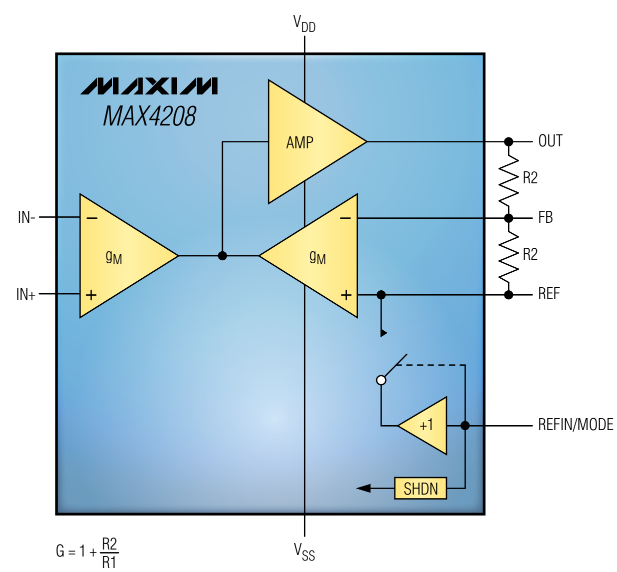
The MAX4208/MAX4209 are precision, CMOS-input instrumentation amplifiers that combine a patented spread-spectrum chopping technique* with a novel, also patented, indirect current-feedback architecture.** This continuous, self-correcting, autozeroing and chopping technique reduces input offset voltage to just 20µV (max), while minimizing drift over temperature and time.

The indirect current-feedback architecture extends the input common-mode voltage range of these amplifiers to below ground, unlike amplifiers using the three-op-amp type of architecture. This feature allows the instrumentation amplifiers to operate from a single-supply voltage rail, eliminating the need for a negative voltage rail, thus reducing space, power, and cost. Also unlike three-op-amp instrumentation amplifiers, an internal REF buffer allows the use of simple resistor-dividers to drive the reference pin. The MAX4208/MAX4209 are available in a small, 3mm x 5mm, 8-pin µMAX® package and are specified over the -40°C to +125°C temperature range.

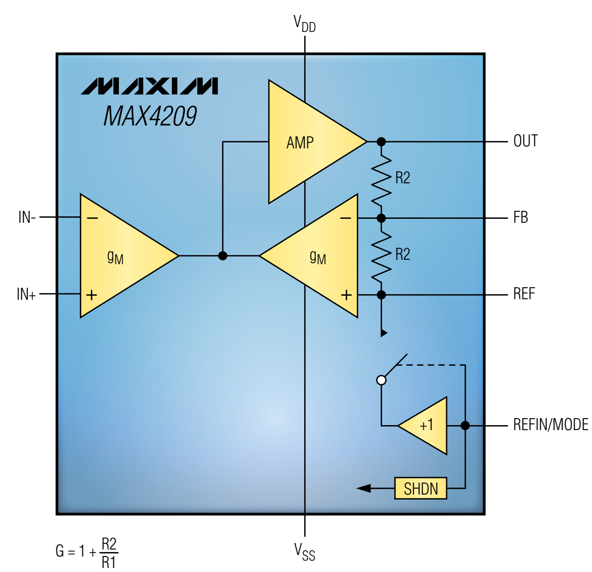
Awarded Product of the Year: Most Innovative Instrumentation Amplifiers by EN-Genius Network in 2008

Benefits

- **Precision signal processing for excellent performance**
  - Ultra-low 20µV (max) input offset voltage
  - Autozeroing circuitry eliminates 1/f noise and temperature drift
  - Low input bias currents due to CMOS inputs
- **Reduce cost and save space when compared to three-op-amp implementations**
  - Operate from a single-supply voltage rail, thereby needing no negative voltage rail
  - Use only simple external resistor-dividers to drive reference pin due to internal REF buffer (MAX4208)
  - Internal matched resistors eliminate need for precision resistor packs (MAX4209)
  - Combine the equivalent of four precision op amps in a single 3mm x 5mm µMAX package



MAX4208 functional diagram



MAX4209 functional diagram

*U.S. Patent #6,847,257.
**U.S. Patent #6,559,720.

Recommended solutions

Part	Description	Features	Benefits
1-Wire memory ICs			
DS2502	1-Wire, 1024-bit, one-time-programmable (OTP) EPROM	Single dedicated contact operation; programmable data protection; ±8kV Human Body Model (HBM) ESD protection	Simplifies design by requiring only minimal contact to add nonvolatile memory for ID, calibration, or authentication
DS28E01-100/ E02*	1-Wire, 1024-bit EEPROM with SHA-1 authentication	Single dedicated contact operation; SHA-1 secure authentication and data protection; 1.8V operation (DS28E02); ±8kV (Contact Discharge)/±15kV (Air-Gap Discharge) IEC 1000-4-2 Level 4 ESD protection	Ensure that consumables are OEM with crypto-strong SHA-1 authentication, thereby increasing reliability
DS2431	1-Wire, 1024-bit EEPROM	Single dedicated contact operation; programmable data protection; ±8kV (Contact Discharge)/±15kV (Air-Gap Discharge) IEC 1000-4-2 Level 4 ESD protection	High-ESD protection typically eliminates need to add protection to sensor, thus saving cost and space
Amplifiers			
MAX9617–20	High-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs	10µV (max) V_{OS} with near zero (5nV°/C, typ) drift; 0.42µV_{P-P} noise; 59µA quiescent current; tiny, 2mm x 2mm SC70	Low drift improves measurement accuracy and reduces calibration requirements
MAX4238	Single, 2µV (max), low-drift, 1MHz op amp in SOT23	Low 10nV/°C (typ) V_{OS} drift; low-charge-injection, self-correcting V_{OS} circuitry	Ultra-low V_{OS} and V_{OS} drift amplify small signals precisely, improving quality of signal capture
MAX4208/09	Ultra-low-offset/drift, precision instrumentation amplifiers with REF buffer	±20µV (max) input V_{OS}; ultra-low 0.2µV/°C drift; 1pA input bias current; 1.4µA shutdown current; fixed and programmable gain versions available; ground-sensing input	Near-ground sensing simplifies design; ultra-low offset/drift ensures accuracy
MAX4194–97	Micropower, three-op-amp instrumentation amplifiers	450µV (max) V_{OS}; 93µA quiescent current; adjustable and fixed (1, 10, 100V/V) gain versions; shutdown mode	Shutdown function and low-current operation save power, thereby extending battery life
Audio ICs			
Audio codecs			
MAX9851/53	Stereo audio codecs with flexible input selection and multiple audio outputs	1.7V to 3.3V digital supply voltage; 2.6V to 3.3V analog supply voltage; 26mW playback power; accept up to two inputs at different sample rates; microphone, DirectDrive® headphones, speaker amplifiers, and/or stereo line outputs	Flexible solutions simplify audio design
MAX9867	Ultra-low-power, stereo audio codec	1.65V to 1.95V supply voltage; 1.65V to 3.6V digital I/O supply voltage; 6.7mW playback power consumption; battery measurement auxiliary ADC; < 6mm² footprint	6.7mW playback extends battery life; super-small footprint enables smallest design
Audio DACs			
MAX9850	Stereo audio DAC with DirectDrive headphone amplifier	Integrated volume control; 1.8V to 3.6V supply voltage; clickless/popless operation	DirectDrive architecture allows elimination of DC-blocking capacitors, which saves board space
Microphone preamplifiers			
MAX4060–62	Differential microphone preamplifiers with internal bias and complete shutdown	2.4V to 5.5V supply voltage; adjustable or fixed-gain options; low input noise; 300nA shutdown; 0.04% THD+N; 3mm x 3mm TQFN	Shutdown and low supply voltage operation extend battery life
Speaker amplifiers			
MAX9700	Mono, 1.2W, Class D audio amplifier	Up to 94% efficiency, filterless operation; 1.5mm x 2mm UCSP™	High efficiency extends battery life; small package minimizes solution size and saves space

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Battery-management ICs			
Fuel gauges			
MAX17043*	Low-cost, I²C fuel-gauge IC	ModelGauge™ algorithm for calculating battery capacity relative state of charge (RSOC) in quick-start mode; small, 2mm x 3mm footprint; low-battery alert	Allows system µC to remain in sleep mode for a longer period of time, thus saving power; quick-start mode decreases cost (needs no current-sense resistor), reduces supply-chain constraints on battery
DS2782	Stand-alone fuel-gauge IC	1-cell Li+ battery fuel gauge; FuelPack™ algorithm with precision voltage, current, and temperature monitoring; I²C interface; EEPROM storage	Stand-alone solution needs no host-side fuel-gauging algorithms, thus simplifying software development
MAX1789	2-/3-/4-cell battery fuel gauge and protector	Accurate fuel-gauge IC; 8-bit RISC microcontroller (µC) core; integrated primary-protection features	High integration reduces development time and design complexity for highly accurate sophisticated designs
Comparators			
MAX9060–64	Ultra-low-power (sub-1µA) single comparators in space-saving UCSP package	50nA/400nA supply current; internal 0.2V reference (MAX9062–MAX9064)	Save space and power in lead-off detection, pace-maker detection, and voltage-rail-monitoring applications
Analog-to-digital converters			
MAX1162	16-bit, 200ksps SAR ADC with serial interface and 10µA shutdown	16-bit resolution; 1 channel; 10µA shutdown; 3mm x 5mm, 10-pin µMAX	Low 12.5mW power dissipation preserves battery life; tiny µMAX package saves space
MAX1167/68	Multichannel, 16-bit, 200ksps SAR ADCs with serial interface	16-bit resolution, no missing codes; 4-/8-channel input mux; 4.096 reference	Integrated mux saves board space and reduces cost; internal reference saves board space
MAX1300*/01	16-bit, 115ksps SAR ADCs with serial interface	16-bit resolution; 8/4 single-ended or 4/2 differential software-programmable analog inputs	Software-programmable input ranges reduce design time; ±16.5V analog input overvoltage protection (OVP) allows elimination of external circuitry to save space
MAX1132	16-bit, 200ksps SAR ADC with serial interface and reference	1 channel; 0 to 12V or ±12V input; 4.096V reference	16-bit resolution with no missing codes allows high precision for wide input-voltage ranges; internal reference saves space and reduces cost
Display ICs			
LED backlight drivers			
MAX1574	180mA, 1x/2x, white-LED (WLED) charge pump in 3mm x 3mm TDFN	Up to 3 LEDs, up to 60mA/LED; 5% to 100% dimming through a single wire; 100nA shutdown current; soft-start limits inrush current	Integrated dimming saves space by eliminating the need for external/additional components
MAX1984–86	Ultra-efficient WLED drivers	1 to 8 LEDs; selectively enable LEDs; switching topology; open-LED detection; up to 95% efficiency	Open-LED detection increases reliability
MAX8630	125mA, 1x/1.5x charge pumps for 5 WLEDs in 3mm x 3mm TDFN	Up to 93% efficiency; PWM dimming; factory-trimmed, full-scale LED current options	Integrated derating function protects LEDs from overheating, thus increasing reliability
LED display drivers			
MAX6950/51	Serially interfaced, +2.7V to +5.5V, 5-/8-digit LED display drivers	Slew-rate-limited drivers for low EMI; blinking control; PWM dimming; small, 16-pin QSOP	Reduce system cost by offloading display control from host to allow a simpler MCU
MAX6978/79	8-/16-port LED drivers with fault detection and watchdog	8/16 constant-current LED outputs, up to 55mA per output; ±3% current matching between outputs; serial interface reports open-circuit LED faults	Meet self-test requirements for displays in medical devices, thus speeding design approval

(Continued on next page)

*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Touch-screen controllers			
MAX11800–03	Low-power, ultra-small resistive touch-screen controllers with I^2C/SPI™ interface	4-wire touch-screen interface; 12-bit SAR ADC; 5:1 multiplexer; 1.7V to 3.6V supply voltage; direct and autonomous modes; 1.6mm x 2.1mm WLP; digital preprocessing; data tagging and filtering	Small, highly integrated solutions reduce design size and cost; digital processing reduces bus loading of applications processor
MAX11811	4-wire touch-screen controller with integrated haptic motor driver	12-bit ADC; I^2C interface; proximity driver; automatic power-down; direct or autonomous mode	Autonomous mode reduces processor burden; automatic power-down extends battery life
MAX1233/34	±15kV ESD-protected touch-screen controllers include DAC and keypad controller	4-wire touch-screen interface; 12-bit SAR ADC; 10MHz SPI interface; keypad controller; low power (6µA at 1ksps, 0.3µA shutdown current)	Combine touch-screen and keypad controllers to simplify design and save board space; low power consumption extends battery life
Interface ICs			
I/O expanders			
MAX7318	2-wire, 16-bit, I/O port expander with interrupt and hot-insertion protection	Bus timeout; 2.0V to 5.5V	Lock-up free operation improves reliability; lower supply voltage simplifies design
MAX7328/29	I^2C port expanders with 8 I/O ports	2.5V to 5.5V operation; address up to 16 devices with 100kHz I^2C interface; 10µA quiescent current	Increase number of available port pins without needing a more costly µC
Logic-level translators			
MAX13030E	6-channel, high-speed logic-level translator	100Mbps (max) data rate; bidirectional; ±15kV HBM ESD protection on I/O V_{CC} lines; 2mm x 2mm UCSP	ESD-protected level shifting enables high-speed data rates
MAX13101E	16-channel logic-level translator	20Mbps (max) data rate; bidirectional; ±15kV HBM ESD protection on I/O V_{CC} lines; 3mm x 3mm WLP	Integrates level translation with ESD protection in a space-saving package
USB transceivers			
MAX3349E	USB transceiver with UART multiplexer	USB compliant, operates at 12Mbps; integrated ESD on D+/D- lines	ESD protection increases reliability; USB and UART share a connector to save space
MAX13481E–83E	±15kV ESD-protected USB transceivers with external/internal pullup resistors	USB compliant, operates at 12Mbps; integrated ESD on D+ and D- lines; 1.6V to 3.6V logic supply voltage	Need no interface chip (compatible with low-voltage ASICs and ASSPs), thereby saving space and reducing cost
RS-232 drivers/receivers			
MAX3221E/23E/43E	±15kV ESD-protected, RS-232 transceivers with AutoShutdown™	1/1, 2/2, and 3/5 driver/receiver options	AutoShutdown functionality extends battery life without changes to existing basic input/output system (BIOS) or operating system (OS)
MAX3224E–27E/44E/45E	±15kV ESD-protected, 1µA, RS-232 transceivers with AutoShutdown Plus™	1/1, 2/2, and 3/5 driver/receiver options; 3.3V or 5V supply voltage options; 1Mbps (MAX3225E/27E/45E)	ESD protection increases reliability; small solutions can be located on main board or in cable; save power without changes to existing BIOS or OS
ESD/line protection ICs			
MAX3202E/03E/04E/06E	Low-capacitance, 2-/3-/4-/6-channel, ±15kV ESD-protection arrays	5pF input capacitance; 1nA input leakage current; 1nA supply current; footprint as small as 1mm x 1mm	Easily add IEC 61000-4-2 ESD protection (and compliance) to any design
MAX3205E/07E/08E	Low-capacitance, 2-/4-/6-channel, ±15kV ESD-protection arrays with TVS	2pF input capacitance; transient voltage suppressor (TVS)	Increase reliability by protecting high-data-rate interfaces
MAX9940	2.2V to 5.5V, signal-line overvoltage protector	Small, 5.3mm^2 SC70; low, 13µA supply current; ±4kV (Contact Discharge) IEC 61000-4 ESD protection	Protects low-voltage circuitry from high-voltage faults, thereby improving reliability

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Keyboard scanner			
MAX7359	2-wire, low-EMI key-switch controller/ general-purpose output (GPO)	1.62V to 3.6V operation; monitors up to 64 keys; key debounce; key-release detection; 6 key-switch outputs + 1 INT pin can be used as GPOs	GPOs free up µC I/O; key monitoring reduces software complexity to minimize total system cost
Microcontrollers			
MAXQ2010	16-bit mixed-signal µC with LCD interface	8-channel, 12-bit SAR ADC; 64KB of flash memory; supply-voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current; DC to 10MHz operation, approaching 1MIPS/MHz	Powerful, highly integrated µC saves space in battery-powered applications
MAXQ8913	16-bit mixed-signal µC	7-channel, 12-bit SAR ADC; 64KB of flash memory; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Integrates multiple functions to minimize solution size
MAXQ612/22	16-bit µCs with infrared (IR) module and optional USB	1.7V to 3.6V supply range; 128KB of flash memory; USB transceiver (MAXQ622); 1 I^2C, 2 SPI, and 2 USART ports; up to 52 GPIOs; low power in stop mode (0.3µA, typ) and at 12MHz (4.8mA, typ)	Low power consumption provides extended battery life; USB port provides easy data transfer from portable device
Power-management ICs			
Linear regulators			
MAX8556	Ultra-low-input-voltage LDO regulator	1.425V to 3.6V input voltage; 4A output current; short-circuit current foldback protection	High-current regulator with short-circuit protection provides robust design
Switching regulators			
MAX5072	Dual-output buck or boost converter	2.2MHz; power-on reset (POR); power-fail output (PFO)	High frequency, 180° out-of-phase outputs, and internal FETs eliminate external components to reduce total solution size
MAX1951	1MHz, all-ceramic, 2.6V to 5.5V input, step-down DC-to-DC regulator	Up to 2A output; internal FET	Internal switch minimizes EMI, reduces board space, and provides higher reliability by minimizing external components
Voltage references			
MAX6034	Precision, micropower, series voltage reference in small SC70	±0.2% accuracy; 30ppm/°C; 90µA quiescent current; 2.048V to 4.096V V_{OUT}	Small SC70 package eases layout and saves board space
MAX6029	Ultra-low-power, precision series voltage reference	Ultra-low 5.25µA supply current; 30ppm/°C tempco; internal compensation capacitor for stability with capacitive loads up to 10µF	Ultra-low operating current saves power to extend battery life; stability over temperature increases reliability and eliminates the need for an external capacitor
MAX6173	Wide supply-voltage range, high-precision voltage reference with temperature sensor	(V_{OUT} + 2V) to +40V supply voltage; excellent temperature stability: 3ppm/°C (max) with capacitive loads up to 100µF; low noise: 3.8µV_{P-P}; ±0.06% initial accuracy	Low noise helps meet system noise budget; stability eliminates need for output bypass capacitor, thus saving board space
Voltage supervisors			
MAX6443–52	Single/dual microprocessor (µP) reset circuits with manual-reset inputs	Two manual-reset inputs with extended setup period (6.72s) can be connected to front-panel switches; precision voltage monitoring down to 0.63V	Precision voltage monitoring prevents short switch closures (nuisance resets); front-panel switch connection eliminates the need for a pinhole in the equipment case
MAX6746–53	µP-reset circuits with capacitor-adjustable reset/watchdog timeout delay	Capacitor-adjustable timing; 3.7µA quiescent current	Integrated, easy-to-use solutions save space and simplifies design

(Continued on next page)

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage supervisors (continued)			
MAX16056–59	Ultra-low-power supervisory ICs with watchdog timer	125nA supply current; capacitor-adjustable timing	Save power and battery life—use one IC across multiple applications due to adjustable timeouts
MAX16060–62	Quad/hex/octal-voltage µP supervisors	Fixed and adjustable thresholds and timeouts; margin-enable and tolerance-select inputs; watchdog timer	Breadth of features and options provides flexibility to meet many design needs
MAX16072–74	µP supervisory circuits in chip-scale package	1mm x 1mm UCSP; ultra-low, 0.7µA supply current	Small package saves space; low-power operation extends battery life
Temperature sensors			
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C; 1.7V to 3.7V operation; industry-standard pinout and registers	Industry-standard pinout simplifies migration from LM75 to lower supply voltage
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
MAX6612	Small, low-power, analog temperature sensor	19.5mV/°C slope; ±3°C accuracy from 0°C to +70°C; SC70 package; 35µA (max) quiescent current	Small, low-power solution saves board space and extends battery life
Watchdog timers			
MAX6814	5-pin watchdog timer circuit	4µA operating current; 1.6s timeout; 140ms watchdog output (WDO) pulse period; push-pull active-low output	Increases safety and reliability by monitoring for and alerting the system of software code execution errors
MAX6369–74	Pin-selectable watchdog timers	Pin-selectable timeout periods and startup delays; disable feature; open-drain or push-pull active-low options	Increase safety and reliability by monitoring for and alerting the system of software code execution errors
Wireless transceivers			
MAX2830	2.4GHz to 2.5GHz RF transceiver with power amplifier	ISM band operation; integrates all RF transceiver circuitry; on-chip monolithic filters (Rx and Tx)	Saves space by eliminating the need for an external SAW filter
MAX2831	2.4GHz to 2.5GHz, 802.11g RF transceiver with integrated PA	IEEE® 802.11g/b compatible; complete RF transceiver, PA, PLL, and crystal oscillator	High level of integration reduces BOM cost and eases implementation
MAX2829	Dual-band, 802.11a/b/g RF transceiver	Designed specifically for OFDM 802.11a/b/g WLAN; supports 2.4GHz and 5GHz bands; integrates all RF transceiver circuitry	High level of integration reduces BOM cost and eases implementation

For a list of Maxim's recommended solutions for an ECG design, please go to www.maxim-ic.com/ECG.

Spirometers

Overview

Spirometers measure the volume and speed of air that is inhaled and exhaled to assess lung function and to provide a first-level diagnostic test for pulmonary diseases such as asthma, emphysema, and cystic fibrosis.

There are two basic classes of spirometers: laboratory units, which are either desktop consoles or cabinet-size machines operated by trained technicians; and portable spirometers, which are either compact desktop units or handheld devices intended for general-practice and home use.

Laboratory spirometers require high performance and accuracy. Desktop units must provide precise spirometry measurements and be able to perform a range of tests, such as flow volume, tidal spirometry, and maximum voluntary ventilation.

Cabinet-size instruments like body plethysmographs are used to perform advanced pulmonary function tests, including total lung capacity, functional residual capacity, and residual volume.

Portable spirometers are gaining popularity as the point of care shifts from clinical laboratories to general-practice settings and homes. General practitioners increasingly use spirometers to establish baseline measurements for their patients and to detect potential pulmonary diseases. Low cost is important to enable spirometer deployment in these new markets. Size and power consumption are also key design considerations. These devices must operate from USB and/or battery power, include charging capabilities, and offer several connectivity options.

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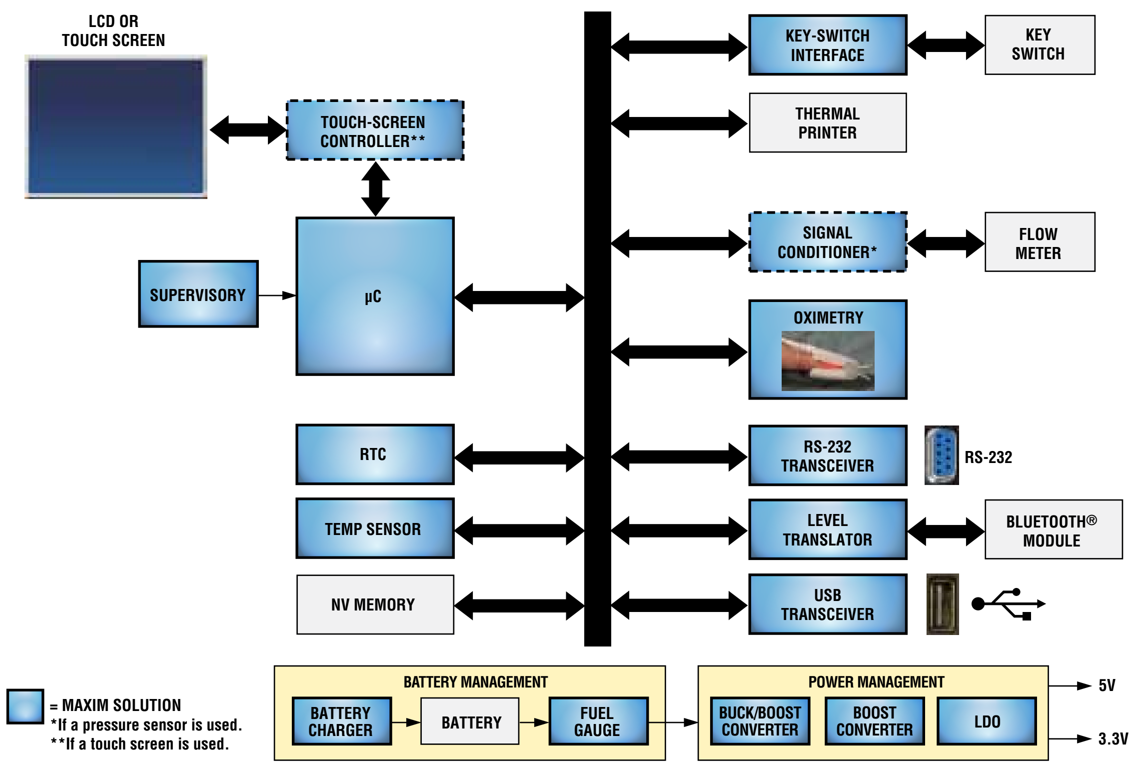


System block diagram of a desktop spirometer. For a list of Maxim's recommended solutions for spirometers, please visit: www.maxim-ic.com/spirometer.

Spirometry

Spirometers can be used to measure several parameters:

FVC (forced vital capacity): The volume of air that can be exhaled after full inspiration.

FEV_1 (forced expiratory volume in 1s): The maximum volume of air that can be forcibly exhaled in the first second during an FVC maneuver.

PEF (peak expiratory flow): The maximum flow (or speed) achieved during the maximally forced expiration initiated at full inspiration.

Additional parameters such as tidal volume, maximum voluntary ventilation, flow-volume loops, and bronchial provocation can be performed, depending upon the complexity of the unit.

Oximetry

The inclusion of pulse oximetry—which noninvasively measures oxygen saturation in arterial blood—can enable diagnostic testing for asthma. This capability can provide an all-in-one solution for walking tests; it also makes the spirometer well suited for fitness testing in sports medicine. (Refer to the “Pulse oximeters” chapter in this guide for a detailed discussion of pulse oximeter design.)

Spirometer solutions

Flow-sensing mechanism

Spirometers frequently use turbine transducers for flow measurement. In this topology, a rotating vane spins in response to the airflow generated by the subject. The revolutions of the vane are counted as they break a light beam to determine airflow rate and volume.

Differential pressure sensors are sometimes used in place of turbine transducers. Commonly referred to as pneumotachs, these designs can measure low flow rates with high accuracy. An added advantage is cost: because they are relatively inexpensive, pressure transducers enable the implementation of disposable pneumotachs.

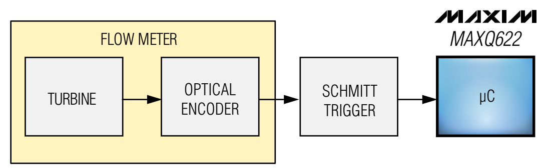


Figure 1. Typical front-end for a turbine transducer.

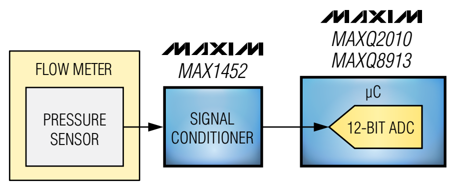


Figure 2. Typical front-end for a pressure sensor.

Front-end

For turbine-based spirometers, the front-end connecting the flow meter to the microcontroller is relatively simple, since the signal coming from the optical encoder can be easily managed by a Schmitt Trigger (**Figure 1**).

The front-end will be more complicated if a pressure sensor is used (**Figure 2**). In this case, a signal conditioner is needed to compensate the sensor output and remove the eventual offset. The resulting signal must then be digitized by an analog-to-digital converter (ADC), which should have a sampling rate of about 1ksps and at least 12 bits of resolution. Microcontrollers that integrate a high-performance ADC are ideal for these designs.

Connectivity

Desktop spirometers generally have a printer plus keyboard and include several communication interfaces such as RS-232, USB, and Bluetooth for telemedicine purposes. Handheld spirometers typically use USB for data transfer and battery charging; they can also include Bluetooth capabilities.

USB and wireless connectivity options are important for managing spirometry data and monitoring patients. They allow data to be transmitted to a PC for storage, analysis, and transfer to healthcare providers, when remote monitoring is required.

Power supplies

Desktop spirometers are frequently line powered, although they normally include lithium-ion (Li+) or nickel-metal-hydride (NiMH) rechargeable batteries as well. They generally use a 6-cell battery pack, due to the high-voltage requirements of thermal printers. Alternately, they can be powered by USB, in which case a step-up converter is used to boost the 5V to 9V. As shown in **Figure 3**, the OR-ing stage selects the source for the LDOs, which are used to generate a 3.3V rail for logic and a 5V rail for oximetry, if included.

Handheld spirometers can be powered by a coin-cell or single rechargeable Li+ battery. In the case of a 3V coin-cell battery, a low-power step-up converter can be used to generate the voltages required (**Figure 4**). For a rechargeable Li+ battery, a battery charger with dual

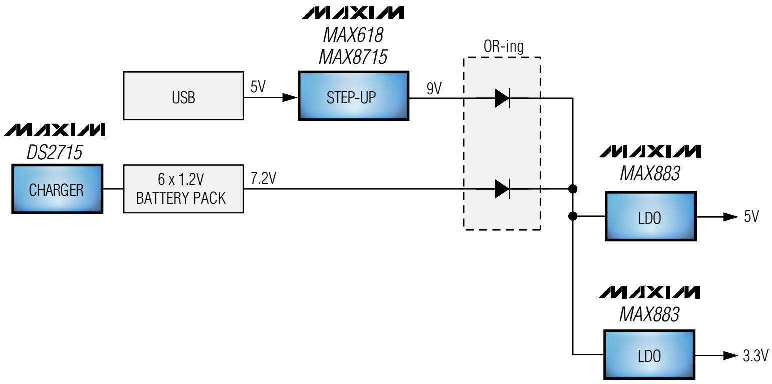


Figure 3. Power-supply example for a desktop spirometer.

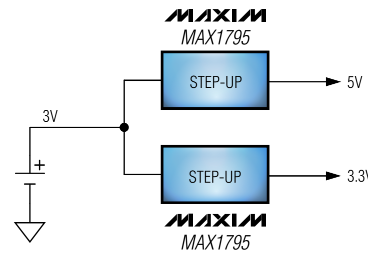


Figure 4. Power-supply example for a handheld spirometer using a coin-cell source.

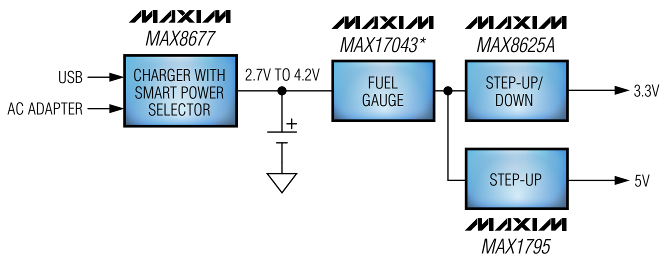


Figure 5. Power-supply example for a handheld spirometer using a single Li+ rechargeable battery.

inputs (USB and AC adapter) can be used to automatically select the best power source (**Figure 5**).

Maxim's Smart Power Selector™ circuitry makes the best use of limited USB or adapter power by charging the battery with any input power not used by the system. This approach has the added advantage of allowing the system to operate with a deeply discharged battery or even no battery at all.

Rounding out the battery-management circuit, a fuel gauge is used to estimate the available capacity, while step-up and step-down converters provide 3.3V and 5V outputs from a 2.7V to 4.2V input supply.

Displays/keyboards

Spirometers typically employ a full-color, backlit LCD to display patient information, spirometry parameters, spirograms, and system information, such as remaining battery life. Modern units increasingly use a touch screen in combination with a graphical user interface (GUI) to make the programming process more intuitive. Visible, audible, and haptic responses to user inputs help designers improve the user experience. Advanced touch-screen controllers from Maxim offer haptic feedback, touch processing to reduce bus traffic, and autonomous modes for precision gesture recognition.

For devices with keyboards or keypads, key switch can be managed by a debouncer that provides electrostatic discharge (ESD) protection. Integrated ESD protection can eliminate the need for discrete protection components, while facilitating compliance with IEC 61000-4-2 ESD requirements.

www.maxim-ic.com/spirometer

* Future product—contact factory for availability.

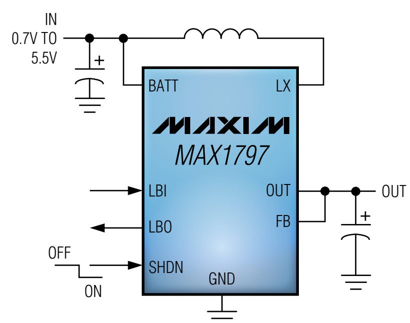
Low-power step-up converter improves efficiency and eliminates the need for additional filtering and shielding

MAX1797

The MAX1797 is a high-efficiency step-up DC-DC converter that extends battery life in handheld devices. Maxim's True Shutdown™ circuitry disconnects the output from the input in shutdown, thereby improving efficiency and eliminating costly external components. Proprietary LX-damping circuitry reduces EMI in noise-sensitive applications. For in-system flexibility, a battery-monitoring comparator (LBI/LBO) remains active even when the DC-DC converter is in shutdown.

Benefits

- **Increases battery life**
  - > 95% efficiency
  - 25µA quiescent current
  - 2µA shutdown current
  - Output disconnects from input in shutdown
- **Reduces EMI to eliminate additional filtering and shielding**
  - Internal damping switch minimizes ringing
- **Prevents device usage when battery is too low to guarantee proper operation**
  - Automatic shutdown when the input voltage drops below a preset threshold



Typical operating circuit for the MAX1797.

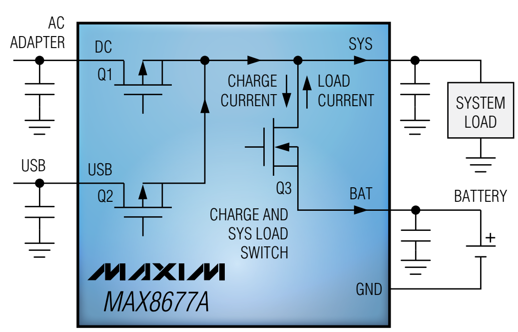
Smart Power Selector™ control maximizes charger rate from USB/AC adapter while supporting system load

MAX8677

The MAX8677 is an integrated single-cell Li+ charger with dual (AC and USB) power inputs. Maxim's Smart Power Selector circuitry automatically makes the best use of limited USB or adapter power, charging the battery with any input power not used by the system. The MAX8677 can operate with either separate inputs for USB and AC adapter power, or from a single input that accepts both. All power switches for charging and switching the load between battery and external power are included on the chip. No external MOSFETs are required.

Benefits

- **More headroom allows reliable operation when powered from USB**
  - Low USB-to-SYS dropout voltage
- **Does not overload the adapter and eliminates the need for external current sense**
  - Adjustable DC input-current limit
- **Allows operation with a deeply discharged battery or no battery**
  - Smart Power Selector circuitry
- **Load peaks over adapter rating are supported by battery**
  - Smart Power Selector control seamlessly distributes power between the external inputs, the battery, and the system load
- **Prevents overheating**
  - Thermal-limiting circuit reduces the battery charge rate and external power-source current



Typical operating circuit for the MAX8677A.

Recommended solutions

Part	Description	Features	Benefits
Microcontrollers			
MAXQ2010	Low-power, 16-bit, mixed-signal LCD microcontroller	8-channel, 12-bit SAR ADC; 64KB flash; supply voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current	Single chip integrates multiple functions to minimize solution size
MAXQ8913	16-bit mixed-signal microcontroller	7-channel, 12-bit SAR ADC; 64KB flash; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Single chip integrates multiple functions to minimize solution size
MAXQ622	Low-power, 16-bit IR microcontroller	1.7V to 3.6V supply, 128KB flash, USB 2.0 transceiver, IR module, up to 52 GPIOs	0.3µA stop-mode current extends battery life
Signal conditioner			
MAX1452	Precision sensor signal conditioner	Provides amplification, calibration, and temperature compensation	Fully analog signal path with 16-bit digital correction enables overall performance approaching the inherent repeatability of the sensor
Battery-management ICs			
Single-input battery chargers			
MAX8677	1.5A, dual-input, USB/AC-adapter charger and Smart Power Selector control	Smart Power Selector control maximizes charger rate from USB/AC-adapter power while supporting system load	Does not overload the adapter; eliminates the need for external current sense; allows operation with a deeply discharged battery or no battery
DS2715	Multicell NiMH pack charger	dT/dt termination; secondary protection via thermistor and timer; continuously monitors cell voltage and pack temperature throughout the charge cycle to ensure safe and reliable charging	Optimized for safe and reliable charging of 1 to 10 NiMH cells in series
Fuel gauge			
MAX17043*	Low-cost, I²C fuel-gauge IC	ModelGauge™ algorithm, 2mm x 3mm footprint, low-battery alert, no sense resistor	Allows system µC to remain in sleep mode for longer, thus saving power
Interface ICs			
Logic-level translator			
MAX13047E	Dual-channel, bidirectional, low-voltage level translator	Bidirectional operation without a direction pin, ±15kV ESD protection, 1µA supply current in shutdown	Saves processor overhead and power
Transceiver			
MAX3224E	±15kV ESD-protected, RS-232 transceiver with AutoShutdown Plus	1µA in shutdown, 1Mbps (max) data rate, 3.0V to 5.5V supply, automatic shutdown/wakeup features	Device automatically enters a low-power shutdown mode when the RS-232 cable is disconnected, reducing power consumption
Keyboard scanners, touch-screen controllers			
MAX7359	2-wire-interfaced, low-EMI key-switch controller/GPO	Monitors up to 64 keys, low-voltage design, key debounce, key-release detection	Simplifies software and frees up microcontroller I/O
MAX6816–MAX6818	ESD-protected, single/dual/octal, CMOS switch debouncers	Robust switch inputs handle ±25V levels, are ±15kV ESD protected, and produce a clean digital output	Provide clean interfacing of mechanical switches to digital systems, freeing the microcontroller to perform other functions
MAX11800	Low-power, ultra-small resistive touch-screen controller with I²C/SPI™ interface	Autonomous operating mode, low-power modes	Frees the application processor to perform other functions; increases battery life
MAX11811	4-wire touch-screen controller with integrated haptic motor driver	12-bit ADC, I²C interface, proximity driver, automatic power-down	Offloads application processor to perform other functions

(Continued on next page)

* Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Power supplies			
MAX618	28V, PWM, step-up DC-DC converter	High-voltage, high-current step-up in QSOP; integrated MOSFET	Integrated MOSFET saves space and minimizes EMI, eliminating the need for additional filtering and shielding to meet regulatory requirements
MAX8715	Low-noise step-up DC-DC converter	Compact µMAX® package, 90% efficiency, integrated MOSFET	Integrated MOSFET reduces external component count, saving PCB space
MAX1795	Low-supply-current step-up DC-DC converter with True Shutdown	25µA quiescent current, True Shutdown circuitry	Extends runtime in battery-operated devices
MAX8625A	High-efficiency step-up/down DC-DC converter with seamless transitions	H-bridge topology provides glitch-free step-up/down transitions	Increases battery life and saves space
MAX883	5V/3.3V or adjustable, 200mA, low-dropout linear regulator with standby mode	200mA LDO consumes just 11µA at any load and in dropout	Low quiescent current provides longer battery life
Real-time clocks (RTCs)			
DS1394	SPI RTC with trickle charger	Provides hundredths of a second to years information, trickle charger for coin-cell backup, UL® recognized, SPI bus to 4MHz, alarm	Provides accurate timing; saves space and power
DS1388	I^2C RTC with trickle charger	Provides hundredths of a second to years information, UL recognized, I^2C bus, supervisor with watchdog, 512 bytes of EEPROM	Provides accurate timing; saves space by integrating multiple functions
Temperature sensors			
DS600	±0.5°C accurate analog-output temperature sensor	Industry's most accurate analog temperature sensor: ±0.5°C accuracy from -20°C to +100°C	Improves system temperature-monitoring accuracy; no external components or calibration required to achieve ±0.5°C accuracy
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
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C, 1.7V to 3.7V operation, industry-standard pinout and registers	Industry-standard pinout facilitates migration from LM75 to lower supply voltage
DS18B20	±0.5°C accurate, 1-Wire® digital temperature sensor	±0.5°C accuracy, 1-Wire interface, unique 64-bit serial number	Simplifies interface when deploying multiple distributed precision sensors
Voltage supervisors			
MAX6381	Single-voltage supervisor	Multiple thresholds and timeout options in tiny µDFN package; only a few external components	Small µDFN and few external components save space
MAX6720	Triple-voltage supervisor	Two fixed and one adjustable threshold, small SOT23 package	Integrates three voltage monitors into one space-saving package

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

Ventilators

Overview

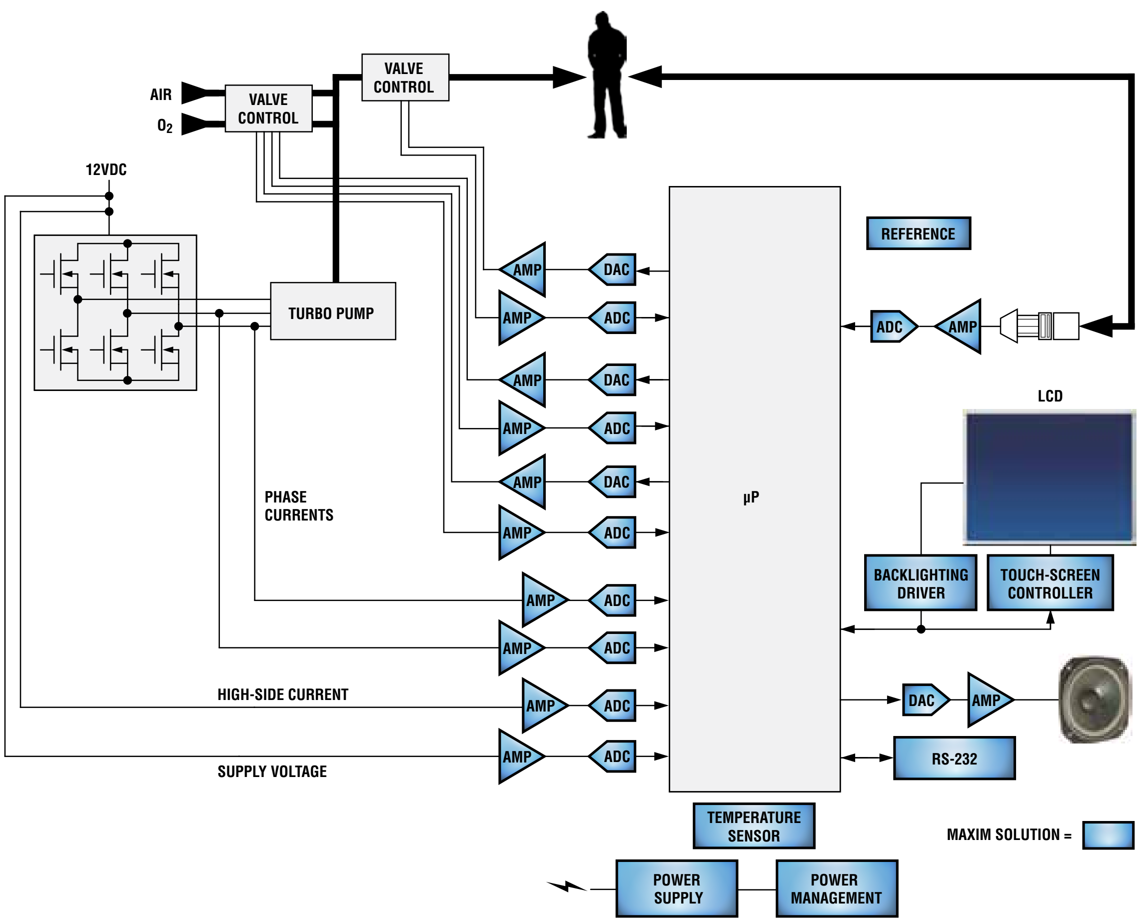
A ventilator is an electromechanical (or, possibly, completely mechanical) device designed to provide all or part of the effort required to move gas into and out of a person's lungs.

Gas exchange in the lungs is required to oxygenate blood for distribution to the cells of the body and to remove carbon dioxide from the blood that the blood has collected. The exchange in the lungs occurs only in the smallest airways and the alveoli, tiny gas-exchange sacs. To determine whether enough gas is being exchanged to keep a person alive, the ventilation rate is measured. Ventilation rate is expressed as the volume of gas entering or leaving the lungs in a given amount of time. It can be calculated by multiplying the volume of gas, either inhaled or exhaled, during a breath (the tidal volume) by the breathing rate [e.g., 0.4 liter (or 0.4L) x 15 breaths/min = 6L/min].

A ventilator, therefore, needs to produce a tidal volume and a breathing rate that provide enough ventilation, but not too much ventilation, to supply the gas exchange needs of the body.

Operation

The process begins with creating the right air-oxygen mixture so as to deliver the desired oxygen concentration to the patient, from 21% to 100%. The inspiration period is the period that the patient is forced to breathe in, and is controlled by closing a solenoid valve. The



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

maximum inspiration pressure is set by the relief setting of the inspiration valve. When the inspiration valve is open, the air-oxygen mixture is vented to the atmosphere, and the patient breathes out. However, if able, the patient may breathe in and out freely while the inspiration valve is open. Hence, the ventilator forces inspiration periodically, but does not limit inspiration.

A ventilator is a life-critical device. It must default to a safe condition if a single component fails, and it must monitor its own activities and deliver alarms when necessary. An alarm system, separate from the control system, monitors critical pressures and takes action should overpressure or underpressure fault conditions be detected, or if the timing of inspiration events falls outside preset limits.

The main subfunctions the system is required to monitor and control can be divided as follows:

1. **Air-oxygen mixture sensing** By monitoring the pressure of both gas flows, the controller can calculate the correct mixture.
2. **Air-oxygen mixture control** The controller can change the mixture by manipulating the state of the solenoid valves connecting the input gases.
3. **Inspiration control** An adjustable valve sets the maximum airway pressure, and a solenoid valve forces periodic inspiration at a rate determined by the therapist. The system to control this solenoid valve has multiple modes, enabling the therapist to deal with a range of patient needs from occasional assistance to complete support.
4. **Communication interface with technician/doctor** This requires the ability to display information as well as receive input from the medical team. This could include LCD drivers, touch-screen controllers, and audio alerts (beeps, tones, etc.).
5. **Alarm system** All aspects critical to safe operation must be monitored, including power-supply status, maximum and minimum inspiration pressures, and timing integrity. This alarm system must be separate from the control system, and certain components, such as pressure sensors, may be duplicated accordingly.

Given the time and expense required to achieve FDA approval, ventilator manufacturers must select a supplier with a customer-oriented discontinuance policy to ensure that system components will be available for many years.

Medical customers rely on Maxim products because, over the years, we have carefully avoided discontinuing parts. We realize how devastating product discontinuance can be to a customer, so we work diligently to transfer some products to newer production lines, create wafer buffers, allow last-time purchases, or develop upgrade devices. Very few Maxim parts have ever been discontinued while demand still existed. Maxim's Discontinuance Policy is one of the most flexible among our peer supplier companies.

www.maxim-ic.com/ventilator

Recommended solutions

Part	Description	Features	Benefits
Amplifiers			
MAX9617–19	10µV, high-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs (RRIO)	Low 59µA quiescent current; very low 10µV (max) input offset voltage; low input noise	Precise sensor interface saves power, extending battery life
MAX4238	2µV precision op amp	2µV (max) V_{OS} at +25°C; 1.5µV (max) V_{OS} drift over +100°C	Low cost and lower V_{OS} drift reduce system cost and improve performance
MAX4475–78	Precision, low-distortion, 4.5nV/$\sqrt{Hz}$ op amps	750µV (max) V_{OS}; 10MHz op amp; 4.5nV/$\sqrt{Hz}$ noise; CMOS inputs; SOT23	Fast settling and low distortion for buffering high-impedance signals into multichannel ADCs, thus reducing space and improving product performance
MAX9939	Programmable gain amplifier with SPI™ bus	0.2V/V to 157V/V wide gain; input common-mode voltage range extends below GND; op amp; 13µA shutdown mode	Wide-dynamic-range signals, such as motor currents and pressure sensors, can be easily measured due to large range of internal gains
Instrumentation amplifiers			
MAX4208/09	Ultra-low offset/drift, precision instrumentation amplifiers with REF buffer	20µV (max) input V_{OS} with ultra-low drift (0.2µV/°C); 1pA input bias current; 1.4µA shutdown current; fixed and programmable gain versions available	Indirect current-feedback architecture allows near-ground sensing with single supply, unlike three-op-amp architecture, simplifying power rail design and routing
MAX4194–97	Micropower three-op-amp instrumentation amplifiers	450µV (max) V_{OS}; 93µA supply current; adjustable or fixed gain (1V/V, 10V/V, 100V/V)	Micropower rail-to-rail I/Os and shutdown increase battery life in portable ventilators
Current-sense amplifiers			
MAX9918–20	-20V to +75V, bidirectional current-sense amplifiers	-20V to +75V input common-mode voltage range; 400µV (max) input offset voltage; 4.5V to 5.5V single-supply operation	Extended input range reduces circuitry, thereby reducing cost of monitoring motors and pumps
MAX9928/29	0 to 28V, bidirectional current-sense amplifiers	Wide -0.1V to +28V common-mode voltage range, independent of supply voltage; -2.5V to +5.5V operating supply voltage; -20µA quiescent supply current	Space-saving, low-power, motor- and battery-current monitor extends battery life
MAX9634	1µA, precision current-sense amplifier	Ultra-low 1µA (max) supply current; low 250µV (max) input offset voltage; tiny 1mm x 1mm UCSP™	Industry's smallest, lowest-power current-sense amplifier reduces solution size and standby power use
MAX9922/23	10µV (max) V_{OS}, ultra-precision current-sense amplifiers	Ultra-precision V_{OS} over temperature; ±0.5% (max) full-scale gain accuracy; bidirectional or unidirectional I_{SENSE}	Ultra-precise current sensors provide accurate battery monitoring
ADC			
MAX1162	SAR ADC with serial interface	16-bit, 200ksps ADC with 10µA shutdown in 10-pin µMAX®	Low 12.5mW power dissipation preserves battery life; tiny µMAX package saves space
Power-management ICs			
MAX15036	3A, buck-boost converter	2.2MHz solution for buck or boost; wide 4.5V to 23V V_{IN} range; can drive second converter 180° out-of-phase; power-on reset (POR)	Out-of-phase operation reduces input capacitance and, thereby, total solution size
MAX8902A	Low-noise, 500mA LDO	16µV_{RMS} noise; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, and temperature	2mm x 2mm TDFN package saves board space, reducing the size of portable ventilators
MAX5064	125V/2A high-speed MOSFET driver with high and low drivers for half H-bridge	High-side driver allows 125V operation of n-channel MOSFET; 2A gate drivers; second-sourced	Enables highly efficient power conversion for cooler operation

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Backlighting ICs			
MAX16814/838	4-/2-channel HB LED drivers with integrated DC-DC controller	Up to 150mA/channel; 4.75V to 40V input voltage	Eliminates need for multiple external components, thus saving space and BOM cost for portable units
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^2C interface	Easily controllable from an MCU
MAX16809	16-channel LED driver with integrated DC-DC controller	8V to 26.5V input voltage; 55mA/channel current capability	Reduces BOM complexity by reducing part count
Temperature sensors			
DS600	Precision analog-output temperature sensor	±0.5°C accuracy from -20°C to +100°C	Improved temperature control increases ventilator effectiveness
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 and registers	Industry-standard pinout allows easy accuracy upgrade and supply-voltage reduction from LM75
DS75LV	Low-voltage digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C; 1.7V to 3.7V operation; industry-standard pinout and registers	Industry-standard pinout allows easy conversion from LM75 to lower supply voltage
Touch-screen controllers			
MAX11800/801	Resistive touch-screen controllers	First-in, first-out (FIFO); spatial filtering; SPI interface; I^2C interface (MAX11801)	Dedicated screen controller reduces design cycle while offloading host processor
MAX11802	Resistive touch-screen controller with SPI interface	Single 1.7V to 3.6V supply; 25MHz SPI interface; 1.6mm x 2.1mm, 12-pin WLP or 4mm x 4mm, 12-pin TQFN	Small footprint helps save space and reduce cost
MAX11811	Resistive touch-screen controller with haptics driver	Integrated haptics driver; I^2C interface	Conveniently adds haptics to resistive touch-screen applications for touch feedback

Continuous positive-airway pressure (CPAP) devices

Continuous positive airway pressure (CPAP) is a type of respiratory ventilation originally developed for combating sleep apnea, which remains its primary use. It is also useful in providing ventilation for newborns and anyone suffering respiratory failure.

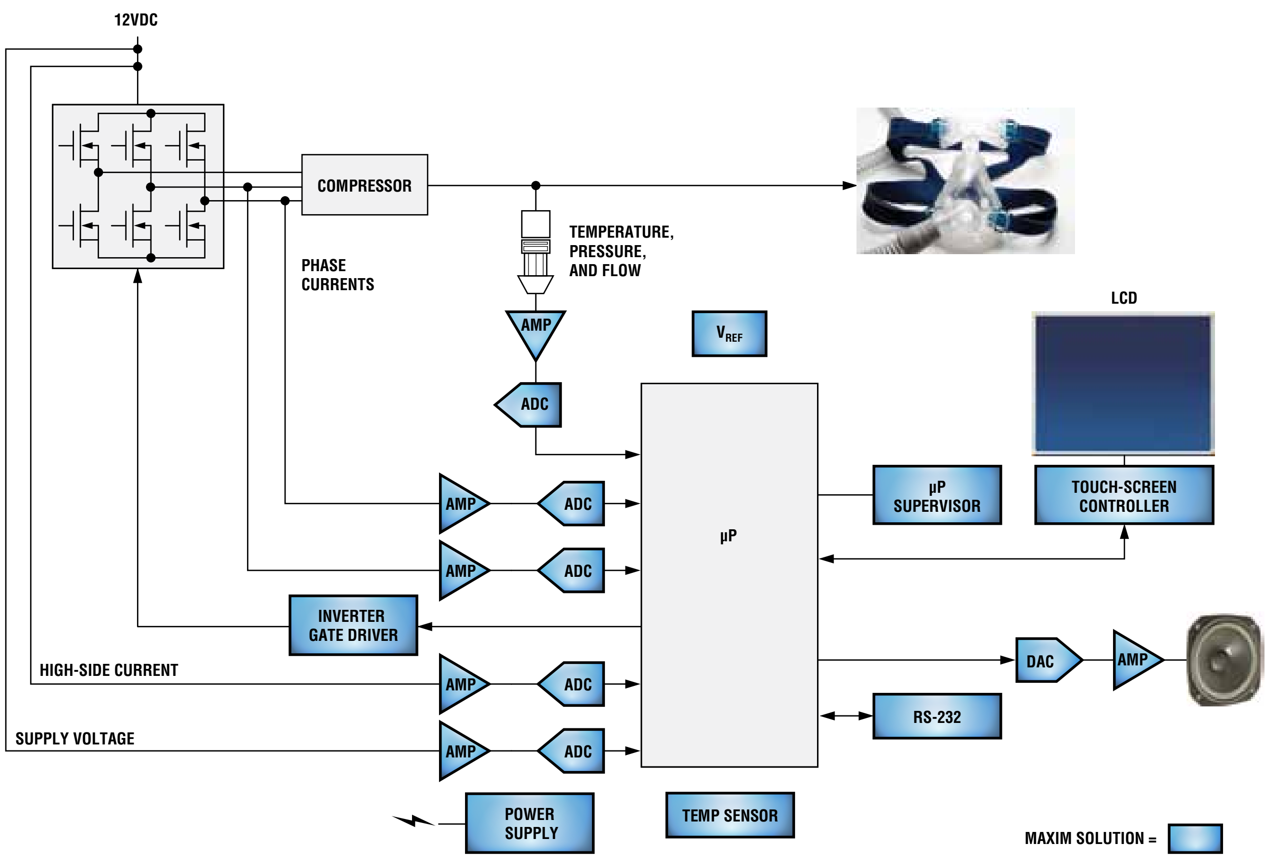
As airway muscles relax during sleep, the airway can become partially obstructed. This can lead to lower blood oxygenation and cause awakening or arousal from deep sleep. Maintaining positive air pressure by supplying a continuous source of compressed air, the face mask forms a seal to the face. It is only this air pressure that maintains the open airway, and not the actual movement of air. A sleep physician usually determines the required air

pressure after completing a sleep study.

Pressure sensors supply feedback of the applied air pressure in the mask/delivery hose to the microprocessor controller. This microprocessor controller manages the motor-drive stage of a compressor to maintain the correct fan velocity necessary to generate the required air pressure.

The main subfunctions that the system is required to monitor and control can be divided as follows:

1. **Air-hose-environment sensing** This covers air pressure, but may also include air temperature, humidity, and flow rate.
2. **Compressor motor-drive feedback** Similar to all motor-drive systems, some feedback must be provided to maintain torque and/or velocity control. Typically, phase currents or shunt current and rotor feedback must be provided.
3. **Motor-drive excitation** This is the generation of the waveforms necessary to both induce current in the electric motor and



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

produce the torque that causes motion.

4. **Communication interface to technician/doctor** This requires the ability to display information as well as input commands and controls from the medical team. This can include LCD drivers and touch-screen controllers, as well as a means for audio communication alerts, such as beeps and tones.

Given the time and expense required to achieve FDA approval, manufacturers must select a supplier with a customer-oriented discontinuance policy to ensure that system components will be available for many years.

Medical customers rely on Maxim products because, over the years, we have carefully avoided discontinuing parts. We realize how devastating product discontinuance can be to a customer, so we work diligently to transfer some products to newer production lines, create wafer buffers, allow last-time purchases, or develop upgrade devices. Very few Maxim parts have ever been discontinued while demand still existed. Maxim's Discontinuance Policy is one of the most flexible among our peer supplier companies.

www.maxim-ic.com/CPAP

Recommended solutions

Part	Description	Features	Benefits
Op amps			
MAX9617	Ultra-low power, zero-drift, precision op amp in SC70 package	Low 59µA quiescent current; very low 10µV (max) input offset voltage (V_{OS}); low input noise	Precise sensor interface saves power, extending battery life
MAX4238	2µV precision op amp	2µV (max) V_{OS} at +25°C; 1.5µV (max) V_{OS} drift over +100°C	Low cost and lower V_{OS} drift reduce system cost and improve performance
Current-sense amplifiers			
MAX9918	Current-sense amplifier with input common-mode range that extends well below ground (-20V)	-20V to +75V input common-mode voltage range; 400µV (max) input offset voltage; 4.5V to 5.5V single-supply operation	Extended input range reduces circuitry, thereby reducing the cost of monitoring motors and pumps
MAX9928F	Ultra-small, 6-bump UCSP™ current-sense amplifier with true, -0.1V to +28V input range	Wide -0.1V to +28V common-mode range, independent of supply voltage; -2.5V to +5.5V operating supply voltage; -20µA quiescent supply current	Space-saving, low-power motor and battery current monitor extends battery life
MAX9922	Ultra-precision, high-side current-sense amplifier	Ultra-precision V_{OS} over temperature; ±0.5% (max) full-scale gain accuracy; bidirectional or unidirectional I_{SENSE}	Ultra-precise current sensors provide more accurate battery monitoring in portable CPAPs
MAX9634	4-bump UCSP/SOT23, precision current-sense amplifier	Ultra-low 1µA (max) supply current; low 250µV (max) input offset voltage; tiny, 1mm x 1mm UCSP package	Industry's smallest, lowest power current-sense amplifier reduces solution size and standby power leakage
Touch-screen controllers			
MAX11800/01	Resistive touch-screen controllers	FIFO; spatial filtering; SPI™ interface (MAX11800); I^2C interface (MAX11801)	Dedicated screen controller reduces design cycle while offloading main processor
MAX11802	Resistive touch-screen controller with SPI interface	Single 1.7V to 3.6V supply; 25MHz SPI interface	Small footprint helps save space and reduce cost
MAX11803	Resistive touch-screen controller with I^2C interface	Single 1.7V to 3.6V supply; 400kHz I^2C interface	Small footprint helps save space and reduce cost
MAX11811	Resistive touch-screen controller with haptics driver	Integrated haptics driver; I^2C interface	Conveniently adds haptics to resistive touch-screen applications for touch feedback
RS-232 transceiver			
MAX3232E	±15kV ESD-protected, 2.5V to 5.5V, RS-232 transceiver in UCSP	Two receivers and two transmitters; 1µA shutdown mode	Internal dual charge pump and UCSP package save space
Temperature sensors			
DS600	±0.5 accurate analog-output temperature sensor	±0.5°C accuracy from -20°C to +100°C	Provides simple solution for temperature-sensing measurement
DS7505	Low-voltage, ±0.5°C accuracy 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 from and supply-voltage reduction for LM75
DS75LV	Low-voltage, ±2.0°C accuracy digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C; 1.7V to 3.7V operation; industry-standard pinout and registers	Industry-standard pinout allows easy conversion from LM75 to lower supply voltage
Supervisory IC			
MAX16056	Supervisory circuit	125nA supply current; watchdog timer	Lowest power supervisory circuit

(Continued on next page)

Recommended solutions *(continued)*

Part	Description	Features	Benefits
ADCs			
MAX1228/29	12-bit, 12-channel, 300ksps ADCs with internal reference	Successive-approximation register (SAR) ADC; serial interface	Integrated multiplexer saves space and simplifies design
References			
MAX6034_25	Precision, micropower, low-dropout, SC70, series voltage reference	25ppm/°C (max) tempco; 95µA (max) quiescent supply current (I_Q)	Increased measurement stability over temp variations; improved power savings with low I_Q
MAX6129	Ultra-low-power, series voltage reference	Ultra-low 5.25µA (max) supply current; 30ppm/°C (max) tempco	Increased power savings and improved performance stability over temp variations
Audio ICs			
MAX9860	Audio codec	Ultra-low-power, mono codec with programmable digital filter	Complete audio solution in a small, 4mm x 4mm TQFN package saves space
MAX5556	Low-cost, stereo audio DAC	No controls to set; built-in interpolation and analog output filters; I^2S-compatible, digital audio interface	Control logic and mute circuitry minimize audible pops and clicks, improving audio quality
Power ICs			
MAX15036	3A buck-boost converter	2.2MHz solution for buck or boost; wide 4.5V to 23V V_{IN} range; can drive second converter 180° out-of-phase; power-on reset (POR)	Out-of-phase operation reduces input capacitance and, thereby, total solution size
MAX8902A	Low-noise 500mA LDO	16µV_{RMS} noise; 100mV (max) dropout at 500mA; ±1.5% accuracy over load, line, and temperature	2mm x 2mm TDFN package reduces board area requirements
MAX16814/38	4-/2-channel HB LED drivers with integrated DC-DC controller	Up to 150mA/channel; 4.75V to 40V input voltage	Eliminate need for multiple external components, thus saving space and reducing BOM cost
MAX16826	Programmable, 4-channel HB LED driver with integrated DC-DC controller	4.75V to 24V input voltage; up to 300mA/channel; I^2C interface	Easily controllable from an MCU
MAX5064	125V/2A high-speed MOSFET driver includes high and low drivers for half H-bridge	High-side driver allows 125V operation of n-channel MOSFET; 2A gate drivers; second-sourced	Enables highly efficient power conversion for cooler operation

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

Overview

Medical instruments include analytical, audiology (except hearing aids), dental, ophthalmic, prosthetic, and surgical instruments. This section focuses on representative examples from the analytical instrument segment: blood gas analyzers and flow cytometers.

Analytical instruments are used in research and diagnostic applications for the medical and life sciences. Traditionally, these instruments have primarily been found in laboratory environments. Yet, as diagnostics continue to move from central laboratories to the point of care, analytical instruments are increasingly used in hospitals and other near-patient settings.

While this trend has increased the available market for analytical instruments, it has also placed new demands on system designers.

Size, power consumption, cost, and ease of use are critical considerations for enabling penetration into nontraditional markets. The instruments must be small enough to fit on benchtops. If portable, they need to be optimized for battery operation. Additionally, they should be inexpensive to enable purchase by point-of-care providers, and versatile to perform multiple tests for improved cost efficiency. Lastly, since operators may no longer be trained technicians, the instruments need to be easy to use and intuitive.

Maxim serves this market with a broad portfolio of medical-grade solutions. The company's advanced process technologies bring new levels of precision, integration, and power savings to medical instrument designs.

Key benefits

- High-performance signal path solutions deliver accuracy that exceeds equipment requirements
- Sophisticated fuel-gauging algorithms pair with advanced power-management circuits to boost battery life in portable instruments
- Integrated supervisors provide multiple levels of self-monitoring for enhanced reliability
- Innovative touch-screen controllers enable more-intuitive user interfaces
- Broad variety of interface solutions supports multiple connectivity options

Blood gas analyzers

Overview

Commonly used for patient monitoring and diagnosis, blood gas analyzers quantify and analyze the amount of various gases within blood. They operate in a similar way to blood glucose monitors (see pp. 3–16). A chemical reagent is mixed with a sample of blood, which is examined using either photo-optical sensors or electrochemical sensors. The readings of the blood sample are compared against a calibration reagent to determine the result.

Applications

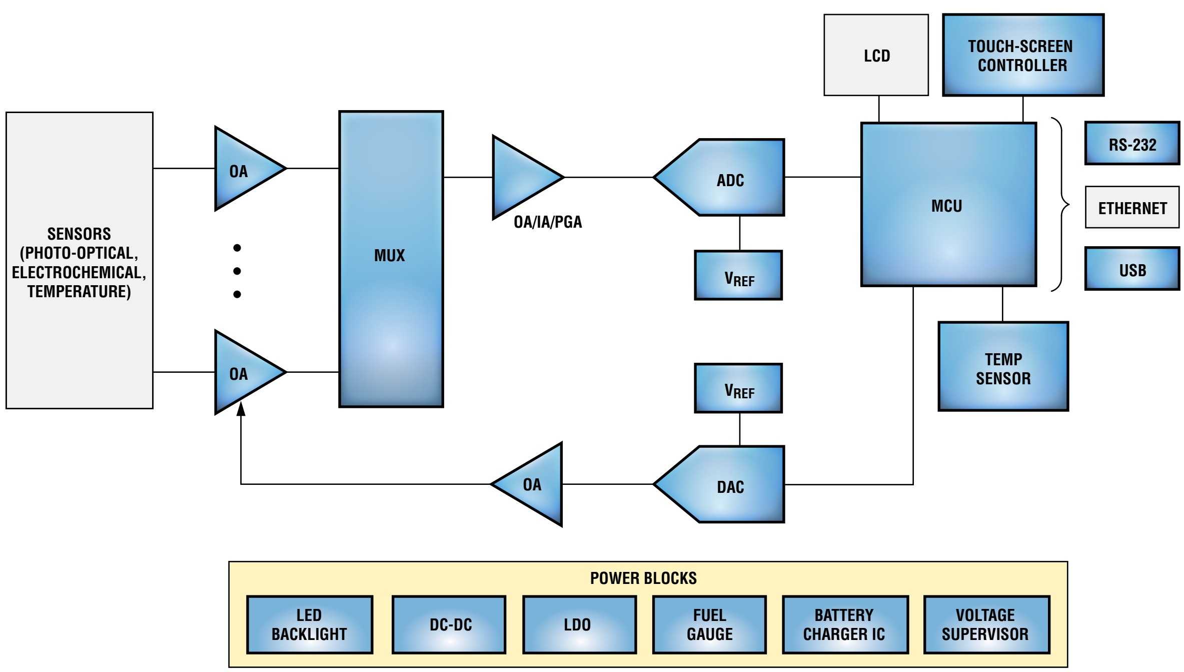
Blood gas analyzers are often used for simple blood tests, as well as for sophisticated suites of tests that allow physicians to monitor patient health in various settings. In addition to clinical diagnostics, blood gas analyzers are finding use in respiratory therapy and point-of-care diagnostics. These markets require device miniaturization and sophistication. Small, sometimes handheld, form factors are needed that integrate multiple testing capabilities, such as blood glucose and electrolyte analysis. This testing versatility increases the cost effectiveness of the device.

Signal path

Most blood gas analyzers have multiple sensors that are driven through an amplifier and a multiplexer to an analog-to-digital converter (ADC). The data is processed in the microcontroller, which is connected to a PC or other instruments through RS-232, USB, or Ethernet. A digital-to-analog converter (DAC) is often used to calibrate the sensor amplifiers to maximize the sensitivity of the electrodes.

Display

Modern blood gas analyzers increasingly employ a touch screen in combination with a graphical user interface (GUI) to make the programming process more intuitive. Visible, audible, and haptic responses to user inputs help designers improve the user experience. Advanced touch-screen controllers from Maxim offer haptic feedback, touch processing to reduce bus traffic, and autonomous modes for precision gesture recognition.



System block diagram for a blood gas analyzer. For a list of Maxim's recommended solutions for blood gas analyzers, go to the solutions page below.

www.maxim-ic.com/bga

Flow cytometers

Overview

Flow cytometers were originally used to count blood cells. Today, they are relied upon to perform a variety of cell-based analyses in disciplines ranging from immunology to stem cell research.

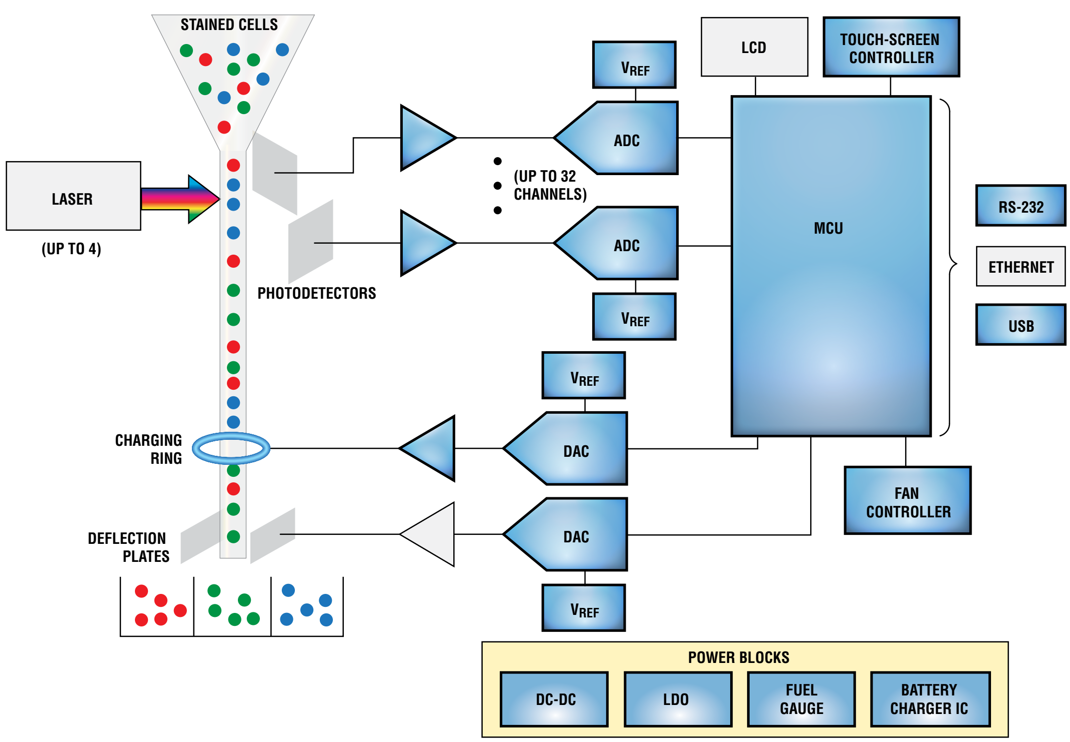
The cells to be counted are first stained with proteins that fluoresce in response to certain wavelengths of light. These proteins are designed to attach only to certain cells. In some cases, cells are not stained, as they have native proteins that fluoresce. The cells are forced down a tube whose pore size has been set to allow only a specific range of cell sizes to pass. These cells flow past one to four lasers with different wavelengths. When passing through the laser beam, the proteins will fluoresce at a longer wavelength than the lasers. Photodetectors capture these wavelengths and measure the scattered light from the original source. The different wavelengths allow the instrument to determine the size and type of cell. The output of the photodetectors is amplified and used to drive the ADCs. Typically, there is one ADC per channel. All of the data is processed by a digital signal processor (DSP), and histograms are generated showing the types of cells counted.

Once the cells pass by the laser, they are charged by a charging ring. The amount of charge is determined by the type of cell. Deflection plates then sort the cells into different test tubes for further analysis.

Applications

Spurred by advancements in genomic and proteomic research, flow cytometers continue to expand their reach into new applications. Yet, in order to enable this broader use, they must be made more affordable. With normal price tags extending from $50,000 to $500,000, flow cytometers remain too expensive for many point-of-care diagnostic facilities and, even more so, for third-world markets, where they are needed for HIV/AIDS therapy.

Miniaturized, integrated point-of-care systems are required to meet the needs of emerging markets. These systems demand high throughputs to allow more samples to be processed, support for multiple colors to deliver extended testing functionality, and increased ease of use with automation capabilities.



System block diagram for a flow cytometer. For a list of Maxim's recommended solutions for flow cytometers, go to the solutions page below.

www.maxim-ic.com/cytometer

Low-noise 24-bit ADC saves space by eliminating external gain stages

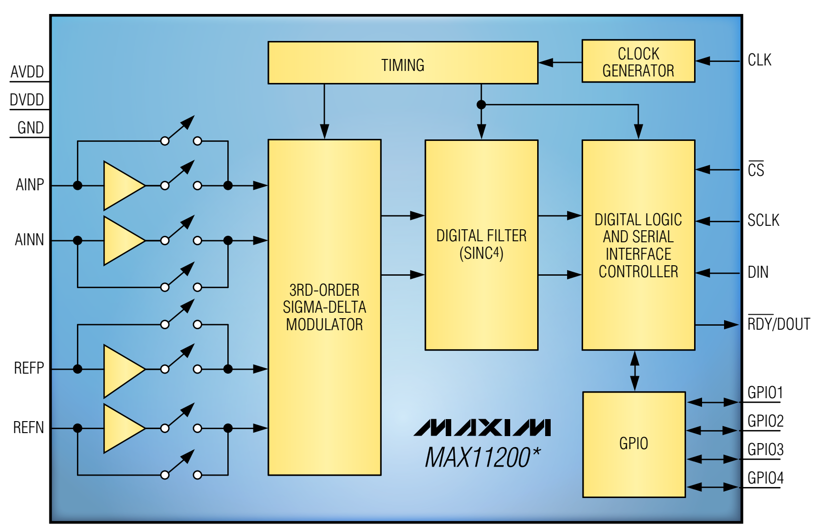
MAX11200*

The MAX11200 offers 23.5 effective bits, allowing designers to eliminate costly external gain amplifiers and connect the ADC directly to the sensor. Operating from a single 3V analog supply and a 1.7V to 3.6V digital supply, the ADC dissipates less than 1mW of power, making it ideal for portable medical instruments. In addition to this high precision and low power, the MAX11200 offers internal self-calibration modes and 16 unique software-selectable sample rates between 0.833sps and 480sps. This makes it easy to achieve low drift measurements over time and temperature, with very good 50Hz or 60Hz rejection.

Four integrated GPIOs allow this single ADC to configure an external multiplexer for up to 16 channels. The MAX11200's GPIOs make it possible to eliminate the isolation components on the I/O lines to the mux, since the control is now localized to the ADC. The MAX11200 communicates through a 4-wire SPI™ interface.

Benefits

- **High resolution allows elimination of external gain amplifiers to save space**
  - 23.5 ENOB at 10sps
  - Integrated analog input and reference buffers
- **Low active power and shutdown current extend battery life**
  - 330µA (max) supply current for sample rates up to 480sps
  - 5µA (max) shutdown current
- **Integrated GPIOs reduce cost by eliminating multiple isolation components**
  - Four GPIOs allow control of 16-channel external multiplexer, so the digital control lines to the mux don't need to pass through the isolation barrier



The MAX11200's integrated GPIOs allow control of an external 16-channel mux without needing additional isolation components.

* Future product—contact factory for availability.

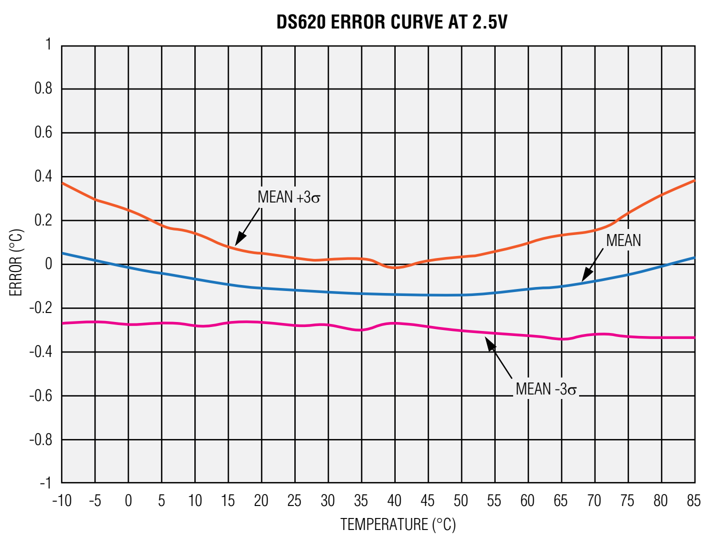
Precision digital thermometer with ±0.5°C temperature-sensing accuracy helps meet medical instrument error budgets

DS620

The DS620 is a digital temperature sensor with performance that meets the exacting demands of medical instrumentation designers. With less than ±0.5°C temperature error (0°C to +70°C), the DS620 helps designs exceed their performance goals. The device also has a versatile thermostat function that detects overtemperature or undertemperature conditions and stores the trip thresholds in nonvolatile memory. The DS620 uses the I^2C bus for communication with the system; three address-selection pins allow up to eight DS620s to reside on the same bus.

Benefits

- **Superior temperature-sensing accuracy helps meet system error budget**
  - ±0.5°C temperature-measurement error from 0°C to +70°C
  - Up to 13-bit (0.0625°C) temperature resolution
  - Nonvolatile thermostat-threshold settings ensure independent on/off control and protect against temperature extremes, even at POR
  - Flexible logic output can be programmed to indicate high-temperature or low-temperature conditions, or to serve as a nonvolatile general-purpose output



The DS620's low temperature-measurement error helps ensure instrument accuracy.

Recommended solutions

Part	Description	Features	Benefits
Amplifiers			
MAX9626*–MAX9628*	Low-noise, low-distortion, differential-in, differential-out fixed-gain amplifiers	Internal matched resistors with gain = 1, 2, 4; 5nV/√Hz; -95dBc THD at 50MHz; 6500V/µs slew rate; 3mm x 3mm TDFN	High-performance ADC drivers for 16-bit, pipelined, differential-input ADCs allow small signal detection, thus improving system resolution and acquisition speeds
MAX9632*	36V, precision, low-noise, wide-bandwidth op amp	1.1nV/√Hz, 55MHz, 30V/µs slew rate, 125µV (max) V_{OS}, rail-to-rail output, 700ns settling to 16-bit accuracy, 3mm x 3mm TDFN	High-performance ADC driver for 24-bit sigma-delta ADCs improves system resolution and performance
MAX9633*	36V, dual op amp for 16-bit SAR front-ends	2.8nV/√Hz, 36MHz, 18V/µs slew rate, 100µV (max) V_{OS}, 600ns settling to 16-bit accuracy, 3mm x 3mm TDFN	High-performance ADC driver for 16-bit ADCs improves accuracy of signal acquisition
MAX4223	2nV/√Hz, 1GHz current-feedback op amp in SOT23	Small SOT23, 6mA quiescent current, 80mA output drive, shutdown mode	Saves space and improves detection of fast signals
MAX4104	2nV/√Hz, voltage-feedback op amp in SOT23	Small SOT23, 70mA output drive, 1400V/µs slew rate	Saves space and allows accurate capture of fast signals
Precision ADCs			
MAX1162/MAX1167/MAX1168	16-bit, 1-/4-/8-channel, 200ksps SAR ADCs	12.5mW power dissipation, 16-bit resolution with no missing codes, single 5V supply, unipolar 0 to 5V input range, tiny µMAX® or QSOP	Low power dissipation preserves battery life
MAX1300*–MAX1303	16-bit, 8-channel, 115ksps, serial SAR ADCs	Up to ±12V bipolar input range, down to 0 to ±2.048V unipolar input range, ±16.5V overvoltage protection	Software-programmable input ranges save design time and eliminate external circuitry
MAX1396	12-bit, 2-channel, 312.5ksps, serial SAR ADC	1.5V to 3.6V supply, 3.1µW power dissipation at 1ksps	Low supply voltage allows direct connection to microcontroller/CPLD/FPGA, thus saving time, cost, and space
MAX11040	24-bit, 4-channel, simultaneous-sampling, serial sigma-delta ADC	Captures accurate phase and magnitude information on up to 32 channels simultaneously; 64ksps; 117dB SNR; internal reference; 38-TSSOP	Reduces firmware complexity
MAX11200*	24-bit, 1-channel, serial sigma-delta ADC	Four integrated GPIOs, 3V supply, 0.45mW, industry-leading effective resolution per unit power, 16-QSOP	Integrated GPIOs save cost by eliminating isolators between multiplexer and microcontroller
High-speed ADCs			
MAX12555	14-bit, 95Msps, 3.3V ADC	Excellent dynamic performance (72dB SNR at 175MHz), DNL of ±0.65 LSB	Combination of high accuracy and speed eases capture of fast, tiny signal events
MAX19588	High-dynamic-range, 16-bit, 100Msps ADC with -82dbFS noise floor	Excellent low-noise characteristics (79dB SNR at 70MHz), 2.56V_{P-P} fully differential analog input voltage	Combination of high accuracy and speed eases capture of fast, tiny signal events
MAX19517	10-bit, 2-channel, 130Msps ADC	Consumes only 74mW/channel of analog power	Long battery life for portable applications
MAX19507	8-bit, 2-channel, 130Msps ADC	Consumes only 74mW/channel of analog power	Long battery life for portable applications
DC-DC MOSFET drivers, converters, and controllers			
MAX15036/MAX15037	Buck/boost DC-DC converters with internal switch	200kHz to 2.2MHz operation, integrated high-side switch, reset output, CLKOUT for 180° out-of-phase operation of second device	Versatile and flexible for use as buck or boost in system power cards
MAX5035	High-voltage, buck DC-DC converter with internal switch	Up to 76V input voltage, fixed 125kHz frequency, 270µA quiescent current	Low quiescent current reduces standby power, enabling longer standby modes

(Continued on next page)

* Future product—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
DC-DC MOSFET drivers, converters, and controllers (continued)			
MAX15026	Buck DC-DC controller with external switch	4.75V to 5.5V or 7V to 28V V_{IN}, 200kHz to 2MHz switching frequency, valley current limit, prebias startup, adjustable hiccup current limit	Increases reliability and dependability with prebias startup and wide input-voltage range
MAX5078A/ MAX5078B	MOSFET drivers for AC-DC power supplies	Inverting/noninverting inputs to control the MOSFET, 4A peak source/sink drive, 20ns propagation delay	Increased flexibility for AC-DC supplies
MAX5095	High-performance, single-ended, current-mode PWM controller	60ns delay from current sense to output, adjustable frequency, high-voltage startup, internal error amplifier, thermal shutdown	Ensures reliable operation of high-performance medical equipment
Multiplexers			
MAX4578	Mid-voltage, 8:1 (single)/4:1 (dual) calibration multiplexers	Dual ±20V supply, on-chip gain and offset divider networks, low off-leakage current (0.005nA, typ)	Integrated resistor-dividers improve the precision of ADC calibration for system self-monitoring applications
MAX336/MAX337	Mid-voltage, 16:1 (single)/8:1 (dual) precision multiplexers	Dual ±20V supply, low off-leakage current (0.05nA), TTL-/CMOS-logic compatible, > ±2kV ESD protection	High-precision, drop-in upgrade to industry-standard DG506/DG507
MAX4649	Mid-voltage, general-purpose dual SPDT in tiny SOT23	Dual ±20V supply, 45Ω max R_{ON}, 5Ω max R_{ON} match between channels, 2nA off-leakage at +25°C, SOT23	Tiny package for compact designs
MAX14752/ MAX14753	High-voltage 8:1 (single)/4:1 (dual) analog multiplexers	Wide single-power-supply range (72V, max), 60Ω (typ) R_{ON}, 0.03Ω (typ) R_{ON} flatness over common-mode voltage	Wide supply range eliminates external protection circuitry; pin compatible with industry-standard DG408/DG409 for easy upgrades
Signal conditioners			
MAX1452	Low-cost, precision sensor signal conditioner	Multitemperature calibration, current and voltage excitation, fast response (150µs), single-pin programmable, 4–20mA applications	Enables accurate, simplified designs in multiple platforms; reduces inventory and cost
MAX1464	Low-power, low-noise, multichannel digital sensor conditioner	16-bit ADC, DACs, and CPU; programmable compensation algorithm; digital, analog, and PWM outputs; 4–20mA applications	Compact and accurate sensor design that directly interfaces with µCs/µPs
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^2C 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^2C interface	I^2C interface	Reduces cost
MAX11811	Resistive touch-screen controller with haptic motor driver	Integrated haptic driver, I^2C interface	Conveniently adds touch feedback to resistive touch screens

(Continued on next page)

Visit digikey.com

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Thermal management			
DS620	Low-voltage, precision I^2C digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C, thermostat thresholds saved in EEPROM, 1.7V to 3.7V operation	±0.5°C accuracy meets tight error budgets
DS7505	Low-voltage, precision I^2C digital thermometer and thermostat with industry-standard pinout	±0.5°C accuracy from 0°C to +70°C, 1.7V to 3.7V operation	Industry-standard pinout and registers enable easy accuracy upgrade and supply voltage reduction from LM75
DS1626	Precision 3-wire digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C, 2.7V to 5.5V operation	±0.5°C accuracy meets tight error budgets
DS18B20	Precision 1-Wire® digital thermometer	±0.5°C accuracy from 0°C to +70°C, unique 64-bit ID code, 3.0V to 5.5V operation	Multiple precision temperature sensors can be connected with fewer wires/traces than any other solution
MAX6639	2-channel temperature monitor and dual PWM fan controller	Internal and external temperature measurement, closed-loop RPM control	Closed-loop control over fan speed minimizes noise and power

Sensor authentication and NV memory for data storage

Overview

Many medical instruments and equipment incorporate sensors, probes, or peripheral items which are collectively considered to be consumables. These consumables are used once and then discarded, or they have a limited usage lifespan. Consequently, there is a continuous cycle of replacing consumables when operating some medical equipment.

The consumable items used for these medical applications must typically have embedded electronic capabilities, including nonvolatile (NV) memory for characteristic data storage, security functionality to prove OEM authenticity, and controls to manage limited use or reuse. These electronic capabilities are required to ensure that the consumable is calibrated to the instrument; to safeguard the quality control of the medical product; to prevent unsanitary reuse of a consumable with a limited lifespan; and to protect against unauthorized aftermarket consumables.

The standard method for attaching the consumable item to the medical instrument is with an electromechanical connector. Typically, this connector interface is pin limited. Therefore, the interface that adds authentication and memory functionality to the consumable must be accomplished with minimal contact. Because the consumable is normally handled by a human, the device providing this interface must also provide strong ESD protection. Finally, with portable medical instruments, low power and low-voltage operation are critical characteristics that must be supported.

1-Wire® products for medical consumables

Consumables are the "lifeblood" of medical suppliers. For over 15 years customers have been using Maxim's 1-Wire products for these applications, because 1-Wire technology provides the interface, the required features and performance, and the packaging designed specifically for sensors, probes, and peripherals.

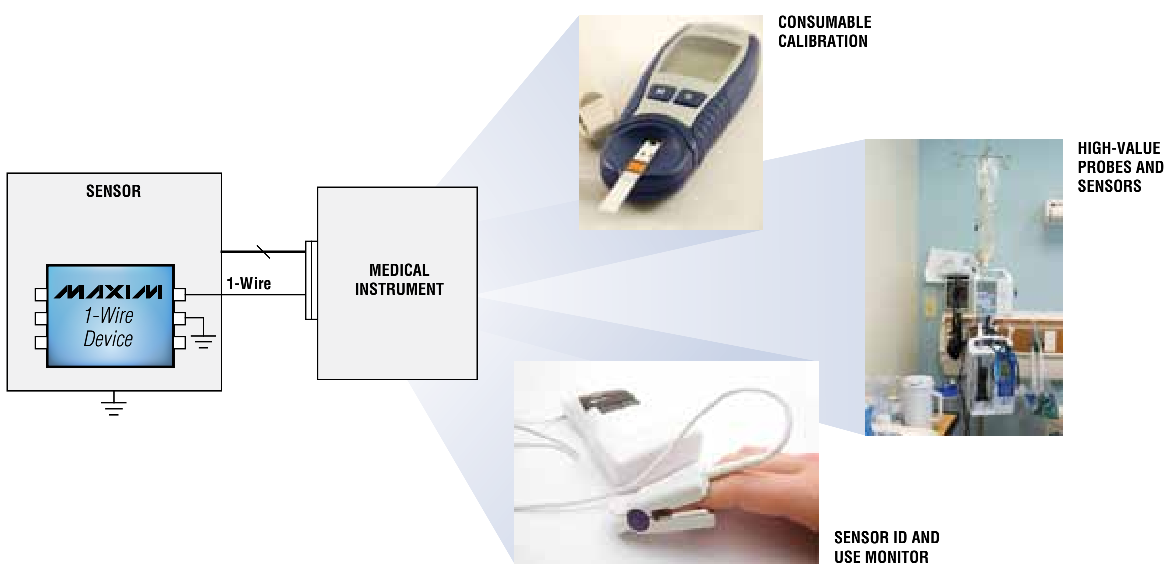
Benefits of 1-Wire

Easily add memory, security, monitoring, and control to consumables

- Single dedicated contact for communication and power minimizes impact to the instrument-sensor interface
- EEPROM and one-time programmable (OTP) arrays for NV storage of sensor characteristics
- SHA-1-based, crypto-strong, secure authentication lets the medical instrument securely test and verify OEM authenticity
- Ideal for usage monitoring and expiration control

Strong ESD performance—no discrete ESD protection needed

- ±8kV (typ) HBM; ±8kV/±15kV (typ) IEC ESD performance



Sensor-embedded 1-Wire device. Learn more about the 1-Wire interface, get samples and starter (EV) kits, and contact technical support at: www.maxim-ic.com/1-WireMedical.

Sensor authentication and NV memory for data storage

Incorporating 1-Wire ICs into sensors and consumables

After many years of experience with medical applications, Maxim has a range of packaging solutions and services that satisfy the diverse and unique requirements of consumables. 1-Wire ICs are available in a variety of standard, off-the-shelf SMT package options. Other unique and/or customized packaging is optimized for medical consumables.

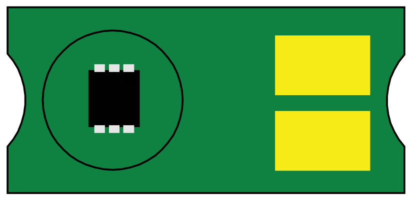
Typical consumable applications for 1-Wire devices include:

- Pulse oximetry sensors
- Blood-glucose test strips
- Dermatological probes
- Electrosurgical tools
- Clinical biosense reagent bottles
- Dental electronic instruments
- Catheters
- EEG sensor

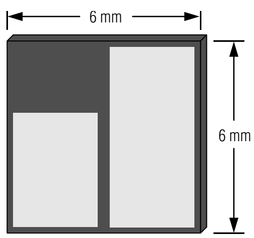
This example shows a 1-Wire solution in a TO92 package that is crimped or soldered to connector pins, and then embedded in the connector backshell.

A 1-Wire device and wired sensor with DB9 connector interface to the instrument.

In another typical example, a consumable must add an electronic ID, authentication, calibration, or other parameter without changing the existing electronics. In this case either Maxim's SFN package or custom IC and printed circuit board (PCB) modules, which are available from the factory, are attached to the consumable. This 1-Wire approach enables electromechanical contact to an instrument interface.

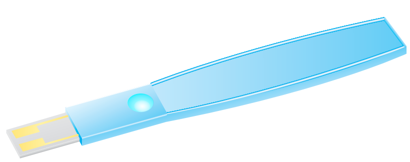


Custom IC and PCB module.



SFN for electromechanical contact.

Calibration is often required for nonelectrical medical consumable materials. Here a 1-Wire module is customized for the application.



Customized packaging allows a 1-Wire device to calibrate insulin test strips.

www.maxim-ic.com/1-WireMedical

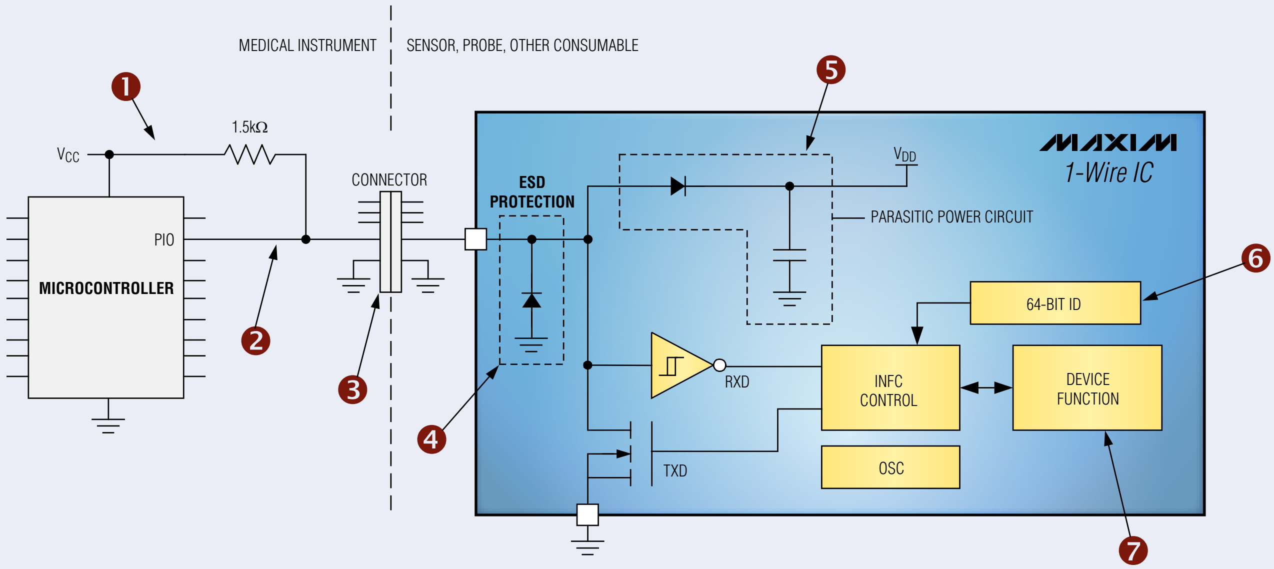
How 1-Wire works

Maxim's 1-Wire bus is a simple signaling scheme that performs half-duplex bidirectional communications between a host/master controller and one or more 1-Wire slave ICs sharing a common data line. The bus master initiates and controls all 1-Wire communication with a waveform similar to pulse-width modulation (PWM).

In a 1-Wire network data is transmitted by wide (logic 0) and narrow (logic 1) pulse widths during data-bit time slots. A communication sequence starts when the master drives a defined-length reset pulse that synchronizes the entire bus. Most 1-Wire devices support two data rates: standard speed of 15kbps, and overdrive speed of 125kbps. The protocol is self-clocking and tolerates long inter-bit delays, which ensures smooth operation in interrupted software environments.

Both power and data communication for slave devices is transmitted over the 1-Wire line. For power delivery, slaves capture charge on an internal capacitor when the line is in a high state, and then use this charge for device operation when the line is low during data transmission. A fundamental feature of all 1-Wire slave devices is a factory-programmed, unique 64-bit ROM ID that can be read by the master. This ROM ID serves several purposes. It provides a unique ID to the medical sensor. It serves as an input element for some device functions, and as an address to select an individual device in a multidevice configuration.

Layered on these 1-Wire fundamentals is a variety of memory, digital, analog, and mixed-signal functions. This variety results in a product portfolio optimized for applications where the single-contact 1-Wire interface can solve an interconnect-constrained problem and/or add value with unique features.



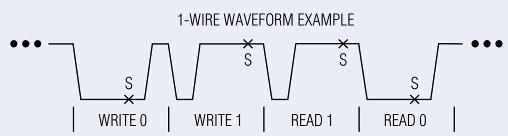
Typical interface from a medical instrument to a 1-Wire device.

❶ Simple and low-cost host interface

- Implemented with a single microcontroller port pin and with software "bit-banging" 1-Wire waveforms
- Optional ICs from Maxim implement 1-Wire line driving (e.g., the DS2482-100 1-Wire master)
- Free C-language source code for host implementation

❷ Straightforward waveform and protocol reduce software complexity

- Half duplex, host/master controlled
- Two data rates: 15kbps and 125kbps
- Protocol supports single or multiple slaves on a common line
- Simple long/short pulse scheme to transmit logic 0/1



S is the sample.

❸ Minimal contact requirement lowers connector cost

- Shared instrument-sensor ground connection
- Only a single dedicated contact is needed for total operation (communication and power)

❹ Integrated ESD protection saves space and cost

- ±15kV/±8kV (typ) IEC 61000-4-2 (Air/Contact); ±8kV (typ) HBM
- Typically eliminates need for a discrete ESD protector

❺ Internal parasitic-power circuit enables single-contact operation

- Captures charge on internal capacitor (approximately 1nF) during communication waveform logic-high states
- Powers internal circuits during communication waveform logic-low states

❻ Unique 64-bit factory-programmed ROM ID ensures authenticity

- Useful as electronic serial number for sensors
- Can be customized by the factory to indicate OEM authenticity, model number, or other identifying parameter
- Important data parameter for 1-Wire devices with crypto-security functions
- Used to identify and select individual parts when a multidrop configuration is implemented

← 64-BIT ROM ID →

CRC (8-BITS)	UNIQUE SERIALIZATION (48 BITS)	FC (8-BITS)

CRC = cyclic redundancy check
FC = device family code

❼ Device functionality requires just one wire

- NV memory for calibration, expiration, model data, or other system parameter
- Crypto functionality for secure OEM authentication and tamper-proof memory settings
- Thermal measurement for monitoring sensor or probe
- General-purpose input/output (GPIO) for ON/OFF control

Recommended solutions

Part	Description	Features	Benefits
Secure and nonsecure memory			
DS2431	1-Wire 1024-bit EEPROM	Single-dedicated-contact operation; programmable data protection; ±8kV HBM and ±15kV IEC ESD performance	Requires minimal contact to add NV memory for ID and calibration data to sensors
DS28E01/02*	1-Wire, SHA-1 bidirectional authenticator with 1KB EEPROM	Secure authentication and data protection	Provide crypto assurance that consumables are OEM authentic for safety, quality, and market-share protection
DS28E10	1-Wire SHA-1 authenticator with 224-bit OTP EPROM	Low cost; single contact; unidirectional; SHA-1 authentication	Lowest-cost SHA-1 solution
DS2401	1-Wire 64-bit ROM serial number	Guaranteed unique electronic serial number	Easily adds unique electronic serial number to ID sensors; provides value-added customization service to authenticate OEM
DS2502	1-Wire 1024-bit OTP EPROM	User-programmable OTP EPROM; programmable with 12V pulse	Simple solution for fixed/static sensor calibration data
Thermal measurement and programmed input/output (PIO) control			
DS28EA00	1-Wire digital thermometer with GPIOs	±0.5°C accurate over -10°C to +85°C; programmable conversion resolution and alarms; chain-mode function or two GPIO pins to control external circuits	Single-wire interface for temperature measurement minimizes connector size and cost
1-Wire host solutions: interface and SHA-1 coprocessing			
DS2460	SHA-1 coprocessor with EEPROM	SHA-1 computation engine with secure memory to store three master secrets for use with authenticating 1-Wire SHA-1 slaves; I²C interface	Offloads SHA-1 processing from host micro-controller; simplifies host system implementation of SHA-1-authenticated sensors and probes
DS2482-100	Single-channel I²C-to-1-Wire master	I²C-to-1-Wire protocol bridging; supports standard and overdrive 1-Wire speeds; low impedance; strong pullup on 1-Wire IO	Generates 1-Wire waveforms from I²C command/communication; greatly simplifies host software development
DS2480B	Single-channel UART/RS-232-to-1-Wire master	UART/RS-232-to-1-Wire protocol bridging; supports standard and overdrive 1-Wire speeds; strong pullup on 1-Wire IO	Generates 1-Wire waveforms from UART/RS-232 command/communication; greatly simplifies host software development
DS1WM	Synthesizable Verilog® core: 1-Wire master	Memory-mapped interface; supports standard and overdrive 1-Wire speeds; external strong pullup	Easily adds a 1-Wire master to medical instrument field-programmable gate array (FPGA)
DSSHA1	Synthesizable Verilog core: SHA-1 coprocessor	Memory-mapped interface; SHA-1 computation engine	Adds Maxim's proven SHA-1 processing to medical instrument FPGA to authenticate SHA-1 secured consumables

*Future product—contact factory for availability.

Trim, calibrate, and adjust

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

Medical equipment is an area where everyone expects accuracy and safety. At the same time, equipment must be affordable. How can manufacturers deliver "perfect" equipment at a reasonable price? In a word, *calibration*.

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 medical systems. This digital approach results in better reliability and improved patient 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 gain during final test to meet system specifications. So, we make measurements in the final production test and have a human set the gain 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 circuit component aging, temperature, humidity, and signal level and bias. 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 syringe, plastic bag, or glass jar. Subtracting the weight of the package (tare weight) 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 medical 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 medical equipment to remove all possible 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. 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 medical circuit.

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

Digitally controlled adjustable devices offer several advantages over mechanical devices in medical 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 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 is another advantage compared to mechanical pots. Digitally adjustable pots can be mounted on the circuit board directly in the signal path, exactly

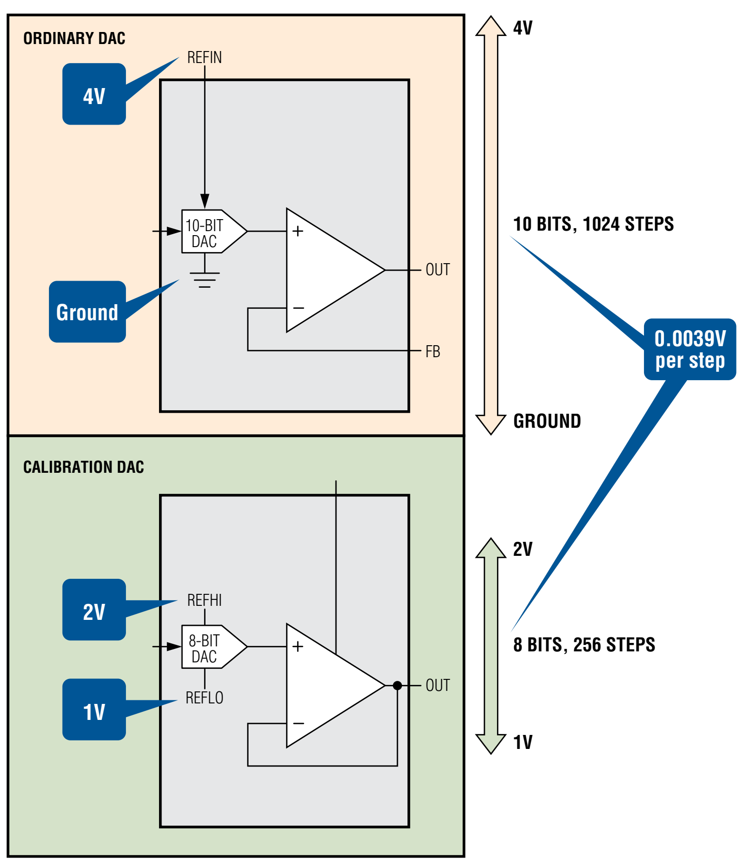


Figure 1. Comparing the calibration range of an ordinary DAC to a CDAC.

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 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 medical 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 medical imaging systems. The second type is an adjustable reference that allows adjustment over a wide range (e.g., 1V to 12V), which is advantageous for medical devices that have wide-tolerance sensors and that must operate on unstable power. Portable devices may need to operate from batteries, automotive power, or emergency power generators. The third type, called an E^2CRef, 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. E^2CRefs benefit medical testing devices that need to establish a baseline or warning-alert threshold.

Figure 2 illustrates the production advantages of using an E^2CRef. In this example, a power-supply manufacturer uses an E^2CRef 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.

"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.

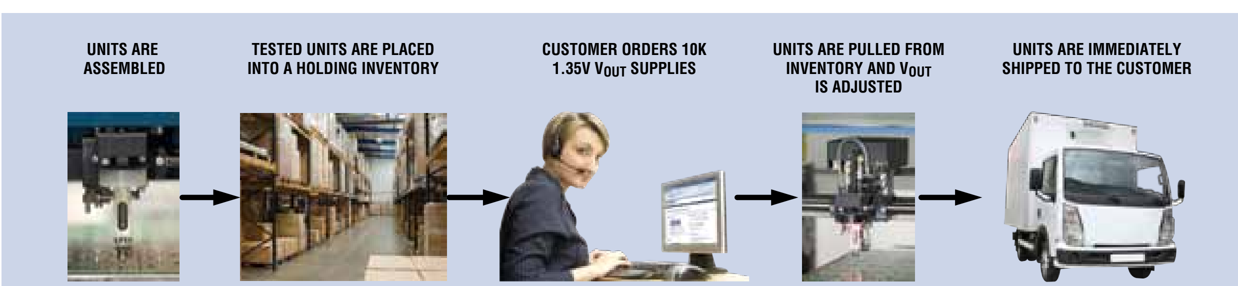


Figure 2. Illustrating the manufacturing benefits of using an E^2CRef.

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 adjustable 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 medical 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^2C 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^2C 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^2C 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^2C 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 E^2CRefs			
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

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