Power-grid monitoring

Overview

Advanced power-grid monitoring systems combine power-supply monitoring, load-balancing, protection, and metering functions to enable safe and efficient power delivery. They also reduce operation and maintenance costs for utilities.

These systems protect transformers, circuit breakers, and other equipment at substations; they enable predictive maintenance by detecting and responding to fault conditions; they dynamically balance loads to conserve energy; and they monitor and control power quality. These advanced capabilities are critical to ensuring uninterrupted power delivery and supporting intelligent grid-management applications.

Accuracy requirements

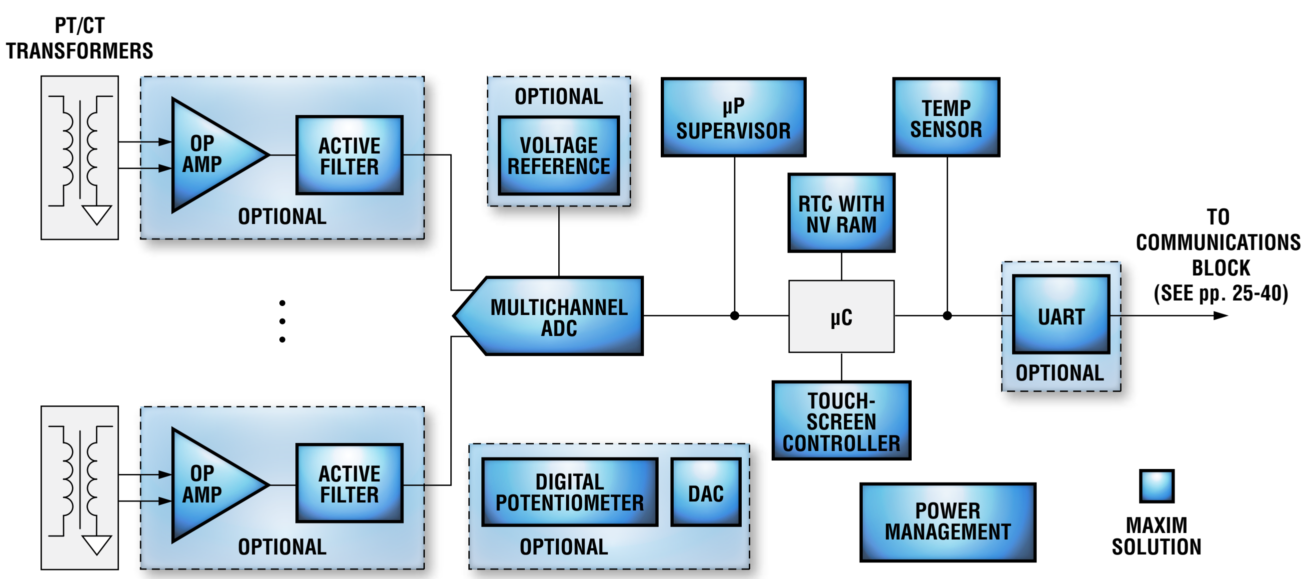
The rollout of advanced power-grid monitoring systems is complicated by the varying international standards that specify the accuracy required for energy measurement. Real-time power-delivery monitoring, fault detection, fault protection, and dynamic load balancing require stringent accuracy. As an example, the European Union IEC 62053 standard for Class 0.2 equipment requires measurement precision to be 0.2% of the nominal current and voltage. For power-factor measurement accuracy, sample-time phase matching should be 0.1% or better.

Polyphase measurements

Power companies distribute three-phase (polyphase) power using a "wye" connection. The term wye refers to the arrangement of three transformer windings that join at a common point, the junction of the Y. The line voltages are offset in phase from each other by 120°, one-third of a cycle. If loads on each of the three phases are equal, the system is balanced and no current flows through the neutral line. A fourth, neutral, wire connects to the junction of the wye. It accommodates imbalanced loads across the line connections.

Power-grid monitoring systems track the voltage and current on multiple phases with ADCs. The converters must be synchronized in order to meet stringent standards requirements and to accurately measure power factor. In a typical scheme, each phase's power parameters are measured with a current transformer (CT) and a voltage transformer (VT). The complete system comprises four such pairs: one pair for each of the three phases, plus a neutral pair. The ADCs simultaneously measure the three phases and neutral voltages and currents. The active, reactive, apparent-energy, and power-factor parameters can be calculated from the sampled data, often by a DSP.

International and local standards also dictate the necessary sample rate. These applications typically require accurate, simultaneous multichannel measurement over a wide dynamic range of 90dB or better with a sample rate of 16ksps or higher. These capabilities enable analysis of multiple harmonics of the AC supply



Block diagram of a typical power-grid monitoring system. For a list of Maxim's recommended power-grid monitoring solutions, please go to: www.maxim-ic.com/grid-monitoring.

as well as detection of high-speed fault conditions, such as spikes and brownouts.

Analog-input signal chain

Designers of polyphase power-grid monitoring systems are increasingly relying on precision, multichannel simultaneous-sampling ADCs. These ADCs simplify the sampling scheme when compared to single ADCs that require digital phase compensation. Simplifying the ADC design leads to reduced system cost, since all of the timing among the ADCs is handled within the IC.

The simultaneous-sampling ADC must offer better than 90dB signal-to-noise ratio (SNR) in order to meet the dynamic range requirements for measuring small voltage fluctuations on large AC signals. Maxim offers two simultaneous-sampling ADC families that meet these requirements: the 24-bit MAX11040 with 4 channels and 117dB SNR, and the 16-bit MAX11044/MAX11045/MAX11046 with 4, 6, or 8 channels and more than 92dB SNR.

The transformers drive directly into the ADC if the input impedance of the ADC is high enough; otherwise, a precision low-noise amplifier (LNA) is also needed. Maxim offers a complete line of amplifiers with less than $10nV/\sqrt{Hz}$ noise and very low offsets. These amplifiers minimize measurement errors in the system to ensure the highest possible accuracy.

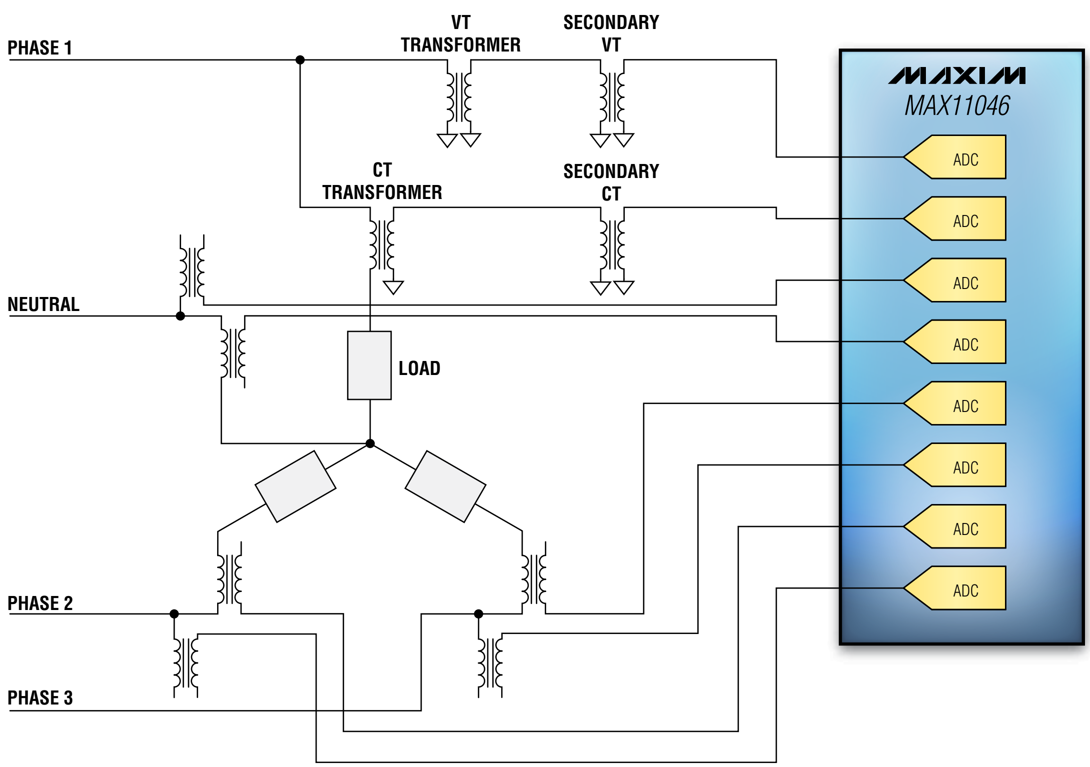
Communications

Aside from the analog-input signal chain, power-grid monitoring systems need specialized communications circuits to overcome the challenges of transmitting and receiving data in the harsh grid environment. Detailed information about power-grid communications is available on pages 25–40.

Electronic 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 more accurate and affordable.

Digitally controlled calibration DACs (CDACs) and potentiometers (CDPots) provide quicker and simpler electronic calibration than mechanical pots. They are also more reliable, and insensitive to vibration and noise. Using these devices, manufacturers can compensate for manufacturing tolerances during the final production test to meet target specifications.



An example of three-phase power monitoring in a wye configuration.

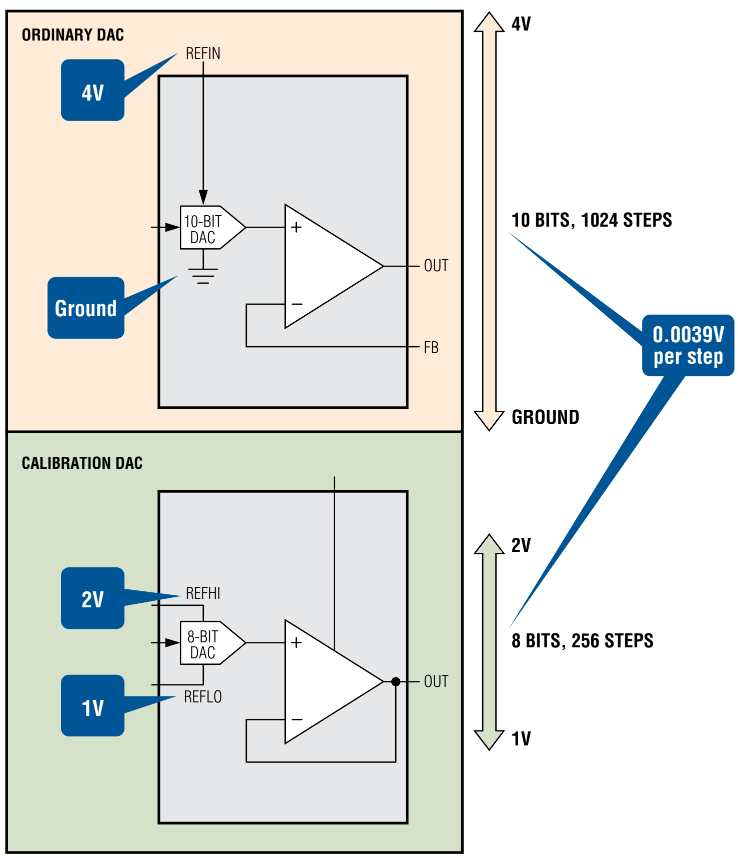
Additionally, electronic calibration allows for periodic self-test and calibration to compensate for environmental factors (e.g., temperature, humidity, and drift) in the field.

CDACs and CDPots allow both the top and bottom DAC voltage to be set to arbitrary voltages, thus removing excess adjustment range. In the calibration diagram below, a low value of 1V and a high value of 2V are selected. To achieve a 0.0039V step size over the 1V to 2V range, only an 8-bit device is needed. This approach reduces cost and increases accuracy and reliability by removing any possibility that the circuit could be grossly misadjusted. The high and low voltages for the CDAC are arbitrary and, therefore, can be centered wherever circuit calibration is required. Thus, the granularity of the adjustment can be optimized for the specific application. In addition, CDACs and CDPots have internal nonvolatile (NV) memory, which automatically restores the calibration setting during power-up.

Precision voltage references

Sensor and voltage measurements with precision 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. They are not accurate enough and drift far too much with temperature.

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.



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

ADC's high-impedance input eliminates external components and reduces system cost

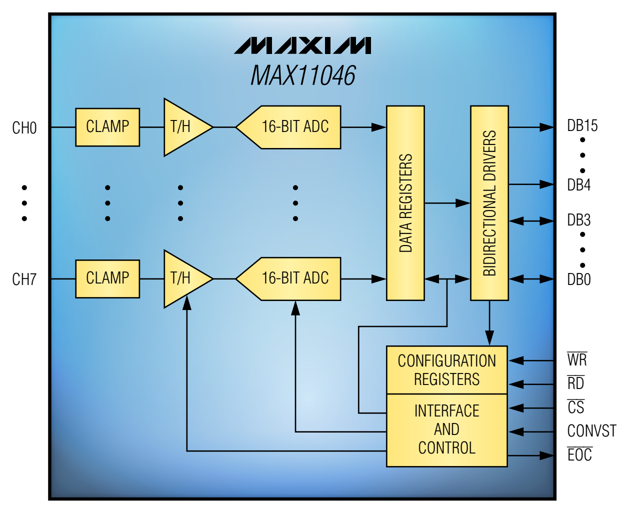
MAX11046

The MAX11046 is the industry's first true 16-bit, 8-channel simultaneous-sampling SAR ADC. The device's proprietary architecture provides an ultra-low-noise, on-chip, negative supply voltage. This innovative technology achieves true 16-bit performance from a high-impedance bipolar input using only a single positive external supply. Performance exceeds the regulatory requirements for Class 0.2 precision (0.2% of 220V) mandated by IEC 62053.

The high-impedance input allows a lowpass filter prior to the ADC inputs, thus eliminating the need for precision external buffers. The bipolar input eliminates a level shifter. Simultaneous sampling eases the typical requirement for phase-adjust firmware and thus speeds end designs and time to market. Together, these benefits simplify the design challenges for power-grid monitoring and measurement equipment. This ADC performance is unprecedented, and designs will save cost, area, and power.

Benefits

- **Saves up to $1/channel***
  - High-impedance input eliminates external buffers for precision designs
  - Bipolar input eliminates a level shifter
  - 5V single-supply operation
  - Integrated 20mA surge protection
- **Provides the highest precision**
  - Industry-leading SNR and THD
  - True 16-bit performance exceeds the EN 50160 and IEC 62053 requirements for Class 0.2 power-grid equipment
- **Simplifies design and shortens time to market**
  - Simultaneous sampling simplifies phase-adjust firmware requirements



Block diagram of the MAX11046 16-bit, 8-channel, simultaneous-sampling ADC. Eight inputs measure voltage and current signals on three phases plus neutral.

*Cost savings achieved by eliminating external amplifiers and level-shifting circuitry.

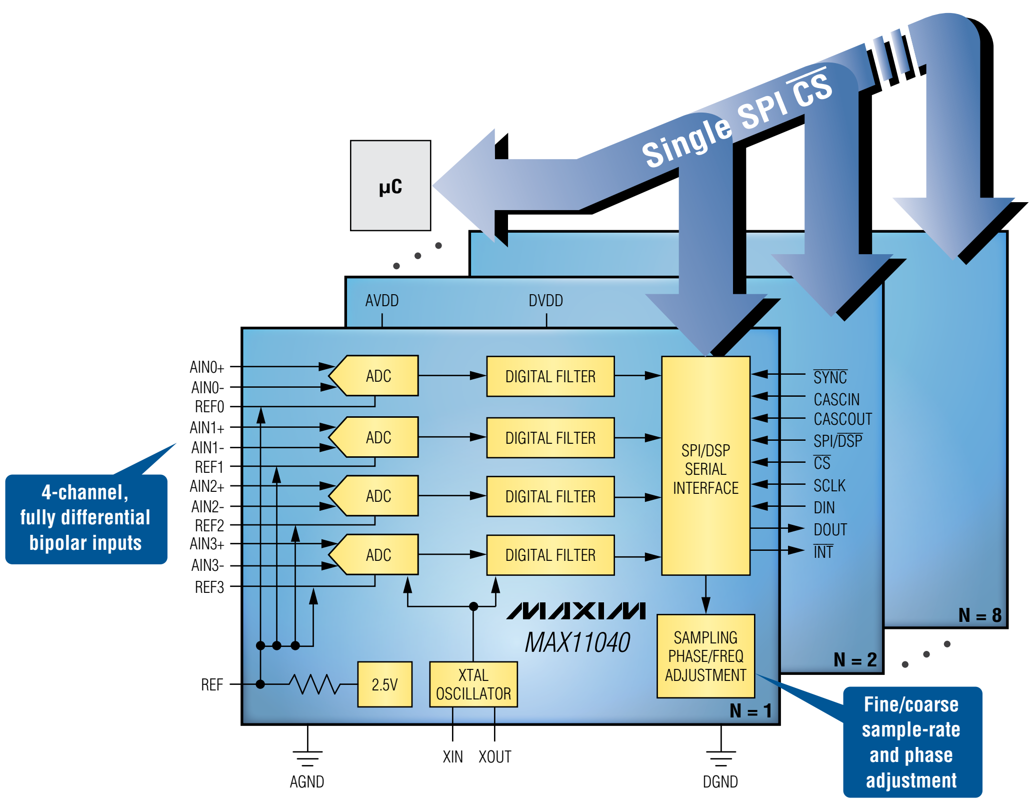
ADC simplifies firmware by capturing accurate phase and magnitude information on up to 32 channels

MAX11040

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

Benefits

- **Simplifies digital interface to a microcontroller**
  - Eight MAX11040 ADCs can be daisy chained through the SPI interface
- **Easily measures a wide dynamic range**
  - 117dB SNR at 1ksps allows users to measure both very small and large input voltages
- **Easily measures the phase relationship between multiple input channels**
  - Simultaneous sampling preserves phase integrity between current and voltage transformers in a polyphase environment



The MAX11040 can be cascaded up to 32 simultaneous channels.

Microprocessor supervisor delivers high accuracy and reliability with reduced total cost

MAX16055

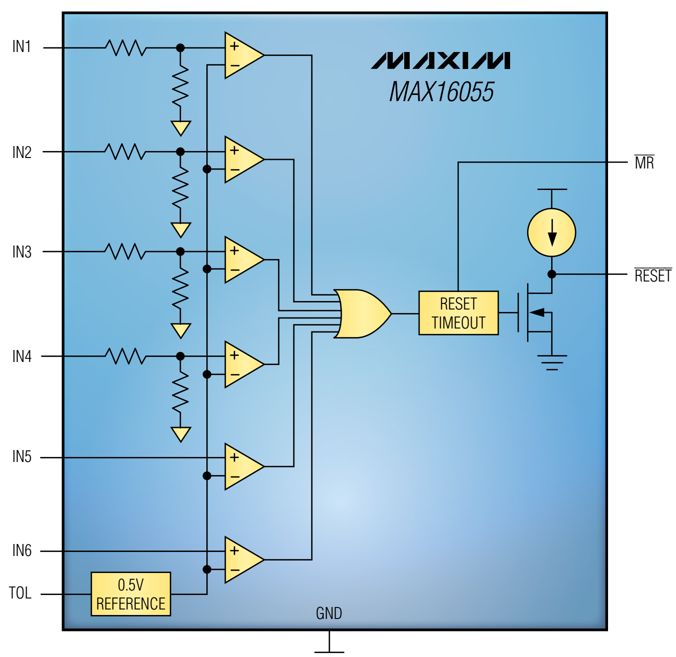
To improve system reliability, you should monitor all the voltage rails for undervoltage conditions. Instead of using separate discrete voltage supervisors that consume valuable board space, you can use a MAX16055 ultra-small microprocessor supervisor. This device integrates six channels of undervoltage monitoring into a space-saving µMAX® package. The MAX16055 thus significantly reduces system size and component count while improving reliability compared to multiple ICs or discrete supervisors.

The MAX16055 also includes a manual-reset input and a tolerance-select input for choosing between 5% and 10% threshold tolerances. The manual-reset feature is especially versatile and practical. Use it to force a reset even when all the voltage rails are within tolerance. It can also cascade multiple voltage monitors or connect to a separate watchdog timer.

The MAX16055 single-chip solution offers up to nine different combinations of fixed-voltage thresholds and resistor-adjustable thresholds. It is fully specified up to +125°C.

Benefits

- **High integration saves board space**
  - Six-channel voltage monitor is available in a tiny 3mm x 3mm µMAX package
- **Highly adjustable to accommodate changing design requirements**
  - Fixed and adjustable voltage thresholds; adjustable threshold monitors down to 0.5V with ±1.5% accuracy
  - Manual-reset and tolerance-select inputs
  - Fully specified to +125°C



Block diagram of the MAX16055 6-voltage microprocessor supervisor.

Simple reset and monitoring circuits enable easy sequencing and flexible monitoring

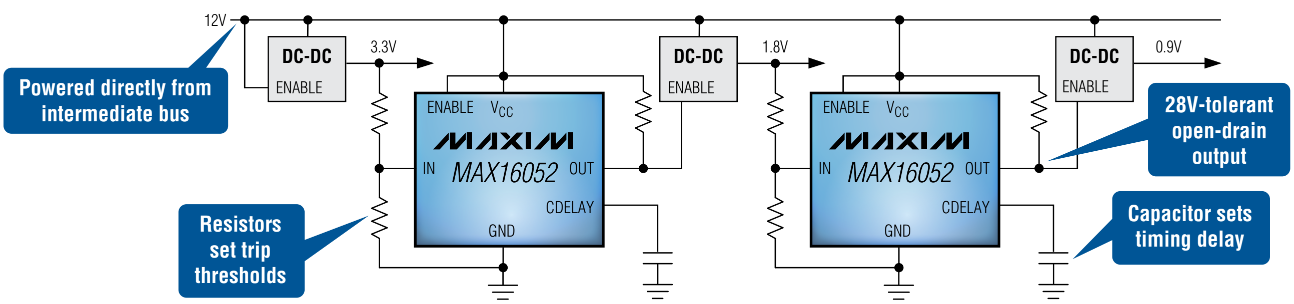
MAX16052/MAX16053

The MAX16052/MAX16053 are low-power, high-voltage monitoring circuits with sequencing capability. Each device monitors a voltage rail with a threshold set by an external resistor. Using this externally adjustable threshold, the MAX16052/MAX16053 monitor a wide variety of power-supply voltages. A single output with a capacitor-programmable delay can be used to adjust the sequencing delay between power-supply rails.

The MAX16052/MAX16053 are ideal for use in power-supply sequencing, reset sequencing, and power-switching applications. The devices work especially well for sequencing the multiple power supplies required by high-performance DSPs and other complex ICs. In a typical application a MAX16052/MAX16053 is powered from a 12V supply rail and monitors a power supply that is derived from the main 12V rail, while turning on a second power-supply rail after a programmable time delay.

Benefits

- **Save cost while offering highest flexibility**
  - Operate over 2.25V to 16V to support high-voltage applications
  - Can be powered up directly from the intermediate bus
  - Use the external resistor/capacitor to monitor a wide range of power-supply voltages and programmable timing delays



The MAX16052 in a typical monitoring application.

Digital potentiometers automate calibration of line-monitoring instruments

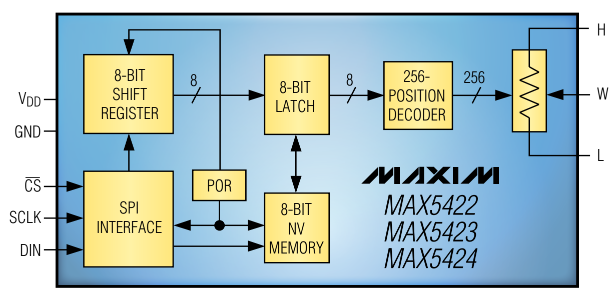
MAX5422/MAX5423/MAX5424

The MAX5422/MAX5423/MAX5424 nonvolatile, linear-taper digital potentiometers perform the function of a mechanical potentiometer, but replace the mechanics with an integrated resistor string controlled with a simple 3-wire, SPI-compatible digital interface. This design minimizes board space and reduces interconnection complexity in many applications. Each device performs the same function as a discrete potentiometer or variable resistor and has 256 tap points.

These digital potentiometers feature internal nonvolatile (NV) EEPROM used to store the wiper position for initialization during power-up. This enables the devices to be used in "dumb" applications where there is no host processor. The 3-wire SPI-compatible serial interface allows communication at data rates up to 5MHz. The devices provide three nominal resistance values: 50kΩ (MAX5422), 100kΩ (MAX5423), or 200kΩ (MAX5424). The nominal resistor temperature coefficient is 35ppm/°C end-to-end and only 5ppm/°C ratiometric.

Benefits

- **Optimize board layout**
  - Tiny 3mm x 3mm TDFN package
- **Retain calibration even during power cycling**
  - Nonvolatile memory restores the wiper position during power-up



Block diagram of the MAX5422/MAX5423/MAX5424.

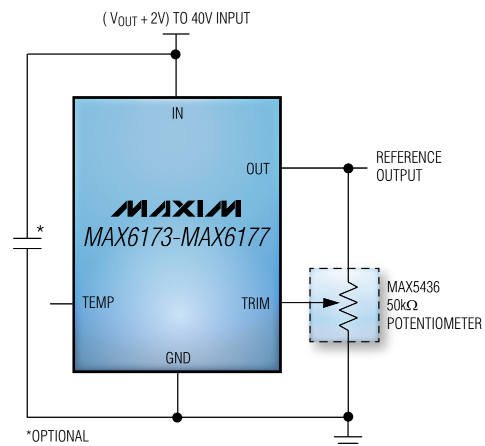
Calibration voltage references with temperature sensor increase system precision

MAX6173–MAX6177

The MAX6173–MAX6177 are low-noise, high-precision voltage references. The devices feature a proprietary temperature-coefficient, curvature-correction circuit and laser-trimmed thin-film resistors that result in a very low 3ppm/°C temperature coefficient and excellent ±0.06% initial accuracy. A trim input allows fine trimming of the output voltage with a resistive-divider network. Low temperature drift and low noise make the devices ideal for use with high-resolution ADCs or DACs. The MAX6173–MAX6177 accept input voltages up to 40V. The devices draw 320µA (typ) of supply current and source 30mA or sink 2mA of load current. They operate over the -40°C to +125°C automotive temperature range.

Benefits

- **Optimize system error budget**
  - ±0.06% (max) initial accuracy
  - ±3ppm/°C (max) temperature stability
- **Save cost and valuable board area**
  - Short-circuit protection
  - No external capacitors required for stability



Block diagram of the MAX6173-MAX6177 precision voltage references.

Recommended solutions

Part	Description	Features	Benefits
Precision analog-to-digital converters (ADCs)			
MAX11040	24-bit, 4-channel, simultaneous-sampling delta-sigma ADC	64ksps; internal reference; cascade to capture phase and magnitude on up to 32 channels; 117dB SNR	Minimal firmware complexity speeds time to market
MAX11044/45/46	16-bit, 4-/6-/8-channel, simultaneous-sampling SAR ADCs	3µs conversion time; 250ksps for all eight channels; 92dB SNR; -105dB THD	> 1MΩ input impedance eliminates external buffers, saving space and up to $1/channel**
MAX11054*/55*/56*	14-bit, 4-/6-/8-channel, simultaneous-sampling SAR ADCs	3µs conversion time; 250ksps for all eight channels	14-bit, pin-compatible versions of the MAX11044/45/46 make it simple to trade off resolution vs. cost
MAX1324/25/26	14-bit, 2-/4-/8-channel, simultaneous-sampling SAR ADCs	3.7µs conversion time; 250ksps for all eight channels; 77dB SNR; -86dB THD	Pin-compatible packages make it simple to design 2, 4, or 8 channels; flexibility with 0 to 5V, ±5V, or ±10V input ranges
Precision operational amplifiers			
MAX9618/19/20	Ultra-low-power, zero-drift op amps	Continuous self-calibration at any voltage or temperature	Save maintenance system downtime and maintain system accuracies
MAX9613/15	Low-power, autotrim op amps	Self-calibration feature on startup	Save maintenance system downtime and maintain system accuracies
MAX9943/44	38V, low-noise, precision op amps	Excellent combination of low power (550µA) and precision (V_{OS} of 100µV)	High-voltage precision conditioning without high power dissipation minimizes temperature errors
MAX9945	38V, CMOS-input, single op amp	Excellent precision with 50fA low-input-bias characteristics	High-voltage CMOS inputs with very low bias current allow signal conditioning of high-ohmic sensors
Active filters			
MAX7409/10/13/14	5th-order, switched-capacitor lowpass filters	Clock- or capacitor-adjustable corner frequency to 15kHz; 1.2mA supply current	Save space and cost by replacing discrete designs
MAX7422–25	5th-order, switched-capacitor lowpass filters	Clock- or capacitor-adjustable corner frequency to 45kHz; 3mA supply current	Save space and cost by replacing discrete designs
MAX274/75	8th-order/4th-order, 150kHz/300kHz, lowpass/bandpass filters	Resistor programmable; continuous-time filters; low noise (-89dB THD)	Save space and cost by replacing discrete designs
Calibration digital potentiometers (CDPots)			
MAX5481	1024-tap (10-bit) CDPot with SPI or up/down interface	1.0µA (max) in standby; 400µA (max) during memory write	1024 taps provide very accurate calibration
MAX5477	Dual, 256-step (8-bit) CDPot with I²C interface	EEPROM write protection; single-supply (2.7V to 5.25V) operation	EEPROM protection retains calibration data so no host processor is required
MAX5427/28/29	Low-cost, one-time-programmable (OTP) digital potentiometers with up/down interface	1µA (max) standby current (no programming); 35ppm/°C end-to-end and 5ppm/°C ratiometric tempco	Increase power savings and improve measurement accuracy over temperature changes
MAX5494–99	10-bit, dual, nonvolatile voltage-dividers or variable resistors with SPI interface function as digital potentiometers	1µA (max) standby current (no programming); 35ppm/°C end-to-end and 5ppm/°C ratiometric tempco	Improve power savings and improve measurement accuracy over temperature variations
MAX5422	Single, 256-step (8-bit) CDPot with SPI interface	Tiny 3mm x 3mm TDFN package	Reduces board space

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*Future product—contact the factory for availability.

**Cost savings achieved by eliminating external amplifiers and level-shifting circuitry.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Calibration digital-to-analog converters (CDACs)			
MAX5134–37, MAX5138/39	1-/2-/4-channel, 16-/12-bit DACs with pin-programmable zero or midscale power-up	Output set to zero or midscale upon power-up	Add extra safety during power-up
MAX5661	Single-channel DAC with 16-bit voltage- or current-buffered output	Integrated high-voltage current and voltage amplifiers; serial interface	Reduces external component count; reduces cost
MAX5500	4-channel, 12-bit DAC with precision amplifier-output conditioners	Output conditioners; 0.85mA quiescent current (I_Q)	Needs no external amplifiers; makes equipment more cost effective
MAX5105/15	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	Avoids grossly misadjusted system at the start of the calibration procedure; reduces cost of the calibration DAC by reducing the required resolution
Touch-screen controllers			
MAX11800	Resistive touch-screen controller	FIFO; spatial filtering; SPI interface	Simplifies the task of identifying touch events
MAX11801	Resistive touch-screen controller	FIFO; spatial filtering; I^2C interface	Simplifies the task of identifying touch events
MAX11802	Resistive touch-screen controller with SPI interface	SPI interface	Basic feature set for lowest cost
MAX11803	Resistive touch-screen controller with I^2C interface	I^2C interface	Basic feature set for lowest cost
MAX11811	Resistive touch-screen controller with haptics driver	Integrated haptics driver; I^2C interface	Adds tactile feedback to resistive touch screens for improved usability
UART			
MAX3107	SPI/I^2C UART with integrated oscillator	24Mbps (max) data rates; power-save features; RS-485 control; four GPIOs; 24-pin SSOP or small TQFN (3.5mm x 3.5mm) packages	Tiny package saves board space; high integration of features frees up microcontroller
Voltage references, calibration voltage references (CRefs), and E^2CRefs			
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; allows easy system temperature compensation
MAX6220	Low-noise, precision voltage reference	8V to 40V input-voltage range; ultra-low 1.5µV_{P-P} noise (0.1Hz to 10Hz)	Enables dependable operation during brownout
DS4303	Electronically programmable voltage reference (E^2CRef)	Wide, adjustable output-voltage range can be set within 300mV of the supply rails with ±1mV accuracy	Automates production test through easy calibration for reference voltages from 0.3V to 2.7V

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage supervisors			
MAX16052/53	High-voltage, adjustable sequencing/supervisory ICs	2.25V to 16V supply range; adjustable voltage thresholds and reset timeout	High-voltage input reduces costs; adjustable voltage thresholds increase flexibility
MAX6746–53	Capacitor-adjustable watchdog timer and reset ICs	Capacitor-adjustable timing; 3µA supply current	Versatile for easy design reuse; save space in small modules
MAX6715–29, MAX6730–35	1-/2-/3-voltage µP supervisory circuits with independent watchdog output	Multiple fixed and one adjustable thresholds	A single multivoltage IC increases reliability and saves board space by replacing multiple devices
MAX16000–07, MAX16008/09	Low-voltage, 4-/6-/8-voltage µP supervisors in TQFN package	±1.5% accuracy; integrated watchdog timer; manual-reset and margin-disable inputs	Improve reliability; simplify design and lower the overall system cost; reduce board space
MAX16055	Ultra-small, 6-voltage µP supervisor	Low 35µA supply current; fully specified up to +125°C	Increases reliability; saves power; reduces total solution size and cost
Power supplies			
MAX15023/26	Low-cost, small, DC-DC synchronous buck controllers (dual/single)	Versatile operation from 4.5V to 28V; suitable for multiple applications	Save space and cost
MAX15046	40V, high-performance, synchronous buck controller	4.5V to 40V input-voltage range; adjustable outputs from (0.85 x V_{IN}) down to 0.6V; 100kHz to 1MHz switching frequency	Versatile for easy design reuse; saves space in small modules
Real-time clocks (RTCs) with NV RAM			
DS1747	RTC with 512k x 8 NV SRAM	Integrated NV SRAM, RTC, crystal, power-fail control circuit, lithium energy source	Saves space and cost by integrating NV memory and RTC; retains data during power outage
DS17285/87, DS17485/87, DS17885/87	3V/5V RTCs	RTC/calendar; one time-of-day alarm; three maskable interrupts with a common interrupt output; programmable square wave; 2KB to 8KB of battery-backed NV SRAM	Save space and cost by integrating memory and RTC; retain clock data during power outage
Temperature sensors			
DS7505	Low-voltage digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C; 1.7V to 3.7V operation; industry-standard pinout	Industry-standard pinout allows easy accuracy upgrade and supply-voltage reduction from LM75
DS18B20	1-Wire® digital temperature sensor	±0.5°C accuracy; 1-Wire interface; 64-bit lasered ID code	1-Wire interface and 64-bit ID code allow multiple distributed precision sensors on a single bus
MAX6603	Dual-channel platinum RTD interface	Two input channels for PT200 RTDs; analog outputs; ±5kV ESD protection	Saves space and cost

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