Smart Grid

Solutions Guide

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MAXIM
INNOVATION DELIVERED®

A message from the CEO

Dear Engineer,

The "smart grid" is developing in response to changes in how people live, work, travel, and play. It is actually a modern-day revolution that changes everything about how electricity is generated, stored, used, and billed. It encompasses new renewable sources and the connection of new loads like electric vehicles. It's global, and it affects us all.

This solutions guide highlights key areas within smart grids where Maxim brings the most value. Our advanced metrology system-on-chip (SoC) solutions offer the best accuracy available for metering applications. They also ensure the development of standards-compliant products that will meet fast-changing infrastructure demands. Our powerline technology enables communication through transformers, and our high levels of integration reduce costs and time to market.

This is not a product selector guide listing all 6400 of our products. Instead, it's a critical selection of the best of our portfolio tailored for specific smart grid equipment areas. For each solution, we list the benefits of the featured products—whether smaller size, more processing power, lower power consumption, or something else—in an easy-to-read format. And we back up our claims with hard technical facts so you can compare our solutions to your alternatives.

Maxim was founded over 27 years ago to create analog and mixed-signal products that not only add value to our customers' systems but also help them to change the world. As a company we are proud to offer products that enable today's smart grid revolution.

You will also see that Maxim remains focused on being the leading solutions provider for industrial equipment including smart grid products, both with innovative ICs and knowledgeable support.

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

Tunç Doluca

President and Chief Executive Officer

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Meeting future energy challenges today

The smart grid represents a new vision for how we can harness technology to renew energy infrastructure, redefine our responsibilities as energy users, and, ultimately, conserve vital energy resources.

Smart grid architects face many challenges in realizing this vision, not least of which is choosing solutions that offer a cost-effective upgrade path. The sheer scale of this infrastructural challenge necessitates a well-defined strategic roadmap. To avoid stranding assets, the selected solution must be both compatible with the existing infrastructure and scalable to meet future needs.

System designers must keep up with a constantly changing regulatory landscape. This task can be greatly eased by choosing a solutions partner who understands the requirements of different countries, and works closely with industry consortia to develop standards.

Maxim is a proven leader in smart energy

Maxim has long been regarded as a leader in power-saving technology. Over the years, we have pioneered new techniques for battery management, high-efficiency power conversion, and low-power design.

Today we are applying our expertise to smart energy applications, including energy metering and measurement, power-distribution automation, smart grid communications, hybrid automobiles, and LED lighting.

In 2010, we expanded our smart grid offering through the acquisition of Teridian Semiconductor. This acquisition firmly positions Maxim as the technology leader for energy metering and measurement.

With more than two decades of expertise and 50 million ICs shipped, Teridian has defined the leading edge of the system-on-chip (SoC) energy-measurement market. System designers worldwide use these SoCs to accelerate system development and reduce engineering costs for new energy-metering and measurement applications.

Maxim's powerline communications technology (G3-PLC) is enabling new smart grid applications around the world. G3-PLC is currently being deployed in France to implement an advanced metering infrastructure for over 35 million customers. It also serves as a base technology for international standards development efforts such as ITU G.hnem/G.9955 and IEEE® P1901.2.

Maxim's PLC and SoC solutions are complemented by a broad portfolio of analog and mixed-signal solutions, including power-management ICs, real-time clocks, RF communications, and interface products. All of which makes Maxim a true end-to-end solutions provider for metering and other smart grid applications.

A committed innovation partner

Maxim's application experts work closely with system designers to develop technology platforms that meet implementation requirements for backwards compatibility, scalability, and compliance with international standards.

This solutions guide addresses key challenges facing smart grid architects and designers. It details how Maxim's solutions are enabling customer innovations in communications, distribution automation, and energy measurement and metering.

Design with Maxim

Develop smarter, more-precise systems

- Proprietary process technologies yield the tightest tolerances, lowest noise, highest voltage/current capabilities, and greatest integration
- Maxim's broad product portfolio enables end-to-end solutions optimized for performance-driven applications
- State-of-the-art communications technologies build intelligence into grid infrastructure, from the substation to the customer premise

Accelerate your time to market

- Benefit from the implementation expertise that Maxim has gained while working with industry consortia, utilities, and equipment manufacturers
- A comprehensive library of application notes, reference designs, and software tools speeds your design projects
- Flexible solutions are easily adapted to meet different international standards

Reduce equipment/infrastructure costs

- Advanced integration minimizes your bill of materials and infrastructure costs
- Application expertise helps you make the right system performance-cost trade-offs
- Integrated protections and industrial-grade temperature ranges ensure that your design survives real-world conditions

Smart meters

Overview

Utility companies worldwide have begun deploying smart meters to service residential and commercial/industrial markets. Smart meters deliver a range of benefits including lower operational and capital expenses, support for new services, and improved operational control.

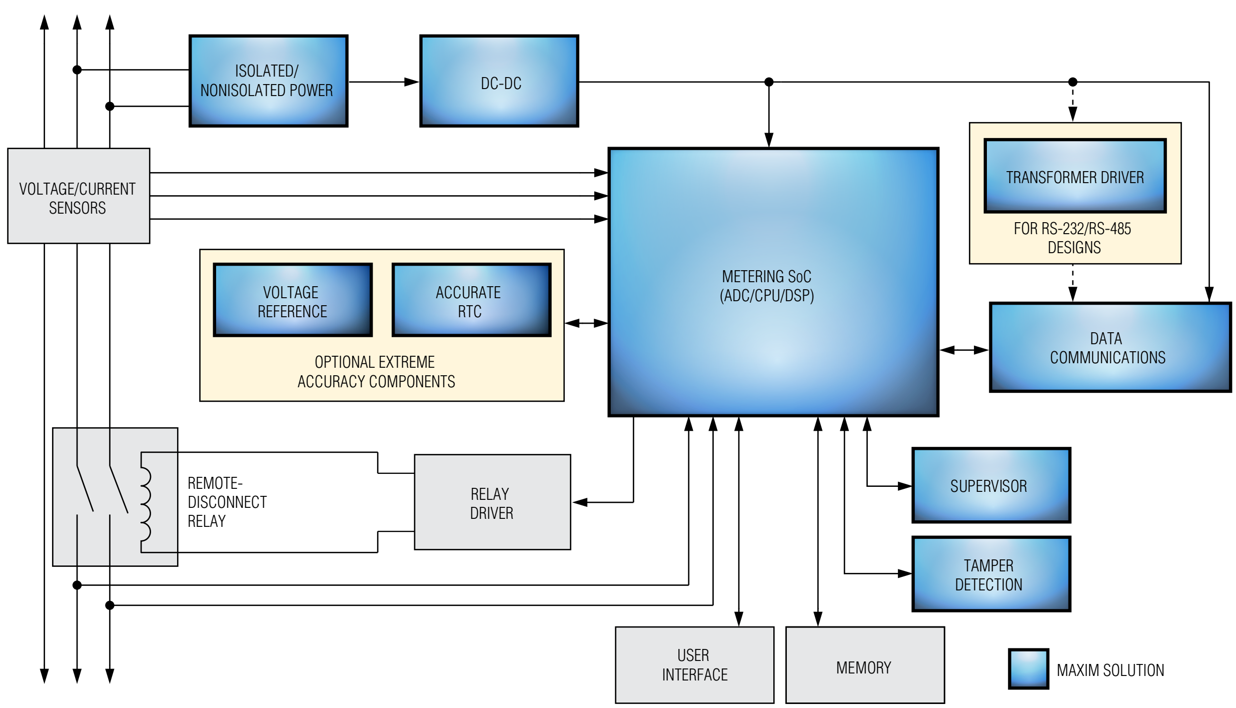
Smart meter requirements

Deployment of smart meters is far from a "one-size-fits-all" undertaking. Manufacturers must account for the varying regulatory requirements of each region, as well as the different functionalities and services required for different markets.

In North America, for example, automated meter reading (AMR) regulations dictate the frequency of meter reading and data transmission. They also specify the amount of data that must be retained locally at any given point in time. Because communications are not always reliable, some of these regulations require utilities to store two or more transmissions to meet billing requirements. This requirement increases the amount of local on-chip memory needed for smart meter ICs. As a result, the regulatory pressures of specific jurisdictions have a direct impact on the design of smart meters down to the chip level.

Another major driver of smart meter functionality is improving local antitampering capabilities. This is especially important in developing markets where electricity theft accounts for a large percentage of overall power usage. The ability of solid-state electricity meters to detect and prevent tampering can significantly improve control and cost recovery for utility companies. Here again, high-level antitampering objectives are both driving the adoption of solid-state metering and dictating required feature sets at the chip level.

Finally, the promise of improving service to customers represents an important goal of smart metering, especially over the long term. By enabling customers to better manage their own energy usage through incentive-based programs—such as direct load control, interruptible rate agreements, and demand bidding/buyback—smart metering can help utilities manage overall energy consumption patterns and cope with peak-demand challenges. With the right capabilities built into chip-level solutions, smart meter deployments can effectively lay the groundwork for expanded customer-service functions, such as wireless integration with thermostats to automatically adjust usage during peak-demand periods.



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

For meter manufacturers servicing global utility markets, the above combination of driving forces presents significant opportunities and challenges. Most utility companies are at least considering the implications of future smart metering applications when making today's deployment decisions. Therefore, meter manufacturers need to be flexible, offering both low-cost metering solutions and high-end smart meter alternatives.

One way that meter designers are addressing this dilemma is by using integrated system-on-chip (SoC) solutions that can be adapted across the entire spectrum of functionality requirements. SoCs deliver lower costs by eliminating the need for discrete components. They also provide rich feature sets for smart metering and simpler upgrade paths with minimum hardware and operational costs.

Evolution of solid-state metering architectures

The earliest solid-state meter architectures combined multiple ICs to implement the required functionality. Typically, a microcontroller performed the system management and display tasks, and multiple ADCs combined with a fixed-function signal processor to handle the metrology functions.

The next generation of meters used proprietary metrology ASICs from large meter manufacturers to combine A/D conversion and DSP functions. However, this architecture still fell short of providing the level of integration and configuration flexibility needed to support dynamically evolving market demands. The ASIC approach also required a high level of in-house R&D investment and entailed relatively long cycles for the creation of each new revision of functionality.

Integrated SoC solutions address these limitations by optimizing for cost, performance, and flexibility. They also shorten time to market and reduce component count.

Multiconverter vs. single-converter designs

Two shortcomings of the traditional multiconverter architecture are reduced accuracy from channel-to-channel crosstalk and high bill-of-materials (BOM) costs. These designs tend to carry crosstalk between channels, necessitating additional hardware and firmware precautions. Additionally, they require a costlier differential mode to achieve a wide analog input range of 2000:1.

A key innovation in the development of integrated metering SoCs has been the Single Converter Technology® approach from Teridian. This architecture streamlines the metrology functions by combining a single sigma-delta ADC with several multiplexed inputs and a programmable real-time computation engine (CE). This technology provides flexibility for customizing the DSP to utility requirements with minimal upgrades to the hardware infrastructure.

Multiplexed systems offer lower cost compared to architectures that dedicate separate ADCs to each channel. Multiplexed designs achieve reduced channel-to-channel crosstalk by using switching circuitry to scan through a number of input channels, sampling each one in rotation for processing by the single ADC.

The multiplexed approach is particularly well suited for applications, such as power management, with separate signals that are similar in nature. A key requirement is the preservation of phase information between the channels. This capability enables the CE in a multiplexed system to perform "simultaneous" measurements across different channels. SoCs that use a single-converter multiplexing approach provide gain uniformity, offset uniformity, reduced channel-to-channel crosstalk, and design flexibility. Altogether, this yields a lower-cost, high-accuracy solution with wider bandwidth (2000:1) for measurement.

An added benefit of these SoCs is their field-programmable firmware. Because the firmware for the real-time CE is easily upgradeable, designers can configure the hardware for measurements utilizing various current sensors such as current transformers, Rogowski coils, and current shunts. This also facilitates support for the tampering technologies required by utilities.

Smart meter requirements

Automated meter reading

AMR systems are typically implemented using one of two approaches, depending on the regulatory environment for the particular country and jurisdiction. One approach uses relatively high-functionality metrology capabilities at the metering endpoint, while the other approach focuses on lower cost and simpler functionality.

As previously mentioned, some regulatory jurisdictions have strict requirements to avoid the loss of data and ensure metering accuracy for billing purposes. With reads taken at relatively short intervals (every 15 minutes), the accumulated data is then communicated at longer intervals (every 8 hours). However, the regulations compensate for potential communications failures by requiring that at least two data builds always be retained at the metering point. This means that the metrology chip must be capable of storing up to 16 hours of data.

In regulatory environments that place less stringent demands on the AMR process, utilities minimize the cost of metrology functionality at the meter (unless they determine that a positive payback can be achieved by using higher end functionality for antitampering purposes).

There is long-term potential for cost savings by combining the AMR functions directly into the metrology SoC. Yet, this is unlikely to be practical in the near term, due primarily to fragmentation of AMR communications methodologies. Communication links may be based on modems (either fixed line or cellular wireless) or powerline communications (PLC), with the BOM cost ranging from $3 for PLC up to more than $20 for cellular modems.

Field programmability

Deploying higher end metrology chips that allow for field programmability (via firmware) enables utilities to bring down both operational and capital investment costs over the long term. This extends the useful life of the infrastructure and helps to justify smart metering investments within rate-based calculations.

Field programmability gives utilities much greater flexibility to adjust policies in response to changing energy usage patterns. For example, the specific times of day set for peak-rate pricing policies may need to be adjusted as significant numbers of users shift their energy consumption, or in response to seasonal fluctuations. Remote upgrades via firmware allow utilities to quickly tailor their rate incentives for customers to help smooth out peak demand while tracking dynamic changes in peak-usage patterns.

Energy-management services

Smart metering gives utilities real-time visibility into usage patterns. Moreoever, it enables them to promote demand-side management, empowering customers to better manage their own usage. For instance, the Californian utility PG&E plans to offer customers enhanced options such as monitoring their hour-by-hour usage on the Internet and adjusting their usage to take advantage of incentive rates. In addition, there are plans for enabling wireless integration of smart meters with customers' thermostats. This will allow minor pre-agreed adjustments to automatically be made to temperature settings during peak periods in exchange for an overall rate reduction.

Smart metering also opens up the possibilities for implementing submetering strategies within larger buildings. By using a single smart meter with multidrop communication links to individual customers, a utility can eliminate the need for individual meters while still providing a high degree of visibility into each customer's energy usage.

Security mechanisms

Antitampering is another key driver for smart metering, especially in developing countries where electricity theft is a major cost concern for utilities. For example, it has been estimated that as much as 40 percent of the power usage in Brazil is stolen.

Typical tampering techniques vary from intrusive means such as breaking the meter housing and jamming the mechanism to more subtle methods like applying magnets to the outside of the meter to saturate magnetic components. Some attempt to alter the characteristics of the load by adding capacitance, half-wave rectified loads, or instantaneous high currents. Others may bypass the meter, wholly or in part, which can cause an increase in the AC current flowing through the meter's neutral terminals.

Deployment of more sophisticated solid-state metrology enables advanced antitampering measurements such as the reflected load (VAR-hours), neutral current, DC currents invoked by rectified loads, and detection of ambient magnetic fields. Substation meters may also be used to detect discrepancies between the total billed and the total generated power and report them via an AMR network. In order to prosecute and recover the costs of stolen energy, detailed information such as the exact times and amounts of energy theft are critical pieces of evidence that can be captured through smart metering technology.

Chip-level feature requirements for smart meters

System on chip

It is clear from the evolving market requirements, jurisdictional regulatory differences, and varying implementation approaches that a single, universal solution is not possible. However, by using highly integrated, flexibly configurable SoC metering solutions manufacturers can bring down their R&D costs and improve their ability to serve the entire range of market requirements. This approach also helps future-proof meter architectures to meet emerging requirements.

Key ingredients of smart meter SoCs include:

- Flexible, multiple-port communications options to support AMR links, integration with local devices such as thermostats, and multidrop submetering topologies
- Streamlined multiread processing capabilities such as the Single Converter Technology approach to reduce unit cost by multiplexing inputs through a delta-sigma ADC in conjunction with a programmable compute engine
- Support for a variety of sensor inputs with minimum hardware; ability to adjust for temperature and other environmental variations for improved efficiency and accuracy

- Field-upgradeable firmware to extend the useful life of the metering solution and allow policies to be dynamically adjusted to optimize energy usage
- Polyphase monitoring and analysis capabilities to help manage energy consumption, enable load analysis, and optimize motor functions
- LCD interface capable of supporting multiple voltages and screen resolutions
- Various levels of internal flash memory sizes, along with external memory-management capabilities to support a wide portfolio of data storage options
- Several tamper-detection mechanisms to prevent energy theft; support for current transformers, Rogowski coils, and current shunts along with their combinational current-sensing mechanisms; open current-sensor detection
- Ability to work with single-wire power measurement for special tamper-detection conditions for single- and polyphase power measurements
- Built-in real-time clock (RTC) functionality

Real-time clock

Many metering AFEs integrate a reasonably accurate RTC, which may drift as much as 60 minutes/year. This inaccuracy should not be a problem if the meter is connected to a smart network that periodically resynchronizes the RTC. If the meter is not connected to such a network, end customers will experience significant billing discrepancies over time—unless, that is, a highly accurate RTC is used.

Maxim has long offered the industry's most accurate timekeeping solutions for metering applications. RTCs such as the DS3231 monitor an onboard temperature sensor and adjust the load capacitance of an embedded crystal in order to compensate for the natural temperature variation of the tuning fork crystal. Because the crystal and die are calibrated across the full operating temperature range as a unit, the resulting frequency accuracy is better than any competing technology. These products exceed the rigorous standards for timekeeping accuracy in metering applications and are armed with a multitude of advanced features. Most importantly, they eliminate the need for user calibration, providing a highly accurate solution straight out of the box.

Maxim's new MEMS-based RTC, the DS3231M, extends the benefits of the DS3231. The device's all-silicon resonator enables the low-frequency and low-current characteristics of the crystal-based DS3231 to be migrated to a smaller package. Additionally, the DS3231M offers extreme resilience against high-temperature assembly processes, can withstand shock and vibration in excess of 20Gs, and includes offsets for aging.

At the heart of the DS3231M is a temperature-compensated silicon oscillator. Based on measurements from the DS3231M's onboard temperature sensor, a temperature-compensation algorithm automatically adjusts the resonant frequency to account for temperature effects. This approach ensures extremely tight accuracy over temperature. Unlike crystal-based products, the DS3231M exhibits less than ±0.5ppm of frequency shift after high-temperature reflows, and it maintains flat frequency-stability characteristics (< ±5ppm) over the entire -40°C to +85°C temperature range.

Summary

By leveraging the flexible SoC feature set described above, manufacturers can effectively address the range of metering options—from low-cost fixed-function devices to premium devices that offer ample memory, reprogrammability, and high accuracy. As the market for smart meters continues to evolve, this flexibility will enable meter manufacturers and utility companies to adapt to the needs of customers and the dictates of regulatory authorities, while simultaneously optimizing operational efficiency and profitability.

Energy-meter SoCs reduce cost while improving design flexibility and accuracy

71M6541D*/41F*, 71M6542F* (single phase) 71M6543F*/43H* (polyphase)

The Teridian 71M6541D/41F/42F (single phase) and 71M6543F/43H (polyphase) are highly integrated, flexible metering SoCs that support a wide range of residential, commercial, and industrial meter applications with up to Class 0.2 accuracy. The devices incorporate a 5MHz 8051-compatible MPU core and a 32-bit computation engine (CE); a low-power RTC with digital temperature compensation; up to 64KB flash memory and 5KB RAM; and an LCD driver. The proprietary Single Converter Technology architecture includes a 22-bit delta-sigma ADC, which provides unmatched linearity performance over a wide dynamic range and consumes less power than a multi-ADC implementation. Automatic switching between main power and three battery-backup modes ensures operational reliability. These SoCs operate over the -40°C to +85°C industrial temperature range. The 71M6541D/41F are packaged in a 64-pin lead-free LQFP, and the 71M6542F/43F/43H are packaged in a 100-pin lead-free LQFP.

The 71M6541D/41F/42F and 71M6543F/43H metering SoCs also feature a proprietary isolation technology. By using low-cost resistive shunts and optional interfaces to one of the Teridian isolated sensors (71M6601*, 71M6103*), these metering solutions eliminate the need for expensive, bulky current transformers. This, in turn, reduces BOM costs and casing size requirements. The metering design will also benefit from immunity to magnetic tampering and enhanced reliability.

A complete array of software development tools, demonstration code, and reference designs is available. These tools enable rapid development and certification of meters that meet all ANSI and IEC electricity metering standards worldwide.

(Block diagrams on following pages)

Benefits

- **Measurement accuracy meets even the most aggressive global standards**
  - Exceeds the IEC 62053/ANSI C12.20 standards
  - 0.1% accuracy over 2000:1 current range
  - Meets Class 0.2 accuracy (71M6543H)
- **High integration and programmability meet changing customer requirements**
  - 8-bit MPU (80515); up to 5 MIPS
  - Dedicated 32-bit CE
  - 64KB flash and 5KB RAM (71M6541F/42F/43F/43H))
  - 32KB flash and 5KB RAM (71M6541D)
  - Support up to 51 digital I/O pins (71M6542F/43F/43H)
  - LCD driver supports up to 336 pixels (71M6542F/43F/43H)
  - Two UARTs for IR and AMR
  - IR LED driver with modulation
- **Accelerate meter development**
  - Complete array of in-circuit-emulation (ICE) and development tools
  - Flash programming and firmware development tools
  - Programming libraries and reference designs
  - Third-party programming tools and support services
- **Improved reliability and cost savings**
  - Using shunts instead of current transformers (CT) lowers BOM costs
  - Eliminate the cost of copper wire needed for CTs
  - Using shunts allows smaller meter enclosure
  - Using shunts enables gain magnetic field immunity

*Future product—contact the factory for availability.

Energy-meter SoCs reduce cost while improving design flexibility and accuracy

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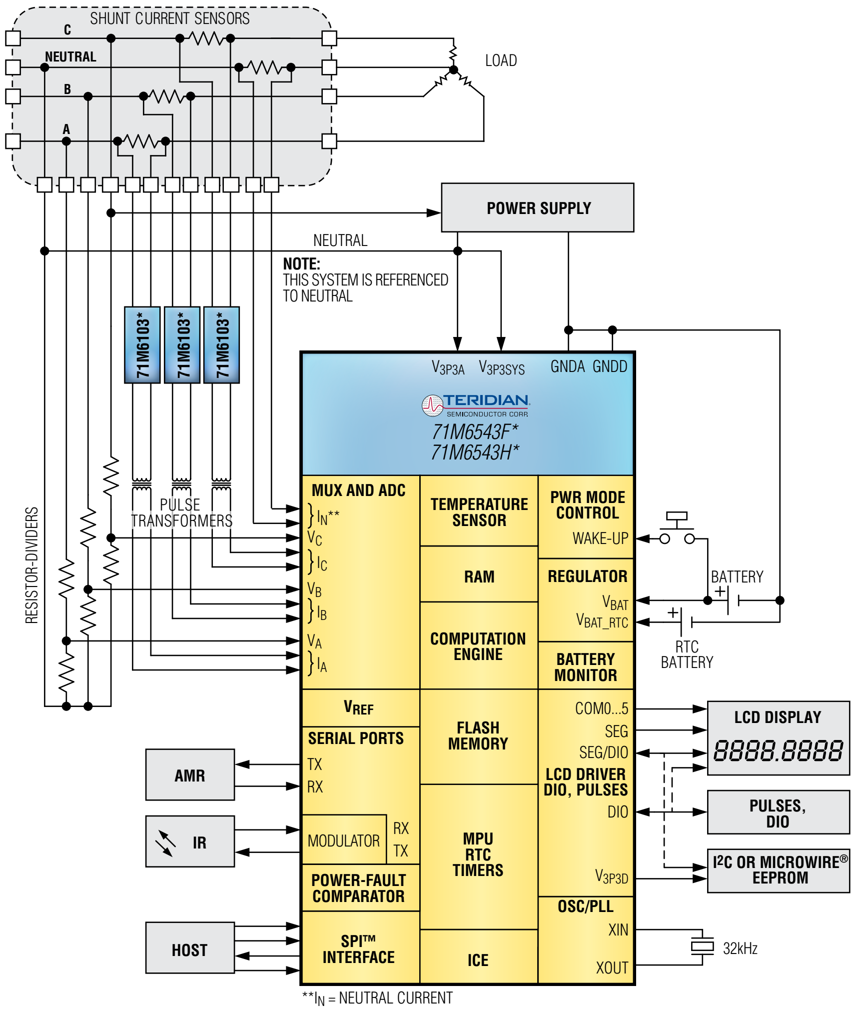

The 71M6543F/71M6543H polyphase metering SoCs are ideal for commercial and industrial applications.

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*Future product—contact the factory for availability.

Energy-meter SoCs reduce cost while improving design flexibility and accuracy

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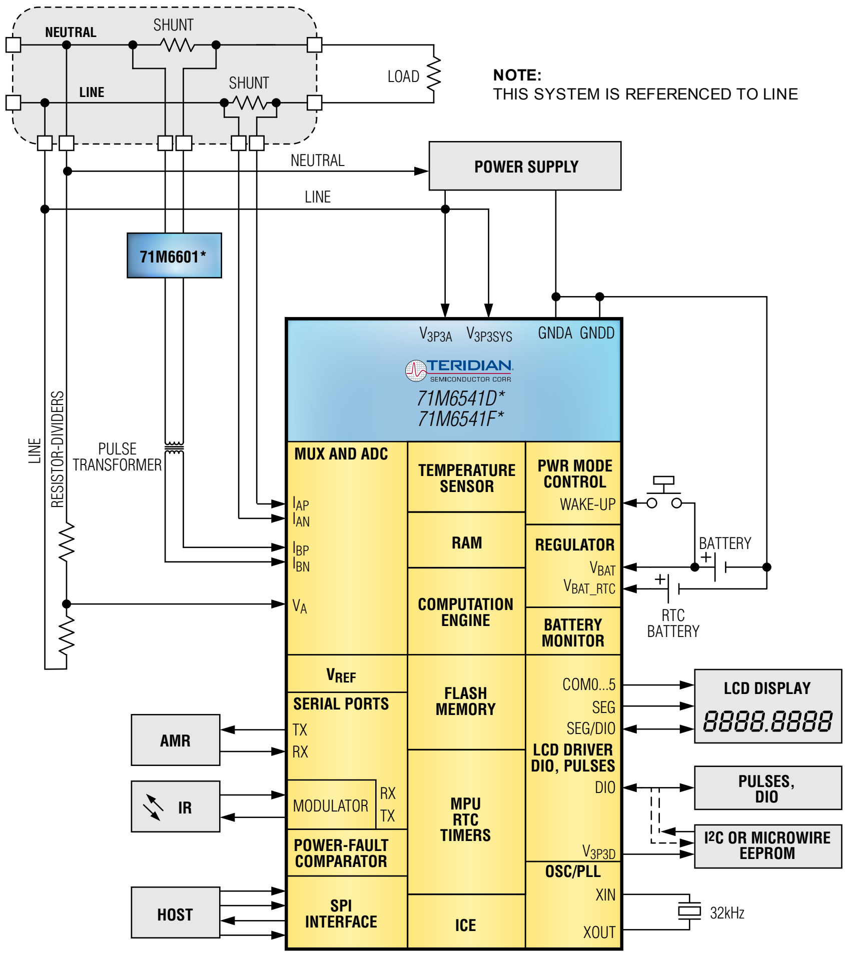


The 71M6541D/71M6541F single-phase metering SoCs are ideal for residential and POL applications.

*Future product—contact the factory for availability.

Highly accurate MEMS RTC is less sensitive to shock and vibration than traditional clocks

DS3231M

The DS3231M is a highly precise real-time clock (RTC) based on MEMS resonator technology. It meets the core requirements for accuracy, stability, power, and compliance testing for smart meters.

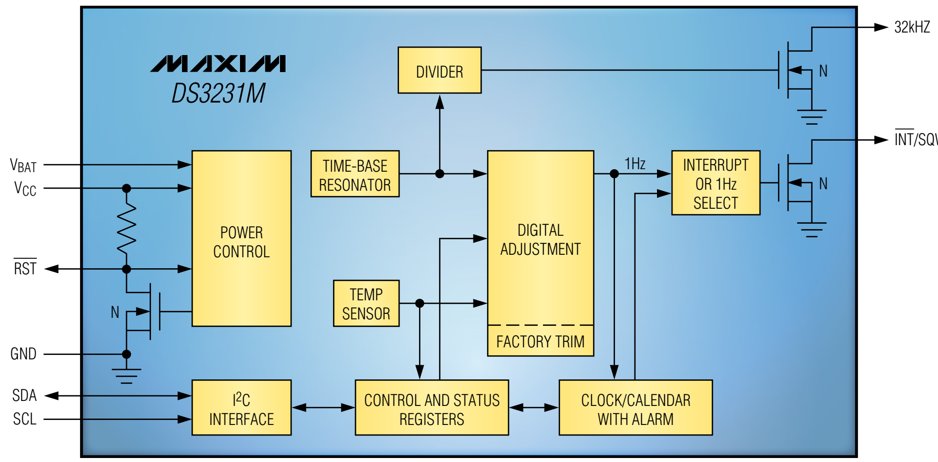
This innovative RTC provides temperature-compensated timing accuracy of ±0.5s/day (< ±5.0ppm) from -40°C to +85°C. The MEMS technology makes the DS3231M less sensitive to shock and vibration than traditional crystal-based clocks. It is also less sensitive to accuracy drift, which is quite common with aging quartz crystals.

The DS3231M is a low-power device (< 3.0µA) that prolongs battery life. Switching automatically between the main and battery power, it meets the industry requirement for dual-supply operation as a safeguard in the absence of main power.

The DS3231M's accuracy and stability make it particularly suitable for multitariff metering. With no crystal to consume space and add cost, it is a low-cost solution for time-based billing and rate charges directly at the meter. It is a viable option for metering networks that do not distribute time-of-day information between meters, but must maintain an accurate time base at the meter.

Benefits

- **Meets the four core timing requirements for smart metering**
  - Accuracy (< ±5.0ppm)
  - Stability (< ±5.0ppm)
  - Power (< 3.0µA)
  - Compliance testing (1Hz output)
- **Highly rugged, dependable solution**
  - ±5ppm lifetime accuracy
  - Optimized for high shock and vibration: > 20,000g
  - Requires no special handling during ultrasonic cleaning vs. quartz crystals
- **Safeguards against power loss**
  - < 3.0µA power consumption extends battery life
  - Dual supply operation
  - Automatic switching between main power and battery power
- **Reduces cost and saves space**
  - Miniature MEMS resonator eliminates the cost of a quartz crystal
  - No user calibration required, thus reducing cost
  - 16- and 8-pin (150 mil) SO packages
  - Pin compatible with crystal-based DS3231S RTCs



Block diagram of the DS3231M RTC.

Recommended solutions

Part	Description	Features	Benefits
Metering SoCs			
71M6531/71M6532	Residential metering SoCs with an MPU core, RTC, in-system programmable flash, and LCD driver	Multiple UARTs, I²C/MICROWIRE interface, and up to 30 DIO pins; support 2-, 3-, and 4-wire single-phase and dual-phase residential metering; tamper-detection mechanisms	High integration and field programmability enable designers to adapt to changing customer requirements, speed time to market, and lower BOM cost
71M6533/71M6534	Polyphase metering SoCs with 10MHz, 8051-compatible MPU core; low-power RTC; 128KB flash; and LCD driver	Advanced power management with less than 1µA sleep current; selectable single-ended or differential current sensing; large-format LCD driver	Higher sampling rate and larger code space offer customers ability to extend metrology functionality and implement advanced functions such as simultaneous broadband/narrowband
71M6541D*/41F*/42F*	Highly integrated single-phase metering SoCs	Exceed IEC 62053 and ANSI C12.20 standards; embedded isolated-sensing technology	Measurement accuracy meets even the most aggressive global standards; offer flexibility in selecting interface
71M6543F*/43H*	Highly integrated polyphase metering SoCs	Exceed IEC 62053 and ANSI C12.20 standards; embedded isolated-sensing technology	Significantly reduce BOM and enclosure size by eliminating the need for current transformers in polyphase designs
Real-time clocks (RTCs)			
DS3231M	Extremely accurate, MEMS-based, I²C RTC	All-silicon MEMS resonator; requires no user calibration; ±5ppm (±0.432s/day) timekeeping accuracy over -40°C to +85°C	Reduces design time; minimizes piece-part count in manufacturing lines; provides enhanced aging characteristics and lower sensitivity to shock and vibration; improves long-term accuracy
DS3231	Extremely accurate, I²C RTC with TCXO and crystal	Better than ±2min/yr accuracy (< ±4ppm) over -40°C to +85°C; requires no user calibration	Single-chip timing solution improves accuracy and lowers design complexity over discrete solutions, which typically require a crystal, RTC, temperature sensor, and microprocessor, as well as user calibration
DS3232	Extremely accurate, I²C RTC with integrated crystal and SRAM	±3.5ppm accuracy over -40°C to +85°C; 236 bytes of battery-backed SRAM	Integrated memory allows storage of battery-backed data, including billing information or configuration data
DS3234	Extremely accurate, SPI RTC with integrated crystal and SRAM	±3.5ppm accuracy over -40°C to +85°C; 236 bytes of battery-backed SRAM	Integrated memory allows storage of battery-backed data, including billing information or configuration data
Isolated power			
MAX5021/22	High-performance current-mode PWM controllers for forward/flyback configuration	Universal power supply (85V to 265V); small SOT23 package; integrated startup circuit	Save board area; ideal for noise-sensitive applications
MAX17499/500	Current-mode PWM controllers with programmable switching frequency	Integrated error amplifier regulates the tertiary winding output voltage; input undervoltage lockout (UVLO)	Eliminate the need for an optocoupler and ensure proper operation during brownout
MAX5974/75	Active-clamped, spread-spectrum, current-mode PWM controllers	Active-clamp topology; regulation without optocoupler; switching frequency is adjustable from 100kHz to 600kHz	Achieve > 90% efficiency, thus reducing power consumption in synchronous forward/flyback power supplies; save space and cost by eliminating the need for an optocoupler; optimize circuit magnetics and filter elements to meet EMI requirements

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*Future product—contact the factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
DC-DC converters			
MAX1725/26	12V, ultra-low-IQ, low-dropout linear regulators	20mA output; 2µA quiescent current across operating range and in dropout; reverse-battery protection	Low-power operation conserves battery life
MAX15062*	36V, 300mA DC-DC regulator with integrated FETs in 2mm x 2mm TDFN	Low quiescent current; internal compensation; synchronous operation; pulse-skip mode for light loads	High integration with small footprint saves up to 50% total board area compared to competing solutions
Transformer drivers			
MAX256	3W, primary-side transformer H-bridge driver for isolated supplies	Provides up to 3W to the transformer in isolated power supplies	Saves board area; reduces design complexity; makes it easy to implement isolated power
MAX253	1W, primary-side transformer H-bridge driver for isolated supplies	Specifically designed to provide isolated power for an isolated RS-485 or RS-232 data interface	Saves board area; reduces design complexity; makes it easy to implement isolated power
Hall-effect sensors			
MAX9639*/40*	Low-power, single Hall-effect sensors	Adjustable magnetic thresholds (MAX9639) simplify system design; ultra-low 2.6µA supply current	Provide simple open/close detection while saving power
Supervisors			
MAX6854–69	Supervisory circuits with manual reset and watchdog timer	Ultra-low 170nA (typ) supply current	Low-power operation decreases drain on battery
MAX16056–59	Supervisory circuits with capacitor-adjustable reset and watchdog timeouts	Ultra-low 125nA (typ) supply current	Low-power operation decreases drain on battery
Voltage references			
MAX6161–68	Precision, micropower, low-dropout, high-output-current voltage references in an 8-pin SO package	±2mV (max) initial accuracy; 5ppm/°C (max) temperature coefficient	Improve system precision; reduce component count and board space

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

*Future product—contact the factory for availability.

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

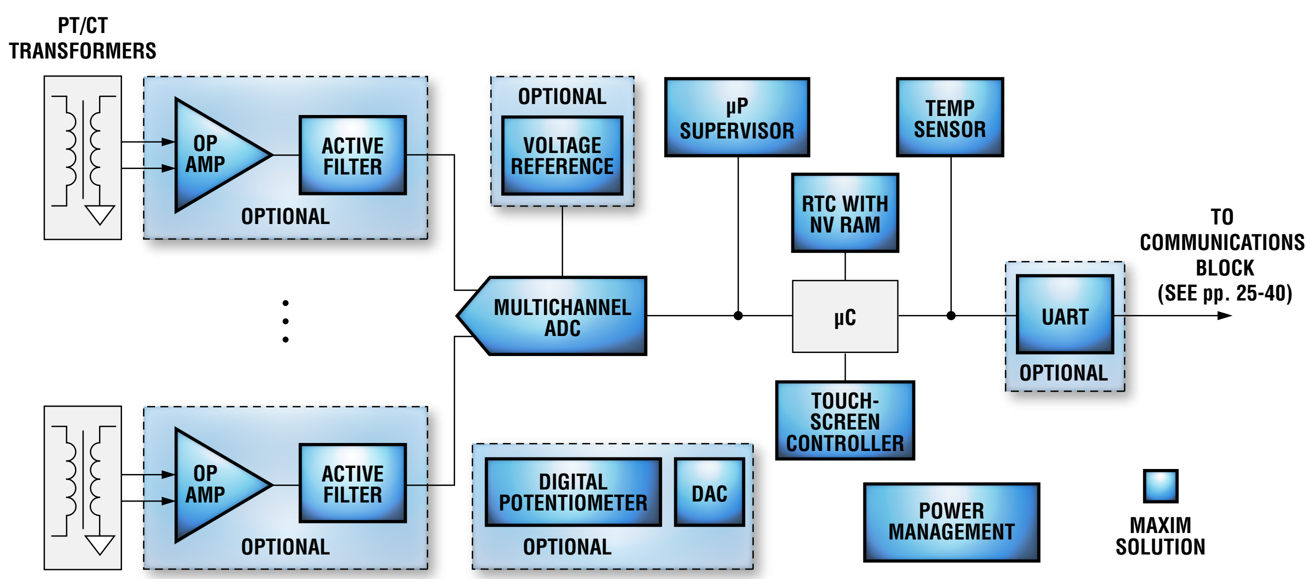
The rollout of advanced power-grid monitoring systems is complicated by the varying international standards that specify the accuracy required for energy measurement. Real-time power-delivery monitoring, fault detection, fault protection, and dynamic load balancing require stringent accuracy. As an example, 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/√Hz noise and very low offsets. These amplifiers minimize measurement errors in the system to ensure the highest possible accuracy.

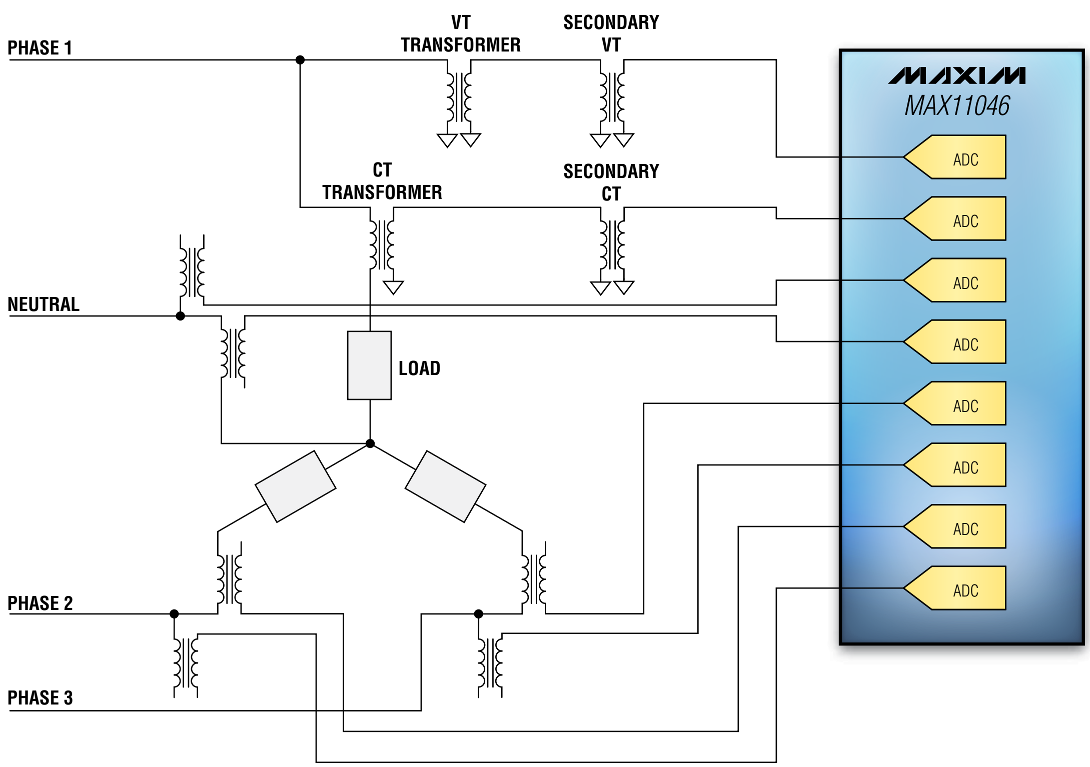
Communications

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.

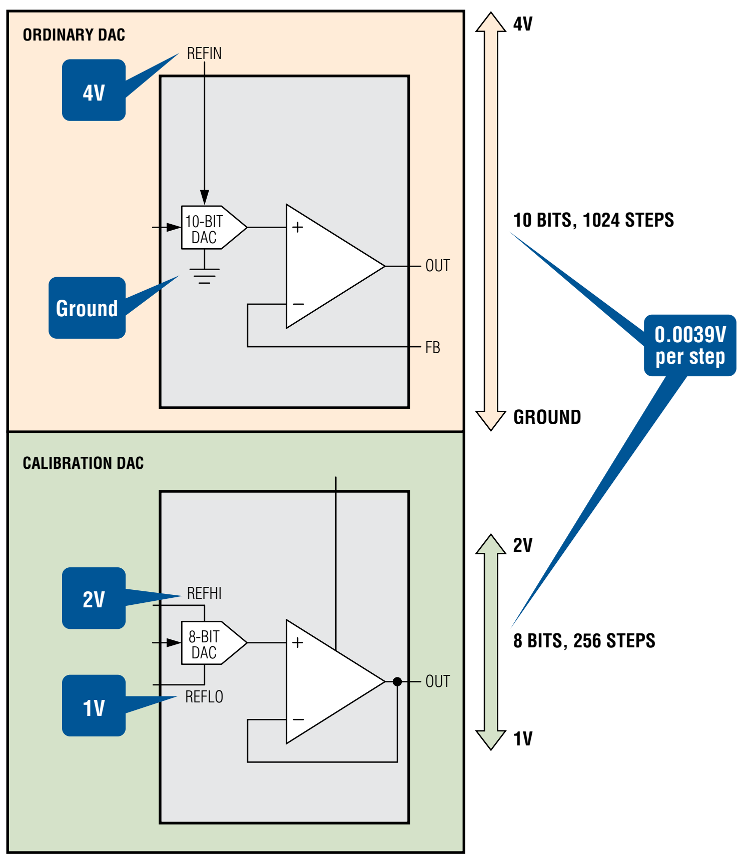
Additionally, electronic calibration allows for periodic self-test and calibration to compensate for environmental factors (e.g., temperature, humidity, and drift) in the field.

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

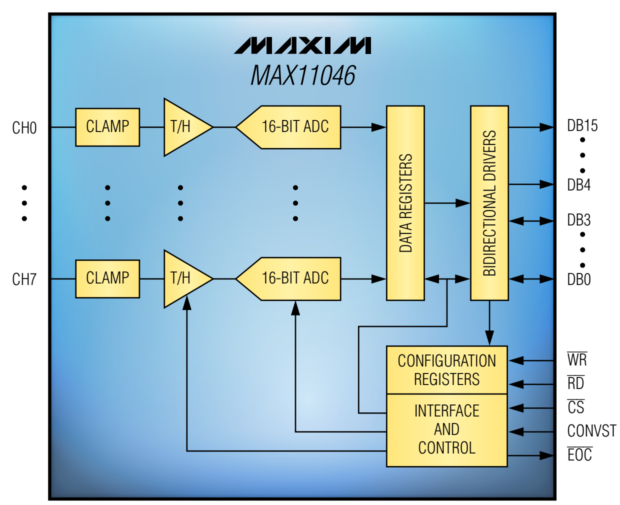
MAX11046

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.

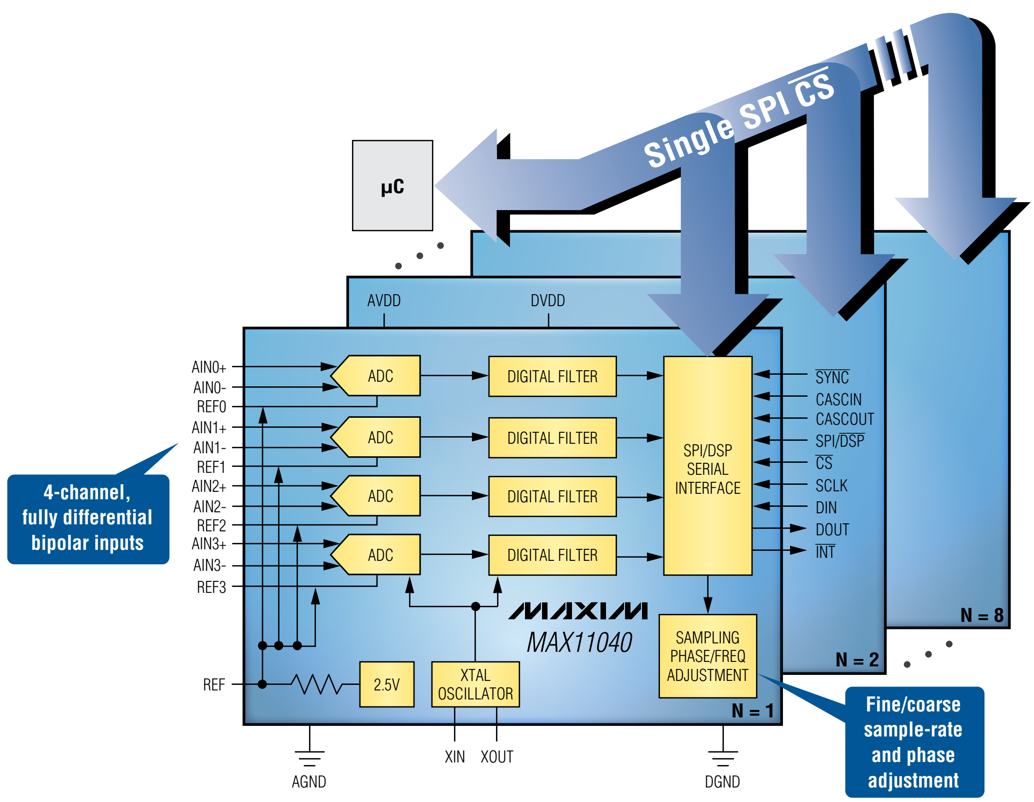
ADC simplifies firmware by capturing accurate phase and magnitude information on up to 32 channels

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

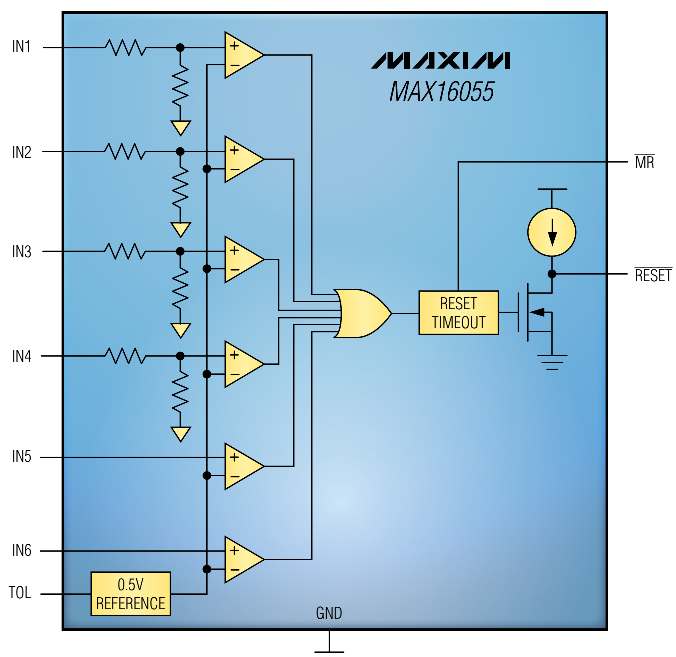
To improve system reliability, you should monitor all the voltage rails for undervoltage conditions. Instead of using separate discrete voltage supervisors that consume valuable board space, you can use a MAX16055 ultra-small microprocessor supervisor. This device integrates six channels of undervoltage 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

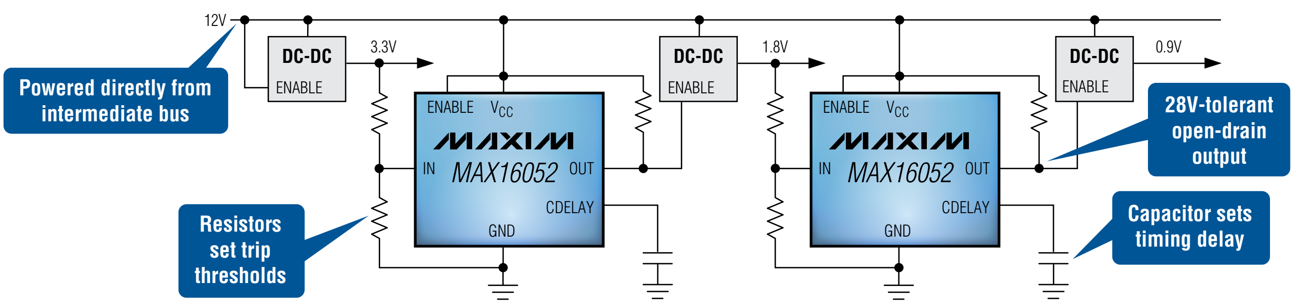
MAX16052/MAX16053

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

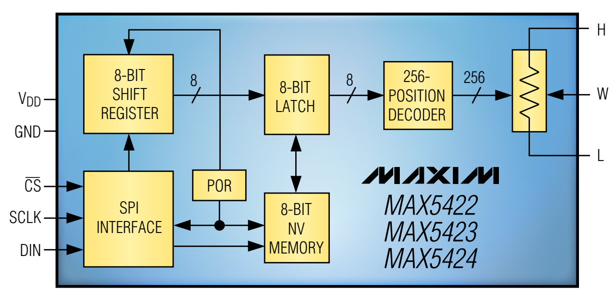
MAX5422/MAX5423/MAX5424

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.

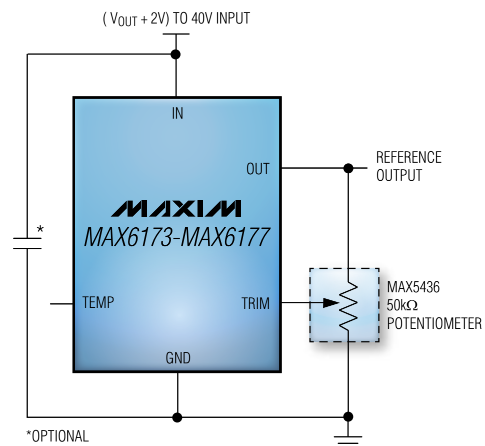
Calibration voltage references with temperature sensor increase system precision

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

(Continued on next page)

*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

(Continued on next page)

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

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

Communications

Overview

An electricity grid without adequate communications is simply a power "broadcaster." It is through the addition of two-way communications that the power grid is made "smart."

Communications enables utilities to achieve three key objectives: intelligent monitoring, security, and load balancing. Using two-way communications, data can be collected from sensors and meters located throughout the grid and transmitted directly to the grid operator's control room. This added communications capability provides enough bandwidth for the control room operator to actively manage the grid.

The communications must be reliable, secure, and low cost. The sheer scale of the electrical grid network makes cost a critical consideration when implementing a communications technology. Selecting a solution that minimizes the number of modems and concentrators needed to cover the entire system can dramatically reduce infrastructure costs. At the same time, the selected technology must have enough bandwidth to handle all data traffic being sent in both directions over the grid network.

Communications networks and protocols

Communications in the smart grid can be broken into three segments.

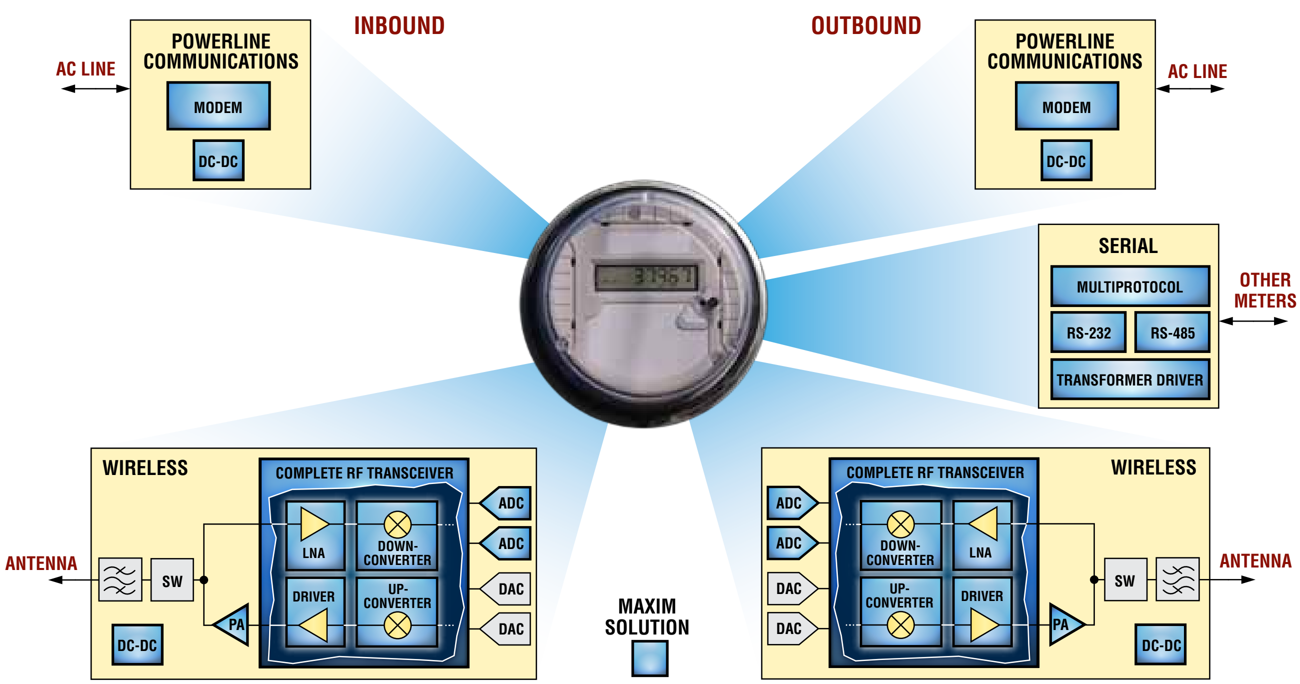
Wide area network (WAN) covers long-haul distances from the command center to local neighborhoods downstream.

Neighborhood area network (NAN) manages all information between the WAN and the home area network using medium-voltage lines.

Home area network (HAN) extends communication to endpoints within the end-user home or business.

Each segment is interconnected through a node or gateway: a concentrator between the WAN and NAN and an e-meter between the NAN and HAN. Each of these nodes communicates through the network with adjacent nodes. The concentrator aggregates the data from the meters and sends that information to the grid operator. The e-meter collects the power-usage data of the home or business by communicating with the home network gateway or functioning as the gateway itself.

Each segment can utilize different communications technologies and protocols depending on the transmission environments and amount of data being transmitted. In addition to the architecture choice between wireless and powerline communications (PLC), there are a variety of wireless and PLC protocols to choose among (**Table 1**).



Maxim offers solutions for powerline, wireless, and serial communications. For a list of Maxim's recommended solutions, please go to: www.maxim-ic.com/communications.

Table 1: Smart grid communications protocols

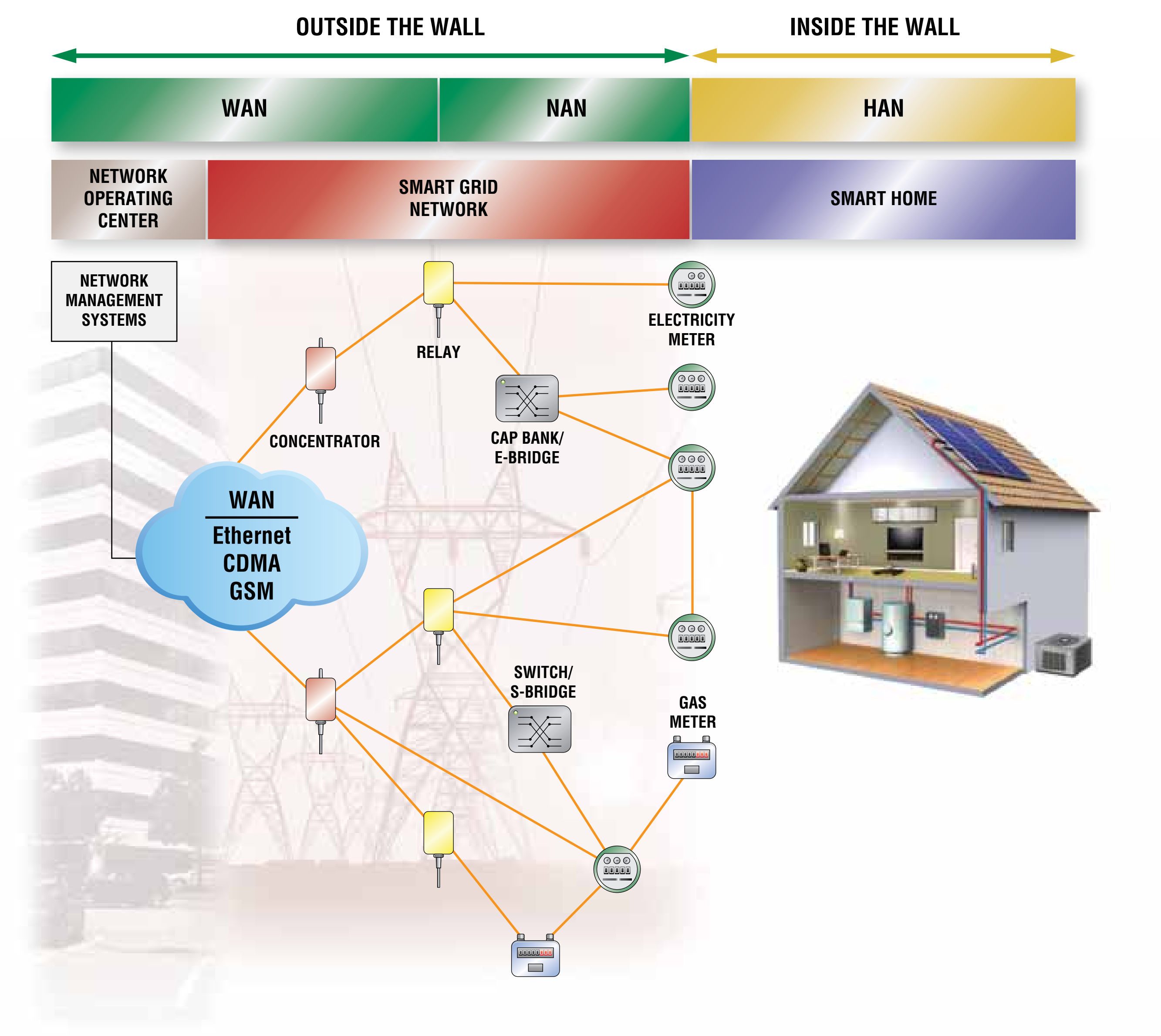
Network	Protocol	Advantages	Disadvantages	Recommendation
WAN	Wireless (2G/3G/LTE cellular, GPRS)	Extensive cellular infrastructure is readily available; large amount of aggregated data can be communicated over a long haul	Utility must rent the infrastructure from a cellular carrier for a monthly access fee; utility does not own infrastructure	Wireless usually works best
NAN	Wireless ISM	Long range; leaps transformers	Currently proprietary; dead spots complicate installation and maintenance	Useful in some topologies, such as in the U.S.
	IEEE® 802.15.4g	Long range; leaps transformers	Not yet an accepted standard	Useful in some topologies
	ZigBee®	Low cost; low power consumption allows battery operation; well-known standard	Low data rate; very short range; does not penetrate structures well	Unlikely to be used in NANs
	First-generation PLC (FSK, Yitran, Echelon®)	Low cost	Unreliable; low bandwidth	Bandwidth and reliability inadequate for the smart grid
	Early-generation narrowband OFDM	Better range, bandwidth, and reliability than FSK	Does not cross transformers; does not coexist with first-generation PLC	Not recommended for new designs due to cost and compatibility concerns
	Broadband PLC	High data rate	Does not cross transformers	Increases infrastructure cost, making it too costly for most large-scale deployments
	G3-PLC	Highly reliable long-range transmission; crosses transformers, reducing infrastructure costs; data rate supports frequent two-way communications; coexists with FSK; open standard; supports IPv6	Not yet an accepted standard	Excellent for NAN worldwide
HAN	ZigBee	Well-known standard that offers low cost and low power	Very short range; does not penetrate structures well	Well suited for communication between water and gas meters
	Wi-Fi®	Popular technology with high data rates	Medium range; does not penetrate cement buildings or basements	Good for consumer applications, but no provisions for meeting utility objectives
	First-generation PLC (FSK, Yitran, Echelon)	Low cost	Not reliable in home environments	Unlikely to be used in homes due to high levels of interference
	Early-generation narrowband OFDM	Better range, bandwidth, and reliability than FSK	Does not cross transformers; does not coexist with first-generation PLC	Not recommended for new designs due to cost and compatibility concerns
	Broadband PLC	High bandwidth	Short range is not sufficient for NAN	Good for consumer applications, but no provisions for meeting utility objectives
	G3-PLC	Highly reliable; sufficient data rate; IPv6 enables networking with many devices	Not yet an accepted standard	Excellent for HAN worldwide

The WAN is the communications path between the grid operator and the concentrator. The WAN can be implemented over fiber or wireless media using Ethernet or cellular protocols, respectively. Cellular or WiMAX® is most commonly used between the grid operator and the concentrator.

The NAN is the path between the concentrator and the meter. It uses either wireless or PLC. Typically, the concentrator communicates with anywhere from a few to hundreds of meters, depending on the grid topology and the communications protocol used. Today, there is no standard for this portion of the network, so most implementations use proprietary wireless or PLC technologies. Several standards bodies are currently working with utilities and technology providers to define standards for wireless and PLC protocols. The IEEE 802.15.4g standard targets wireless; the IEEE P1901, OPEN meter, and ITU-T G.hnem standards are being developed for PLC (**Table 2**).

The HAN is used by utilities to extend the reach of their communication path to devices inside the home. This network can support functions such as cycling air conditioners off during peak load conditions, sharing consumption data with in-home displays, or enabling a card-activated prepayment scheme. The arrival of electric/plug-in hybrid electric vehicles (EV/PHEVs) presents a special communications scenario for HANs. Standards bodies are defining PLC protocols for communicating with vehicle charging systems.

In addition to supporting the data requirements for smart grid activities, a HAN might also include: peer-to-peer (P2P) communications between devices inside the home; communications with handheld remote-control devices, lighting controls, and gas or water meters; as well as broadband



The smart grid communications architecture.

Table 2: Communication protocols under consideration around the world

Region	WAN	NAN	HAN
North America	Cellular, WiMAX	G3-PLC, HomePlug®, IEEE 802.15.4g, IEEE P1901, ITU-T G.hnem, proprietary wireless, Wi-Fi	G3-PLC, HomePlug, ITU-T G.hn, Wi-Fi, ZigBee, Z-Wave
Europe	Cellular	G3-PLC, IEEE P1901, ITU-T G.hnem, PRIME, Wi-Fi	G3-PLC, HomePlug, ITU-T G.hn, Wi-Fi, Wireless M-Bus, ZigBee
China	Cellular, band-translated WiMAX	G3-PLC, RS-485, wireless to be determined	G3-PLC, RS-485, Wi-Fi, to be determined
Rest of the World	Cellular, WiMAX	G3-PLC, HomePlug, IEEE 802.15.4g, IEEE P1901, ITU-T G.hnem, PRIME, RS-485, Wi-Fi	G3-PLC, HomePlug, ITU-T G.hn, RS-485, Wi-Fi, Wireless M-Bus, ZigBee, Z-Wave

traffic. Protocols such as RS-485, ZigBee, Z-Wave®, and HomePlug are used for this network. If there is a separate home gateway, it is possible that additional protocols could be used to communicate with appliances, thermostats, and other devices.

Communications alternatives in the HAN can often coexist, but utility support will probably be limited to technologies needed to support the utility's primary objectives.

RF communications

Wireless communications is used in some areas for automated meter reading (AMR). Several proprietary and standardized wireless protocols are available today. Frequency bands of interest range from 200MHz to 3.9GHz.

Several blocks are used to implement RF communications (**Figure 3**). The signal is received through an antenna and goes through a bandpass filter, which rejects frequencies beyond the one of interest. The signal is then switched to the receive signal chain, where one or more downconverters translate from the carrier frequency to an intermediate frequency (IF), then to the in-phase/quadrature-phase (I/Q) stage, and then to the baseband.

More recent architectures eliminate one or more of the IF downconversion stages with a low-IF or zero-IF sampling architecture. These designs use either a single ADC to digitize a high- or low-IF signal or, typically, two ADCs to digitize a complex I/Q baseband signal. The ADC output is fed into a DSP or digital ASIC where the baseband is processed. Sometimes a microprocessor is also used to handle the higher layers of the protocol. For transmission, the processing path and signal chain are reversed, and the signal is sent out to the antenna.

The system can be partitioned in several ways. ZigBee or Maxim's Simplelink radios, for instance, can provide a complete system-on-chip (SoC) solution. In other cases, such as proprietary protocols, a digital ASIC and an RF transceiver are used to build the complete radio link. Maxim has both standard RF transceivers as well as custom ASICs that can be configured as transceivers.

Powerline communications

Overview of modulation schemes

Powerline communications uses AC power lines as the transmission medium. Some systems, such as Maxim's, work over DC and cold wires as well. There are several powerline protocols in the market today. These protocols break down into one of two basic modulation schemes: frequency-shift keying (FSK) and orthogonal frequency-division multiplexing (OFDM).

FSK is an older modulation scheme that has been used by the utility industry in the past for rudimentary purposes, such as infrequent one-way communications from meters to a concentrator. However, FSK suffers from a significant drawback: if an interferer coincides with one of the transmit frequencies, the receiver loses reception. As FSK only switches between two frequencies, bandwidth is not used efficiently, resulting in low data rates. This low data rate is insufficient for smart grid applications that demand bidirectional control.

Real-world PLC rollouts frequently require up to several hundred meters to be connected to a single data concentrator over the medium-voltage (MV) portion of the network. This requires data communication across low-voltage/medium-voltage (LV/MV) transformers. Since these transformers can cause several tens of decibels of (frequency-selective) signal attenuation to FSK signals, more advanced and robust communication methods than FSK are needed.

OFDM has been used in many modern communication systems such as digital radio and TV, Wi-Fi, and WiMAX, as well as early-generation narrowband protocols such as PRIME. Today, OFDM technology is enabling exciting new functions and capabilities for PLC networks. Among the most significant benefits, it gives the utility industry the bandwidth needed to build intelligence into the power grid while meeting aggressive cost targets.

Advancements offered by G3-PLC technology

G3-PLC employs OFDM to optimize bandwidth utilization. Since OFDM uses multiple carriers to transmit data, interference at a specific frequency or frequency-selective attenuation can now effectively be eliminated. In addition to increased reliability, this capability allows considerably more data to be sent.

Additionally, OFDM's spectral efficiency allows the use of advanced channel-coding techniques. In Maxim's powerline solutions, advanced channel coding is used along with OFDM to maximize communication robustness in adverse channel conditions. Two layers of error-correction coding (convolutional and Reed Solomon) are used to ensure reliable data transmission. In addition, data is interleaved in both time and frequency domains across OFDM carriers to decrease the sensitivity to impulse noise and protect against burst errors.

Maxim's next-generation G3-PLC technology includes additional capabilities:

- MAC-level security using an AES-128 cryptographic engine
- Mesh routing protocol to determine the best path between remote network nodes

- Adaptive tone mapping for optimal bandwidth utilization
- A robust mode of operation to improve communication under noisy channel conditions
- Channel estimation to select the optimal modulation scheme between neighboring nodes
- Coexistence with older S-FSK systems

G3-PLC is so robust that transmission across transformers is achievable with an inexpensive coupler. This reduces the number of concentrators needed in smart grid installations, saving system implementation cost and making PLC cost competitive with, or even superior to, wireless advanced meter infrastructure (AMI) systems. Distances up to 6km have been achieved on low- and medium-voltage lines, allowing remote sites to be monitored as well. The complete G3-PLC profile specification, as well as specifications for the PHY and MAC layers, can be downloaded from: www.maxim-ic.com/G3-PLC.

Maxim provides both high-frequency and low-frequency PLC chipsets for smart grid applications. Maxim recommends using narrow-band OFDM to transmit data in a spectrum consistent with world-wide spectral power-density standards for PLC (below ~500kHz in CENELEC®, FCC, and ARIB).

Serial communications

Achieve long cable runs in noisy environments

In harsh and noisy environments, such as multi-unit residential buildings or industrial settings, an RS-485 bus architecture can be used to implement a low-cost, yet robust communications network. The differential nature of RS-485 signaling makes it less susceptible to external interference. Moreover, the RS-485 specification supports multidrop configurations, thus allowing the connection of multiple meters to a single bus.

For instance, RS-485 can be used in an apartment building to transmit data from meters in each apartment to a central unit that aggregates the data from the individual meters, which can then be read through a wireless or PLC link. A similar approach can be used in industrial systems that require multiple cost centers to be metered.

Selecting an RS-485 transceiver

To maintain signal quality over long cable lengths through noisy environments, designers should look for transceivers with the following features.

ESD protection to prevent damage from handling and connection of the transceivers.

Fail-safe circuitry to protect the design from open- and short-circuit conditions.

Slew-rate limiting to reduce radiated emissions and data errors.

Hot-swap capability to eliminate false transitions on the bus during power-up or live insertion of the transceiver.

Isolation to protect against voltage spikes, ground loops, electrical storms, etc.

AutoDirection control to save an optocoupler by eliminating the need for an isolated control channel.

±80V fault protection to eliminate the need for external components such as polyswitch limiters and zener diodes.

Add a point-to-point link with RS-232 transceivers

The RS-232 protocol is intended for short-distance communication between two devices. Meter designers typically use RS-232 for implementing a point-to-point link between a utility meter and a computer, remote display, or modem.

Because the RS-232 port is only used a fraction of the time, it should include automatic shutdown circuitry to conserve power. Additionally, designers should look for devices with extended ESD protection to prevent damage during handling.

Maxim's RS-232 family combines proprietary AutoShutdown™ technology with robust ESD protection, fast data rates, and small footprints—basically, everything that you need in an RS-232 transceiver.

Multiprotocol transceivers provide design flexibility

In cases where the protocols are either not known in advance or where there needs to be flexibility, Maxim's multiprotocol transceivers allow you to use a single board layout to support either RS-232 or RS-485 communication. This saves time because one design can support different market requirements, and each board can simply be programmed to the desired protocol during production.

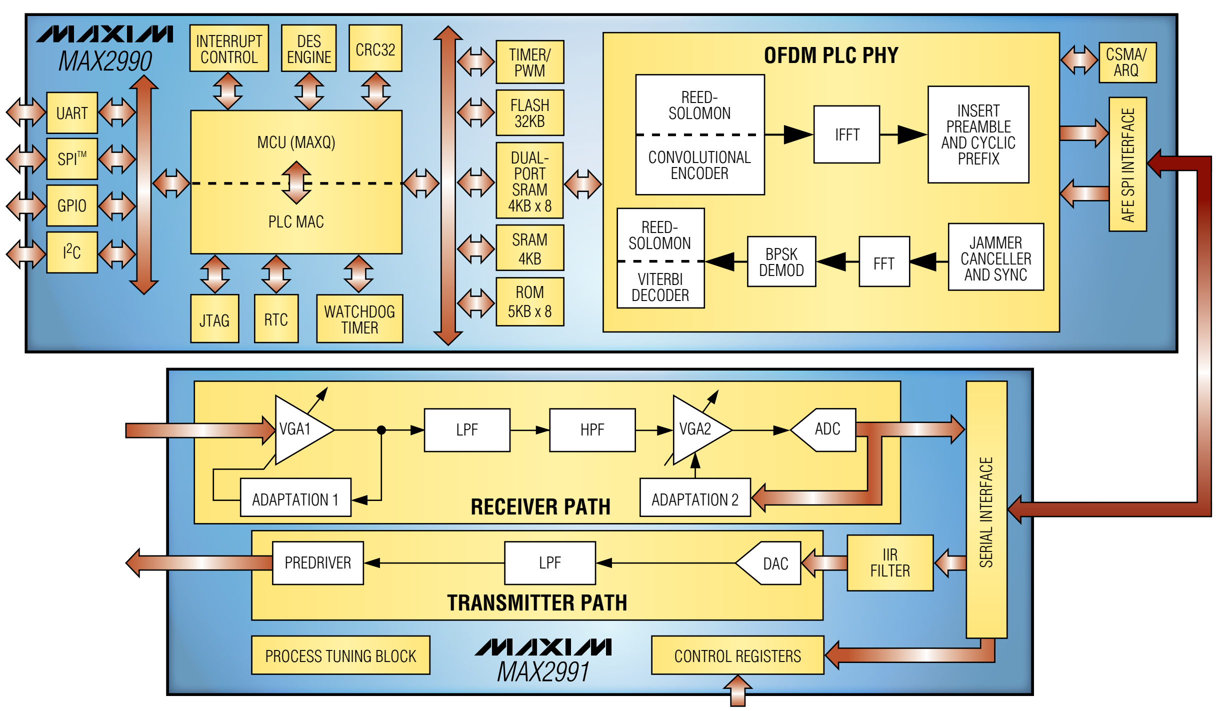
OFDM-based PLC chipset dramatically improves reliability and network data rate

MAX2990/MAX2991 (G3-PLC Lite)

The MAX2990 modem and the MAX2991 analog front-end (AFE) comprise a PLC chipset that achieves reliable long-range data communications. The MAX2990 is a highly integrated SoC that combines the PHY and MAC layers using Maxim's 16-bit MAXQ® microcontroller core. The MAX2991 is a state-of-the-art, stand-alone IC that features two-stage automatic gain control (AGC) with a 62dB dynamic range and on-chip programmable filters. Both devices operate in the CENELEC, FCC, and ARIB frequency bands.

Benefits

- **Robust long-distance transmission**
  - Up to 100kbps data rate at 10kHz to 490kHz; 32kbps at 10kHz to 95kHz
  - Built-in AGC with 62dB dynamic range and DC offset cancellation
  - Includes forward error correction (FEC), CRC16, and CRC32
  - CSMA/CA controls traffic in multinode networks
  - ARQ enhances data transmission reliability
- **High integration lowers BOM cost and speeds design**
  - On-chip band-select filter, VGA, and 10-bit ADC for the Rx path
  - On-chip band-waveform-shaping filter, programmable predriver, and 10-bit DAC for the Tx path
- **Built-in security protocols prevent tampering**
  - Fast DES/3DES engine



Block diagrams of the MAX2990 and MAX2991.

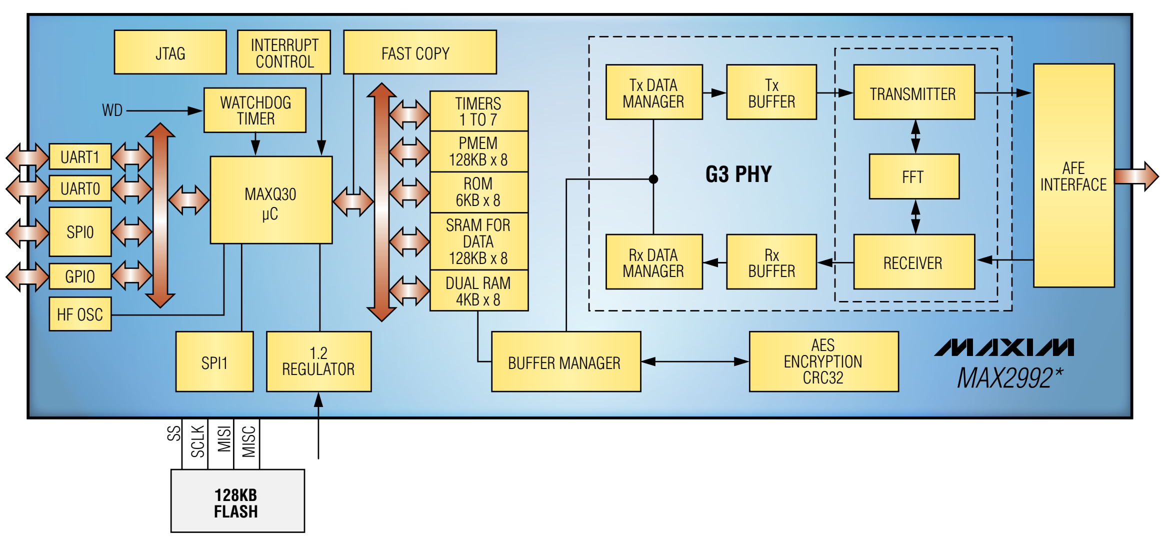
Next-generation OFDM-based PLC modem improves network reliability and coverage over earlier generations

MAX2992* (G3-PLC)

The MAX2992 modem improves long-range data communications by extending network capabilities to transmission over transformers. This highly integrated SoC combines the PHY and MAC layers using Maxim's 32-bit MAXQ microcontroller core. Two forms of FEC are added to further improve communication reliability over earlier generations and add backwards compatibility with older FSK-based PLC technologies. This device operates in the CENELEC, FCC, and ARIB frequency bands. When combined with the MAX2991, a full PLC modem can be realized.

Benefits

- **Reliable long-distance transmission**
  - Up to 225kbps effective data rate at 10kHz to 490kHz; 44kbps effective data rate at 10kHz to 95kHz with a maximum data rate of 298kbps
  - Adaptive tone mapping monitors sub-channel conditions and automatically selects the optimal transmission parameters
  - FEC, CRC16, and CRC32
  - CSMA/CA controls traffic in multinode networks
  - ARQ enhances data transmission reliability
  - Fast AES-128 engine for high data security
- **Reduces system cost**
  - Long-distance (6km) transmission means fewer repeaters
  - Communication across transformers requires fewer data concentrators
  - Backwards compatibility with FSK-based solutions improves interoperability
- **Full IPv6 addressing extends system addressability all the way into the home**
  - Implements 6LoWPAN adaptation layer supporting IPv6



Block diagram of the MAX2992.

*Future product—contact the factory for availability.

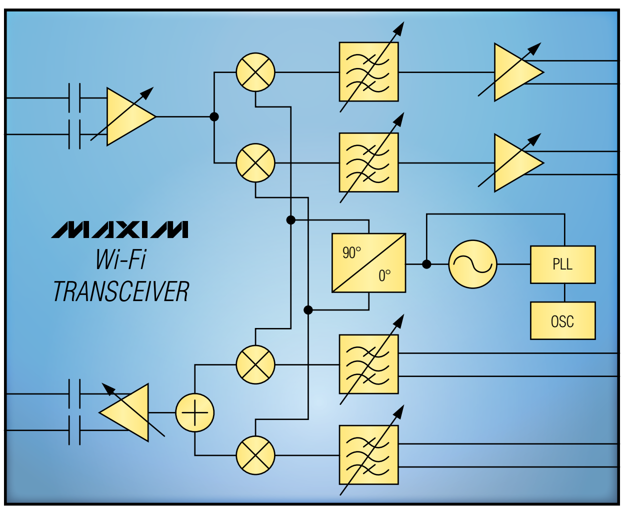
Wi-Fi transceivers enable communication over the longest distances

MAX2830/MAX2831/MAX2832

The MAX2830/MAX2831/MAX2832 Wi-Fi RF transceivers support wireless communication standards in the unlicensed 2.4GHz frequency band. Maxim's line of Wi-Fi products are direct-conversion, zero-IF OFDM transceivers providing best-in-class performance to support the longest distances. Custom frequency bands for nonstandard and multimode applications are also available.

Benefits

- **Transceivers support industry standards for easier, faster design**
  - Support for the IEEE 802.11b/g standards to leverage a large ecosystem of HAN devices
- **Low noise and high sensitivity enable larger networks**
  - Low noise figure (2.6dB) and receive sensitivity (-76dBm) enable the longest range
- **On-chip filters eliminate external SAW filter and reduce BOM count and cost**
  - Integrated PA with +18.5dBm transmit power reduces BOM count and PCB area

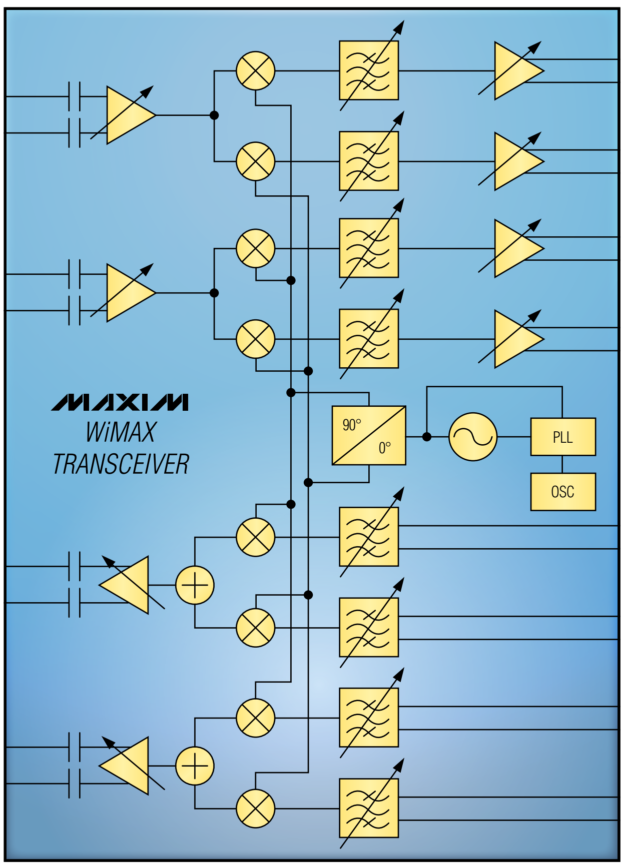


Block diagram of Maxim's Wi-Fi transceivers.

WiMAX transceivers boost range and throughput for faster data access

MAX2839/MAX2842

The MAX2839/MAX2842 WiMAX RF transceivers provide the flexibility to support wireless communication standards in the licensed 2GHz and 3GHz frequency bands. Maxim's WiMAX products are direct-conversion, zero-IF, MIMO OFDM transceivers that use a dual-receiver architecture to maximize data throughput and link range. Custom frequency bands for nonstandard and multimode applications are also available.



Block diagram of Maxim's WiMAX transceivers.

Benefits

- **Best-in-class performance extends link range**
  - Lowest noise figure (2.3dB) provides longest range—18% farther than closest competitor
- **Smallest WiMAX transceiver fits the tightest designs**
  - Tiny 3.6mm x 5.1mm wafer-level package (MAX2839AS)
- **Complete frequency coverage with MIMO support to reach customers worldwide**
  - 2.3GHz to 2.7GHz with 1x2 MIMO support (MAX2839)
  - 3.3GHz to 3.9GHz with 2x2 MIMO support (MAX2842)

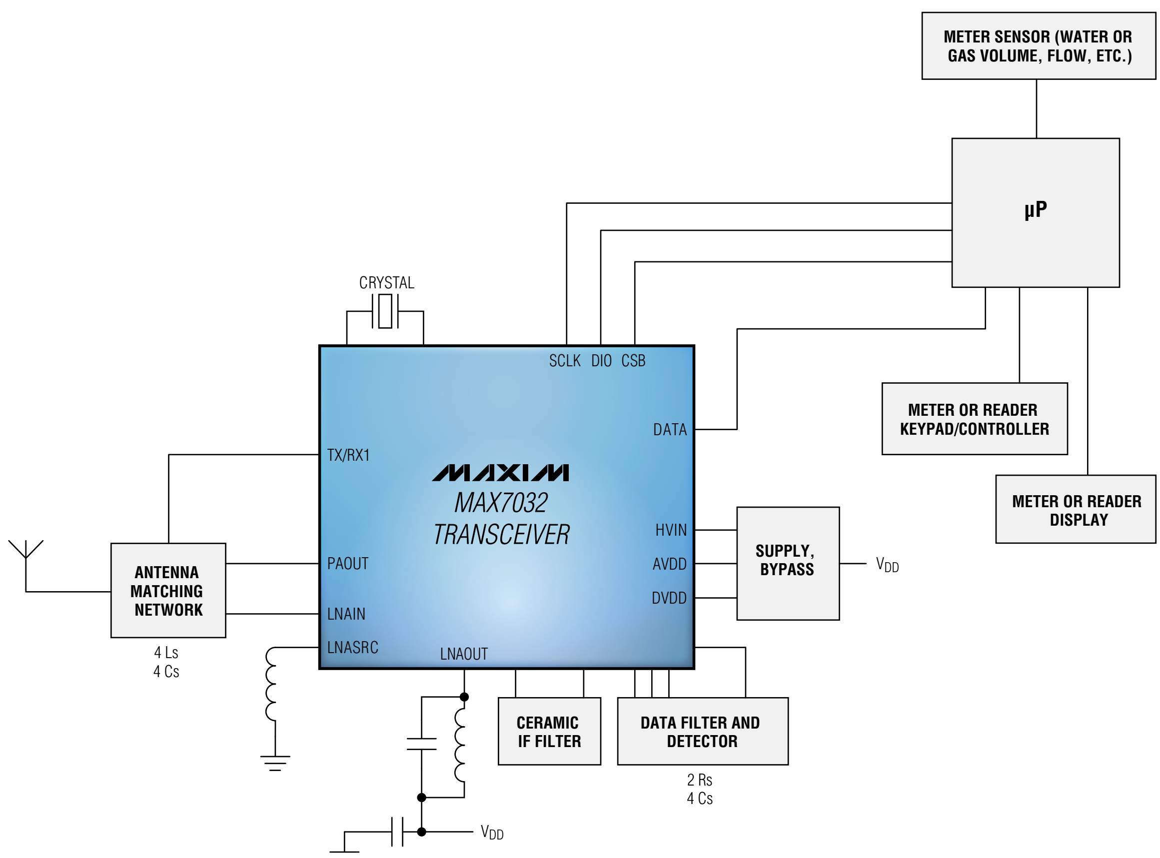
260MHz to 470MHz ISM radio for HANs and NANs extends battery life up to seven years

MAX7032

The MAX7032 transceiver offers an inexpensive, low-power solution for one-way and two-way reporting from meters in HANs and some NANs. The transceiver uses the license-free low-frequency radio bands in the U.S. (260MHz to 470MHz) and Europe (433.05MHz to 434.79MHz). The radio's simple ASK or FSK modulation technique, outstanding sensitivity, wide selection of data rates, and low current drain make it the perfect choice for local radio links and networks in these frequency ranges. The transceiver can achieve link margins better than 120dB, which means that it can reach 1km over open flat terrain or maintain a link between an underground water meter and a local concentrator. The MAX7032 is flexible enough to work with multiple smart grid communication standards.

Benefits

- **Extends battery life**
  - Low active (< 7mA Rx, < 12mA Tx) and shutdown (< 1µA) current extends battery life
  - Programmable receiver shutdown/wake-up cycle for additional current savings
- **Compact radio module for space-constrained metering applications**
  - Small 5mm x 5mm TQFN package
- **Good penetration in buildings**



System diagram for the MAX7032.

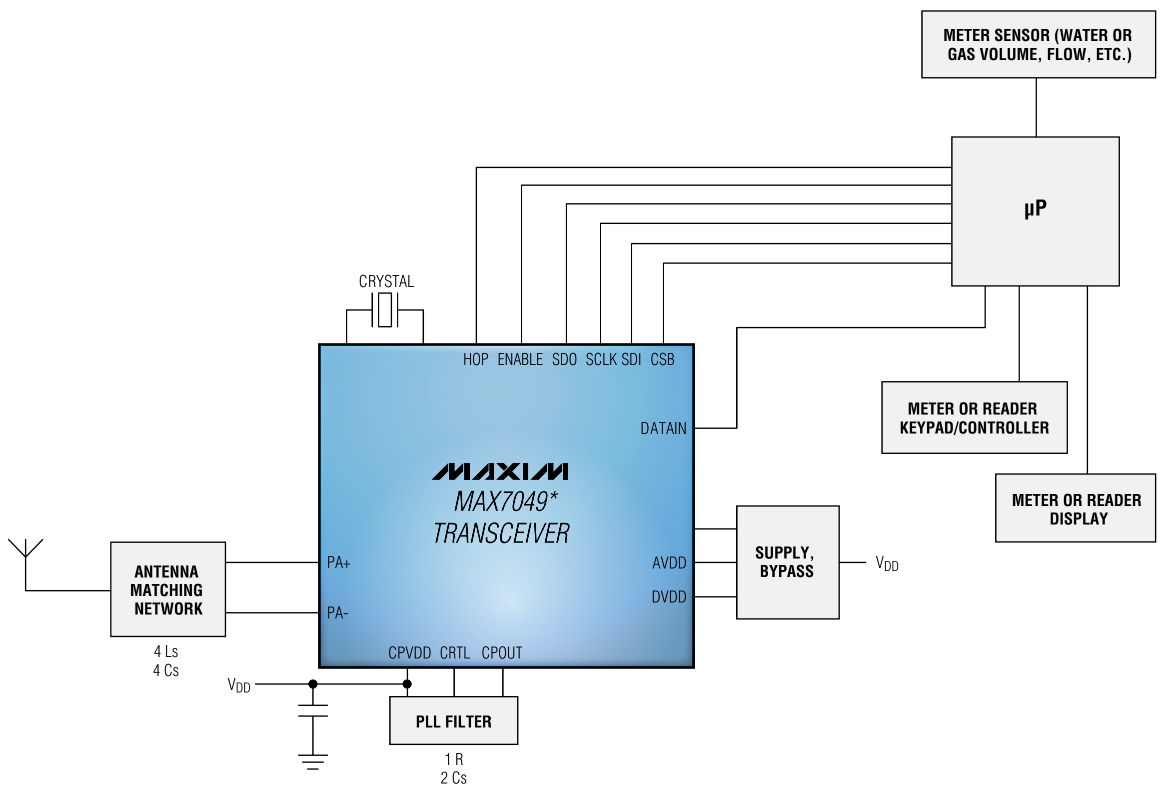
Low-/high-band transmitter for HANs/NANs extends battery life up to seven years

MAX7049*

The MAX7049 ASK/FSK transmitter offers an inexpensive, low-power solution for one-way reporting from meters in HANs and some NANs. The transmitter uses the license-free low- and high-frequency bands in the U.S. and Europe, making it a very flexible solution. The shaped ASK or FSK modulation technique reduces the transmitted frequency bandwidth so that more frequency channels can be used. The wide selection of data rates and low current drain make it well suited for local radio links and networks. This IC is flexible enough to work with multiple smart grid communication standards and is compatible with modes S and T of the European M-Bus standard.

Benefits

- **Extends battery life**
  - Low active (< 35mA) and shutdown (< 0.5µA) current conserves battery life
- **Low BOM cost**
  - Only crystal and matching components are needed
- **Good penetration in buildings**
  - Maximum allowable Tx power (25mW) for European ETSI standard



System diagram for the MAX7049.

*Future product—contact the factory for availability.

RF expertise to deliver custom-tailored solutions for your specific smart grid needs

ASIC Services

Maxim's ASIC services are available to meet your specific application requirements. Maxim offers flexible engagement options from foundry sales through turnkey design to joint-development projects. Our smart grid solutions include:

- **Wireless backhaul; distribution asset management**
  - WiMAX and rebanded WiMAX transceivers
- **AMR; fault diagnostics**
  - FSK, ASK, OFDM, DSSS transceivers
- **AMI**
  - WiFi, ZigBee/802.15.4 transceivers
- **Proprietary solutions**
  - 400MHz to 5GHz RF/wireless transceivers

Benefits

- **Maxim's expertise gives you a high first-silicon success rate**
  - Over 15 years of experience in the ASIC business
  - Rich analog and RF IP catalog speeds your time to market
- **In-house process technologies provide optimal performance-cost tradeoff**

www.maxim-ic.com/ASICs

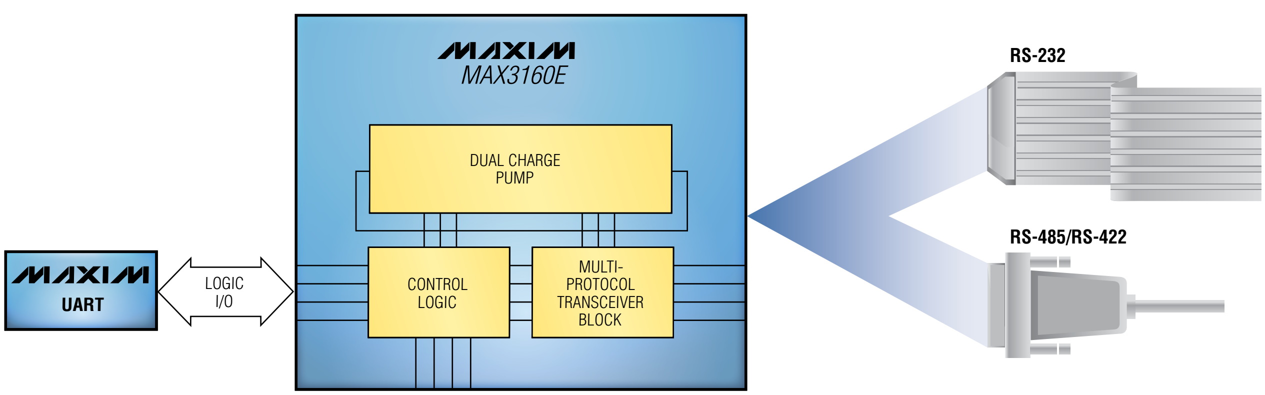
Multiprotocol transceivers enable on-the-fly protocol selection for power-meter communications

MAX3160E/MAX3161E/MAX3162E

The MAX3160E/MAX3161E/MAX3162E are multiprotocol transceivers that allow designers to use a single device to support both RS-232 and RS-485 serial communications in power-meter applications. These devices offer flexibility and convenience through a pin-selectable interface, which makes it easy to program each board to the desired protocol during production. In addition, the transceivers have extra protection against static electricity; true fail-safe circuitry that guarantees a logic-high receiver output when the receiver inputs are open or shorted; a 10nA shutdown mode; short-circuit limiting; and thermal shutdown circuitry to protect against excessive power dissipation.

Benefits

- **Provide adaptability without additional parts or design work**
  - Pin-programmable half- or full-duplex communication
  - Pin-selectable RS-232 or RS-485/RS-422 operation
- **Save board space and cost**
  - Integrated ±15kV ESD protection eliminates external protection circuitry
  - Allow up to 256 transceivers on the bus without requiring an extra serial bus, UART, or microprocessor
- **Reduce power consumption**
  - First 3V multiprotocol solution in the industry
  - 5x lower supply current than the competition—significantly reduces power dissipation



Block diagram of Maxim's multiprotocol transceivers.

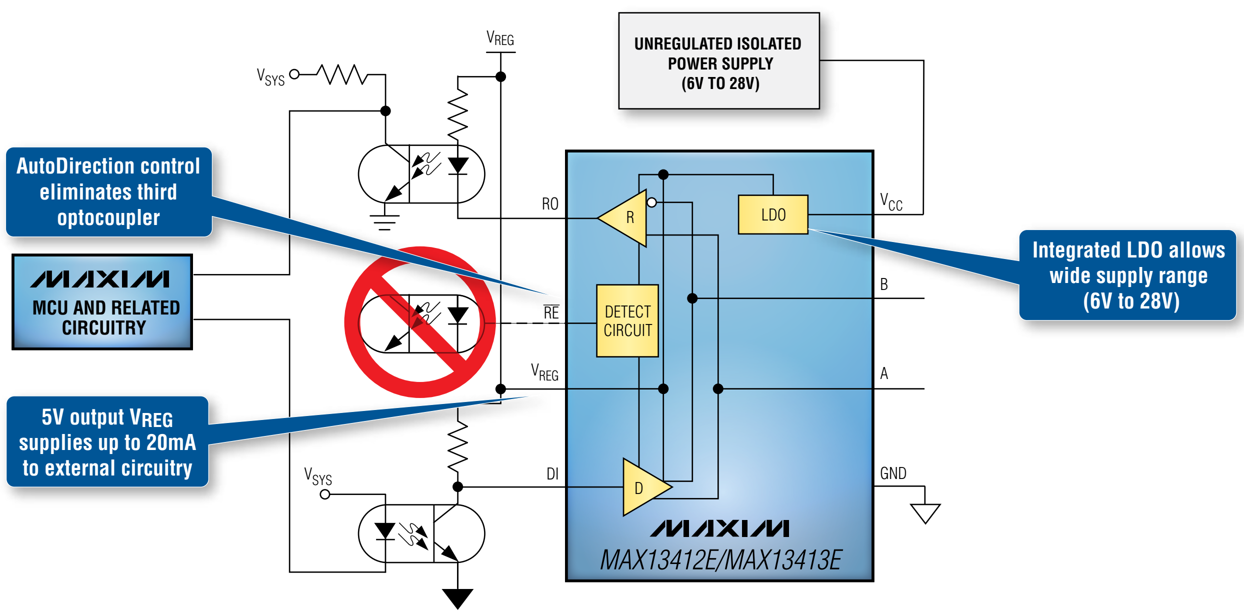
Highly integrated RS-485 transceivers simplify power-meter interface designs

MAX13412E/MAX13413E

The MAX13412E/MAX13413E are half-duplex RS-485/RS-422 transceivers optimized for isolated power meters. These devices reduce design complexity by integrating a low-dropout regulator (LDO) and a sensing circuit for AutoDirection control. The internal LDO allows the devices to operate from a wide, unregulated voltage range (6V to 28V), simplifying power-supply designs. AutoDirection control reduces cost and board space by eliminating an optocoupler in isolated power-meter applications. Other features include enhanced ESD protection, fail-safe circuitry, slew-rate limiting, and full-speed operation.

Benefits

- **AutoDirection control saves cost and board space**
  - Reduces the number of optical isolators needed in isolated applications
- **Built-in LDO offers convenience without the worry of providing a regulated voltage level**
  - Operates from an unregulated 6V to 28V power supply and provides 5V/20mA of power to external circuits
- **Extended ESD level of ±15kV (Human Body Model) eliminates external ESD protection circuitry**
- **1/8-unit load receiver input impedance enables up to 256 peripheral sensors in the system**



System block diagram of the MAX13412E/MAX13413E.

Recommended solutions

Part	Description	Features	Benefits
RF transceivers			
MAX2830/31/32	Direct-conversion, zero-IF RF transceivers for 2.4GHz 802.11g/b	Integrated PA, antenna diversity switch, and crystal oscillator; best-in-class receive sensitivity (-76dBm)	Low-cost, low-BOM implementation for 802.11b/g standards
MAX2839	Direct-conversion, zero-IF RF transceiver for 2.3GHz to 2.7GHz MIMO WiMAX	1x2 MIMO RF transceiver with best-in-class noise figure (2.3dB) and linearity specifications; 8mm x 8mm TQFN package	Best-in-class performance supports longer range; small package enables compact designs
MAX2842	Direct-conversion, zero-IF RF transceiver for 3.3GHz to 3.9GHz MIMO WiMAX	2x2 MIMO RF transceiver with best-in-class noise figure (3.8dB) and linearity specifications	Best-in-class performance supports longer range
MAX7032	300MHz to 450MHz ASK/FSK transceiver with low current drain	Under 7mA active receiver current; SPI programmable; programmable sleep/wake mode	Good in-building range with long battery life
MAX7031	300MHz to 450MHz FSK transceiver with low current drain	Under 7mA active receiver current; hardwired or microprocessor controllable; factory-preset frequencies	Good in-building range with long battery life
MAX7030	300MHz to 450MHz ASK transceiver with low current drain	Under 7mA active receiver current; hardwired or microprocessor controllable; factory-preset frequencies	Good in-building range with long battery life
RF transmitter			
MAX7049*	288MHz to 945MHz ASK/FSK transmitter with low current drain	Up to 25mW Tx power; SPI programmable; less than 500nA shutdown current	Good in-building range (including 800MHz/900MHz) with long battery life
Powerline communications ICs			
MAX2981/82*	Broadband HomePlug 1.0 chipset	Up to 14Mbps data transmission	Robust, high-data-rate transmission with guaranteed latency for industrial environments
MAX2990/91 (G3-PLC Lite)	Narrowband OFDM PLC chipset	Up to 100kbps data transmission or lower-data-rate robust mode for extremely noisy environments; DES/3DES encryption engine	Lower network implementation cost from ability to cross transformers
MAX2991/92* (G3-PLC)	Narrowband OFDM PLC chipset	AES-128 encryption engine; adaptive tone mapping allows coexistence with FSK protocols; 6LoWPAN compression enables IPv6	Lower network implementation cost from ability to cross transformers
Multiprotocol transceivers			
MAX3160E	Programmable 2Tx/2Rx RS-232 or 1Tx/1Rx RS-485/RS-422	Supports RS-232, RS-422, and RS-485; handles up to 128 devices on the bus; 20-pin SSOP	Eases system configuration while saving space
MAX3161E	Programmable 2Tx/2Rx RS-232 or 1Tx/1Rx RS-485/RS-422	Supports RS-232, RS-422, and RS-485; handles up to 256 devices on the bus; 24-pin SSOP	Eases system configuration while saving space
MAX3162E	Dedicated 2Tx/2Rx RS-232 and 1Tx RS-485/RS-422	Supports RS-232, RS-422, and RS-485; handles up to 256 devices on the bus; 28-pin SSOP	Eases system configuration while saving space
UART			
MAX3107	Single-channel SPI/I²C UART	Integrated oscillator; 24Mbps data rate; PLL; shutdown modes	Reduces solution cost and size; offloads µC

(Continued on next page)

*Future product—contact the factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
RS-485 transceivers			
MAX13442E	Fault-protected RS-485 transceiver	±80V fault protection; ±15kV ESD protection	Eliminates external circuitry
MAX13485E	RS-485 transceiver with enhanced ESD protection	±15kV ESD protection; fail-safe circuitry; hot-swappable	Saves space and provides robust protection
MAX3535E	Isolated RS-485 transceiver with enhanced ESD protection	Robust ±2.5kV capacitive isolation	Eliminates external optocoupler and power supply
MAX13412E/13E	RS-485 transceivers optimized for isolated applications	AutoDirection circuitry; integrated LDO	Minimize solution size
MAX13430E	RS-485 transceiver for multivoltage systems	Integrated low-voltage logic interface	Interfaces directly to low-voltage FPGAs and ASICs, eliminating level translator
Transformer drivers			
MAX253	1W primary-side transformer H-bridge driver for isolated supplies	Simple solution for producing an isolated power supply up to 1W	Simple open-loop circuit speeds PSU design, allowing faster time to market
MAX256	3W primary-side transformer H-bridge driver for isolated supplies	Simple solution for producing an isolated power supply up to 3W	Simple open-loop circuit speeds PSU design, allowing faster time to market
Power amplifier			
MAX2235	1W autoramping power amplifier for 900MHz applications	+30dBm (1W) typical output power from a 3.6V supply or +28dBm from a 2.7V supply	Maximizes read range; operates directly from a single 2.7V to 5.5V supply, making it suitable for use with 3-cell NiCd or 1-cell Li+ batteries
DC-DC regulator			
MAX15062*	36V, 300mA DC-DC regulator with integrated MOSFET	Low quiescent current; 2mm x 2mm TDFN package	High integration with small footprint saves up to 50% total board area compared to competing solutions
Analog-to-digital converters (ADCs)			
MAX11103/05	12-bit, 3Msps/2Msps SAR ADCs	73dB SNR; SPI interface; high 1.7MHz full linear bandwidth; 1-channel (SOT23) and 2-channel (µMAX®, TDFN) options	Tiny SOT23, µMAX, and TDFN packages save space; serial interface simplifies data transmission
MAX1379/83	12-bit, 1.25Msps, 4-channel, simultaneous-sampling SAR ADCs	0 to 5V, 0 to 10V, or ±10V inputs; 70dB SNR; four single-ended or two differential inputs; SPI interface	Serial interface saves cost and space on digital isolators

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

Energy measurement

Overview

Energy demand around the world is predicted to increase at a rate that will likely outstrip our ability to generate it. Estimates by the U.S. Department of Energy forecast total energy consumption in the U.S. to increase by 30% to over 5,000 billion kWh in 2035, while new planned generation (including renewable sources) is expected to grow only 22% during this period. Increased energy efficiency and improved energy management are critical to averting this potential energy crisis.

Traditional open-loop strategies for managing power usage are crude and inefficient, resulting in lower reliability and reduced distribution stability. Engineers are working to improve power efficiency in all electronic applications—commercial equipment, home appliances, industrial motors, and network equipment. Increasing efficiency, however, is only part of the equation. Better energy management and, consequently, comprehensive measurement systems are essential. Incorporating feedback about how power is consumed yields the benefits of a closed-loop system and reduces waste. Additionally, giving energy users greater visibility into their power consumption can help overcome consumer indifference to energy concerns.

Accurate measurement provides the feedback necessary to understand, confirm, and modify our power consumption. It is critical to implementing an energy-management control loop and providing insight for maintenance and failure diagnostics.

This chapter addresses two key areas that benefit from new energy-measurement technologies: residential/commercial point of loads (POLs) and data centers.

Measuring point-of–load efficiency

Intelligent power-management schemes require accurate energy measurement, not only at an aggregate level (e.g., an entire building) but also at the POL (e.g., air conditioner, lighting, dishwasher, or computer).

Smart meters can track time-of-day power consumption and enable utilities to offer incentives to consumers to change their usage patterns. To improve automation we need to equip consumers with choices and enhanced services. Individual POLs must be tied to a local data and control network that monitors and allows control of the various loads within a building or household. Services can be enhanced through power-quality measurements and usage statistics, which can be used to schedule maintenance. Such a network can be implemented using a wide variety of configurations and protocols, depending upon the application.

A local data and control network that includes accurate power measurement can enable significant cost savings by identifying how power is being used. Consumers who can see that running the air conditioner costs $200/month (value of use) or quantify the cost difference between running the dryer at noon instead of 7 p.m. (time-value of use) are more likely to change their usage patterns.

Data that used to be acquired by expensive high-end utility meters is now available for an order-of-magnitude less cost. Power factor (PF), harmonic distortion, active power (watts), and apparent power (VA) information can be readily available for optimizing power-delivery

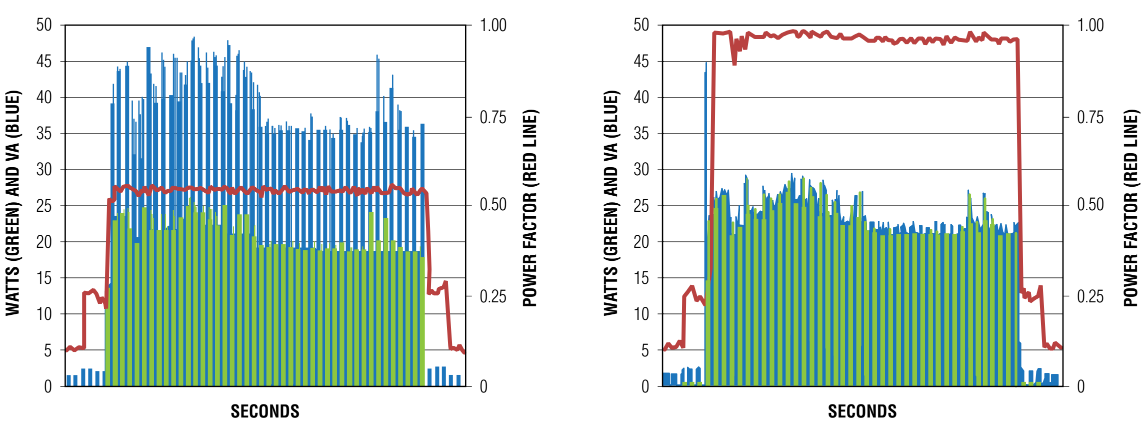


Figure 1. The power profile of a laptop computer during power-up, steady-state, and power-down using two different plug-in power supplies.

budgets, for predicting maintenance, and for understanding the strain on a system.

Figure 1 shows the power consumption of a laptop computer using two different plug-in power supplies. Even though the actual load is the same, the power supplied from the line by the utility, called apparent power, is substantially different from the power consumed by the load, called active power. Such differences lead to unnecessary and unaccounted for power loss. With energy-measurement solutions, statistics can be used to adjust device operating behavior to optimize energy efficiency.

Measurement accuracy is important to effectively protect against power failures and safeguard equipment. Small drops in voltage or line frequency can indicate pending power failure, enabling devices to switch into a protection mode. Additionally, voltage zero-crossing information can be used to time when relays should be turned on and off to reduce wear from arcing.

Measuring data center efficiency

Data centers are getting a lot of attention. The Environmental Protection Agency (EPA) estimates that data centers accounted for 1.5% of U.S. electricity consumption in 2006, and this demand is expected to nearly double by 2011, necessitating the development of an additional 10 power plants. Increasing data center energy efficiency can help avoid these infrastructural costs, while offering data center operators significant savings on their electricity bills.

ENERGY STAR recently released guidelines for data centers to mitigate this demand through increased energy efficiency. Key to these guidelines is a new metric called power usage effectiveness (PUE), which measures facility infrastructure efficiency. PUE is calculated by dividing total data center energy consumption by the IT equipment energy consumption. This requires metering at multiple locations within the data center, including the uninterruptible power supply (UPS) and power distribution units (PDUs).

Real-time power consumption data is needed to prevent costly overloading of breakers, as well as overallocation to equipment in idle or standby modes. Armed with this information, data center managers can implement operational strategies for dynamic power capping and reallocation to maximize PUE.

An added benefit of energy-measurement systems is that they give data center managers early failure notification so that preventative maintenance can be scheduled. Early-warning notification provides the extra time needed to seamlessly utilize a redundant option before failure. Energy-measurement systems enable continuous monitoring of the health of the power network. This capability is especially important as equipment is sequenced, because it can allow mechanisms that avoid circuit overloads such as those found during a black-start recovery.

Energy-measurement SoCs

Implementation of intelligent power-management algorithms requires clear representation of both actual power consumption and actual demand. This necessitates high accuracy and multiple metrology functions, including: distortion; active, reactive, and apparent power; energy; RMS voltage and current; and frequency. This information provides valuable feedback for improving operating efficiency, preventing power failure, and facilitating power-up sequencing during a black start.

Measurement accuracy is determined by resolution, precision, and dynamic range. Many general-purpose MCUs are limited in their accuracy and dynamic range because of their 10- or 12-bit ADCs. Discrete designs, meanwhile, require multiple components, in-depth knowledge of AC metering, and extensive development time.

Today, SoCs are available that bring the capabilities of intelligent metering to individual devices, from POLs to PDUs. Advances in manufacturing and design technology enable the metrology contained in a single SoC to meet critical cost, functionality, robustness, and size requirements. Today's state-of-the-art SoCs can now be integrated into server cabinets, UPSs, AC-DC power modules, PDUs, smart appliances, and luminaires.

Figure 2. A ZigBee®-based outlet-monitoring unit.

Figure 2 shows an easy-to-use data collection system for POLs. This low-cost outlet-monitoring unit demonstrates the capabilities of the 78M6612 energy-measurement SoC. It allows users to collect time-stamped data from a power outlet and wirelessly transfer it for graphical analysis or comparison to a reference meter.

The 78M6612 AC-power-monitoring SoC can measure from 10mA to 20A with less than 0.5% measurement error across a wide -40°C to +85°C temperature range. Its onboard 22-bit ADC enables this wide dynamic range and accuracy, allowing the device to detect various POL low-power modes. Additionally, the wide dynamic range allows the same circuitry to monitor a diverse range of applications, providing economy-of-scale cost savings.

Technical benefits of using an energy-measurement SoC

- Accurate power measurement across a wide current dynamic range can be used to confirm different low-power modes. For example, a single SoC can measure from 10mA to 20A with 0.5% accuracy.
- Voltage and line-frequency measurements can be used to determine the appropriate time to use power, especially when the source is not the local utility supplier. Small drops in voltage or line frequency are an indication of pending power failure.
- AC-voltage zero crossing can be used to synchronize when switches should be turned off or on—an opportunity that occurs every 8ms to 10ms, depending on the line frequency.
- Statistical data can be collected to detect early failure of a local AC-DC power-supply module or to provide information about the type of load that was just plugged into the outlet.

A single chip implements a highly integrated outlet-monitoring system, saving the time, space, and cost of a multichip solution

78M6612/78M6613

The 78M6612/78M6613 are highly integrated, single-phase AC power-measurement and monitoring (AC-PMON) ICs for consumer and enterprise applications. While the 78M6612 targets general-purpose AC power-measurement applications, the 78M6613 provides a simplified integration of single-phase AC power measurement for the power-supply market. With accuracy of 0.5% Wh or better over a 2000:1 current range and over temperature, each single chip provides the metrology data typically found in complex, multichip metering systems.

Featuring four analog inputs, both devices use Teridian's Single Converter Technology® design and an integrated 32-bit computation engine (CE) to measure up to two AC loads or wall outlets. The devices are highly integrated, which reduces board space and lowers costs. Each includes an 8-bit MPU core with 32KB of embedded flash memory, a UART interface, and multiple GPIOs for easy integration into any power supply or outlet-monitoring unit. The 78M6612/78M6613 consume roughly 30mW under typical operating conditions. The 78M6612 is available in 64-pin LQFP and 68-pin QFN lead-free packages, while the 78M6613 is available in a 32-pin QFN lead-free package.

Designing with the 78M6612/78M6613 is greatly simplified with a complimentary suite of development tools. Complete energy-measurement firmware supports the serial UART interface and simplifies calibration, configuration, and data extraction. Firmware options are available for emulating I²C, PMBus™, or SMBus interfaces using the onboard GPIOs. Firmware can be preloaded during IC manufacture or modified by customers as needed. Software libraries greatly expedite the development process.

Benefits

- **Single-chip solution provides the metrology accuracy typically found in multichip metering systems**
  - 0.5% Wh accuracy over 2000:1 current range and over temperature
- **Adds intelligence to energy monitoring**
  - Full range of embedded energy diagnostics (power factor, harmonic distortion, voltage sag and dip) for each outlet
  - Predicts power-supply failures
  - Intelligent switch relay control, including zero-crossing detection for each outlet
- **High integration reduces the bill-of-materials (BOM) cost**
  - Monitors two outlets simultaneously
  - Dual-outlet power reduces cost per outlet
  - Complete energy-measurement communication protocol
  - Eliminates the need for external components to boot or load calibration parameters
- **Reduces time to market**
  - Software support tools simplify design cycles
  - No code development is required by the customer
  - Complete energy-measurement and host-interface firmware available

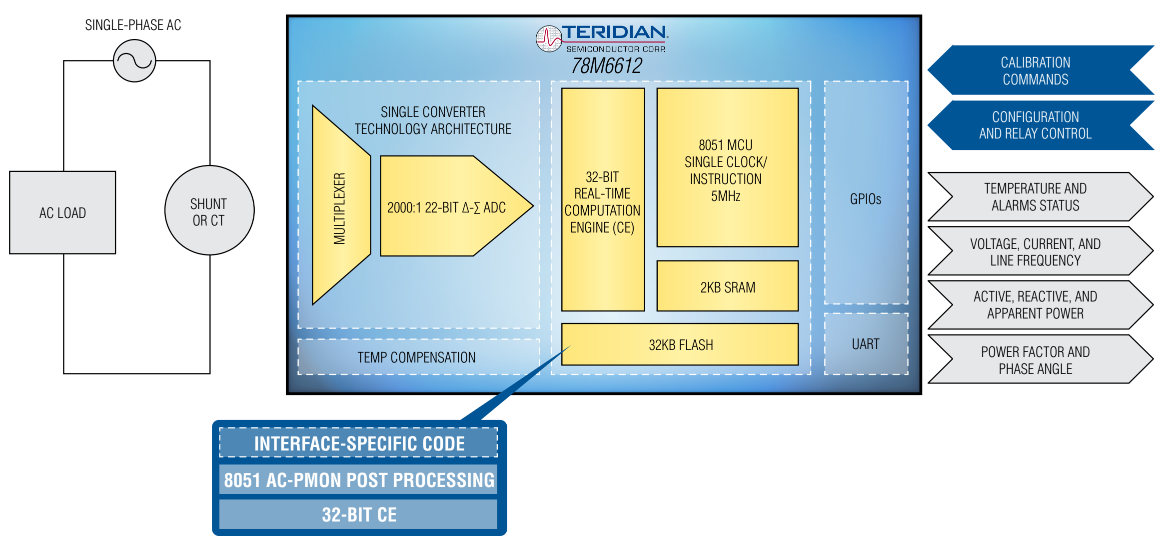


Diagram of a typical energy-measurement SoC embedded in a single-phase application.

8-channel energy-measurement IC simplifies complex server PDU system design while reducing costs

78M6618

The 78M6618 is a highly integrated, single-phase, 8-outlet, power-measurement and monitoring SoC. It is designed for multichannel power monitoring in PDUs, smart breakers and relay panels for homes, and building automation.

The 78M6618's accuracy is 0.5% Wh over a 2000:1 current range and over temperature—what one would typically find in multichip metering systems. It has unprecedented integration in an energy-measurement IC: a 32-bit CE, an MPU core, 128KB flash memory, 4KB shared RAM, and an RTC; three low-power modes with internal timer or external event wake-up; two UARTs; and an I^2C/MICROWIRE® EEPROM interface or an SPI™ interface. The SoC also features Teridian's Single Converter Technology design, which incorporates a 22-bit delta-sigma ADC, 10 analog inputs, digital temperature compensation, and a precision voltage reference. With these many capabilities, the 78M6618 supports a wide range of single-phase metering applications. Needing very few external components, this single chip also greatly reduces the cost of implementing complex PDU systems.

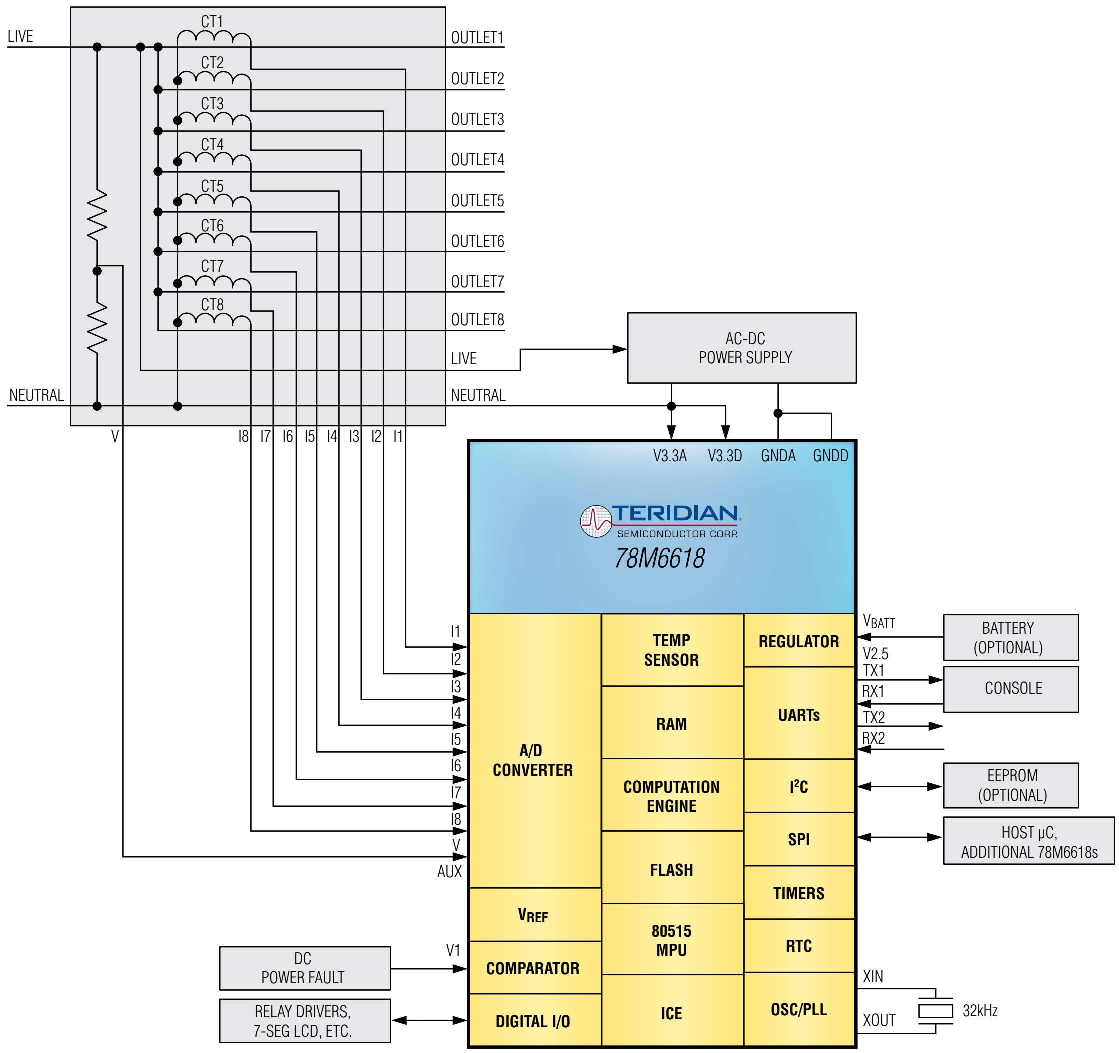
A complete array of in-circuit emulation and development tools assists customers and reduces design time. Metrology libraries are specifically designed for measurement and switch control of eight single-phase AC outlets (same phase). A software development kit, reference designs, and reference manuals expedite development and certification of power and energy measurement.

Benefits

- **Single-chip solution provides the metrology accuracy typically found in multichip metering systems**
  - 0.5% Wh accuracy over 2000:1 current range and over temperature
- **Adds intelligence to energy monitoring**
  - Measures the power factor for each outlet
  - Predicts power-supply failures
  - Intelligent switch relay control, including zero-crossing detection for each outlet
- **High integration reduces BOM cost**
  - Monitors eight outlets simultaneously
  - Octal-outlet power reduces cost per outlet
  - Complete energy-measurement communication protocol in a single chip
- **Shortens time to market**
  - Software support tools simplify design cycles
  - No code development is required by the customer
  - Complete energy-measurement and host-interface firmware available

(Block diagram on next page)

8-channel energy-measurement IC simplifies complex server PDU system design while reducing costs *(continued)*



Block diagram of the 78M6618 power- and energy-measurement IC.

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