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.

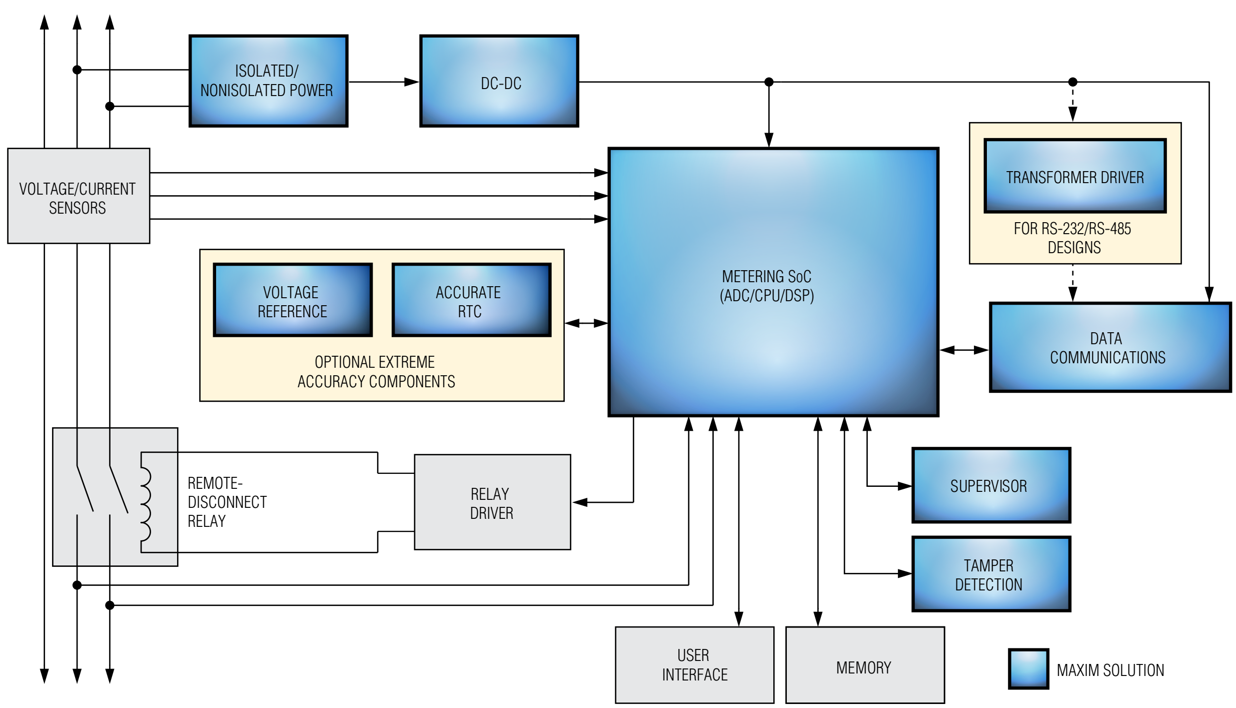
Smart meter requirements

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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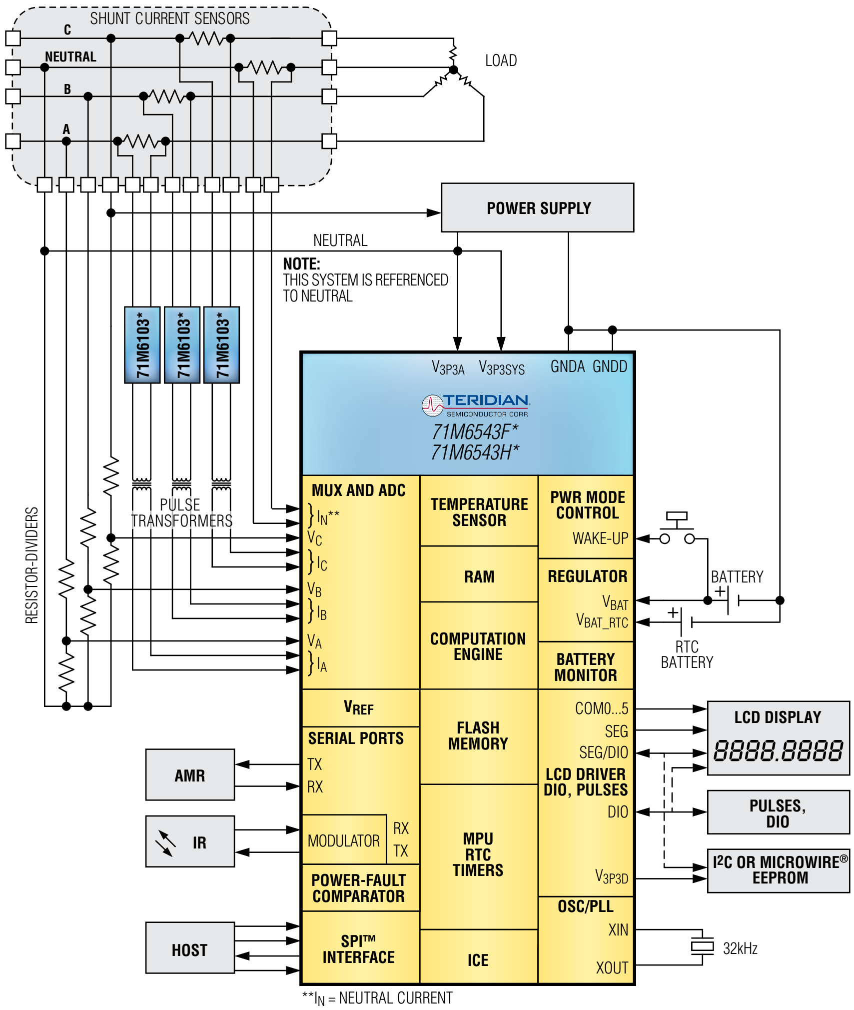

The 71M6543F/71M6543H polyphase metering SoCs are ideal for commercial and industrial applications.

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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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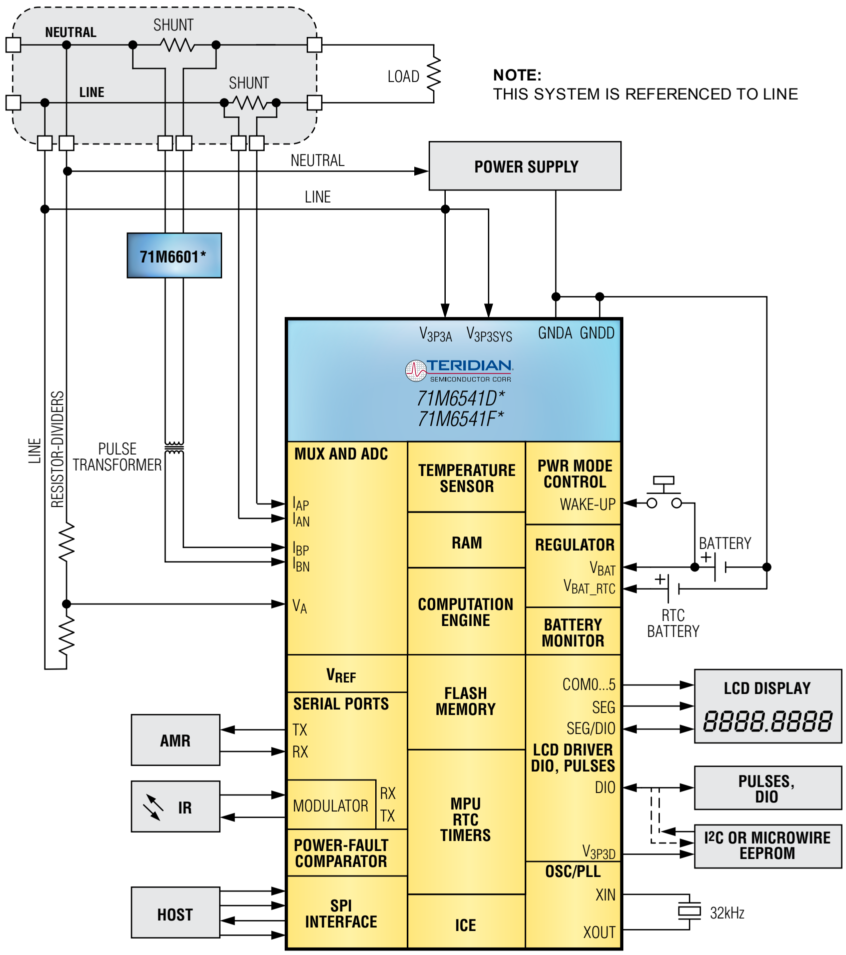


The 71M6541D/71M6541F single-phase metering SoCs are ideal for residential and POL applications.

*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.

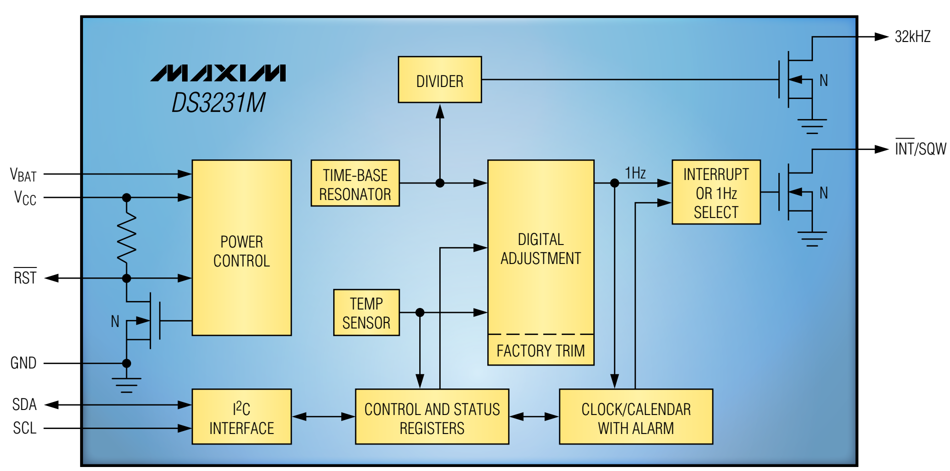
This innovative RTC provides temperature-compensated timing accuracy of ±0.5s/day (< ±5.0ppm) from -40°C to +85°C. The MEMS technology makes the DS3231M less sensitive to shock and vibration than traditional crystal-based clocks. It is also less sensitive to accuracy drift, which is quite common with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

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