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APPLICATION NOTE 5790

BOOST PERFORMANCE AND ADD FUNCTIONALITY TO PORTABLE MEDICAL DEVICES WITHOUT AFFECTING THE POWER BUDGET

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Abstract: This application note presents a new integrated solution from Maxim Integrated that overcomes reliability, cost, and board space limitation of discrete solutions by boosting performance.

Introduction

A significant percentage of the worldwide adult population needs to monitor personal vital signs (i.e., blood glucose level, blood pressure, oxygen saturation level) regularly. Not surprisingly, we are seeing more and more requests for portable medical devices that perform these tasks and even integrate more functions. This trend will not stop.

Space, weight, reliability, security, and power consumption are the key elements for designing modern portable medical devices. A typical portable medical device today usually requires several macro blocks: battery management to handle the power source, either a primary or rechargeable battery; an analog front-end (AFE) to condition and convert the signal coming from the sensor into a digital word; and a microcontroller to perform mathematical calculations on the acquired signal, display that information on an integrated LCD, or transmit the data to a wired/wireless device. Typically different discrete devices are used to provide all these functions.

Efficient power management is critical for these portable devices. In this article we will present a single low-power system on chip (SoC) suitable for both a portable medical device using a primary battery (coin cell or alkaline) as a power source and a medical device powered from a rechargeable battery. We will also discuss a second design in which a power-management IC (PMIC) can be added to support additional device functions.

This presentation of the two solutions requires us first to examine a typical discrete design. Then we can discuss the benefits of moving to an integrated solution that boosts performance without affecting the power budget. We will also investigate new integrated circuits that save space, maximize power usage, and increase safety with a USB connection. We will even learn how easy it is to connect a modern portable medical device to a smartphone and how the resulting range of applications and uses for the data seem limitless.

Complexity, Cost, and Space for a Discrete Solution

Our discussion begins with a brief examination of a typical functional block diagram for a discrete power solution (**Figure 1**). The battery-management block consists of the battery isolator, battery charger, fuel gauge, backlight supply, and linear/switching regulator. The AFE usually requires an ADC, DAC, op amps, comparators, analog switches, and voltage reference. This use of so many discrete devices can potentially impact system reliability, while they definitely increase cost and add board space.

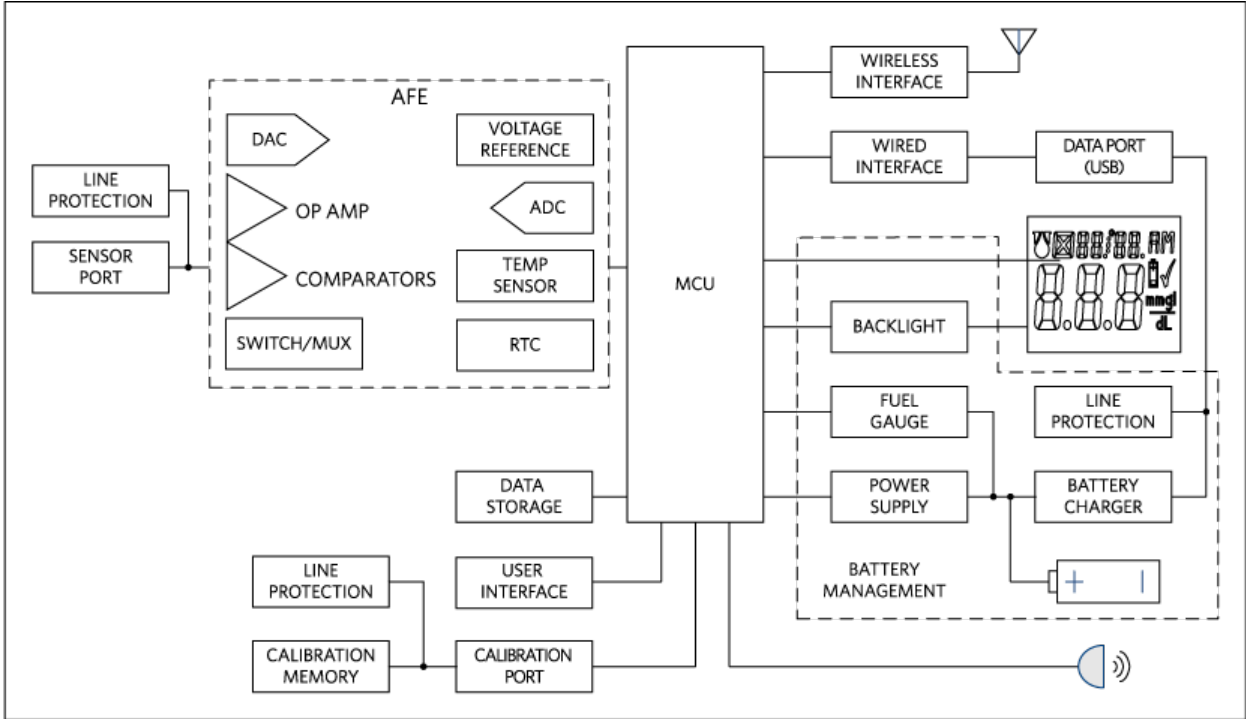


Figure 1. Block diagram of a basic power solution with multiple discrete components for a portable medical device.

Integrated Solution Gives Higher Performance

Now there is a new dual-chip integrated solution comprised of a microcontroller SoC and a PMIC that boosts overall device performance (**Figure 2**). We will examine the SOC and PMIC next.

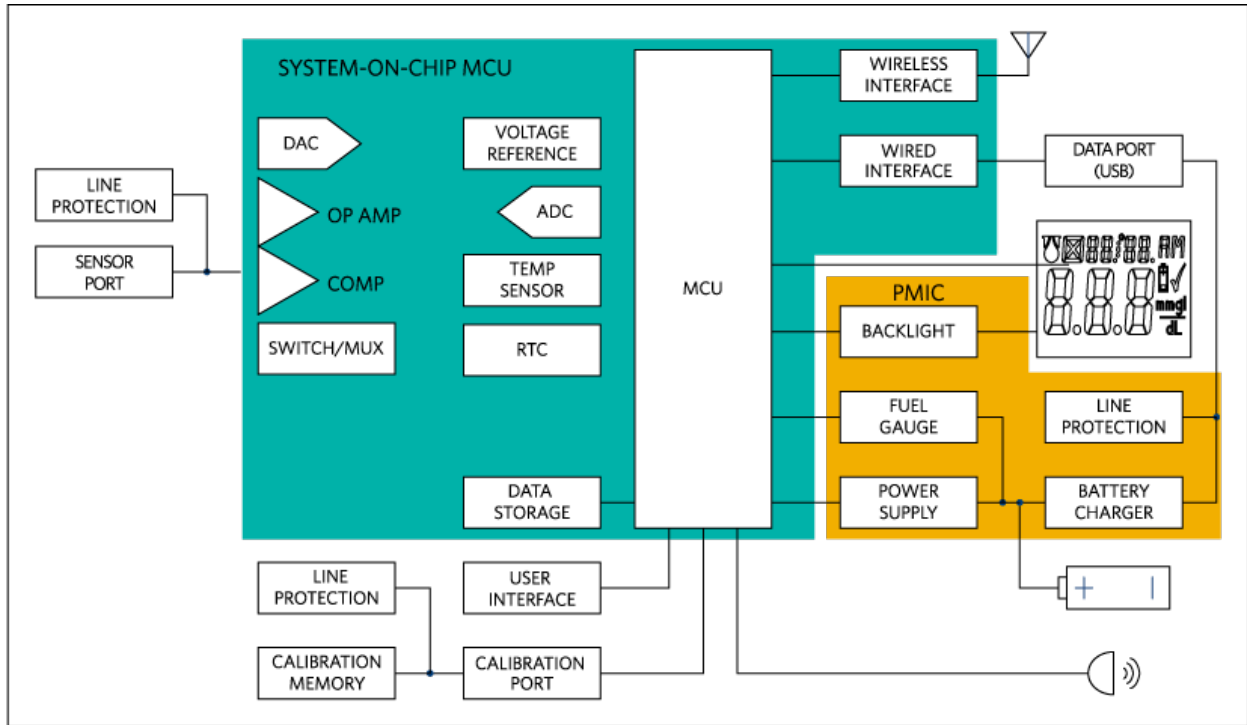


Figure 2. An integrated solution with a MAX32600 microcontroller SoC and PMIC simplifies the design and improves performance.

The Secure, Medical Microcontroller SoC

This MAX32600 microcontroller SoC (Figure 3), based on a Cortex[®] M3 core, is differentiated from competing power solutions by its high-performance analog front-end (the AFE) and by its integrated, advanced security for trust protection. A wired and wireless communication interface gives the user multiple choices to connect the medical device to another portable host like a PDA or smartphone.

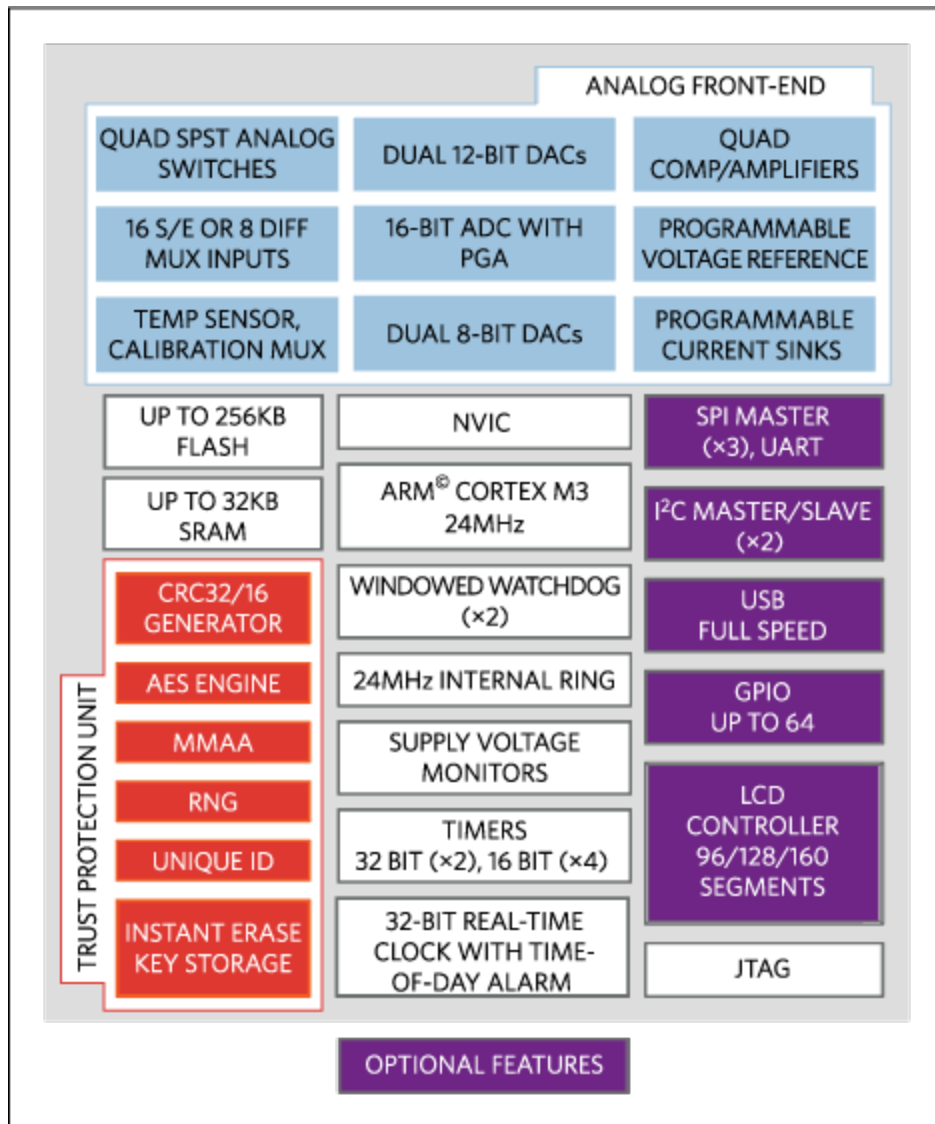


Figure 3. This highly integrated microcontroller SoC is optimized for portable medical devices. It features an AFE and high security in a Trust Protection Unit. Wired peripherals augment system flexibility and multiple power-management modes save power.

The AFE Manages the Analog Functions

The AFE consists of a SAR ADC at its core. The ADC's high 500ksps sampling rate and the 16-bit resolution let the microcontroller increase resolution using oversampling and averaging, if the bandwidth of the input signal is limited. Oversampling and averaging, in fact, increase the SNR, thereby gaining additional bits of resolution. For each additional bit of resolution, the signal must be oversampled by a factor of four:

$$f_{os} = 4^W \times f_s \quad (\text{Eq. 1})$$

Where:

w is the number of additional bits of resolution desired

f_s is the original sampling frequency required

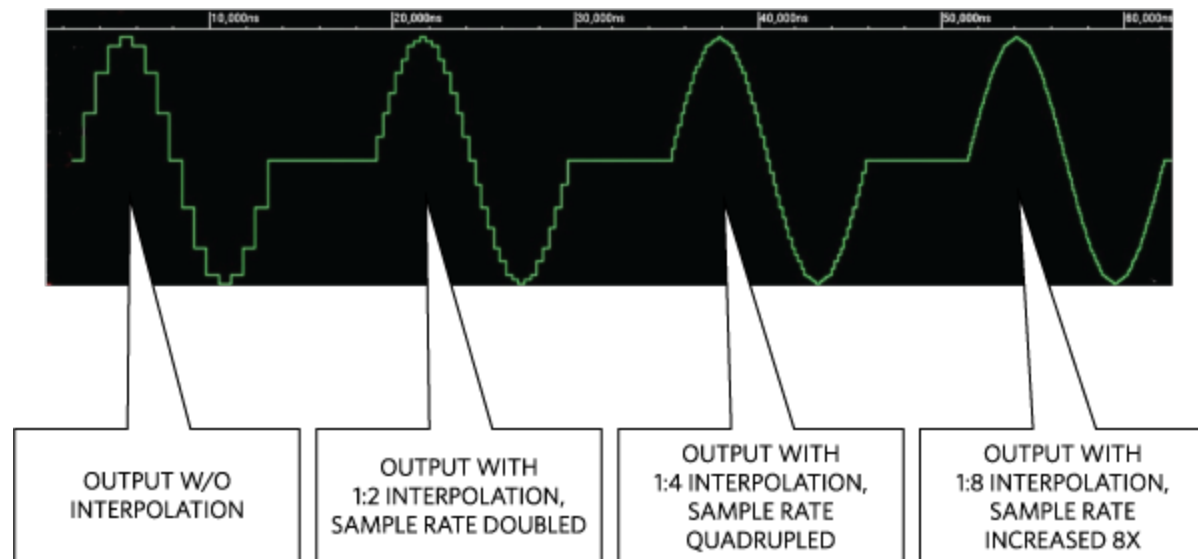
f_{os} is the oversampling frequency

This ADC can be configured to collect bursts of data at a regular interval; provide direct memory access (DMA) for the data to SRAM; and then wake up the processor. The ADC's interface provides a programmable burst sample rate (T_s is independent of the T_{s_avg}) and a programmable burst length for averaging (2, 4, 8, 16, 32, 64, 128).

The input signal is selected through a configurable, single-ended/differential multiplexer. In front of the ADC is a differential amplifier with a programmable gain of 1, 2, and 4. A reference voltage programmable at 1.0V, 1.5V, 2.0V, and 2.5V maximizes the dynamic range. Four uncommitted op amps with comparator mode and four SPST switches can be used for additional signal conditioning.

Two 12-bit DACs, two 8-bit DACs, an additional voltage reference (also programmable, as the previous one), a temperature sensor that can use an internal or external PN junction, and programmable current sinks for driving LEDs complete the analog design.

An interpolation filter (1:2, 1:4, and 1:8) (**Figure 4**), is available on the 12-bit DACs and 8-bit DACs to improve dynamic performance and reduce bus bandwidth.



It is possible to synchronize the start of the DAC pattern with ADC sampling. This enables easy impedance measuring using digital waveform synthesis and synchronizes circuits for coherent waveform generation and ADC data collection (**Figure 5**).

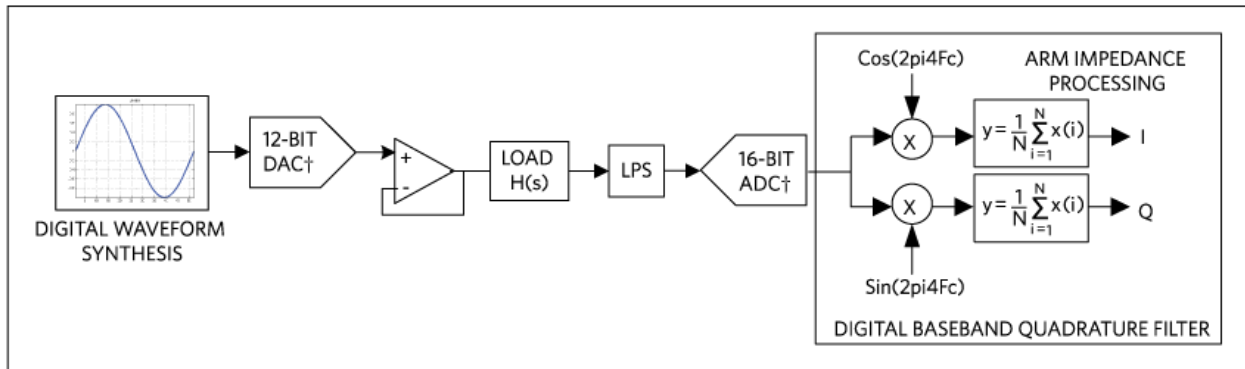


Figure 5. Signal-processing block diagram for impedance measurement.

Trust Protection Unit Provides the Essential Security

Embedded security is essential to protect the integrity of the data generated by the medical device. This SoC firmware is protected, because the flash and SRAM can be encrypted using a key stored in an internal battery-backed memory. Device authentication is provided through embedded crypto blocks and is suitable for both symmetric and asymmetric schemes.

Much has been written about embedded security, cryptography, secret and public keys. This is not the place to repeat all that information. Rather, we emphasize that the MAX32600 supports AES for encryption and ECDSA for authentication.¹ When the integrated tampering dynamic sensors are triggered, the system's public and secret keys will be destroyed. The system's FIPS-approved pseudorandom number generator will resist and thwart a security attack. A separate asynchronous internal ring oscillator is used to mitigate a timing attack.

Low Power Is Essential

Several integrated mechanisms save power. The SoC operates with a voltage down to 2.2V, a major benefit for a portable medical device powered from a primary battery. The embedded core has a 175µA/MHz operating current at 24MHz, a 1.8µA low-power mode with a real-time clock (RTC) enabled, and multiple power-management modes to save power. The option to shutdown inactive peripherals saves even more power.

A 6-channel DMA controller enables peripheral operation while the microcontroller is in sleep mode. In this way the ADC can be programmed to scan input channels, collect data, and wake up the core only when processing is needed.

Wired Peripherals Add Interface Flexibility

Embedded peripherals provide all the functions needed to implement a portable medical device. A USB 2.0 full-speed controller with physical interface (PHY) allows direct connection to the USB cable. This design reduces board space and overall system cost. An integrated voltage regulator enables smart switching between the main supply and V_{BUS} when connected to a USB host. This feature is especially beneficial in systems where the V_{DD} power supply is a battery.

Up to three SPI master UARTs enable synchronous communication with multiple peripheral slave devices. Data transfer is possible up to 24MHz. DMA is supported for both the transmit and receive buffer. The two

I²C bus master/slave interfaces permit communication with a wide variety of other I²C-enabled peripherals. Both the master and slave protocols are supported. Two universal synchronous/asynchronous receiver/transmitter (USART) ports support either full-duplex asynchronous or half-duplex synchronous communications.

Optional Wireless Peripherals (Future addition) Add Connectivity with No External Wires

A Bluetooth[®] v4.0 low-energy slave covers the 2.400GHz to 2.4832GHz RF frequency range. This interface can be used to connect to a glucose sensor and insulin pumps for an artificial pancreas application. A [free stack with source code](#) is available with a medical profile.

An ISM quad-band transceiver (315MHz, 433MHz, 868MHz, and 915MHz) supports FFSK, FMSK, AFSK modulation, and multiple sleep modes with fast wake-up.

Power Solution Adds Safety Features and Saves Space for Rechargeable Medical Devices

Our discussion now considers a portable medical device powered by an external rechargeable source. The **MAX14663 PMIC (Figure 6)** integrates a Lithium-ion (Li+) switching charger and is an optimized power solution for space-constrained portable medical devices. Used with the MAX32600 microcontroller SoC, it will maximize power, save valuable design space, and add additional features. We have already examined the MAX32600 SoC, so now we will investigate the MAX14663's features for battery management and USB connectivity.

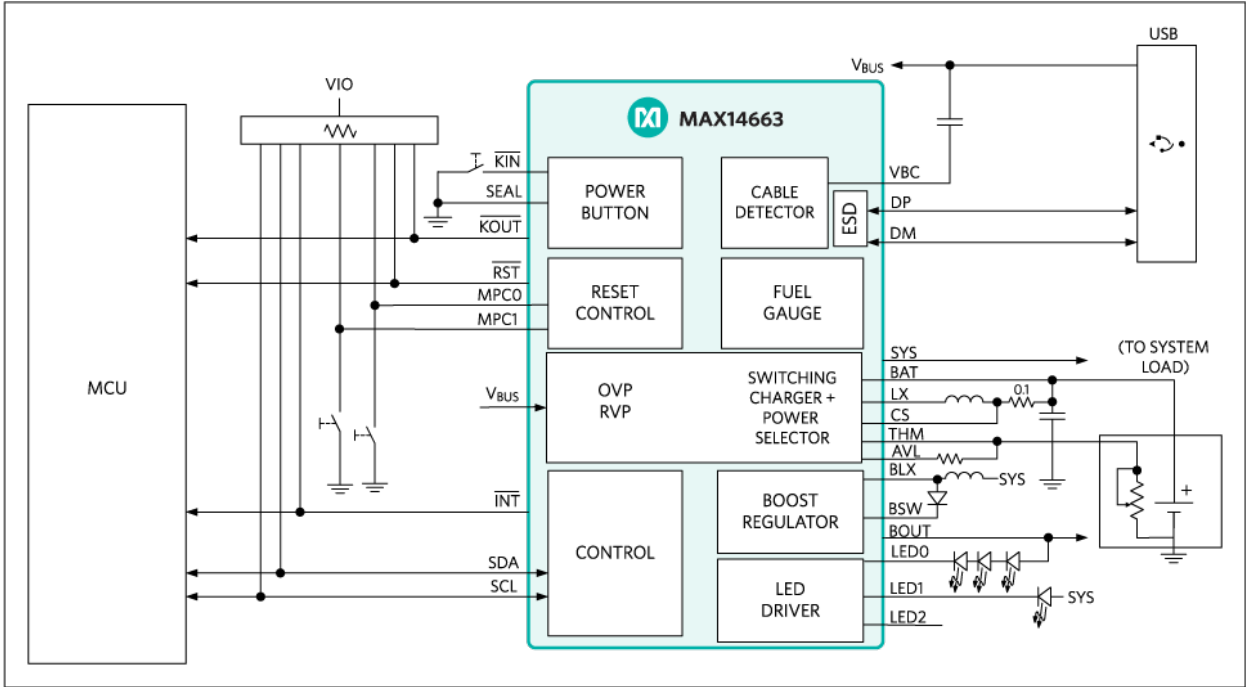


Figure 6. BGM-optimized power solution with cable detection.

Integral Battery Functions

Battery Seal Guarantees Long-Lasting Power

Portable medical equipment must retain a reliable charge and be available for use at any moment. Consequently, the design focus is on preserving the charge during the device's "shelf life." The MAX14663 integrates a switch to turn the battery off and keep it disconnected until the medical device is turned on for the first time by the end user. For example, at the end of production phase an I²C command or a proper connection of the SEAL pin can be used to disconnect the battery, thereby preserving the charge during the device's shelf life.

Simply activate a pushbutton connected to the KIN input or connect to the USB host to reconnect the battery (Figure 7).

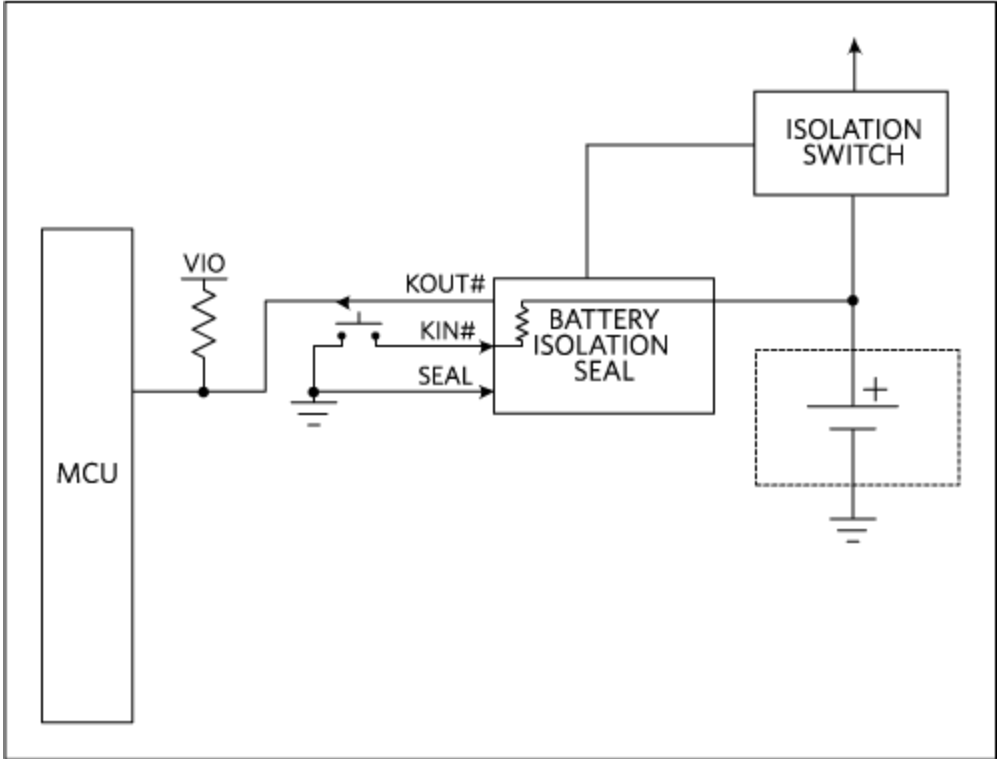


Figure 7. The battery seal in the MAX14663 in conjunction with an isolation switch preserves a battery charge.

Fuel Gauge Maximizes State of Charge

An integrated fuel gauge, based on ModelGauge™ technology, uses only voltage information to provide a state of charge (SOC) for the battery. Using a very detailed, nonlinear model of the battery, it accurately monitors the charge and battery behavior. The battery model, provided by Maxim following a characterization in its factory, has to be loaded in the device's internal volatile memory for proper operation.

Figure 8 illustrates the performance of ModelGauge technology. Random load sessions and charge sessions for random amounts of time show the battery SOC rising and falling. The green line is the reference SOC and red line is what ModelGauge reported as the SOC. You see that the green line is very difficult to distinguish from the red line. In fact, the lines are almost identical. The difference between these two curves appears in black on the right Y Error axis.

These data show that the ModelGauge fuel gauge acts like a healing mechanism in the error, moving error up and down around 0%, rather than an accumulating mechanism like a coulomb counter.

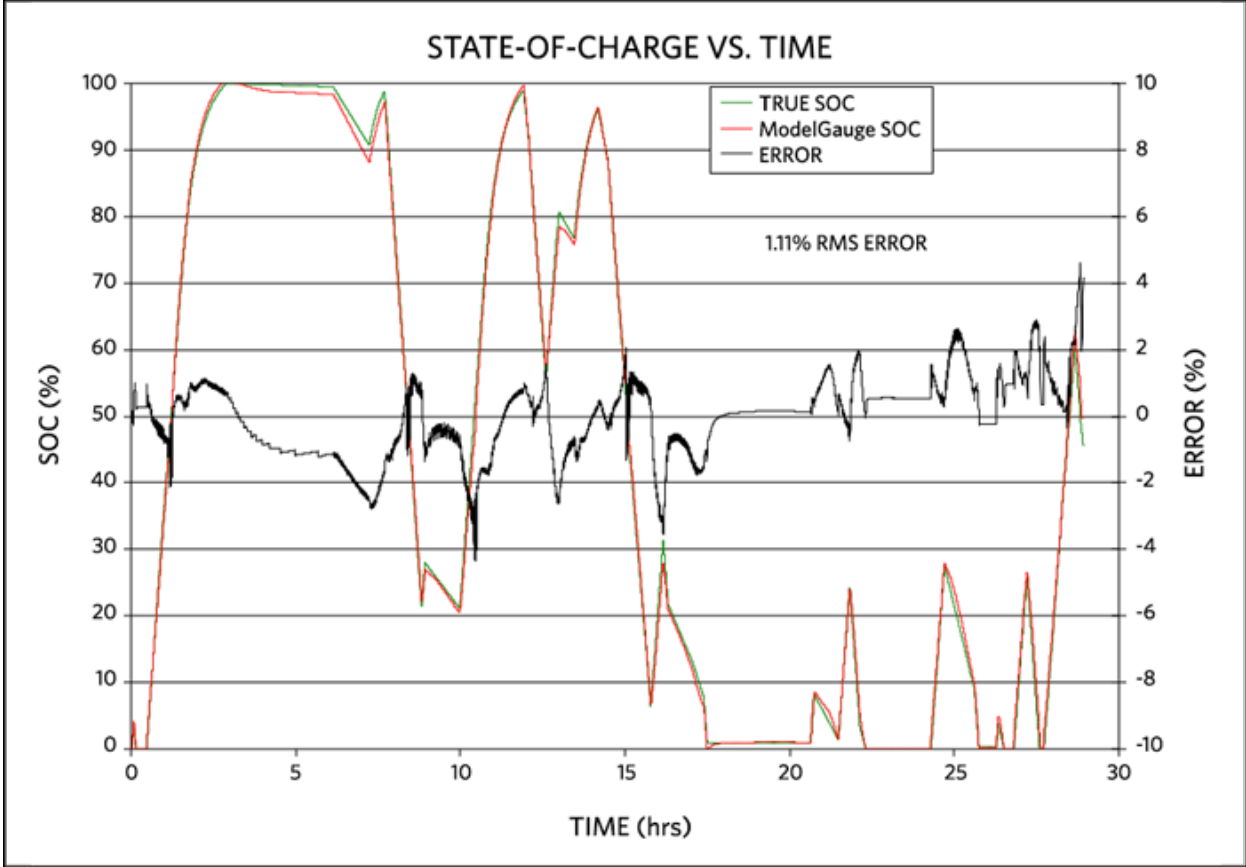


Figure 8. State of charge (SOC) vs. time. Data show that ModelGauge technology does not accumulate error over time.

Fuel gauge active current is 23µA. This fuel gauge automatically goes into a 4µA hibernate mode when the charge/discharge rate is low. This background mode does not compromise fuel-gauge accuracy. Alerts can be used to reduce the system power by allowing the system to completely shut down, even shut down some oscillators, and to reach this 4µA background mode. The fuel gauge uses an alert to wake everything up.

Battery Charger Minimizes Power Loss

A switch-mode battery charger minimizes power dissipation. During the charging, this function prevents PCB hot spots that can compromise accuracy when small signals, sensitive to temperature variation, have to be measured.

Current is regulated according to the operating mode:

- **Prequalification mode.** When the battery voltage is less than the prequalified threshold voltage

(programmable via I²C from 2.4V to 3.1V), current is limited to less than 0.1C.

- **Fast-charge mode.** In this CC/CV mode current is regulated according to the programmed fast-charge current. The range is from 50mA to 500mA in 25mA steps.
- **Autostop mode.** If autostop mode has been set, then the charge will be terminated when the programmed constant voltage (from 3.5V to 4.4V) is reached and the current has dropped to the programmed value from 12.5mA to 150mA. The charger can also be stopped using an I²C command.

The charger also monitors battery temperature through a battery thermistor. Temperature information can be used to implement a JEITA recommendation where, for safety, the termination voltage and fast charge current are modified according to the battery's temperature (**Figure 9**).

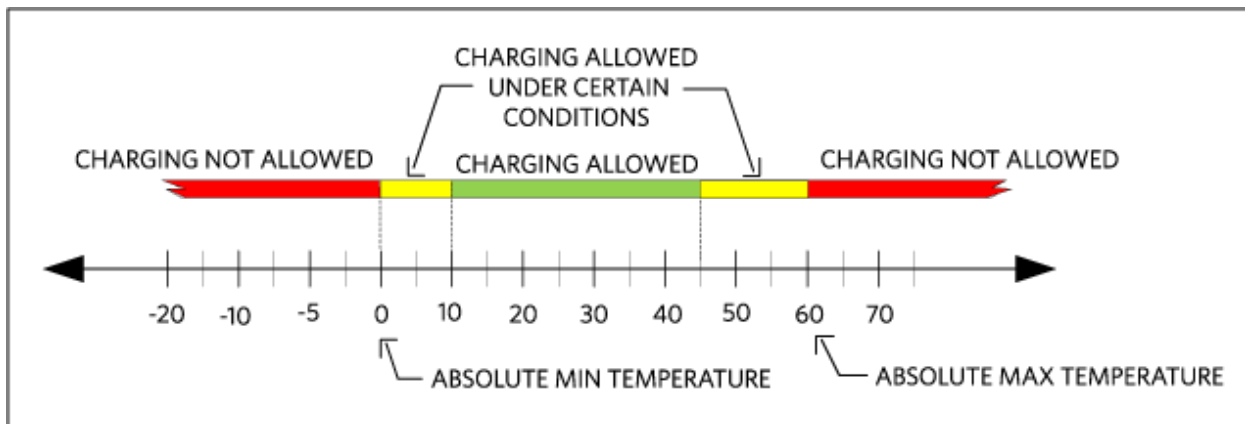


Figure 9. Following the JEITA recommendation, charge current and termination voltage are modified according battery temperature.

Power Selector Increases Battery Life

Voltage provided to the system comes from USB when V_B is within an acceptable range, and from the battery when V_B is not present. This operation occurs automatically.

Boost Regulator Allows Direct Connection of WLED String and OLED Display

An inductor-based boost converter can generate the high voltage needed for an OLED display or a white-LED string used for LCD backlight. The output voltage is adjustable via I²C from 6V to 17V in 1V steps. A true-shutdown switch disconnects the load completely to minimize current consumption.

Current Sink for Independent Regulation of LED String Current

Three independent, linear current regulators can be connected directly to the voltage generated from the boost converter. Now the current can be regulated up to 32.5mA in 25 steps. A PWM signal can be used for dimming (**Figure 10**).

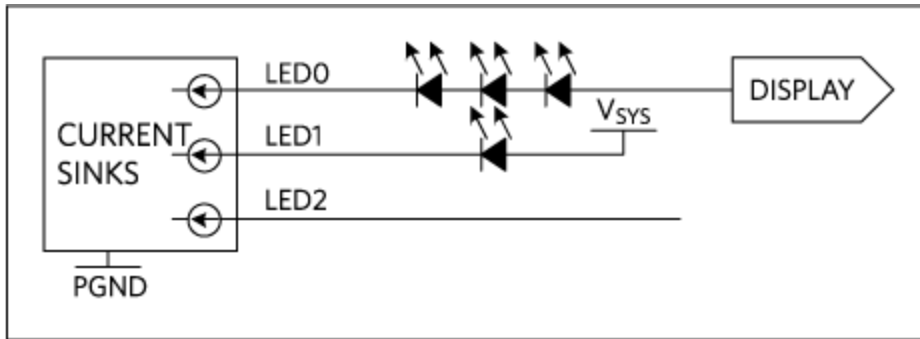


Figure 10. Current draw from current sinks can be adjusted in 25 steps.

Built-in ESD Reverse and Overvoltage Protection Safeguard the System

The system (**Figure 11**) is protected against a reverse voltage (RVP) up to -5.5V applied to V_{BUS} , and is protected against an overvoltage (OVP) up to 28V. This protection prevents any fake battery charger that tries to use the USB interface to damage the equipment. The system voltage is regulated to 5V; it is regulated for a V_{BUS} voltage up to 6.6V. If the V_{BUS} voltage rises above these thresholds, the system voltage is automatically disconnected to protect the equipment.

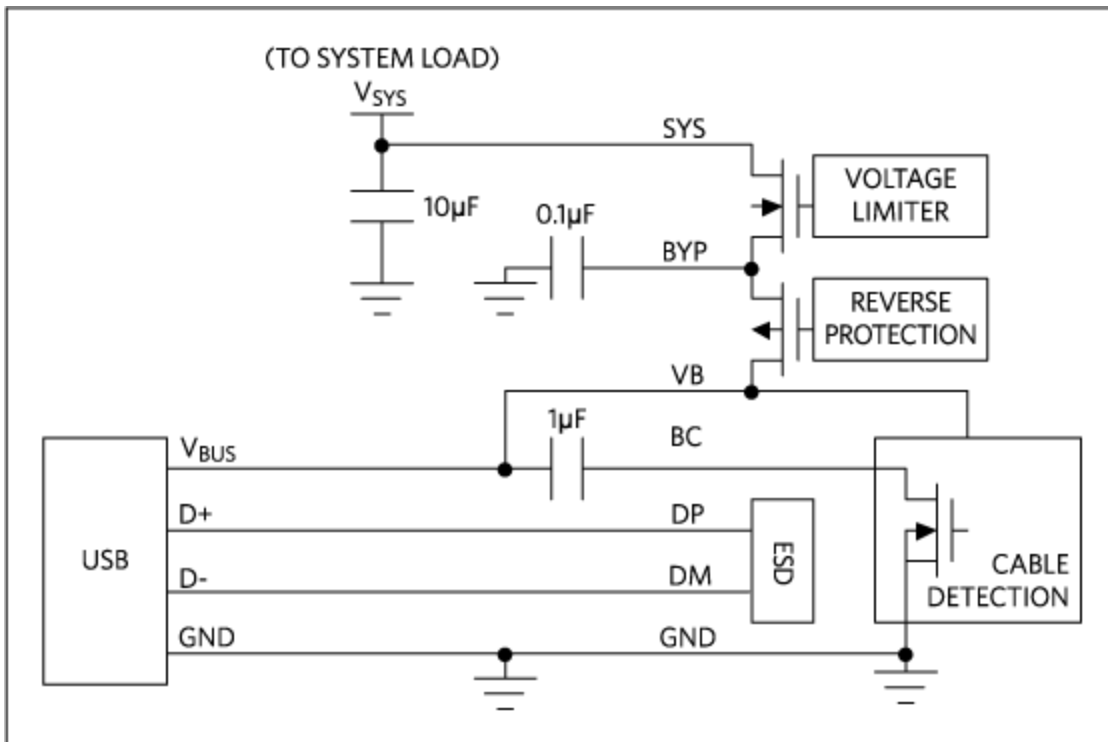


Figure 11. Built-in ESD reverse and overvoltage protection.

Referring again to Figure 11, $\pm 15\text{kV}$ ESD protection (HBM) is provided on the VB, DP, and DM pins. Another feature implemented on the USB side is cable detection. The system will detect a cable presence when the upstream port is OFF and, therefore, when V_{BUS} is not present or when the cable is connected on the device side only.

Detection is accomplished by injecting a small current when V_{BUS} is not present, and measuring the cable capacitance and capacitor connected to the upstream port. The threshold used for detection can be programmed via I²C to accommodate different PCB layouts and connector type.

Conclusion

We started this discussion talking about the millions of people who need to monitor their personal vital signs. Clearly people need the tools to make these checks at their convenience anywhere. It is thus no surprise that we are seeing the emergence of more portable medical devices: small, highly accurate, and power efficient.

In this article we focused on an efficient power-management system for a modern portable medical device. We discussed two devices. First, we presented a low-power, medical microcontroller system on chip (SoC, the MAX32600) with an integrated AFE for analog functions and Trust Protection Unit for advanced data security. It is suitable for portable medical devices using a primary battery (coin cell or alkaline) as a power source. We also presented a medical device powered from a rechargeable battery. This system uses a PMIC (MAX14663) with the microcontroller SoC to maximize power, save valuable design space, and add additional functions including battery management and USB safety.

These new integrated circuits maximize power utilization, increase flexibility, and facilitate scalable solutions without major architectural changes. For example, you can now add an optional wireless peripheral for connection to a smartphone. Once you do that, you can harness the almost-daily advances of smartphones for even more portable medical applications.

Finally, our message has been about the advantages of high integration, compared to the traditional power solution with many discrete parts. Beyond the obvious benefits of space and cost savings, fewer discrete devices also mean a more reliable solution, beneficial both for the manufacturer and the end user—you and me.

Reference

1. See Maxim Integrated application notes: 5725, "[Silicon, Security, and the Internet of Things](#);" 5716, "[Hardware Security ICs Offer Large Security Returns at a Low Cost](#);" 5522, "[Industrial Systems Need the Added Protection of Security ICs](#)."

A similar version of this article appeared January 2015 in *Electronic Specifier*.

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Related Parts

MAX14663	BGM-Optimized Power Solution with Cable Detection	Free Samples
MAX32600	Wellness Measurement Microcontroller	Free Samples

More Information

For Technical Support: <http://www.maximintegrated.com/en/support>

For Samples: <http://www.maximintegrated.com/en/samples>

Other Questions and Comments: <http://www.maximintegrated.com/en/contact>

Application Note 5790: <http://www.maximintegrated.com/en/an5790>

APPLICATION NOTE 5790, AN5790, AN 5790, APP5790, Appnote5790, Appnote 5790

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