Technical Article

Enabling Automation in Logistics and Retail—Part 1

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Exponential growth in the logistics and retail end market is driving the need for productivity and sustainability improvements throughout the supply chain. Global parcel shipments are expected to reach 256 billion in 2027 with a CAGR of 8.5%, highlighting the increasing demand for efficient customer satisfaction.[1] However, today's logistics infrastructure cannot easily keep pace and meet consumer demand for same day delivery cycles combined with a better customer experience.

This two-part article series will look at trends in the logistics and retail market, specifically investment into the use of handheld logistics devices to enable the automation transformation of the logistics supply chain. Part 1 will explore the impact of battery management in handheld devices on the bottom line. "Enabling Automation in Logistics and Retail—Part 2" will focus on how overall automation efficiency can be improved by introducing advanced capabilities in handheld devices, including high-*g* impact detection, dynamic speaker management, and built-in automatic object dimensioning.

The Automation Transformation

The typical warehouse or distribution center operates only at somewhere between 80% and 85% efficiency because of various space utilization, product transfer, and conveying inefficiencies. Furthermore, according to a recent survey of operation managers in warehouse automation, only 20% of warehouses are automated today.[2] However, this figure is expected to rise to more than 90% by 2027 with extensive investments planned over the next 5 years.

This massive logistics automation transformation will be enabled by end applications such as asset tracking, machine vision, and object dimensioning. Specifically, the efficient movement of goods through the supply chain requires the use of sophisticated barcode scanners and handheld computers. The design challenge for OEMs is that these devices must deliver a growing set of advanced capabilities in a small form factor while remaining widely battery operated.

Safety and Efficiency in Logistics Automation

Logistics companies are increasingly focused on achieving aggressive sustainability targets. To meet these goals, companies are not only modernizing their fleets with electric vehicles but also investing in the automation of the entire logistics supply chain.

One aspect of this automation includes the implementation of object, parcel, and pallet dimensioning at the beginning of the logistics cycle (see Figure 1). This information makes earlier downstream planning possible, leading to higher utilization of delivery vehicles and cargo containers. Combining this with in cabin/container asset tracking allows for end-to-end product tracking throughout the delivery process, helping to reduce product misplacement errors and enhance safety and security.

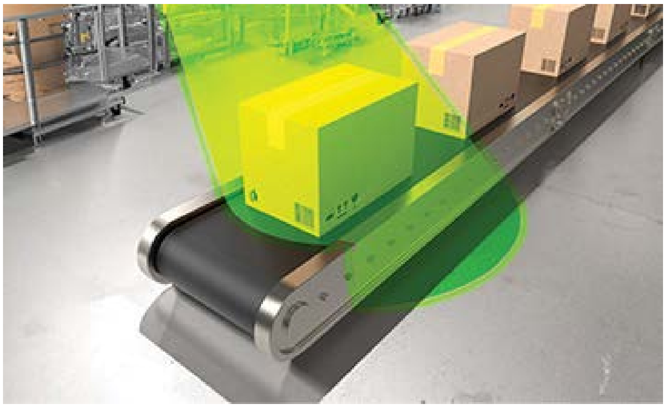

Figure 1. 3D time of flight (TOF) dimensioning over conveyor systems.

Automatic Data Capture Scanners

Automatic data capture (ADC) is a key technology for enabling transformative automation. ADC devices range from simple barcode scanners to more sophisticated handheld computers. Scanners are typically used for logistics transportation, inventory tracking, order fulfillment, and product tracking in manufacturing. While these devices perform relatively simple tasks, they need to be robust, safe, and secure. They must also be capable of operating in many diverse environments. Key requirements for scanners (see Figure 2) can be summarized as follows:

- Fast charging: The ability to quickly charge batteries means facilities can operate handheld devices with fewer batteries and fewer chargers, helping to lower overall capital investment.
- Accurate charging: Being able to completely charge a battery maximizes utilization and reduces losses due to unnecessary extra charging cycles.
- Improved edge node authentication: An estimated 5% to 7% of all batteries are clones. Battery clones can create safety hazards during charging and discharging, as well as cause operational downtime, leading to revenue losses.

- Warranty protection: Accidental drops can damage handheld devices. Integrating high-*g* accelerometers enables devices to identify when they have been dropped and potentially compromised.
- Dynamic speaker management (DSM): Automated environments tend to be loud and chaotic. Devices with audio capabilities as part of the user interface need improved speaker output using high quality audio amplifiers to retain fidelity with small form factor speakers while maximizing output power and minimizing battery operation.
- Built-in automatic object dimensioning: Handheld devices that can sense and dimension objects and products can provide information critical to improving logistics transportation and enabling significant downstream efficiencies.

We'll cover the first three items in Part 1 and the remaining three in Part 2.

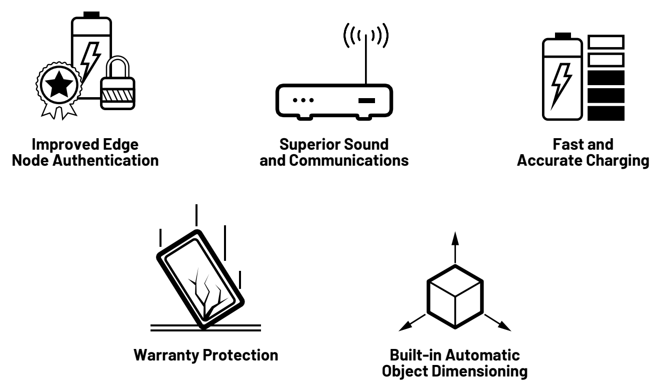

Figure 2. A summary of the key design requirements for handheld scanners.

Smart Battery Gauges for Fast, Accurate, and Secure Charging

One of the most important capabilities of a battery-operated handheld device is its battery gauge. Consider a warehouse that operates 24 hours/day. If the battery gauge on devices has a 10% error, this means that an 8-hour battery could be marked as discharged after only 7.2 hours of operation instead of its actual capacity. Compared to an accurate gauge, this equates to over 120 additional battery swaps every year for each scanner. Accurate charging can improve the uptime of handheld devices by maximizing the use of each battery pack before it is replaced. When calculated over the many devices employed in a large warehouse, the overall savings can be significant.

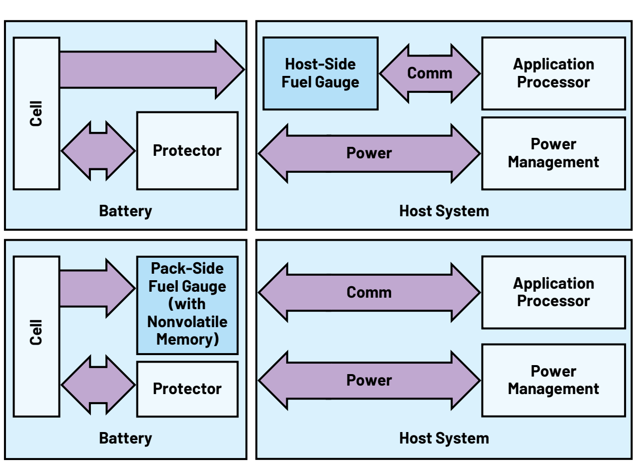

Figure 3. Host-side (top) and battery-side (bottom) fuel gauge architectures.

Fuel gauges can be implemented in two ways: host-side or battery-side (see Figure 3). In a host-side system, a simple battery pack is connected to the host charger. The host charger contains the application processor that communicates with the fuel gauge IC attached to the host-side. This architecture is suitable for a system with an embedded battery, or even a removable battery if the system is expected to be used for just a few years. It is also appropriate for cost-sensitive applications.

In contrast, in a battery-side system, the battery pack contains the fuel gauge IC. This architecture is suitable for long-life systems with a removable battery. This approach also allows secure authentication of batteries by authenticating the battery pack when it is first mounted on handheld devices (see Addressing Counterfeits Through Authentication section).

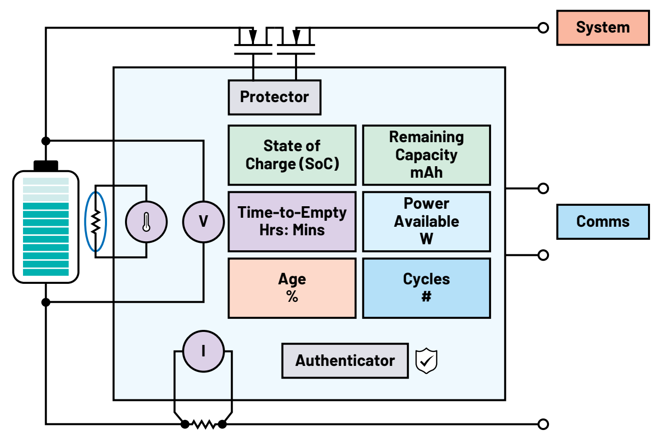

Figure 4. General architecture of a fuel gauge device with both a coulomb counter and voltage sensing.

Traditional fuel gauge methods are mainly based on either a coulomb counter that measures the charging and discharging currents through a sense resistor to estimate the flow of charge, or an open circuit voltage (OCV) measurement to estimate the remaining charge (for example, 4.2 V correspond to 100% charge and 2.8 V represent a depleted battery)—or a combination of the two (see Figure 4). Both methods have their own pitfalls: coulomb counters accumulate an offset over time (see Figure 5) that requires an error reset only possible when the battery is fully relaxed (no load) or depleted. Voltage gauge devices instead rely on the open circuit voltage of the cell. However, it can be hard to determine this given the flat behavior of a typical cell discharge curve. It is also greatly impacted by load conditions (see Figure 6).

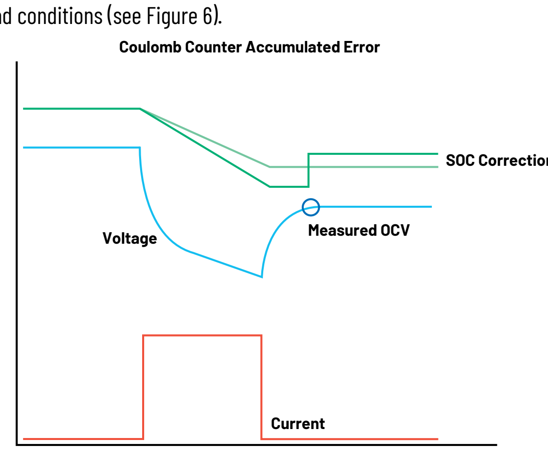

Figure 5. Example of accumulated offset error of a coulomb counter over time and correction after OCV measurement.

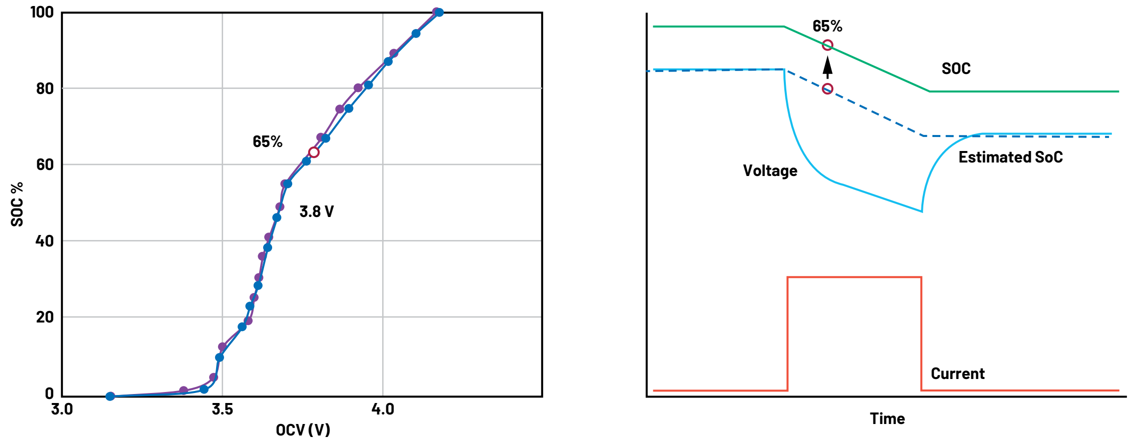

Figure 6. Mismatch between real SoC and estimated SoC from OCV measurement in voltage gauge devices under load conditions makes it difficult to accurately measure voltage on the open circuit voltage of a cell.

Moreover, coulomb counters and voltage gauge devices don't intrinsically account for internal self-discharge, aging of the cell, or temperature, each of which can greatly affect the state of charge of a battery.

To improve accuracy, more advanced sensing is required. For example, the Analog Devices ModelGauge™ family provides accurate fuel gauge data (see Figure 7) by using two separate algorithms to accurately assess the state of charge of batteries: ModelGauge and ModelGauge m5.

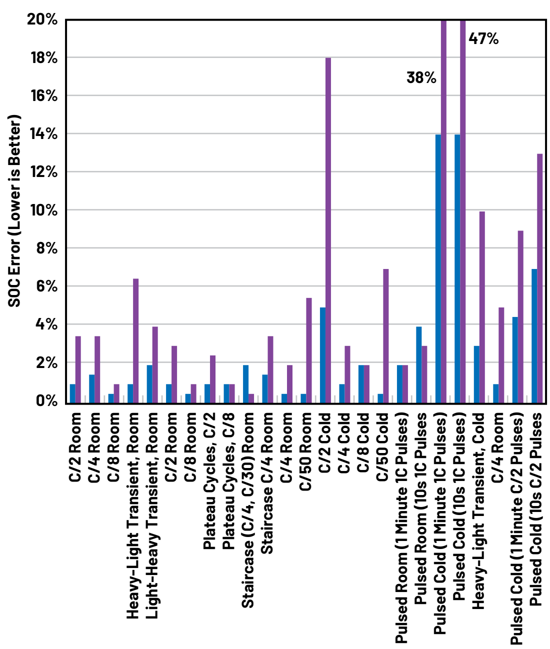

Figure 7. The state of charge error in a variety of test conditions: ModelGauge (blue) vs. traditional algorithms (violet).

ModelGauge provides the state of charge as a percentage. It estimates the OCV under load conditions without disconnecting the load. The OCV is computed using a real-time simulation with the battery voltage as input and the dynamic parameters of the battery. This approach provides good accuracy for temperatures above 0°C.

ModelGauge m5 is a considerably more sophisticated algorithm and provides much more data than just the state of charge, including absolute capacity in mAh, time to empty, time to full, cell age, age forecast, and other detailed information about the battery. This algorithm measures voltage, current, and temperature. Because of this, it provides accuracy across all operating conditions, including complex conditions such as cold temperatures or high loads. This algorithm is suitable for both host-side and battery-side implementations.

ADI offers a wide portfolio of fuel gauge devices with integrated protectors and authenticators for both host-side (MAX1726x series) and battery-side designs (MAX17201/MAX17211 and MAX17300/MAX17310 with self-discharge detector). For larger 2S+ cell batteries, both ModelGauge (MAX17049) and ModelGauge m5 (MAX17261/MAX17263) are available with integrated chargers (linear: MAX17330/MAX17332 or buck: MAX77840/MAX77818) to provide a one-chip battery management system.

For devices that need to charge using USB, ADI has AccuCharge® technology that provides a complete signal chain for battery charging using standard USB BC1.2 and the more advanced USB-C power delivery (PD) latest charging technologies. For example, the MAX77757 and MAX77787 offer automatic Type-C and BC1.2 detection with JEITA charging profile compliance. All configurations are made using resistors or digital input pins, with priority given to the resistor settings to allow correct boot from a depleted battery. As all USB detection is already built-in, architectures designed around these devices allow for a firmware-free design process (see Figure 8).

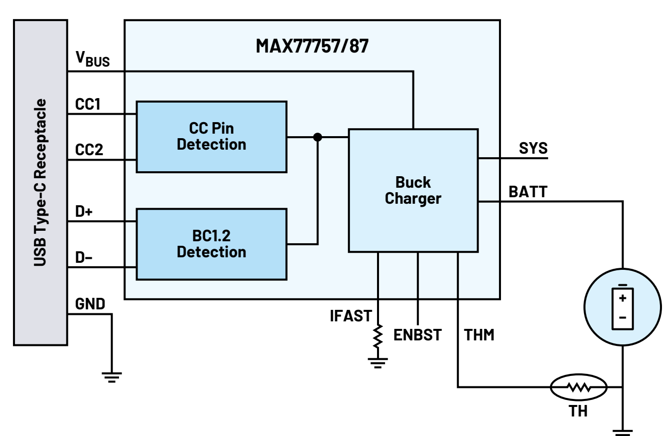

Figure 8. Power devices like the MAX77757/MAX77787 enable a single-chip architecture for standard USB Type-C (≤15 W) charging with a firmware free design process.

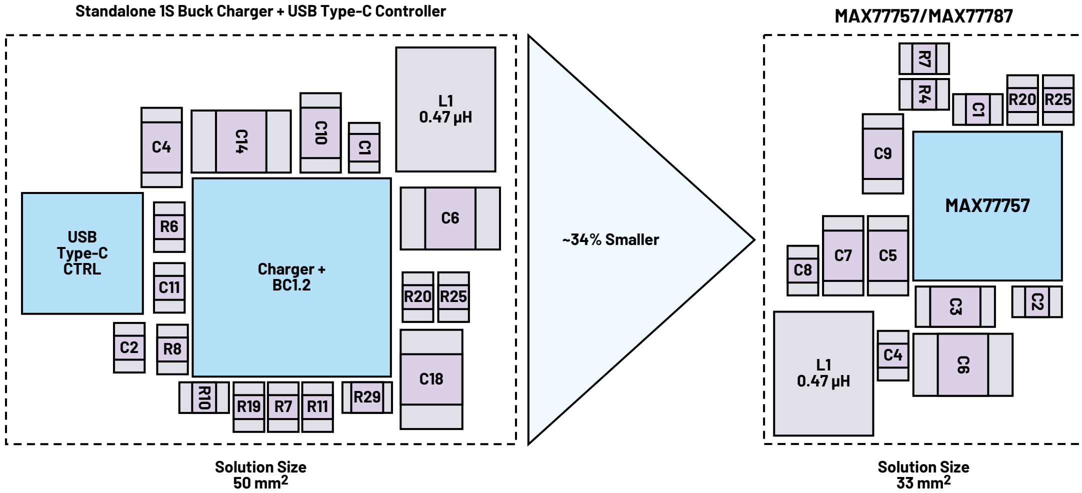

Figure 9. Integrated design and better thermal management result in a 34% smaller form factor to support even the most compact wearable designs.

Because of their high level of integration, these devices enable a smaller and more efficient final design. For example, with better thermal management, systems can charge faster and more efficiently in a 34% smaller form factor to support even the most compact wearable designs (see figures 9 and 10).

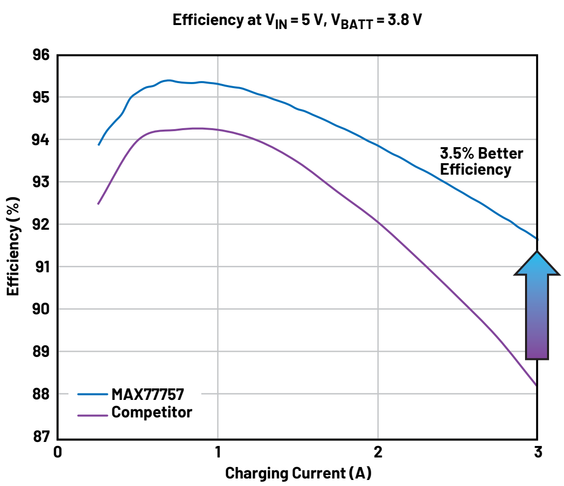

Figure 10. The design shown in Figure 9 (based on the MAX77757) offers superior charging efficiency on the order of 3.5% better.

For charging beyond 15 W, ADI offers USB-C PD systems combining the MAX77958 PD controller together with MAX77985/MAX77986 chargers with AccuCharge technology for 1-cell batteries, or MAX77960/MAX77961 chargers for 2+ cell batteries. The MAX77958 PD controller provides a fully compliant USB-C PD3.0 charger control with automatic cable orientation and power role detection, and an I^{2}C master interface to control the charger (see Figure 11).

The MAX77985/MAX77986 deliver efficiency for USB-C PD battery-powered device. Given that many battery packs are swapped in handheld computers and mobile scanners every day, charging them at high speeds means less downtime. Chargers built with efficient, integrated controllers and chargers allow high performance charging over USB-C PD. The result is faster charging of battery packs while remaining cool to minimize battery stress and maximize battery operating life (see Figure 12).

With these architectures, OEMs can improve the efficiency of applications using single lithium cell batteries as well as multicell batteries for higher voltage use cases (see Figure 13).

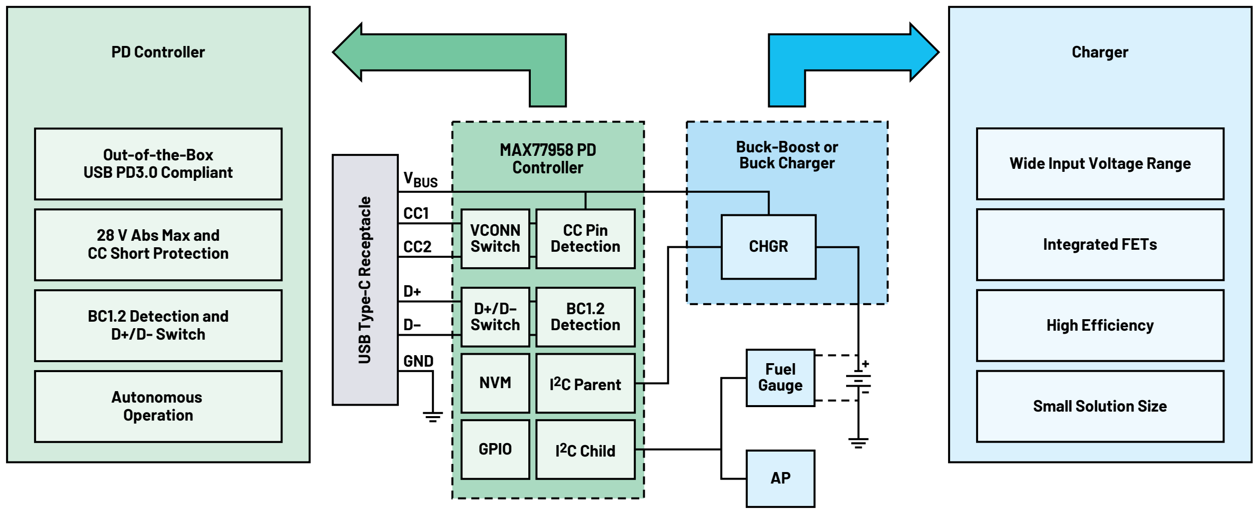

Figure 11. A block diagram of a two-chip architecture for USB PD (>15 W).

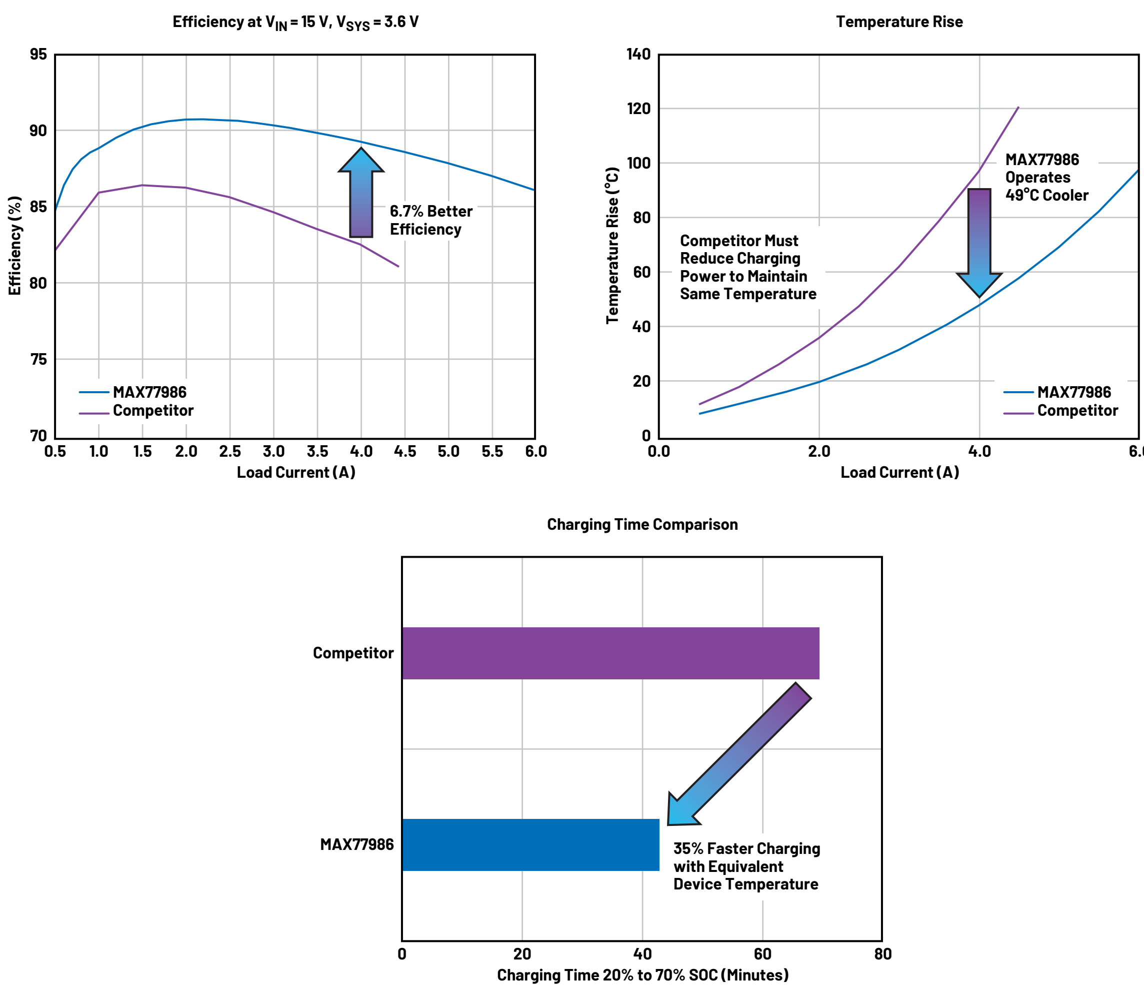

Figure 12. High performance chargers allow for cooler and faster battery charging, lowering battery stress and maximizing battery operating life.

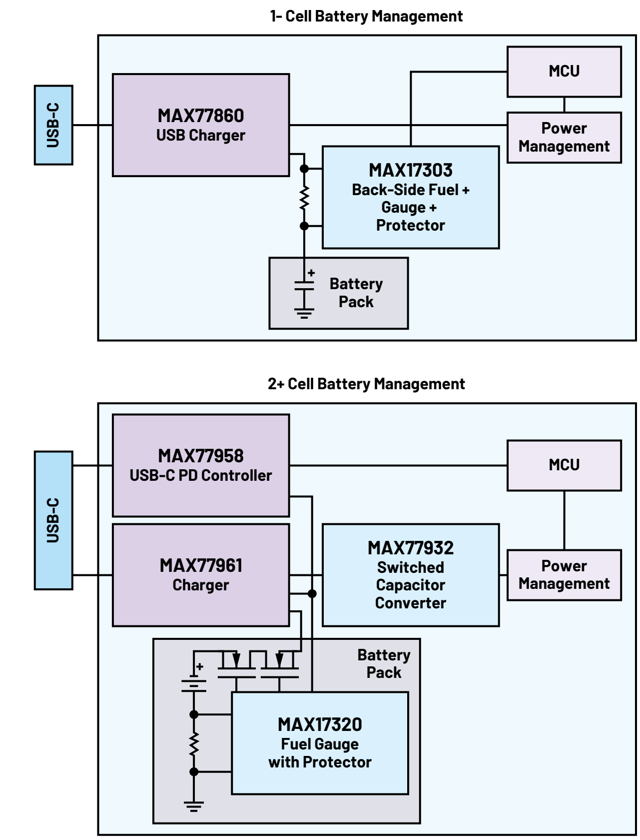

Figure 13. Complete 1S and 2S+ battery charging architectures over USB-C.

Addressing Counterfeits Through Authentication

An important consideration when designing battery-operated devices is counterfeiting. The large volume and high value of batteries required across industries makes batteries a lucrative target for counterfeiters. Counterfeit batteries are typically not built following high standards. As such, they introduce a much higher risk of dangerous internal short circuits that can lead to thermal runaways, causing a chain effect that can result in smoke or fire events (see figures 14, 15, and 16).

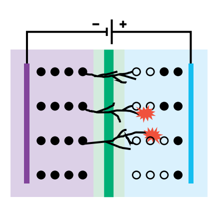

Figure 14. An internal short circuit in a counterfeit battery can lead to thermal runaway, smoke, and fires.

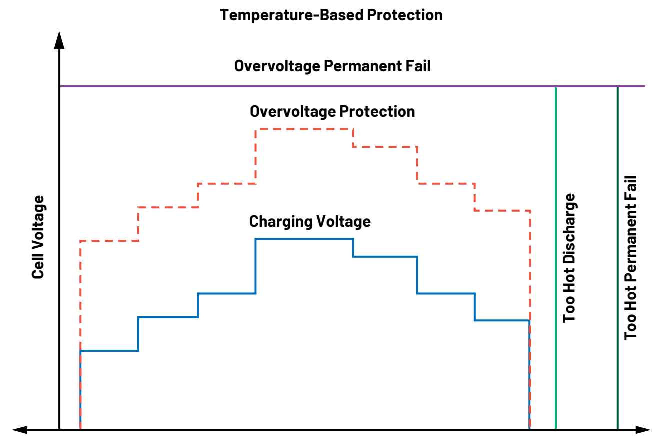

Figure 15. Stages of battery degradation due to overcharge that lead to thermal runaway.

A smart battery gauge circuit can alert the system of an internal short and cut off the battery, thus avoiding potential issues. Furthermore, systems with a battery-side smart fuel gauge can use the gauge to authenticate the battery. Both the battery and device share a secret key that enables the battery to verify its authenticity to the device upon mounting. If the battery is determined not to be authenticated, the device can prevent operation and avoid the potential safety issues that could arise from using a counterfeit battery (see Figure 16).

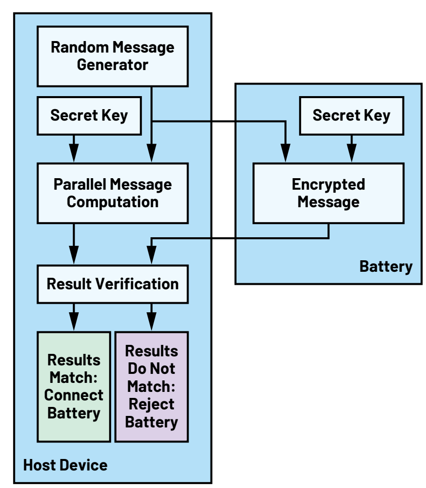

Figure 16. Battery authentication process with host-side authenticator to prevent the potentially unsafe use of counterfeit batteries.

Conclusion

ADI provides a wide portfolio of battery gauge devices with accuracy, featuring an added battery protection and authentication function with SHA-256 secure authentication using a secret key size of 160 bits to prevent battery clones. The fuel gauge IC can be programmed in the factory with the secure key before it is shipped to the battery manufacturer for final assembly of the battery pack.

In "Enabling Automation in Logistics and Retail—Part 2", we'll cover advanced capabilities that can be introduced into handheld devices to improve overall automation efficiency.

References

[1] James Melton. "Global parcel volume to grow at 8.5% CAGR through 2027." Digital Commerce 360, September 2022.

[2] "Making Modern Warehousing a Reality." Zebra.

About the Authors

Colm Slattery graduated from the University of Limerick with a bachelor of electronics engineering degree. He joined Analog Devices in 1998 and has held various roles including test development and product and system applications. Colm has also spent three years on assignment in a field role in China. Colm is currently a marketing manager in the Industrial Business Unit, focusing on new sensor technologies and new business models.

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