Battery Manager Enables Integrated, Efficient, Scalable and Testable Backup Power Systems

by Mark Gurries

Introduction

Customers of information management systems demand a guarantee that critical data is always safe. Redundant data storage systems and data backups preserve data once it is written to persistent media such as disk or tape, but data stored in cached RAM is vulnerable in the face of a power failure. Some systems always have a significant amount of data in RAM, and in a complete power loss, this data is lost. The typical solution to preserving transient data is an uninterruptible power supply (UPS), which provides AC power to the entire system. The drawback to this method is that it is not easily scalable—one oversized and expensive system must cover all scenarios.

Varying Scales of Battery Backup

The scale of the battery backup ranges from an entire system of multiple information products working together to smaller, self contained products. In the case of the large system, the system must remain running until it has had time to properly save the data and then shutdown. Often this means everything connected to the system must also remain alive. In short, the battery backup system must support the entire system while it running full blast. If the data of concern is contained entirely in the CPU processor, then naturally the size of the battery back up system scales down appropriately.

AC Backup is Inefficient

As mentioned in the introduction, the typical approach to solving the transient data problem is to supply power to the entire system via its AC input. Unfortunately, AC-level backup requires inefficient power conversions from DC to AC and back to DC, thus assuring a relatively large battery capacity for a given backup time. This is good for battery manufacturers, but bad for systems customers. The result is a physically huge and very expensive third party UPS battery backup system that must be capable of supplying worst case power consumption levels at worst case efficiencies.

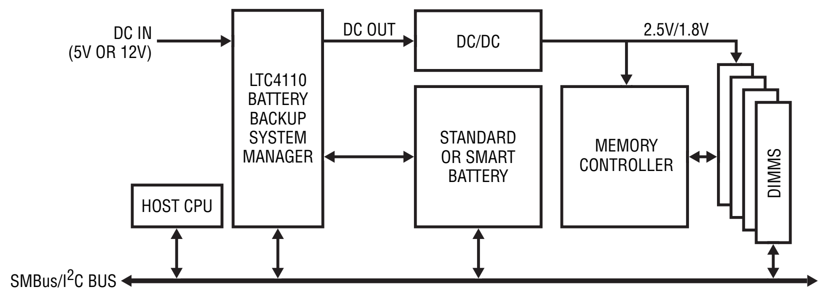

Figure 1. Block diagram of LTC4110 in a CPU/server system

The current third-party UPS paradigm takes profits that should be in the pockets of information system vendors and puts them into the pockets of UPS vendors.

A new paradigm places compact, tightly integrated, efficient and cost-effective battery backup solutions directly into the information system. The integrated system offers features and performance beyond the abilities of any UPS system.

Poorly Integrated Solutions

As is often the case, these information systems were never designed with battery backup in mind, which is one of the big reasons why AC backup is used. The lack of interoperability between the battery backup and the data system means it is difficult to optimize the complete system to save money, manage energy or generate status reports on what is really going on. The solution looks and acts like it is a cumbersome afterthought, which it is. In an extreme contrast, the every day notebook computer is an excellent example of what could be achieved in integrated power management.

The False Perception of High Cost

The consequence of traditionally large and expensive UPS solutions is that it limits the market opportunity for a system builder to offer battery backup as a built-in feature. Customers must weigh the advantages of a UPS against its reputation as a mini power station, often rationalizing ways to avoid it. Low demand drives down the incentive for system designers to integrate a UPS system. Unfortunately, this type of thinking shuffles profits into the UPS vendor's pocket that should be in the pockets of the information system vendors.

The reality is that a compact, tightly integrated, efficient and cost-effective battery backup solution can be designed directly into the information system, and it can offer features and performance beyond the abilities of any UPS system. First of all, there is a huge reduction in power needed since the backup power can be directed just to those circuits that need to be kept alive. Likewise, there are no AC efficiency losses to deal with. The combined power savings significantly reduces the physical size of the battery, making it possible to fit the entire battery backup system inside the product chassis. To address scalability issues, the integrated battery backup concept can be extended to other parts of the information system as required if multiple points of data need to be protected.

New Competitive Edge

By integrating battery backup into the information system, an information system vendor can offer better monitoring and reporting functions than a third party UPS system at a significant overall *cost savings* to the customer. This is a competitive advantage, as it is a clear win for both the system designer and the customer.

The Challenge

If the information system's design engineer is to integrate a reliable backup system as an extension of the product, there are some technical challenges encountered right up front. There are three basic subsystems involved in a complete solution.

- ❑ Battery charger
- ❑ PowerPath management
- ❑ Status reporting

These subsystems are readily available as separate integrated devices, but what if you want features that require these systems to work closely together? For instance, knowing and maintaining the battery's health and state of charge at all times in all conditions requires the concerted effort of all three systems. Other desirable features in a battery backup system include:

- ❑ Good battery verification to eliminate backup failure surprises.
- ❑ Scalability as the system grows.
- ❑ Efficiency to keep the box cool.
- ❑ Redundancy support for customers with contracts guaranteeing no data loss.
- ❑ Retain failure status even when the battery has failed, to prevent a false sense of security.

Complete Backup Battery Manager

The LTC4110 makes it possible to implement a reliable, efficient and scalable battery backup system by integrating the following functions in a single IC:

- ❑ **An efficient multi-chemistry standard and smart battery charger:** No need to burden processor with charging task.
- ❑ **Automatic PowerPath management:** Offers smooth switching between all power sources.
- ❑ **Flexible status reporting:** Status of all modes and faults over SMBus.
- ❑ **Gas gauge support:** Supports both Smart Battery and simple capacity verification for standard batteries.
- ❑ **Test load the battery:** Verify it is still good so there are no surprises.
- ❑ **Scalability:** Able to add more LTC4110's to increase total available battery capacity.
- ❑ **Efficiency:** Synchronous rectification, low loss FET ideal diode and zero heat test loading battery.
- ❑ **Redundancy support:** Use multiple LTC4110's in parallel to provide full single fault tolerance.
- ❑ **Flexible I/O pins:** Use definable GPIO pins or status output pins.
- ❑ **Status retention:** Retains battery backup failure status after battery has died.

This is only a summary of features. Let us look at an example application to see how all of these features come together.

The LTC4110's Tightly Coupled Architecture

Figure 1 shows how the LTC4110 fits into a battery-backed-up server memory system. The LTC4110 connects to the existing I^2C bus, thus leveraging existing communication infrastructure. It stands between the main distribution supply and the memory system power supply, ready to cut in the battery when the input fails.

Table 1. LTC4110 battery pack charge mode capabilities

Parameter	Chemistry			Maximum Charge Time (SLA excluded)
	Li-ion	NiMH or NiCd	SLA/ Lead Acid	
Standard Battery Support	✓		✓	Adj. up to 12 Hours
Smart Battery Support	✓	✓	✓	Unlimited

Table 2. The LTC4110's battery pack charge voltage capabilities

Chemistry	V_{CELL} Full Charge (V)	V_{CELL} Adj. Range (V)	Series Cell Count	Nominal Stack Voltage (V)
Lead Acid	2.35	±0.15	2, 3, 5 & 6	4, 6, 10 and 12
Li-ion	4.2	±0.3	1, 2, 3 & 4	3.6, 7.2, 10.8 and 14.4
NiMH or NiCd	N/A	N/A	4, 6, 9 &10	4.8, 7.2, 10.8 and 12
Super Caps	2.5, 2.7 or 3	Yes	2 to 7	5 to 18

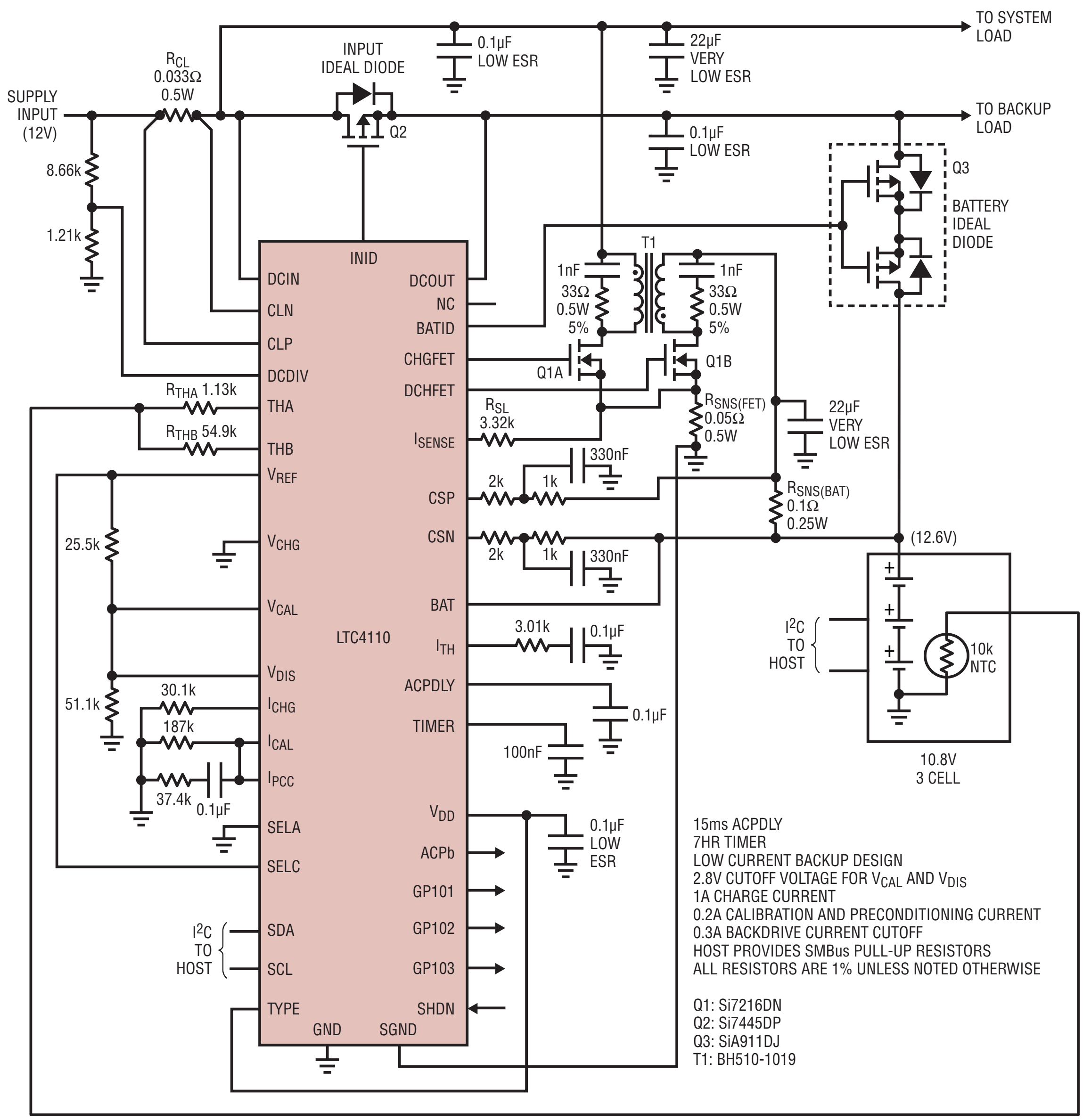

Figure 2. A LTC4110-based battery backup system

It isolates DCIN from DCOUT so that the only load the battery is supporting is memory. The existing DC/DC converter converts the unregulated battery voltage and continues to provide the regulated voltage to the memory.

Figure 2 shows the LTC4110 battery backup controller schematic. The schematic shows a 12.6V Li-ion being charged from a fixed 12V power source.

Super Flexible Battery Charger

The 300kHz battery charger consists of an efficient synchronous rectified flyback charger with an input range of 4.5V to 19V intended for charge rates of up to 3A. The wide 2.7V to 19V output voltage range is capable of charging batteries to full termination voltage whether the voltage is less than or greater than the input supply voltage. There is no need to configure the battery pack voltage to work within the limits of the input supply, thus giving you total freedom to optimize the battery for the application. For batteries that use constant voltage charge, the output accuracy is ±0.5%, but at the same time adjustable allowing you to optimize a battery for longer battery life or maximum capacity. Float voltage temperature compensation is also offered for sealed lead acid batteries.

The LTC4110 contains many battery charge protection systems, including charge-preconditioning qualification for all chemistries before entering bulk charge and a thermistor interface to monitor battery temperature. Safety timers are also used in various ways to prevent battery overcharge or to help detect defective batteries. If a battery faults, charge status is updated. In Standard Battery mode, the LTC4110 uses built in charge termination capabilities. In Smart Battery mode, the battery itself controls charge termination. Regardless of the mode, the battery charger is capable of charging many different types of battery chemistries in many different cell configurations. Tables 1 and 2 provide a quick overview of the LTC4110 charge capabilities. Figure 3 shows the power flow in charge mode.

Building Confidence in Your Battery While Keeping Your Cool

Knowing the condition of the backup battery at all times is essential if one is to have any confidence in the system. Under the watchful eye of a host CPU or power manager, there are three things you can do to build that confidence:

- ❑ **Test loading the battery:** Does the battery still work?
- ❑ **Verify battery capacity:** Does it still have the retained capacity to support the backup?
- ❑ **Gas gauge status:** What is the State of Charge (SOC) of the battery?

Test loading the battery at first seems straightforward enough. Simply connect a test load to the battery and watch it work. Ideally, the battery is tested while in the product, avoiding the need to open up the box. The big issue one must deal with is the heat the load generates during the test. In many applications, the product itself is already operating close to thermal limits, which means putting that extra heat inside the box may not be possible.

In LTC4110 terms, test loading the battery is part of a mode called "calibration." In calibration mode, the LTC4110 uses its flyback charger in reverse to discharge the battery with a programmable constant current into the "system load" eliminating heat generation. During calibration, the main AC/DC power supply simply sees a reduction in the system load current equal to the current provided by the battery. There is no temperature change inside the product. The battery continues to discharge until conditions are met to terminate discharge. Upon termination of discharge, the LTC4110 automatically starts a recharge cycle to return the battery back to ready status. Figure 4 shows the power flow in calibration Mode.

Verifying battery capacity can be easily done during the same calibration process. With a battery discharge current accuracy of ±3% at $R_{SNS(BAT)}$ in Figure 2, the host can start the calibration process while monitoring the elapsed time it takes for the full battery to reach empty. The host, knowing the fixed load current, can use the time information to determine the battery's present storage capacity (amp-hour) with reasonable accuracy.

If one desires to have full time high accuracy battery SOC monitoring, the industry standard Smart Battery System (SBS) Gas Gauge, as found in every notebook PC made today, is the only real solution. The LTC4110 fully supports this standard in charge, discharge and calibration modes of operation.

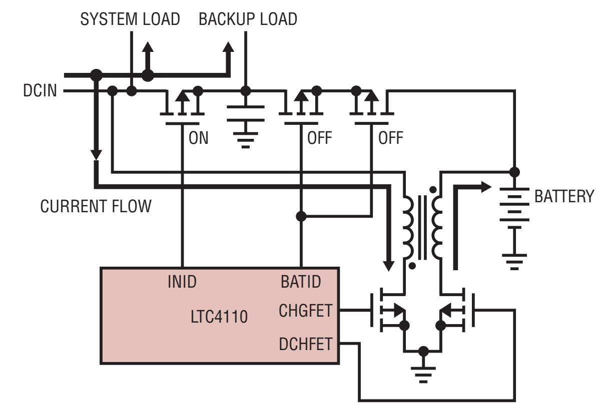

Figure 3. The LTC4110 in charge mode

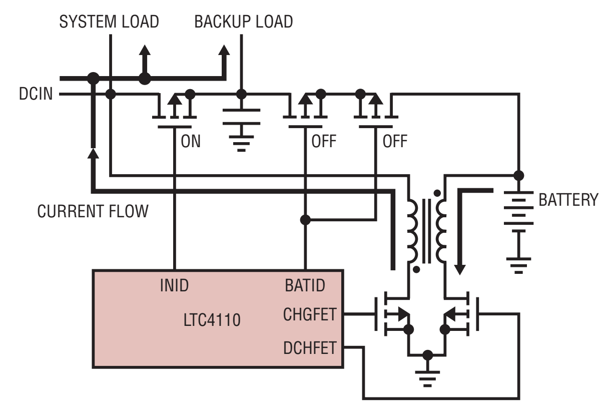

Figure 4. LTC4110 in calibration mode

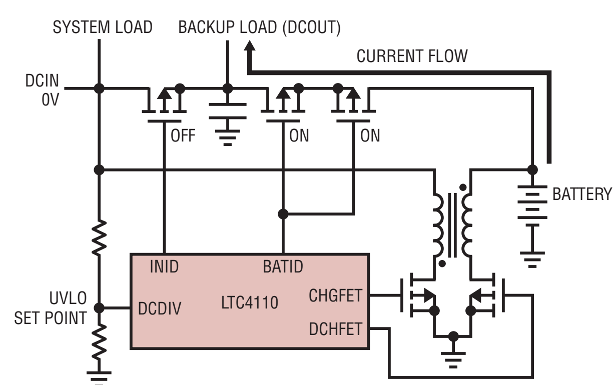

Figure 5. The LTC4110 in battery backup mode

Lossless Automatic PowerPath Operation

The LTC4110 uses ideal diode circuitry to drive its PowerPath™ MOSFETs. An ideal diode circuit uses a MOSFET where normally a diode would be used to control the flow of power. Like a true diode, current is only allowed to flow in one direction despite the fact that MOSFETS can conduct current in both directions. The forward voltage drop of an ideal diode is far less (25mV) than that of a conventional Schottky diode (350mV), and the reverse current leakage can be smaller for the ideal diode as well. The tiny forward voltage drop reduces power losses, minimizes self-heating and ,in the case of a battery, extends battery life.

In Figure 2, there are two sets of ideal diodes forming a power-OR between the supply input (DCIN) and the battery, forming an output called *backup load* (DCOUT). In the Figure, two back-to-back MOSFETs are used in the battery path since in this application the full charge battery voltage is greater than the DCIN voltage. However, if the battery voltage is less than DCIN, only one MOSFET is needed.

Under normal conditions, the input ideal diode is always on. If the DCIN voltage divider senses a condition where battery backup is desired, the battery ideal diode is turned on with the input ideal diode left to figure out when to turn off on its own. The diode action allows the highest supply to take up the backup load. But since DCIN is falling, the input ideal diode turns off as soon as it senses a reverse current flow. The goal of the ideal diode design is to always attempt to do a "make before break" handover if possible, minimizing the need for any "bridging" or "holdup" capacitance. Figure 5 shows the LTC4110 in battery backup mode. The thick line shows the active power path.

Expandable Capacity or Creating Redundancy

Ideal diode technology is also the key that allows one LTC4110 to work with other LTC4110s in safely paralleling batteries for redundancy. Multiple LTC4110s can be connected in parallel at the backup load (DCOUT) point. At no time will the batteries exchange current between them regardless of any difference in SOC or voltage.

Assuming the batteries are the same make, model and age, the batteries automatically act as one big battery, sharing discharge load current based on their relative SOC ratios. If all the batteries are the same SOC, the current is equal among them. Charge current remains independent.

Some battery chemistries, such as Li-ion, have rules about the size of the battery that can be safely transported. If your backup needs exceed 95 watt-hours of capacity, you must use multiple batteries. Simply add another LTC4110 to support dual battery operation. Fortunately, this expansion also gives the system true redundancy by minimizing the number of parts shared between each backup system. Figure 6 shows a dual LTC4110 system using two standard (not Smart) batteries.

Flexible SMBus Addressing and Registers

Whether you are using Smart Batteries or standard batteries, the LTC4110 supports an SMBus interface that the host CPU can use to control and monitor each part. To make configuration easier with standard batteries, the LTC4110 supports up to three unique SMBus addresses. However, if you use Smart Batteries, all of the LTC4110s must use the same address and each LTC4110 and associated Smart Battery local SMBus must be isolated from all the other LTC4110s. This is easily done with SMBus multiplexer such as the LTC4305 or LTC4306 under the control of the host CPU. Wherever possible, the LTC4110 follows the Smart Battery System (SBS) Charger Specification for registers definitions for compatibility with software that works with Smart Batteries.

Complete Status and Flexible GPIO Lines

Internally, the LTC4110 uses two 16-bit SMBus read registers to report 27 unique status items. This includes a bit that retains and reports if the battery backup has failed, even after the battery has gone below the user defined end of discharge cutoff (dead) threshold. Another 16-bit SMBus write register controls the charger and how the three GPIO bits are to be used.

Each GPIO bit can be programmed to report selected internal status information or work as generic digital I/O independently of the other bits. A fixed AC present status output bit is offered

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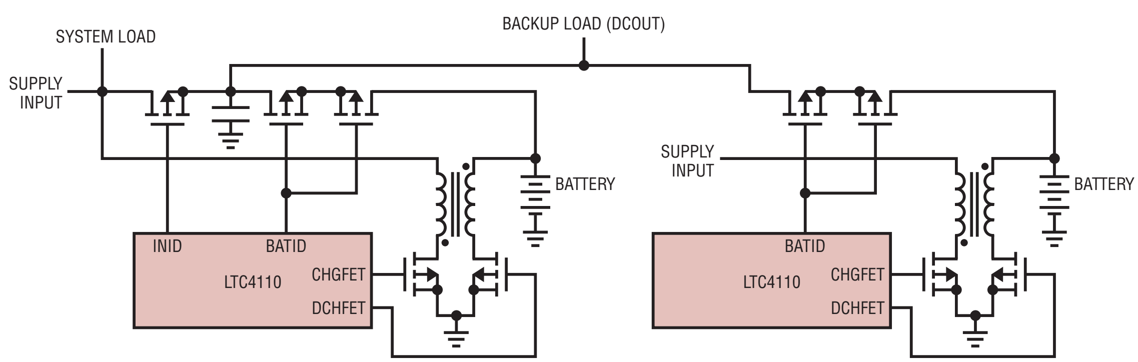

Figure 6. Dual LTC4110 system using standard batteries

(falling), so low voltage monitoring is possible.

The falling threshold accuracy for both the LTC2934 and LTC2935 is ±1.5% over the full operating temperature range. Minimum V_{CC} is a low 1.6V. Configuration details are discussed in the LTC2934 and LTC2935 data sheets.

Manual Reset and Reset Timing

The LTC2934 has two selectable reset timeout periods. Tie the RT input low for a 15ms timeout. Tie the RT input high for a 200ms timeout. The LTC2935 has a fixed 200ms timeout. Both parts have a manual reset input which asserts $\overline{RST}$ low when the $\overline{MR}$ input is pulled low (typically with a switch). The $\overline{MR}$ input has an internal 900k pull-up resistor to V_{CC}, used to pull up the $\overline{MR}$ input when the switch is open. Alternatively, the $\overline{MR}$ input may be pulled low with an external logic signal. When the $\overline{MR}$ input returns high, $\overline{RST}$ pulls high after the reset timeout period has elapsed, assuming that the monitored input voltage is above the reset threshold.

Monitoring a 2-Cell Li-Ion Stack

Some portable applications utilize a stack of batteries to achieve greater product operating lifetime. For a product using two stacked 4.1V Li-ion cells (or similar), the total stack voltage (8.2V) exceeds the maximum operating voltage (5.5V) of the LTC2934. However, if the center tap of the 2-cell stack is available, cell monitoring is still possible. Figure 4 shows how the center tap of the stack is used to bias the LTC2934. The total stack voltage is monitored at the power-fail input (PFI). The application is configured to pull the $\overline{PFO}$ output low when the sum of the battery voltages drops below 6.00V. The adjustable input (ADJ) monitors the LDO output. $\overline{RST}$ pulls low when the LDO output drops below 3.00V.

Super Hysteresis

Some applications have a large load transient when powered. This transient can cause significant supply voltage drop if battery series resistance is large. If the load is enabled after the reset output pulls high, the subsequent voltage drop could put the voltage at the V_{CC} monitor input below threshold, causing the reset and power-fail outputs to pull low. In such cases, active threshold control (shown in Figure 5) is helpful. The LTC2935 power-fail output ($\overline{PFO}$) can be used to change any (or all) of the threshold control input states (S2, S1, S0). The power fail comparator threshold is always 150mV larger than the reset threshold and the power-fail output does not experience the 200ms reset timeout delay. If the power-fail output pulls high before the reset output (which is almost always the case with rising supplies), it can then be used to lower the falling thresholds to one of the other seven threshold selections. In Figure 5, the reset falling threshold is changed from 3.3V ($\overline{PFO}$ low) to 2.25V ($\overline{PFO}$ high), which provides a generous 1.05V of falling hysteresis.

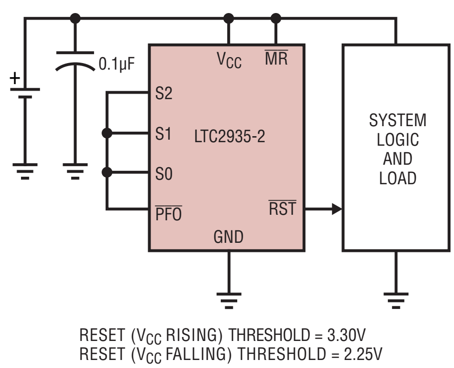

Figure 5. Active threshold control

Conclusion

The 500nA current required by the LTC2934 and LTC2935 supervisors is so small, it can be placed into the "Don't Care" column of your device power budget. Although the power is low, these supervisors don't discard features. The power-on reset and early power-fail warning signals provide glitch-free logic controls to your system logic. Reset delay time is built in. Manual reset is available in both parts. Configuring these supervisors is easy, and few if any external components are necessary. Ultra-low input leakage specifications make high impedance applications possible. Specifications are guaranteed from –45°C to 85°C. Both parts are available in space saving 8-lead, 2mm × 2mm DFN and TSOT-23 (ThinSOT™) packages.

LTC4110, continued from page 21

at all times. However, if you do not have SMBus in the product, the LTC4110 can be configured to enable preset status information to drive the GPIO bits on power up. This information can be used to drive status LEDs.

Micropower Shutdown and Shipping

The LTC4110 shutdown pin is designed to prevent false shutdowns on power up or power down. Reading the pin status is pre-qualified such that it is only honored under normal conditions. This qualification allows the product to ship with the battery installed without fear of the part entering into battery backup mode and draining the battery. The shutdown current only draws 20µA from the battery. This is the same shutdown mode that the LTC4110 enters when the backup battery reaches its end of discharge point.

Conclusion

The LTC4110 is a flexible standalone battery backup controller. By integrating key features into a single IC, functions work together seamlessly, allowing the designer to offer a reliable and complete battery backup system with minimal design effort.

Authors can be contacted at (408) 432-1900