Smart Batteries and the Intersil X3100

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Introduction

Smart Batteries today are a requirement for the latest high performance portable laptop computers. These new machines must squeeze more performance into smaller packages while at the same time increasing battery life. To achieve these goals the designer must incorporate new methods of managing system power consumption and available battery capacity. As battery management techniques mature and become more common, application of smart batteries will extend beyond the PC into other portable devices, such as medical electronics, portable test equipment and other battery powered systems

Portable Laptop PCs have migrated almost exclusively to Lithium-Ion (Li-ion) type batteries. These batteries provide increased capacity per weight and per volume, allowing a more portable product in a smaller form factor. However, Li-ion batteries have some characteristics that require additional circuitry to manage their operation. Extra electronic content is also required in smart battery designs to squeeze more capacity out of the Li-ion cells and to provide the user with better "fuel gauge" information.

This application note examines the Intersil X3100 Li-ion Battery Protection and Monitor IC and it is used in smart battery designs for the next generation of PCs, portable equipment and medical electronics.

Battery Pack Considerations

Battery Pack Design

Battery packs consist of 1 or more cells. Connecting cells in series provides higher voltage, connecting cells in parallel provide higher capacity[1]. Some packs utilize combinations of serial and parallel cells. Typically there is a trade-off between available space, capacity (run-time) and required voltage.

A battery powered design should start with the consideration of battery space and weight of the system. Knowing this, and having a knowledge of the operating voltage of the various system components, plus total system power requirements and desired operational life, the designer determines the cell capacity, voltage and pack configuration. Finally, to optimize battery usage and run time, the designer specifies the requirements for the system power management.

A typical PC might use three series combinations of 2 parallel Li-Ion cells. This is termed a 3S-2P pack. If each cell is nominally 3.6V with 1350mAh capacity, then the overall pack provides 10.8V at 2700mAh.

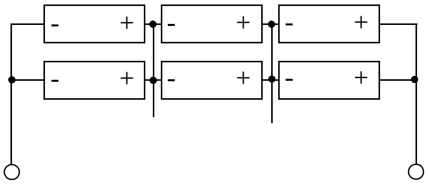

FIGURE 1. 3S-2P ARRANGEMENT OF CELLS IN A BATTERY

Safety

Lithium Ion batteries are key to achieving increased PC perfomance in laptop computers in the near future[2]. They have very good volumetric and gravimetric energy density. However, they also have some challenging design and safety issues that must be observed.

Lithium Ion batteries need special safety circuits in every battery pack to monitor over-charge, under-charge and short circuit conditions. If these conditions occur, the battery pack must be "shut down." In the worst case, over charging lithium Ion batteries can result in sudden, automatic, and rapid dissassembly (explosion). In the best case, overcharging lithium Ion batteries can result in damage to the cells, reducing capacity and cycle life.

To be safe, the battery pack safety circuit limits the voltage on the battery pack cells to prevent unsafe conditions. An over-voltage limit set too high can result in damage to the cells and unsafe operation, however an over-voltage limit set too low significantly reduces run time as capacity is given up. Similarly, the undervoltage limit must be set accurately, since overdischarging the Li-Ion battery results in chemical changes that are irreversible, reducing the capacity and cycle life, while stopping discharge too soon leaves usable capacity in the battery. The safety unit must, therefore, have the correct over-voltage and under-voltage limits and these limits must be accurate to a very narrow range. Because of the critical nature of the safety circuits in a battery pack, some systems require redundant or backup mechanisms for shutting down the battery pack and removing the load from the cells.

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[1] Higher capacity can be obtained from a single cell instead of parallel devices, however higher capacity devices have a larger diameter or height. In some applications, such as a PC, there are more limitations on pack height than on length and width.

[2] See Application Note AN126 "Battery Primer" from Intersil.

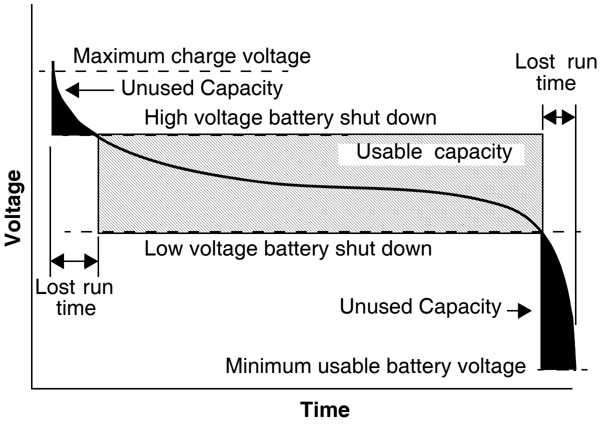

FIGURE 2. EFFECTIVE BATTERY CAPACITY

Cell Balancing

A careful examination of the operation of typical protection circuits reveals an obstacle that the pack designer needs to consider. Since the pack stops charging when any ONE of the cells reaches the overvoltage limit, there may be other cells that are below the limit and not fully charged. Additionally, the pack will turn off when ONE of the cells reaches the minumum voltage, even though other cells may not be at the minimum value.

The mismatch of the voltage between cells does two things. First, it reduces the overall capacity of the pack. The cells are not all fully charged nor discharged, even though the electronics sense that the pack is fully charged or discharged. This leads to reduced run time. Second, having cells charged or discharged to different values leads to increasing pack imbalances and reduced cell life.

Cells become unbalanced in two ways. First, although quality control is improving, manufacturing variations can contribute errors of a few percent across all cells in a pack. Second, cell imbalances can be accelerated by temperature. This is especially true in newer PCs that have a high performance CPU that generates more heat than surrounding circuits. Placing a battery pack in close proximity of the processor could result in one cell being heated disproportionately. The heat applied to one side of the pack causes one or more cells to charge or discharge more slowly, accentuating cell disparities.

Fuel Gauging

Lithium ion batteries need very precise electronic monitors and safety circuits built into the battery pack, but the pack also needs other electronic content. The pack and system designer must implement cost effective hardware and software to provide the user with the greatest possible run time and the most accurate information possible on the status of the battery. To do this requires the ability to monitor the current put flowing into and taken out of the battery over a wide dynamic range[3]. The circuit must factor in temperature, cycle history, battery chemistry, charge/discharge state, application usage and other conditions to achieve the highest accuracy gauge of remaining capacity.

Finally, battery pack electronics must be very small, to fit within ever smaller battery pack geometries. Space requirements depend on the desired level of pack functionality and the level of electronic integration.

The X3100 Safety Unit

Intersil designed the X3100 to meet the specific needs of a three or four cell (series configuration) Lithium-Ion battery packs, such as found in a laptop computer. Special features provide flexibility in dealing with safety parameters for various Li-Ion chemistries and the X3100 provides building blocks for implementing fuel gauging, cell balancing and pack monitoring hardware. This section describes some of the key circuits and how they increase the safety, performance and flexibility of the battery pack design.

Pack Architectures

All Li-Ion battery packs with three or four series cells require basically the same functions, however there are several ways to partition the electronics. The major components consist of a safety unit, monitoring circuitry, a fuel gauge, an EEPROM nonvolatile memory and a controller. The X3100 integrates the safety unit with the EEPROM and provides circuits that allow a low cost microcontroller to monitor various battery voltages and load current. A general purpose microcontroller, through software and the analog building blocks in the X3100, provides fuel gauge operation, cell balancing, redundant pack monitoring and control (if desired) and a communication link to the host CPU.

The X3100 operates at battery pack voltages of up to 24V maximum, and provides voltage regulation and voltage reference to the microcontroller. This combination of functions isolates the microcontroller from the high battery pack voltages, gives the flexibility of a fully programmable, but low end microcontroller, and offers an overall cost effective solution. This system partition is shown in Figure 3

Other battery pack configurations group the components differently. This choice of pack architecture is based on two primary considerations. The first is technology. Fuel gauging and controller circuits are predominatly digital, while safety circuits are analog and EEPROMs are a mixture of analog and digital. Combining all of these functions on a single chip is difficult and requires non-standard semiconductor processes. These processes have historically lead to higher cost components.

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[3] A system in idle state might consume as little as a few milli-amps, while pulses of several amps are not uncommon in graphic subsystems or during spin-up of disk drives.

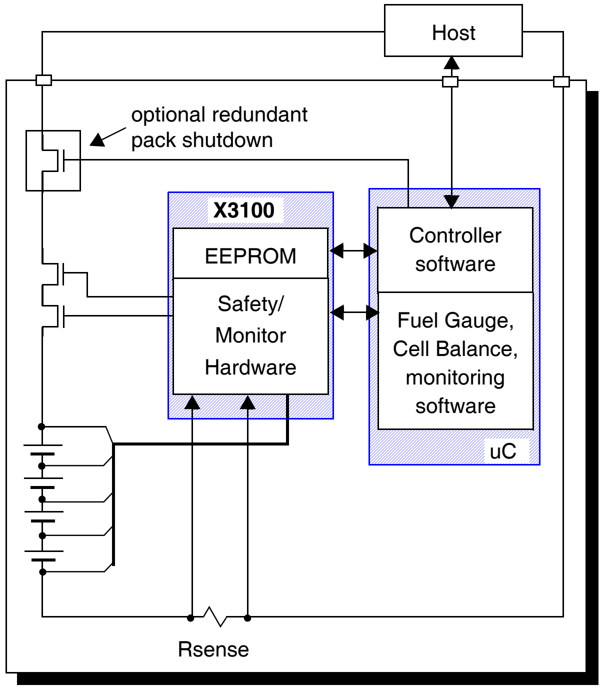

FIGURE 3. BATTERY PARTITION USING THE X3100

The second consideration that determines battery pack implementation is design philosophy - the use of standard “off-the-shelf” components vs. the creation of a custom solution. Using standard components provides a solution with less effort and in less time, while using a programmable solution allows the designer to take advantage of system knowledge to improve performance and cost.

Pack Power Supply

Since the smart battery has electronics, it must have a source of power. This seems obvious, since the pack contains batteries, but the implementation is not easily handled. The first obstacle is voltage. Either all components in the pack need to operate at up to 24V[4] or there needs to be a voltage regulator. If all components operate to 24V, they also need to operate down to 7V or less (as in the case of a 3 cell battery with each cell at the minimum of 2.3V). Using a general purpose microcontroller over these voltages is not possible, since none exist.

To deal with these issues and more, the X3100 operates over the range of 6V to 24V and includes a voltage regulator circuit that provides 5V+/-0.5% at up to 250mA (with an external PNP transistor, such as the 2SA1461, see Figure 4) The regulation accuracy provided by the X3100 is also high enough to serve as a voltage reference for a microcontroller with a built in A/D converter. A 50Ω limiting resistor (RLMT) sets the maximum current of the power supply output to about 50mA - See Figure 4.

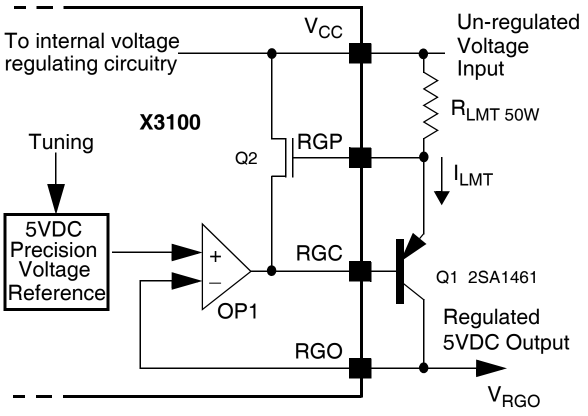

FIGURE 4. VOLTAGE REGULATOR CIRCUIT

Another subtle issue related to the pack power supply relates to what happens in an under-voltage condition. In this case, the discharge MOSFET turns off to prevent excessive discharge of the cells into a load and the charge MOSFET turns off as part of the power down mode to reduce internal current consumption. With both MOSFETs off, there is no way to charge or discharge the pack without another mechanism. The recommended solution consists of using one diode from the cells to V_{CC} and another diode from the pack positive terminal to V_{CC}, see Figure 5.

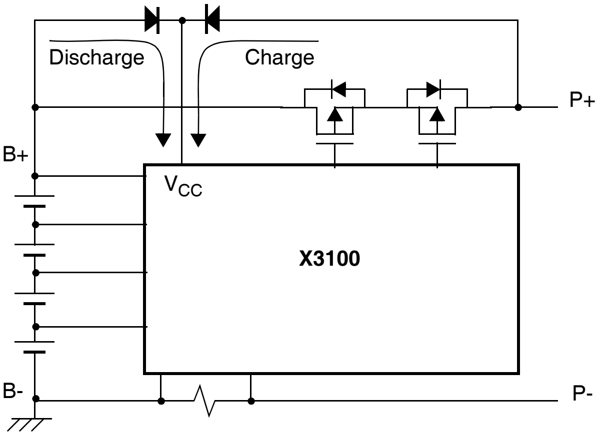

FIGURE 5. X3100 V_{CC} SUPPLY

Battery Pack Control

A smart battery must be able to control energy coming into or going out of the battery pack. The control elements are P channel MOSFET devices. The MOSFETs are electronic switches that can handle current peaks of 6A to 10A or greater. Typically, in a 3 or 4 cell Li-ion battery pack there are 2 MOSFETs, one to enable charging the pack and the other to enable discharge (See Figure 6) When both

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[4] With 4 cells the shut down voltage is less than 14.4V. Without regulation, however, peak currents during charging can rise to over 20V.

MOSFETs are off, the cells are isolated from the outside world to provide safety or to protect the battery from damaging conditions. The X3100 safety unit controls the MOSFETs.

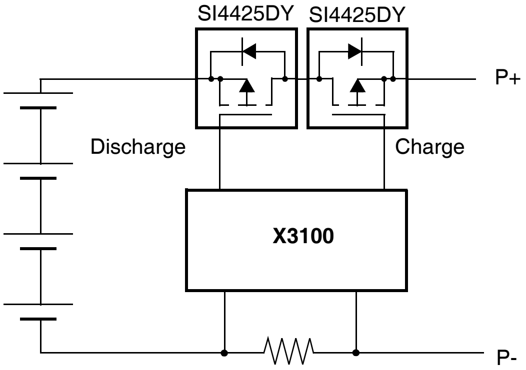

FIGURE 6. BATTERY PACK CONTROL CIRCUITS

Protection Circuits

Li-Ion batteries require safety circuits for over-voltage, under-voltage, and over-current conditions. These need to provide proper threshold levels with very tight tolerances to achieve the greatest level of protection and optimal battery capacity. Since different Li-Ion chemistries have different protection voltages, the X3100 provides selectable levels. With selectable levels, battery pack designers do not need to change the safety unit when using Li-ion batteries from different manufacturers. This might happen when introducing a new battery pack model or when cell production shortages require an unexpected change.

The protection circuits in the X3100 have three other characteristics. First, the cell voltages are sampled for over or under voltage conditions at a rate determined by a selectable timer. This reduces the current consumption of the battery pack. Second, after detecting a protection condition, an adjustable delay prevents pack shutdown for a short period of time. This keeps the pack operating when there is a very short protection condition. Otherwise, noise or a sudden surge state could power down the system without warning. Also, the protection circuits do not allow the system to return to normal operating mode until the protection mode no longer applies (with a hysteresis margin).

PROTECTION SAMPLE RATE TIMING

The over-voltage and under-voltage conditions are normally sampled, rather than being monitored continuously. The Protection Sample Rate Timer samples the cell voltages every 120ms. This sampling rate reduces current drain in the battery pack while maintaining good control over the protection conditions. Over current conditions are monitored continuously, since current flow can change rapidly.

OVER-VOLTAGE

After detecting any cell in an over-voltage condition of greater than 4.2V[5] for a period of 1 second (typical, but selectable with an external capacitor), the battery pack turns off the charging MOSFET. This disconnects the cells from the charger. The discharge MOSFET is unaffected, so the pack can still power the system. This condition remains in effect until all cell voltages drop below the over-voltage release value of 4.0V. The 0.2V hysteresis prevents re-charging a “full” battery.

UNDER-VOLTAGE

When the under-voltage circuit detects any cell voltage below 2.25V[6] for a period of 1 second (typical, but selectable with an external capacitor), the X3100 turns off both the discharge and charge MOSFETs, turns off the regulated voltage and enters a low power SLEEP Mode. This prevents further cell discharge to the load and minimizes the internal current consumption. Exiting this mode requires application of more than 16V to V_{CC} (from the charger) and that all cell voltages exceed 2.95V for 7ms. The 0.7V hysteresis and delay time ensures that an undercharged battery is not re-used before the capacity has been restored to a minimum value.

OVER-CURRENT

In the over-current protection circuit, the X3100 monitors the voltage across an external 10mΩ to 100 mΩ resistor that is in the pack current path. Voltage across the resistor greater than an internally selectable value[7] signals an over-current condition. When this condition persists for more than a programmable period of time (typically 10ms, but selectable with an external capacitor), the X3100 turns off the discharge FET. To recover from an overcurrent condition, a small current continues to flow from the OVP/LMON pin through the pack load (see Figure 7) When the X3100 senses that the voltage on the OVP/LMON pin exceeds 2.5V, (corresponding to a drop in the load current to below the equivalent of that through a 250kΩ resistor) for a period of time, the discharge MOSFET is turned on again. Since the voltage passes through a diode in addition to the load, the typical LMON current is:

$$\frac{2.5V - 0.7V}{250k\Omega} = 7.2\mu A$$

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[5] Over voltage options are: 4.2V, 4.25V, 4.3V, and 4.35V.

[6] Under voltage options are: 1.95V, 2.05V, 2.15V, and 2.25V.

[7] Voltage options are 75mV, 100mV, 125mV and 150mV. Assuming a sense resistor of 20mΩ, this corresponds to maximum currents of 3.75A, 5A, 6.25A, and 7.5A, respectively.

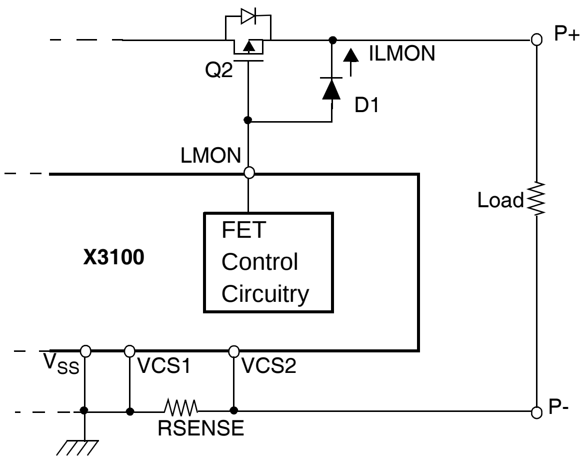


FIGURE 7. OVERCURRENT RECOVERY

Cell Balancing

The cell balancing circuits of the X3100 provide the pack designer a mechanism for dealing with potential or actual cell imbalances. Four control lines on the X3100 provide control of external FETs. Through software algorithms, the cell balancing scheme can be tailored to the specific application or improved as new information becomes available.

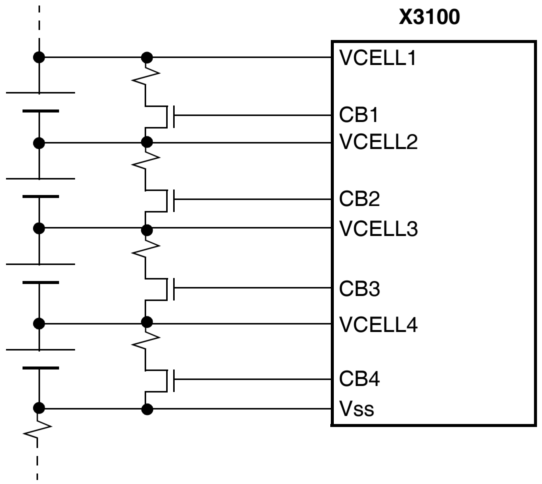


FIGURE 8. CELL BALANCING CIRCUITs

There are several ways to implement cell balancing and the selection of the resistor and FET depends on the implementation method. Some cell balancing options are:

- When any cell reaches an overvoltage condition, charging stops and all over-voltage cells are partially discharged through an FET and resistor during the next discharge cycle.
- When any cell reaches an over-voltage condition, charging stops. Marking the over-voltage cells at this time allows the controller to partially bypass the over-voltage cells while the other cells continue to charge normally.
- When the pack recovers from an under voltage condition, or even during normal operation, voltages between cells can be compared and overvoltage cells partially bypassed as necessary during the charging sequence to equalize the cells.
- Based on history of the pack, some cells might be partially bypassed during charge or discharge based on specific conditions that had previously occured.

Each of these techniques, combinations or variations can improve the capacity and life of the cells in the pack.

When designing cell balancing circuits, it is important to keep in mind that Li-ion batteries have a lot of capacity, so balancing the cells either takes a long time (tens to hundreds of seconds) or requires a very small resistor (Ohms) and an FET that can handle a great deal of current (amps). In either case, the best time to do cell balancing is likely at the end of charge condition, when the voltage drops faster under a load than at the working voltage.

If cell balancing is not desired, the cell balancing FET controls can be used by the pack microcontroller for general purpose control of other functions, such as controlling redundant shut pack shutdown or turning on of the external thermistor circuit to reduce pack current.

Monitor Functions

The X3100 is unique in it’s ability to provide an external microcontroller the voltages on each cell in the pack and the current into or out of the pack. The X3100 reduces the high voltages on the cells to a manageable level for the microcontroller and amplifies the current reading to better suit external measurement.

In order for the microcontroller the to measure various battery pack voltages, the X3100 uses an multiplexed analog switch. Three inputs from the microcontroller directly select control which voltage appears at the analog output AO. Two sense resistor readings are available with opposite polarity which cancels out any internal DC offset. Also, the current sense output has a 2.5V DC offset to allow the system to determine current direction. See Figure 9.

Two bits in the X3100 control register select the gain of the current sense amplifier. A command over the SPI serial port sets a gain 10, 25, 80 or 160. This gain allows measurements of the current over a wide dynamic range. This is important when implementing fuel gauge algorithms, which must be accurate when the system is both idle and during high power consumption operations. The gain also allows the use of a low cost microcontroller with a 10-bit A/D converter and provides greater than 14-bit resolution of the current.

The current is easily calculated by the microcontroller in the pack by using the following equation:

$$\text{current} = \frac{VCS_{21} - VCS_{12}}{2 \times \text{gain} \times CSR}$$

where CSR = Current Sense Resistor

In operation, the pack microcontroller uses three general purpose output ports to select the voltage or current being measured. An A/D converter in the microcontroller determines the voltage or current. These values are then operated on or stored for later use or reporting. The voltage values might be used for cell balancing or fuel gauge operations. The readings of current are critical to fuel gauging.

While reading any cell voltage (or current) through the analog port, the cell voltage protection circuits are monitoring continuously, since the monitor circuit over-rides the Protection Sample Rate Timer.

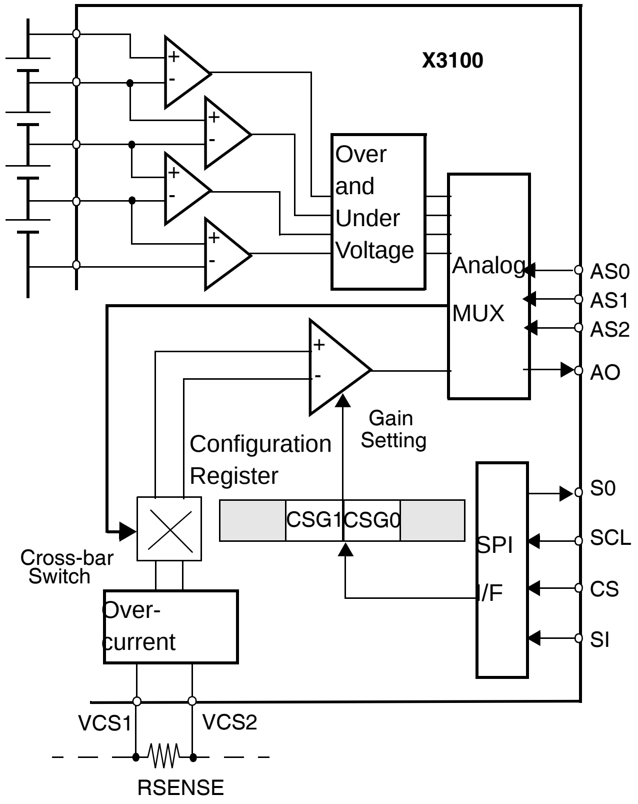


FIGURE 9. ANALOG MUX AND CURRENT SENSE VOLTAGE GAIN

SLEEP Mode

SLEEP mode is entered in three ways. First, initial power up of the device (such as during manufacture of the pack) places the X3100 and the pack into SLEEP mode. Second, the system (as based on the algorithm programmed by the designer) selects this mode. Third, the X3100 goes into this mode automatically when detecting an under-voltage condition. In the SLEEP mode, power to the pack circuitry turns off. The X3100 shuts down, the voltage regulator turns off and the microcontroller stops operating. In this condition, the pack draws minimal current and is intended to prevent additional drain of cells that are determined to be low already. Some systems might use manual sleep control just prior to removing a pack from the system, though this implies that the pack must be connected to a charger to be re-used.

Application of a “Return from Sleep” voltage (V_{SLR}) (about 16V) to the X3100 V_{CC} pin reactivates the pack as the X3100 exits the SLEEP mode.

Cell Charge Threshold

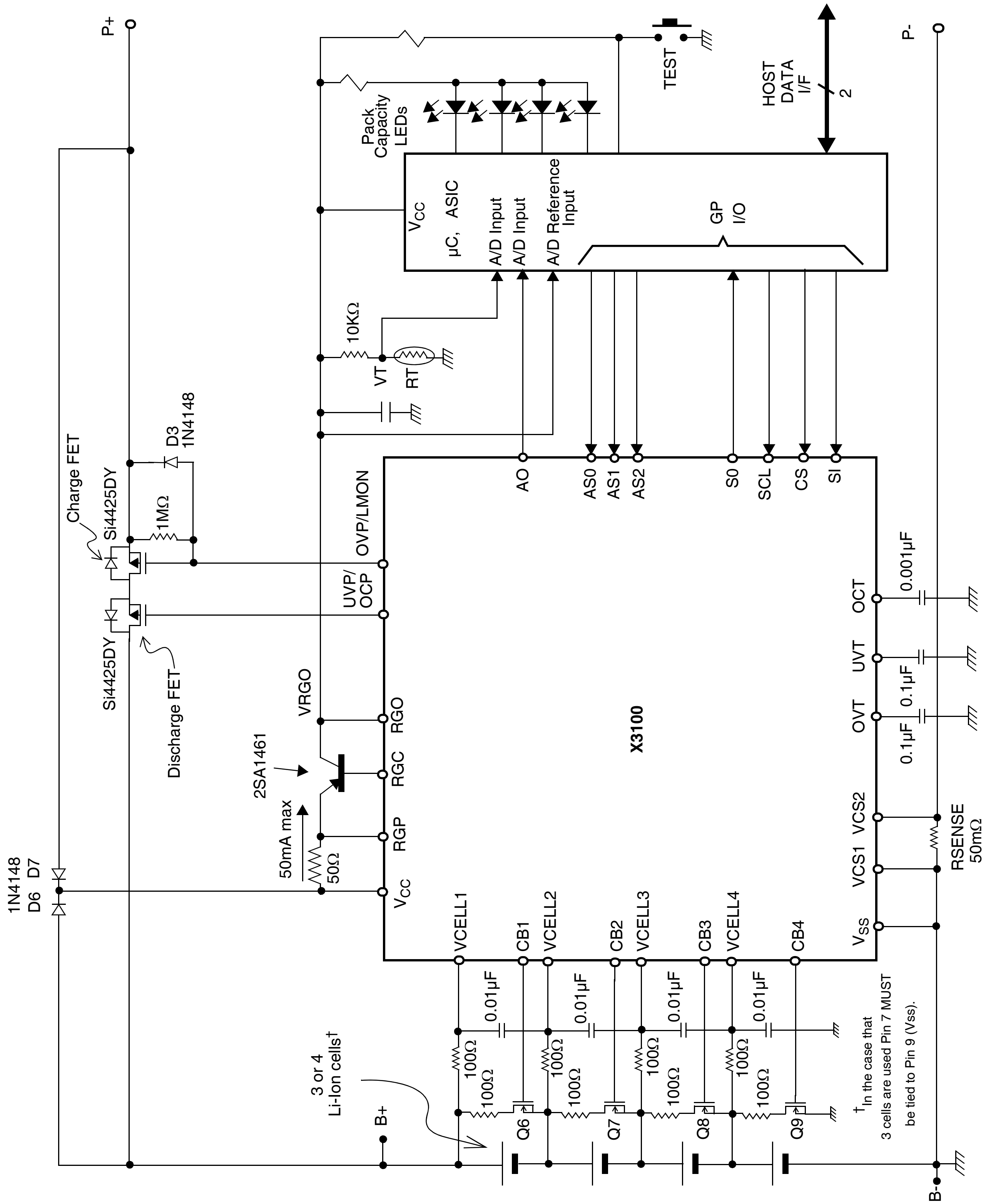
The X3100 has one additional safety feature. Cell charge threshold is optional and selected with a non-volatile bit in the configuration register. In many 3-4 cell Li-Ion battery packs, there are both serial and parallel combinations of cells (typically 8 to 12 cells). Over time, over temperature, during cycling and abusive conditions some cells fail. A typical failure is cell shorting. This reduces the overall capacity of the pack and can quickly damage other cells in the pack.

When enabled, the cell charge threshold circuit prevents battery pack from turning on the Charge FET after returning from the sleep mode when one cell or more fails to exceed a selected voltage. The options are 0.5V, 0.8V, 1.1V, and 1.4V. For example, if one of the cells in the pack reads 1.2V and the charge threshold setting is 1.4V, the pack cannot be re-charged. This effectively ends the life of the battery pack. It is possible to write to the X3100 and turn off this function, which would re-enable the charge control FET, however the pack voltage will be below the recommended operating voltage, so the operation may not work in all cases.

Integrated EEPROM

As battery packs increase in power and sophistication it is increasingly important to integrate EEPROM into the battery pack. Why EEPROM and not SRAM, since there is a battery there for backup? As discussed, cells can fail. This failure may occur after a long period of non-use or after misuse. When the cell voltages drop too low, contents of RAM is lost, while EEPROM data remains. This can be critical in making a determination about pack failure. Since the EEPROM contains information about the battery chemistry, manufacturer and manufacturing date, operating conditions, cycle history and more, failure mechanisms are easier to determine.

The EEPROM, by being able to store information about how the battery is treated, depth of discharge, temperature conditions, peak currents, minimum cell voltages and such, adds insight into pack capacity. These values allow the designer to more fully charge the pack and to allow the pack to be more fully discharged. This increases the available capacity in the pack. The data in the EEPROM also provides more information to the fuel gauge computations, making capacity readings more accurate.



Q6-Q9 = 2N7002

FIGURE 10. EXAMPLE SMART BATTERY PACK DESIGN

Putting it all Together

When designing the battery pack, the X3100 simplifies much of the design. There are, however, additional external components that need to be considered. (See Figure 10)

Microcontroller

Any low cost general purpose microcontroller will work in the battery pack applications, however, there are several characteristics that are either mandatory or highly recommended. These are listed below.

A/D Converter

The A/D converter should have at least 10-bit resolution with ±1 LSB typical absolute accuracy. A 10-bit A/D converter is sufficient, because the current sense amplifier of the X3100 provides a gain of up to 120. In this way, the X3100 effectively turns the 10-bit A/D converter into a 16-bit[8] converter.

The microcontroller needs two or more A/D inputs. One input connects to the X3100 multiplexed output and the other connects to a thermistor/resistor divider to monitor temperature. With additional inputs, other pack voltages, such as B+ and P+ can be monitored for additional safety conditions.

A/D conversion time should be as short as possible. Faster conversion rates reduce software overhead and allow the microcontroller to remain in low power modes longer, but faster A/Ds normally consume more current or add cost to the design. An A/D converter with conversion times around 15µs provides a good trade-off.

Timers

In order to implement a fully functional battery pack, the microcontroller needs to measure the current both into and out of the pack. The easiest way to do the measurements is to use timers built into the microcontroller. In the implementation, the designer can choose from timer, event count, pulse output, or pulse period measurement modes.

Serial I/O

Most battery packs for PCs today are moving to the Smart Battery System standard. This standard specifies that the battery be compatible with the System Management Bus (SMBus). As such it needs an I^2C-like interface. This interface uses 2 wires, clock (SCL) and data (SDA). A standard I^2C bus can work, but the the SMBus has some small differences in voltage level and timing specifications. Many microcontrollers today are equipped with built in I^2C ports. Some even have ports which are explicitly SMBus compliant. It is advantageous to have these on the microcontroller, since software implementation is very easy. The software reads and writes from registers and the hardware handles the communication protocol. Maximum SMBus speed is 100kHz.

Because the X3100 uses an SPI port for communication, it is beneficial for the microcontroller to have one of these ports (in addition to the I^2C port). Neither of these ports are necessary, since they can be implemented by toggling general purpose I/O ports, but having them greatly simplifies the software design and improves the software performance.

Low-Power Dissipation

The microcontroller should have multiple operating modes to conserve battery power. This might include both power down and sleep modes. A variable speed main clock can also be useful for improving power consumption. Choosing a high performance microcontroller with an efficient architecture will allow full implementation of all features, while running at a lower clock speeds. Lower clock speeds translate to lower pack current. The micro should have sleep mode current on the order of 1µA.

Battery Voltage Filtering

In a battery pack, there is a possibility of noise or high voltage spikes generated in the pack, especially when connecting the battery to the system or during unusually high rates of current consumption. This input noise can affect the precision comparators and amplifiers in the X3100. Voltage spikes can be hazardous to the device or be interpreted as over-voltage conditions in the pack, leading to pack shut-down. Adding filters to the battery inputs reduces the effect of noise and voltage spikes on the X3100. This filter is optional, but a simple RC type filter with recommended values of 100Ω and 0.01µF can improve pack performance.

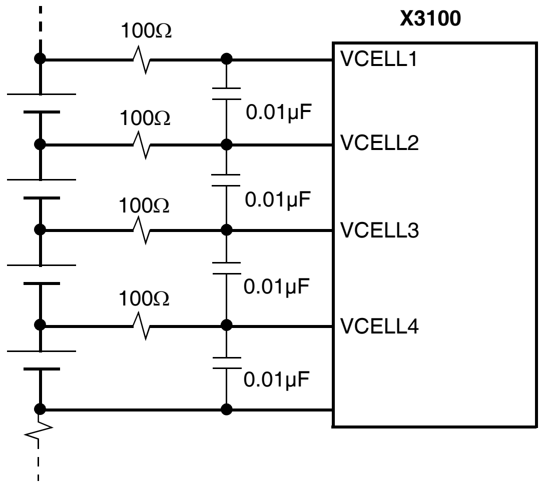


FIGURE 11. INPUT FILTERING

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[8] The minimum resolution of the 10-bit A/D converter is about 5mV. At a gain of 120, the minimum resolution is about 41uV.

Fuel Gauge

A fuel gauge in the battery pack is much like the fuel gauge in an automobile, except with the battery the reading is in coulombs, not gallons or liters. Coulomb is a measure of current per unit of time (and can be represented by the equation:

$$Q = I \times t$$

A battery pack fuel gauge periodically monitors the current at known intervals. There is an assumption that the current does not change, or changes only marginally during the sample period. Typically the current going out of the pack subtracts from a pack capacity value and current going into the pack adds. A new pack contains a "full capacity" value as a starting point. This value is reset after each full charge. The fuel gauge algorithm, for more accuracy must also do the following.

- Reduce the total capacity based on the number of cycles, age of the cells, temperature extremes, anticipated self discharge and other factors.
- Sample the current sense voltage fast enough to capture quick, high energy pulses.
- Track the history of the pack for accurate fuel gauging and reporting. This data resides in an EEPROM in the battery pack (provided in the X3100).

In a smart battery pack, the fuel gauge must also complete a number of calculations. These are discussed briefly in the next section.

Often on the battery pack, LEDs and a switch allow the user to determine the status of the pack prior to using it in an application. The switch turns on the LEDs, which indicate an approximation of the capacity. The LEDs remain on for only a brief period to conserve battery capacity.

Smart Battery Standards

Communication between the battery pack and the system is an important consideration. This interface should have few signal lines to reduce the number of connections at the pack. Many single cell battery packs, such as those found in cellular telephones, use a single wire interface. In a single wire interface, a one or zero is determined by the duration of a "0" on the line. This type of interface provides an asynchronous link. Because of the way a single wire interface operates, transmission speeds are very low. In battery packs with multiple cells there is more information passed between the system and the pack, requiring higher speeds.

A two-wire communication link provides synchronous communication between the system and battery pack. A typical interface is based on the I^2C specification from Philips. In this case, single wire provides the data and the other provides a clock. Embedded start and stop bits provide command synchronization.

In 1996, Intel (along with a number of other companies) developed a variation of the I^2C bus for the PC called the System Management Bus. This uses the same two wires as the standard I^2C bus, but adds additional low voltage options and restrictions on how long a device can hold the bus.

As part of the development of the SMBus, Intel and others created the Smart Battery Standard (SBS). This specification adds a protocol an top of the SMBus interface and defines a set of commands for communication with the battery pack, a battery charger and battery selector circuits. While not all of the commands and communication protocols are necessary, they provide a common framework from which all PC system designers and battery pack providers can work. Using the SMBus standard in non-PC applications also gives the designer a starting place for developing a communication procedure.

The commands defined by the Smart Battery Standard include:

- Commands to identify the battery, to determine the chemistry, read battery pack serial numbers, manufacurer, manufacture date and determine design capacity or design voltage.
- Commands to read pack voltage, current, average current and temperature, plus charging voltage and current.
- Commands to read battery status, such as alarms, condition flags, or cycle count .
- Commands to read battery capacity data, such as relative state of charge, absolute state of charge, remaining capacity and full charge capacity.
- Commands to read remaining useful life of the battery. These commands require the pack to complete some computations. Smart batteries that adhere to the SBS specifications will provide information on whether the battery can deliver a specified current for 10 seconds (for example) or, alternatively, will return a value that indicates how long the battery can supply a specified current. The SBS specification also defines commands that report on the time remaining to complete the charging operation at the specified current.
- The smart battery standard also specifies some commands to control and monitor a "smart charger" on the SMBus.

For more information about the Smart Battery System and the SMBus, please look on the world wide web at http://www.sbs-forum.org.

Summary

This application note has examined the development of smart batteries in general and the use of the Intersil X3100 specifically. The idea of smart batteries is an emerging and intriguing area of development. Because of the sudden and rapid changes in this area, however, there are many new concepts and new, but evolving, standards. Batteries, too are improving rapidly. With these improvements come greater capacity and longer system run time, but also greater risks. These new batteries need tight tolerance in the design for safety, maximum available cell capacity and least abuse of the cells.

To ease the burden of battery pack development, Intersil developed the X3100 safety unit. This provides a major building block for the smart battery pack. It combines safety and monitoring functions with programmability to give the designer the flexibility needed to keep up with todays rapid battery system changes.

For More Information

This application note was condensed from source material originating from many sources, including those listed below. Additional details on battery operation, circuit design considerations and smart battery standards are available through these sources.

Huret, Barry, Huret Associates, Inc., Yardley, PA.

Linden, David, “Handbook of Batteries,” McGraw-Hill, Inc., 1995.

Panasonic, “Lithium Ion Batteries Technical Handbook”, 1998

Vincent, Colin and Scrosati, Bruno, “Modern Batteries, An Introduction to Electrochemical Power Sources,” John Wiley & Sons, Inc. 1997.

Intel Corporation, et al., “System Management Bus Specification, Revision 1.1,” December 11, 1998. (http://www.sbs-forum.org)

Intel Corporation, et al., “Smart Battery Data Specification, Revision 1.1,” December 11, 1998. (http://www.sbs-forum.org)

Intersil, Inc., “X3100 Data Sheet,” October 1999. (http://www.intersil.com)

Intersil, Inc., Application Note AN126 “Smart Battery Primer,” October 1999. (http://www.intersil.com)