High Voltage, High Current Battery Charger Works with All Converter Topologies, Any Battery Configuration

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The market for rechargeable batteries in consumer electronics has reached a level of stable maturity, where designing a battery charger requires little more effort than dropping a purpose-built battery charger IC into the design. This is because the batteries in consumer electronics follow well-worn standards, with popular configurations, float voltages, charge currents, output voltages and charge algorithms. Even so, there is an ever-growing demand for batteries that don't fit these standard molds. Much of this demand is driven by industrial green initiatives, coupled with a general move to portable equipment in medical and other specialized fields.

Dedicated charger ICs can't keep pace with the current explosion in application diversity. The growing variety of battery setups is simply too extensive, ranging from kilowatt-powered indoor forklifts and isolated medical equipment to micropower energy harvesting industrial sensors. Many applications have unique requirements for optimal energy storage, which cannot be met by existing charger ICs.

For example, there are no dedicated charger ICs on the market that can charge battery stacks with 30V or higher float voltage, provide 10A charging current, and support efficient charging in a buck-boost, boost or flyback topology. As a result, designers have turned to

The LTC®4000 takes on battery charger jobs that dedicated charger ICs can't handle. It pairs with just about any DC/DC converter to produce a complete, feature-rich battery charger solution—forget cobbling together discrete components.

LINEAR TECHNOLOGY

The LTC4000 battery charger fills the gap between applications supported by easy-to-use dedicated charger ICs and those that would otherwise require complex discrete solutions. The LTC4000 uses a 2-IC model to bring single-IC simplicity to a wide range of charger solutions.

(LTC4000, continued from page 1)
relatively cumbersome discrete component solutions, essentially returning to the pre-charger-IC dark ages. Although discrete solutions can satisfy many charger requirements, they cannot match the ease-of-use and compact nature of dedicated charger ICs. Designers demand a solution that retains the simplicity of a dedicated charger IC with the versatility of discrete component solutions.

Linear's LTC4000 battery charger fills the gap between applications supported by easy-to-use dedicated charger ICs and those that would otherwise require complex discrete solutions. The LTC4000 retains the simplicity of a dedicated single-IC charger, but uses a 2-IC model to match the applications versatility of discrete solutions. It can be paired with any DC/DC or AC/DC converter topology, including but not limited to buck, boost, buck-boost, SEPIC and flyback.

The LTC4000's wide input voltage range (3V–60V) and virtually unlimited current capability produces efficient, high performance, full-featured battery chargers that rival the performance of dedicated charger ICs. Figure 1 shows a typical application: the LTC4000 paired with the LTC3786 to create a 5A, 5-cell Li-ion battery charger.

FEATURE SUMMARY

The LTC4000 converts virtually any Linear Technology externally compensated DC/DC power supply into a battery charger featuring:

- wide input and output voltage range of 3V to 60V
- accurate (±0.25%) resistor programmable battery float voltage
- pin-selectable timer or current termination
- temperature qualified charging using an NTC thermistor
- automatic recharge
- C/10 trickle charge for deeply discharged cells
- bad battery detection and status indicator outputs
- precision current sense enables low sense voltages in high current applications

The LTC4000 also includes intelligent PowerPath™ control via low loss external PFETs. One external PFET is used to prevent reverse current from the battery or system output going back to the input. Another PFET is used to control battery charging and discharging.

In this case, the low loss nature of the PFETs is crucial for systems requiring high charge current for high capacity batteries. This second PFET also facilitates an instant-on feature that provides immediate downstream system power even when connected to a heavily discharged or short faulted battery.

PowerPath control preferentially provides power to the system load. When input power is limited, the system load is always prioritized over charging. Furthermore, if the system load requires more power than the input can support, the battery

Figure 1. 6V to 21V at 5A boost converter charger for five Li-ion cells
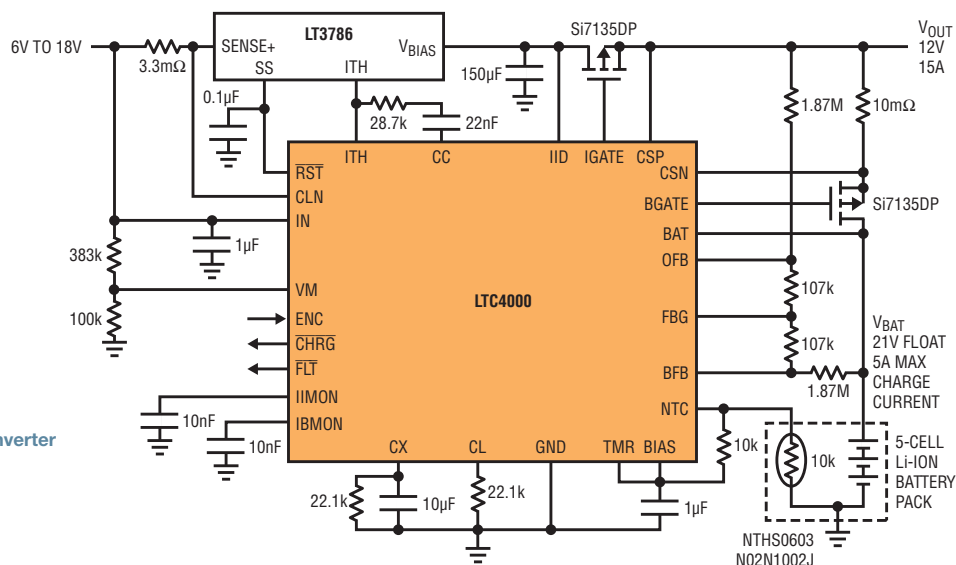
At the core of the LTC4000 are four internal error amplifiers, whose outputs combine to drive the external DC/DC converter control loop. In this way, it can control almost any battery charging cycle, regardless of chemistry and float voltage.

is used to provide additional power to satisfy the total system output load.

The LTC4000 is available in low profile 28-lead 4mm × 5mm QFN and SSOP packages.

FOUR CONTROL LOOPS KEEP THE BATTERY CHARGED AND OUTPUT IN REGULATION

At the core of the LTC4000 are four internal error amplifiers, whose outputs combine to drive the external DC/DC converter control loop. In this way, it can control almost any battery charging cycle, regardless of chemistry and float voltage.

Figure 2 shows a simplified block diagram of the four internal error amplifiers (A4-A7). Each of the four input transconductance amplifiers is responsible for a different regulation loop: input current, charge current, battery float voltage and output voltage. The output transconductance amplifier (A10) ensures that the loop requiring the lowest voltage on the ITH pin for regulation controls the external DC/DC converter.

The input current regulation loop (A4 in Figure 2) prevents the input current from exceeding the resistor programmable input current limit. This input current limit prevents the overall system from overloading the source, allowing for more predictable and reliable behavior. Furthermore, this adds an extra layer of protection to extend the life of the power components of the DC/DC converter and any sources that lack overcurrent protection.
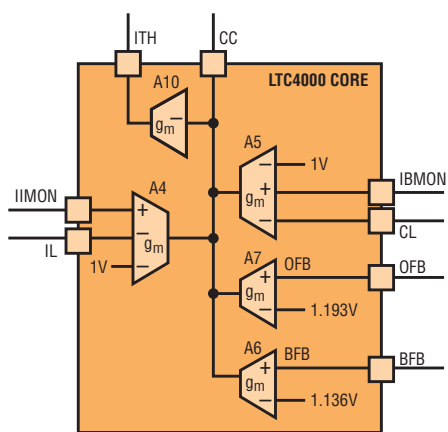

Figure 2. Simplified block diagram of the LTC4000 core—four error amplifiers with combined output

The other current regulation loop is the charge current regulation loop (A5). This loop controls the constant current phase of the charging cycle, ensuring that the charge current sensed through the charge current sense resistor does not exceed the resistor programmable full charge current.

The constant current regulation loop controls charging until the battery reaches its float voltage. At this point, the battery voltage regulation loop (A6) takes over, the charge current begins to drop and the charger enters the constant voltage phase of the charging cycle.

The float voltage is programmed using the feedback resistor divider between the BAT pin and the FBG pin. The FBG pin disconnects the resistor divider load when v_{IN} is not present. This ensures that the float voltage resistor divider does not

consume battery current when the battery (connected to BAT pin) is the only available power source. For $v_{IN} \geq 3.0v$, the typical resistance from the FBG pin to GND is 100Ω.

When the battery is not being charged, nor supplying power to the load, the external PFET connected to the battery is turned off (Figure 4). In this scenario, the output voltage regulation loop (A7 in Figure 2) controls the external DC/DC converter. The output voltage regulation loop is similar to the battery voltage regulation loop. This loop regulates the voltage at the CSP pin based on the feedback resistor divider between the CSP pin and the FBG pin. This output voltage regulation is important to ensure that the system output voltage remains well regulated when the battery is disconnected from the load.

Figure 3. Battery charging phases for 3 series LiFePO$_4$ cells with the circuit shown in Figure 1
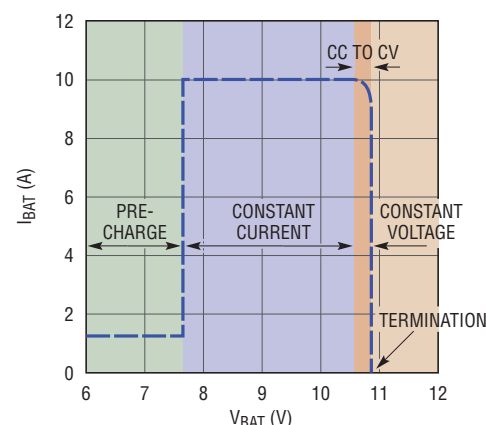
The LTC4000's PowerPath control feature consists of two functions: the input ideal diode control, providing a low loss ideal diode function from DC/DC converter to the output; and the battery PowerPath control, providing a smart PowerPath route between the system output and the battery.

POWERPATH CONTROL

The other important feature of the LTC4000 is PowerPath control, which-consists of two functions: the input ideal diode control, providing a low loss ideal diode function from DC/DC converter to the output; and the battery PowerPath control, providing a smart PowerPath route between the system output and the battery.

The input ideal diode feature provides low loss conduction from the output of the DC/DC converter (IID pin—anode) to the system output (CSP pin—cathode). Low loss conduction is important for efficiency and heat management in high current systems. This feature also prevents reverse current from the system output to the DC/DC converter. Such reverse current causes unnecessary drain on the battery and in some cases may result in undesir-able DC/DC converter behavior. This ideal diode behavior is achieved by control-ling an external PFET (M1) whose gate is connected to the IGATE pin (Figure 4).

The PowerPath controller of the exter-nal PFET connected to the BGATE pin is similar to the input ideal diode controller driving the IGATE pin (Figure 4). When not charging, the PMOS behaves as an ideal diode between the BAT (anode) and the CSN (cathode) pins. The ideal diode behavior allows the battery to provide current to the system load when the DC/DC output is in current limit or the DC/DC is slow to react to an immediate load increase at the output. This feature ensures a stable system output voltage.

In addition to the ideal diode behavior, BGATE allows current to flow from the CSN pin to the BAT pin during charging. There are two regions of operation when current is flowing from the CSN pin to the BAT pin. The first is when charging into a heavily discharged battery (battery volt-age is below the INSTANT ON threshold, $V_{BAT(INST\ ON)}$). In this region of operation, the controller (A11 in Figure 4) regu-lates the voltage at the system output to approximately 86% of the final float voltage level. This feature provides a system output voltage significantly higher than the battery voltage when charging

into a heavily discharged battery. This INSTANT ON feature allows the LTC4000 to provide sufficient voltage at the system output independent of the battery voltage.

The second region of operation occurs when the battery feedback voltage is greater than or equal to the INSTANT ON threshold. In this region, the BGATE pin is driven low to allow the PMOS to turn completely on, reducing any power dissipa-tion due to the charge current.

Figure 4. Input ideal diode and battery PowerPath controller
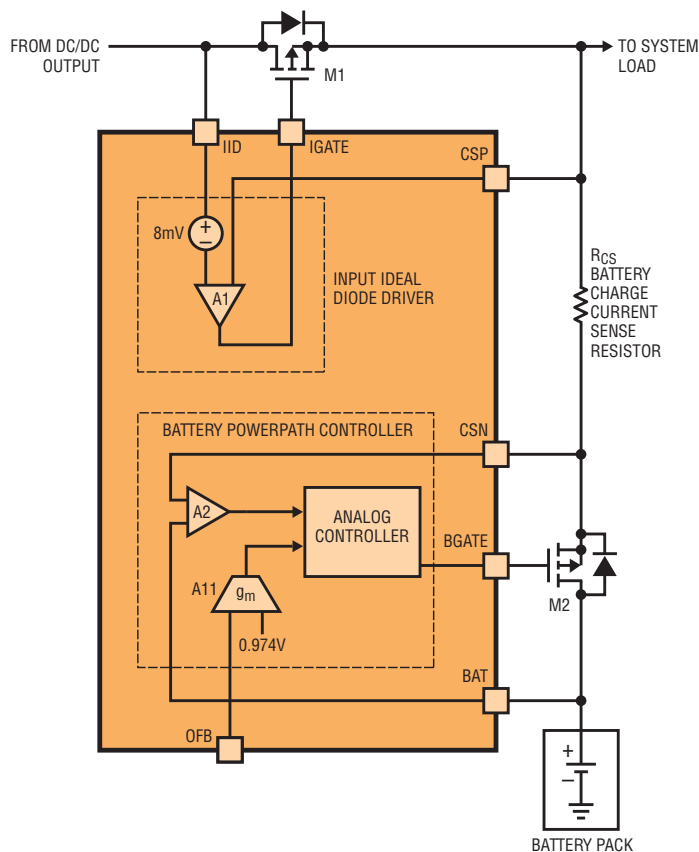
The LTC4000 has broad applications versatility—it can be paired with a DC/DC converter to produce a battery charger for any battery configuration.

APPLICATIONS

The LTC4000 has broad applications versatility—it can be paired with a DC/DC converter to produce a battery charger for any battery configuration. The following applications illustrate this versatility.

High Voltage, High Current Charger
Building a complete charging system with the LTC4000 and a DC/DC converter is as easy as using a dedicated charger IC. Figure 5 shows the LTC4000 controlling an LT3845A buck converter in a charger designed for a 3s LiFePO4 battery pack (3s refers to three cells in a series configuration). The LT3845A buck converter is selected for its simplicity and high, 60V input voltage capability.

Each of the LiFePO4 cells has a typical float voltage of 3.6V, resulting in an overall float voltage of 10.8V. The 10.8V float voltage is set by R_{BFB2} = 133k and R_{BFB1} = 1.13M. Once the float voltage is set, the value of R_{OFB1} and R_{OFB2} are

determined—this sets the output voltage when charging is terminated. Here, R_{OFB2} is set at 127k and R_{OFB1} at 1.15M to set the output regulation voltage at 12V.

After setting the float and output voltages, set the full charge current for the battery. In this particular example, the full charge current is set to 10A using an R_{CS} value of 5mΩ and an R_{CL} value of 24.9k. The regulated sense voltage across R_{CS} should be as large as possible for the highest accuracy. However, a larger sense voltage causes R_{CS} to dissipate more power. Since the charge current regulation error amplifier has a maximum regulation level of 1V, this means that the regulated sense voltage across R_{CS} is limited to a maximum of 50mV (=1V/20). For a 10A charge current, the maximum power dissipation on this sense resistor is 0.5W.

Any value of R_{CL} that is larger than 20k will not affect the full charge current

level, but as long as it is less than 200k, it affects the regulated trickle charge current level. In this example, the 24.9k value is chosen to set the trickle charge current level at 1.25A. Trickle charging can occur at the beginning of a charge cycle when the voltage at the battery is less than 68% of the float voltage. This trickle charge feature is especially important for lithium-ion batteries, as they require a smaller current (typically <20% of full charge current) to safely and gradually bring the battery voltage higher before supplying them with the full charge current.

The only other regulation loop with a set point is the input current regulation loop. Using a similar method to setting R_{CS}, in this example R_{IS} is set to 5mΩ and the IL pin is left floating (internally pulled to a voltage above 1V) to set a maximum input current limit of 10A.

Figure 5. 48V to 10.8V at 10A buck converter charger for 3-series LiFePO4 battery pack

LTspice IV
circuits.linear.com/549
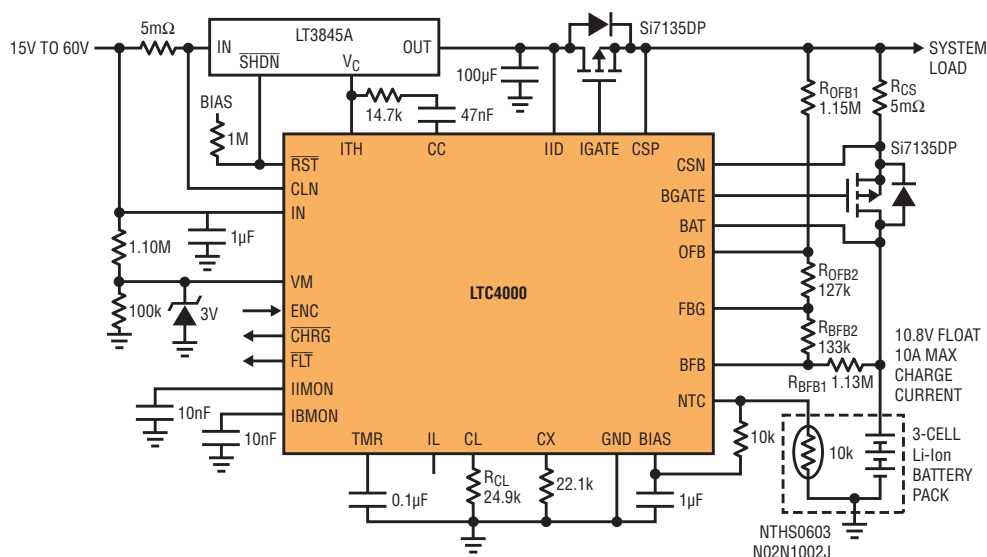
Building a complete charging system with the LTC4000 and a DC/DC converter is nearly as easy as using a dedicated charger IC. Just a few resistors and capacitors are needed to set the float voltage, charge current, input current limit and charge termination (current level or timer termination).
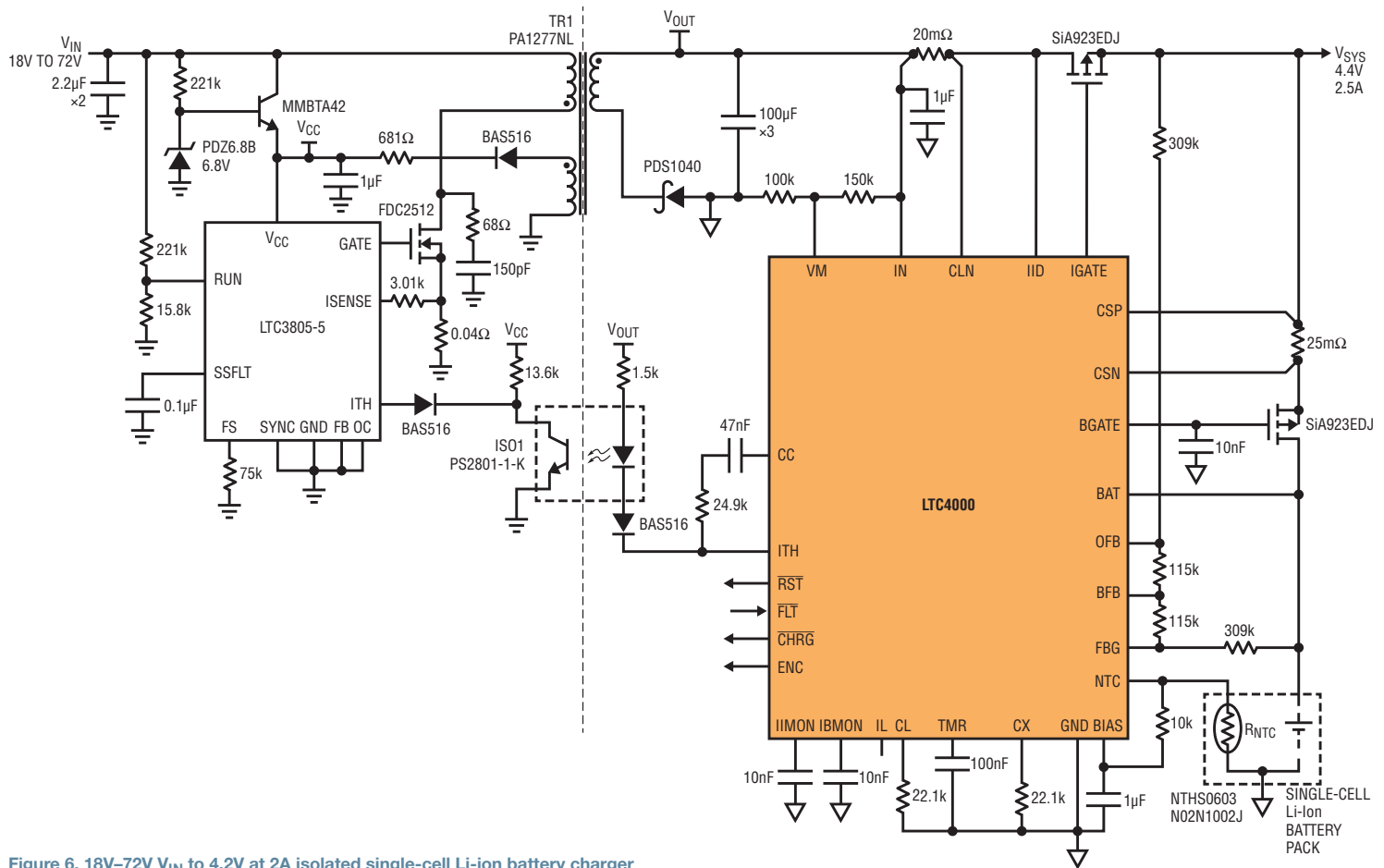

Figure 6. 18V–72V V_IN to 4.2V at 2A isolated single-cell Li-ion battery charger

The four simple steps described here are sufficient to customize an LTC4000 charging solution to charge many generic battery configurations. To customize the solution further, a few other component values can be chosen to program the charge termination algorithm. LTC4000 offers both timer termination and charge current level termination.

With charge current level termination, the charging process is terminated when the charge current level drops

(in the constant voltage mode) to the level programmed at the CX pin.

With timer termination, the charging process continues in the constant voltage mode until a time period programmed with a capacitor on the TMR pin expires. In this example, the LTC4000 is set up with a timer termination period of 2.9h using a 0.1µF capacitor connected to the TMR pin. The 22.1k resistor connected to the CX pin sets a 1A charge current level,

at which point the charge status indicator pin (CHRG) assumes a high-z state.

LTC4000 offers temperature-qualified charging via the NTC pin. A negative temperature coefficient (NTC) resistor, thermally coupled to the battery, is connected in a resistor divider network between the BIAS, NTC and GND pins. This NTC resistor allows charging to be paused when the battery temperature is outside a particular range. In this example, the battery temperature range is set between

With the LTC4000, the task of designing an isolated charger is reduced to selecting the appropriate isolated converter, choosing PFETs and determining the values of some resistors and capacitors.

−1.5°C to 41.5°C. Temperature-qualified charging protects batteries from hazardous charging conditions, such as extreme hot or cold, which can potentially damage the batteries and shorten their life.

The only remaining components that may need to be customized are the series resistor and capacitor compensation network between the CC and ITH pins, as well as the resistor divider network connected to the VM pin. As starting values, the compensation network can be set to a 10k resistor in series with a 100nF capacitor. It can then be optimized by looking at the time domain response to small signal perturbation for each of the four regulation loops. In this example, the final optimized values are 14.7k and 47nF.

The VM pin is an input to a comparator with a threshold set at 1.193V. When the voltage at this pin is below the threshold, the $\overline{RST}$ pin is driven low. When it is above the threshold, the $\overline{RST}$ pin assumes a high-z state. By connecting the $\overline{RST}$ pin to the DC/DC RUN or $\overline{SHDN}$ pin, this comparator provides a simple and accurate UVLO (undervoltage lockout) signal that can be used to start the external converter. In this example, the input UVLO level is set to 14.3V. Setting a minimum voltage ensures that the input to the converter is within its operating range before it is allowed to start up. This in turn allows for a more consistent and predictable power-up behavior of the overall charging solution.

A discrete solution with similar features to the 10A/3-cell LiFePO4 battery charger

would have required at least two high side current sense amplifiers, four operational amplifiers as well as two high voltage ideal diode controllers. Each of these would need to be tested and qualified separately to ensure compatibility of their specifications such as common mode range, speed and input supply voltage range. Furthermore a discrete solution would require a microprocessor to handle charging algorithm.

As shown in the example, the LTC4000 eliminates these components and the need to test them. Design is simplified to choosing an appropriate DC/DC converter for the voltage and power requirement, and a few passive components—mostly resistors to set the important charger system parameters.

Isolated Battery Charger

Figure 6 shows the LTC4000 paired with the LTC3805-5 to build an isolated single cell Li-ion charger with 2A charging current. This application shows the power of the LTC4000 to create a unique battery charger solution using readily available DC/DC converters of practically any topology. This simple LTC4000-based solution eliminates the need to design a complex discrete solution.

With the LTC4000, the task of designing an isolated charger is reduced to selecting the appropriate isolated converter, choosing PFETs and determining the values of some resistors and capacitors. For the application shown in Figure 6, we use the LTC3805-5 isolated flyback converter with a high input voltage

capability. Two relatively low voltage PFETs are used for PowerPath control since only voltages less than 6V appear on the secondary side. The only unique connection in this particular application is the use of the opto-coupler to deliver the ITH feedback signal from the LTC4000 on the secondary side to the ITH pin of the LTC3805-5 on the primary side.

The resulting charger is capable of charging a single cell Li-ion battery (4.2V float) at 2A in an isolated environment. The system has a wide input range of 18V to 72V with a 2.9h charging termination time as well as a 220mA trickle charge current.

The overall solution limits the total system output current to 2.5A in a controlled manner. By preventing current overload of the primary, the input current limit provides an extra level of protection for the power components and provides greater overall system reliability.

High Voltage Buck-Boost Battery Charger

Another unique, but commonly requested battery charger solution is a buck-boost battery charger. Again, there is no dedicated IC solution currently available. Figure 7 shows the LTC4000 paired with the LTC3789 to create a full-featured buck-boost 12V lead acid battery charger.

The buck-boost topology allows the battery to be charged from a voltage lower or higher than its float voltage, easing the battery and input voltage choice in the system design. The number of battery cells in series can then be optimized for other system parameters or perhaps the

Figure 7. 6V–36V V_{IN} to 14.4V at 4.5A buck-boost 6-cell lead acid battery charger
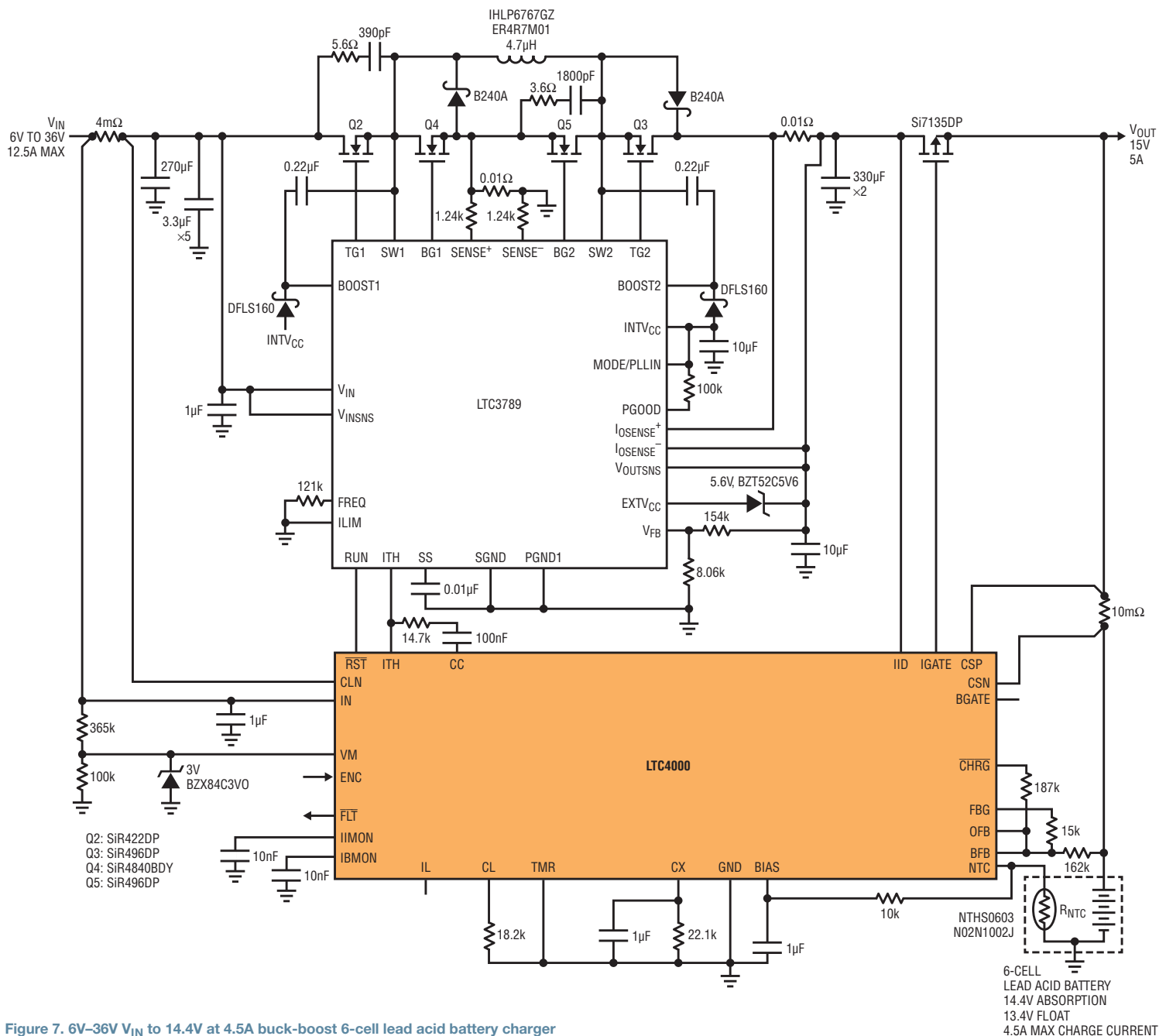
pricing and availability of such battery packs. Similarly, the flexibility and simplicity of programming the charge current by setting the values of two resistors (R_{CS} and R_{CL}) also further ease the battery capacity choice in the system design.

The overall charging solution of the LTC4000 and LTC3789 pairing shown above is capable of charging a 12V lead acid battery (14.4V absorption and 13.4V float)

at 4.5A from an input source voltage that can range from 6V to 36V. The system is programmed with an input current limit of 12.5A, allowing load sharing between the input and the battery if a system load demands more that 12.5A from the input. This feature is especially important at the lower end of the source voltage range, where input current increases rapidly to meet increasing output power demands.

The charger solution shown here provides no termination, allowing continuous constant voltage charging at the final float voltage of 13.4V. Connecting the CHRG pin to the BFB pin through the 187k resistor implements a 2-stage charging algorithm (absorption and float) common for lead acid batteries. The overall charging algorithm first charges to an absorption level of 14.4V until the charge current drops to 500mA. At this point

The LTC4000's wide input voltage range (3V–60V) and virtually unlimited current capability allow it to be combined with just about any power converter to form an efficient and high performance full-featured battery charger typically occupying less than 3.6cm².

Figure 8. Demonstration circuit showing a complete battery charger formed by pairing the LTC4000 and LTC3789
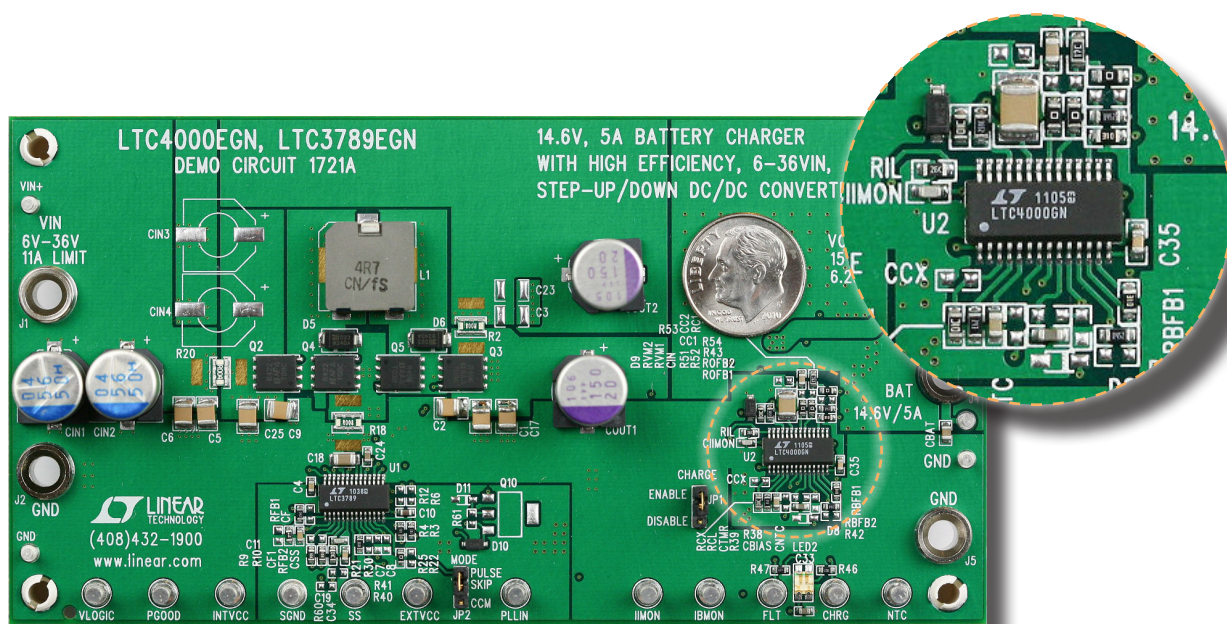
the $\overline{\text{CHRG}}$ pin assumes a high-z state, changing the feedback resistor network connected to the BFB pin. In this way the battery charger enters final float constant voltage mode with a final float target of 13.4V. If the battery drops below 13.1V (recharge threshold), the $\overline{\text{CHRG}}$ pin turns low impedance again and the battery charger is again set to charge the battery to the absorption level of 14.4V.

Because this is a buck-boost charger setup, a battery stack with any float voltage between 3V to 36V can be supported with a simple adjustment of the resistor dividers and the PFET choice. Similar changes allow the battery charge current to be programmed from a few milliamps to tens of amps.

Figure 8 shows a demo board of the LTC4000 and LTC3789 pairing. Note that the required space occupied by the LTC4000 and its passive components is small, occupying an area less than 3.6cm². This allows for a compact charging solution for virtually any battery.

CONCLUSION

Increases in demand for alternative energy sources, coupled with an explosion in portable industrial and medical applications, have resulted in the need for a wide variety of rechargeable-battery-powered systems. Many of these systems have requirements that dedicated battery charger ICs—geared to specific battery chemistries/configurations and input/output voltages—cannot meet. Discrete solutions can satisfy the needs of these systems, but

such solutions are more difficult to implement, occupy considerably more PC board space and require significantly more design time than dedicated IC solutions.

The LTC4000 battery charger fills the gap between applications supported by easy-to-use dedicated charger ICs and those supported by more complex discrete solutions. The LTC4000's wide input voltage range (3V–60V) and virtually unlimited current capability enable pairing with any DC/DC or AC/DC converter topology, including buck, boost, buck-boost, SEPIC and flyback. When paired with the right power converter, the LTC4000 forms an efficient and high performance full-featured battery charger typically occupying less than 3.6cm². ∎