Simple and Highly Efficient Super Capacitor Charger

Super capacitors with high capacitive density are used in conjunction with batteries because super capacitors can charge and discharge continuously. Synchronous buck regulators can serve as a quick and simple charger to provide the adjustable fully charged voltage. **Marian Chang, Application Engineer, International Rectifier, El Segundo, USA**

Super capacitors are used as power failure backups without degrading like batteries [1]. As capacitor makers develop super capacitors with higher voltage capability, they need adjustable chargers that may not yet be readily available commercially. Synchronous buck regulators, in this case, can serve as a quick and simple charger to provide the adjustable fully charged voltage. However, general-purpose synchronous switch-mode converters are not suitable super capacitor chargers due to their high inrush current.

Typically, dedicated controller and discrete switches are combined to control the charging current and the final super capacitor voltage. These are excellent choices for charging a wide range of super capacitors with different charging current and fully charged voltage. These dedicated controllers usually have a wide input voltage range and adjustable output voltage and output current limit. However, the discrete solutions require many external components, including MOSFETs that are used as switches, and compensation components for conventional voltage mode regulation.

Integrated COT solution

In this paper, a simple integrated solution based on a constant-on-time (COT) SupIRBuck® is presented. The COT SupIRBuck is a family of general-purpose synchronous buck regulator that integrates constant on-time hysteretic controller and power MOSFETs to provide an easy-to-use and highly efficient DC/DC voltage regulation. The proposed application circuit senses the charging current and uses it to control the output voltage to prevent a high inrush current during the initial charging stage.

The advantages of using a COT SupIRBuck to charge super capacitors include: adjustable fully charged voltage, adjustable initial charging current, automatic power save mode when the super capacitor is fully charged, and minimal number of external components.

To address the high inrush current in a general-purpose synchronous buck converter, a resistor is placed in series with the super capacitor (C_{super}) to sense and feedback the charging current information to the converter. The proposed circuit is shown in Figure 1. IR3863 COT SupIRBuck® is used as an example here. This scheme can be applied to other synchronous buck converters.

Theory of operation

For applications where connecting the

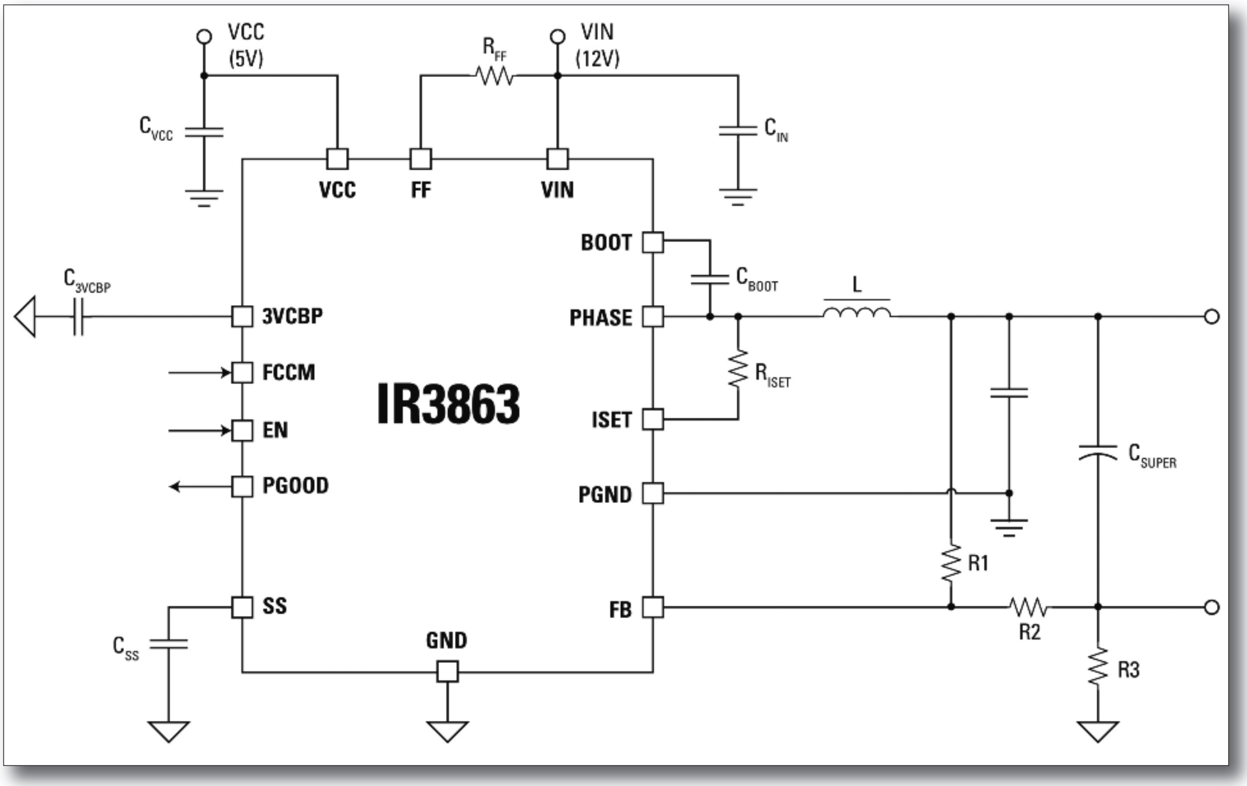

Figure 1: **Proposed super capacitor charger circuit**

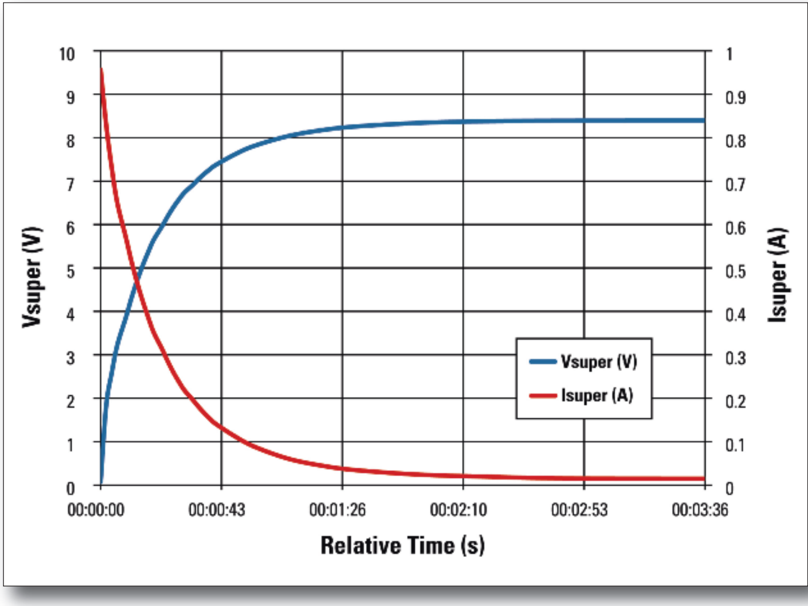

Figure 2: Super capacitor I-V charging characteristic over time

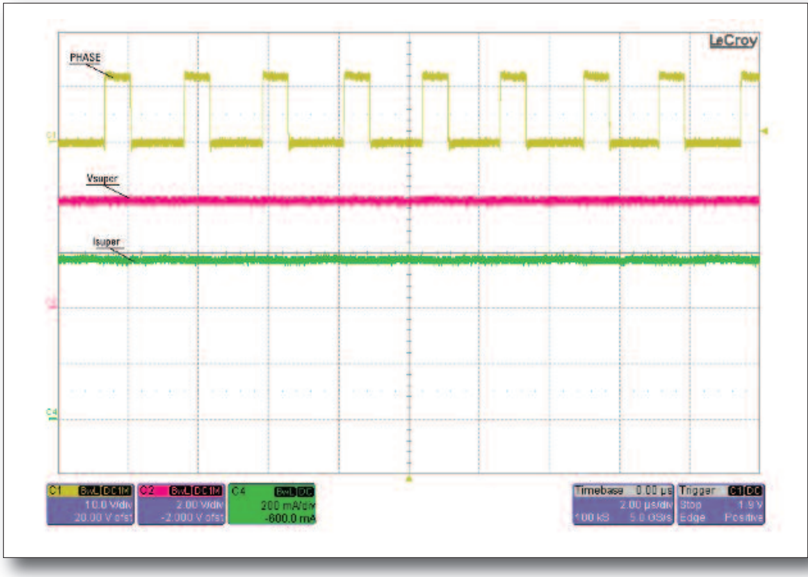

Figure 3: Typical converter switch node waveform during the initial charging stage

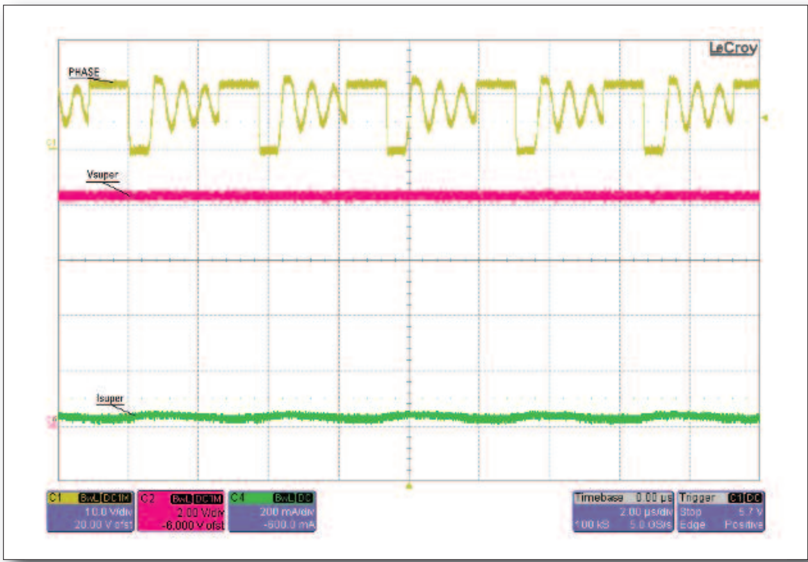

Figure 4: Typical converter switch node waveform during the final charging stage

negative terminal of C_{super} to the system ground is preferred, simply connect VIN and VCC ground to the negative terminal of C_{super}. In both cases, the sensing resistor, R3, in Figure 1 should be chosen to ensure that the inrush current stays below the maximum charging current specified for the super capacitor. For IR3863, the regulator reference voltage is 0.5 V; to limit the initial charging current to below 1 A, a 500 mΩ resistor is selected for R3. To set the fully charged voltage (V_{final}) of C_{super}, R1 and R2 are chosen according to the equation below:

$$R2 / (R1 + R2) \times V_{final} = 0.5\ V$$

During the initial charging stage, the voltage (V_{super}) across the super capacitor is zero, so the voltage across R2 is zero. The feedback node (FB) sees the voltage across R3. As current flows through C_{super} to charge it, this charging current information is sensed by R3 and fed back to the FB node to be regulated to the regulator reference voltage. The regulator reference voltage may also be programmed to ramp up from zero volts to the internally designed reference (which is 0.5V in this case for IR3863). The voltage ramp rate can be set through the choice of the soft-start capacitor (C_{ss}). During the initial charging stage, even though V_{super} is close to zero, IR3863 does not push out a high inrush current because the voltage across R3 satisfies the regulation condition.

As the controlled charging current flows to C_{super}, V_{super} increases such that the voltage fed back from the resistive divider composed of R1 and R2 increases. To regulate the FB voltage, the voltage across R3 needs to be reduced. IR3863 then reduces the charging current delivered to the super capacitor to accommodate the V_{super} increase. This process continues to reduce the charging current as V_{super} increases until the voltage across R3 becomes negligible, and the super capacitor is fully charged to the final super capacitor voltage defined by R1, R2, and the regulator reference voltage that FB is being compared to. The charging characteristic over time of this application circuit is shown in Figure 2.

Wide adjustable fully charged voltage range

Super capacitor chargers composed of synchronous buck converters have a wide adjustable fully charged voltage range and charging current limit. For example, with IR3863, the fully charged voltage can be programmed from 0.5 V to 12 V, and the charging current limit can be programmed up to 6 A. In this example design, the initial charging current is programmed to 1 A and the fully charged super capacitor voltage is programmed to 8.5 V.

In addition to having adjustable output voltage and charging current limit, the COT SupIRBuck family also features power save mode and fast transient response to V_{super} variations. By grounding the FCCM (forced continuous conduction mode) pin, IR3863 is allowed to operate in DCM (discontinuous conduction mode) when the charging current delivered to the super capacitor is below half of the inductor current ripple. This feature allows the converter to automatically enter a power saving mode when the super capacitor is fully charged. The switching frequency of IR3863 varies with load, so during the initial charging stage, converter operates in the CCM (continuous conduction mode) to quickly charge up V_{super} as shown in Figure 3. The converter also operates in the CCM when the super capacitor is discharged by its load to restore the super capacitor back to the specified fully charged voltage. Once V_{super} is in the proximity of the fully charged voltage, IR3863 operates in DCM to reduce the charging current and converter switching loss while maintaining the V_{super} voltage. A typical converter switch node waveform during this stage is shown in Figure 4.

Another advantage of using COT SupIRBuck converters as super capacitor charger is having minimal external components. The COT device family integrates the controller, driver and power MOSFETs in a low profile 4 mm x 5 mm or 5 mm x 6 mm QFN package. Unlike voltage-mode buck regulators, COT SupIRBuck converters do not require the usual PID compensation circuit thus further reduce the number of external components. In addition, COT SupIRBuck adjusts its on-time through feed-forward to compensate for input voltage changes, allowing stable operation over a wide input voltage range which typically impacts controller stability in conventional voltage-mode regulators.

Conclusion

With adjustable fully charged super capacitor voltage, adjustable initial charging current, automatic power save mode, and the ease to design with minimal number of external components, COT SupIRBuck can serve as a simple and highly efficient super capacitor charger with the current sensing circuitry presented.

Literature

[1] Supercapacitors, Illinois Capacitor Inc., www.illinoiscapacitor.com/pdf/Papers/supercapacitors.pdf

SupIRBuck Online Design Tool

IR has expanded its online design tool for the SupIRBuck® family of integrated point-of-load voltage regulators to include new devices utilizing hysteretic constant on-time (COT) control designed to offer improved light load efficiency.

The web-based tool enables the rapid selection, electrical and thermal simulation and design optimization of over 15 SupIRBuck integrated voltage regulators. The expanded product line includes high-voltage (27 V) devices, current ratings up to 15 A and regulators in both 5 mm x 6 mm and 4 mm x 5 mm packages. Enhanced simulation capabilities now include the unique ability to compensate COT control devices using Aluminum Electrolytic capacitors for lower cost applications as well as all-ceramic capacitors for higher frequency applications.

Based on a designer's given input and output parameters, the SupIRBuck online tool selects suitable devices for a given application. Once basic requirements are entered, the tool allows the user to capture schematics, create a reference design along with associated bill of materials (BOM), view waveforms, and perform complex thermal and application analysis.

SupIRBuck voltage regulators integrate IR's snchronous buck control ICs and HEXFET trench MOSFETs in a compact Power QFN package, shrinking the silicon footprint compared to discrete solutions, and offering between 8 to 10 percent higher full-load efficiency than monolithic ICs.

http://mypower.irf.com/SupIRBuck

RIGHT: Online design tool for the SupIRBuck family of integrated POL voltage regulators