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IN THIS ISSUE

Combined Voltage and Current Control Loops Simplify LED Drivers, High Capacity Battery/Supercap Chargers & MPPT* Solar Applications

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The rapid expansion of constant-current/constant-voltage (CC-CV) applications, especially in LED lighting and high capacity battery and supercapacitor chargers challenges power supply designers to keep pace with the increasingly complicated interplay of current and voltage control loops. A switch-mode converter designed specifically for CC-CV offers a clear advantage, especially when the supply has limited power, or its power is allocated among several competing loads.

Consider, for instance, the challenge of charging a supercapacitor in a minimum amount of time from a *power-limited* supply. To maintain constant input power, the controlled charging current must decrease as the output (supercapacitor) voltage increases. The LT®3796 solves the problem of power limited or constant current/constant voltage regulation by seamlessly combining a current regulation loop and two voltage regulation loops to control an external N-channel power switch. The inherent wired-OR behavior of its three transconductance error amplifiers summed into the compensation pin, V_C, ensures that the correct loop (that is, the one closest to regulation) dominates.

(continued on page 4)

The LTC4155 is a monolithic switching battery charger that efficiently delivers 3.5A charge current in a compact PCB footprint. See page 13.

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* Maximum Power Point Tracking

> The LT3796's wide V_{IN} range (6V to 100V) and rail-to-rail (0V to 100V) output current monitoring and regulation allow it to be used in a wide variety of applications from solar battery chargers to high power LED lighting systems.

(LT3796, continued from page 1)

The additional, standalone current sense amplifier can be configured for any number of functions, including input current limit and input voltage regulation.

The LT3796's wide V_{IN} range (6V to 100V) and rail-to-rail (0V to 100V) output current monitoring and regulation allow it to be used in a wide variety of applications from solar battery chargers to high power LED lighting systems. The fixed switching frequency, current-mode architecture results in stable operation over a wide range of supply and output voltages. The LT3796 incorporates a high side current sense, enabling its use in boost, buck, buck-boost or SEPIC and flyback topologies.

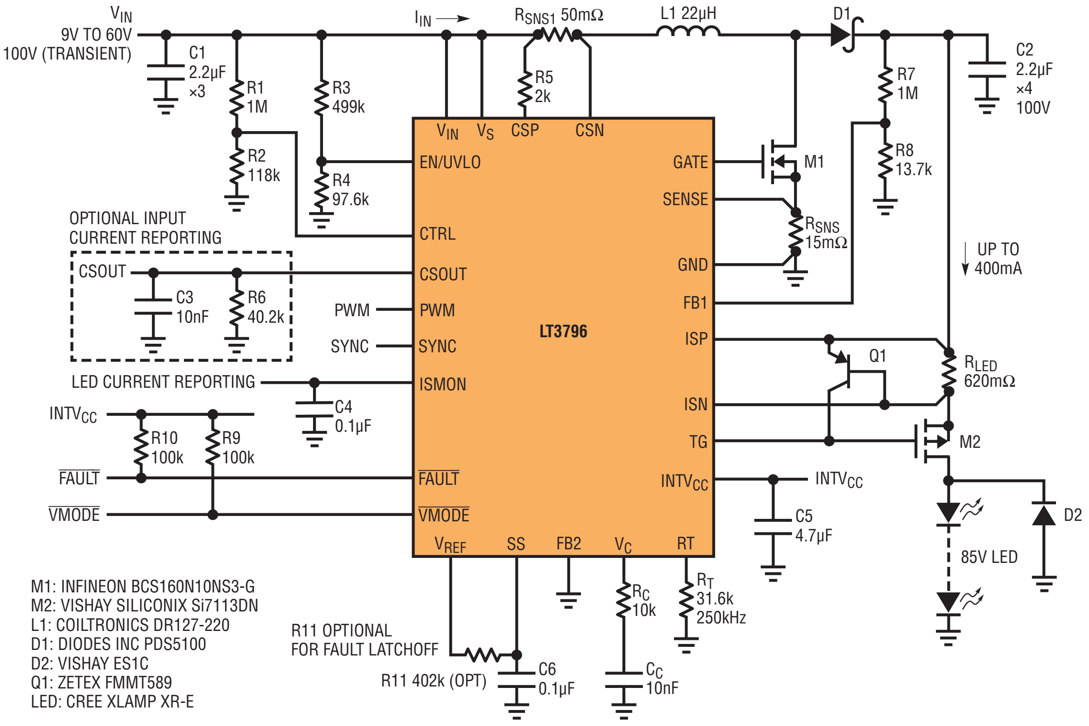
HIGH POWER LED DRIVER WITH ROBUST OUTPUT SHORT CIRCUIT PROTECTION

Figure 1 shows the LT3796 configured as a boost converter to drive a 34W LED string from a wide input range. The LED current is derated at low input voltages to prevent external power components from overheating. The front-end current sense amplifier monitors the input current by converting the input current to a voltage signal at the CSOUT pin with

$$V_{CSOUT} = I_{IN} \bullet R_{SNS1} \bullet \frac{R6}{R5}$$

The resistor network at the FB1 pin provides OPENLED protection, which limits the output voltage and prevents the ISP pin, ISN pin and several external components from exceeding their maximum rating. If an LED fails open or if the LED string is removed from the high power driver, the FB constant voltage loop takes over and regulates the output to 92.5V. The $\overline{\text{VMODE}}$ flag is also asserted to indicate an OPENLED event.

The LT3796 includes short-circuit protection independent of the LED current sense. The short-circuit protection feature prevents the development of excessive switching currents and protects the power components. The protection threshold (375mV, typ) is designed to be 50% higher than the default LED current sense threshold.



M1: INFINEON BCS160N10NS3-G
M2: VISHAY SILICONIX Si7113DN
L1: COILTRONICS DR127-220
D1: DIODES INC PDS5100
D2: VISHAY ES1C
Q1: ZETEX FMMT589
LED: CREE XLAMP XR-E

Figure 1. A 34W LED driver with robust output short-circuit protection.

LTspice IV
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The LT3796 solves the problem of power limited, or constant-current/constant-voltage regulation by seamlessly combining a current regulation loop and two voltage regulation loops to control an external N-channel power switch.

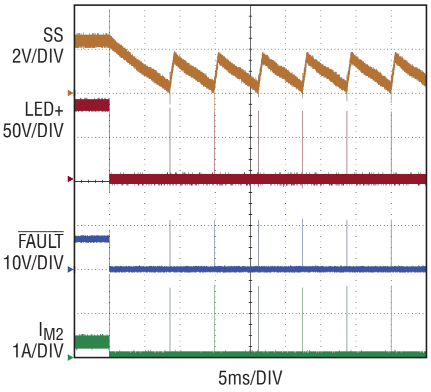


Figure 2. Short LED protection: hiccup mode (without R11 in Figure 1)

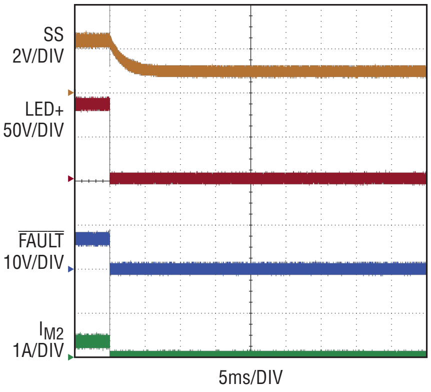
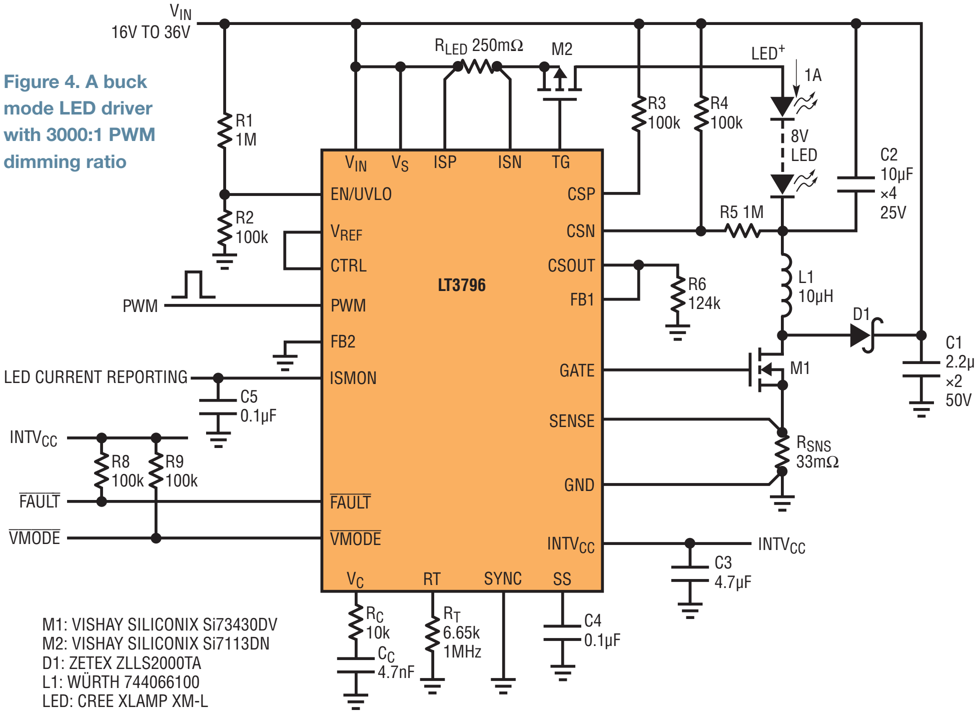


Figure 3. Short LED protection: latchoff mode (with R11 in Figure 1)

Once the LED overcurrent is detected, the GATE pin drives to GND to stop switching, the TG pin is pulled high to disconnect the LED array from the power path and the $\overline{\text{FAULT}}$ pin is asserted. The Schottky diode D2 is added to protect the drain of PMOS M2 from swinging well below ground when shorting to ground through a long cable. The PNP helper Q1 is included to further limit the transient short-circuit current.



M1: VISHAY SILICONIX Si73430DV
M2: VISHAY SILICONIX Si7113DN
D1: ZETEX ZLLS2000TA
L1: WÜRTH 744066100
LED: CREE XLAMP XM-L

Figure 4. A buck mode LED driver with 3000:1 PWM dimming ratio

If there is no resistor between the SS pin and V_{REF} pin, the converter enters hiccup mode and periodically retries as shown in the Figure 2. If a resistor is placed between V_{REF} and SS pin to hold SS pin higher than 0.2V during LED short, then the LT3796 enters latchoff mode with GATE pin low and TG pin high, as shown in Figure 3. To exit latchoff mode, the EN/UVLO pin must be toggled low to high.

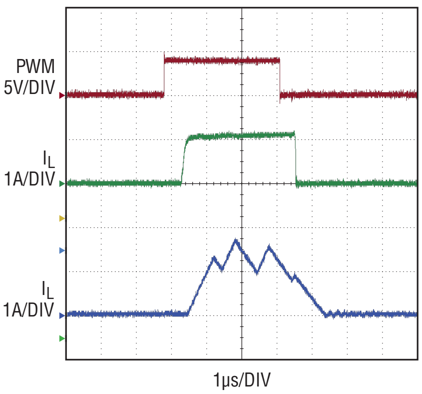
LED DRIVER WITH HIGH PWM DIMMING RATIO

Using an input referred LED string allows the LT3796 to act as a buck mode controller as shown in Figure 4. The 1MHz operating frequency enables a high PWM dimming ratio. The OPENLED regulation voltage is set to

$$1.25V \bullet \frac{R3}{R6} \bullet \left(\frac{R5}{R4}+1\right)$$

through the independent current sense amplifier at CSP, CSN and CSOUT pins. During the PWM off phase, the LT3796 disables all internal loads to the V_C pin

Figure 5. 3000:1 PWM dimming ratio of the circuit in Figure 4 at V_{IN} = 24V and PWM = 100Hz



Voltage drops in wiring and cables can cause load regulation errors. These errors can be corrected by adding remote sensing wires, but adding wires is not an option in some applications. As an alternative, the LT3796 can adjust for wiring drops, regardless of load current, provided that the parasitic wiring or cable impedance is known.

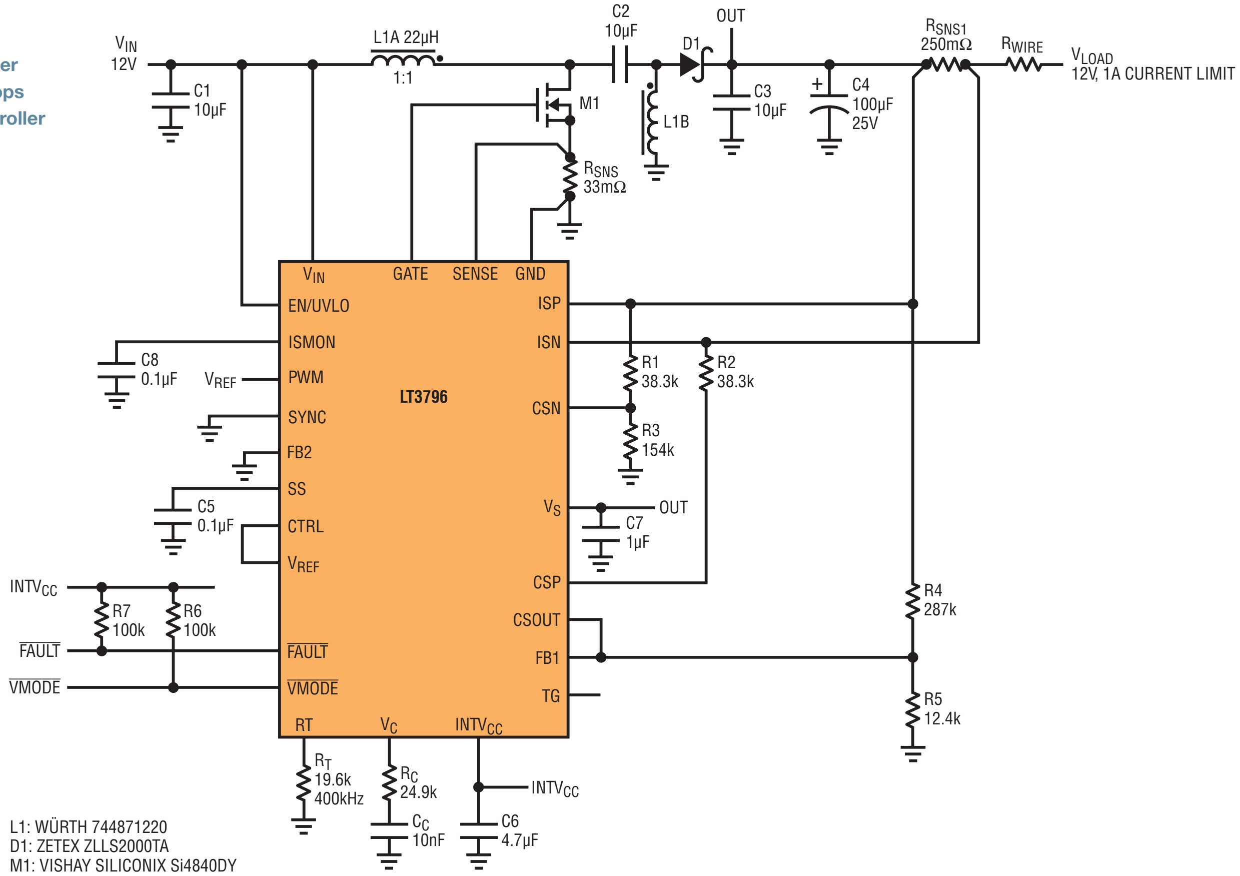


Figure 6. This SEPIC converter compensates for voltage drops in the wire between the controller and the load (R_{WIRE})

and preserves the charge state. It also turns off the PMOS switch M2 to disconnect the LED string from the power path and prevent the output capacitor from discharging. These features combine to greatly improve the LED current recovery time when PWM signal goes high. Even with a 100Hz PWM input signal, this buck mode LED driver can achieve a 3000:1 dimming ratio as illustrated in Figure 5.

SEPIC CONVERTER WITH R_{WIRE} COMPENSATION

Voltage drops in wiring and cables can cause load regulation errors. These errors can be corrected by adding remote sensing wires, but adding wires is not an option in some applications. As an alternative, the LT3796 can adjust for wiring drops, regardless of load current, provided that the parasitic wiring or cable impedance is known.

Figure 6 shows a 12V SEPIC converter that uses the R_{WIRE} compensation feature. R_{SNS1} is selected to have 1A load current limit controlled by the ISP, ISN pins. The resistor network R1–R5, along with the LT3796's integrated current sense amplifier (CSAMP in Figure 7), adjusts the OUT node voltage (V_{OUT}) to account for voltage drops with respect to the load current. This ensures that V_{LOAD} remains constant at 12V throughout the load range.

Figure 7 shows how the LT3796's internal CSAMP circuit plays into the operation. The LT3796's voltage loop regulates the FB1 pin at 1.25V so that I_3 stays fixed at 100µA for R5 = 12.4k. In Figure 7, V_{OUT} changes

The LT3796 in a 28-lead TSSOP package performs tasks that would otherwise require a number of control ICs and systems. It offers a reliable power system with simplicity, reduced cost and small solution size.

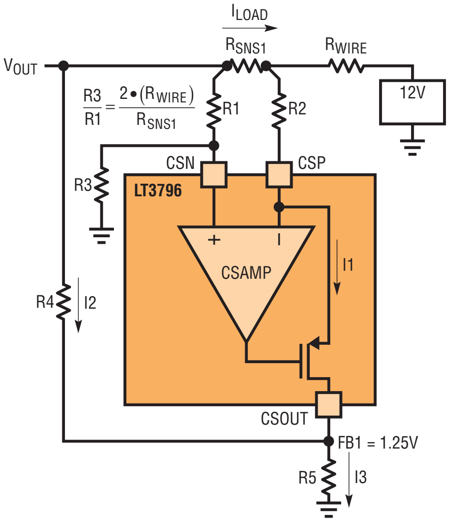


Figure 7. R_{WIRE} voltage drops are compensated for via the LT3796's CSAMP circuit

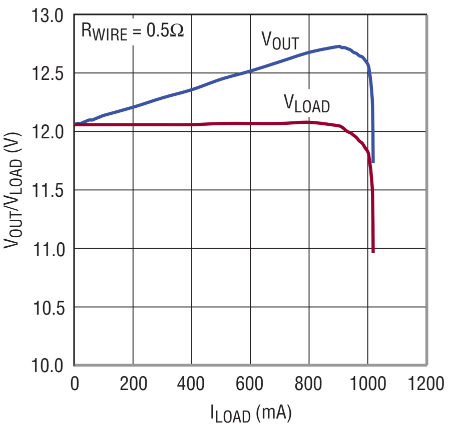


Figure 8. Measured V_{LOAD} and V_{OUT} with respect to I_{LOAD}

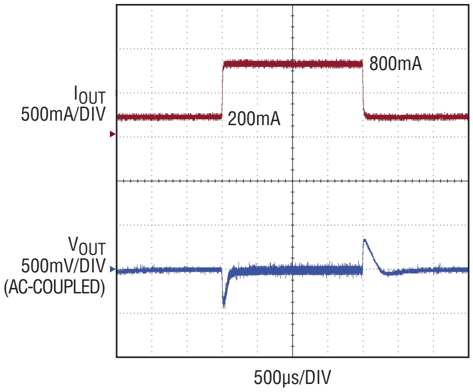


Figure 9. Load step response of the circuit in Figure 6

with current I_2 as $V_{OUT} = 1.25V + I_2 \bullet R4$. If the change of $I2 \bullet R4$ can offset the change of $I_{LOAD} \bullet (R_{SNS1} + R_{WIRE})$, then V_{LOAD} will stay constant.

Referring to Figure 7, the divider R1/R3 from V_{OUT} sets the voltage regulated at CSP by the current I_1 flowing in R2. I_1 is conveyed to the FB1 node where it sums with I_2.

As the output current increases, I_1 decreases due to the increasing voltage drop across R_{SNS}; its decrease must be compensated by a matching increase in the current I_2 to maintain the constant 100µA into FB2. This increase in I_2 with output current is what gives V_{OUT} the positive load regulation characteristic. The positive load regulation is just what is needed to compensate for the cable drop.

The measured V_{LOAD} and V_{OUT} with respect to I_{LOAD} are shown in Figure 8. Clearly, V_{LOAD} is independent of I_{LOAD} when I_{LOAD} is less than the 1A current limit. When I_{LOAD} approaches 1A, the current loop at ISP and ISN pins begins to interfere with the voltage loop and drags the output voltage down correspondingly. The load transient response is shown in Figure 9.

SOLAR PANEL BATTERY CHARGER

Solar powered devices rely on a highly variable energy source, so for a device to be useful at all times, energy from solar cells must be stored in a rechargeable battery. Solar panels have a maximum power point, a relatively fixed voltage at which the panel can produce the most power. Maximum power point tracking (MPPT) is usually achieved by limiting a converter's output current to keep the panel voltage from straying from this value. The LT3796's unique combination of current and voltage loops make it an ideal MPPT battery charger solution.

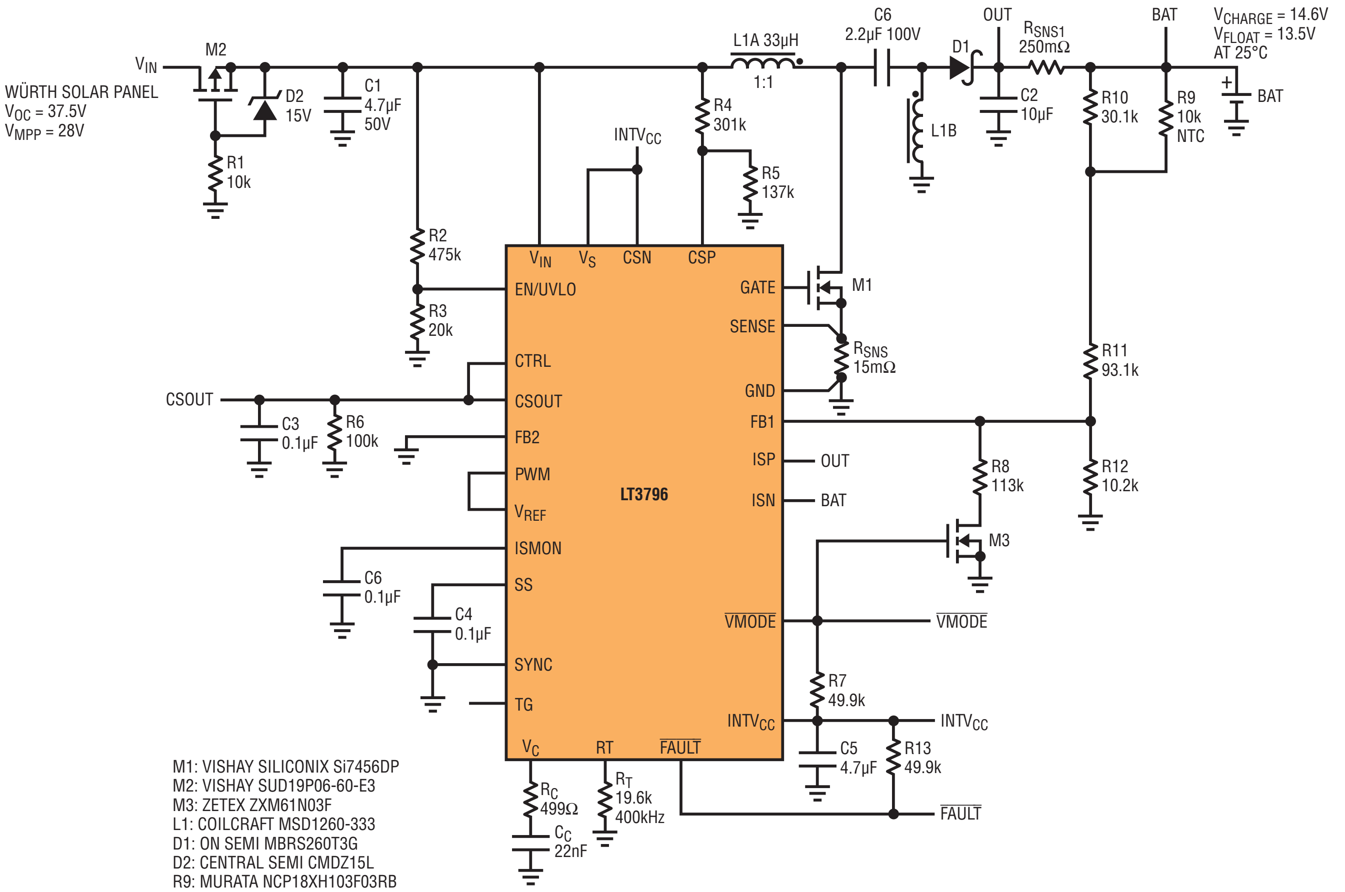


Figure 10. A solar panel battery charger maximum power point tracking (MPPT)

Figure 10 shows a solar panel to sealed lead acid (SLA) battery charger driven by the LT3796. The charger uses a three-stage charging scheme. The first stage is a constant current charge. Once the battery is charged up to 14.35V, the charging current begins to decrease. Finally, when the required battery charge current falls below 100mA, the built-in C/10 termination disables the charge circuit by pulling down $\overline{\text{VMODE}}$, and the charger enters float charge stage with V_{FLOAT} = 13.5V to compensate for the loss caused by self-discharge.

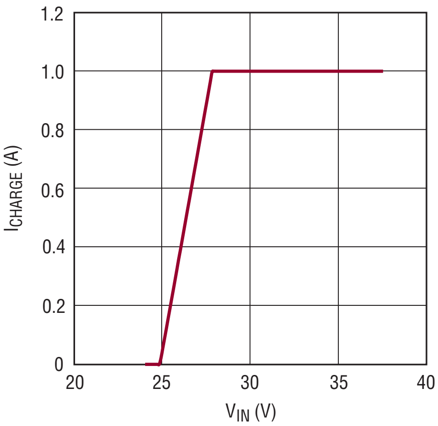


Figure 11. I_{CHARGE} vs V_{IN} for the solar charger in Figure 10

The charging current is programmed by the resistor network at the CSP and CSOUT (CTRL) pins as follows,

$$V_{CTRL} = R6 \bullet \left(\frac{V_{IN} - V_{INTVCC}}{R4} - \frac{V_{INTVCC}}{R5}\right),$$

$$\text{FOR } V_{IN} \ge V_{INTVCC}\left(1+\frac{R4}{R5}\right)$$

$$V_{CTRL} = 0V,$$

$$\text{FOR } V_{IN} < V_{INTVCC}\left(1+\frac{R4}{R5}\right)$$

Maximum power point tracking is implemented by controlling the maximum output charge current. Charge current is reduced as the voltage on the solar panel output falls toward 28V, which corresponds to 1.1V on the CTRL pin and full charging current, as shown in Figure 11. This servo loop thus acts to dynamically reduce the power requirements of the charger system to the maximum power that the panel can provide, maintaining solar panel power utilization close to 100%.

SUPERCAPACITOR CHARGER WITH INPUT CURRENT LIMIT

Supercapacitors are rapidly replacing batteries in a number of applications from rapid-charge power cells for cordless tools to short term backup systems for microprocessors. Supercapacitors are longer lasting, greener, higher performance and less expensive over the long run, but charging supercapacitors requires precise control of charging current and voltage

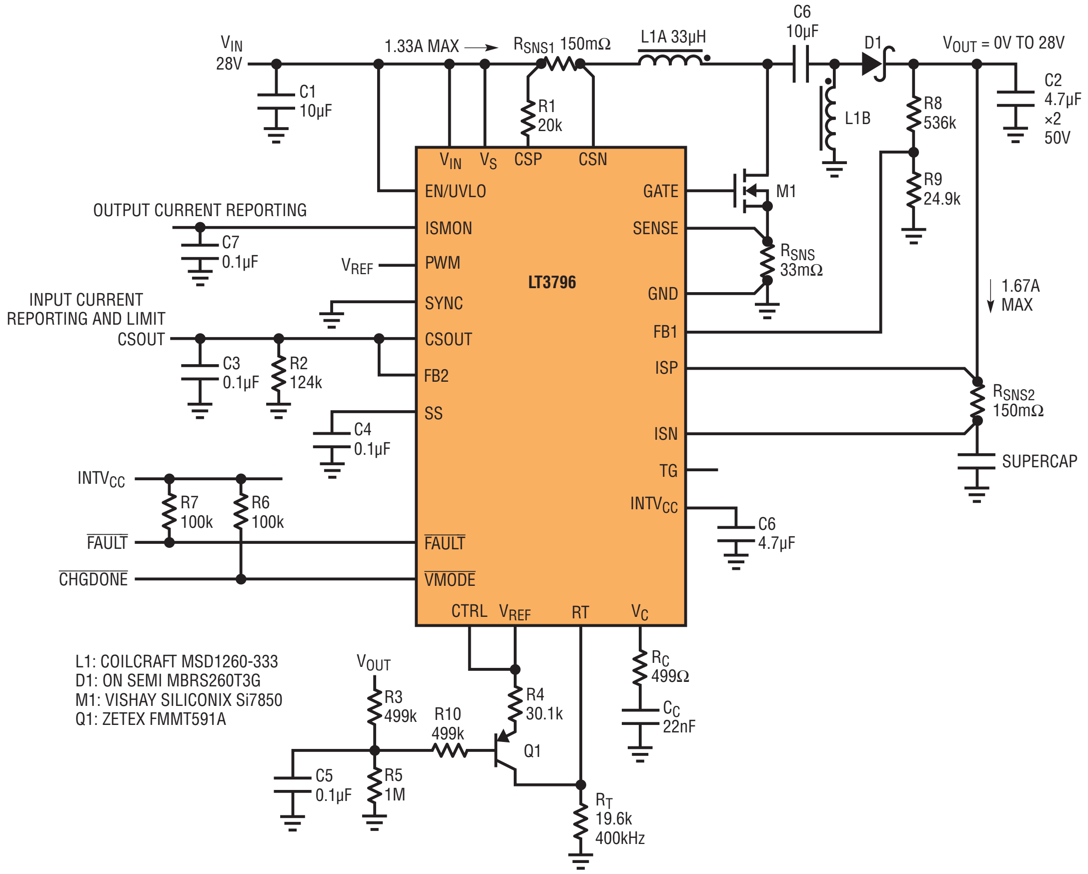


Figure 12. A 28V/1.67A supercapacitor charger with input current limit

limiting to prevent any system-wide damage or damage to the supercapacitor.

Some applications require that the input current is limited to prevent the input supply from crashing. Figure 12 shows a 1.67A supercapacitor charger with 28V regulated output voltage and 1.33A input current limit. The input current is sensed by R_{SNS1}, converted to a voltage signal and fed to the FB2 pin to provide input current limit.

In each charging cycle, the supercapacitor is charged from 0V. The feedback loop from V_{OUT} to the RT pin through R3, C5, R5, R10, R4, and Q1 to R_T works as frequency foldback to keep regulation under control. In Figure 13, the input current and output charging current are plotted against output voltage for this charger, showing the LT3796 maintaining the output current regulation until the input current moves close to the 1.33A input current limit.

CONCLUSION

The LT3796 is a versatile step-up DC/DC controller that combines accurate current and voltage regulation loops. Its unique combination of a single current loop and two voltage loops makes it easy to solve the problems posed by applications that require multiple control loops, such as LED drivers, battery or supercapacitor chargers, MPPT solar battery chargers, and step-up or SEPIC converters with input and output current limit. It also includes a number of fault protection and reporting functions, a top gate driver and current loop reporting.

The LT3796 in a 28-lead TSSOP package performs tasks that would otherwise require a number of control ICs and systems. It offers a reliable power system with simplicity, reduced cost and small solution size. ■

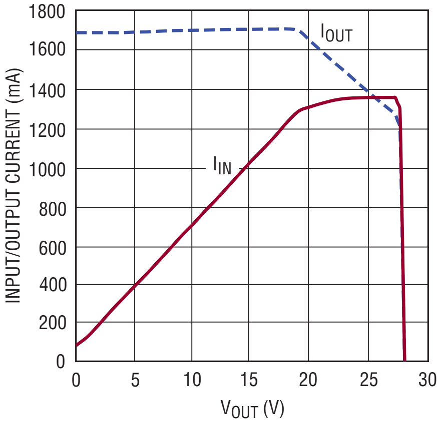


Figure 13. Input/output current vs output voltage for 28V/1.67A supercapacitor charger in Figure 12