

# 140W Monolithic Switching Regulator Simplifies Constant-Current/Constant-Voltage Regulation

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The LT3956 is a monolithic switching regulator that can generate constant-current/constant-voltage outputs in buck, boost or SEPIC topologies over a wide range of input and output voltages. With input and output voltages of up to 80V, a rugged internal 84V switch and high efficiency operation, the LT3956 can easily produce high power in a small footprint.

The LT<sup>®</sup>3956 combines key amplifier and comparator blocks with a high current/high voltage switching regulator in a tiny 5mm × 6mm package. See Figure 1 for an example of how little board space is needed to produce a complete constant-current, constant-voltage boost circuit ideal for LED driving, supercap charging or other high power applications that require the added protection of input or output current limiting.

## WHAT MAKES THE LT3956 TICK?

The big mover in the LT3956 is an 84V-rated, 90mΩ low side N-MOSFET switch with an internally programmed current limit of 3.9A (typ). The switching regulator can be powered from a supply as high as 80V because the N-MOSFET switch driver, the PWMOUT pin driver, and most internal loads are powered by an internal LDO linear regulator that converts  $V_{IN}$  to 7.15V, provided the  $V_{IN}$  supply is high enough. The switch duty cycle and current is controlled by a current-mode pulse-width modulator—an architecture that provides fast transient response, fixed switching frequency operation and an easily stabilized feedback loop at variable inputs and outputs. The switching frequency can be programmed from 100kHz to 1MHz with an external resistor, which allows designers to optimize component

size and performance parameters, such as min/max duty cycle and efficiency.

And at the heart of the LT3956 is a dual input feedback transconductance ( $g_m$ ) amplifier that combines a differential constant current sense with a standard low side voltage feedback. The handoff between these two loops is seamless and predictable. The feedback loop operating closest to its set point is auto-selected to be the loop controlling the flow of charge onto the compensation R-C network attached to the  $V_C$  pin. The voltage

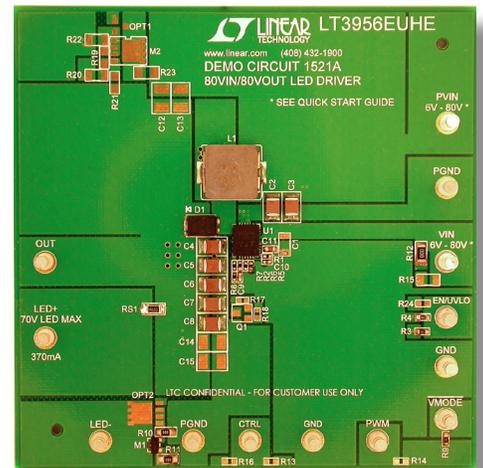


Figure 1. Complete high power, constant current, constant voltage boost circuit

level at the  $V_C$  pin in turn controls the current and duty ratio of the switch. A more thorough description of operation can be found in the LT3956 data sheet.

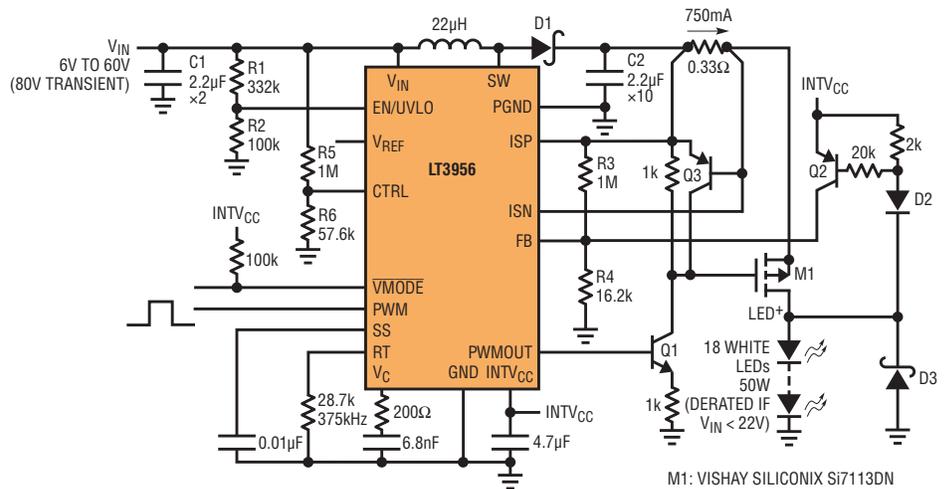


Figure 2. This 50W boost LED driver provides wide input range, PWM dimming and LED fault protection and reporting.

- M1: VISHAY SILICONIX Si7113DN
- D1: DIODES INC PDS5100
- L1: COILTRONICS DR125-220
- C1,C2: MURATA GRM42-2X7R225
- Q1: ZETEX FMMT497
- Q2,Q3: ZETEX FMMT589
- D2: BAV116W
- D3: DIODES INC B1100/B

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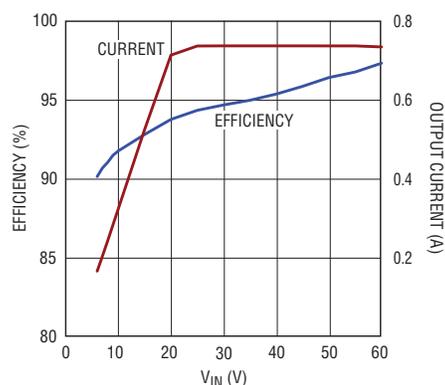


Figure 3. High 94% efficiency means less than 3W dissipation in the converter shown in Figure 2.

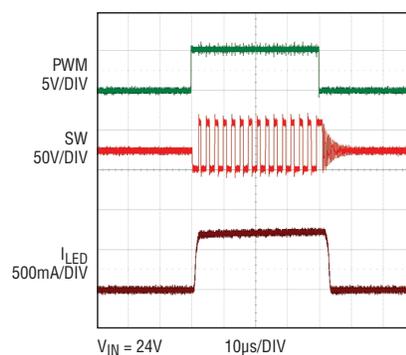


Figure 4. Boost PWM dimming waveforms for 60V of LEDs shows microsecond rise and fall times and excellent constant current regulation even over short intervals.

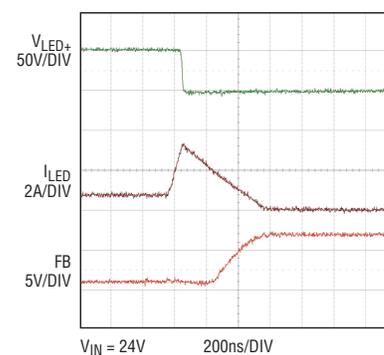


Figure 5. LED+ terminal of boost shorted to GND is prevented from damaging switching components by a novel circuit.

## A RUGGED HIGH POWER BOOST LED DRIVER

Figure 2 shows a 50W boost LED driver that operates from a 24V input, showing off some of the unique capabilities of this product when applied as an LED driver. This boost circuit tolerates a wide input range—from 6V to 60V. At the low end of this  $V_{IN}$  range, the circuit is prevented from operating too close to switch current limit by scaling back the programmed LED current as  $V_{IN}$  declines—set by the resistor divider ( $R_5$  and  $R_6$ ) on the CTRL pin. Figure 3 shows efficiency and LED current versus  $V_{IN}$ . The high efficiency (94%) means passive cooling of the regulator is adequate for all but the most extreme environmental conditions.

## ANALOG AND PWM LED DIMMING

The LT3956 offers two high performance dimming methods: analog dimming via the CTRL pin and the ISP/ISN current sense inputs, and PWM dimming through the PWM input and PWMOUT output.

### Analog Dimming

Analog dimming is achieved via the voltage at the CTRL pin. When the CTRL pin is below 1.2V, it programs the current sense threshold from zero to 250mV (typ) with guaranteed accuracy of  $\pm 3.5\%$  at 100mV. When CTRL is above 1.2V, the current sense threshold is fixed at 250mV. At CTRL = 100mV (typ), the current sense threshold is set to zero. This built-in offset is important to the feature if the CTRL pin is driven by a resistor divider—a zero programmed current can be reached with a non-zero CTRL voltage. The CTRL pin is high impedance so it can be driven in a wide variety of configurations.

### PWM Dimming

Pulse width modulation (PWM) of LED current is the preferred technique to achieve wide range dimming of the light output. Figure 2 shows a level shift transistor Q1 driving a high side disconnect P-MOSFET M1. This configuration allows PWM dimming with a single wire

solution for the luminary—the LED cathode current can return on a common GND. A scope photo of PWM dimming waveform (Figure 4) shows sharp rise and fall times, less than 200ns, and quick stabilization of the current. Although a low side N-MOSFET disconnect at the cathode is the simpler and more obvious (and a bit faster) implementation for this particular boost circuit using the LT3956, the use of high side PWM disconnect is important to a boost protection strategy to be discussed below.

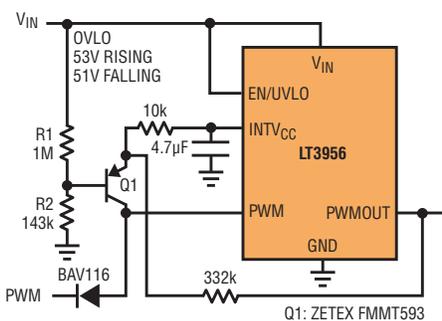
## CONSIDERATIONS FOR PROTECTING THE LED, THE DRIVER, AND THE INPUT POWER SUPPLY

LED systems often require load fault detection. Limiting the output voltage in the case of an open LED string has always been a basic requirement and is achieved through a resistor divider ( $R_3$  and  $R_4$ ) at the FB input. If the string opens, the switching regulator regulates  $V_{FB}$  to a constant 1.25V (typ). In addition to the  $g_m$  amplifier that provides this constant

voltage regulation, the FB input also has two fixed setpoint comparators associated with it. The lower setpoint comparator activates the  $\overline{V_{MODE}}$  open collector pull-down when FB exceeds 1.20V (typ). After the disconnection of the LED and loss of the current regulation signal, the output rises until it reaches the constant voltage regulation setpoint. During this voltage ramp the  $\overline{V_{MODE}}$  pin asserts and holds, indicating that the LED load is open. This signal maintains its state when PWM goes low and the regulator stops switching, allowing for the likelihood that output voltage may fall below the threshold without an occasional refresh provided by switching. The  $\overline{V_{MODE}}$  pin quickly updates when PWM goes high. The  $\overline{V_{MODE}}$  signal can also indicate that the regulation mode is transitioning from constant current to constant voltage, which is the appropriate function for current limited constant voltage applications, such as battery chargers.

The boost circuit in Figure 2 uses the voltage feedback (FB) input in a unique fashion—protecting the LED<sup>+</sup> node from a fault to GND while preserving all the other desirable attributes of the LED driver. A standard boost circuit has a direct path from the supply to the output, and therefore cannot survive a GND fault on its output when the supply current is not limited. There are a number of situations where one might desire to protect the switching regulator from a short to GND of the LED anode—perhaps the luminary is separated from the driver circuit by a connector or by a long wire, and the input supply is a high capacity battery.

The LT3956 has a feature to provide this protection. The overvoltage FB (OVFB) comparator is a second comparator on the FB input with a setpoint higher than the  $V_{FB}$  regulation voltage. It causes the PWMOUT pin to transition low and switching to stop immediately when the FB input exceeds 1.31V(typ).



**Figure 6.**  $V_{IN}$  overvoltage circuit halts switching and disconnects the load during high input voltage transients.

The OVFB comparator can be used in an output GND fault protection scheme (patent pending) for the boost. The key elements are the high side LED disconnect P-MOSFET (M1) and its supporting driving circuit responsive to the PWMOUT signal, and the output GND fault sensing circuit consisting of D2, Q2 and two resistors that provide signal to the FB node. The circuit works by sensing the current flowing in D2 when the output is shorted, and thereby triggering the OVFB comparator. In response to the OVFB comparator, the high side switch M1 is maintained in an off-state and the switching is stopped until the fault condition is removed. Figure 5 shows the current waveform in the M1 switch during and output short circuit event.

#### Additional Considerations for Protecting the LED

Some harsh operating environments produce transients on the input power supply that can overdrive a boosted output, if only for a short while, and potentially damage the LEDs with excessive current.

To discontinue switching and disconnect the LEDs during such a transient, a simple add-on circuit to the PWM input, shown as a breakout in Figure 6, disconnects the LED string and idles the switcher when  $V_{IN}$  exceeds 50V. The circuit works by sourcing current to the PWM input of the LT3956 from the collector of Q1 when  $V_{IN}$  is low enough, but cutting off that current when the base of Q1 (set

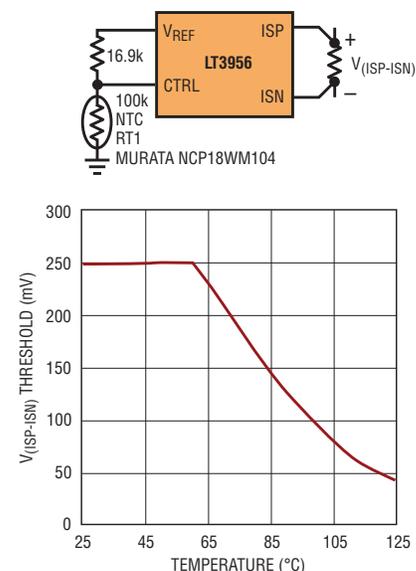
by the resistor divider from  $V_{IN}$ ) exceeds 6.5V (INTVCC minus a  $V_{BE}$ ). When PWM falls below its threshold, PWMOUT goes low as well. Hysteresis of ~2V is provided by PWMOUT. Because of the high PWM threshold (0.85V minimum over temperature), the blocking diode D1 can be added to preserve the PWM dimming capability.

The LT3956 provides solutions to thermal dissipation problems encountered driving LEDs. With high power comes the concern about reduced lifetime of the LED due to continuous operation at high temperatures. Increasing numbers of LED module applications implement thermal sensing for the LED, usually employing an NTC resistor coupled to the LED heat sink with thermal grease. A simple circuit employing the CTRL and  $V_{REF}$  pins of the LT3956 and an NTC resistor sensing the LED temperature produces a thermal derating curve for the LED current as shown in Figure 7.

#### A CONSTANT-CURRENT/VOLTAGE REGULATOR SERVES A WIDE RANGE OF APPLICATIONS

Driving LEDs makes excellent use of the LT3956 features, but it isn't the only application that requires constant

**Figure 7.** CTRL and  $V_{REF}$  pins provide thermal derating to enhance LED reliability.



voltage at constant current. It can be used for charging batteries and supercapacitors, or driving a current source load such as a thermoelectric cooler, just to name a few examples. It can be used as a voltage regulator with current limited input or output, or a current regulator with a voltage clamp.

Pursuing this line of thinking, Figure 8 shows a SEPIC supercap charger that draws power from a fixed 24V input, and has an input current limit of 1.2A. The SEPIC architecture is chosen for several reasons: it can do both step-up and step-down, and it has inherent isolation of the input from the output. A coupled inductor is chosen over a 2-inductor approach because of the smaller, lower-cost circuit. The magnetic coupling effect allows the use of a single coupling capacitor and the switch current levels of the LT3956 make strategic use of the readily available coupled inductor offerings of major magnetics vendors.

A charging circuit for a large value capacitor (1F or more) might be found in a non-battery based backup power system. These chargers would draw power from some inductive based DC supply that operates

intermittently, but the available power might be limited based on an overall system budget. The output charging rate of the circuit of Figure 8 is not based on any timer, but rather on the output voltage level as sensed by the CTRL pin. Below a certain output voltage, 22V in this case, the input current is limited so that the switching regulator is maintained within its own current limit. At higher output voltages, the default internal current sensing threshold of 250mV (typ) establishes that the input current cannot exceed 1.2A, and so the output current drops. At very low output voltages less than 1.5V, the network driving the SS pin of LT3956 reduces the switching frequency and the current limit to maintain good control of the charging current. When the load is within 5% of its target voltage, the  $\overline{\text{VMODE}}$  pin toggles to indicate the end of constant current mode and entry into constant voltage regulation.

This circuit is intended for a situation where  $V_{\text{IN}}$  does not experience much variation during normal operation. The design procedure for this type circuit begins with setting the maximum input current limit with the  $R_{\text{SENSE}}$  value and the 250mV default threshold. The next design step is to determine the  $V_{\text{OUT}}$  level below

which  $V_{\text{IN}}$  current is to be reduced through CTRL to maintain less than 2.5A average switching current. Assuming slightly less than 90% efficiency, set the resistor divider R5 and R6 to give CTRL = 1.1V when

$$V_{\text{OUT}} = \frac{V_{\text{IN}} \cdot 0.9 \cdot I_{\text{IN}}(\text{MAX})}{2.5\text{A} - I_{\text{IN}}(\text{MAX})}, \text{ at CTRL} = 1.1\text{V}$$

The values of R5 and R6 should be an order of magnitude higher value than resistor R7. The resistor divider R7 and R8 is set to provide a minimum voltage at CTRL, greater than 125mV, which is needed to set non-zero value for input current.

## CONCLUSION

The LT3956 simplifies power conversion applications needing both constant-current and constant-voltage regulation, especially if they are constrained by board area and/or bill-of-materials length. Its features are selected to minimize the number of external analog blocks for these types of applications while maintaining flexibility. Careful integration of these components into the switching regulator makes it possible to easily produce applications that would otherwise require a cumbersome combination of numerous externals. ■

Figure 8. Supercapacitor charger with current limited input provides controlled charging current over a wide output range.

