Boost-Buck LED Driver Topology for Automotive LEDs Operates with Low Input and Output Ripple

Keith Szolusha

Automotive LED drivers often require step-up/step-down DC/DC converters that can produce constant current at a voltage stepped up and stepped down from a varying input voltage (battery). Another important requirement for automotive applications is low EMI, namely, low input and output ripple. EMI requirements can be difficult to satisfy, as few of the most commonly used step-up/step-down DC/DC converter topologies can operate with both low input *and* low output ripple, while also meeting other requirements. These demands, however, are easily met by the unique, patent-pending, *boost-buck* topology described here.

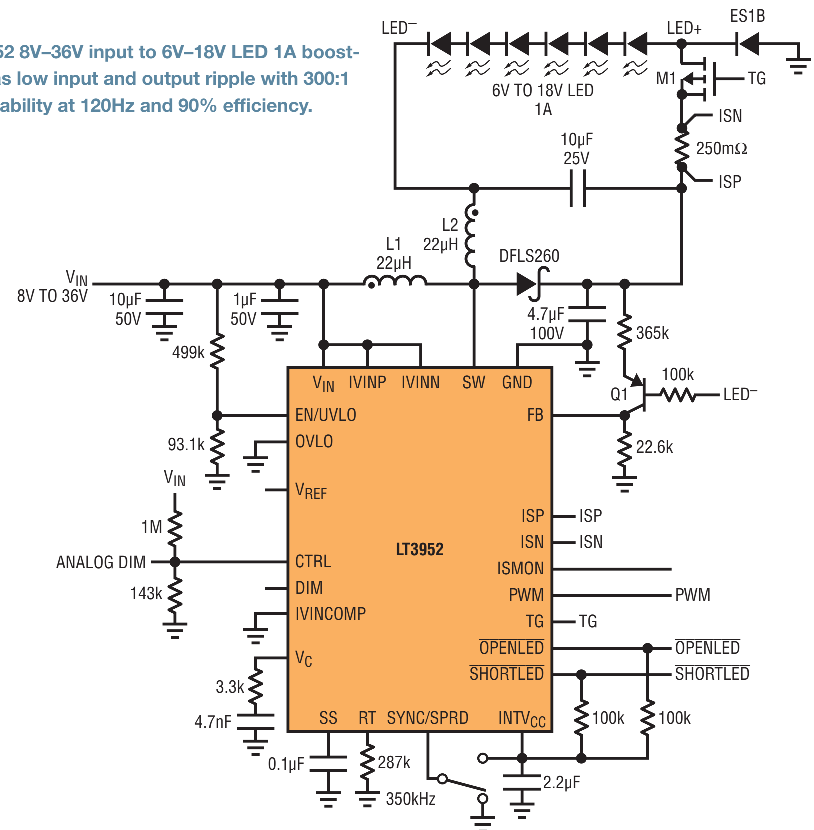
This new topology is not the only step-up/step-down topology available. There are a number of other topologies that can convert a wide-ranging input voltage to a V_{LED} within that range. The most commonly used nonisolated step-up/step-down LED driver topologies include:

- 4-switch *buck-boost* for very high power and efficiency
- coupled or uncoupled SEPIC
- single inductor *buck-boost mode*
- positive-to-negative (buck-based) *single inductor buck-boost*.

There are advantages to each of these topologies, but none can produce both truly low input and output ripple. Linear Technology's patent-pending "boost-buck" (boost-then-buck-mode) floating output LED driver topology features low input and output ripple, due to the input-and output-facing inductors (or coupled windings). In various ways, it resembles a single inductor buck-boost mode, a single-switch-node SEPIC and a positive version of a Cuk (which also has low input and output ripple, but requires a negative-referenced feedback circuit).

The overall size of the combined boost-buck inductors (or coupled inductor) is similar to the single inductor in buck-boost mode. The input ripple is similar to a SEPIC, but the output ripple is much lower. The inductor size

Figure 1. The LT3952 8V–36V input to 6V–18V LED 1A boost-buck LED driver has low input and output ripple with 300:1 PWM dimming capability at 120Hz and 90% efficiency.



L1: SUMIDA CDRH8D43-220NC (UNCOUPLED)
L2: SUMIDA CDRH6D38-220NC
L1A, L1B: COILCRAFT MSD1278-223ML (COUPLED)
M1: VISHAY Si7309DN
Q1: ZETEX FMMT591A

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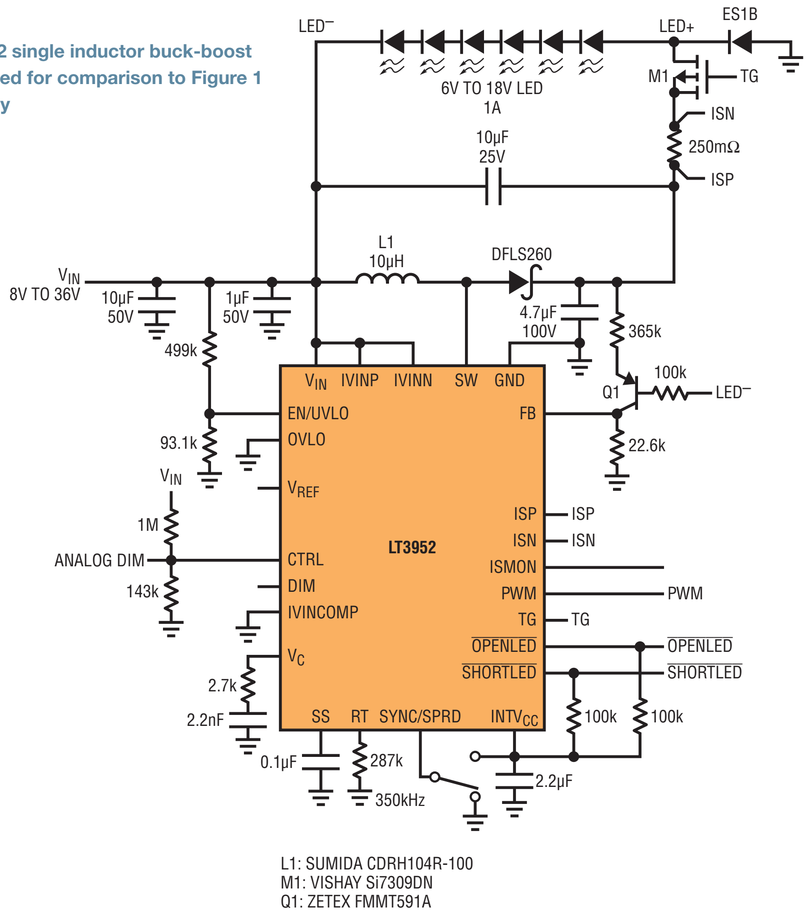

Figure 2. The LT3952 single inductor buck-boost mode LED driver used for comparison to Figure 1 boost-buck topology

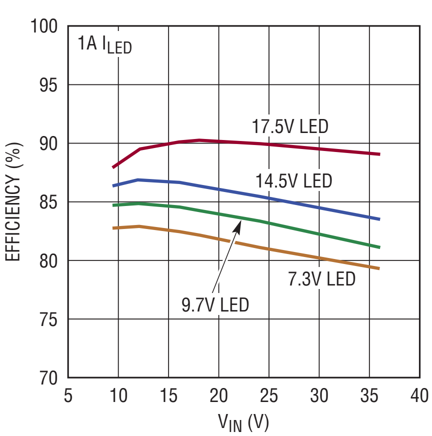

Figure 3. Boost-buck efficiency of Figure 1 is as high as 90% with 12V input and 17.5V 1A LED string.

is the same as a SEPIC, but with a single switch node instead of two (a smaller hot-loop) and without the complication of a coupling capacitor between the two windings. The input and output ripple resemble that of a low input and output ripple (inverting) Cuk converter, but again, with a single switch node instead of two, and most importantly, without the need for a negative-referenced circuit feedback architecture.

A low EMI positive boost-buck can easily be built with a boost LED driver, such as the LT3952.

BOOST-BUCK TOPOLOGY AND FLOATING LED OUTPUT

Figure 1 shows a single switch 60V monolithic LT3952 LED driver with 4A peak switch current, which can be used as an automotive boost-buck LED driver. This 350kHz, 1A LED driver can power 6V to 18V of LEDs from an 8V to 36V input with up to 90% efficiency at maximum load. High conversion efficiency is a result of the powerful internal MOS switch. Efficiencies with various LED string voltages are shown in Figure 3.

Like other LED drivers, the LT3952's versatile single, low side power switch architecture can be used to power floating output step-up and step-down converters such as boost-buck and single inductor buck-boost mode. The LED string's voltage reference to ground is not important since LED output is visible light only. Because of this, the unique floating LED driver topologies such as boost-buck and buck-boost mode are possible.

The LT3952's ability to PWM dim the floating LED string with the floating top gate (TG) pin PWM MOSFET driver easily supports floating LED loads. The boost-buck in Figure 1 can PWM dim at ratios of 300:1 and higher (at a "no-flicker" 120Hz). The high side TG driver effortlessly provides PWM dimming to boost, SEPIC, buck-boost mode, buck mode and boost-buck LED drivers. It even doubles as a short-circuit protection disconnect to protect against dreaded LED+-to-GND conditions. The LT3952 protects against and reports short-circuit and open LED conditions in boost-buck topology.

The boost-buck LED driver topology can both step-up and step-down the input-to-output voltage as it regulates the LED current. Boost-buck duty cycle, efficiency, switch current and V_{OUT} node voltage are the same as both single inductor buck-boost mode and SEPIC. Here are some properties of the boost-buck LED driver:

- $V_{OUT} = V_{IN} + V_{LED}$
- $DC = V_{LED}/(V_{IN} + V_{LED})$
- $I_{SW(PEAK)} = I_{IN} + I_{LED} + I_{L(P–P)}/2$
- $I_{L(P–P)} = I_{L1(P–P)} + I_{L2(P–P)}$

LOW INPUT AND OUTPUT RIPPLE TOPOLOGY = LOW EMI

Figure 2 shows an “equivalent” single inductor buck-boost driver—comparable to the boost-buck driver shown in Figure 1. Although there are similarities between the two, they differ greatly in input and output ripple. Figure 4 demonstrates the reduced conducted EMI of the boost-buck driver (Figure 1) versus the buck-boost mode version (Figure 2). The separation of input and output windings prevents the output ripple current from coupling to the input capacitor of the boost-buck, thus reducing EMI. The EMI in Figure 4 shows low AM band EMI from 530kHz to 1.8Mhz, reducing the requirement for a large EMI input filter.

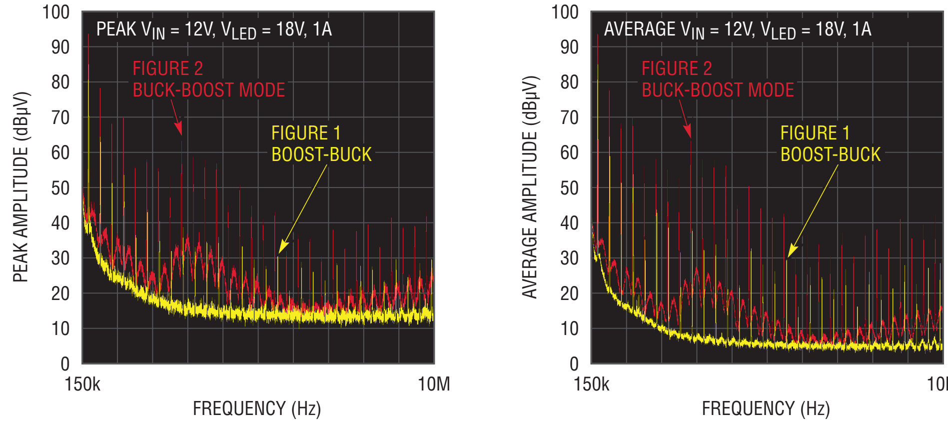

Figure 4. (a) Figure 1 boost-buck conducted EMI is much lower than (b) Figure 2 buck-boost mode conducted EMI for 12V input, 18V, 1A LED string.

Figure 5 compares the input and output ripple paths of the boost-buck topology with those of a SEPIC converter, which does not have the same low output ripple. High ripple on either the input or output lines can radiate and increase EMI, especially if those lines are several meters long, as in a car. Mitigating radiated EMI with additional LC filtering on the output of an LED driver is not recommended, since it can inhibit optimal PWM dimming performance by slowing PWM transitions and causing unwanted ringing. The low ripple, output-facing inductor of the boost-buck yields the best combination of PWM dimming performance and low output EMI, similar to a buck-only converter.

Note that the positive-to-negative single inductor buck-boost converter also has low output ripple and high bandwidth, but its input and output ripple are coupled into the large system input capacitance, creating greater conducted EMI.

Both the input and output capacitors in the boost-buck topology easily filter low triangular ripple current equal to $I_{L1(P–P)}/\sqrt{12}$. A bit more capacitance or inductance can further reduce EMI in this topology. Neither the input nor output capacitor is crucial in the converter’s high dI/dt hot-loop. In this topology, the critical hot-loop is constrained to the catch diode, OUT-to-GND capacitor, and the internal low side switch, as indicated in Figure 5, simplifying the layout. If the two inductors or windings of the boost-buck are tied together and the LED– node is connected to the input, the boost-buck is converted to buck-boost mode. In this scenario, the hot-loop currents and the input and

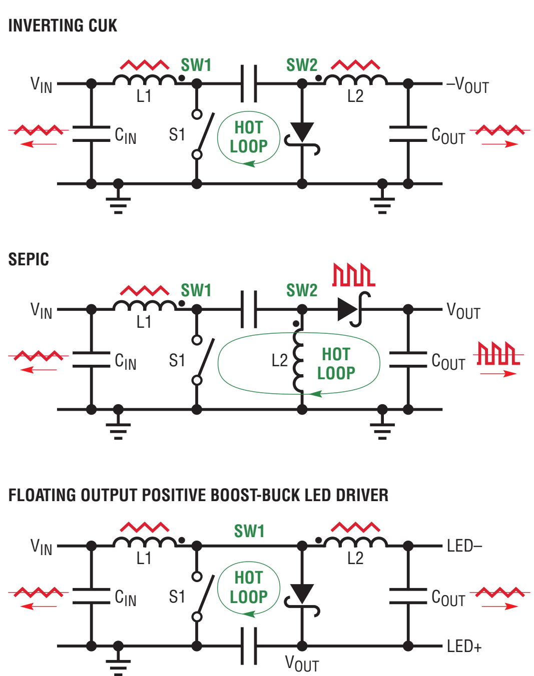

Figure 5. Boost-buck LED driver is similar to SEPIC LED driver topology

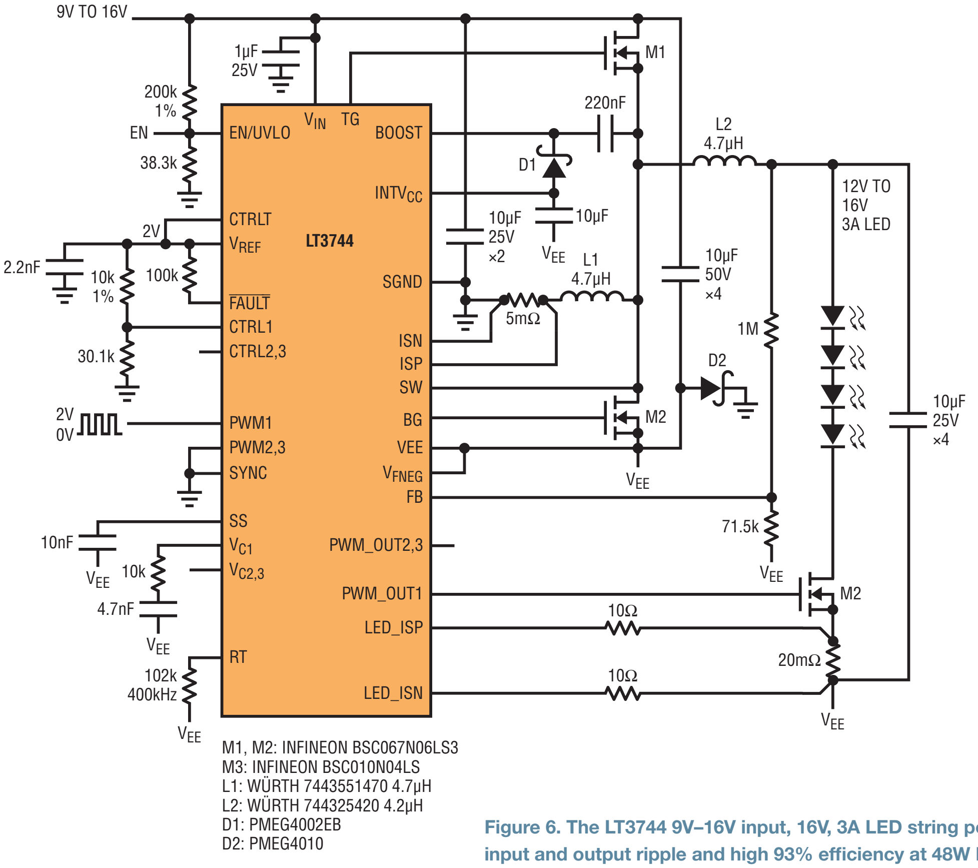

Figure 6. The LT3744 9V–16V input, 16V, 3A LED string positive-to-negative boost-buck LED driver has low input and output ripple and high 93% efficiency at 48W LED.

output ripple currents can find their way onto the input and output capacitors, respectively, resulting in increased input and output ripple measurements.

LOOP ANALYSIS FOR STABILITY (SEPIC-LIKE CONTROL LOOP)

The control loop of the boost-buck converter has the personality of a SEPIC. The loop response can be measured with a network analyzer by injecting a noise perturbation into the ISN line and measuring the gain and phase of the loop response at the sense resistor. The uncoupled boost-buck in Figure 1 produces a 7kHz crossover frequency and well over 60° of phase margin and 10° of gain margin at 12V input to 18V V_{LED} at 1A.

If no network analyzer is available, the loop dynamics can be determined by the shape of LED current transient response waveforms when the CTRL input is toggled from 50% to 100% LED current or vice versa. The merged lower frequency boost response and higher frequency buck response of this boost-buck can be seen in both the loop Bode plots and in the transient response.

POSITIVE-TO-NEGATIVE BOOST-MODE-THEN-BUCK TOPOLOGY WITH SIMILAR PERFORMANCE ADVANTAGES

Another patent-pending boost-buck LED driver topology with low ripple input and output is shown in Figure 6. The LT3744 positive-to-negative boost-buck (boost-mode-then-buck) is also a low input and output ripple LED driver, but instead uses using a synchronous step-down converter with negative regulation capability.

This unique floating negative output topology takes advantage of the strengths of the synchronous step-down LT3744 LED driver with PWM and output flag level-shift capabilities. One of those strengths is the high efficiency that is only possible with a synchronous switching IC, especially when driving a high power LED string, such as the 3A, 48W LED load in Figure 6. Synchronous step-up and down boost-buck LED drivers are possible with both synchronous boost and buck LED drivers.

CONCLUSION

New, patent-pending boost-buck LED driver topologies from Linear Technology provide step-up and step-down input to V_{LED} ratios with low input and output ripple. New LED drivers such as the LT3952 and LT3744 can be used for both simple and high power LED strings in automotive and industrial applications, where high power and low noise are crucial, without sacrificing PWM dimming performance. ■