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IN THIS ISSUE

20A LED Driver with Accurate ±3% Full Scale Current Sensing Adapts to Multitude of Applications

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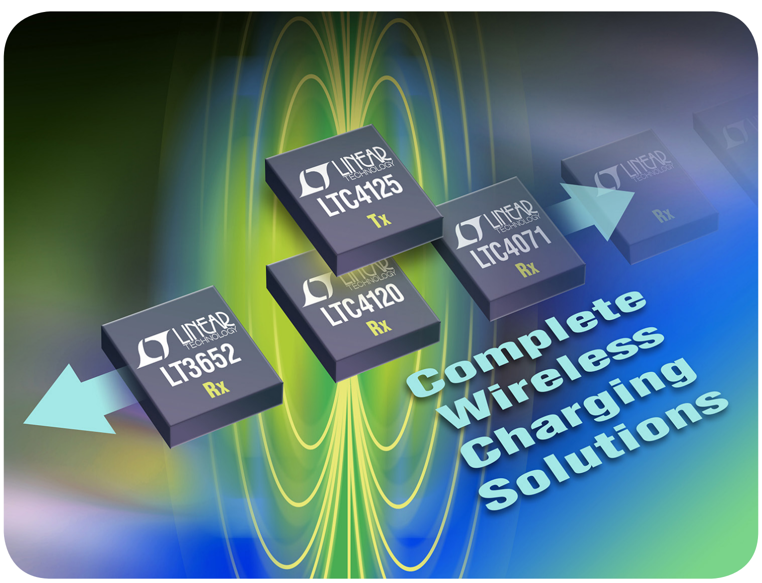
Rapidly evolving LED lighting applications are replacing nearly all traditional forms of illumination. As this transformation accelerates, power requirements for LED drivers increase, with higher currents making it more challenging to maintain current sensing accuracy without sacrificing efficiency. LED drivers must do this while managing current delivery to multiple independent LED loads at high speeds, and be able to connect parallel drivers with accurate current sharing.



The LTC4125 5W AutoResonant wireless power transmitter features foreign object detection and completes linear wireless charging solutions (see page 31).

Some high power LEDs have unique mechanical and electrical considerations, where the anode is electrically tied to the thermally conducting backtab. In a traditional LED driver with a step-down regulator configuration, where thermal management is achieved by cooling the chassis, the anode connection to the backtab creates a mechanical-electrical design challenge. The backtab must have good thermal conductivity to the heat sink, but also be electrically isolated from it if the voltage at the tab is different from the chassis. Since is it difficult for LED manufacturers to change processing or packaging, the LED driver itself must meet this design challenge.

One option is to use a 4-switch positive buck-boost LED driver, but the additional switching MOSFETs add system complexity and cost. An inverting buck-boost topology uses only one set of switching power MOSFETs, and allows the anode heat sink to be tied directly—electrically and

(continued on page 4)

To meet high performance demands, the LT3744 can be configured as a synchronous step-down or inverting buck-boost controller to drive LED loads at continuous currents exceeding 20A. The supply input for the LT3744 is designed to handle 3.3V to 36V.

(LT3744, continued from page 1)

mechanically—to the chassis ground, eliminating the need for electrical isolators on the heat sink, and simplifying the mechanical design of the system.

To meet high performance demands, the LT®3744 can be configured as a synchronous step-down or inverting buck-boost controller to drive LED loads at continuous currents exceeding 20A. The supply input for the LT3744 is designed to handle 3.3V to 36V. As a step-down converter, it regulates LED current from 0V up to the supply voltage. As an inverting buck-boost converter, the LT3744 can accurately regulate LED currents with output voltages from 0V down to −20V.

Full-range analog current regulation accuracy is 3%, and even at 1/20th scale, it is better than ±30%. The LT3744 has three independent analog and digital control inputs with three compensation and gate drive outputs for a wide range of LED configurations. By separating the inductor current sense from the LED current sense, the LT3744 can be configured as a buck or inverting buck-boost. For ease of system design, all input signals are referenced to board ground (SGND, signal ground), eliminating the need for complex discrete level-shifters.

In the inverting buck-boost configuration, the total LED forward voltage can be higher than the input supply voltage, allowing high voltage LED strings to be driven from low voltage supplies. When PCB power density calls for spreading the component power

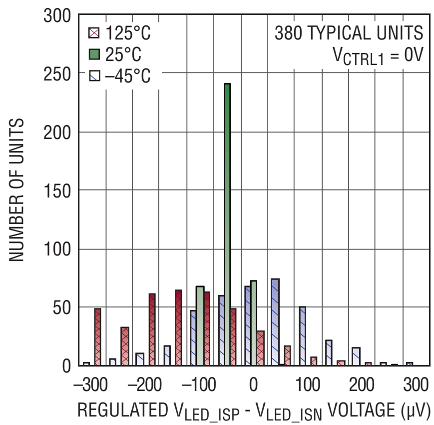


Figure 1. The LED current regulation amplifier in the LT3744 has a typical offset of ±300µV with V_{CTRL} = 0V.

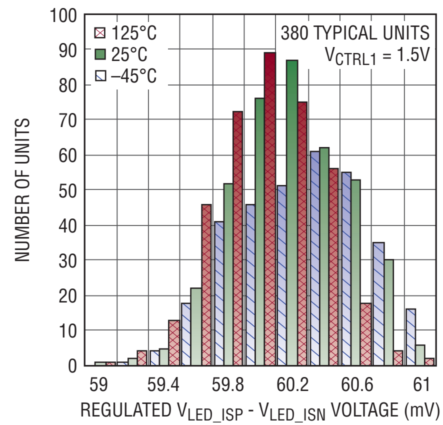


Figure 2. At full current, the LED current regulation loop has a typical accuracy of ±1.7% with V_{CTRL} = 1.5V.

dissipation, the LT3744 can be easily paralleled with other LT3744s to drive high pulsed or DC currents in LED loads.

HIGH ACCURACY CURRENT SENSING

The LT3744 features a high accuracy current regulation error amplifier, which achieves accurate analog dimming down

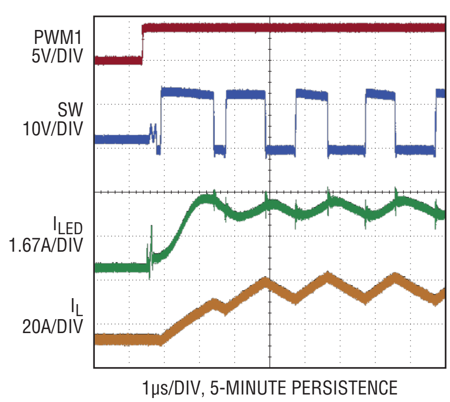


Figure 3. The LT3744 features flicker-free LED dimming.

to 1/20th of the total current control range. This is critical in applications where the total digital PWM dimming range is limited—or in applications where very high dimming range is required. As an example, with a 100Hz PWM dimming frequency and a 1MHz switching frequency, the LT3744 is capable of 1250:1 PWM dimming, which can be combined with 20:1 analog dimming to extend the total diming range to 25,000:1.

Figure 1 shows the production consistency of the LT3744 with regard to offset voltage over temperature, in this case 380 typical units when the analog control input is at 0V. With the low offset of the error amplifier, the control loop is capable of a typical accuracy of ±10% at 1/20th scale analog dimming. The distribution of the regulated voltage across the LED current sensing pins with the control input equal to 1.5V is shown in Figure 2. The accuracy at full range is better than

In projection systems, reducing the turn-on time of the light source reduces timing constraints. With a reduction in timing constraints, the image refresh rate can increase, allowing higher resolution images and a reduction in the rainbow effect from fast-moving white objects. The LT3744 is capable of transitioning between the different output current states in less than three switching cycles.

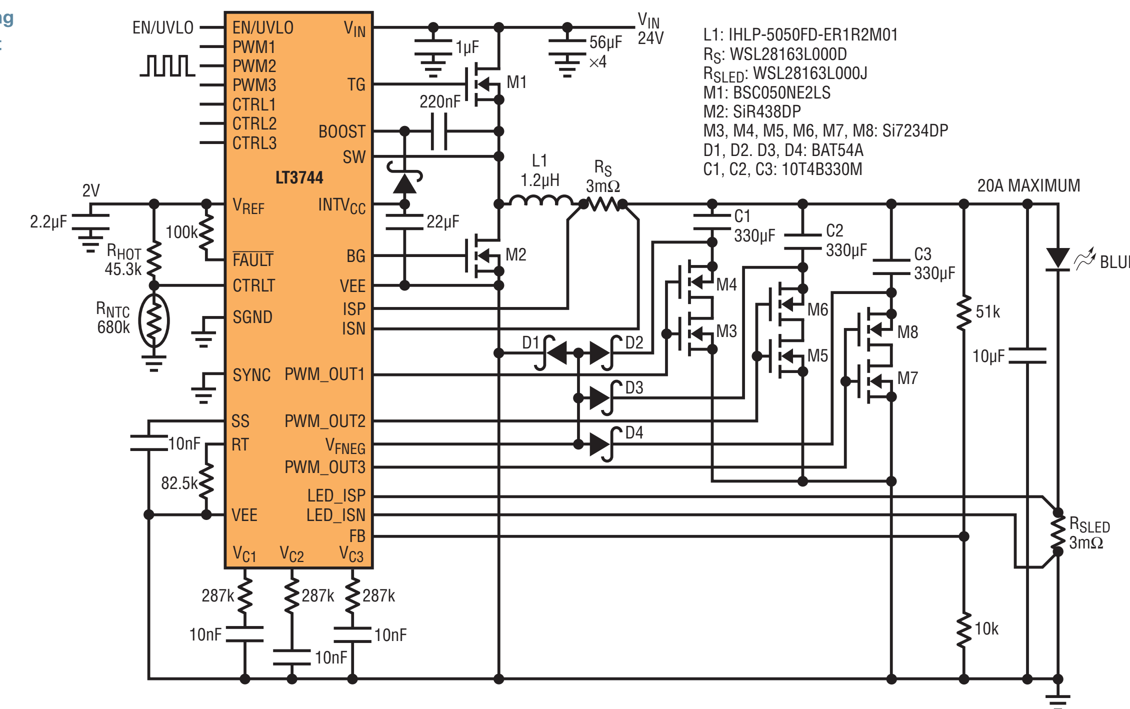


Figure 4. The LT3744 is capable of driving a single LED with three different current levels.

±3%, which corresponds to ±1.8mV on the 60mV full-scale regulation voltage.

FLICKER-FREE PERFORMANCE

One of the most important metrics in LED driver performance is in the recovery of the LED current during PWM dimming. The quality of the end product is highly dependent on the behavior of the driver in the first few switching cycles after the rising edge of the PWM turn-on signal. The LT3744 uses proprietary PWM, compensation and clock synchronization technology to provide flicker-free performance—even when driving LEDs to 20A.

Figure 3 shows a 5-minute capture of the LED current recovery with a 12V supply delivering 20A to a red LED. The switching frequency is 550kHz, the inductor is 1µH, the PWM dimming frequency is 100Hz with an on-time of 10µsec (1000:1 PWM dimming). Roughly 30,000 dimming cycles are shown, with no jitter in the switching waveform—every recovery switching cycle is identical.

HIGH SPEED DIMMING BETWEEN THREE DIFFERENT REGULATED CURRENTS

In projection systems, reducing the turn-on time of the light source reduces timing constraints. With a reduction in timing constraints, the image refresh rate can increase, allowing higher resolution images and a reduction in the rainbow effect from fast-moving white objects. The LT3744 is capable of transitioning between the different output current states in less than three switching cycles.

The LT3744 features three regulated current states, allowing color-mixing system designers to sculpt the color temperature of each LED. Color mixing delivers high color accuracy, corrects inaccurate LED colors, and eliminates variations in production systems. While the LT3743 has low and high current states, the LT3744 features three current states so that all three RGB LED colors can be mixed with each other at their own light outputs to independently correct the other colors.

Figure 4 shows a 24V input/20A output, single LED driver with three different regulated currents—determined by the analog voltages on the CTRL and the digital state of the PWM pins. Note that since R_S is only used for peak inductor current and absolute overcurrent protection, Within miniature "pocket" or smartphone projection systems, total solution space and cost are paramount. The LT3744 combines switched output capacitor technology with a floating gate driver to create a complete RGB solution from a single LED driver, a significant space savings over multi-IC drivers.

it does not need to be a high accuracy resistor—which reduces system cost.

PWM dimming between the three different current states is shown in Figures 5 and 6. In Figure 5, the PWM signals are sequentially turned on and off. PWM3 has the highest priority and PWM1 has the lowest. This allows rapid, single input signal transitions to change the output current. As shown in Figure 6, there can be any arbitrary interval between the PWM input signals.

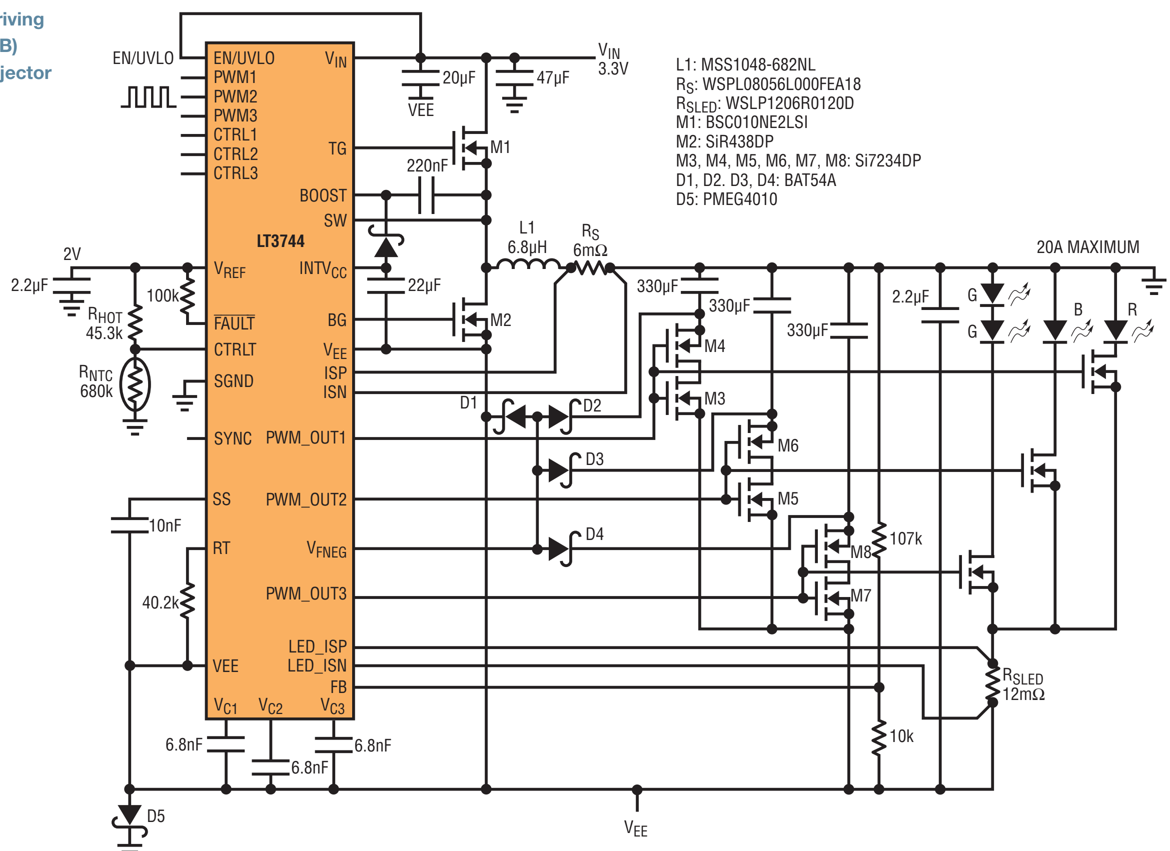
A COMPLETE RGB LED SOLUTION FOR POCKET OR SMARTPHONE PROJECTORS

Within miniature "pocket" or smartphone projection systems, total solution space and cost are paramount. In these applications, PCB space is extremely limited and the total volume of the driver solution (including component height) must be minimized. Using only one LED driver for all three LEDs drastically reduces space—allowing use of larger batteries or higher power LEDs for improved battery lifetime and projected lumens.

The LT3744 combines switched output capacitor technology with a floating gate driver to create a complete RGB solution from a single LED driver. The LT3744 uses a unique gate driver for the PWM output pins. The negative rail of the driver floats on the V_{FNEG} pin, allowing it to pull down the gates of all of the switches that are off to negative voltages. This ensures that the switches in-series with the output capacitors do not turn on in any condition. This driver allows up to a 15V difference between any string of LEDs.

Each LED can be turned on sequentially, with a time delay in between, or with any

Figure 7. The LT3744 is capable of driving all three color component (R, G and B) LEDs in a pocket or smartphone projector from a single Li-ion battery.



In addition, with the three independent analog control inputs, each LED can operate at a different regulated current. When the LT3744 is configured as an inverting buck-boost, a single lithium-ion battery can drive three independent LED strings using only a single controller.

Summary of Linear's high power LED driver-controller family

	LT3741	LT3743	LT3744	LT3763	LT3791
V_{IN} range	6V–36V	6V–36V	3.3V–36V	6V–60V	4.7V–60V
LED output range	0V–34V	0V–34V	−20V–36V	0V–55V	0V–52V
Topology	buck	buck	buck and inverting buck-boost	buck	buck-boost
LED current regulation accuracy	±6%	±6%	±3%	±6%	±6%
1⁄10 scale LED current accuracy	±60%	±60%	±17%	±60%	±35%
Full-scale LED current sense	50mV	50mV	60mV	50mV	100mV
Common anode connection for LEDs			✓		
LED fault indication			✓	✓	✓
Low side LED PWM gate driver(s)	0	2	3	1	1
Individual LED current states	1	2	3	1	1

pattern input into the PWM digital inputs. In addition, with the three independent analog control inputs, each LED can operate at a different regulated current. When the LT3744 is configured as an inverting buck-boost, a single lithium-ion battery can drive three independent LED strings using only a single controller. Figure 7 shows a 3.3V/5A inverting tri-color buck-boost LED driver designed specifically for RGB pocket projectors.

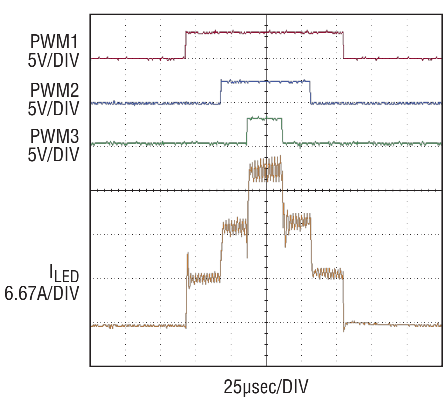


Figure 5. The LT3744 transitions between any of three regulated current states and off in less than three switching cycles.

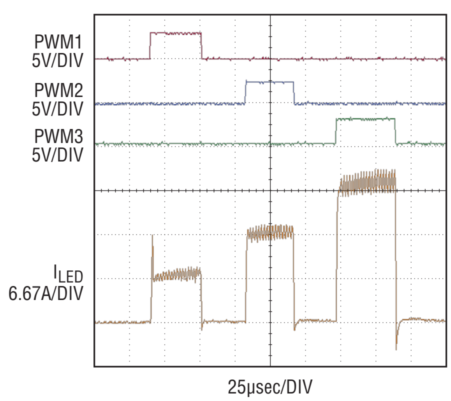


Figure 6. The different current states can be turned on at any time—with or without time in between each state.

324W 2-LED DRIVER USING TWO PARALLEL LT3744 LED DRIVERS

A significant limiting factor in any high power/high current controller design is power density in the PCB. PCB power density is limited to roughly $50W/cm^2$ to prevent excessive temperature rise within the power path components. In extreme cases, where an LED load requires more power than a single driver can support (while remaining within power density limits), multiple converters can be paralleled to spread the load.

An efficient high current LED driver-controller, with modern power MOSFETs, can provide roughly 200W (at a solution size of approximately $4cm^2$) and limit all power path component temperatures to under 80°C. For LED loads higher than 200W, the LT3744 can be paralleled with other LT3744s to limit the temperature rise

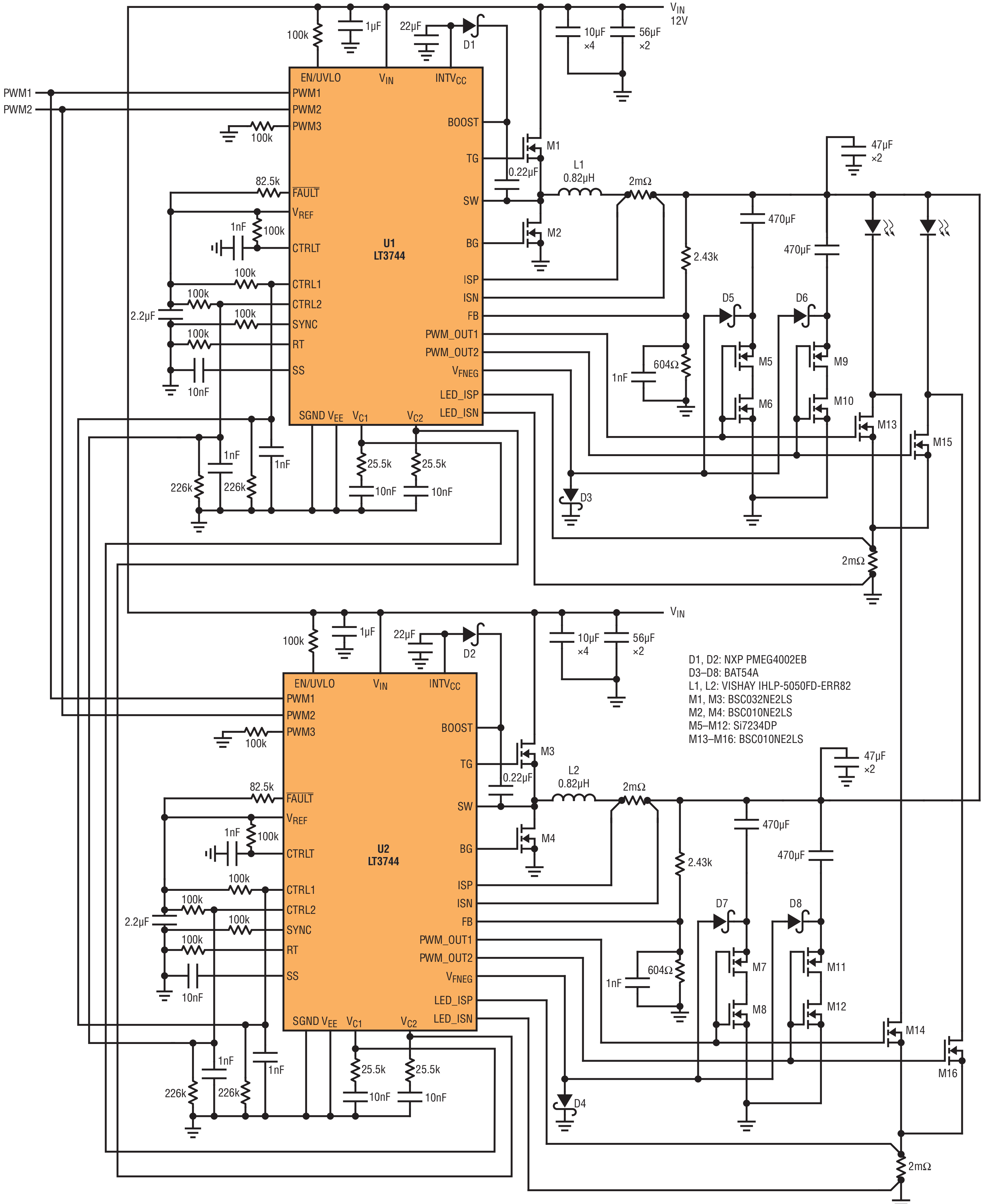


Figure 8. A 57A/324W 2-LED driver

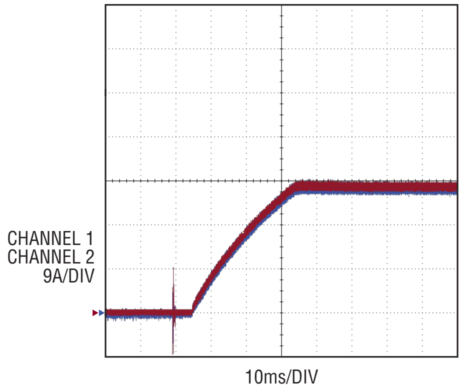


Figure 9. LED current sharing during start-up

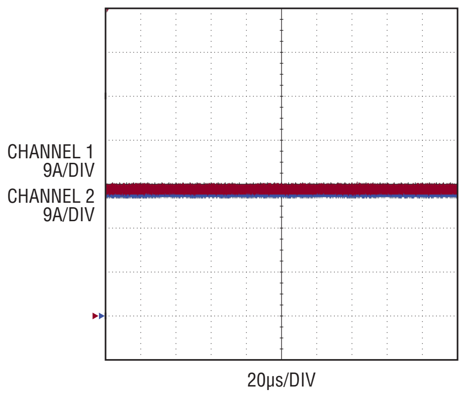


Figure 10. DC LED current sharing at full load—showing very little variation between the two parallel drivers

in any particular component. All compensation outputs should be paralleled, allowing current sharing between each regulator.

Figure 8 shows a 324W converter using two Linear DC2339A demo boards connected in parallel. Each of the parallel controllers in this design produces 27A—for a total of 54A at 6V. By tying the corresponding compensation outputs together, both controllers behave in unison to provide a smooth, well behaved start-up and accurate DC regulation.

Figure 11. Parallel board temperatures at 100% duty cycle delivering 324W to the LED

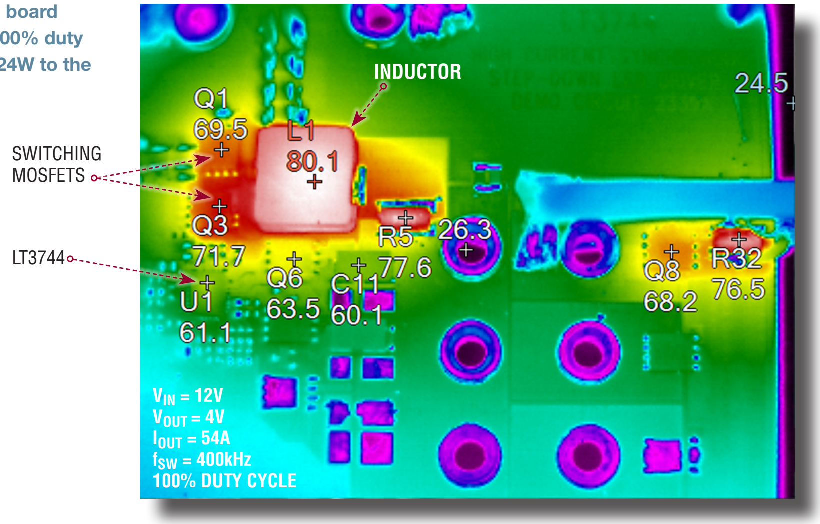


Figure 9 shows the LED current start-up behavior of each board. Note that the regulated current provided by each board is identical throughout the entire start-up sequence. In DC regulation, without PWM dimming, Figure 10 shows excellent current sharing between the two application boards (the waveforms are directly on top of each other). Figure 11 shows that the temperature rise above ambient of the board at 100% duty cycle is about 55°C. Component L1 is the inductor, Q1 and Q3 are the switching power FETs, R5 is the inductor current sense resistor, R32 is the LED current sense resistor, and U1 is the LT3744.

In this application, two independent LED strings can be PWM dimmed at the full 54A. When PWM dimming, Figure 12 shows that the LED current is completely shared between the two drivers. In this test, the rise time of the current in the LED from 0A to 54A is 6.6µs. The electrical connection from the output of each driver to the LED must be carefully balanced to avoid added inductance in either path—which reduces the effective rise time.

Figure 13 shows the temperature rise in each demo board with a 50% PWM-dimmed LED current of 54A. To

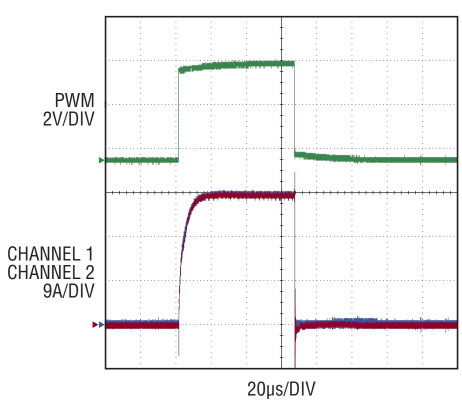
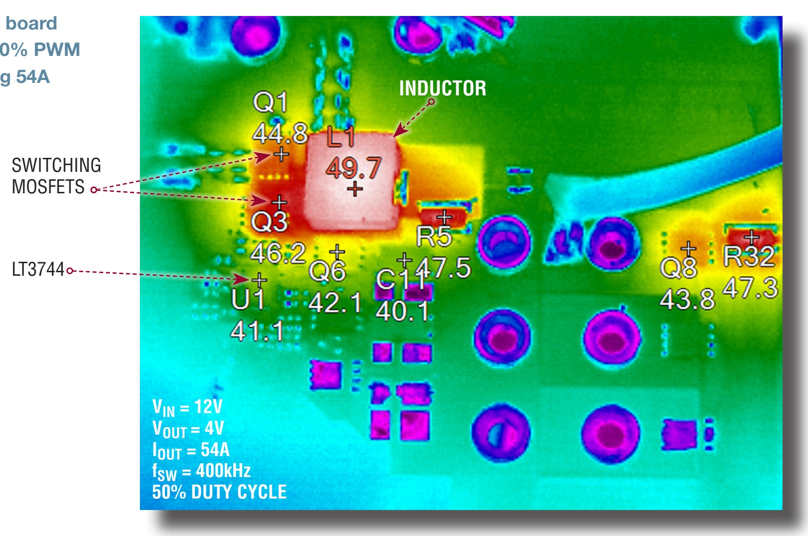


Figure 12. The LT3744 features excellent LED current sharing between parallel drivers during PWM dimming.

Figure 13. Parallel board temperatures at 50% PWM dimming delivering 54A pulses to the LED



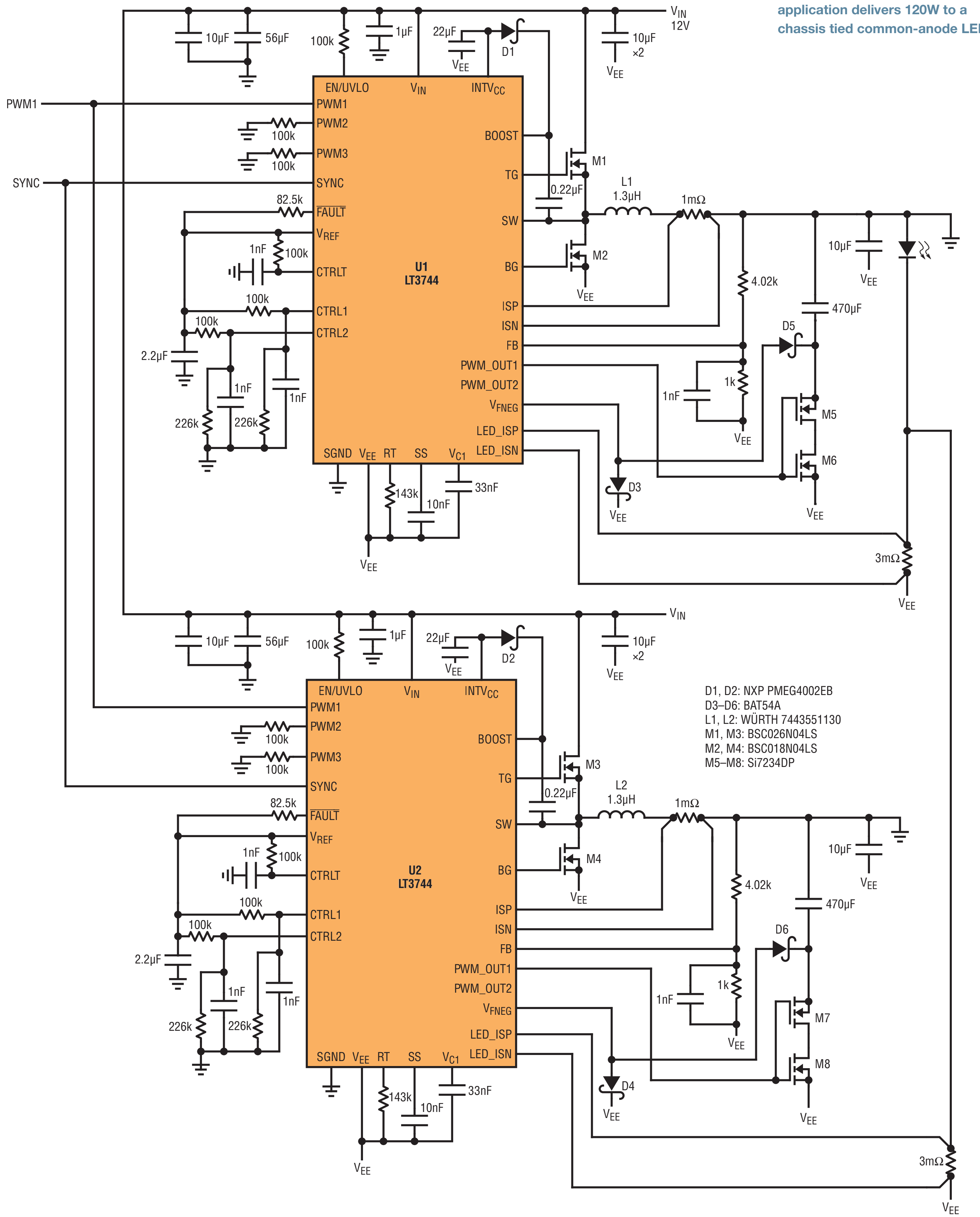
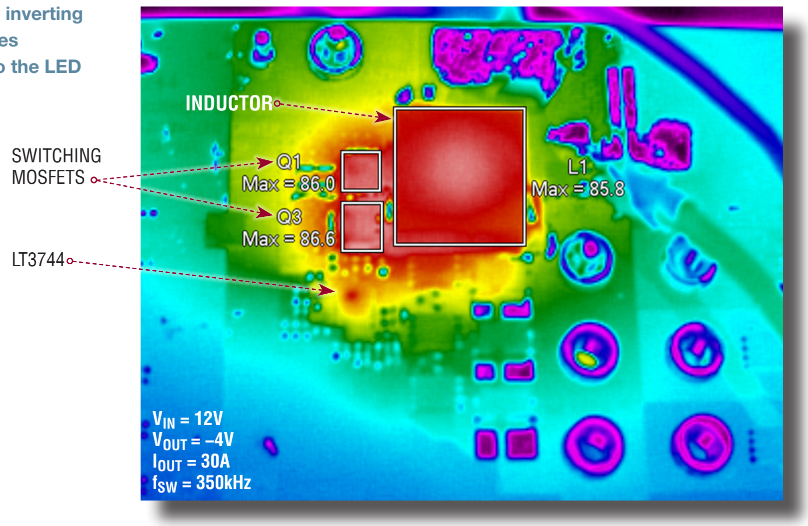


Figure 14. This parallel inverting application delivers 120W to a chassis tied common-anode LED.

By regulating the LED current directly and level-shifting all input signals, the LT3744 is capable of producing negative voltages, allowing low voltage battery operated systems to drive multi-LED strings with a simple 2-switch solution.

minimize the inductance from each of the demo boards to the LED, the parallel LED driver boards were mounted directly on top of each other. A more optimized layout would feature both drivers mounted on a single board, with the driver layouts mirroring each other, reflected across their mutual connection to the LED. Whenever designing the conduction path from a LED driver to a high current LED, careful attention should be placed on the total inductance. Since inductance is a function of wire length, the longer the wire, the longer the current recovery in the LED—no matter how fast the driver.

Figure 15. Parallel inverting board temperatures delivering 120W to the LED



INVERTING BUCK-BOOST, 120W LED DRIVER WITH TWO PARALLEL LT3744s

Inverting buck-boost applications have the same thermal concerns as non-inverting converters, with the additional design challenge of increased inductor current. For low input voltages and high LED voltages, the average current in the inductor could be very high. For example, if the input is 3.3V and the output is one green LED—which has a forward voltage of 6V at 20A—the peak inductor current is 70A. The inductor used in the design should have a saturation current at least 20% higher—in this case, greater than 80A.

Since this current flows in the switching MOSFETs, the MOSFETs must be rated for greater than 80A. By placing two LT3744 inverting buck-boost converters in parallel, the peak switched current is cut in half, reducing the requirements of the power path components.

In the inverting buck-boost topology, the inductor current is delivered to the load only during the synchronous FET conduction time. If the two parallel converters are allowed to run at their free-running frequencies, there is noticeable beat frequency apparent in the LED current ripple resulting from the slight switching frequency differences. To avoid this, each converter uses the same R_T resistor value, but they are synchronized using an external clock. In the application in Figure 14, the converters are designed to run at a non-synchronized frequency of 300kHz—with a 350kHz synchronizing clock.

Figure 15 shows the component temperature rise when delivering 30A to the LED in a parallel inverting buck-boost application.

CONCLUSION

With features including high current regulation accuracy, a floating PWM gate driver, and level shifted input signals, the LT3744 can be configured to drive LEDs in a wide range of applications. The LT3744 has the capability to be used as the single driver in an RGB projection system, drastically reducing total solution space—making it possible to produce high lumen video projection from a smartphone.

Through the use of three current regulation states, the LT3744 gives system designers freedom to sculpt LED color, producing more faithful video images. By regulating the LED current directly and level-shifting all input signals, the LT3744 has the capability to produce negative voltages, allowing low voltage battery operated systems to drive multi-LED strings with a simple 2-switch solution. The LT3744 can be easily paralleled with other LT3744s to efficiently deliver extremely high current to an LED, while maintaining current accuracy and sharing even when PWM dimming. Paralleling the LT3744 lowers board temperatures, reduces inductor currents and expands supported LED power to hundreds of watts. ■