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IN THIS ISSUE…

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Reliable, Efficient LED Backlighting for Large LCD Displays

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Introduction

LEDs are rapidly becoming the preferred light source for large LCD displays in computers, TVs, navigation systems, and various automotive and consumer products. LEDs offer several benefits over fluorescent tubes: high luminous efficacy (lm/W), more vivid colors, tunable white point, reduced motion artifacts, low voltage operation and low EMI. However, system engineers face certain problems associated with driving LEDs for LCD backlight applications, including effectively providing sufficient power, regulating the LED current, matching current in multiple LED strings, achieving high LED dimming ratios, and fast LED current turn on/off.

All of these issues can be easily addressed in compact and reliable circuits that use the LT3476 high current LED driver and LT3003 3-channel ballaster.

The LT3476 is a quad output, current mode DC/DC converter operating as a constant current source with up to 96% efficiency. It is ideal for driving up to 1A of current for up to eight-per-channel RGB or white LEDs (such as Luxeon III) in series. That results in a total output power of about 100W.

The LT3003 is a 3-channel LED current ballaster, which can be used to triple the number of LEDs driven by a single LT3476 channel. When LED strings are in parallel, special care is required to ensure safe operation and accurate current matching. Otherwise, one string will almost always draw much more current and eventually be damaged. The LT3003 can be used with the LT3476 or other LED drivers to regulate current in the LED strings. This is one way to reduce the per-LED current and increase brightness uniformity across a large display. For

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continued on page 3

LT3476, continued from page 1

example, the 1A output LED current of the LT3476 can be safely shared by three parallel strings of LEDs when the LT3003 is added. Each string carries up to 350mA. The LT3003 guarantees 3% LED current matching.

Dimming ratio is defined as the ratio between the highest and the lowest achievable brightness of a system. A large dimming ratio is often required for instantaneous setting of the backlight brightness according to the image information and environment in which the device is used. A large dimming ratio also helps reduce motion artifacts. Without adding components and cost, both the LT3476 and the LT3003 can achieve at least 1000:1 PWM dimming ratio with less than 5µs rise/fall time. Additional analog dimming is also possible.

Features

High Side Current Sensing for Versatility and Reliability

High side LED current sensing is generally more flexible than low side, in that it supports buck, boost or buck-boost configurations. High side sensing also allows for "one-wire" operation. For example, in a boost circuit with a high side sense resistor, if the LEDs are

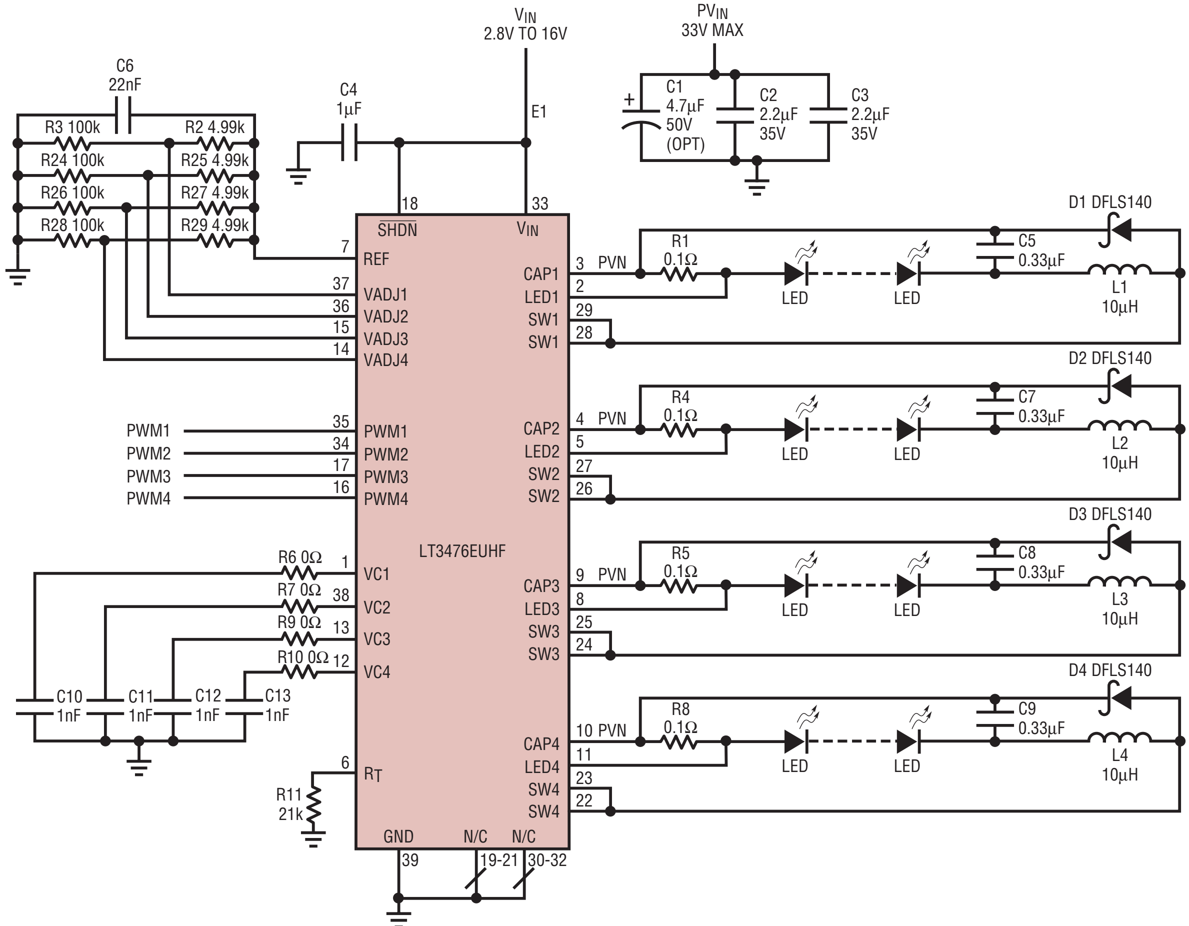

Figure 1. The LT3476 delivers 100W in buck mode

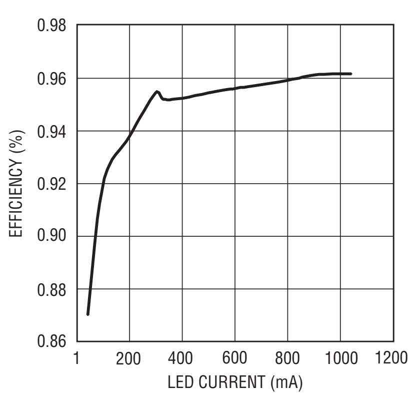

Figure 2. Efficiency of the buck mode circuit in Figure 1

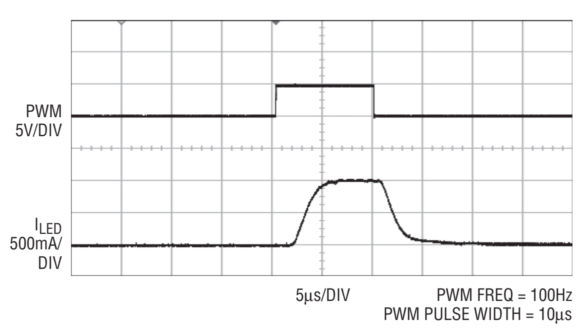

Figure 3. 1000:1 PWM dimming

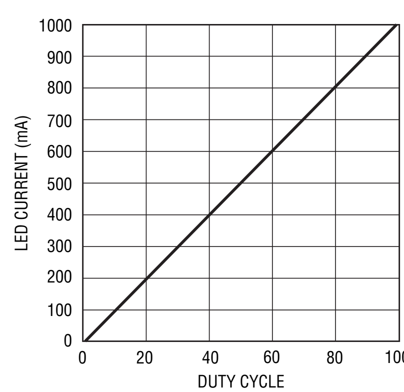

Figure 4. Average LED current vs PWM duty cycle

remote from the driver in some way, such as in a hinged laptop display, the LED current can return to the local display ground, saving a wire in the return path. Low side sensing requires an extra wire, because the LED current must return to the driver side for low noise operation. The one wire setup lowers cost and improves reliability, especially as the channels multiply in high performance displays.

Buck, Boost or Buck-Boost Operation

Because of the high side current sense scheme, the LT3476 and the LT3003 support buck, boost or buck-boost operation. In buck mode, an LT3476 circuit can achieve 96% efficiency, generating less heat and providing more reliability. For automotive applications where the LEDs must be powered from a lead-acid battery, the LT3476 can be configured for boost mode to drive up to eight LEDs per channel. Furthermore, returning the LED current in a boost configuration to the battery enables buck-boost operation, where the input voltage can be higher or lower than the output voltage. As a result, the LT3476 and LT3003 can accept a variety of power sources.

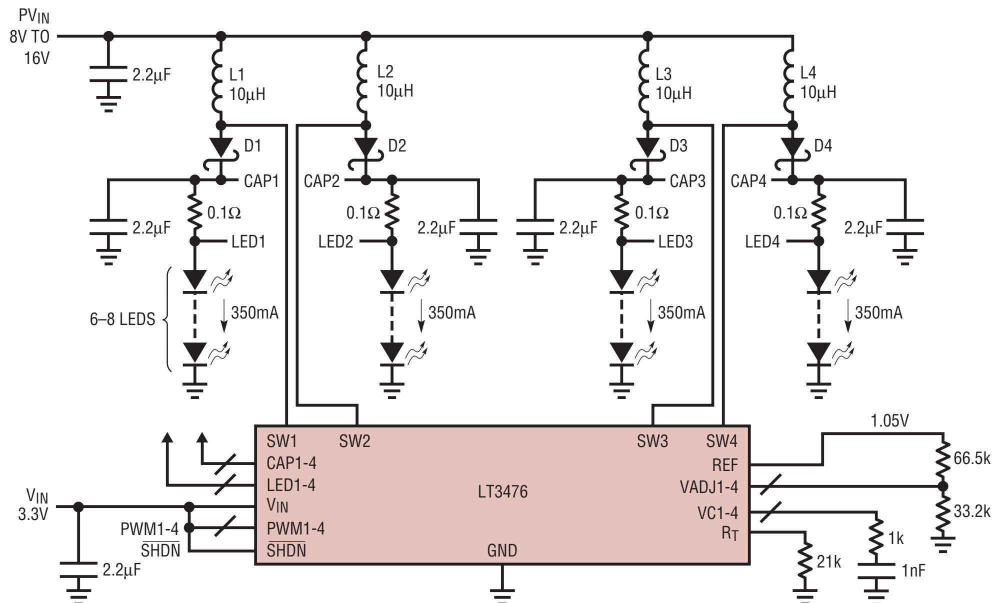

Figure 5. The LT3476 configured into a boost circuit for automotive applications

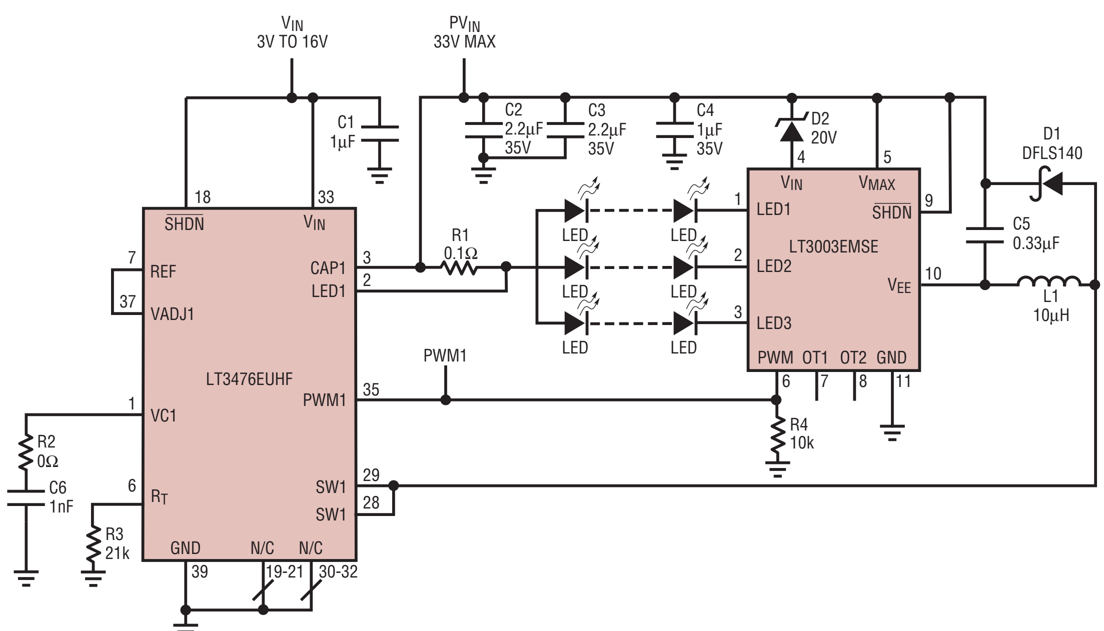

Figure 6. The LT3476 and LT3003 in buck mode

PWM and Analog Dimming

Dedicated PWM dimming circuitry inside the LT3476 and LT3003 allows a 1000:1 dimming ratio. Additional analog dimming is possible through the VADJ pins. This allows for a significant number of hues and tones, resulting in finer and more exact color definition.

Accurate Current Monitoring and Matching

Each of the four LT3476 current monitor thresholds is trimmed to within 2.5% at the full scale of 105mV. The LT3003 drives three separate strings of LEDs at up to 350mA/string with 3% accurate current matching. Both measures result in uniform LED brightness and intensity.

Wide Range of Operating Frequencies to Match any Application

The LT3476 frequency is adjustable between 200kHz and 2MHz, allowing the user to trade off between the efficiency and the solution size.

Small Packages

The LT3476 is available in a 5mm × 7mm QFN package. The LT3003 comes in a small MS10 package. Both packages are thermally enhanced with exposed metal ground pads on the bottom of the package.

Applications

LT3476 Delivers 100W in Buck Mode

In today's large LCD TVs with LED backlights, the power requirement for driving the LEDs can be a couple hundred watts. Figure 1 shows a circuit for a high power LED driver. It is configured as a buck mode converter, delivering 100W to the LEDs from a 33V supply at 96% efficiency. Two of these circuits are enough to drive all the LEDs for a 32-inch LCD TV. For simplicity's sake only channel 1 is discussed here.

All four LT3476 channels are independent and function in the same way. When the internal power switch turns on, the SW1 pin is grounded. The voltage crossing the inductor L1 is PVIN – V_{LED1}, where the V_{LED1} is the voltage drop on the LED string at the given current. As a result, the inductor L1 current ramps up linearly and energy builds up. When the power switch is off, the inductor sees V_{LED1}. The energy in the inductor is discharged and transferred to the LEDs through the catch diode D1. The capacitor C5 filters out the inductor current ripple. The LED current is the average of the inductor current. Figure 2 shows the efficiency as a function of the LED current.

To change the maximum LED current, adjust the R1 value or the resistor divider values at the VADJ1 pin. The VADJ pins can be used for white balance calibration. At 100Hz PWM frequency, the PWM control of this circuit allows 1000:1 dimming as shown in Figure 3. Figure 4 shows that the PWM dimming ratio has a good linear relationship to the average LED current. Faster switch on/off time is possible if a PFET disconnect circuit with a level shifter is in series

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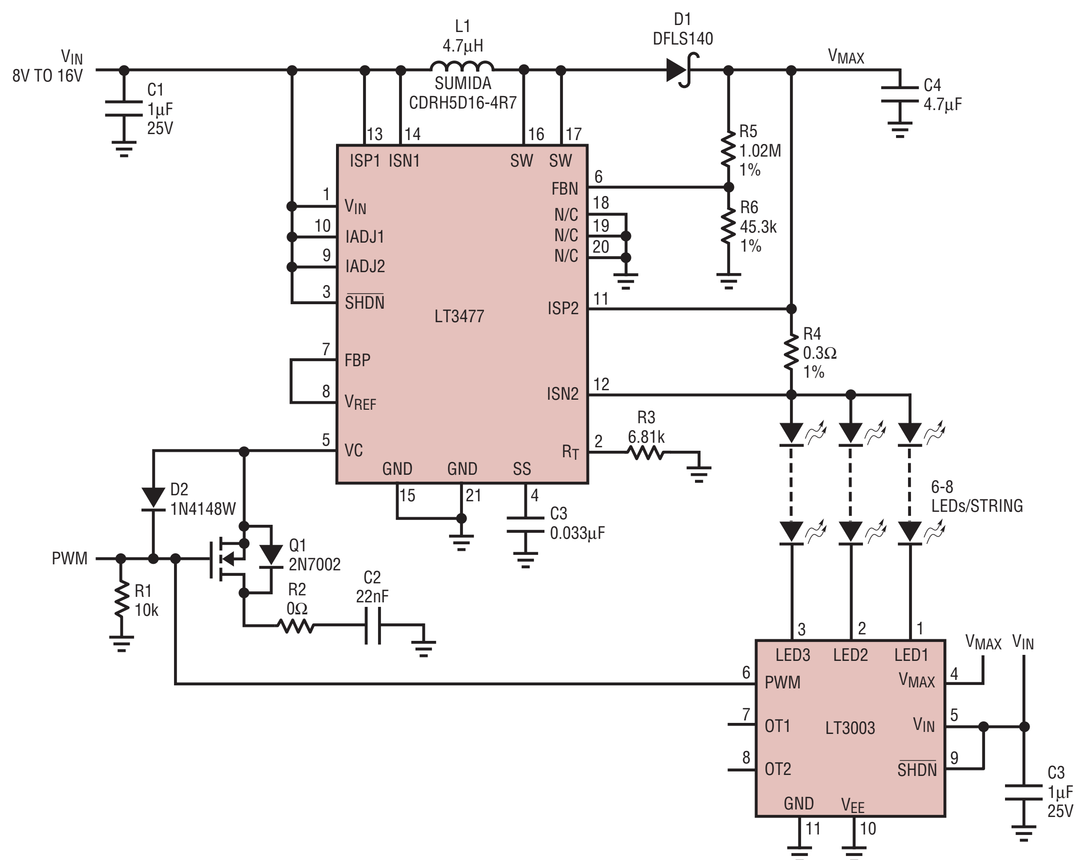

Figure 7. The LT3476 and LT3003 in boost mode

Better than Buck-Only or Boost-Only Solutions

To avoid the cost or real estate requirements of traditional SEPIC or cascaded boost-buck topologies, some designers opt for buck-only or boost-only solutions. For example, in two AA alkaline cell applications such as MP3 players, 2.5V often serves as the main rail since it drives both the flash memory and the main processor I/O. In such applications, some designers use a synchronous boost converter to save cost and space. The problem is that the boost converter is very inefficient while the battery voltage is above 2.5V because a boost converter incurs both the losses inherent in an LDO *and* the switching losses an LDO doesn't have. Figure 4 shows that the boost converter operates inefficiently for 28% of the battery runtime (the portion of the battery life when the battery's voltage declines from a fully charged 3V to 1.8V). An LTC3530 solution results in significantly longer battery runtimes compared to these solo boost or buck solutions.

Conclusion

Linear Technology's synchronous buck-boost converter simplifies the design of lithium-ion or 2-AA-cell powered handheld devices that require up to 600mA output. Programmable soft-start and switching frequency, as well as external compensation, make the LTC3530 a flexible and compact solution. The buck-boost topology helps a designer extend battery runtime while the automatic Burst Mode operation further maximizes the runtime in applications with widely varying load requirements.

LT3476, continued from page 5

with a LED string. With this PFET disconnect circuit, the switch off time is less than 2μs.

Boost Circuit for Automobile Lighting

It is straightforward to use the LT3476 for a boost application given the fact the main power switch is tied to the ground. Figure 5 shows a boost circuit for applications such as automotive exterior and interior lighting. This circuit provides 350mA to eight Luxeon LEDs per channel from a car battery. The efficiency is over 92% with a 16V input.

Triple the Number of LED Strings with the LT3003

Each LT3476 channel can be configured to drive three parallel LED strings by adding the LT3003. In such a configuration, each LED string uses one third of the output current of the channel. The LT3003 easily operates in boost mode, or in buck mode with an architecture that allows the power ground (V_{EE}) to move with the output capacitor voltage. Figure 6 shows LT3476 channel 1 plus a LT3003 circuit in buck mode. The string-to-string current matching is 5%, important to maintaining uniform LED brightness between the strings. Figure 7 shows a LT3477 and a LT3003 circuit in boost mode. The V_{MAX} of the

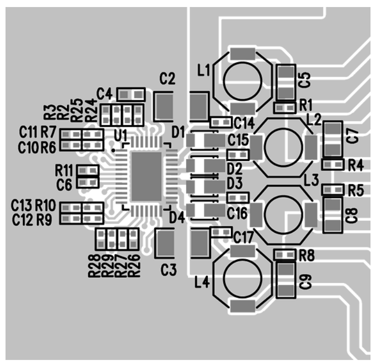

Figure 8. Recommended parts placement and layout

LT3003 should be tied to the highest voltage in a circuit. In the buck mode, it is PVIN. In the boost mode, it is the cathode of D1.

Layout Considerations

For proper operation and minimum EMI, care must be taken during the PCB layout. Figure 8 shows the recommended components placement for LT3476 in buck mode for a 4-layer board. The schematic is shown in Figure 1. In a buck circuit, the loop formed by the input capacitors (C2 and C3), the SW pins and the catch diodes (D1, D2, D3 and D4) should be as small as possible because of the present of high di/dt pulsing current in this loop. The second layer should be an unbroken ground plane. The SW nodes should be as small as possible. From each sense resistor, the traces to the CAP pin and to the LED pin should be a Kelvin trace pair. Those traces should be in the third layer for best shielding. The fourth layer should be another ground plane.

If long wires are used to connect a power supply to PVIN of the LT3476, an aluminum-electrolytic capacitor should be used to reduce input ringing which could break down the LT3476 internal switch. See *Linear Technology Application Note 88* for more information.

To ensure reliable operation, good thermal designs for both the LT3476 and the LT3003 are essential. The exposed pads on the bottom of the packages must be evenly soldered to the ground plane on the PCB so that the exposed pads act as heat sinks. Unevenly soldered IC package degrades the heat sinking capability dramatically. To keep the thermal resistance low, the ground plane should be extended as much as possible. For the LT3476, on the top layer, ground can be extended out from the pins 19, 20, 21, 30, 31 and 32. This also allows tight loop components placement mentioned above. The second and fourth layers should be reserved for the ground plane. Thermal vias under and near the IC package helps transfer the heat from the IC to the ground plane and from inner layers to outer layers.