Optimal LED Driver Solutions for Automotive & HDTV Applications

Huge demand needs competitive and comprehensive designs

There is a wide variance of high brightness LED market analysis statistics. One trend however, is clear: the high brightness (HB) LED market is growing at a staggering rate. According to Yole Development in France, the market size for all LEDs will reach $10.3 billion by 2012. High and ultrahigh-brightness LEDs combined will be responsible for approximately $4.45 billion of this total; almost 5.5 times the $783 million market size in 2007 (based on packaged LEDs).

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What supports such an impressive growth potential? First, LEDs are ten times more efficient at producing light than incandescent bulbs and almost twice as efficient as fluorescent lamps, thus reducing the required electrical power to deliver a given amount of light output (measured in lumens) dramatically as well as the dissipated heat. As LEDs are further developed, their efficiency at producing lumens from electrical power will continue to increase. Secondly, in a very environmentally conscience world, LED lighting does not require the handling, exposure and disposal of the toxic mercury vapor found in fluorescent bulbs. Thirdly, incandescent bulbs need to be replaced every 1,000 hours, while fluorescent bulbs last 10,000 hours compared to a 100,000+ hour lifetime for LEDs. In most applications, this allows the LEDs to be permanently embedded into the final application without the need for a fixture. Examples include body panels in automobiles or LCD screens in HDTVs as they will never require replacement during the life of the car or HDTV. Additionally, LEDs are orders of magnitude smaller and flatter then their counterparts and can be manufactured in very low profile form factor so they can be permanently embedded in both interior and exterior applications in cars as well as low profile consumer electronics. Furthermore, by using a configuration of Red, Green and Blue LEDs, an infinite number of colors can be delivered. LEDs have the ability to dim and turn on/off much faster than the human eye can detect, enabling dramatic improvements in backlighting of HDTVs and other types of displays. Without LEDs, dramatic contrast ratios and high resolution unblurred LCD HDTVs would not be possible.

Nevertheless, one of the lighting systems designers' biggest challenges is how to optimize all the benefits of the latest generation of LEDs. As LEDs generally require an accurate and efficient DC current source and a means for dimming, the LED driver ICs must be designed to address these requirements in a wide variety of applications. Power solutions must be highly efficient, robust in features and very compact and cost effective. Arguably, two of the most demanding applications for driving LEDs will be found in automotive

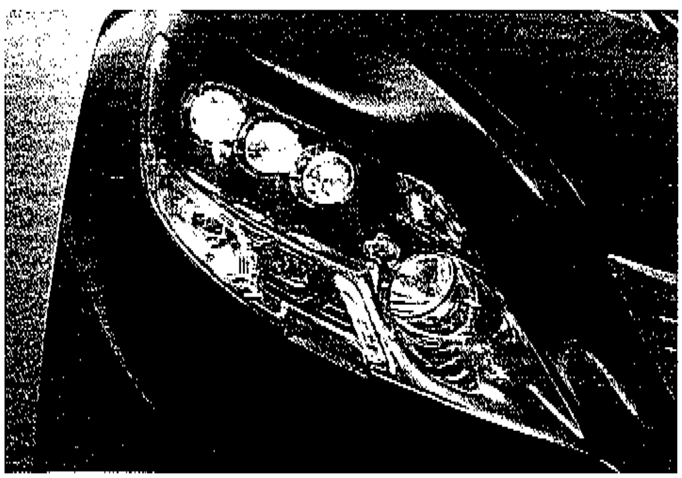

Figure 1: HB LED Lexus LS600h Headlights/Turn Signals/ Running Lights.

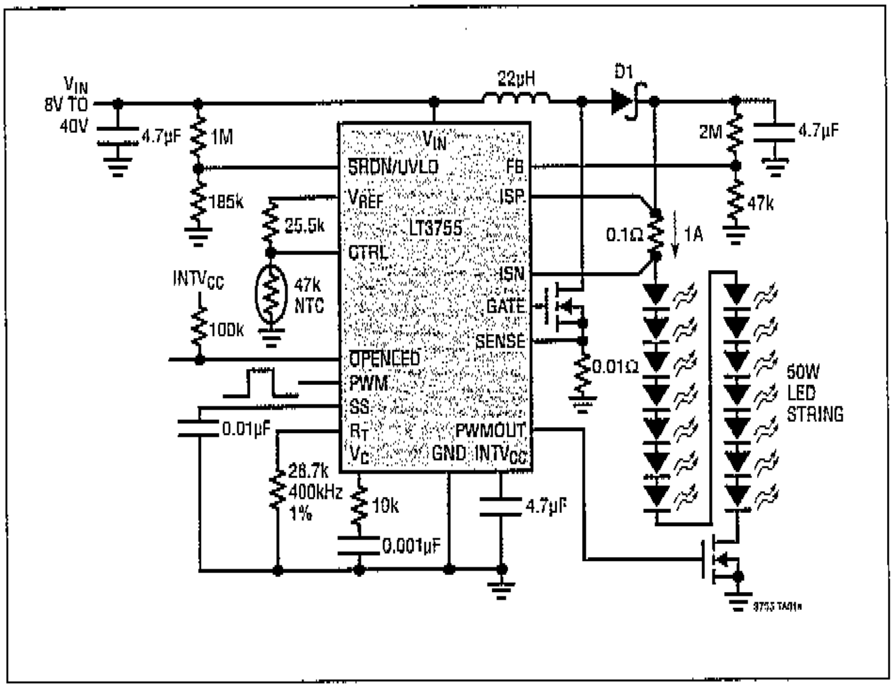

Figure 2: 50 Watt Headlamp Circuit Using the LT3755.

applications and in backlighting applications for large HDTV LCD displays. Because of the collective advantages of LEDs in automotive applications, they have found their way into every form of automotive lighting from headlights to instrument panel/navigation backlighting as well general interior/exterior lighting. LCD HDTV backlighting applications which have traditionally been serviced by CCFL (Cold Cathode Fluorescent Lamps) are being replaced by relatively large arrays of high brightness LEDs that can be dimmed in individual clusters, thus offering very precise local dimming. This enables contrast ratios an order of magnitude higher than convention CCFL backlight HDTVs. As previously mentioned, through local dimming and their ultra fast response time, they enable the LED brightness to be instantly adjusted to eliminate the historic motion blur inherent on CCFL backlight HDTVs.

Automotive LED Lighting

Benefits such as small size, low power consumption and fast turn-on time have initiated the wide spread adoption of high-brightness LEDs in Today's automobiles. The initial LED applications were in center high-mounted stoplights (CHMSLs); these applications used red LEDs to provide a very thin lighting array which was easily mounted and never needed replacement.

Traditionally, incandescent bulbs were the most economical light source and are still used in many cars. However, the decreasing available space for lighting and increasing requirements for long service life, light colorations and streamlined designs offered by LEDs are quickly replacing incandescent bulbs in many applications. It is becoming more common for traditional CCFL-LCD backlighting in Infotainment systems to be replaced by arrays of white LEDs which provide more precise and adjustable backlighting as well as a service life that will easily out live the vehicle. Even headlights, primarily the domain of Halogen/Xenon filament designs, are being developed with an electronically "steerable" array of high current LEDs (see figure 1). Almost all automotive lighting applications including interior/exterior and backlighting applications are transitioning over to LEDs. The benefits of using LEDs in this environment have several positive implications. First, they never need to be replaced, since their solid state longetivity of up to 100K+ hours (11.5 service years) surpasses the life of the car. This allows auto manufactures to permanently embed them into "in cabin" lighting, without requiring accessibility for replacement. Styling can also be dramatically changed as LED lighting systems don't require the depth or area that incandescent bulbs require.

Figure 1 shows Lexus's LS600h LED headlights, which have recently been offered in production. Audi's R8 and GM's Escalade have similar options. The overall lighting configuration is similar for all of these vehicles. Each headlight assembly contains 5 LED powered beams optimized for all lighting requirements, these include: a low beam, a high beam, a corner beam, a daytime running light and a turn signal—all serviced by LEDs. The standard beams will generally require between 35 and 50 watts of power. It doesn't sound like much, but remember LEDs deliver 10x the lumens compared to halogen, so the LED's light output is the equivalent of 500 watts of halogen. The high beams generally require the same or slightly higher power, whereas the cornering, daytime running lights, and turn signals will require less power. Each of these beams can be driven by a single HB LED driver, Linear Technology's LT3755. With the potential of over 200 watts of electrical power, one can see how having high efficiency LED drivers which minimize generated heat is of paramount importance.

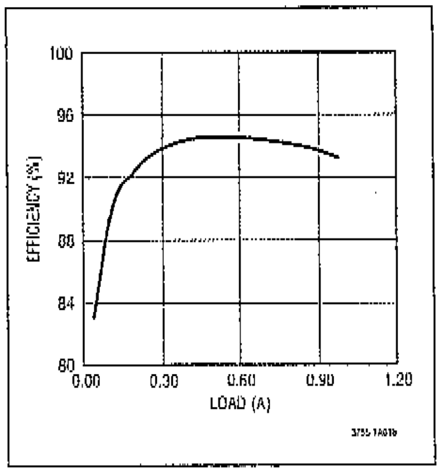

Figure 3: Efficiency of LT3755 Circuit in Figure 2.

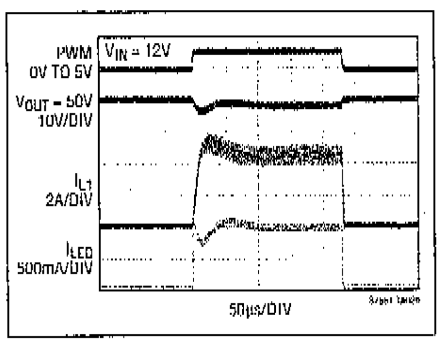

Figure 4: True Color PWMTM Dimming in Figure 2.

Design Parameters for Automotive LED Lighting

In order to ensure optimal performance and long operating life, LEDs require an effective drive circuit. These drive circuits must be capable of operating from the caustic automotive power bus, and also be both cost and space effective. In order to maintain their long operating life, it is imperative that the LEDs current and temperature limits are not exceeded.

Most headlamp applications require approximately 50W of LED current. Linear Technology's LT3755 has been designed to service this type of application. It can boost the automotive bus voltage (nominal 12V) to as high as 60V to drive up to fourteen 1A LEDs connected in series as seen in figure 2.

Figure 3 illustrates the LT3755's efficiency which can be as high as high as 93%. This is of great importance as it eliminates any requirement for heat sinking any of the power components, enabling a very compact footprint. Although the circuit in figure 2 is a boost mode topology, the LT3755's unique high side current sense design enables it to also be configured in a boost, buck mode, buck-boost mode or flyback topology depending on the application's specific requirements.

The LT3755 drives a low side external N-channel MOSFET from an internally regulated 7V supply. The fixed frequency, current-mode architecture provides

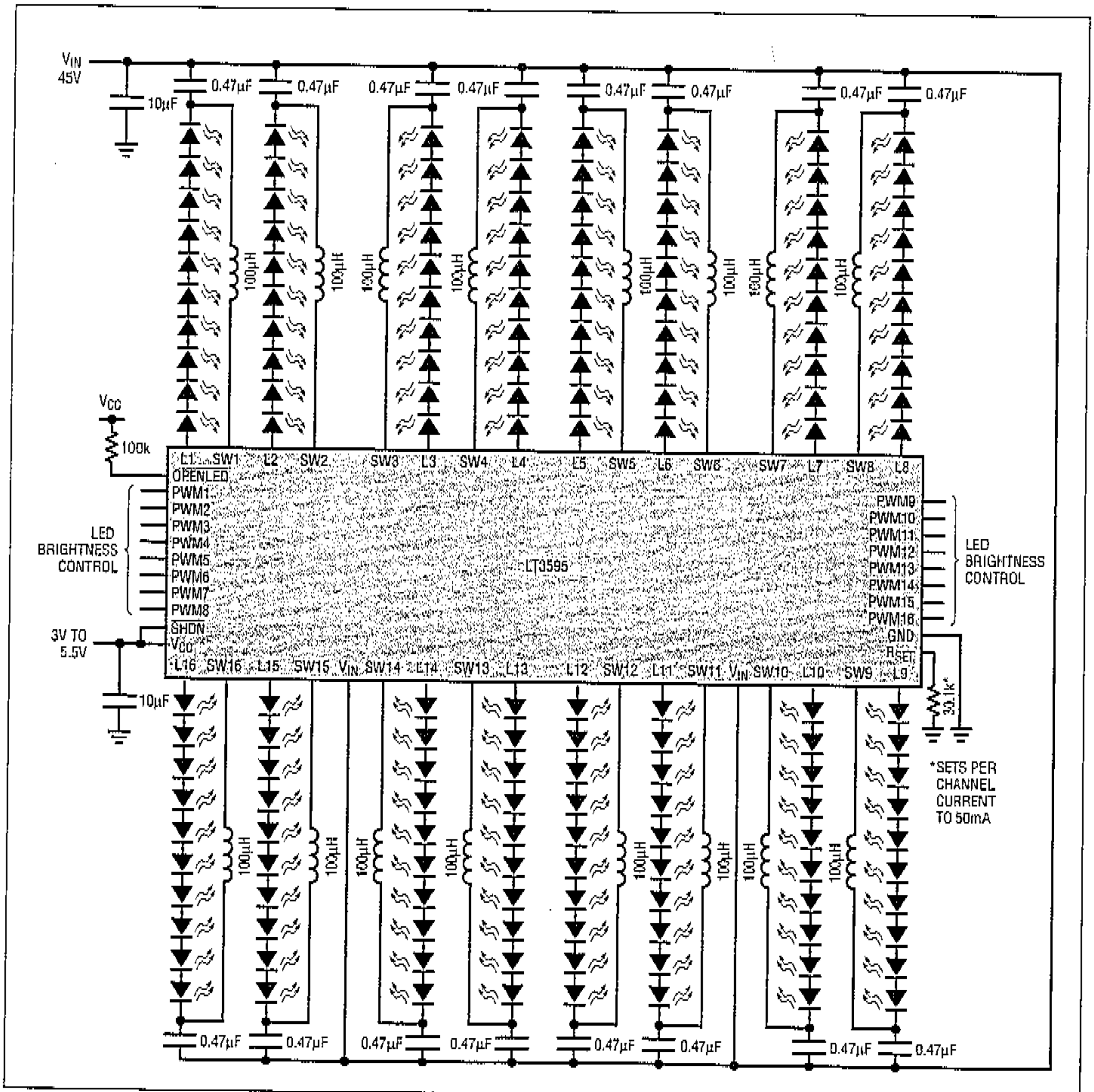

Figure 5: A 16-channel LED driver for 160 white LEDs from a 45V input. PWM dimming ratio is 5000:1.

stable and precise operation over a wide range of supply and output voltages. The LT3755 offers a constant current source which is imperative for LED driver ICs to enable constant brightness of the LEDs despite the irregularities of the input voltage. This is of particular importance in automotive applications, as the input voltage can swing dramatically due to transients encountered during scenarios such as cold crank and load dump. The LT3755's maximum input voltage of 40V enables it to regulate LED current and voltage even when the primary automotive bus is subjected to 40V transients commonly seen in a load dump condition.

A ground referenced voltage feedback pin serves as the input for many LED protection features, such as open LED protection and also makes it possible for the converter to act as a constant voltage source. A frequency adjust pin allows the user to program the efficiency between 100kHz to 1MHz to optimize efficiency and performance while minimizing external component size. If external synchronization is required, the LT3755-1 version can be synchronized to an external clock throughout its 100kHz to 1MHz frequency range.

The LT3755's True ColorTM PWM dimming enables dimming ratios as high as 3,000:1 with no change in color (see figure 4) of the emitted light enabling the LED headlamps to be constantly adjusted via the duty cycle of the PWM for a wide variety of ambient conditions. Because Linear Technology's high current LED drivers are current mode regulators they do not directly modulate the duty cycle of the power switch, instead the feedback loop controls the peak current in the switch during each cycle. Compared to voltage mode control, current mode control improves loop dynamics and provides cycle-by-cycle current limit.

HDTV Backlighting

Although seemingly unrelated, the LED backlighting of infotainment and navigations displays in cars, spurred the use of HB LED backlighting with high dimming ratios, the wide array of ambient lighting conditions in the interior of the vehicle drove the necessity for very wide dimming ratios which are also required in HDTV applications to produce the most dynamic range of colors.

One of the highest growth consumer electronics markets is flat panel HDTVs. As consumers demand larger panel HDTVs and higher resolution, the demand has rapidly shifted from plasma HDTVs to LED HDTVs. According to DisplaySearch, sales of plasma HDTVs will peak in 2008 at $24 billion whereas LCD HDTVs will enjoy a $75 billion market in 2008 and grow to $93 billion by 2010. However, LCD HDTVs have a variety of shortcomings ranging from motion blur to color reproduction. Namely, with the current generation of LCD HDTVs, true blacks can not be attained, and offer a lower dynamic range of all colors. Conventional HDTVs are backlight with CCFL tubes and can only offer contrast ratios between 450 and 650 cd/m^2. The primary problem of these HDTVs, is the inability to completely turn off or locally dim the CCFL backlighting.

Conversely, with HB LED backlighting, an array of LEDs (up to 1,600 for a 46" display) that can be dimmed or turned off locally in backlighting "clusters", offers contrast ratios almost an order of magnitude higher(>4,000 cd/m^2) than CCFL designs. Additionally, by adjusting the brightness of the backlighting LED clusters, more midtones of colors can be replicated adding a more vivid picture.

Another benefit of being able to completely, turn off the LEDs locally, is the reduction of motion blur. By turning the LEDs completely off between frames, the blur associated with fast moving objects in virtually eliminated. The LEDs very fast response rate is critical in resolving this fast motion blur issue encountered by CCFL backlit LCD TVs.

One of the key factors in making LED backlit HDTVs feasible are the LED driver ICs. Because there are so many LEDs per panel, the LED driver circuits must be very efficient or the display will have severe thermal issues and require very large heat sinks, which is not consistent with consumers desires for flatter and lighter flat panel HDTVs. Additionally, these driver ICs must have the capability to deliver very wide dimming ratios, as high as 5,000:1 to offer the desired wide contrast ratios. Finally, the entire LED driver solution must be very compact to enable the very thin format that most HDTV consumers require.

Linear Technology's LT3595 buck mode LED driver has 16 individual channels—each can drive a string of up to ten 50mA of LEDs from inputs up to 45V. Each channel can be used to drive a cluster of 10 LEDs to provide local dimming. Each LT3595 can drive up to 160 50mA white LEDs. A 46" LCD TV would require approximately 10 LT3595' s per HDTV. Each of its 16 channels can be independently controlled and has a separate PWM input that is capable of up to a 5,000:1 PWM dimming ratio

Each channel requires only a tiny chip inductor and an even tinier ceramic output capacitor. The only other required components are a single input capacitor and current-determining set resistor (Figure 5). All sixteen channels of catch diodes, power switches, and control logic with compensation are squeezed inside the LT3595's relatively small

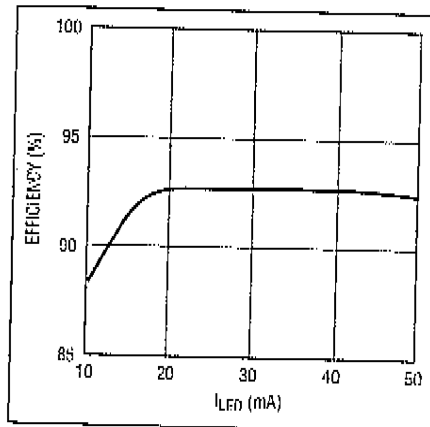

Figure 6: Efficiency of the 160-LED driver shown in Figure 5 is over 92%.

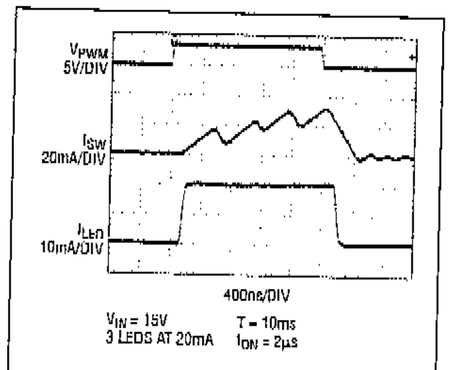

Figure 7: 5,000:1 PWM dimming waveforms for the circuit in Figure 5.

56-pin, 5mm — 9mm QFN package.

The LT3595 boasts 92% peak efficiency at a 2MHz switching frequency eliminating and requirements for external heat sinking.

The PWM dimming capability of the LT3595 is as high as 5,000:1. Figure 7 shows the 5000:1 PWM dimming waveform and a very square looking LED current waveform. Even at a mere 2µs on-time, a 20mA LED current turns on and off in sync with the 100Hz PWM signal. Higher PWM dimming ratios are achievable with lower PWM frequencies, but 100Hz guarantees that there is no visible flicker.

Full LED brightness is set via a single external resistor for all 16 channels. Each channel has the same programmed LED current—set between 10mA and 50mA. LED current accuracy is within 8% from channel to-channel. True Color PWM dimming uses a reduced duty cycle to offer accurate dimming without any shift in emitted light color. The fixed frequency, current mode control scheme provides stable operation over a wide range of input and output voltages and currents. Direct control of the LED current through internal sense resistors for each channel and internal switches and control circuitry for each channel provide excellent constant current source regulation for LED driving. The internal 100mA power switches and exposed thermal pad of the 56-pin QFN provide enough power and thermal management to handle the power and heat of 16 channels at 50mA.

Conclusion

The unprecedented acceleration of LED lighting applications in automobiles and LCD HDTVs has created many specific performance requirements for LED driver ICs in high current LED applications. In cars, these applications range from head lamps to interior lighting. In HDTVs, LEDs offer a much more sophisticated means of local dimming greatly enhancing picture quality. Additionally, many LED applications outside of the automotive and HDTV market can be found in a myriad of commercial and industrial environments also require most of those high performance requirements. These LED drivers must also provide constant current in order to maintain uniform brightness, regardless of input voltage or LED forward voltage variations, must operate with high efficiency and offer wide dimming ratios. These applications also require very compact, thermally efficient solution footprints. Linear Technology has taken the automotive, HDTV and a myriad of other LED design requirements "head-on" and has developed a family of high current LED driver products. Lighting system designers now have an easy and available LED driver source for their challenging lighting designs.

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