Automotive LED Lighting Needs Special Drivers

High-brightness LEDs offer substantial benefits in automotive lighting applications, but they require power converters that can function over a wide range of input and output voltage and provide immunity to electrical transients.

Light-emitting diodes (LEDs) have been the choice for automotive interior lighting for years, particularly for signal applications. And now, due to recent advances in solid-state lighting, LEDs are being designed in the exterior applications as well. Although used primarily in center high-mount stop lamps (CHMSL) and rear combination lamps, LEDs continue to gain ground for most automotive interior and exterior lights. The widespread adoption of solid-state light sources is taking place because of appealing attributes such as small size, robustness, long lifetime and high efficiency.

Automotive manufacturers are attracted by the potential reduction in energy consumption as well as the space savings realized by smaller lighting fixtures. The styling potential of LEDs also is a great benefit for consumers, which enables more attractive and distinctive designs. Consumers also benefit from safety aspects of using solid-state signal lighting. For example, faster turn-on of the stop lamps can reduce the risk of rear-end collisions. And perhaps the most compelling reason for using LEDs is their expected reliability and lifetime. These are benefits manufacturers and consumers can both appreciate, as they will potentially significantly reduce replacement and maintenance costs for automotive lighting. Exterior LED lighting has been increasingly popular on trucks and buses because of the compact size and shock resistance of solid-state lights.

These advantages of the LED lighting fixtures simplify compliance with various safety regulations. The exterior applications include tail lights, stoplights, marker lights and identification (ID) lights. For example, the National Highway Transportation Safety Administration (NHTSA) has issued a new compliance that truck trailers 80-in. wide or over must have ID lamps mounted over the rear door even if the space available is only 1-in. high. LED narrow-rail lamps provide the only solution practical in such minimum-space applications.

Although solid-state forward lighting is not expected in the near future, most of the major car manufacturers have experimented with LED headlights in their concept models. One such model by Hyundai Motor Corp. has all of its signal and lighting devices, including headlights, using high-brightness LEDs from OSRAM Optoelectronics powered by LED driver solutions from Supertex Inc. (Fig. 1). However, production models having LED headlamps are not expected to arrive until 2007. Until then, the forward-lighting applications of LEDs will continue to be limited to daytime running lights (DRLs), which are simply signal lights indicating a vehicle is in use. The trend of using LEDs in forward-lighting applications is mainly driven by their styling potential. However, manufacturers are looking into the hood-opening space savings from using LED headlamps, as well as the reduction of the front over-hang, which is mainly dictated by the headlamp construction.

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Dashboard lighting is the most common interior application of high-brightness LEDs. Nearly every European car is equipped with LED backlights in the instrument panel.
LED backlighting improves styling and makes the instrument panels more readable and comfortable for drivers. Other interior applications of LEDs include map and reading lights, door sill lights and ambiance lighting. LED-based dome lamps are becoming increasingly attractive for their compact size, uniform light and low heat.

Due to the electrical properties of high-brightness LEDs, they cannot be powered directly from the automotive battery voltage. They require specialized power converters delivering constant current output. The large variety of LED fixtures used in automobiles calls for various types of LED driver topologies. These power converters must be in compliance with numerous industry specifications. This article will address applicable power-converter topologies useful for driving LEDs. The emphasis will be on LED driver immunity to conducted electrical disturbances that exist in automobiles.

Automobile Transient Conditions

Under normal operation of the vehicle, voltage at the supply lines ranges between 9 V and 16 V (12-V system), or between 18 V and 32 V (24-V system). However, a substantially wider range of voltages of both positive and negative polarity may appear along the supply lines as a result of conducted electrical transients.

Electrical disturbances generated by disconnecting inductive loads, sudden power cutoff in the main circuit or switch bouncing are commonly referred to as inductive switching. Disconnecting an inductive element causes a high inverted overvoltage on its terminals. Positive high-voltage transients occur at the supply lines after the ignition key cuts the battery-supply circuit. In this case, the ignition circuit continues to release disturbances until the engine stops rotating.

Switching the power supplied by electric motors acting as generators (the air conditioning fan, for example) also generates overvoltage spikes. Their amplitude is increased by the absence of filtering, which would normally be carried out by the battery. Although inductive switching transients occur at the supply lines after the ignition key cuts the battery-supply circuit. In this case, the ignition circuit continues to release disturbances until the engine stops rotating.

Switching the power supplied by electric motors acting as generators (the air conditioning fan, for example) also generates overvoltage spikes. Their amplitude is increased by the absence of filtering, which would normally be carried out by the battery. Although inductive switching transients can generate high voltages up to 600 V of both positive and negative polarity, the highest energy available from these transients usually does not exceed 2.3 J per one pulse. Therefore, LED lighting devices can be protected from the inductive switching transients by mere clamping of the supply voltage at an acceptable level.

A much more aggressive electrical disturbance occurs when the car battery is suddenly disconnected while being charged by the alternator. During such a load-dump condition, the voltage on the alternator terminals increases rapidly. The length of this disturbance depends on the time constant of the generator excitation circuit and can be as long as several hundred milliseconds. Series resistance of the alternator circuit is only a fraction of 1 Ω. Therefore, the energy available from the load-dump transient can
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reach as high as 50 J. Positive overvoltages of up to 87 V (12-V system) or 174 V (24-V system) can appear along the supply lines. This type of transient can be lethal for the LED lighting devices.

Most modern alternators are equipped with a special centralized clamping circuit, which typically clamps the load-dump transient voltage below a 40-V level. Various automotive standards give somewhat different definitions of a load dump test. A typical wave shape is shown in Fig. 2 as it is defined in Reference 1. The dotted line designates the centrally clamped load-dump pulse. However, some interior or exterior lighting fixtures may be intended as retrofits for legacy devices. These fixtures may require protection from unsuppressed load-dump transients.

Fast input transients can present a serious problem for LED lighting devices due to low dynamic impedance of the LEDs themselves. The driver circuitry must provide very fast input supply rejection to protect the LED devices from high peak currents that could be potentially destructive. Both the power topology and the control scheme of the LED drivers must be carefully selected in order to ensure reliable operation of the LED lighting devices.

Certain exterior safety signals may be expected to produce light down to supply voltages of 6 V or 7 V, sometimes for as long as 2 minutes. These devices may include tail and marker lights that can potentially create a rear-collision hazard when not lit. This type of voltage drop occurs in the supply source when the starter circuit is activated. Cold-temperature ambient conditions aggravate the supply voltage drop. The typical “cold cranking” test wave shape is depicted in Fig. 3. Some automotive standards are less explicit about the cranking wave shape. However, there is a common understanding that a normal operating voltage condition always precedes the cranking transient. Therefore, the safety signal devices are not required to be able to start from the 7-V supply, as long as they do not extinguish at this low supply voltage. It will be shown later in the text how this consideration can simplify the LED driver design.

In addition, LED lighting devices are expected to survive continuous application of +24 V/-12 V (12-V systems) or +48 V/-24 V (24-V systems) during a jumper start. Garages and emergency road services have been known to utilize 24-V sources for emergency starts, and there are even reports of 36 V being used for this purpose. High voltages such as these are applied for up to 5 minutes and sometimes with reverse polarity.

Thus, automotive LED driver devices are required:

- To operate from a wide input-supply voltage range

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● To provide immunity to input voltage transients
● To include protection from input overvoltage and undervoltage condition
● To include input reverse polarity protection.

LED Driver Topologies

One traditional low-cost way of driving LEDs in automotive applications uses a resistor in series with the LED device. Although this driving scheme is simple and inexpensive, it suffers several disadvantages. The LED current can vary substantially over the battery voltage range even in normal operation of the vehicle, thus affecting the brightness and reducing the service life of the lighting device. Additionally, protection is needed from automotive voltage transients and reverse polarity. These disadvantages are typically resolved by using constant-current linear regulators. Besides driving the LEDs at a programmed current, these regulators can inherently protect from a reverse-polarity application and block voltage transients up to tens of volts. Linear current regulators do not require input EMI filters and can yield inexpensive LED driver solutions.

However, both the resistor ballasts and the linear regulators exhibit low efficiency. They may become impractical for driving high-brightness LED loads due to the excessive heat dissipation. Therefore, switching power converters are needed for driving many signal and lighting LED devices in automobiles.

The buck dc-dc regulator is the most commonly used topology for automotive lighting devices due to its simplicity, low cost and ease of controlling the output LED current. Fig. 4 shows a stoplight/taillight controller using a buck regulator. The HV9910 is a peak-current control PWM IC with an internal high-voltage regulator that powers the IC from an 8-V to 450-V supply voltage. The HV9910 control scheme provides high immunity to transients and surges on the input supply. The control IC allows user selection between constant frequency and constant off-time modes of operation. The regulator of Fig. 4 is configured for the fixed \( t_{\text{off}} \) mode, thereby permitting stable operation at duty cycles greater than 50% and reducing the effect of input voltage variation on the output LED current.

Automotive tail lamps may be required to maintain certain light outputs even during cranking of the starter motor. Available supply voltage may become insufficient for enhancing standard-level MOSFETs typically having a maximum threshold voltage.
(\(V_{\text{TH MAX}}\)) of 4 V to 5 V. On the other hand, the load-dump conditions will dictate the MOSFET drain voltage requirements, in some cases ruling out most of the logic-level MOSFETs available in the industry.

Adding a charge pump circuit in the \(V_{\text{IN}}\) path of the HV9910 maintains it in operation down to an input voltage of 5 V to 6 V. As soon as the HV9910 starts upon initial application of the nominal battery voltage, the charge pump doubles the supply voltage and applies it to the \(V_{\text{IN}}\) pin. This voltage will keep the HV9910 running even during the cold cranking transient.

The LM555 timer IC is configured in the astable multivibrator mode to decrease the duty cycle for the tail-light function. Its low-frequency PWM signal modulates switching of the HV9910 via the PWMD input. Sufficient hold-up capacitance must be provided at the \(V_{\text{DD}}\) pin to maintain continuous operation of the HV9910 in this operating mode.

Boost regulators are typically used in automobiles for driving long strings of LEDs in instrument panel backlights and other lighting devices that require series connection of multiple LEDs. A typical boost converter is shown on Fig. 5. It can drive strings of LEDs having forward voltage in excess of 100 V. However, recent advances in the high-brightness LED technology have substantially increased the power ratings of a single LED package. LED currents of 350 mA, 700 mA or even 1 A are typical. Therefore, the number of series-connected LEDs in the string used in automotive lighting devices has become smaller.

Despite its simplicity, the boost converter of Fig. 5 suffers a serious drawback in automotive systems where the supply line voltage can easily exceed the forward voltage of the LED string. Disabling the switching MOSFET in this converter topology does not protect the LED load from a potentially damaging overcurrent stress. The problem worsens as the LED string voltages become lower. Input supply regulators, voltage clamps or load disconnect switches will become unavoidable for this converter topology.

A boost converter operating in continuous conduction mode (CCM) presents stability problems that put a limitation on the control-loop bandwidth. The peak current-mode control scheme used in many PWM controllers does not do as good of a job of rejecting the input supply transients for a boost converter either. Therefore, the LED loads will see substantial output current surges. In addition, the LED string voltage in some lighting devices may require both step-up and step-down conversion within the nominal supply voltage range. Such applications rule out both the buck- and boost-converter topologies. A more suitable power-supply topology is needed that is not limited to just step-up or step-down voltage conversion.
Boost-buck converters (commonly referred to as Cuk converters) can offer a solution for most of the higher-power automotive lighting applications, including both exterior and interior lighting. It can fit well even in forward-lighting devices, when they become available. A CCM boost-buck converter integrates an input boost stage and an output buck stage, thus being able to step the input voltage up or down as needed. Both the input and the output currents of the converter are continuous, yielding good EMI performance.

Unlike the boost converter, this converter topology inherently protects the LED load from load-dump transients. Its load is decoupled from the input source with a coupling capacitor, which would protect it even from the switching MOSFET failure. Fig. 6 shows a boost-buck converter driving a string of four high-brightness LEDs in a stoplight application. The HV9930 is a hysteretic input/output current regulator specifically designed to drive the boost-buck converter topology in an automotive lighting device. It offers ultimate input transient immunity and stable operation over a wide range of input and output voltages. The supply voltage for the HV9930 is derived from the drain of the switching MOSFET ($V_{DS} = V_{IN} + V_{OUT}$) for the cold-cranking test compliance.

Although the output current loop is inherently stable, the overall stability of the converter still needs to be considered when the boost-buck topology with the HV9930 control IC is used. A damping circuit ($R_D$ and $C_D$) across the coupling capacitor is needed to prevent oscillation. This damping circuit carries little current without causing noticeable reduction of the LED driver efficiency. Damping capacitor $C_D$ must be selected to be 5 to 10 times the value of the coupling capacitor. An aluminum electrolytic or tantalum capacitor can be used to reduce the cost.

Recent advances in the solid-state lighting open new horizons in automotive applications. Unsurpassed reliability, ruggedness, safety, high efficiency, compact size and great styling features of the LEDs bring significant advantages. However, optimal solutions for driving LEDs in the automotive environment are needed. Immunity to conducted transient emissions is one of the key requirements that must be addressed by designers. The right choice of a power topology and a control scheme for the LED driver circuit becomes critical for meeting these requirements.

References


