Powering Next-Generation Solid-State Lighting

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As LED luminous efficacy exceeds that of incandescent lamps, solid-state lighting is taking hold in automobiles and portable electronics.

As the complexity of electronics in automotive applications increases, so does the need for more efficient methods of operation. This is especially true for lighting applications. For years, light emitting diodes (LEDs) have been the choice for interior automotive lighting, particularly signal applications. With the many recent improvements in technology, LEDs are also being designed into exterior applications.

Although primarily used in center high-mount stop lamps (CHMSLs) and rear stop/turn/tail lamps, LEDs continue to gain ground in additional exterior applications as the luminous efficacy (lumens per watt) and thermal characteristics, particularly the thermal resistance between junction and case (θ_{JC}), improve. LEDs offer advantages over traditional incandescent type lighting, including:

- Faster turn-on time, increasing the time and distance available to the motorist resulting in fewer rear-end collisions.
- Increased efficiency and lower power consumption.
- Vibration and shock resistance.
- Longer operating life.

In recent years, high-intensity discharge (HID) lamps have displaced incandescent lamps for driving lights in luxury vehicles. A quick look in the rearview mirror on the freeway at night is sufficient to verify their popularity. The HID lamp is a complex negative impedance load with sophisticated ballast requirements. Electromagnetic compatibility is an issue, and the latest generation of ballasts is microprocessor-controlled. LED driving lights are simpler and more reliable. The main challenge, once luminous efficacy exceeds 80 lm per watt, is removing heat from the semiconductor junction. Another issue is that LEDs are highly directional compared to conventional light sources. Secondary optics are required for beam shaping.

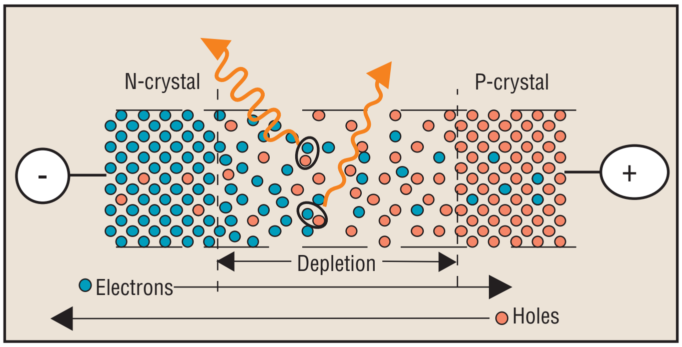

Fig. 1. *Mechanism of photo-emission.*

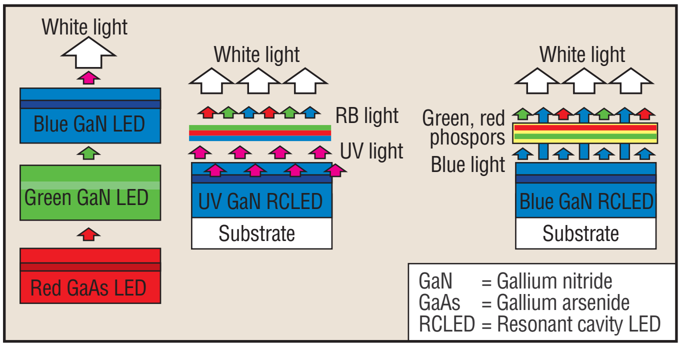

Fig. 2. *White LED construction.*

Recently, Audi announced it would feature white LEDs in its top-of-the-line A8 L 6.0 Quattro, noting that "solid-state emitters for daytime running lights offer more than a distinctive design feature" and that the 5-point headlight had "virtually no effect on the fuel consumption of the vehicle." Automotive manufacturers project that a vehicle with full LED lighting offers a potential 80-W energy saving over one equipped with conventional lamps. To engineers searching for energy to run all the new telematic features, that is compelling.

To put things in perspective, a high-flux white LED source uses 15% less power (30 W) than an HID source (35 W), which is about 30% efficient, producing 3000 lm and putting 800 lm on the road. In contrast, halogen bulbs consuming 55 W produce 1000 lm and put 400 lm on the road. A typical high-flux LED consumes 1 W at 350 mA of drive current; a high-flux LED consumes up to 5 W at 700 mA to 800 mA of drive current.

LED Physics and Fabrication

LEDs are semiconductor diodes and belong to the group of electroluminescent luminaires. The mechanism shown in Fig. 1 occurs when recombining charge-carrier pairs in a semiconductor with an appropriate energy band-gap generate light. This diagram is simplistic for the sake of clarity.

In a forward-biased diode, little recombination occurs in the depletion region. Most occurs within a few microns of either the n or p region, depending on which one is more lightly doped. The LED produces narrowband radiation, with wavelength determined by the energy band of the semiconductor. LEDs that emit white light can either be created by mixing several LED chips of different colors to make white light in a common LED housing, or by using a blue or ultraviolet LED with a phosphor down-converter, which converts the blue/ultraviolet light into white light (Fig. 2).

LED brightness has increased over the years to the extent that a law analogous to Moore's Law has been applied. Haitz's Law, as illustrated in Fig. 3 by one LED manufacturer, states that LED luminous output will double every 18 to 24 months. This has been the case since the first practical LED was developed in 1962. Two mechanisms are at work in the LED chip: one that generates light and one that extracts it to the outside world. Thinner die are more efficient, and flipping the die upside down increases the efficiency of light extraction.

Forward current and junction temperature determine the light intensity output from an LED. As the LED junction temperature increases, the light output decreases and the forward drop decreases. The dominant wave-

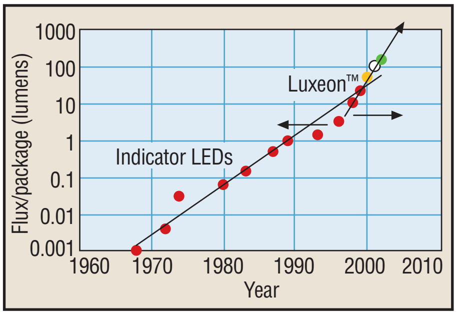

Fig. 3. *Haitz's Law for LED flux. (Courtesy of Lumileds Inc.)*

length of the light output also increases. LEDs are nonlinear devices; therefore, the forward current through the device must be limited by a resistor or by feeding it from a constant current source. LEDs from the same batch also will often exhibit different forward drops at the same current. Pulse width modulation (PWM) is recommended for dimming LEDs as the wavelength of light emission changes with forward current.

The two main causes for LED failure are high forward current or excessive junction temperature. High forward current can cause hot spots and recombination sites that do not radiate, degrading light output. Exceeding the glass transition temperature of the encapsulating resin leads to catastrophic failure. The light intensity variation with change in forward current and ambient temperature is shown in Fig. 4.

Application Considerations

If a boost converter is used for the current regulator, care should be taken to limit the overshoot of the load voltage that may occur at application of power. This is usually affected by a soft start, which slowly increases pulse width once an enable threshold is exceeded. This doesn't prevent the resonant charging of the filter capacitor, if one is used, but prevents instantaneous overvoltage as the output overshoots and returns to the regulation band.

When an LED string replaces the upper resistor of the divider chain, it can cause stability issues. A recent article[1] proposed high-side differen-

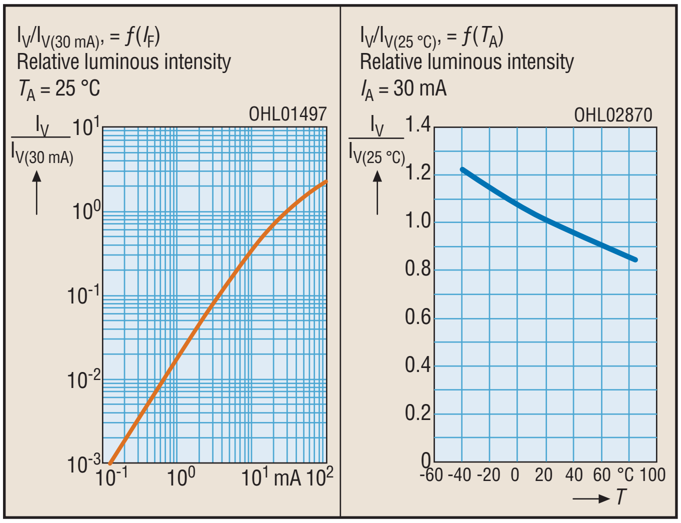

Fig. 4. *White LED characteristics. (Courtesy of Osram Semiconductor)*

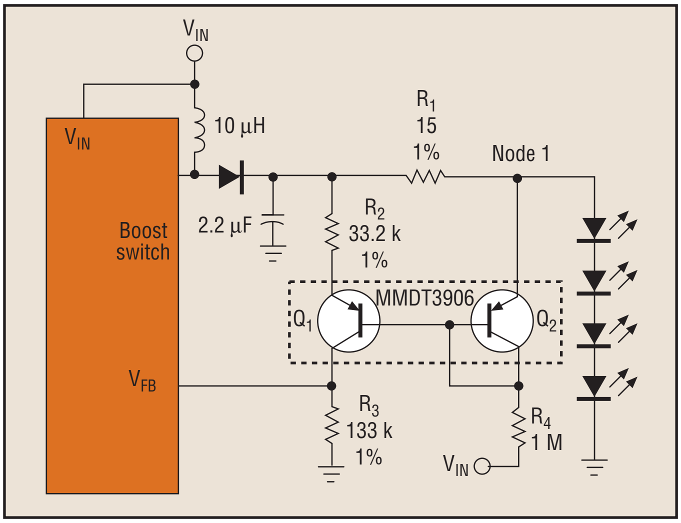

Fig. 5. *High-side current-sense scheme.*

tial current sensing to overcome this effect and to minimize the number of interconnects to a remote display. In Fig. 5, R_1 acts as a current-sense resistor or shunt. The diode-connected Q_2 level-shifts the voltage at Node 1 and applies it to the base of Q_1. These transistors are on the same die and provide a closely matched V_{BE} voltage when they operate at the same current.

Because the V_{BE} values match, the emitter of Q_1 is at the same voltage as Node 1. As a result, the voltage across resistor R_2 matches the drop across R_1 and produces Q_1 emitter current that equals V_{R1}/R_2. This current flows to Q_1's collector and creates a voltage drop across R_3. The boost-regulator regulates the voltage across R_3 at the IC's reference voltage. R_4 provides current bias for Q_2. If the voltage across R_1 is selected to be less than 250 mV, to improve efficiency, the collector currents in Q_1 and Q_2 must be

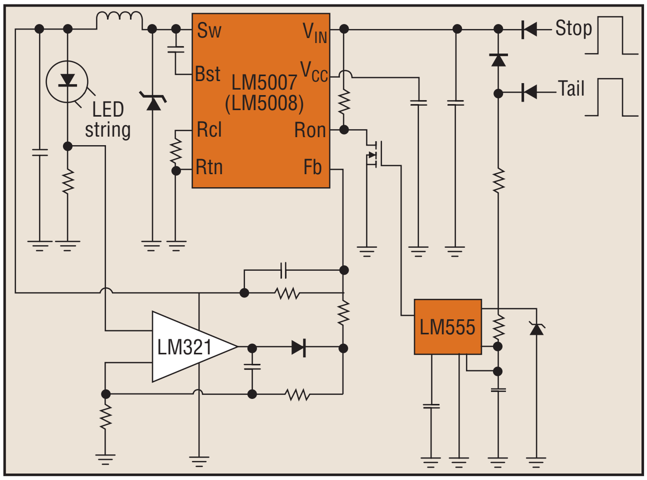

Fig. 6. *Stop/tail light circuit.*

matched by setting R_4. This minimizes V_{BE} mismatch. R_4 is connected to V_{IN} rather than ground so that negligible current flows in the external circuit when the boost converter is in shutdown mode.

Fig. 6 shows a stop/tail light application using a buck regulator. The LM5007 is a hysteretic regulator with an internal 80-V, 0.7-A DMOS power switch. In this regulator, the on-time of the high-side power switch is inversely proportional to input voltage, a feed-forward scheme that keeps the switching frequency virtually constant over a range of input voltage. The LM555 timer is configured as an astable multi-vibrator, which decreases the duty cycle for the tail-light function.

When the brake is applied, the astable is disabled and a higher current flows in the string of LEDs (shown as a single device in the schematic). The LM321 amplifies the current-sense signal generated across the resistor in series with the LEDs, increasing power train efficiency. This circuit is an excellent candidate for higher levels of integration, a prerequisite in automotive electronics that has spawned many of today's merged processes, particularly bipolar-CMOS-DMOS.

Fig. 7 shows a high-voltage boost converter driving a string of 20 white LEDs for an instrument panel backlight. This application illustrates the high forward drop of power white LEDs as the typical voltage across the string is greater than 70 V. The LM5000 is a switching regulator optimized for single-ended topologies (boost, flyback and forward). It's a current-mode regulator, simplifying loop compensation and giving high immunity to transients and surges on the supply. This is a key requirement in automotive applications where extensive susceptibility testing is part of the qualification process.

The input range of the control and drive circuit is 3.1 V to 40 V, satisfying typical requirements for information systems and telematics. Load dump requirements of 65 V would dictate the need for a bias supply regulator or voltage clamp on the analog power input, currently filtered by R_f and C_f.

One consideration when using the boost topology is the

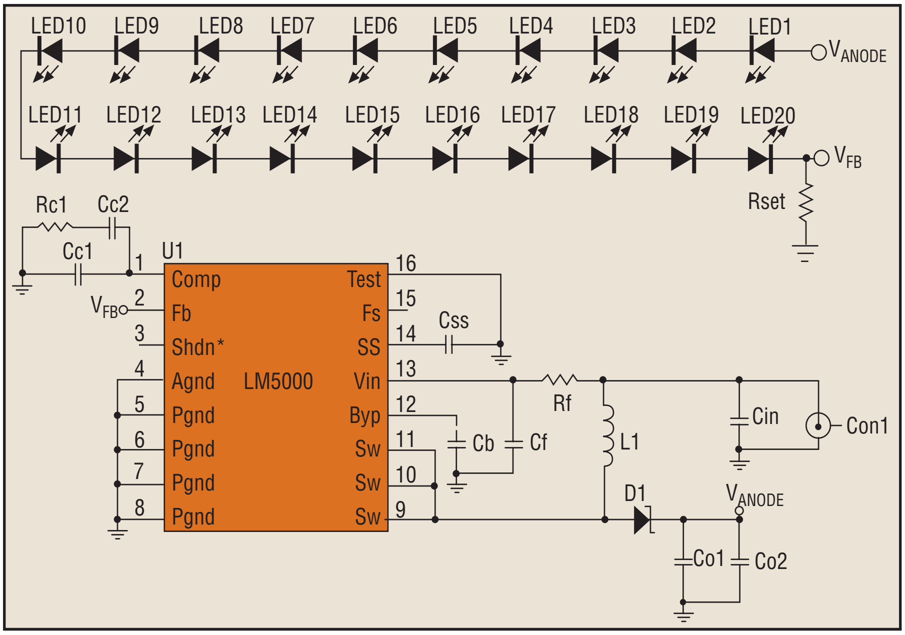

Fig. 7. *Instrument panel backlight circuit.*

possibility of lock-out at extended duty cycle. The ideal boost regulator gain characteristic tends toward infinity at maximum duty cycle.

In practice, losses intervene at higher duty cycles (typically greater than 90%) rolling off the (Vo/V_{IN} vs. duty cycle) gain curve. If a boost regulator exceeds the duty cycle at which the gain rolls off during a transient, or at application of the supply rail, lockout may occur. This fault is prevented by the inclusion of a maximum duty cycle clamp and soft-start function.

Solid-state lighting shows great potential in automotive applications. Luminous efficacy and the ability to dissipate power without excessive temperature rise are key elements in achieving the next steps. There is also the challenge of creating LED lighting that meets the SAE and ECE standards for beam patterns. One significant advantage is that the projector part of the LED lamp assembly extends to less than a quarter of the depth of the conventional solution. European and Japanese automotive manufacturers have recently announced white LED diving lights in car shows and shown concept vehicles.

One prominent automotive lighting supplier recently stated, "My dream is to have the first peel-and-stick headlamp." Naturally, semiconductor manufacturers are keen to address this exciting business. **PETech**

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