Solid State Lighting

Next Generation Power

MUDIT AGARWAL

As LED luminous efficiency surpass that of incandescent lamps, solid-state lighting is taking hold in portable electronics and automobiles. Still there are many challenges to be faced in designing solid-state lighting fixtures using light-emitting diodes.

Semiconductor Industry has gone from indicator lamps to devices that rival incandescent and fluorescent lamps in luminous efficacy. There are still many challenges to face on the road from research lab to commercial production. High-flux LEDs are the equivalent of bare incandescent and fluorescent lamps. But few issues in the systems must be addressed before affordable solid-state lighting fixtures will be seen in our homes and offices. Power-hungry equipment, cost lakhs of rupees now days lighting fits on the tip of your finger, consumes micro-watts of power and costs much lesser. Latest technology have enabled the practical integration of embedded microcontroller technology into almost everything we use, including architectural lighting applications. There are many types of hotel lighting applications including exterior, general interior, decorative and emergency lighting. For example, emergency lighting should be able to perform self-diagnostics and communicate with fire-alarm systems. Decorative lighting may need variable color control. Interior lights may need to respond to an occupancy sensor or communicate with a central lighting controller. Most general lighting applications require 'white' light. This is currently produced by incandescent, fluorescent, and high intensity discharge lamps. There are two approaches to generating white light with LEDs phosphor-coated LEDs and multicolor LED assemblies. Phosphor coated LEDs consist of blue LED dies that are coated with rare-earth phosphors. These absorb a portion of the blue light and re-emit it as yellow. The combination of the blue and yellow produces cool white light. By adding re-emitting phosphors, warm white light can also be produced.

Fig.1. Solid State Room Power Saver Lighting

Multicolor LED assemblies consist of separate red, green, blue (RGB) and sometimes amber (RGBA) LED dies mounted on a common substrate. Mixing of the colored light from these LEDs again produces white. The challenge facing the luminaire manufacturer is that color LED dies is currently based on dominant wavelength and intensity. Phosphor-coated LEDs are similarly binned by intensity and chromaticity. This makes it difficult to maintain product consistency without resorting to single bins. Further improvements in semiconductor or phosphor technologies should enable LED manufacturers to produce LED dies with tightly-controlled dominant-wavelength intensity and chromaticity characteristics. Until then, luminaire manufacturers will continue to struggle to maintain product consistency in terms of color and intensity. Phosphor-coated LEDs and RGB LED assemblies tend to have acceptable color

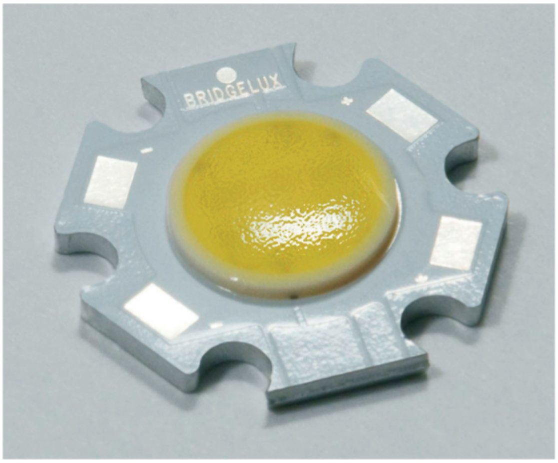

Fig.2. High Power LED

rendering capabilities, but there is room for improvement. The addition of red-emitting Phosphors to phosphor coated LEDs and amber LEDs to multicolor LED assemblies offer improvements. LEDs are effectively point light sources. It is much easier to design LED-based luminaries that are small and aesthetically pleasing than it is incandescent and Fluorescent lamps. The current Generation of high flux LEDs use molded epoxy and acrylic lenses, but diffractive micro-optics offer design advantages. The fact that LEDs are point sources can also be a disadvantage. The extreme luminance of high-flux LEDs can result in glare if the lights are viewed directly. In addition, color fringing of shadows can occur if the light from multicolor LED modules is not sufficiently mixed. Frosted glass and plastic diffusers commonly used in luminaire design are applicable to LED-based designs, but holographic and deterministic diffusers offer improved transmittance and better optical control. Heat dissipation remains one of the critical issues for LED-based luminaire design. The luminous efficacy of LED dies decreases with increased junction temperature. As a worst-case example, the efficacy of amber LEDs decreases by 80% when the junction temperature increases from 25 C to 120 C. Worse, the mean time between failures of LED packages decreases by half forevery10degree centigrade increase in LED junction temperature over the manufacturer's recommended maximum. Maintaining reasonable junction temperatures can be a challenge, particularly for outdoor luminaries with sealed housings and ceiling-mounted luminaries with limited air circulation. Current designs feature massive aluminum heat sinks. These are obviously more expensive than the sheet metal constructions use d for many architectura lluminaires. Miniature heat pipes are useful in transporting the heat from the LED package store mote heat sinks, but the heat sinks are still required. The situation will improve as LED manufacturers increase the luminous efficacy of their products. This will reduce the thermal load of LED-based luminaires considerably, leading to smaller, less-expensive heat sink. Designing an optical feedback system for these features poses interesting design challenges. Firstly, the peak wavelength of LED emissions shifts with junction temperature, typically 0.4-0.9 nm per degree Celsius. In addition, the spectral responsivity of the photosensors may change with ambient temperature. This makes it difficult to distinguish changes in intensity from changes in chromaticity. Another challenge is that the feedback controller must have a response time of less than 50ms. If it is too slow, the luminaire will be perceived to flicker when the feedback controller responds to sudden changes in luminaire intensity. Worse, the dynamic range of the photosensor signals should be at least 14 bits to accommodate the full range of intensity and color temperature changes. This pushes the performance of inexpensive microcontrollers to their limits. The different temperature dependencies of the LEDs must also be taken into account. Without an optical feedback system, the chromaticity shifts during dimming or changes in ambient temperature can be unacceptable. Yet another issue is the need to reliably and unobtrusively sample light from the LED assemblies over a wide range of intensities and chromaticities while ignoring ambient light conditions. Innovative optical designs are still required to solve this problem. LEDs are constant-current devices whose intensity can be controlled using analog or digital techniques. These include pulse width and pulse-code modulation. The modulation rate must be at least 300Hz in order to avoid visual flicker. However, the thermal time constant of most LED dies is approximately 10ms. A modulation rate of at least 1000Hz is needed to avoid thermal stressing of the wire bonds that may lead to premature device failure. The response time and stability of the power supply feedback system is also important. Most commercial DC power supplies are designed for constant loads, and perform poorly with light or rapidly changing loads. In general, power supplies must be designed specifically for high-flux LED applications. When 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. High-side differential current sensing to overcome this effect and to minimize the number of interconnects to a remote display. In Fig.3 , R1 acts as a current-sense resistor or shunt. The diode-connected Q2 level-shifts the voltage at Node 1 and applies it to the base of Q1. These transistors are on the same die and provide a closely matched VBE voltage when they operate at the same current. Because the VBE values match, the emitter of Q1 is at the same voltage as Node 1. As a result, the voltage across resistor R2 matches the drop across R1. Current flows to Q1's collector and creates a voltage drop across R3. The boost-regulator regulates the voltage across R3 at the IC's reference voltage. R4 provides current bias for Q2. If the voltage across R1 is selected to be less than 250 mV, to improve efficiency, the collector currents in Q1 and Q2 must be matched by setting R4. This minimizes VBE mismatch. R4 is connected to VIN rather than ground so that negligible current flows in the external circuit when the boost converter is in shutdown mode. Fig.4. shows a stop/tail light application using a buck regulator. The LM5007 is a hysteretic regulator. 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 taillight function. When the brake is applied, the astable is disabled and a higher current flows in the string of LEDs. The LM321 amplifies the current sense signal generated across the resistor in series with the LEDs, increasing power train efficiency. 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. 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 Rf and Cf. One consideration when using the boost topology is the possibility of lock-out at extended duty cycle. The ideal boost regulator gain characteristic tends toward infinity at maximum duty cycle.

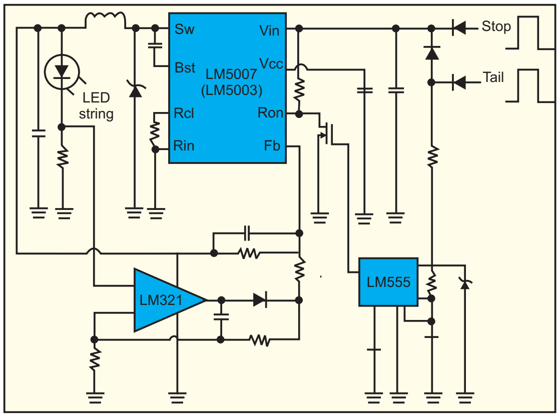

Fig.4. Tail light Circuit

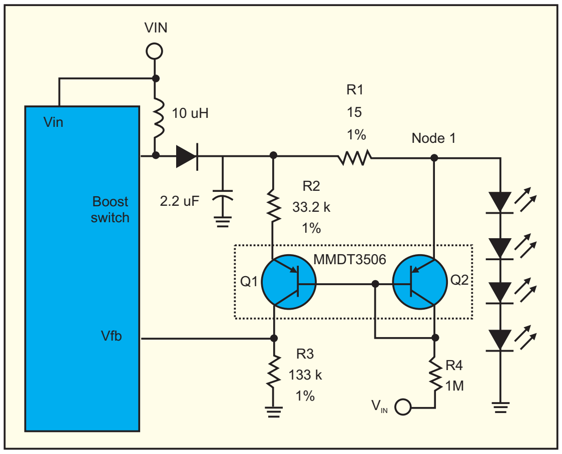

Fig.3. Current Sense

In practice, losses intervene at higher duty cycles (typically greater than 90%) rolling off the (Vo/VIN 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.