 By Bill Schweber, Executive Editor

THE VERSATILE LED IS NOW BRIGHT AND COLORFUL ENOUGH TO USE IN APPLICATIONS BEYOND SIMPLE INDICATORS AND READOUTS, BUT YOU STILL NEED TO GRAPPLE WITH ISSUES OF SOURCE DRIVE, BRIGHTNESS, DERATING, SPECTRAL OUTPUT, AND VIEWING ANGLE.

LEDs move from indication to illumination

LEDs HAVE COME A LONG WAY from their humble beginnings as simple on-off indicators on panels and displays. Although vendors increased LED brightness and learned to sort LEDs to match their brightness for use in seven-segment displays, the LED color palette still remains mostly red, followed by green and then yellow and orange, and their brightness was still only enough for indoor applications.

Many of the older limitations associated with LEDs have changed dramatically in the past few years. New high-efficiency LEDs boast brightness that makes them usable in daylight and provides colors that include long-sought blue and even white. As a result, applications such as traffic lights, machine-vision-inspection lighting, illumination, backlighting, and even large signs use LEDs (**Reference 1**). Although LEDs are not yet ready to replace incandescents in general lighting situations, such as room and reading illumination, they compare favorably in some lighting applications as well as well-focused (pun intended) design situations.

The virtues of LEDs, compared with incandescent sources, are clear: long life plus power efficiency. But to realize these attributes and use LEDs in more than simple indicator applications, you need to understand LED-drive models, compensation for temperature increases, the legitimate ways of assessing brightness, and viewability factors. Dozens of high-performance-LED vendors exist, and they generally follow industry practice in their specifications. However, because of the nature of the LEDs, you end up comparing their various specifications with different metrics, depending on how the vendor positions the LED.

YOU LIGHT UP MY LIFE

Most LED vendors cite an operating LED life of 100,000 hours under nominal operating conditions. In contrast, an incandescent bulb is usually rated at 1000 to 10,000 hours. In many cases, the savings in the replacement unit's cost, the labor to replace the bulb, and the overall user distress due to a malfunctioning light easily offset any higher initial cost for the LED.

Further, the vendor provides the incandescent life rating at a specified voltage, but many incandescent lamps operate directly from the ac-power line. The actual line voltage that the bulb operates at can be several volts above the nominal value. (In the Boston area, the power company considers the line voltage satisfactory if it is 115 to 125V ac rms at the drop into the house). However, operating the bulb at even a few volts above test conditions quickly shortens the life of the bulb compared with its stated specification. In contrast, LEDs often operate from a regulated dc-supply or current-limited source, so the operating conditions are more tightly constrained. Another factor for incandescents is thermal shock and mechanical stress on the filament that results from the full voltage's hitting the cold filament. LEDs are not immune to a similar shock, because on-off operating cycles and temperature swings can degrade packages and bonds, but the power levels and thus thermal steps are much smaller.

The power savings with LEDs are dramatic, but you still need to understand the vendor's intentions and what you need. The common signal-integrity unit for defining the amount of light emitted compared with energy input is lumens per watt, which may be misleading (see **sidebar** "So, how bright is it?"). An incandescent bulb distributes its photons relatively evenly around its source in a nondirectional, spherical mode, whereas an LED is inherently a directional source. In addition, the output of the incandescent lamp covers most of the visible spectrum, whereas LEDs are wavelength-specific. As a rule, an incandescent source is 10 to 20% efficient, but an LED is 80 to 90% efficient. **Reference 2** thoroughly examines general factors related to LEDs as light sources.

But there's more to the efficiency story than just the watts' input and lumens' output measurement. If you have to optically filter the white incandescent light to a specific color, you can lose half or more of the output intensity at the filter itself. The red LED, in contrast, produces nearly all its lumens at any desired color.

The incandescent's spherical output profile is both good and bad. If you need broad-area illumination, you'll make good use of the lumens; to achieve the same broad coverage with an LED requires an optical diffusing lens, which reduces brightness in the primary direction, or an LED array.

Incandescents are voltage-driven devices, whereas LEDs are current-driven. Usually, a voltage source provides this current through a current-limiting resistor at a low cost. Most LEDs, regardless of efficiency, have a nominal current drive of 20 mA; some units can use a maximum drive of 70 mA. Regardless of current level, you need to maintain the drive current within specification and compensate for changes in both junction and ambient temperature. As an additional complication, many illumination systems use an array of LEDs to develop the desired overall intensity, and you must factor the differences between individual LEDs in brightness versus drive into your drive design.

It may seem simplest to just connect all your LEDs in series, which ensures that each LED has the same forward current (**Figure 1a**). This topology works, but you have to make sure that your current source has enough compliance for the sum of the forward-voltage drops of the LEDs, nominally 1.4V for each LED. Further, any single LED failure in the open mode cuts off all current flow and illumination.

At the other extreme, you could run each LED from its own parallel branch for maximum redundancy and lowest compliance voltage at the source, with a single resistor for the entire array that a resistor in each branch optionally supplements (**Figure 1b**). However, another problem arises; compared to the alternatives, the overall supply current is greatest, and any change in an LED's forward voltage due to drift, thermal differentials in the array, or other hard-to-anticipate factors compromise overall brightness

AT A GLANCE

▷ LEDs can now go beyond simple indicators and act as area illuminators.

▷ You need to balance the various LED-drive trade-offs as well as account for thermal issues and device variability.

▷ You can choose among a large number of vendor offerings, unique products, and hard-to-compare specifications.

SO, HOW BRIGHT IS IT?

The value of what we call brightness is a key specification for any display, indicator, or illuminator. Describing brightness is complex, unlike describing electrical power, which is measured at one point with a power meter or sensor. Brightness involves different yet legitimate ways of characterizing what our eyes and brain perceive, as well as specific colors (dominant wavelengths or color temperature) and eye sensitivity to these colors and beam widths.

You measure the electrical power that goes into the LED in watts, which is the easy part (**Reference A**). You could also measure the output in watts because the light emitter is another form of power; however, measuring it is not useful for most applications. Luminous flux is the flow rate of light energy from the source measured in lumens. The total flux is the sum of the flux that is the incident over the entire inside surface of a sphere that encloses the source.

Intensity, in contrast, characterizes the flux density at a position in the space of this surrounding sphere, so it is the flux per unit of solid angle. You measure photometric density in candelas. Be sure you understand what intensity situation the vendor is using and how it matches your application.

When looking at vendor specifications, you also have to consider the color factor and visible light. The total output intensity may be less interesting to you than the intensity at a given color. If the LED converts its input energy into photons at wavelengths that don't interest you or are outside the visible spectrum, the meaningful output for your situation decreases.

Reference

A. Technical Information–Solid State Lamp Theory, www.lumex.com/tech_notes/thery_3c.html.

consistency. Using more LEDs on a string results in lower total supply current, but using fewer emitters means that the forward-current change becomes larger as the input voltage varies its range.

Between these two extremes, you can use a combination of series and parallel strings to manage the trade-offs (**Figure 1c**). In practice, most LED arrays use a 12 to 24V-dc source and three to six LEDs per series string to achieve a satisfactory trade-off. Ironically, although LEDs are diodes and, thus, simple two-terminal devices, you may need to look at optical, electrical, and thermal models to make sure you are properly designing them in. **Reference 3** gives some insight into both the general multi-aspect modeling situation as well as the particulars related to one vendor's product line.

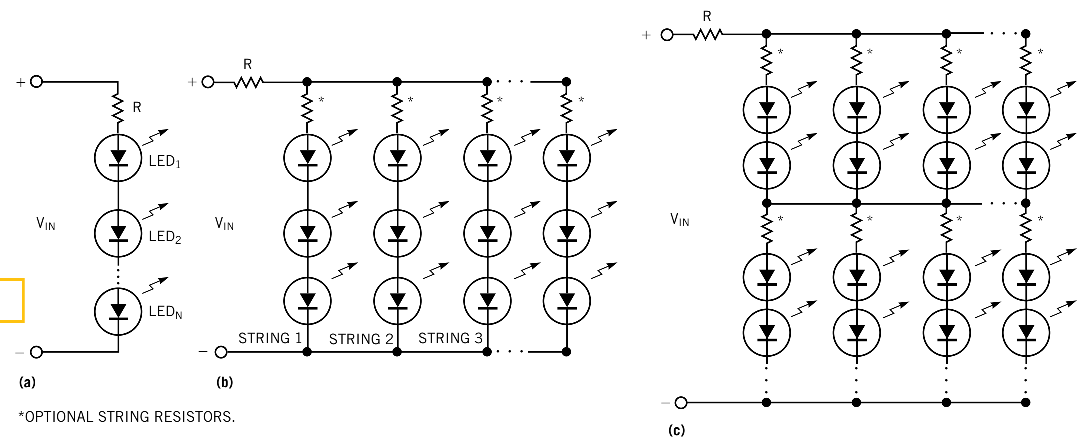
WHAT LIGHT THROUGH YONDER WINDOW…?

If you want to replace incandescent lamps with LEDs, you need to consider numerous optical factors that contrast, so to speak, with the incandescent world. The first factor is color. You can now get relatively bright blue, bluish-white, or even white LEDs, which may lead you to think that a direct LED replacement for a low-intensity incandescent unit is no problem; however, that's not the situation.

As **Reference 2** discusses, LEDs can provide white light in two ways. One way is to use a trio consisting of RGB LEDs. This option is more costly than a single LED but gives you the best control over color. For this reason, designers often use the RGB trio in signs, just as they use RGB CRTs to produce full-color images. However, you have to compare intensities, because a red LED at a given current level may be much brighter than a blue LED at that level. You may need to use a pair of blue LEDs to balance the intensity of a red LED and carefully set current levels of the blue pair compared with the red LED.

Another way vendors produce white light is to use an InGaN blue LED and a phosphorus filter in the lens of the LED;

Figure 1



You can connect an array of LEDs using basic series (a), parallel (b), or mixed topologies (c) to get the right balance among factors, such as current consumption, source-voltage compliance, number of resistors, and performance sensitivity to parameter variations.

FOR MORE INFORMATION…

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Global Lighting Technologies Inc
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the phosphors produces a cool white light similar to a standard fluorescent light. By adding more phosphors, the light is more incandescent in color, but the trade-off is less brightness; in contrast, less phosphorus yields a brighter but cooler white output. The single-LED approach works where you need a white-like light, such as an indicator lamp or small-area illumination.

But if you intend to use this so-called white light for color judgment or to produce specific colors using optical filters, you will have a problem. The InGaN-based white LED does not contain red in its spectrum, so you'll get unexpected but entirely explainable results. The white LED fronted with a red lens yields a faint pink color, a yellow lens produces a yellow-green output, and a green lens produces a greenish-blue color. Therefore, you wouldn't use this LED as a backlighting source behind a translucent panel with different-color filters, such as in a display sign. You can use this LED in situations in which you have matched the color needs to the LED-output capability and limitations.

You rarely use LED chips without some sort of lens, usually fabricated of molded epoxy, which serves to protect the chip and further shape both the LED's color spectrum and its luminous spatial distribution. The lens color also serves a literally dark purpose: A tinted lens shows what color the user sees when the LED is off, which is important in some applications.

A standard LED lens without any diffusion produces a relatively narrow viewing angle of about 12° on either side of the LED center. (Viewing angle is the angle at which intensity drops to 50% of its on-axis value; it is analogous to a directional antenna's 3-dB beam width.) This narrow dispersion works well in applications, such as backlighting, in which the LED's output is directed at a translucent panel that further diffuses the light. By embedding tiny glass particles in the lens epoxy, vendors can make the LED viewing angle spread to as much as ±35°. Of course, you don't get something for nothing. Just as with an antenna, if you spread the beam, you reduce its intensity in any specific direction, because the total energy output is fixed.

Lens construction and color are just two factors that affect viewing. To control viewability, OEMs can also adjust the shape, the size, and the front-to-back distance of the lens, as well as the shape of the reflector cup behind the lens.

Figure 2

With the S6 candelabra-screw-base LED lamps from Ledtronics, you get plug-in replacements in a variety of colors for this standard small bulb.

Figure 3

Ledtronics also offers LED-based bulbs that replace standard-base household incandescents and that draw as little as 2W yet have light output roughly equivalent to incandescent bulbs with 10 times that rating.

A THOUSAND POINTS OF LIGHT?

If you are looking for bright or efficient LEDs, prepare for both good and bad news. Dozens of vendors offer these LEDs in a bewildering selection of combinations of color, current, intensity, lens shape, lens color, viewing angle, mounting style and base, and thermal capability, as well as price and delivery schedules. You have to do your homework by looking at data sheets and viewing the products. Compare similar and sometimes dissimilar parameters, make some necessary trade-offs among available LEDs, and you should find one or more devices that meet your needs.

A few examples illustrate these points. Ledtronics offers LED-based replacements for S6 candelabra-screw-based incandescent lamps in a choice of colors and corresponding brightnesses: green (10,000 mcd), white (6000 mcd), blue (3000 mcd), yellow (7000 mcd), red (3500 mcd), and orange (6500) (**Figure 2**). The brightness is a function of both the color and the typical application, as well as human perception factors. These LEDs are available for supplies of 5 to 220V ac or dc and have built-in current-limiting resistors, so they are drop-in replacements. As an added feature, you can order them with either a single light emitter or with two or more emitters, so you'll get light output even if one emitter fails.

As part of its DecorLED series, Ledtronics also has LED bulbs, which use a combination of InGaAlP and SiC/GaN materials and fit the standard 25-mm Edison base of common household lamps (**Figure 3**). Available in a variety of colors and drawing 1 to 1.7 W, these bulbs are roughly equivalent to a household 15 or 20W incandescent bulb. Although you can't use these bulbs to provide overall room lighting, they are suitable for message panels, exit signs, time and temperature signs, and accent and ornamental lighting. Despite their initial cost of $17 to $50, compared with less than $1 for an ordinary bulb, you more than make up this expense in operating-cost savings (energy, replacement, and labor) over their 100,000-hour life.

Toshiba America Electronic Components has a white LED based on an indium-doped GaN emission layer, which in turn excites RGB phosphors in the transparent resin of its package. Toshiba's 3.2×2.8-mm TLWA1100, priced around $2, provides 100 mcd at 20-mA drive current with color output of 6500 to 9000K, depending on the specific doping and RGB-phosphor mix.

For a different package style, look at the Shark series from Opto Technology (**Figure 4**). This vendor uses 50-LED dice mounted on a BeO substrate for efficient heat transfer; the substrate attaches to a TO-66 power-package base. Typical brightness is 55 lm, whether you choose blue, green, amber, red, or white, but with an operating current range of 300 to 800 mA. Opto Technology's standard Shark product, which costs $30 to $67 (1000), has a half-power beam angle of ±54°, and you can increase the on-axis light intensity and decrease the beam angle by adding a beam-concentrator lens.

If you prefer surface-mount bright LEDs for status or backlighting applications, such as instrument panels and industrial controls, the Stanley Electric 1104B series with 2.2×2.8-mm footprint has a ±60° viewing angle and as much as 120- mcd luminous intensity at 20-mA drive, depending on color. Further, the LEDs can withstand a maximum operating temperature of 100°C, which is higher than many other LEDs. For extra-bright needs, the vendor's through-hole AlGaInP LEDs have a maximum luminous intensity of 5000 mcd at the same drive level, depending on the color. This intensity level makes them suitable for outdoor indications, signs, and accent lighting. These higher intensity LEDs have a relatively narrow beam width of ±5°.

Another major vendor is Lumileds, a joint venture of Philips Lighting and Agilent Technologies. The company's Super Flux LEDs are primarily targeted at automotive and similar multi-LED applications, which require a wide operating-temperature range and uniform brightness for array configurations. They also generally function as part of a more complex electromechanical support and lens structure. Lumileds provides detailed design guides that use electrical, mechanical, thermal, and optical modeling and analysis.

You are not restricted to buying LEDs or basic LED arrays and then building up your own final electromechanical assembly. For example, Global Lighting Technologies uses tricolor LEDs with integrated molded light guides to provide backlighting for LCD modules. A single LED with its light guide can backlight a display area measuring as much as 3×3 in. (7.6×7.6 cm); the backlighting color depends on the mix of RGB emitters that you specify for that LED (**Figure 5**).

For more intense applications, Dialight provides a red LED-based marker light in a weather- and corrosion-resistant housing that is used for airport runways, radio towers, and similar critical applications. These markers operate from 12V-dc or 120/230V-ac sources and produce a 360° visibility pattern with 70 cd flux. The company also offers drop-in retrofit replacements for 8- and 12-in., red, yellow, and green traffic signals with intensities spanning 130 to 800 cd. These signals also meet the numerous requirements of highway regulatory agencies. These traffic-signal units include temperature-compensation circuitry to maintain intensity in the mandated range over −40 to +74°C and have drive-voltage regulation to maintain intensity within ±10% over the 80 to 135V ac source variation.□

Figure 4

By placing 50 emitter dice on a thermal substrate and then on a TO-66 package base, the Opto Shark series from Opto Technology gives you wide-angle brightness with built-in thermal management.

Figure 5

Global Lighting Technologies combines an LED with a molded assembly to function as a backlight for PDA-sized LCD panels.

References

1. Schweber, Bill, "Blue LEDs, digital TV bring daylight-bright signs to masses," *EDN*, April 13, 2000, pg 56.

2. "Utilizing LEDs in Today's Energy Conscious World," www.ledtronics.com/utilizing LEDs.

3. Application Note 1149-3, *Electrical Design Considerations for Super Flux LEDs*; Application Note 1149-4, *Thermal Management Considerations for Super Flux LEDs*; Application Note 1149-5, *Secondary Optics Design Considerations for Super Flux LEDs*, available at www.lumileds.com.

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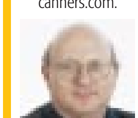

Author's biography

Executive Editor Bill Schweber does most of his technical reading and writing by flickering candlelight or by the glow of the NASDAQ sign built of 16-million LEDs in Times Square, New York.