## LIGHTING TECHNIQUES

**By Marcus Thielen**

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# Sign Spotting

LEDs' radiation characteristics and uniform signface lighting

Despite their disadvantages, LEDs are more frequently used in illuminated signs than other major light sources because they're aggressively and sometimes incorrectly marketed and advertised.

However, most LED-illuminated signs, when installed, produce a "spotty" or "patchwork," rather than a uniformly lit, appearance.

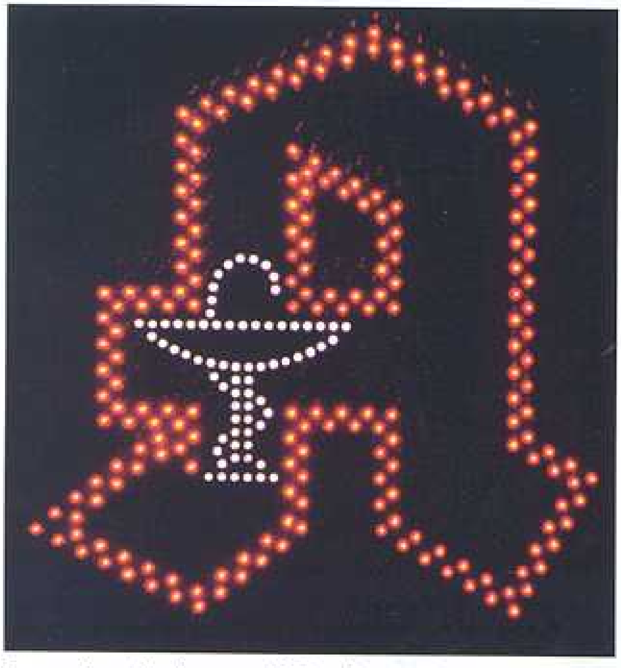
Why? The signshop that planned the sign probably didn't consider LEDs' "radiation characteristics," which this column will try to explain.

The spots that many newer, LED-backlit signs produce stem from unevenly spaced, individual LEDs, LED clusters or LED modules. Digging more deeply, you'll find LEDs' physical characteristics are the culprits (*see ST, August 2007, p. 30*). The rather small, semiconductor crystal, which is generally placed in a metallic, bowl-shaped reflector, directs the light forward. This "big-picture" examination doesn't differentiate between a front-emitting or a side-emitting crystal, and the source can be considered a "point source."

**An LED-backlit channel letter with insufficient light diffusion produces a "patchwork appearance."**

In most cases, the LED package (I'll call the LED an electrical/electronic component, because manufacturers use it to make "modules") also contains an optical element (a lens), which is often directly molded into the component's shape to modify the directional, light-radiation characteristics.

No light source – not even our sun – radiates with equal intensity



**Even rather closely spaced LEDs, directly viewed, are seen as separate light spots.**

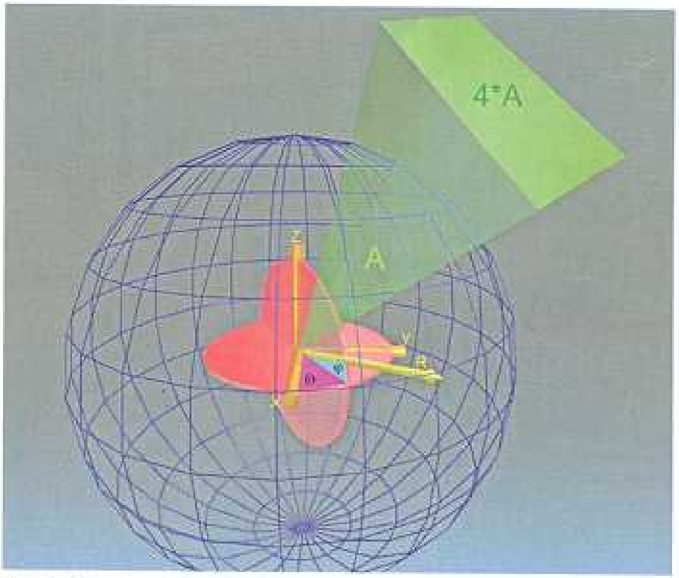


**Fig. 1: A schematic of spherical coordinates R,Θ,φ. In the Cartesian coordinate system *x, y, z,* they are the azimuthal and elevation planes. The amount of light projected from a source in the center through area A in distance R will fill four times the area (4A) in double the distance (2R) from the source.**

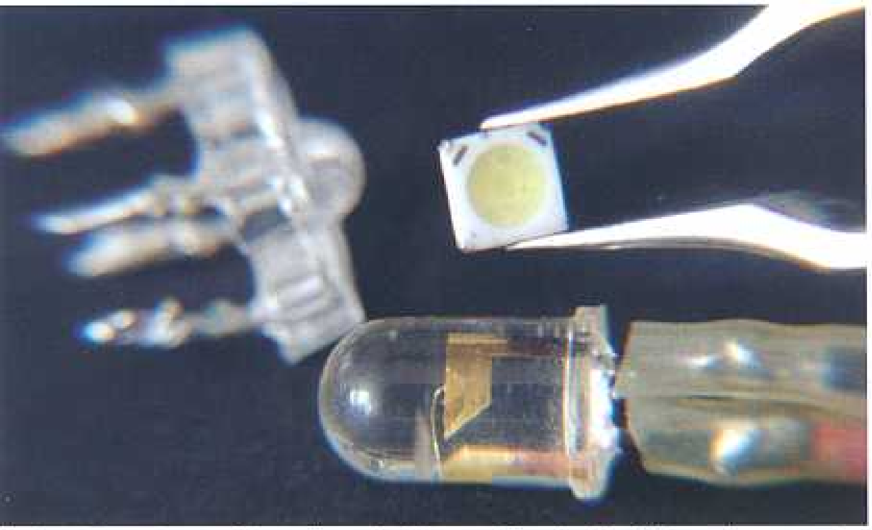
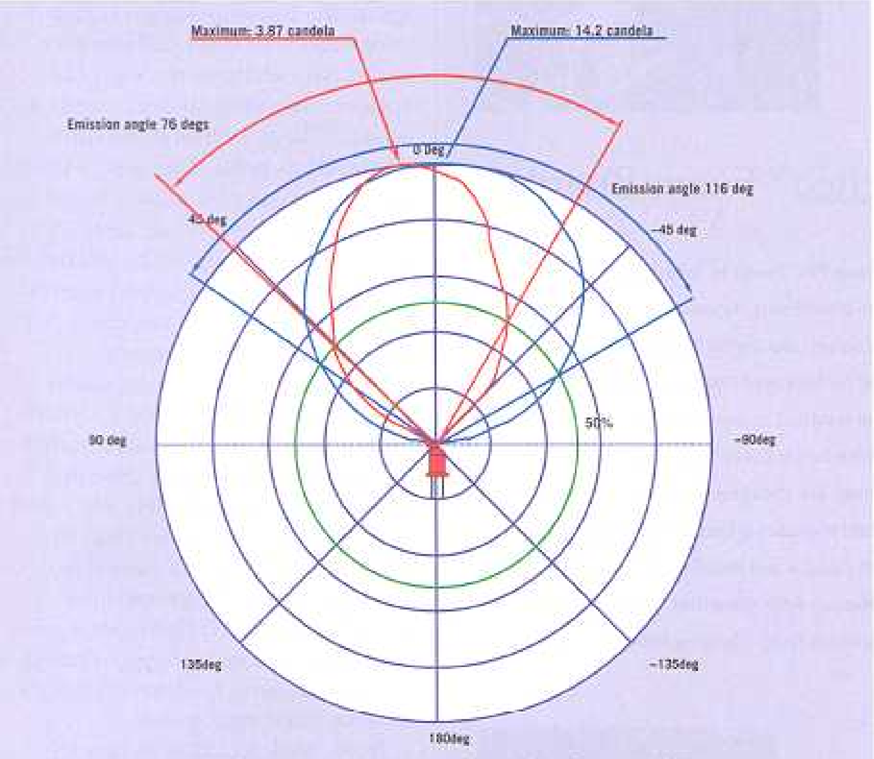


Fig. 2a: LED packages with a reflector (golden metal) and molded-in lens (bottom and op left) or a wide-angle, surface-mounted device without a lens (top right). The diameter of the bottom glass body is ⅕ in.



Elevation curve at 0 degrees Azimuth for white + red LED

Fig. 2b: The measured emission characteristics of the two LEDs pictured in Fig. 2a, in a polar diagram.

in every direction. Light doesn't radiate from certain angles in most light sources - just think of a lightbulb's opaque base. Radiation characteristics or radiation diagrams reveal the varying light intensity radiated into different directions (space angle).

The presentation of the full characteristic information is the problem – it's four-dimensional. For ease of understanding, I use spherical coordinates R, Θ (azimuth angle) and φ (elevation angle) here, instead of Cartesian coordinates *x*, *y* and *z*, because they can be converted into each other.)

If we want to know the source's intensity distribution at distance R, we must place the source into the center of a sphere with a radius R and measure the light intensity at every point of the said sphere – and so on for each Θ and every φ (**Fig. 1**).

If we want to know the intensity for different distances, these measurements must be repeated for all possible radii R. Thus, for each radius R, we obtain an intensity value for each point $\Theta$, $\varphi$ (assuming intensity, for now, is a color-independent value).

To simplify the presentation of such data, we can use a fundamental light property. Through a homogeneous medium, light always propagates in a straight path.

Thus, if we know the intensity in one particular direction at a given distance, we can calculate the intensity at another distance in the same direction. The dependency is an inverse quadratic – if we double the distance to two times R, the intensity is only one-fourth the intensity at distance R. The surface of a sphere is defined as $4 \times \pi \times R \times R$.

When R is doubled, the surface is four times (2 x 2) the surface; the same amount of light going through four times the surface equals a light intensity of ¼ at double distance.

Assuming the straight propagation of light, if we've measured the intensity in all possible directions for one distance R, we can calculate it for other values of R. So, we've reduced the dimensions of our problem to three.

In most cases, you don't need to know the intensity for each pair of coordinates $\Theta$, $\varphi$ It's sufficient to make two sections through the sphere: one vertical and one horizontal. These sections are then displayed as polar diagrams, whereas the intensity is normalized to 100%.

So, the highest value, 100%, will be assigned a point at the maximum radius in the diagram; zero intensity in one direction would yield a point in the center of the diagram.

Such measurements are taken with an instrument called a Goniophotometer, a directional light meter that records intensity at different angles to the lamp. Often, it's easier to move the lamp rather than the light meter (think of a turntable). However, many lamps must be operated in a fixed (horizontal or vertical) position, so large, rotating mirrors are used to deflect the light into the fixed light meter.

Now, back to LEDs. When we point one of the LEDs from **Fig. 2a** upward into our sphere and scan the light level in $\varphi$ direction from -180 to 180°, we obtain the emission intensity diagram shown in **Fig. 2b**.

In many cases, the azimuthal curve is simply a circle when the LED's light cone is symmetric around the optical axis. Thus, the elevation curve is most important. In this situation, the maximum intensity is usually 0° – straight forward. For this angle, most LED manufacturers list the apparent brightness in candela (cd) or millicandela (mcd). This value doesn't reveal the total light output – you need to consult the full polar diagram of the intensity distribution.

Some LED datasheets give the "emission angle" in degrees, which is the angle produced when the intensity is half of its maximum value (**Fig. 2b**). When measuring different LEDs, the light-distribution curves vary widely. Even if LEDs claimed to radiate 180°, you can't expect a uniform intensity distribution over that wide of an angle.

The narrower the emission angle, the more focused the light spot that emerges from the LED. This isn't desirable for sign applications.

Every LED is a point source. The human eye can distinguish two points that enclose an angle of more than 2 arc minutes. For example, if two LEDs are placed 1 in. apart, the normal, unaided human eye will see them as two, separate spots, from up to a 300-ft. distance.

The only way to achieve a uniform appearance, even at closer distances, is to place a translucent, but not necessarily transparent, surface between the light source and the observer. The key lies in the light diffusion, or how light is scattered. On a microscopic scale, a lightbeam won't be straight if the medium isn't homogeneous.

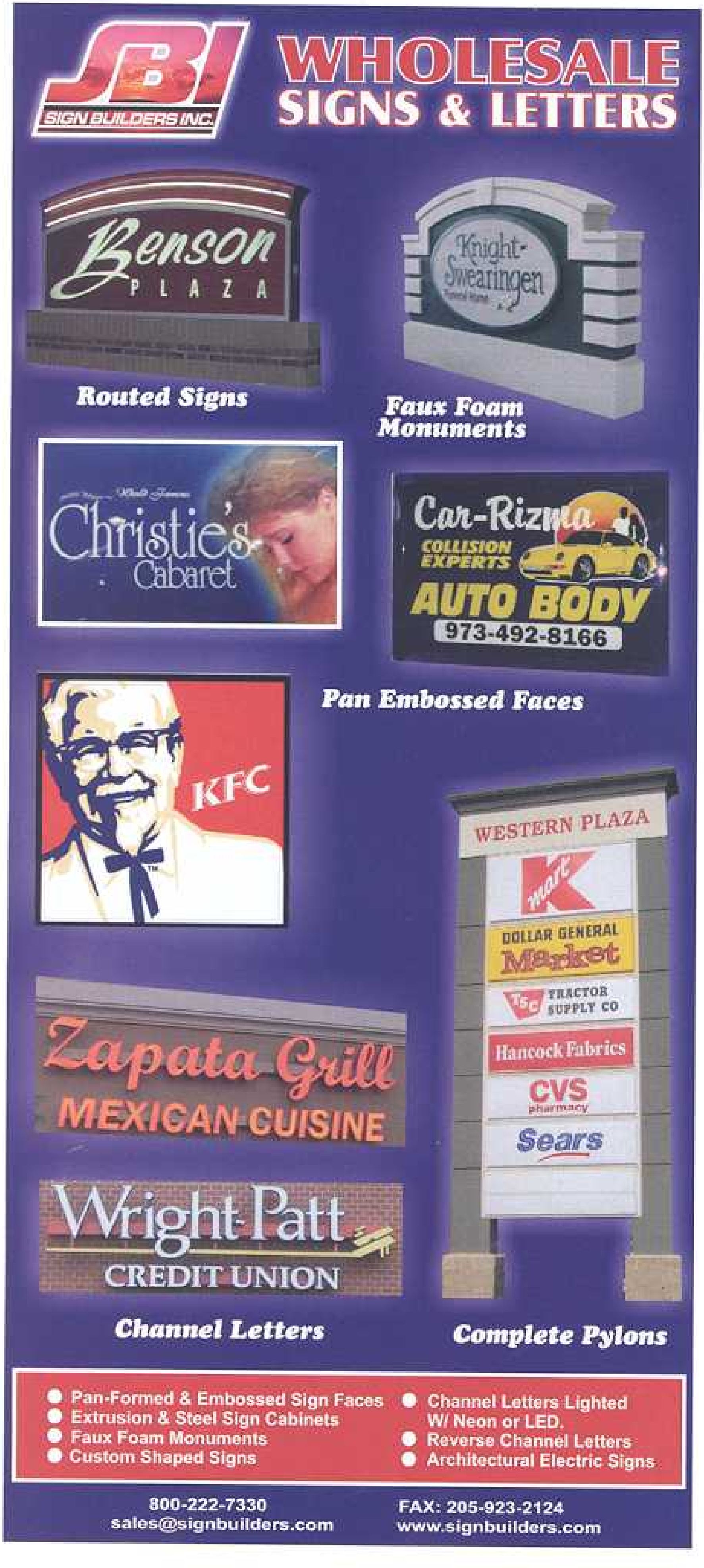
Here's a simple experiment. Place an LED behind a glass of water. From a distance, you'll see a bright spot. Add a minute amount of plaster of paris to the water, and stir well to obtain a milky liquid. From a distance, the whole glass appears to be lit, because every grain of plaster, which is hit by the light, reflects the light into all directions.

Also, the intensity of the diffused light is much lower than the light that passes through the clear water. Each microscopic collision between light and inhomogeneities dissipates some energy and, thus, lowers the light intensity.

Because both transmitted and reflected light, as on matte-white surfaces, are diffused, some LED manufacturers instruct installers to direct the LEDs backwards, so the light faces the back of the channel letter instead of the cover face.

In this case, only the diffusely reflected light hits the sign face, instead of the sharp, beam cone from a direct LED. The overall light loss is enormous, as I will show next month with many, recently installed shopping-mall signs.

So, only a fraction of the few lumens generated by a weak LED hits the backside of the sign face. (A company even developed a highly reflective paint to reduce the back-reflection losses.) This hides the LEDs' separation within the modules, but the patchy appearance caused by low intensities between the modules persists.



The introduction of high-power LEDs heightened the problem. If fewer LEDs produce the same light output, and each LED is brighter, the spacing can be wider.

Or can it? Brighter spots require much better diffusion to obtain a uniformly lit surface; thus, the face materials must have higher scattering ratios and increased light losses in the scattering material. Even if LEDs would permit much shallower returns, there must be enough space between the light source and the face material so the cones of each LED and the modules can overlap.

Another important aspect in the use of colored, translucent materials is their filter characteristics, or the transmission for different wavelengths (*see* ST, *March 2008, p. 52*). Because LEDs are available in only a few colors/monochromatic wavelengths, the filter material either allows the color to pass through or blocks it, but it doesn't change the color (except for white LEDs, in which only part of the emission spectrum is transmitted by the dye in the acrylics).

Note that RGB color-mixing LEDs emit only three, narrow, wavelength light bands in the red, green and blue ranges; the mix colors (yellow, orange, cyan, etc.) are just impressions that the eye mixes, without a corresponding wavelength in the spectrum.

Consequently, colored acrylic covers can reduce LEDs' intensity if the passband (the range of frequencies or wavelengths that can pass through a filter without being attenuated) doesn't correspond to the emission peak – disregarding the reduced transmission due to the necessary scattering action.

Numerous parameters preclude a recipe for obtaining a uniformly lit sign with LEDs. The only way to do so is to conduct tests – or use a light source that isn't so concentrated. ■

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