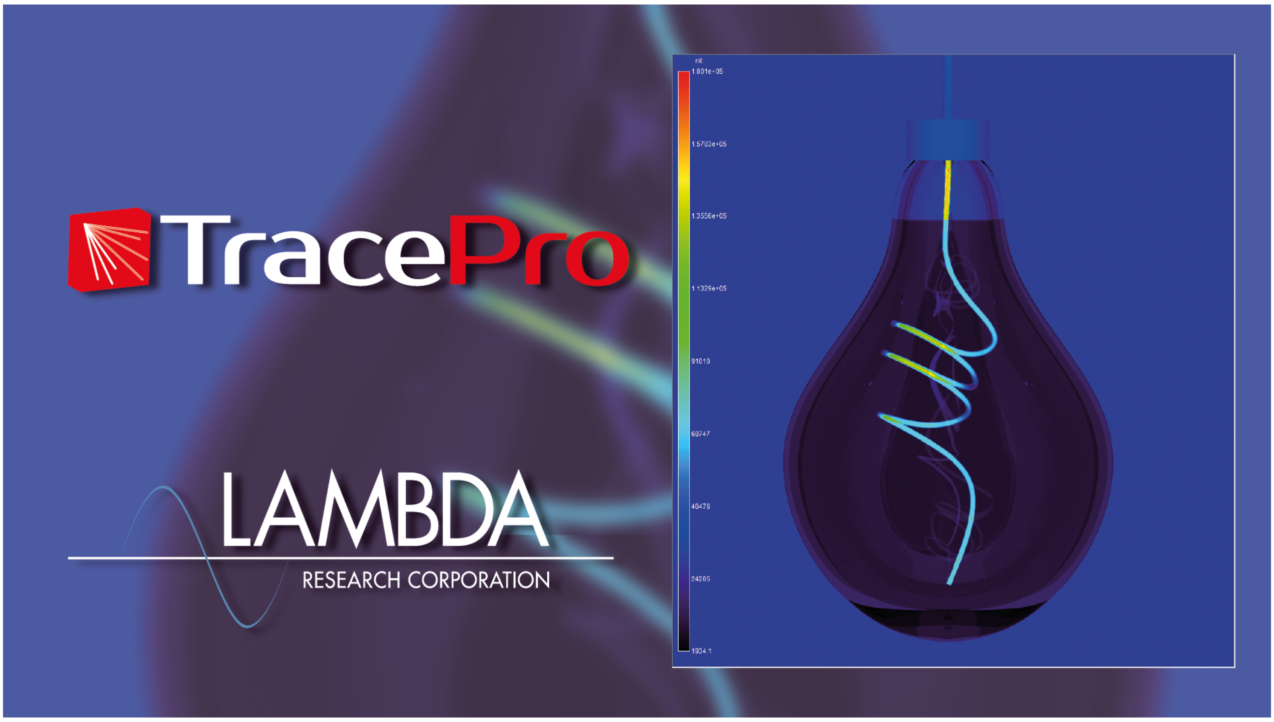
Visualizing Light Guide Performance using Photorealistic Rendering



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Dave Jacobsen is a Senior Applications Engineer at Lambda Research Corporation with over 30 years of optical engineering experience. Dave is Lambda Research Corporation's senior sales engineer and teaches many TracePro training classes, both in the US and worldwide. Prior to coming to Lambda Research Corporation, Dave worked as a Principal Optical Engineer at PerkinElmer, formerly EG&G, working with xenon flashlamp based systems for illumination, machine vision, UV sterilization, and process control, as well as designing spectroscopy systems for biomedical applications.

Light guides, or light pipes, are optical devices that move light from one point to another. For example, you may need to guide light from an LED source to a detector. Light guides do this using the principle of total internal reflection. Examples of light guides are all around us. The speedometer needle in your car or truck is probably a light guide. The On/Off power indicator on an appliance or electronic device is a light guide. The backlight for your computer monitor is a light guide. Fiber optic cables can also be considered light guides. In many cases the most important metric of light guide performance is how it looks to a user or viewer. This is especially true for indicators and displays.

Light guides, light pipes, and fiber optic cables all work by the principle of total internal reflection, often abbreviated TIR. Total internal reflection means that light rays that meet certain conditions are reflected inside of a light guide with no loss in flux or power. This is key when transmitting light from one point to another where little or no loss is important.

Snell's Law governs how light is refracted or bent when it goes from one medium to another, for example, from air into plastic, or from plastic back into air. Snell's Law is: $n_1 sin\Theta_i = n_2 sin\Theta_t$ where:

- n_1 = index of refraction of incident material
- n_2 = index of refraction of transmitted material
- Θ_i = incident angle
- Θ_t = transmitted angle

Snell's Law can be used to calculate what is called the Critical Angle. The critical angle is the incident angle of light, relative to the surface normal, at which TIR begins to occur. Light rays at an incident angle greater than the critical angle will be TIR'ed. Light rays at an angle less than the critical angle will be partially reflected and partially refracted out of the light guide. The critical angle varies with the indices of refraction of the light guide material and the surrounding material, which is often air. For a hypothetical plastic with an index of refraction of 1.5 in air, the critical angle is 41.8 degrees. Figure 1 shows examples of a light guide with a light ray below and above the critical angle.

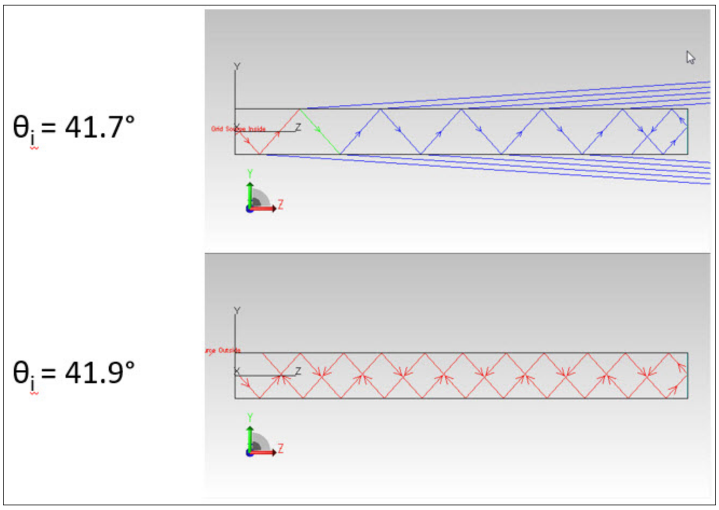

Figure 1: Ray in a light guide, greater than and less than critical angle.

In many applications, such as the speedometer needle, power indicator, or backlight displays mentioned earlier, it is necessary to break TIR to direct light in a specified direction. A couple of ways of breaking TIR are adding surface features or surface textures to the light guide. Figure 2 shows an example of adding a geometric feature to the light guide to break TIR, and Figure 3 shows adding a surface texture to the output surface.

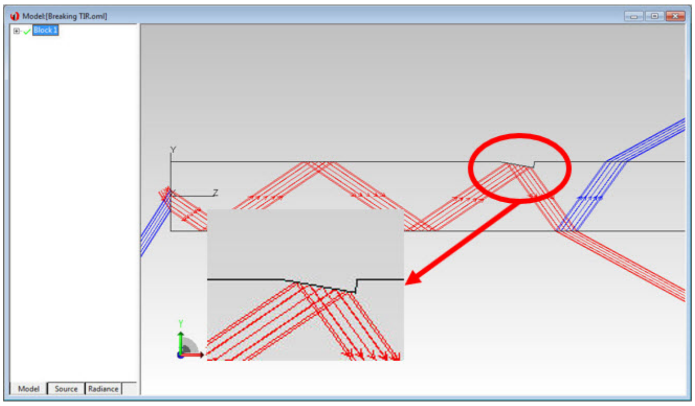

Figure 2: Using a geometric feature to break TIR.

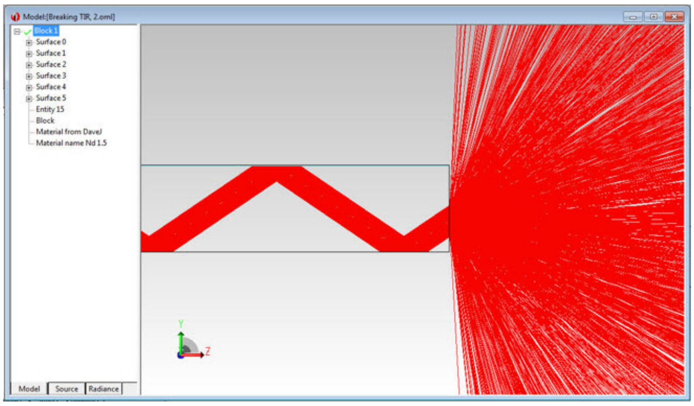

Figure 3: Surface texture used to break TIR.

In applications such as those listed above, how the light guide or display looks to a viewer is extremely important. Qualities such as uniformity, viewing angle, luminance (brightness), and color are extremely important. Optical design and analysis programs like TracePro allow designers and engineers to evaluate these performance parameters in a virtual environment rather than having to make physical prototypes and test them in an optical lab. Most optical design and analysis programs can show the spatial and the angular distribution of light from a light guide. TracePro features the Irradiance/Illuminance Maps and Candela Plots for displaying these parameters. These tools can give the designer some good information on the performance of the light guide, but they may not show the full results. To see the full picture, the ability to see Luminance/Radiance Maps and Photorealistic Rendering is required.

Let's look at an example to illustrate this need. The light guide shown in Figure 4 is a 10mm square profile light with a 90-degree radius bend. The light guide is made of clear polycarbonate. All surfaces are smooth and polished. A three-color, RGB LED was used as the light source.

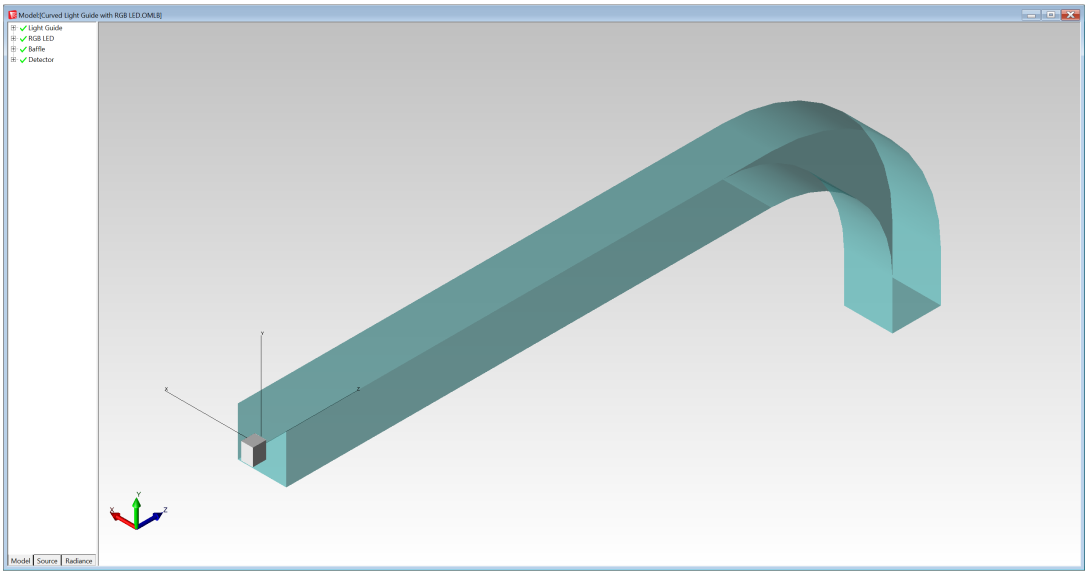

Figure 4: Example light guide.

The first thing we may want to look at is the irradiance or illuminance of the light that exits the light guide. To do this we can add an object to the model to act as a detector or target. This detector is placed just outside the light guide. The reason for this is that we want to make sure we are only "measuring" light that exits the light guide. Some of the light that strikes the end of the light guide may be totally internally reflected back into the light guide and not actually exit the light guide. Figure 5 shows the light guide with the target/detector object. Figure 6 shows the Illuminance Map for this target and Figure 7 shows the Candela Plot or intensity distribution from this light guide. Looking at these two plots, there is not much to suggest that this would not be a good performing light guide for a visual application.

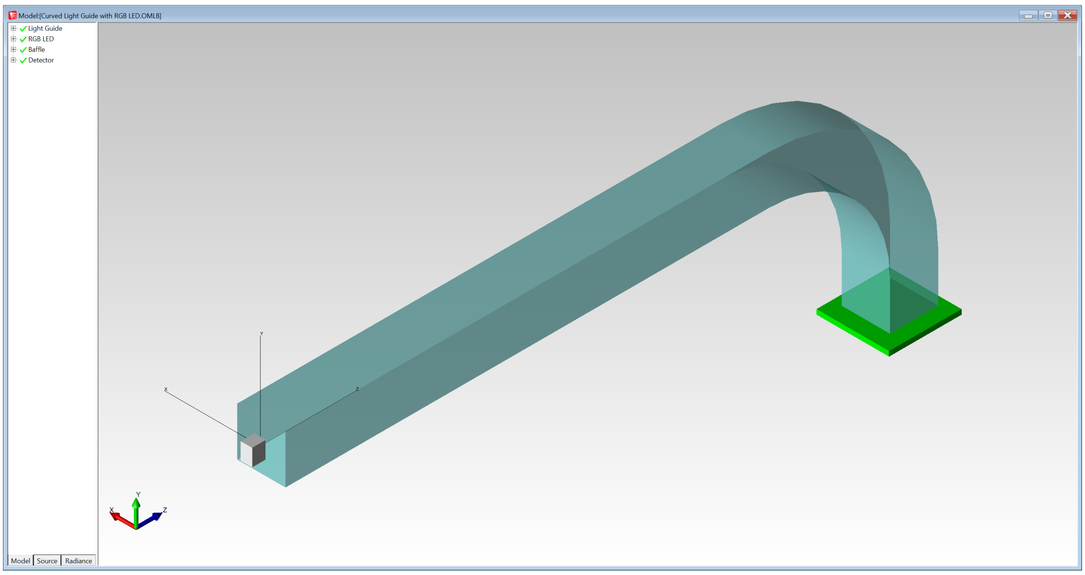

Figure 5: Light guide with target/detector.

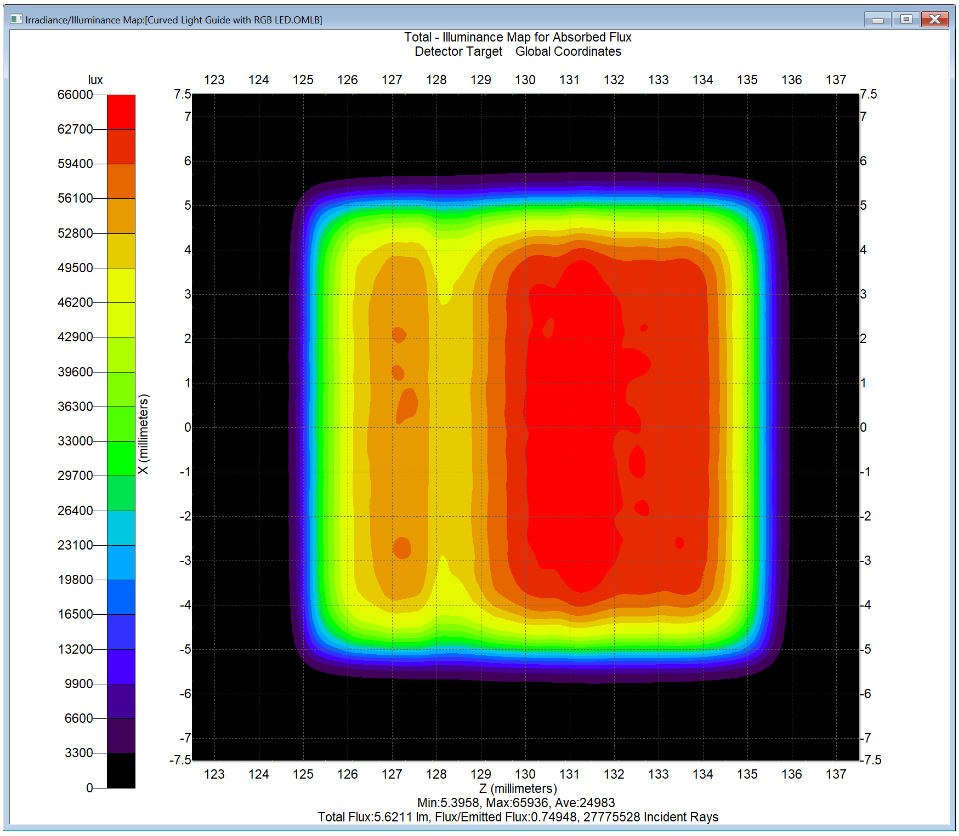

Figure 6: Illuminance Map for light guide output.

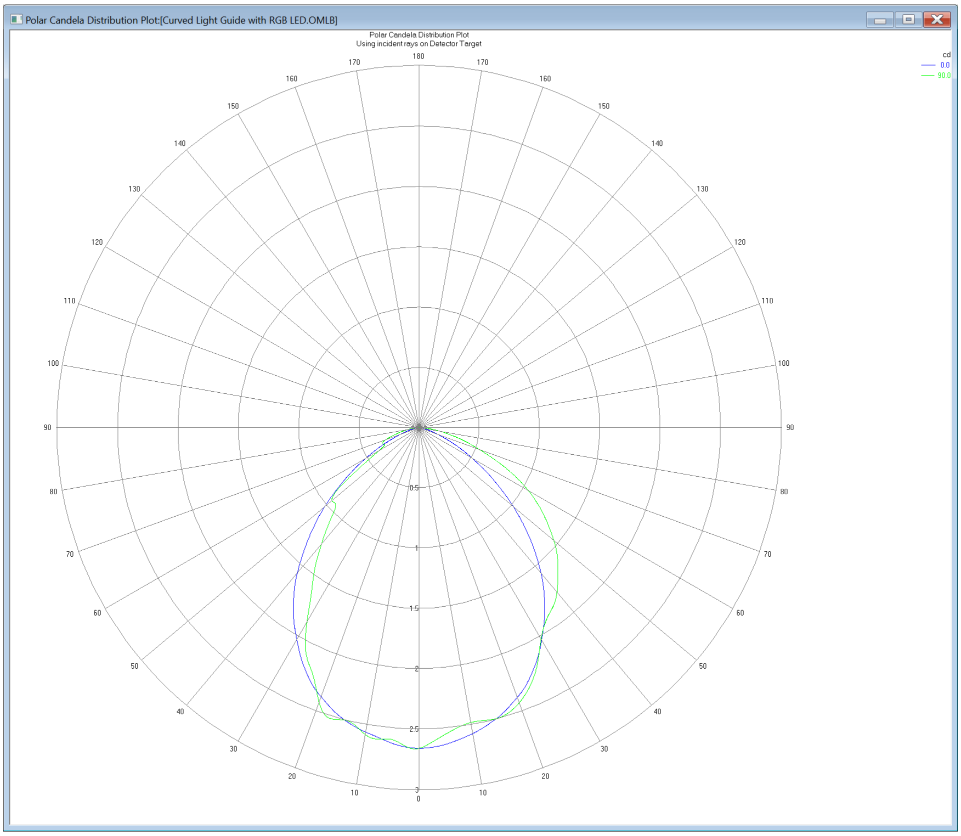

Figure 7: Candela or intensity plot for light guide output.

The Illuminance Maps and Candela Plots are very useful tools, but neither of them tells the whole story of a light guide's performance. The Illuminance Map will show the spatial distribution of the light in units of flux per unit area, such as lumens per square meter, also called lux. This does not consider the angular distribution of the light. The Candela Plot will show the angular distribution of the light, but it will not show the spatial distribution. The solution in this case is to use the Luminance Map.

Luminance is a function of the emitting area of the source and the angular distribution of the light. Luminance is a photometric term, meaning it takes into account the response of the human eye. The equivalent radiometric term is radiance. A typical unit of luminance is cd/m^2, also called a nit. Related to a luminance raytrace is photorealistic rendering. Photorealistic rendering will show the results as they are seen by your eye. This is a great tool for assessing the performance of a light guide or a display. Figure 8 shows the output end of the light guide in TracePro. The model is oriented as it would be viewed. The results of the photorealistic rendering are shown in Figure 9. This shows that the light guide will not perform as we expect. In this case, rather than a nice uniform square of light, we see multiple small "images" of the source LED. This is due to the fact that all surfaces of the light guide are polished and smooth. This is not the result we were hoping for. If we had just used the results of the Illuminance Map and Candela Plots we would not have known this until a physical prototype was produced and tested.

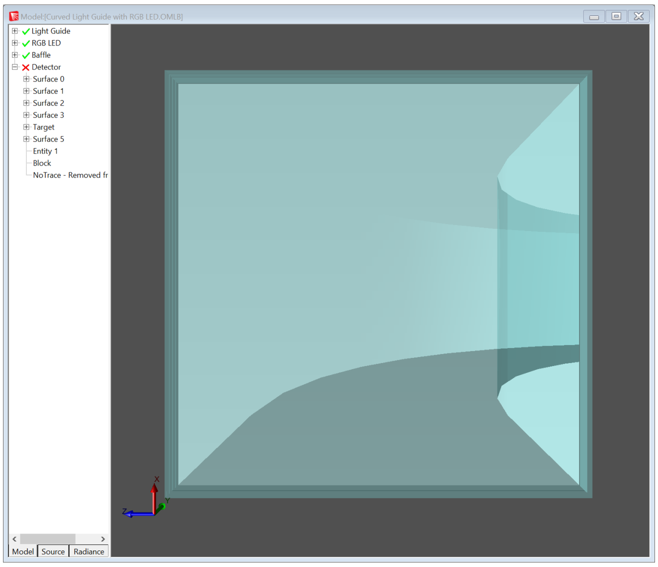

Figure 8: Light guide as oriented in TracePro for photorealistic rendering.

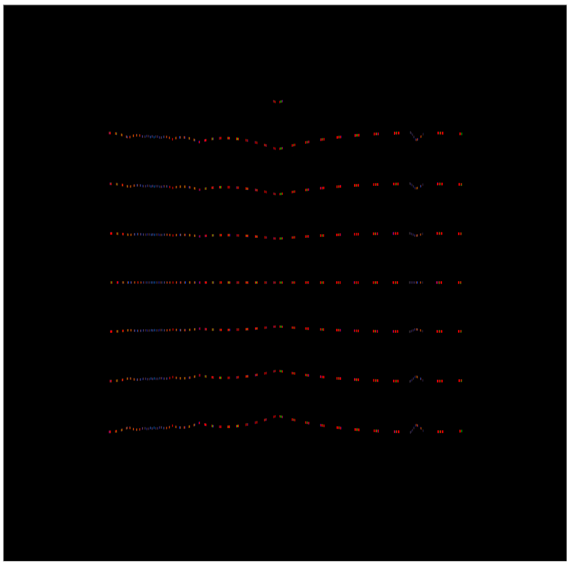

Figure 9: Photorealistic rendering results.

One possible solution in this case is to add a texture, such as a sandblasted or ground glass texture, to the output surface of the light guide. This helps to break the TIR at the output surface as well as homogenize the output spatially and angularly. The photorealistic rendering results are shown in Figure 10. Now we can see a much better-looking result. There is still some structure visible in the image, but it is much improved compared to the initial results. Figure 11 shows the same image but with the plot set to show luminance in nits. The scale in this image is logarithmic. Additional examples of photorealistic rendering are shown in Figures 12 and 13.

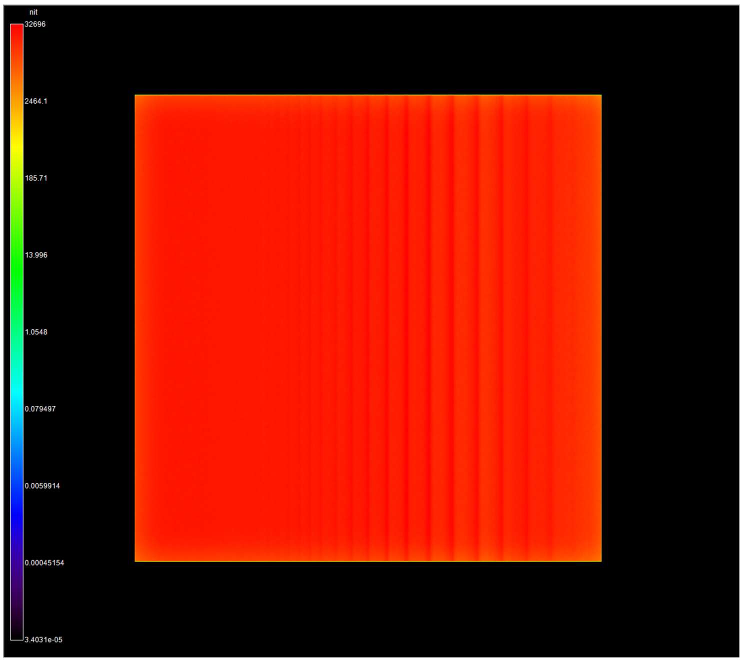

Figure 11: Luminance results with texture added to light guide output.

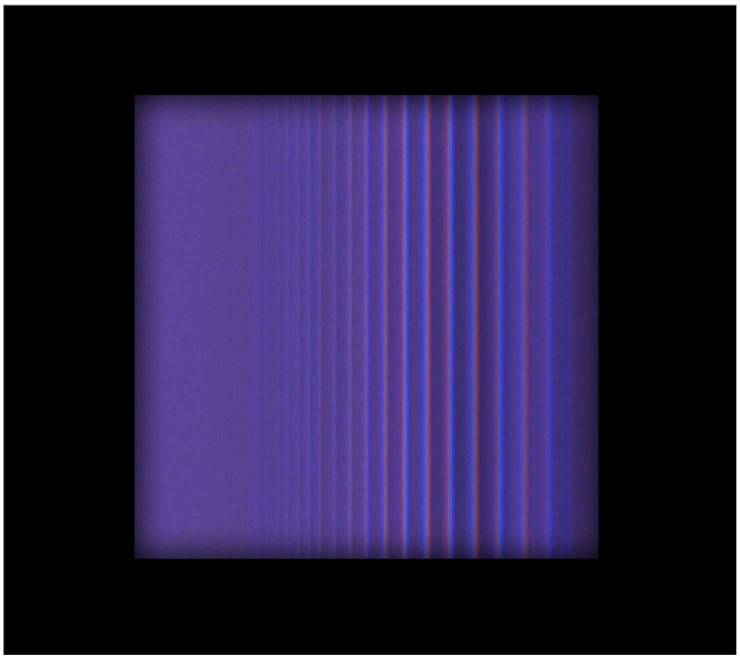

Figure 10: Photorealistic rendering results with texture added to light guide output.

Figure 12: Filament in coated glass bulb. Note reflections of the filament are easily visible.

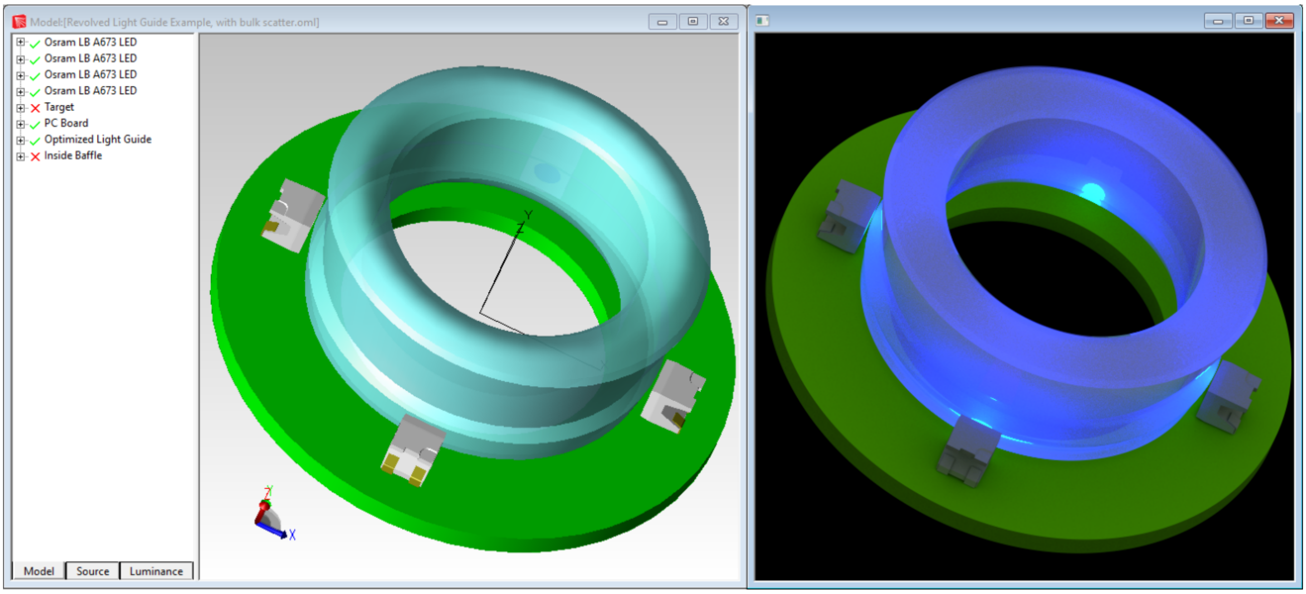

Figure 13: Light guide with diffusing plastic material and blue LEDs.

Photorealistic rendering and luminance maps give the engineer and designer the ability to see how a light guide or display will look to a viewer qualitatively as well as supply quantitative data in units such as nits (cd/m^2). The ability to see this data in the design phase of a project is essential in designing light guides and displays of many types. Not having this capability in optical design software means that engineers and designers may not be able to see the actual results until the design is finished and a physical prototype has been constructed and tested. Being able to use photorealistic rendering and luminance plots saves time and money during the design process and allows for the engineer or designer to produce a better design and ultimately a better product.

Are you looking to take your design skills to the next level? Get a free trial of TracePro at lambdares.com/trial and put those newly acquired skills into practice!