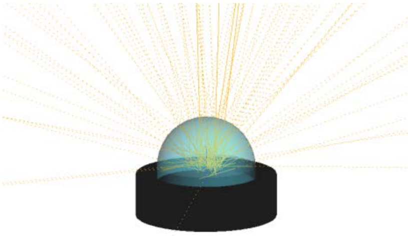
FRED LED Application Note



Introduction

Light Emitting Diodes, or LEDs, have surpassed incandescent light sources in recent years for most applications. Benefits of the LED include compact size, high power efficiency, and a long lifespan[1]. LEDs also have undesirable qualities that optical engineers must address, such as the need for color mixing and collimation. In this application note, we explore three applications of LEDS: a flashlight, a color-mixing lightpipe, and a hybrid collimator lens. FRED enables intuitive modeling and optimization capabilities for these systems.

Example 1: LED Flashlight

The flashlight modeled in this example consists of three white LEDs. The LED geometry is based on the basic LED sample file, which can be found by navigating to C:\Program Files\Photon Engineering\FRED 14.40.1\Resources\Samples\Illumination\sourcesBasicLED. The LEDs are arranged in a triangular configuration. A phosphor-based white light spectrum is assigned to the Wavelength of the Volume emitter source. This is done by creating a new spectrum, and specifiying “Sampled”. Enter spectral irradiance values, upload a data file, or digitize a curve to obtain the spectrum.

The flashlight body is a composite structure consisting of two basic shapes (a rod and a pipe). Create each shape with the correct dimensions and positions, making sure to leave no gaps between the rod and pipe. Then, create a New Element Composite which is a Union of the rod and pipe.

Figure 1. Left: Flashlight model in FRED. This model consists of the body, faceted reflector, and arrangement of three white-light LEDs. Right: Schematic ray trace of the flashlight. Rays reflected by the faceted reflector are shown in red.

To increase optical efficiency, a faceted reflector can be placed just behind the LEDs. This reflector consists of two components: a curve and a surface. Under Geometry, create a new Custom Element. Within the element, create a surface of revolution and a segmented curve. The Segmented curve requires (X,Y,Z) coordinates of each breakpoint. This curve has parabolic shape in the X-Z plane, with Z values proportional to X^2. The segmented curve is assigned as the Generatrix Curve for the surface of revolution. Exact parameters of the segmented reflector curve and surface are shown in Figure 2, along with a schematic of the finished reflector.

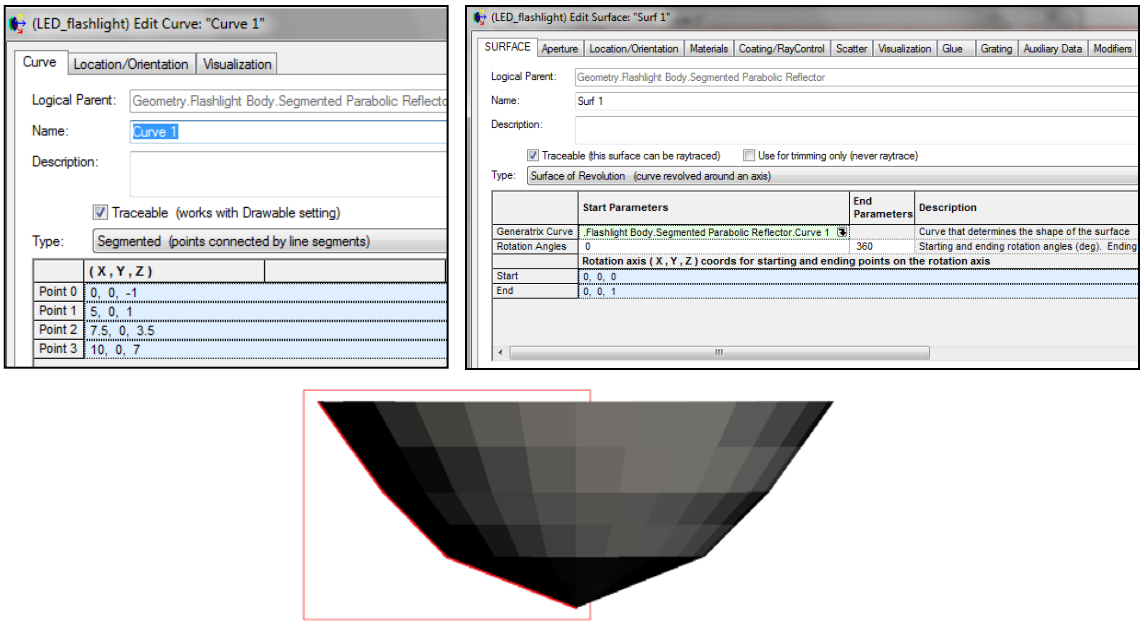


Figure 2. Top Left: Breakpoint coordinates for the segmented curve. Top Right: Parameters for the surface of revolution. Make sure to assign reflective Ray Controls to this surface. Bottom: Faceted reflector modeled in FRED. The segmented curve is shown in red. The bottom of the reflector can be trimmed by reducing the Z value under the Aperture tab of the surface.

Irradiance, intensity, and color image of the flashlight are analyzed at various distances (Figure 3). Collimation of emitted light can be optimized by adjusting the shape of the parabolic faceted reflector.

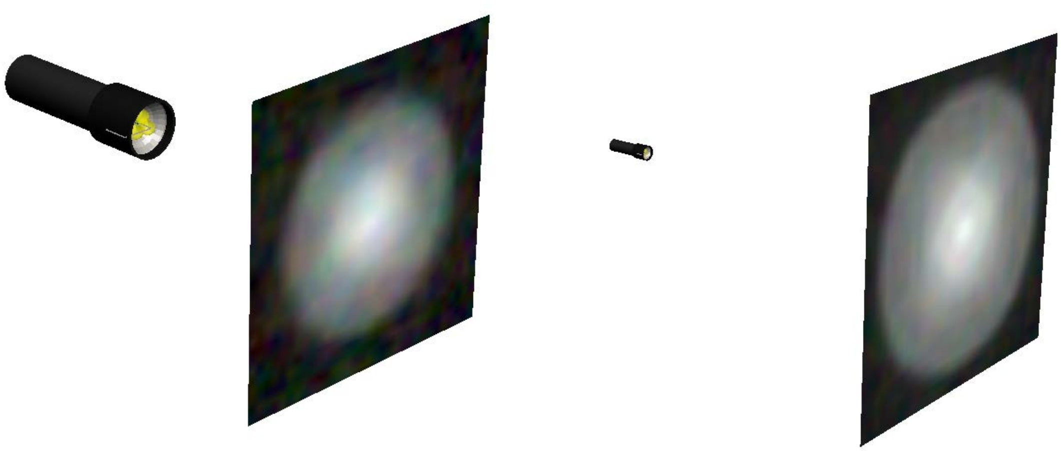


Figure 3. Colorimage from flashlight illumination at two different distances: 0.1 m (left) and 0.5 m (right).

Example 2: Color-Mixing Lightpipe

As shown in the flashlight example, white light can be created using LEDs with a blue emitter and yellow phosphor. Another way to create white light is to mix appropriate proportions of red, green, and blue light. This approach gives more precise control of color temperature. If red, green, and blue LEDs are placed close together, color will eventually mix at a great enough distance. However, irradiance is spread over a much larger area and is not spatially uniform (Figure 4).

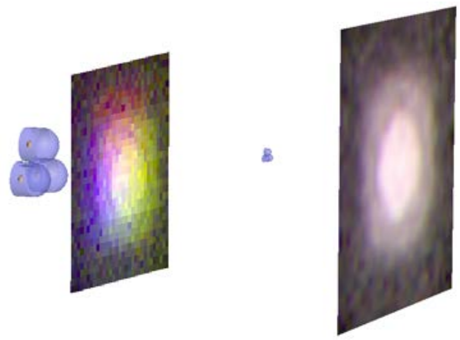


Figure 4. Color image at two distances from the RGB LEDs: 14.5 mm (left) and 100 mm (right). Each LED diameter = 4.79 mm. The Basic LED sample is used to model eacth LED. Equal power levels are assigned, and RGB wavelengths are 632.8 nm, 565 nm, and 455 nm.

To uniformly mix wavelengths within a controlled area, a plastic hexagonal lightpipe can be constructed. The lightpipe is modeled as an Element Boolean. The first component of the Boolean is a rectangular block with dimensions of 14 x 14 x 100 mm (width x height x length). Four more rectangular blocks of the same dimensions are added. These blocks are displaced and rotated such that they trim each corner of the first block into a hexagonal rod. Finally, create an Element Boolian expression to allow the trimming to take place (Figure 5).

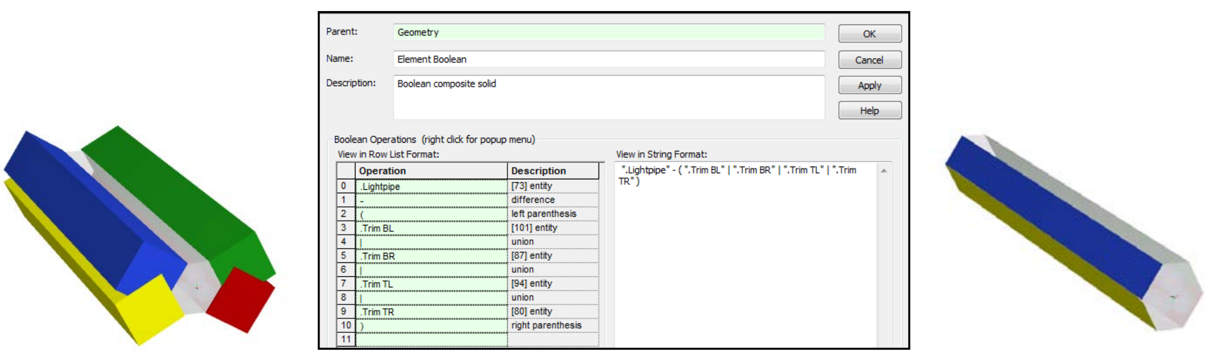


Figure 5. Creation of a hexagonal rod using an Element Boolian function. Left: Rectangular blocks shown before trimming. Center: Boolian operation. Right: Remaining hexagonal rod shape.

An alternative approach to model the lightpipe is to create a custom element consisting of a segmented curve (each point of the hexagon) extruded into a Tabulated Cylinder.

After performing a raytrace of the RGB LEDs through the lightpipe, uniform color mixing occurs. However, color temperature is too warm: red is dominating the color image. Once relative power output amongst LEDs is adjusted, white light is achieved in the color image (Figure 6).

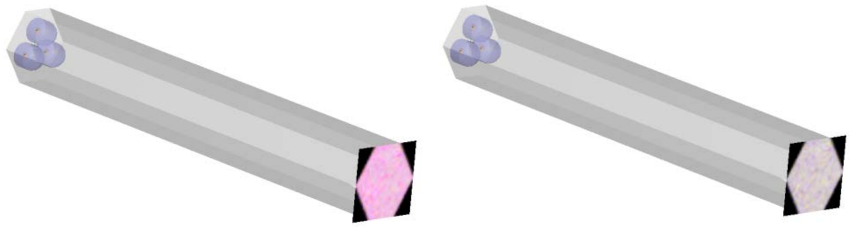


Figure 6. Left: Color image at the end of a 100 mm long hexagonal lightpipe with equal RGB power output. Right: Color image with adjusted RGB power output (0.4 W, 1.0 W, 0.7 W).

Example 3: Hybrid LED Collimator Lens

LEDs emit light over a full hemisphere, but most lighting applications require directional control over light output. A simple positive lens is not fast enough to refract large angles into a collimated beam. To redirect all emitted light, a hybrid refractive/reflective lens can be designed. One example of a hybrid collimator is shown in Figure 7. The central portion consists of a positive axicon to refract rays with small emitted angles. The outer portion has sloped parabolic sides. This region utilizes total internal reflection to redirect rays with large emitted angles.

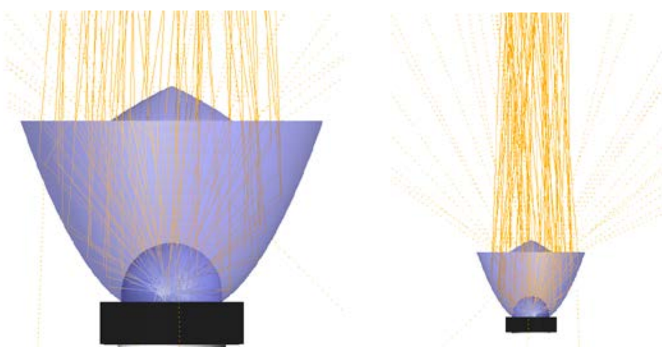


Figure 7. Schematic raytrace of a refractive/reflective collimator lens placed above a LUMILEDS Rebel Amber LED[2].

To evaluate collimating capability of the hybrid lens, intensity is evaluated on a detector plane located 1 m away from the LED. Intensity of +/-50° FWHM occurs without the collimator. After the collimator is added, intensity is reduced significantly to +/-6° FWHM (Figure 8).

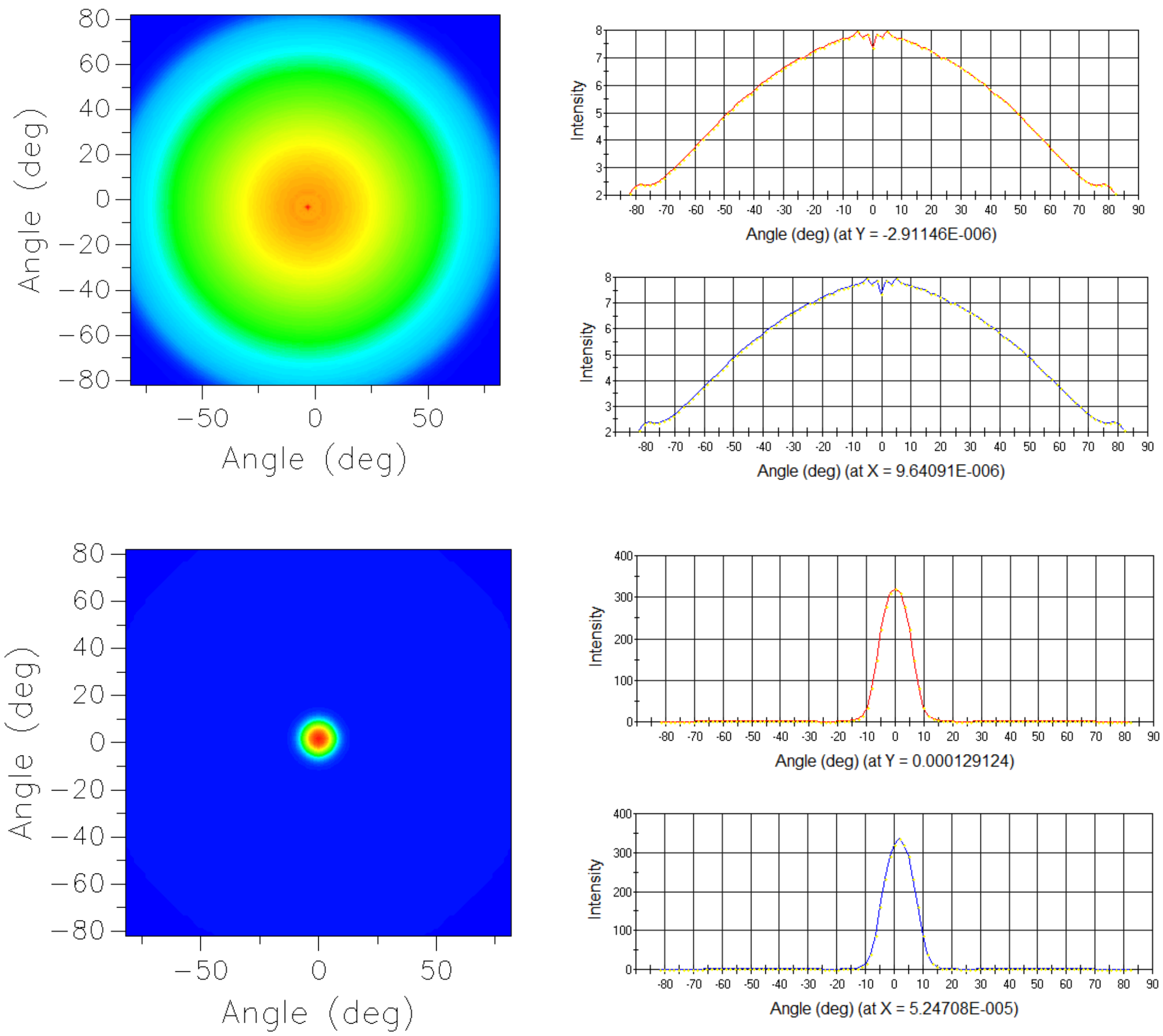


Figure 8. Intensity from LUMILEDS Rebel Amber LED without (top) and with (bottom) hybrid collimating lens.

Conclusions

LEDs are used in numerous applications, from vehicle headlights and traffic lights, to indoor and outdoor lighting, to displays. Each application demands a different performance in terms of intensity and irradiance distribution, color mixing, and uniformity. This application note illustrates just a few of the techniques used by FRED to model, optimize, and simulate LED optical systems.

References:

1. "New Report Explores the Global Industrial and Commercial LED Lighting Market to Be Propelled by Government Prohibition on the Use of Incandescent Lamps." WhaTech. September 28, 2015. Accessed September 29, 2015. https://www.whatech.com/market-research/consumer/97505-global-industrial-and-commercial-led-lighting-market-to-be-propelled-by-government-prohibition-on-the-use-of-incandescent-lamps.
2. "LUXEON Rebel and LUXEON Rebel ES Colors." LUMILEDS. Accessed September 29, 2015. http://www.lumileds.com/products/color-leds/luxeon-rebel-color.

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