WHITE PAPER
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Optimization of LED Lens Components using TracePro® Illumination Design and Analysis Software

Light Emitting Diodes (LEDs) used in lighting products and systems have become a global revolution, leading to significant changes to how designers build lighting into their automotive lighting, industrial lighting, digital signage, flat panel display, and mobile device applications. The advantages of LEDs over traditional light sources include efficiency, durability, lamp life, and the opportunity for sophisticated digital control systems.

In parallel with the increased use of LEDs, advancements in computing power combined with the continuous improvement of illumination systems design and analysis software are stimulating advances in the field of lighting systems design. The result is more sophisticated products, design productivity improvements, and accelerated time-to-market.

TracePro® is award-winning opto-mechanical design software for layout, optimization, and analysis of illumination systems. Recognized for its familiar and intuitive CAD interface, computational accuracy, ray tracing performance, and sophisticated analysis capabilities, TracePro adds 2D (symmetric) and 3D (asymmetric) optimization to the illumination system designer's toolkit.

TracePro optimization utilities improve illumination designs by allowing users to interact with the entire optimization process on a step-by-step basis. In the traditional black box approach to optimization, the designer creates a predefined set of optics, specifies variables and a desired merit function, and then clicks the start button. This often results in a poor and/or non-manufacturable design. The TracePro optimization process is different. It offers an easy-to-use and unique capability to interactively monitor and control the process during optimization.

TracePro's 2D and 3D optimization utilities are specifically designed to help CAD designers without optical engineering expertise to design LED optical components quickly. With TracePro optimization, the user starts with an initial or basic design. Before the iterative optimization process begins, the user validates the initial design with interactive mouse-based ray tracing. This gives the user immediate insight on how to improve the design before starting the iteration process.

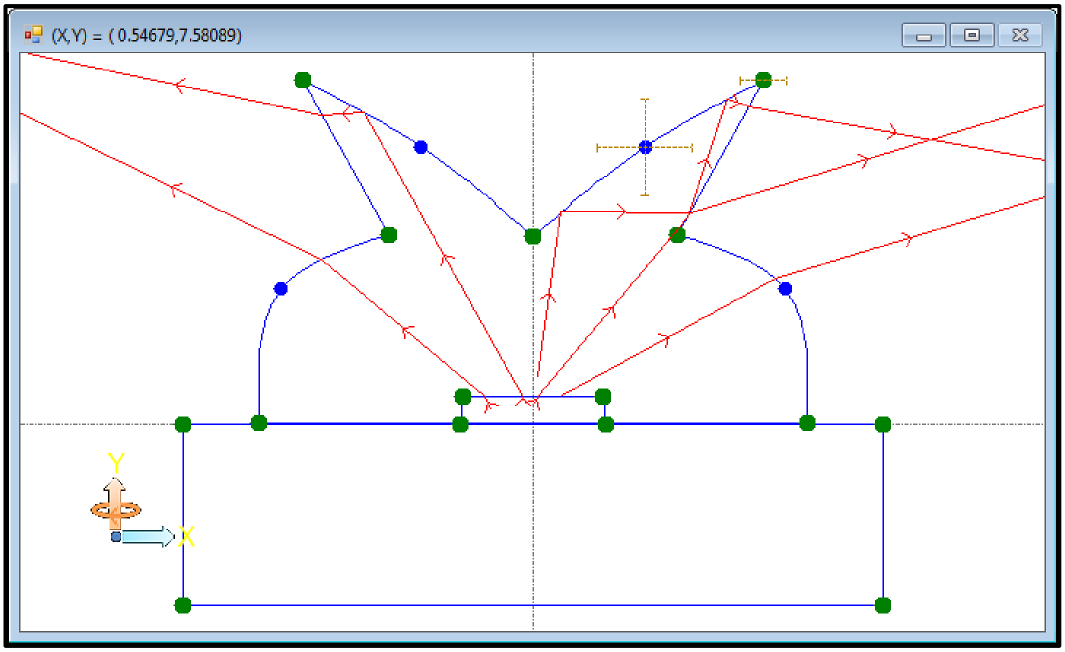

***Figure 1* – Side Emitting LED lens with interactive raytracing showing general light output using the new TracePro 2D interactive optimizer sketch utility. Notice that the variable limits are shown directly in the sketch for verification**

TracePro also allows the user to digitize variable limits directly into the CAD sketch utility so that each variable can be visually checked before and duringoptimization. This also ensures, through visual confirmation, that control and segment variable points do not overlap during the iterative process, which greatly reduces the possibility of creating an unmanufacturable design.

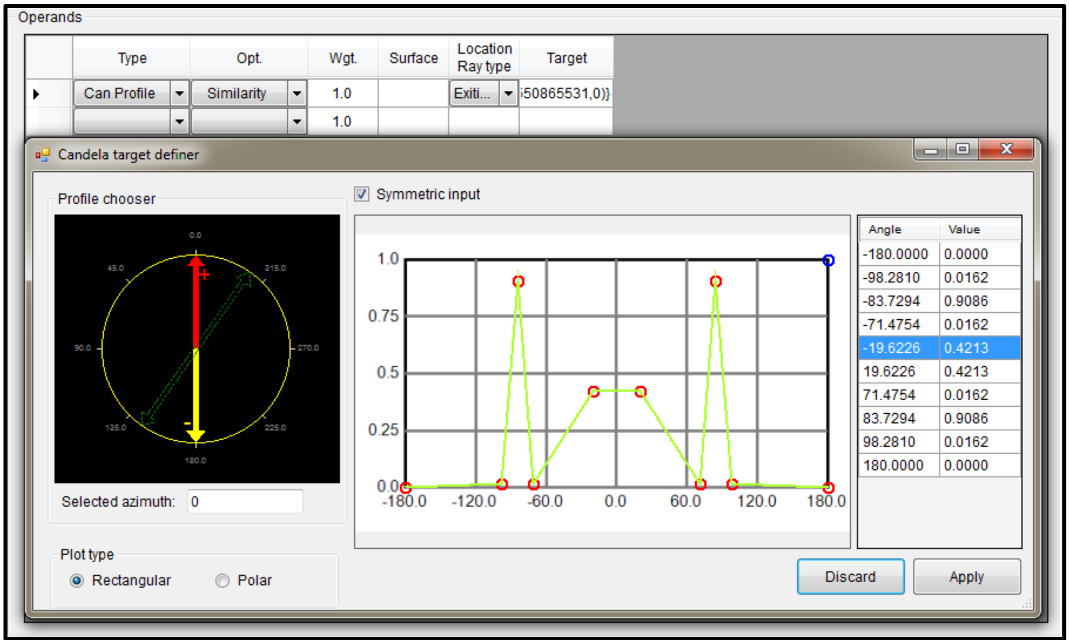

***Figure 2** – Interactive Optimizer Candela Target Definition using Digitization*

At this point, the user establishes desired intensity, irradiance, color and/or uniformity parameters through specification of one or more operand functions. The target or merit function setup process is simple. The optimizer utilities allow the user to directly digitize target points using the mouse to enter uniformity, angle, and color control targets anywhere in the system. Finally, a powerful macro language is used to control the interaction of created geometry using Boolean operations, modify optical property selection for each surface and solid object, and to control positioning of solid objects. Multiple output variables can be visually checked at each step of the iteration process to ensure manufacturability. Data output for each iteration are saved for post-optimization analysis.

Optimization of LED lighting designs has unique challenges compared with traditional lighting. These include:

1. *Smaller and more powerful light sources* – the focusing elements need to follow the same trend and become smaller in size while better facilitating conformity to the required system performance, e.g. light intensity distribution profile.
2. *Etendue* – Narrow-angle LED emission is needed in many display applications. Optics are needed to establish a normal Lambertian emission into narrow angular coupled components.
3. *Color variation* – Needs to be controlled due to LED phosphor shapes and die size limitations.

The display industry illustrates the value of TracePro optimization in product design. The latest trends in cell phones and automotive interior display designs provide unprecedented product differentiation, enhanced safety, smaller footprints, increased energy efficiency, miniaturization, and cost-effectiveness. New LED-based displays offer these benefits, but simultaneously pose new challenges to display designers due to the LED's unique characteristics.

Visualization and simulation of LED systems in TracePro allows users to familiarize themselves with performance of a new light source in a virtual environment. This simulation is a requirement to avoid unnecessary costs associated with expensive fabrication, while also reducing the time to market. Designs created with TracePro typically require only one prototype as compared to old build-and-test design methods which require many prototypes during development. TracePro provides the tools to design faceted and freeform reflectors and lenses utilized in LED applications for display lighting. It also performs an interactive ray trace and provides the tools to analyze the output from display lighting models.

There are four different ways to model an LED source in TracePro.

1. As a grid light source with angular intensity distribution.
2. Through specification of its geometry (e.g., reflector cup and die, encapsulation, lens, and mounting assemblies, including reflection, refraction, and scattering effects).
3. As a Surface Source property in TracePro using the spectrum and angular distribution of the LED.
4. As an extended source using externally acquired photometric data translated to source ray files to provide a high fidelity representation of the LED source, such as those derived from an opsira robogonio or gonio'2π available from Lambda Research Corporation.

The grid light source method is simple, but far less accurate for classical optics design. This method is especially limited in the near field, as the spatial distribution from the LED is not accurately modeled.

The geometry-specification method requires a detailed knowledge of the LED, including material and surface properties that are often not available from LED manufacturers. This method takes into account secondary effects like light blocking and reflection, and is therefore accurate for near-field optical applications.

The surface-source-property method uses a surface in the model as the light source and allows the full definition of the spectrum and angular profiles of the source. TracePro features the Surface Source Property Generator Utility that can quickly and easily create these properties by digitizing graphs of emissivity versus angle and wavelength in an LED datasheet supplied by the manufacturer.

The extended-source method is the most common approach and offers an accurate solution for most LED applications. Ray files for most LED sources are available from manufacturers and can be easily imported into TracePro.

One of the main design challenges with LEDs is the design of a lens and/or a reflector shape that meets a desired lighting pattern.

There are four different surface design concepts in TracePro to fit design requirements of various LED applications:

1. Imaging Lens
2. TIR Lens
3. Hybrid lens concept using both imaging and TIR concept
4. Reflectors

With the Imaging Lens concept, the LED, which is a wide angle emitter, uses an imaging lens to narrow the output beam angle from the usual Lambertian emission to a more collimated emission. Applications that benefit from this concept are light pipe coupling, cell phone display and LED TVs. In this concept, light is coupled into a light pipe or light guide that then funnels the light to the display area. A collimated or narrow angle emission is better to guide the light to areas that are concerned with user visualization of the display.

The TIR Lens concept uses Total Internal Reflection (TIR) rather than refraction to guide the light from the LED.

The Hybrid Lens concept uses a combination of the imaging and Total Internal Reflection principle to send LED light where it's needed. In the example shown in Figure 3, a non-imaging optic in the middle is used to focus the beam and TIR in the outer shape narrows the angular emission.

***Figure 3* – Hybrid design with non-imaging optic to shape emission**

Photo courtesy of: Innovations in Optics, Inc. www.innovationsinoptics.com

The Reflector concept uses reflective material, typically metal or coated glass, with a specified profile to guide and shape the light.

These design concepts can be combined in three different ways for LED applications. Based on the position of lenses and reflectors in the design, LEDs can be used inside a reflector (R), behind a lens (L) and in combination with a lens and a reflector (L+R). As an option, the LED can also have a primary optic situated directly above its emission area. All four techniques, including the addition of the LED primary optic, can be modeled in TracePro.

LED concentrators can be used either to focus LEDs or to achieve a desired mix of colors. There are several display applications (e.g. LED TVs, and large displays) where the light distribution is specified in the far field. There are also applications (e.g. mobile devices, automotive instrument panels, interior reading and lighting lamps) where light distribution is specified in the near field. Each of the techniques described above are selectively used in TracePro, depending on the specific application.

The Reflector with Lens concept allows the greatest flexibility by combining the imaging capability of a lens with the specular capability of a reflector. This combination can be used to eliminate the LED structure from being seen by the user.

Using the side emitting LED from the first figure and coupling this with a reflector as an initial setup, we can let the outer points of the lens vary while the reflector's outer segment points are also allowed to vary. The side emitting lens directs the LED chip emission outward to the reflector. This scrambles the view of the chip outline which can no longer be seen by anyone looking directly at the LED system.

TracePro's interactive optimizer can be used to shape the beam and maximize efficiency. In figure 4, the initial setup is shown with the side emitting lens coupled with a reflector to minimize the angular output while maximizing flux. An illuminance and rectangular candela output are shown to the right of the 3D plot of the system. Next, in the interactive optimizer we set up a merit function using two operands: one to maximize flux, and the second to specify a narrow angular output. After a few iterations (about 5 minutes on a modern PC), the optimizer increased the efficiency by 18% and narrowed the angular output to ±7 degrees as shown in Figure 5.

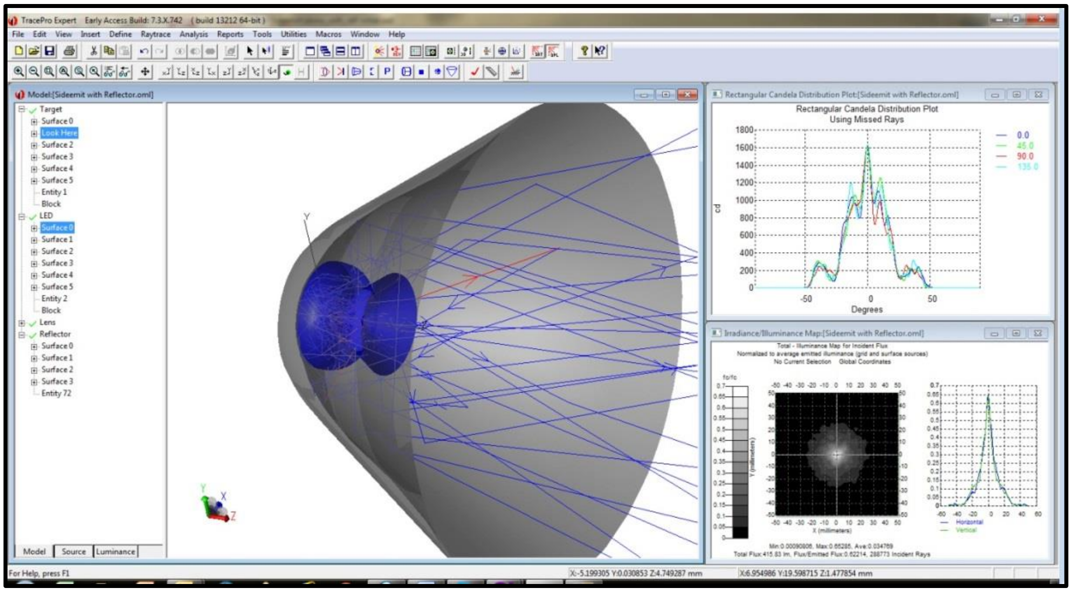

***Figure 4** – Side Emitting lens and reflector combination initial configuration with large angular output and 62% efficiency.*

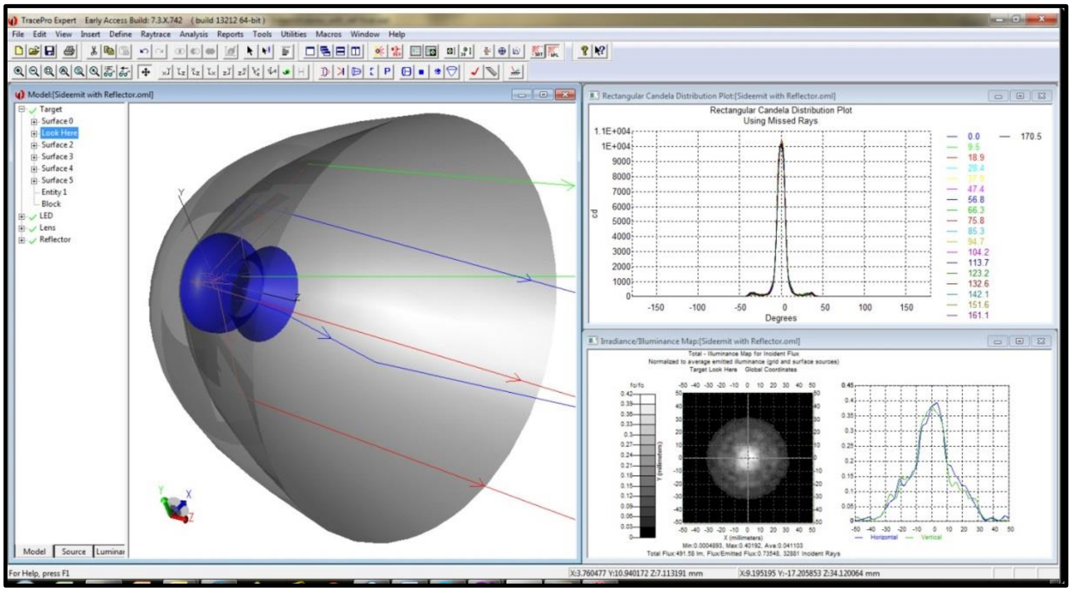

***Figure 5** – After optimization, the angular output shrinks substantially and the combination is now 73.5% efficient.*

Color Optimization

TracePro's interactive optimizers can also be used to optimize LED output color. In some cases the mechanical design of the LED chip and the phosphor emission of the LED die can create a blue inner ring and a yellow outside ring. This problem can be analyzed and removed by modeling the LED package and then optimizing the LED internal structure for uniform color. A second color optimization capability of the optimizer adjusts the position, number, and flux of multicolor LED chips to create either uniformly white output or any desired color pattern using multiple chips. Figure 6 shows the typical color non-uniformity of an LED phosphor observed close to the LED, with the blue inner output and the yellow ring in the outer output area. The image on the right was captured using a cell phone camera with image 10 cm away. The image on the left is a TracePro irradiance map in True Color mode of the same configuration.

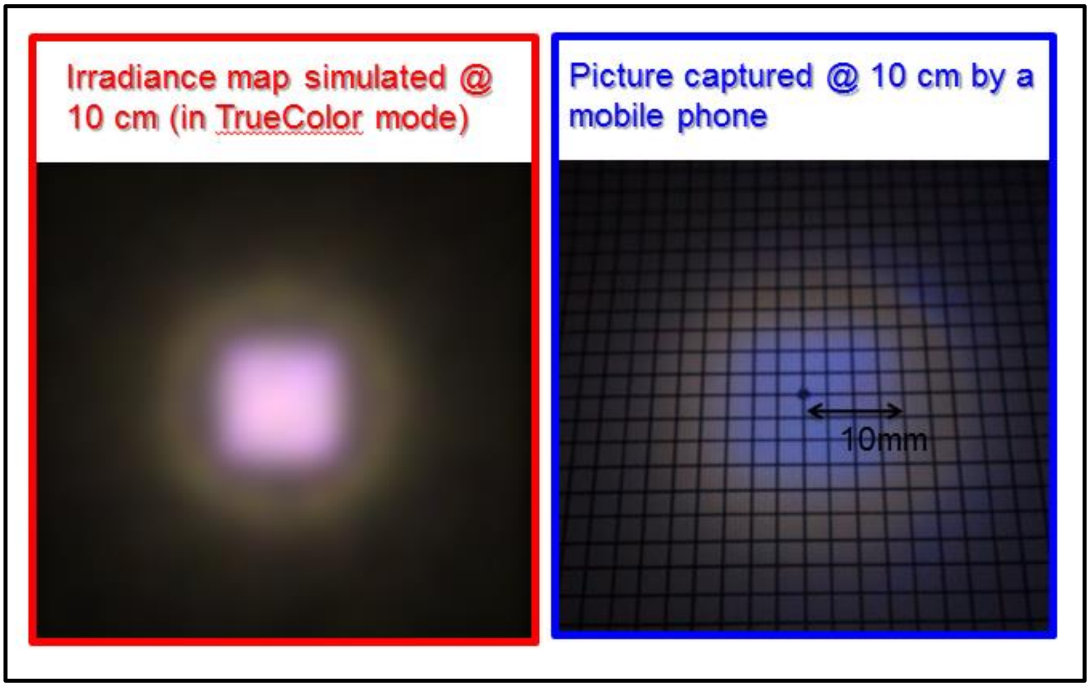

Figure 6 – LED phosphor setup with true color plot shown 10cm away from the LED die and lens

Lit Appearance

TracePro has several ways to visualize how an LED chip, lens, reflector, or combined system emits light, before manufacturing a prototype. The product has both a luminance viewer and a photo-realistic rendering capability to view LED system emission from any eye position around the LED. This capability is vitally important to check for color separation problems and to verify LED light output visually, especially at large angular polar and azimuth angle emission.

Conclusion

Future development of lighting and optical systems will be closely tied to LED technology and enabled with illumination design and analysis software. TracePro's unique 2D and 3D optimization capabilities are suitable for a variety of LED applications, making it an ideal tool for design engineers needing to design LED lighting products and systems. The optimization capabilities of TracePro lead the designer through a process to maximize the technical merits of the device or system in the shortest amount of time. TracePro minimizes the learning curve, decreases new product development cost, and saves valuable engineering time while offering immediate and interactive visual and quantitative feedback to the designer.

About Lambda Research Corporation

Lambda Research Corporation, a privately-held company founded in 1992, is an industry leader in light analysis, illumination system design and analysis, and custom software development. Lambda Research Corporation publishes TracePro®, an award-winning opto-mechanical design software used for designing and analyzing illumination and optical systems. TracePro streamlines the prototyping to manufacturing process by combining an intuitive 3D CAD interface, advanced utilities, and seamless interoperability with other mechanical design programs.

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