WHITE PAPER
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LED Reflector and Lens Simulation using TracePro® Illumination Design and Analysis Software

TracePro® allows users to design, analyze, and optimize LED lighting systems using software simulation prior to building hardware. The resultant accuracy of these models depends on the accuracy of the components that make up the model. These include light source characteristics, surface and material properties, and model geometry.

In parallel with the increased use of LEDs, rapid advancements in reflector and lens design combined with the continuous improvement of illumination systems design software are driving advancements across industries in the field of LED optical 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 advanced reflector and lens simulation 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 reflector and lens simulation utilities are specifically designed to help CAD designers without traditional optical engineering expertise design LED optical components quickly. Using TracePro's simulation utilities, such as the Interactive Optimizer, the user is able to begin a project with an initial or basic design, which can be validated with interactive ray tracing and analysis, to easily create complex reflector shapes.

Optical Analysis or Raytracing with Refraction and Reflection

Optical systems analysis using raytracing involves tracing rays of light through an optical system, and using Snell's Law and the Law of Reflection to determine the path of each individual ray as it interacts with the geometry.

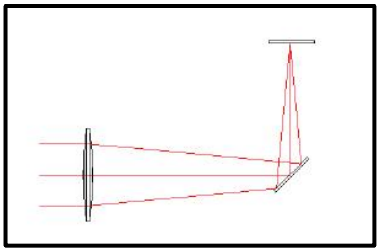

***Figure 1* – Raytrace of a simple lens with refraction and reflection**

More detailed optical analysis can involve scattered transmission and reflection, absorption, bulk scattering, polarization, fluorescence, aperture diffraction, and gradient index properties. These factors can also vary as functions of wavelength, temperature, and incident direction. The more accurately the physical properties of the objects in an optical system are defined, the better the likelihood for obtaining an accurate simulation of the system. This same caveat applies to the light sources used in the model; the more accurately the sources are defined, the more accurate the results.

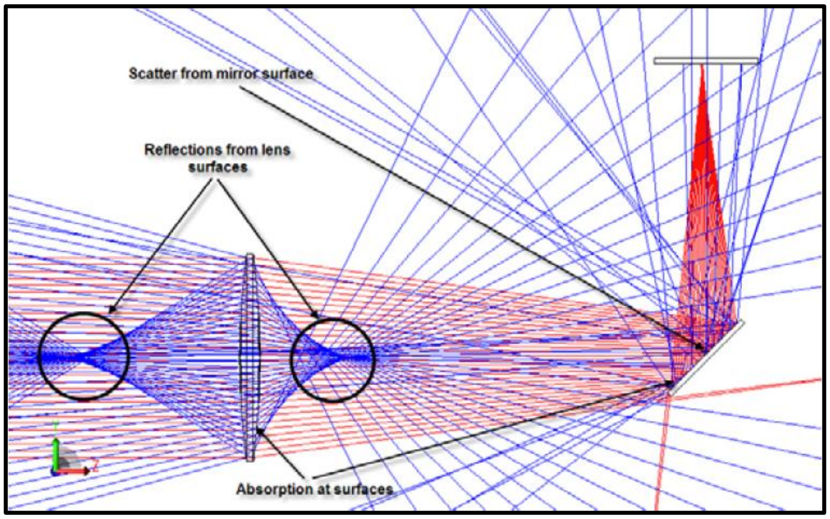

***Figure 2* - Raytrace including reflections and other additional factors**

Light source models can run the gamut from simple to complex. The simplest LED source model is a point source where all rays are emitted from a single point. An expansion of the point source model would be a grid source where a grid of point sources is traced. The grid source can be more representative of the actual LED source being modeled since the extents of the grid can represent the physical size and shape of the actual LED source, though the rays may still be starting from a two-dimensional (2D) plane. Typically point and grid sources can be defined at multiple wavelengths with weighting to simulate the spectral distribution of the source.

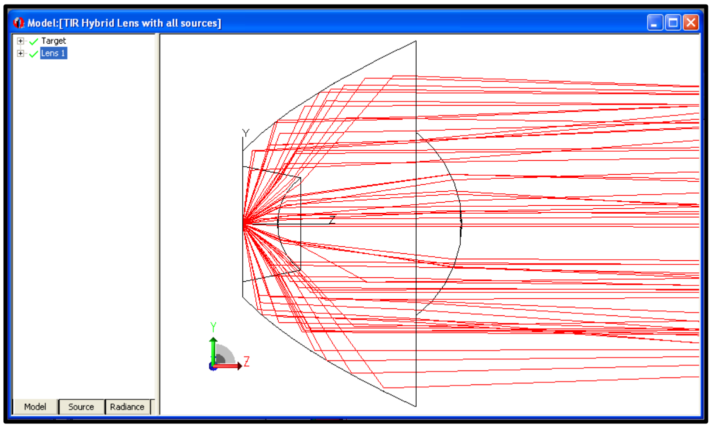

***Figure 3* – TIR hybrid lens with point source**

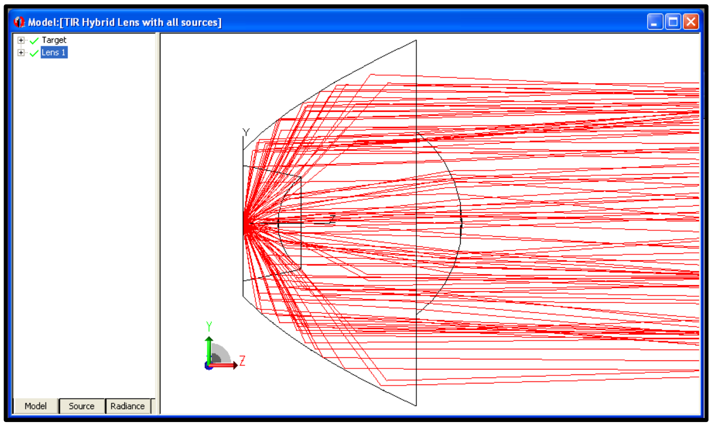

***Figure 4* – TIR hybrid lens with grid source**

The next level of sophistication in LED source representation is a ray file. Ray files, normally produced by the source manufacturer, use measured data about the source acquired using a goniophotometer or similar instrument to create a file containing information about the source light characteristics and distribution represented as a set of rays. Ray files are often available for download from the LED manufacturer. Each ray is represented with a three-dimensional (3D) starting point, direction vector, and luminous flux. Figure 5 shows an example of a portion of a ray file1. Since ray files are based on measured data of complete sources they include the effects of the lamp packaging in the results. One drawback of ray files is that they are typically defined monochromatically.

!! Source file:

TracePro Release: 6 0 2
Data for Block 1 Surface 1
Linear Units in mm
Data generated at 15:51:06 January 20, 2010

X Pos.	Y Pos.	Z Pos.	X Vec.	Y Vec.	Z Vec.	Inc Flux
0.000000000000000e+000	0.000000000000000e+000	4.900000000000000e+001	0.000000000000000e+000	0.000000000000000e+000	1.000000000000000e+000	9.164210624726462e-001
3.241904746004420e-002	0.000000000000000e+000	4.900000000000000e+001	-1.943468304810075e-002	0.000000000000000e+000	9.998111287112282e-001	9.164242320047675e-001
1.620952373002205e-002	2.807571866689163e-002	4.900000000000000e+001	-9.717341524050380e-003	-1.683092923415404e-002	9.998111287112282e-001	9.164242320047675e-001
-1.620952373002205e-002	2.807571866689163e-002	4.900000000000000e+001	9.717341524050373e-003	-1.683092923415404e-002	9.998111287112282e-001	9.164242320047675e-001
-3.241904746004420e-002	1.158548475946197e-016	4.900000000000000e+001	1.943468304810075e-002	0.000000000000000e+000	9.998111287112282e-001	9.164242320047675e-001
-1.620952373002205e-002	-2.807571866689174e-002	4.900000000000000e+001	9.717341524050387e-003	1.683092923415403e-002	9.998111287112282e-001	9.164242320047675e-001
1.620952373002205e-002	-2.807571866689163e-002	4.900000000000000e+001	-9.717341524050380e-003	1.683092923415404e-002	9.998111287112282e-001	9.164242320047675e-001

***Figure 5* – Example of ray file data**

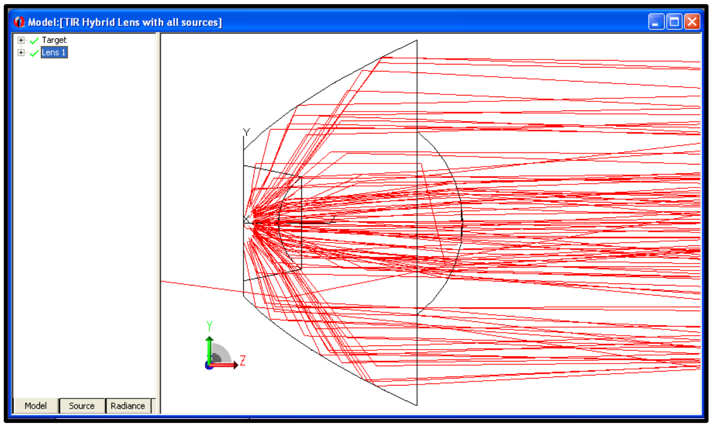

***Figure 6* – TIR hybrid lens with ray file source**

Surface sources can be used in TracePro to model LED light sources. Surface sources are light emitting surfaces that have angular and specular distribution properties. A surface source can be applied to any geometry shape, including flat and curved surfaces. The user can define complex angular distributions, including polar and azimuth angles to model sources with asymmetric angular emission patterns. Spectral properties can also be included in the property to accurately model polychromatic sources.

Surface sources can be combined with 3D solid models of lamp geometry, including material and surface properties for glass, plastic, reflective coatings, paints, diffusers, bandpass and dichroic filters, hot and cold mirror coatings, and surface finishes. Figure 7 shows a Luxeon K2 LED modeled as a surface source using TracePro Bridge, an add-in to SolidWorks.

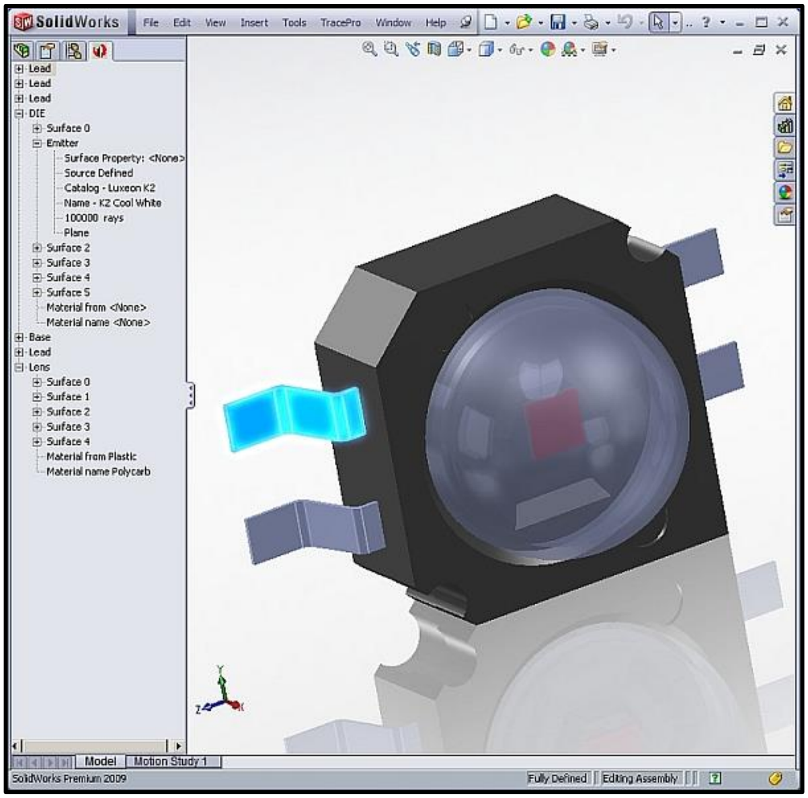

***Figure 7* – Luxeon LED as modeled as a surface source using the Tracepro Bridge in SolidWorks**

Temperature	Wavelength	PolarAngle	AzimuthAngle	Emissivity
300	0.2683	0	0	0.004471306
300	0.2683	3.103	0	0.004462601
300	0.2683	6.207	0	0.004437427
300	0.2683	9.31	0	0.004398287
300	0.2683	12.414	0	0.004348366
300	0.2683	15.517	0	0.00428925
300	0.2683	18.621	0	0.00422081
300	0.2683	21.724	0	0.004141673
300	0.2683	24.828	0	0.004049205
300	0.2683	27.931	0	0.0039418
300	0.2683	31.034	0	0.003820064

***Figure 8* – Example of data from a surface source property**

Putting it all together

After modeling LED sources, users can add lenses and reflectors to represent the complete LED lighting system. TracePro's interactive optimizer utility can be used to create complex reflector shapes as shown in Figure 9. In this case, 11 LEDs as are represented as separate CAD geometry components, each with surface source emitters.

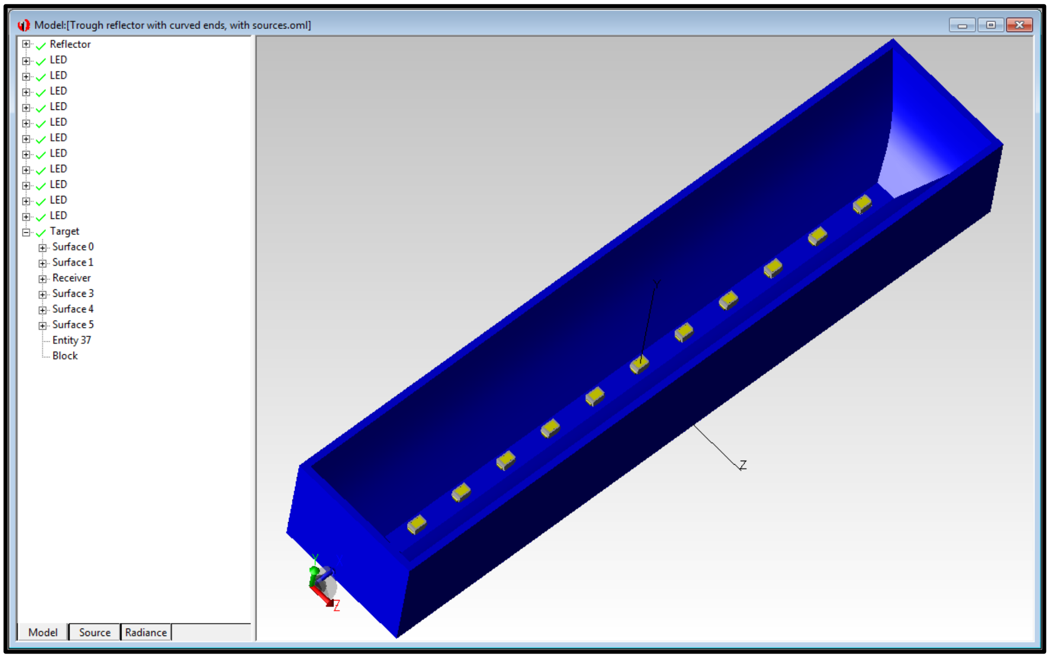

***Figure 9** – Complex reflector with 11 LEDs as modeled in TracePro*

Optimization targets for irradiance and candela are specified in the interactive optimizer to create a specific output pattern. Certain parameters are established as degrees of freedom for the optimizer, thus permitting it to alter reflector shape within certain limits to achieve the desired output pattern. Figure 10 shows the optimized pattern on the target along with the candela plot showing the standard luminaire output.

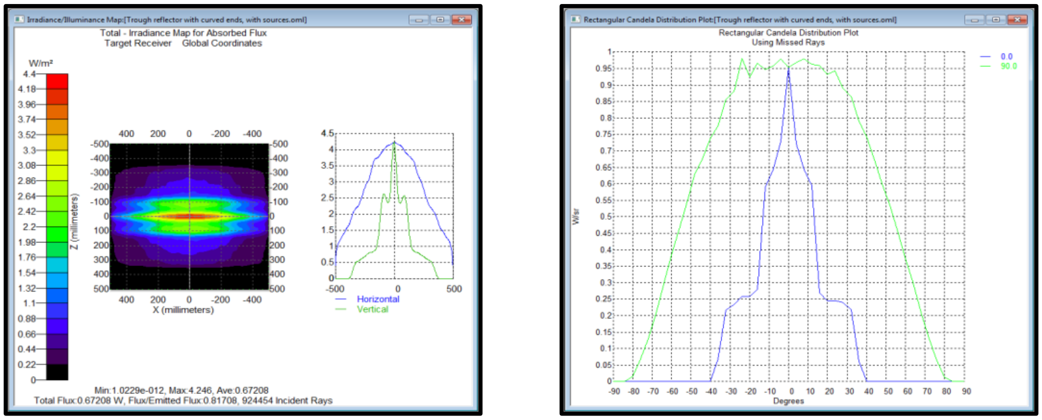

***Figure 10** – Irradiance and Candela output for the Complex reflector with 11 LEDs as simulated in TracePro*

Case Study: Simulating LED Reflectors and Lenses in Street Lamps

More than ever, transportation departments and municipalities are using LEDs for illuminating streets and roadways to save costs and adhere to environmental directives. LED-based streetlamps have several advantages over classic single-lamp systems including:

- Elimination of darks spots between poles – possible because there is more than one light source in the streetlamp providing greater control of the illumination distribution
- Reduction of unwanted light spill – baffling and contoured optics help to minimize up-lighting in cities and areas concerned about urban sky glow
- Better color control – color temperature can be setup as a warm or neutral color between 2700 and 3500 Kelvin for better nighttime visibility when compared to high pressure sodium (HPS), fluorescent, or metal halide systems.

A good example is shown in Figure 11 where the HPS system in Alameda, California is replaced by Leotek's Green Cobra system yielding improvements in both color and uniformity, and resulting in better nighttime visibility.

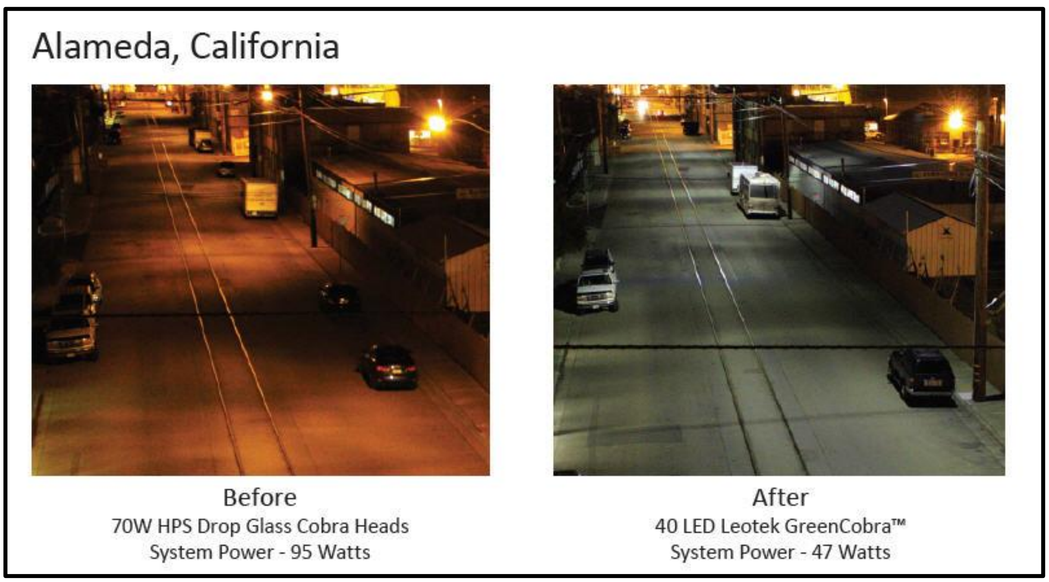

Figure 11

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

When using today's wide angle LEDs, designers are challenged to create optics that put light where it is needed on streets and roadways, to create uniform illumination patterns, and that avoid unwanted light spillover onto sidewalks and nearby properties. In addition, spillover can result in glare and become a hazard to pedestrians and motorists.

The first challenge in LED streetlamp lighting design is to take a wide emitting source and shape the light so that the emitted light is contained in the roadway or street area. There are three choices to control LED angular output: reflectors; lenses; or a hybrid version using both. In the reflector scenario, light is shaped by the reflector to a specific angular pattern. With the lens scenario there are many more options, including simple lenses and hybrid lens options using a combination of total internal reflection (TIR) and refraction on to place light where it is needed. Side emitting scenarios and specific angular targets are also possible. The hybrid scenario can also use both lenses and reflector combinations to provide uniformity across targeted areas. There are tradeoffs with all three of these designs including manufacturing costs, thermal issues, tolerancing, and aging problems.

For a reflector design, the main constraint is incorporating a cost-effective manufacturing process that can be reproduced and assembled quickly. The typical design consists of a printed circuit board with high-powered LEDs in a 2D array and a reflector plate that either snaps or screws into place over the LEDs to provide the beam shaping. The typical reflector system consists of 20 to 100 LEDs and has an average output of 5,000 lumens. These systems are usually not the most efficient and may have uniformity issues that need to be fixed by adding a transparent diffuser below the reflector assembly.

A typical lens system uses lenses placed on top of the LED arrays to produce the angular output needed for the specified uniformity on the street or roadway. Usually TIR lenses with conventional optical features in the center of the lens are used to place light where needed. A typical individual streetlamp lens with rays traced is shown in Figure 12. The LED and lens arrays can be placed in either a planar array or rotated around an axis to send light into zones that overlap to create the best total uniformity on the roadway. Diffusers are also used in this scenario below the LED and lens arrays to create better uniformity and reduce the harsh, direct light from the LED/lens source.

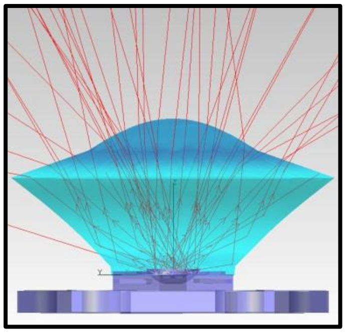

***Figure 12* –TIR lens with rays traced**

The final hybrid scenario can be the most costly since it uses both lenses and reflectors. These systems use reflectors to shape the large angular LED emission pattern and lenses with diffusers on the front of the lenses to create better uniformity, without the harsh LED point source emission. Angled reflector structures provide angular output cutoff to keep the light in the targeted roadway or street area, as shown in the Carclo Technical Plastics design shown in Figure 13.

***Figure 13* – Hybrid Reflector and lens design – courtesy of Carlo Technical Plastics**

The second challenge is to get enough illumination output with acceptable uniformity across the roadway. A singular LED does not provide sufficient illumination, so an array strategy is used. Two possible array options are a linear array where the LEDs and lenses are in a planar pattern and a rotational array where rows of LEDs and lenses are rotated about a central axis. In most cases worldwide, a 3:1 uniformity ratio is best, but many city specifications allow for a 5:1 ratio.

Finally, the glare cutoff pattern and up-lighting standards must be taken into account in the streetlamp design. This is where baffle design must be used to stop light exiting into undesirable roadway regions and also out of motorist and pedestrian sight lines. With TracePro's easy-to-use simulation features, design engineers are able to incorporate accurate baffles to redirect light back into the streetlamp. Then it can be re-reflected to enhance the overall light output, create a softer effect, and when used judicially, lower the number of LEDs needed to meet light output specifications.

Conclusion

LED lighting is having a revolutionary effect on the lighting industry and optical systems in general. The added design flexibility available with LED systems combined with the power, ease of use, and flexibility of TracePro, the future of LED optical systems is bright indeed. TracePro's advanced LED reflector and lens simulation capabilities are suitable for a variety of LED applications, making it an ideal tool for design engineers interested in developing LED lighting products and systems. The optimization capabilities of TracePro lead the designer through a process to maximize the technical merits of the intended result 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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