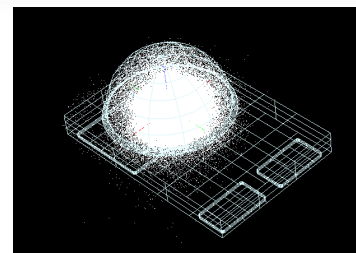# FRED® Application Note
Light Emitting Diodes

> This Application Note describes two methods that can be used to model an LED and highlights useful analysis tools.
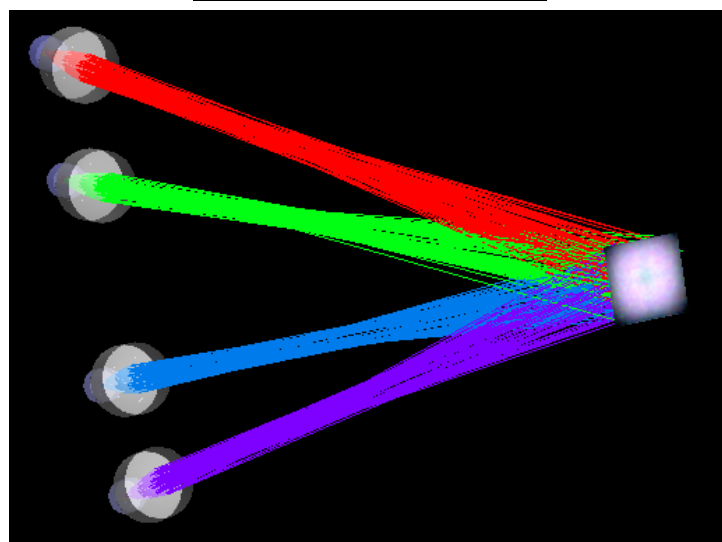
FRED Tools for LED Modeling

✓ **CAD Import**
- FRED imports CAD models in IGES and STEP formats, allowing rapid integration of optical and mechanical components.
- *SomeLED manufacturers who provide CAD files online are Cree, OSRAM, Philips Lumileds, Bridgelux.*

✓ **Ray File Import**
- Ray files can be dynamically loaded into FRED source definitions.
- *Some LED manufacturers who provide ray files online are Cree, OSRAM, Philips Lumileds, Bridgelux.*

✓ **Digitizer**
- Spectral plots from datasheets can be digitized and used to generate source wavelengths.
- Angular distribution plots from datasheets can be digitized and used for source power apodization.
- 2-D Mechanical drawings can be digitized and used to generate precise geometry.

✓ **Intensity on a Polar Grid Calculation**
The angular distribution can be calculated, allowing for comparison with manufacturer's specifications for model verification.

✓ **Color Image**
Accurate color images can be computed and rendered providing not only data for colorimetric calculations (such as RGB values and chromaticity coordinates) but also visual and contextual plots of the color image distribution.

✓ **Visualization View**
Any plot or rendering can be displayed in the 3D view for rapid verification of the model setup or for a visually-appealing presentation of the system.

Contents

Introduction

Light Emitting Diodes (LEDs) are quickly becoming the source of choice for a wide range of fields, including the automotive industry, backlighting and projection, medical instruments, industrial applications, and decorative lighting. There are several distinct approaches to creating LED models, the specific intent of the simulation dictating which is appropriate. Some manufacturers such as Cree, OSRAM, Philips Lumileds, and Bridgelux post raysets in various formats on their websites, which are available for download. These ray files contain (at minimum) ray positions and directions and can be directly imported into **FRED**. Additionally, software tools such as ProSource, from Radiant Imaging, can be used to generate raysets from measured data. Use of these rayfiles is one method for modeling the light distribution of an LED. A second method is to encode the angular distribution of an LED, typically printed in its technical datasheet, as a power apodization.

There are two regimes for LED emission modeling: the near-field and the far-field. The near-field describes rays close to the emitter, which typically have a unique spatially structured distribution. In the far-field, the emitter is approximated as a directional point source and the rays obey a stable, predictable pattern. There is no precise definition of the start of the far-field regime; it depends on variety of factors such as the emitter size and shape and encapsulating lens parameters. Rule of thumb values for the beginning of the far-field cited in the literature include 5 to 15 times the source size and 10 cm from the emitter. For far-field applications, using a rayset and using the angular distribution are of similar validity. In cases where the near-field pattern of an LED is relevant to a simulation, a completely accurate model must consist of a high fidelity construct of the internal LED geometry, including proper assignment of optical properties to all the elements. Constructing such an extensive model is a costly, time-consuming effort which is neither necessary nor practical in most cases. Oftentimes an approximate model of a few key internal structures is sufficient to generate an appropriate near-field representation. Good awareness of the type and level of detail required is therefore key to a smart and successful model. The two LED modeling procedures described in this Application Note provide a good starting point and the user is encouraged to add more detail and precision where required for the specific design and application.

Practical Example in **FRED**: Modeling an LED

An increasing number of LED manufacturers offer CAD models and ray files on their websites (Cree, OSRAM, Philips Lumileds, Bridgelux). The first method describes importing and modeling an LED using CAD geometry and a ray files. The second method describes modeling an LED using only datasheet specifications. Philips Lumileds Amber LUXEON Rebel Color, part number LXML-PL01-0030, is used throughout this example.

Method 1: CAD geometry and ray file

1. Import CAD geometry

   FRED's *CAD Import* makes it simple to import any STEP or IGES file. The *CAD Import* dialog includes options such as randomizing unassigned colors to surfaces and curves, creating and drawing independent curves, displaying the model as shaded surfaces or a wire frame, and assigning default raytrace control sets. Figure 1 shows the imported CAD geometry of the LUXEON Rebel LED in wire-frame. Note that the CAD geometry is

set as "non-traceable," meaning that it will not be used in the raytrace. It serves as a reference for correctly positioning the LED model relative to other elements in the system.
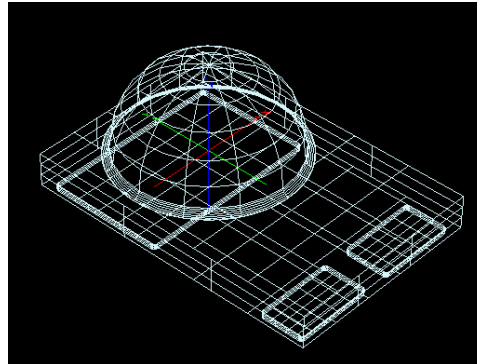

Figure 1. CAD model of a LUXEON Rebel LED imported into FRED, displayed in wire-frame.

2. Import ray file

A ray file can be directly loaded into the "Positions/Directions" specification of a *Detailed Source*, as shown in Figure 2. Supported ray file formats in FRED: FRED compact rayset (*.fcr); ASAP distribution file (*.dis); ProSource binary format which supports files from Zemax, OPTICAD, and TracePro; ASCII/Text which supports LightTools and TracePro formats; LucidShape binary file. FRED allows the user to specify whether to use all the rays in the ray file or a user-specified subset. Clearly, the more rays used, the more accurate the model. However, a balance between speed and ray count must be found. It is often desirable to test the model with a smaller subset of rays before doing the full raytrace with a large number of rays.
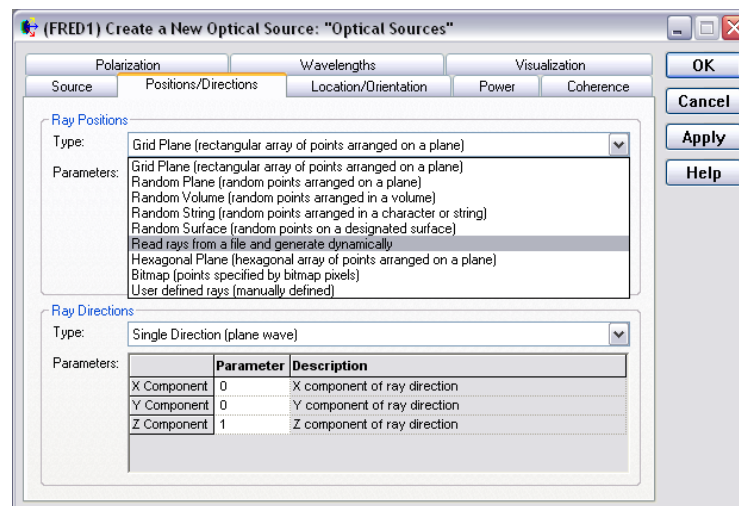

Figure 2. Detailed optical source dialog showing option to import a ray file.

3. Set the correct power and units

Depending on the format of the imported ray file, FRED may read in and assign a power value to the LED source and display a pop-up window showing the power setting. The LED datasheet should be consulted to verify this value because manufacturers often provide a single ray file for LEDs of different powers. If no

power is included in the ray file, a default value of 1 is used. The source power can be entered in the *Power* tab of the *Detailed Source* dialog. **FRED** offers the choice of specifying power in Watts, Lumens or arbitrary units. Figure 3 shows the LED model with the newly defined source rays drawn in white.
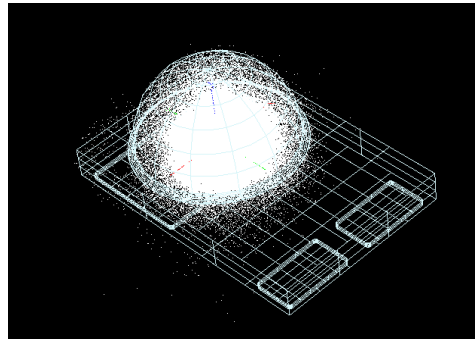

Figure 3. LED model with rays imported from ray file.

4. Digitize spectrum

FRED has an easy-to-use digitization tool which can be used to extract spectrum data points from a plot in BMP or JPEG format, as shown in Figure 4. The digitized spectrum can then be assigned to the source. Every **FRED** document has a folder specifically for creating, managing, and plotting spectra. Spectra can be specified as Gaussian, blackbody, or sampled. The sampled spectrum type is the proper choice for a digitized spectrum.
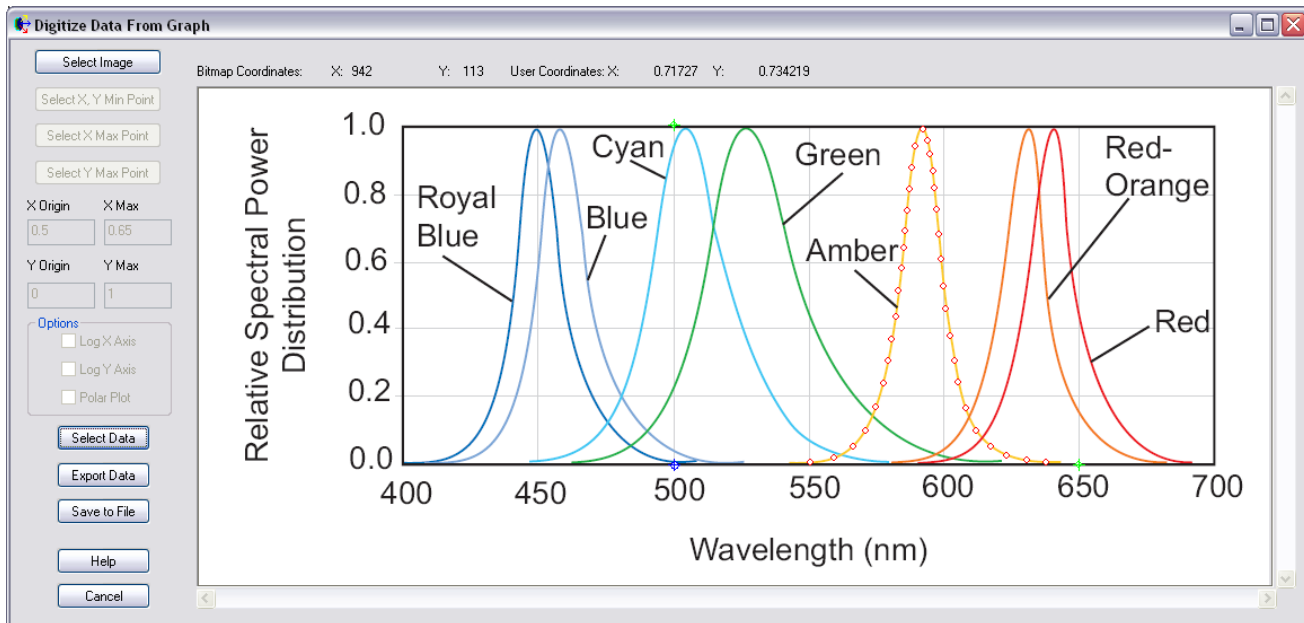

Figure 4. Digitization of Amber LUXEON LED spectrum based on the spectral power distribution plot from the datasheet.

5. Verify model

FRED's *Intensity on a Polar Grid* calculation can be used to verify the LED model by comparing the result to the angular distribution plot provided on the datasheet. A special FRED construct called a *Directional Analysis Entity* is used for the analysis. The DAE is designed exclusively for ray filtering, computation, and display of Intensity data on a spherical polar grid. Figure 5 shows good agreement between the published Lumileds LUXEON Rebel angular distribution plot (left) and the corresponding FRED model distribution (right).
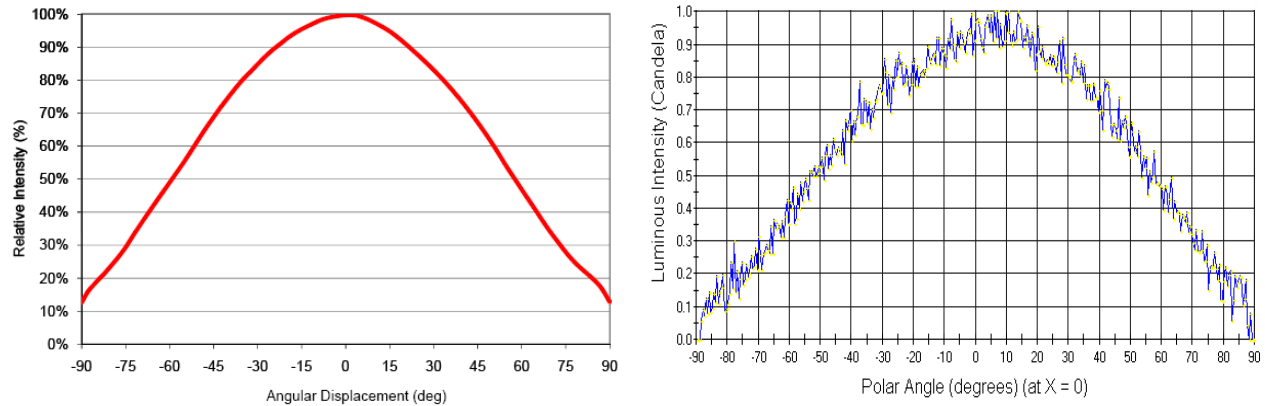

Figure 5. Angular distribution of LUXEON Rebel LED, (left) published manufacturer plot and (right) FRED model plot.

Method 2: Datasheet only

1. Create source

A new *Detailed Source* is created with the ray positions set as "Random Pane (random points arranged on a plane)" to avoid artifacts that arise from structure in the rays. The desired number of rays is input and the ray direction is specified as "Random directions into an angular range" using an *Isotropic* angular distribution. An angular distribution plot will be used to define the ray directions (Step 4); setting the distribution as *Isotropic* ensures that a secondary internal apodization is not applied. Angular distribution plots represent far-field radiation patterns, so a small ray grid should be used (recall that in the far-field the emitter is approximated as a directional point source).

2. Set correct power and digitize spectrum

Follow Steps 3 and 4 described in Method 1 above.

3. Digitize angular distribution as a power apodization

Just as a digitized spectrum can be assigned to the source, a digitized angular distribution can be assigned to the *Directional Power Apodization* to model the angular spread of the LED. Both linear and polar plots can be digitized. Figure 6 shows the digitization of a polar apodization plot. The simple LED model is complete after this step.
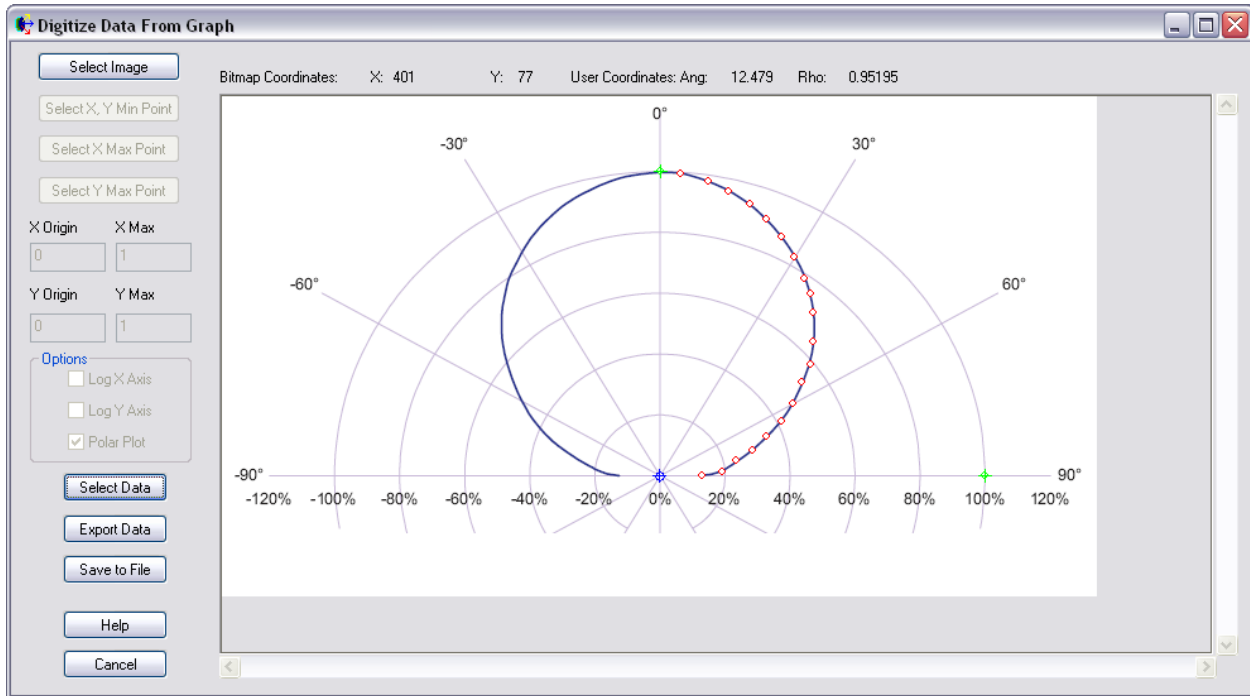
Figure 6. Digitization of Amber LUXEON LED angular distribution based on the polar plot from the datasheet.

Comparison of the two methods

The two methods outlined above are compared by calculating the irradiance distribution on a plane located at multiple distances from the LED model, as shown in Figure 7. Both models were simulated with 5,000,000 rays. The distributions look very similar, the main difference being that the ray file model has a lower irradiance. Small variations such as these are expected, as the models are using different raysets. Note that even 2 mm from the source, which falls in the near-field region, the irradiance distributions are very similar.
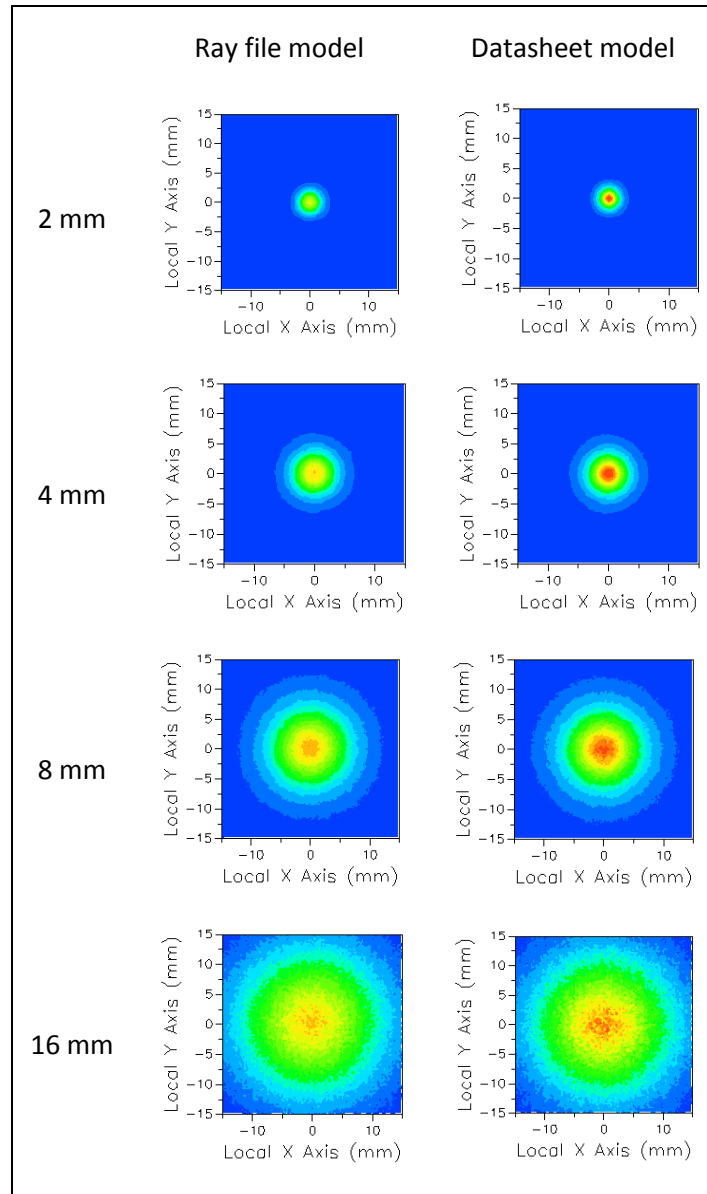
Figure 7. Irradiance distributions of the two LED models at 2, 4, 8, and 16 mm from the source. 5M rays were used in the simulations. The two plots at each distance are on the same scale.

Focus on a FRED Tool: Color Image

FRED has an analysis tool, *Color Image*, for color visualization and colorimetric calculations. For example, multiple wavelengths with different weights can be combined and the corresponding color synthesized. Figure 8 shows four LEDs of different colors passing through collimating lenses and illuminating a screen. The rendered *Color Image* is displayed on the screen in the 3D View. Any analysis plot can be displayed in the 3D View using FRED's *Visualization View* feature. Figure 9 shows the full *Color Image* calculation result window.
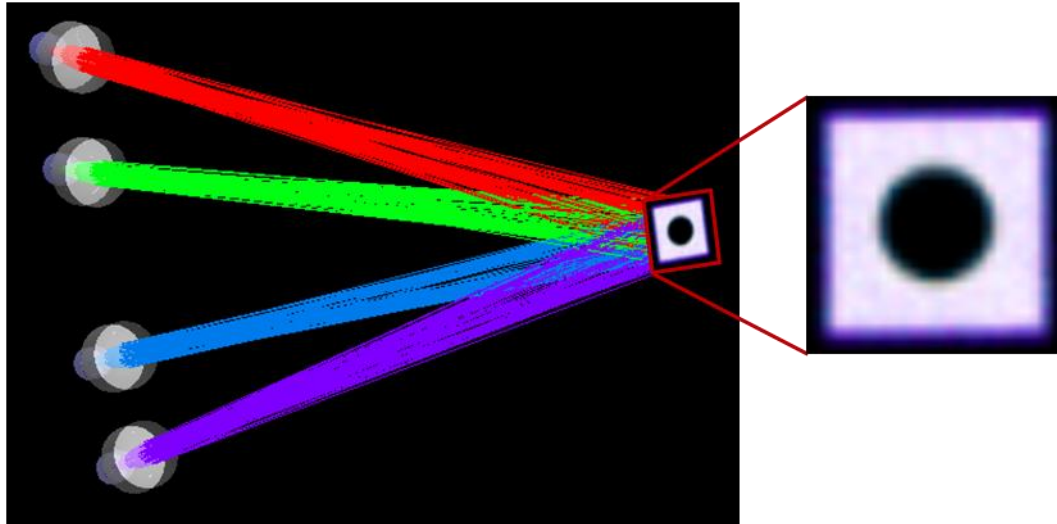
Figure 8. Four single-wavelength LEDs passing through collimating lenses and combining on a screen. The color image resulting from mixing the four LEDs is rendered by the Color Image analysis and displayed in the 3D View via the Visualization View feature.
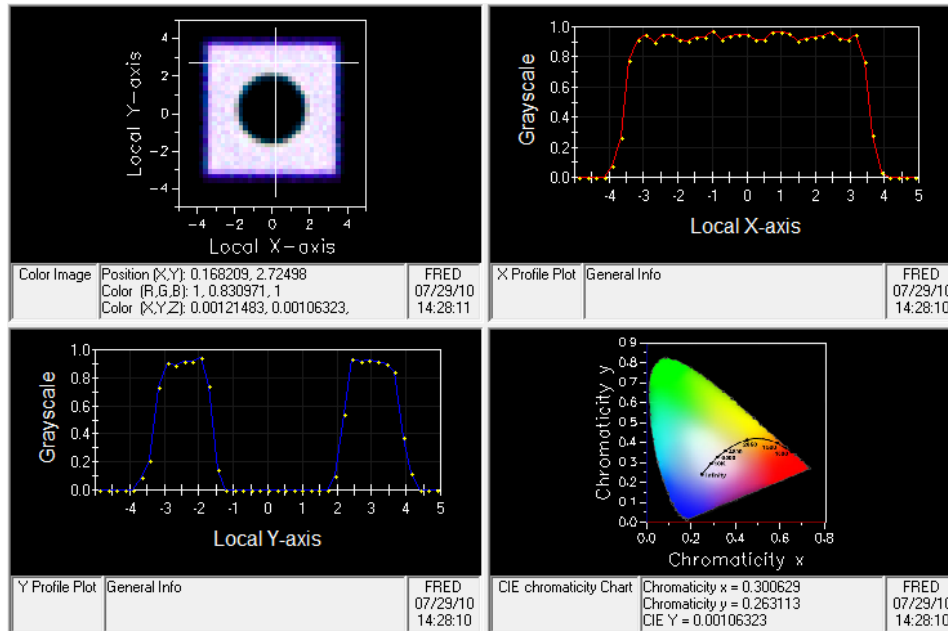

Figure 9. Color Image analysis result window showing 4 panes (top-left to bottom-right): Rendering of the color image with RGB values; grayscale x cross-section; grayscale y cross-section; chromaticity chart with chromaticity coordinates.

The color rendering in Figure 9 has a defined structure. The LEDs are modeled as cubic die emitters with a circular bonding pad in the center. This is an example of modeling a few key internal structure elements to represent a relevant aspect of the near-field pattern. The collimating lenses are placed with the emitter at the front focal point, which provides good collimation but also images the emitter's structure into the far-field, as seen on the screen. If such an effect is undesirable, as is most often the case, there are two solutions: shifting the lens or using non-imaging optics. Moving the lens a little further from the LED shifts the focus from the emitter and the structure disappears, as shown in Figure 10. The beams are more divergent, but only slightly so.

Non-imaging optics such as a concentrator or reflector can also be used to direct the rays without creating unwanted structures.
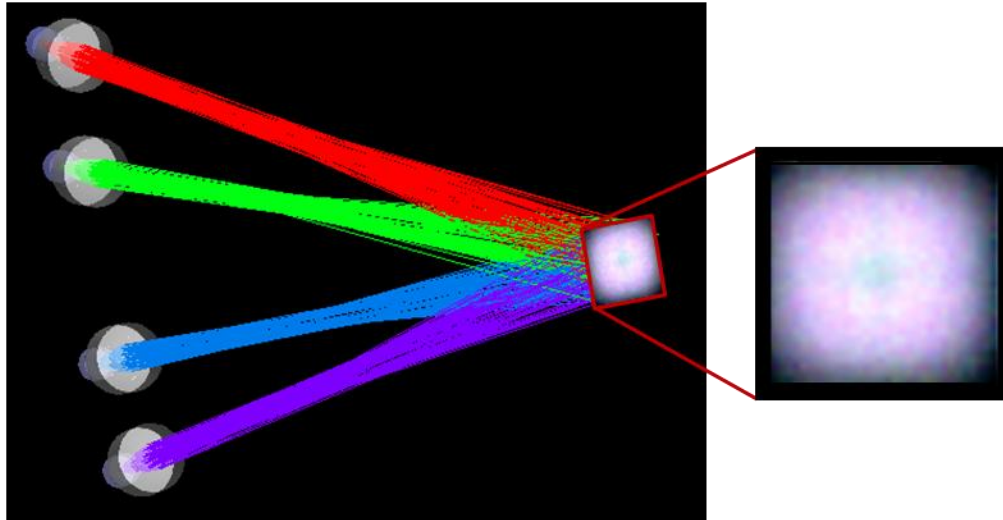
Figure 10. Color rendering with lenses shifted slightly away from the LEDs to eliminate the emitter structure seen in Figure 8.

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