

# Color Design and Analysis in LightTools

## Using Colorimetric Data to Achieve High-Fidelity Lighting Systems

### Features at a Glance

- Fully integrated optimization capability that allows color metrics to be merit function items
- True color plots; including true color illuminance in the 3D model view
- Materials, surfaces, and diffusers modeled with spectral dependence
- Dispersive and non-dispersive ray trace modes
- Color support for ray files using spectra or tristimulus values
- CIE u'v' color coordinates and backward ray trace test points
- Spectral source distributions: built-in blackbody, Gaussian spectra, and user defined
- Color triangle plot
- Color difference plots
- Color rendering index
- Color quality scale and gamut area index
- Photorealistic rendering for visually communicating the effects of color to others

### Overview

LightTools® has a comprehensive suite of tools for accurately and efficiently simulating chromatic effects in an optical system. Additionally, LightTools allows you to optimize your system using color metrics in your merit function to achieve the best possible chromatic performance. You can fine tune your simulations, sources, and receivers to maximize efficiency, minimize statistical noise, and get the most out of your design time. LightTools includes a full range of analysis and charting options, as well as a powerful photorealistic rendering capability that can accurately depict lit sources in your model.

In the following sections, some of LightTools' many color features are discussed in more detail.

### Charting and Analysis Options

#### Spectral Analysis, CRI, CQS, and GAI

Among LightTools' color analysis options, you will find spectral analysis and calculation of the Color Rendering Index (CRI) with the values for each of the eight standard color swatches (TCS1-TCS8) as well as the seven additional color swatches (TCS9-TCS15) used to test more vivid colors and skin tones. The chromaticity distance (distance from the blackbody curve) is also calculated. In addition, LightTools includes the newer Color Quality Scale (CQS) and Gamut Area Index (GAI) metrics. CQS is similar to CRI, but instead uses 15 saturated colors and helps to address shortcomings of the CRI standard, especially for commercial applications and when measuring the color rendering effectiveness of solid-state lighting. GAI measures the overall color area encompassed by a source, making use of the CRI swatches in CIE u'v' color space. The CQS colors and chart are shown in Figure 1.

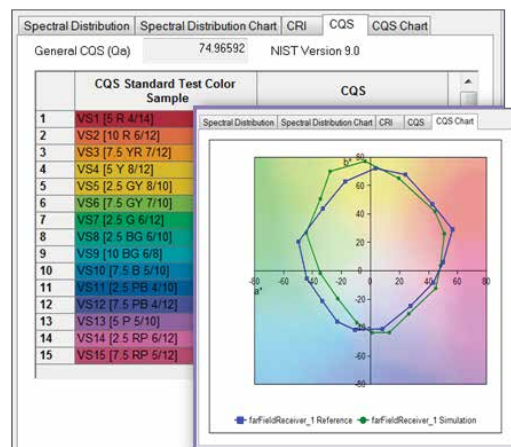


Figure 1: CQS switch calculations and CQS chart

## CIE Mesh, CCT Mesh, Color Difference, Color CIE and CCT Meshes, Color Difference, Color Triangle, RGB True Color

LightTools collects statistical data in different types of meshes. CIE and CCT meshes are available separately for each parent mesh type, e.g., intensity and illuminance parent meshes. CIE coordinates are provided separately in two meshes – either  $x$  and  $y$  or  $u'$  and  $v'$ . In each mesh you can view coordinate data, color difference values, and red, green, or blue values. All meshes can be viewed as raster plots. The color difference data is useful when you need to quantify or visualize small variations in color coordinates that would be less obvious in a true color plot. It is also possible to view each bin of the CIE mesh as a crosshair overlaid on the CIE color triangles in either the  $xy$  or  $u'v'$  color spaces.

LightTools features an (RGB) true color plot that is available for each parent mesh type. True color illuminance plots can be viewed either as a stand-alone chart, or, in most cases, directly in the LightTools 3D model view as shown in Figure 2. This figure shows a model with five colored LEDs that are imaged to a plane. Several intermediate planes along the optical axis show color mixing at various distances from the imaging optics.

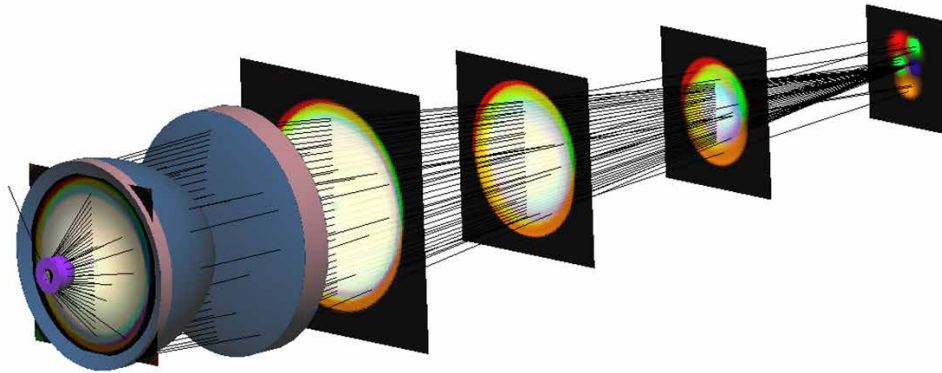


Figure 2: RGB LED imaging system showing true color raster plots at various planes along the optical axis. The colors mix best near the lens where the light from each die overlaps the most

## Simulation, Source, and Receiver Settings

### Simulation Settings: Dispersive, Non-Dispersive, and Spectral Range Limits

LightTools allows two chromatic ray trace modes: dispersive and non-dispersive. In dispersive mode (the default), each ray represents a probabilistically selected wavelength that is chosen based on the originating source's spectrum. The color information at the receiver is determined by the collected rays. Dispersive mode takes into account all the optical properties of the materials and surfaces modeled in LightTools at each ray's sampled wavelength. Additionally, dispersive mode allows you to limit the spectral range of the rays used. This option can increase efficiency and eliminate the need for redefining source, filter, surface, and other spectral ranges. Dispersive mode may be required when modeling systems with lenses, prisms, color-selective coatings, and wavelength-dependent absorption.

Non-dispersive mode can greatly reduce statistical noise, but should only be used when there is no significant dispersion in the model. In non-dispersive mode, each ray traces through the system at a single, user-specified wavelength. However, each ray carries the entire spectral information of its associated source to the receiver. This method of ray tracing is very efficient for analyzing color mixing systems that do not have significantly dispersing elements. For example, it is especially useful for reflector designs.

### Source Settings: Emittance, Spectrum Type, Discrete/Continuous, Wavelength Weighting, Ray Data Sources

Radiometric or photometric units can be used to specify the source emittance. You have the option of distributing the simulation rays evenly across the source spectrum or weighting the wavelength distribution of the simulation rays to match the photometric response curve. The former option is more efficient at generating accurate color data, especially when dealing with broad-spectrum sources. The latter is more efficient at generating non-color specific data (such as illuminance or intensity) in systems intended for a human observer. LightTools uses intelligent defaults to select the appropriate option, though this can be controlled directly if desired.

In LightTools, the spectrum type can be user defined via entry of data into a grid or loaded from a text-based spectral file. Additionally, there are integrated blackbody and Gaussian spectra that can be set up quickly.

Spectra can be modeled as either discrete or continuous. In discrete mode, the rays are only traced at the specified wavelengths, whereas in continuous mode, LightTools samples from the whole spectrum. Sometimes it is advantageous to use continuous spectra to help eliminate artifacts caused by discrete sampling of the spectrum.

When spectra are user defined, each wavelength gets a relative weight (the source emittance is used for the absolute calibration). In radiometric mode, the weights are directly related to the absolute power (watts), and when photometric weighting is used, the relative weights are related to the photometric flux (lumens) of the source.

Another powerful feature in LightTools is the ability to use ray file sources. In LightTools, there are three options for modeling color with ray files. First, specify a spectrum associated with the full source as you would for any other source (each ray has a wavelength chosen randomly based on the source spectrum). The advantage of this is that the data is simple and easy to obtain. The drawback is that angular or spatial color variations of the source are not modeled. To help overcome this limitation, it is possible to split the source into two (or more) ray files, each having a different spectrum. An example of where this is useful is a white phosphor LED—the direct, ‘blue’ unconverted light, and the ‘yellow’, phosphorescent light can be separated into two ray file sources. With this type of source, all colorimetric analyses are possible.

Secondly, ray data files can use tri-stimulus data stored directly in the file for each ray. This is most commonly available with ray files originating from measured data. When tristimulus values are used, you must trace in non-dispersive mode. CIE-based colorimetric quantities, such as CIE color coordinates and true color output, can be analyzed. Direct analysis of the spectrum and derived quantities (such as CRI, CQS and GAI) is not available.

Finally, each individual ray in the ray data file can have a unique wavelength specified. The advantage of this is that you can trace in dispersive mode, all angular and spatial color variations are modeled correctly, and all color analysis options are available. The drawback is that this data is rarely available from measured sources, but most commonly comes from simulation results.

## Receiver Settings

### CIE Coordinates, White Point

LightTools allows you specify whether the xy (1931 standard) or u’v’ (1976) color space should be used for CIE-based calculations. You can also specify a receiver’s RGB white point. The white point can be specified as a CCT value (i.e., on the blackbody locus) or in terms of xy or u’v’ coordinates. This number will be what appears ‘white’ in your RGB plots. Typically, you want to set this value to be the nominal white color of your application. For instance, you might set it to 5000K if you are designing a 5000K CCT LED-based system and you want to observe what portions of your system appear blue or red compared to that value.

## Photorealistic Rendering

Photorealistic Rendering (PRR) is another powerful feature included in the LightTools Illumination Module that allows you to understand chromatic effects. Using state-of-the-art ray trace techniques, PRR renders scenes as they would be captured by a digital camera. These techniques give you the freedom to ray trace once and then create scene renders from any point of view without requiring another ray trace, saving time and effort.

PRR ships with a large, built-in finish library and the ability to quickly add user finishes. User finishes can, for instance, include image files that you wish to map onto a surface, as has been done for some of the items in the office scene shown in Figure 3. LightTools can use your source geometry, complete with spectral information, to trace and render a scene in the model.

In the example shown in Figure 3, fluorescent tube sources with an advertised 5000K CCT were used to design recessed, louvered luminaires that provided enough light and followed standard office glare guidelines for their intensity distribution.



Figure 3: Comparison of photorealistic renderings of an office scene using three spectra:  
(a) 5000K black body spectrum, (b) 5000K Fluorescent spectrum of the lamps used to design  
the fixtures, and (c) 5000K white phosphor LED

In order to gain an understanding of the look and feel of the resulting lit space, a PRR image of the office was created with the fluorescent tube sources (Figure 3b). Then, for comparison, the source was re-traced using a 5000K black body spectrum (Figure 3a) as well as a 5000K white phosphor LED spectrum (Figure 3c) and re-rendered. In each scene, the light appears 'white' when you look at it by itself. However, when you put the three images next to each other, as in the figure, you can really see a difference in how the colors appear for the three different spectra.

For more information about LightTools and its colorimetric capabilities, please contact Synopsys' Optical Solutions Group at (626) 795-9101, visit [synopsys.com/optical-solutions/lighttools](https://www.synopsys.com/optical-solutions/lighttools) or send an email to [optics@synopsys.com](mailto:optics@synopsys.com).