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In The Box

Optics of Digital Projectors Weekly eNewsletter

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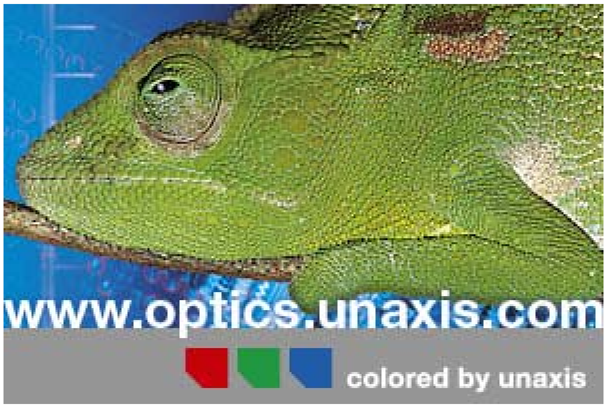
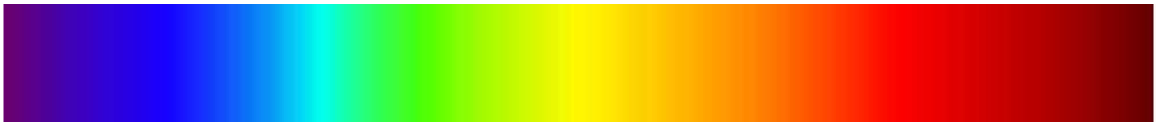


What is Color?



Understanding Color In Digital Projectors

Color is a visual human perception. From a young age we are trained to correlate a particular visual perception with the name of a color like red, green, blue, black, and white. These simple primary colors are satisfactory for early learning and simple coloring books, however as we become more sophisticated in the artistic areas and mediums we develop a more detailed correlation of visual perceptions.

In all areas of learning and personal growth we become more skilled and knowledgeable in our artistic and vocational pursuits and our precision skills and talent grows. In order to grow and rise to the next level of language, techniques, and methods we must grow. Refining methods, language and techniques enables us to communicate many of the subtleties associated with advancing our talents. This is where we find the digital projection industry with respect to color technology, skill, language and the state of the color technology in general. Strap in for the ride to the next level of color technology in digital projectors.

Retina - Color Sensor of the Eye

Since the human eye is the color sensor used to view digital projector images we need to understand how this sensor perceives color. The detector in the eye is called the retina, it serves a similar function as film does in a 35 mm camera or the color pixels in a digital camera. In the human retina these are rods and cones. The cones are used to sense color. There are three types of cones each with a different dye for different color absorption.

Recall that Sir Issac Newton discovered the color spectrum in white light with a prism in the 1660's.

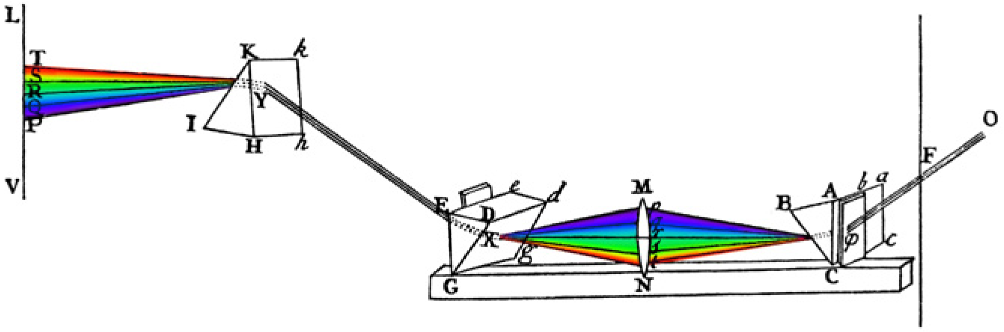
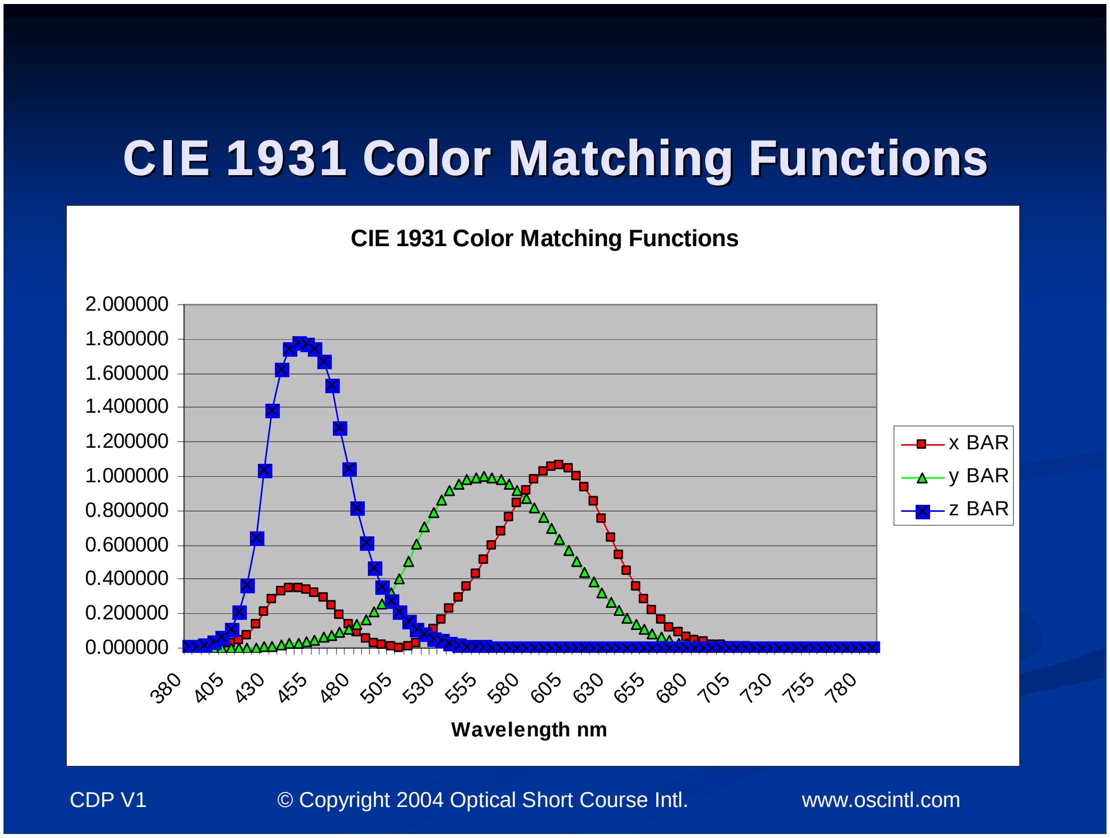


FIG. 16.

Figure 1. Newton's Spectrum http://www.as.wvu.edu/%7Escmcc/3prismesmall.jpg
Dyes are responsive to different wavelengths or colors, see the color matching function x, y, and z graphs of the CIE 1931 Standard Colorimetric Observer. The y color matching function has the same exact shape as the photopic response or V(λ) of the human eye.



CIE 1931 Color Matching Functions

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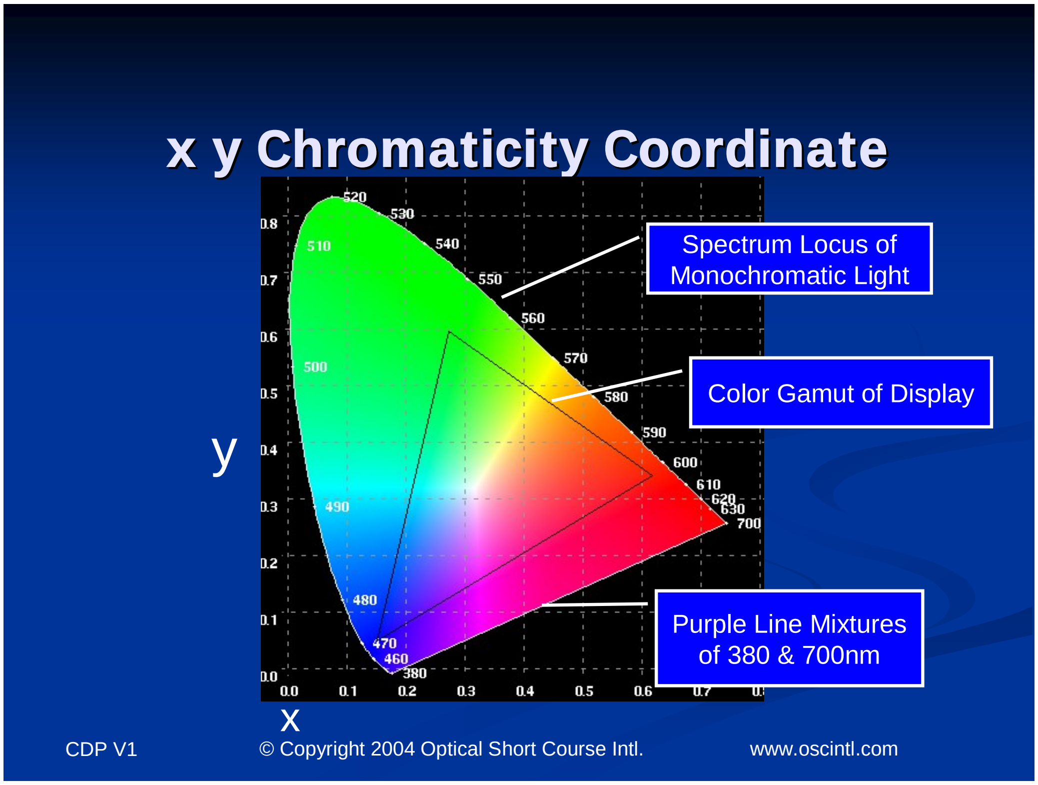
Figure 2. Color Matching Function of Human Eye
Illustration from our new DVD course Color in Digital Projectors at
http://www.oscintl.com/prod03.htm

Color scientists use wavelength to specify pure colors or ranges of pure color accurately. Engineers typically love graphs and they are useful to communicate relationships of different interrelated parameters of interest. Let's learn about some color graphics used to precisely communicate colors that we can perceive with the human eye.

Monochromatic Wavelengths or One Single Color

The 1931 CIE Chromaticity Diagram was created to specify colors using two parameters x and y, to locate a specific color or range of colors on a chart. There are several important characteristics of the CIE Chromaticity diagram: the spectrum locus and the purple line. The spectrum locus is the outside boundary of the curve. If a color lies on the spectrum locus the color is a pure color or monochromatic single color or single wavelength. The spectrum locus ranges from 380nm in the blue then moving clockwise up into the green and then down again into the red ending at 780nm. If a color moves off of the spectrum locus it will be a mixture of colors. The purple line on the CIE Chromaticity diagram is a mixture of 380nm blue light and 780nm red light in various amounts. Since it is a mixture of colors it is not monochromatic or pure color so it is not on the spectrum locus.

Back to Newton's prism experiment, we know that white light is made up of a mixture of the various colors in the spectrum. If we want to get white light then we need to mix three different single wavelengths or three different bands of colors. The wavelength bands are typically centered about red, green, and blue. If we have three bands of wavelengths centered around red, green, and blue they are located at the corners of the color gamut triangle, as shown in Figure 3 below. Remember only monochromatic colors are located on the spectrum locus. Bandwidths of colors are located off of the spectrum locus, like shown below. As we change the nature of the light from a monochromatic single wavelength to a band of wavelengths around a certain color, we move from the spectrum locus inwards to the center where finally the light is made from the full spectrum or white light.



x y Chromaticity Coordinate

Spectrum Locus of Monochromatic Light

Color Gamut of Display

Purple Line Mixtures of 380 & 700nm

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Figure 3. 1931 CIE Chromaticity Diagram
Illustration from our new DVD course Color in Digital Projectors at
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Color scientists like to use the CIE Chromaticity diagram because they can specify exact color by in an x, y rectangular coordinate system. It is also a very precise method of color description and thus can be communicated world wide by two numbers, the x and y coordinates. For example find x = 0.63 y = 0.33 which is red, and x = 0.15 y = 0.75 which is green. The 1931 CIE Chromaticity diagram is just one of many different color scales.

If we map three primary colors red, green, and blue on the CIE Chromaticity diagram and calculate the area of this triangle we can give this triangular area a name called the color gamut. If it is the human eye, or sensor like film, or a CCD detector we can quantify and compare the ability to see colors by the device color gamut. The bigger the color gamut the more colors a sensor or display can see or display.

For reference a CRT TV can only display about 30% of the human color gamut or total area of the 1931 CIE Chromaticity diagram. Movie film can only record about 42% of the human color gamut. As we move further into the digital age with digital presentations, digital photography, digitally generated movies and gaming we will naturally want to make use of the full human color gamut.

Color Temperature

The term color temperature is used to describe the spectrum of a light source using one parameter. The color temperature is used to specify a radiator or light source that has the same chromaticity coordinates as a black body radiator. On the 1931 Chromaticity Diagram there is a curve called the blackbody curve where radiators or light sources lie on or near depending upon their color temperature. For our discussion here we will assume at all sources lie on the blackbody curve. The blackbody curve starts in the bottom right corner of the 1931 Chromaticity Diagram at 780nm in the red and as the temperature of the light source heats up from 0 degrees to 100,000 degrees Kelvin and higher. The hue or color of the light source changes from red, to orange, yellow, gold, tan, yellowish white, white, to bluish white as the temperature increases. You may have noticed that light from a tungsten bulb at about 2850 K gives a yellow color.

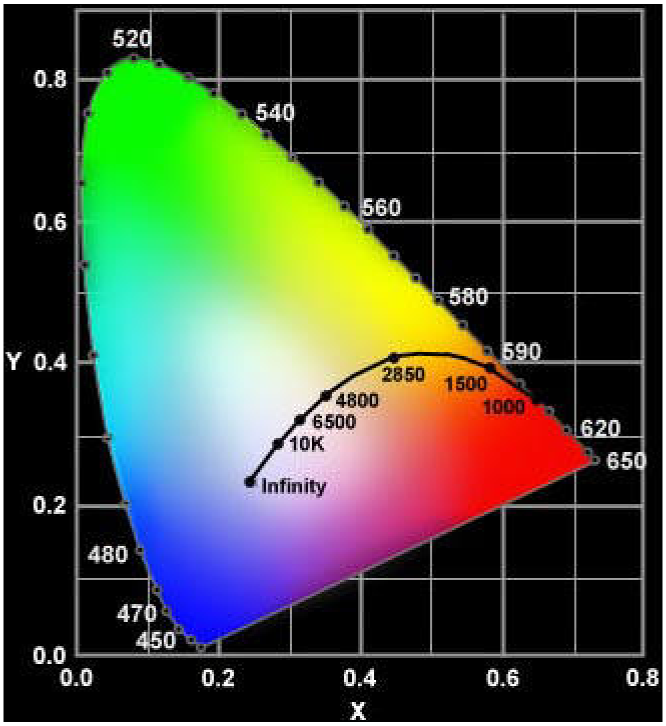


Figure 4. Blackbody Curve
Graphic Courtesy of http://www.ledproductstore.com/colorimetry.htm

We can see from this blackbody curve that light sources of a particular color temperature have a specific location on or near the blackbody curve. We can see for example at x = 0.43 and y = 0.41 a source with color temperature 2850 K this is very close to Standard Illuminant A at 2856 K.

Standard Illuminants were created as radiometric and colorimetric standard sources to enable optical scientists to create light sources for calibration and testing in this area of science. There are other Standard Illuminants such as C, D50, D55, D65, D75 and so on. We can see from the blackbody curve that each of these light sources or radiators has a different chromaticity coordinates and that means each of the light sources are composed of a different spectral distribution to achieve this color temperature location on the blackbody curve. This relationship of light source spectral distribution to color temperature is an important difference between light sources that can be used for digital projectors. The different spectral distribution has an effect on the ability to display accurate colors and the total amount of lumens available from a light source.

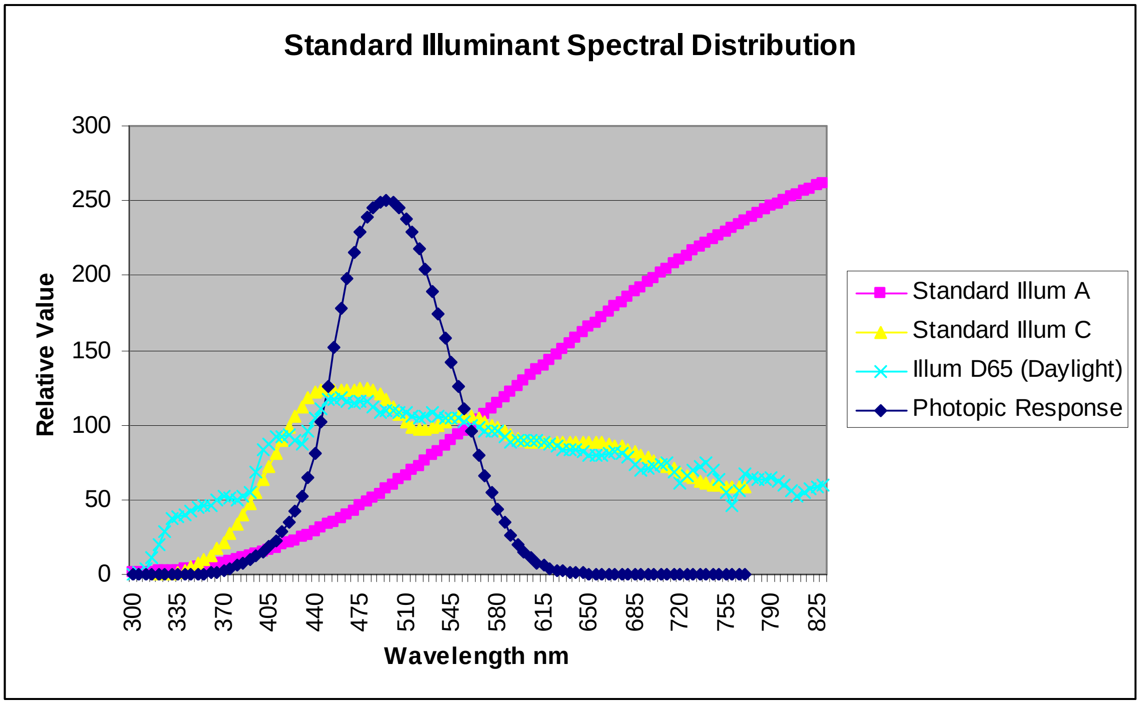


Figure 5. Graph of Standard Illuminant A, C, D65 and the Photopic Response of the Eye.

One can see the relative photopic response of the eye and compare this to the different spectral distributions of the various standard illuminants. We can see that Standard Illuminant A, a tungsten source at 2865 K has much more irradiance in the yellow and red portion of the spectrum than in the blue and green. This tells us why this source is yellow. If we look at the Standard Illuminant C or the D65 we can see that these sources are more color neutral and have more even spectral distributions throughout the visible region of the spectrum.

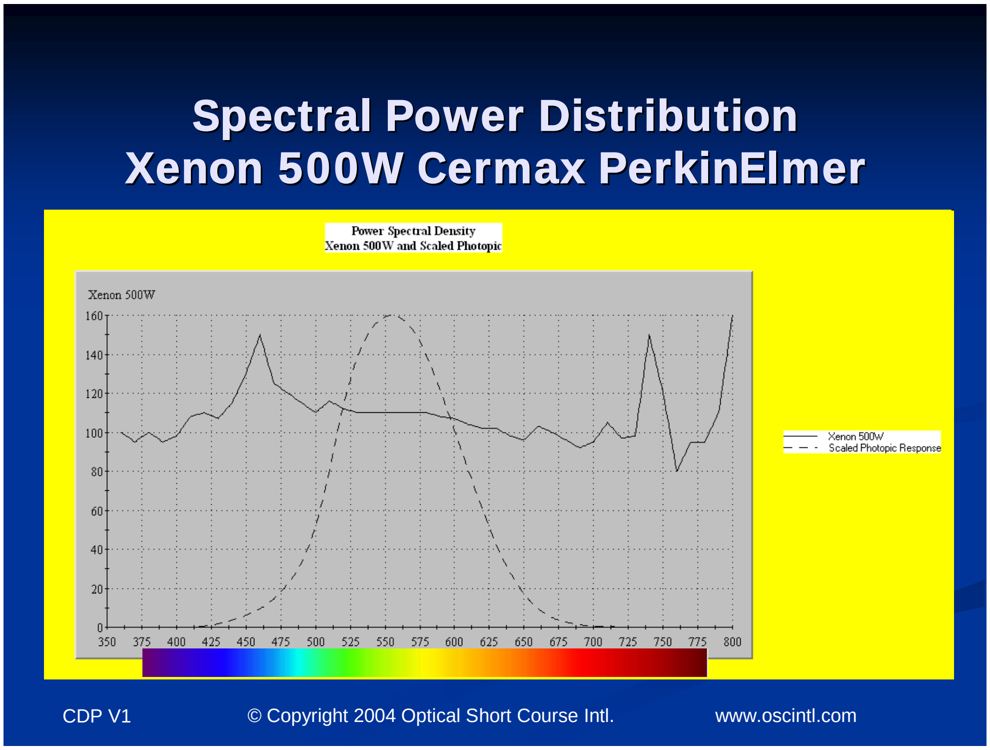
There are spectral filtering methods called color temperature conversion filters where we can transform the spectral distribution and therefore the color temperature of one light source into the spectral distribution of another source. Unfortunately these color temperature conversion filters must waste energy and throw light away. For example if we wanted to transform a light source from Standard Illuminant A to C we would need to throw away light starting at about 420nm and longer, and as one can see at the longer wavelengths is where most of the energy is located. The message here is transforming certain light sources so that they can be more color balanced for the visual region typically involves wasting large amounts of light so we can display accurate colors from a source.

Correlated Color Temperature

Because most light sources are not perfect blackbody radiators they will not have the exact chromaticity coordinates of a color temperature on the blackbody curve. Color scientists have developed a name for light source color temperature for sources that are not on the blackbody curve – correlated color temperature. The correlated color temperature is then the color temperature of the blackbody radiator that most closely visually matches the light source of the same brightness and under the same viewing conditions.

Source Power Spectral Distribution

We have been discussing the color spectrum of humans and we should also look at how the color spectrum of light sources are measured and specified. One of the important parameters of a light source is how much power there is in each wavelength interval. The graph that communicates this information about a light source is called the spectral power distribution graph or spectral irradiance graph.



Spectral Power Distribution
Xenon 500W Cermax PerkinElmer

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Figure 6. Spectral Power Distribution of Xenon Lamp
Illustration from our new DVD course Color in Digital Projectors at http://www.oscintl.com/prod03.htm

This measurement is usually made with a spectradiometer which has a prism or diffraction grating to spread narrow bands of wavelengths onto the detector area at one time. The detector has a know area in m^2 and measures the power in watts in each wavelength band, which enables the spectradiometer to read the spectral irradiance or spectral power distribution in W/m^2 – nm. Above in Figure 6 we can see the spectral power distribution of a 500 W Cermax™ Xenon bulb and we have overlaid the photopic response of the human eye.

What is a Lumen?

Light sources as we know have a certain radiant power or radiant flux given in units of watts. This radiant flux as we know can range in wavelength from the ultraviolet through the visible region and into the near, mid, and far infrared regions of the electromagnetic spectrum. In many cases we only are concerned with the radiant flux in the visual region from the light source. In these cases we need to convert the radiant flux into a luminous flux which has the units of lumen. This conversion is done by multiplying the radiant flux by the photopic response curve $V(\lambda)$ and then multiplying this product by the proportionality constant K=683 lumens/watt over the wavelength region from 380 to 830nm.

Light Source Efficiency

One important parameter that is often used to compare different lamp technologies is the lamp efficacy. Efficacy means the power to product effects. In lamps it means the efficiency with which electrical power in watts is turned into luminous flux in lumens. For example the efficacy of certain Xenon lamps are 53 lumens/watt. These lamps would provide 53 lumens of luminous flux for every watt of electrical input power.

Color Summary

We have presented many of the different parameters in light sources that have an effect upon the color that is perceived by the human eye. These different parameters are used to specify and communicate how a light source will work in a particular application. Learning about these different color parameters will enable you to communicate to other and select the best light source solution for your application. If you need additional information please consider our new DVD course Color in Digital Projectors or if you just need some technical consulting help give us a call or see our consulting services section of the website http://www.oscintl.com/services.htm.

OSCI performs technical consulting to help clients with digital projection systems reach their full color potential. We leverage our alliances with the leading companies in the display industry to achieve these objectives for our clients. We also educate our clients about color in digital projectors with our DVD courses Optics of Digital Projectors and our newest course Color in Digital Projectors. See our website for more details: http://www.oscintl.com

See our newest DVD short course: Color In Digital Projectors

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