Optical Short Course International

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In The Box

Optics of Digital Projectors Bi-Monthly eNewsletter

Color from Projectors with Mercury Lamps?

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This week we will take a look at how color is generated in a digital projector that uses a mercury lamp as the light source. We will quantify the color performance from these mercury lamps and also from several digital projectors which use mercury lamps. The goal of this enewsletter is for you to understand how color is generated in digital projectors with mercury lamps and to understand what design choices and tradeoffs exist. The color filter design bandwidth and center wavelength will be investigated and compared to the mercury lamp color spikes. We also look at several color gamut's in measured digital projector displays to understand how some color tradeoffs are made in digital projector design and analysis work.

C.I.E. 1931 Chromaticity Diagram

An international organization called C.I.E. (Commission Internationale de l'Eclairage) developed a quantitative method to describe color precisely on a two dimensional orthogonal XY position chart. We talked about this important color diagram last week and how we can use it to accurately describe a specific color.

C.I.E. 1931 Chromaticity Diagram in x y Color Space

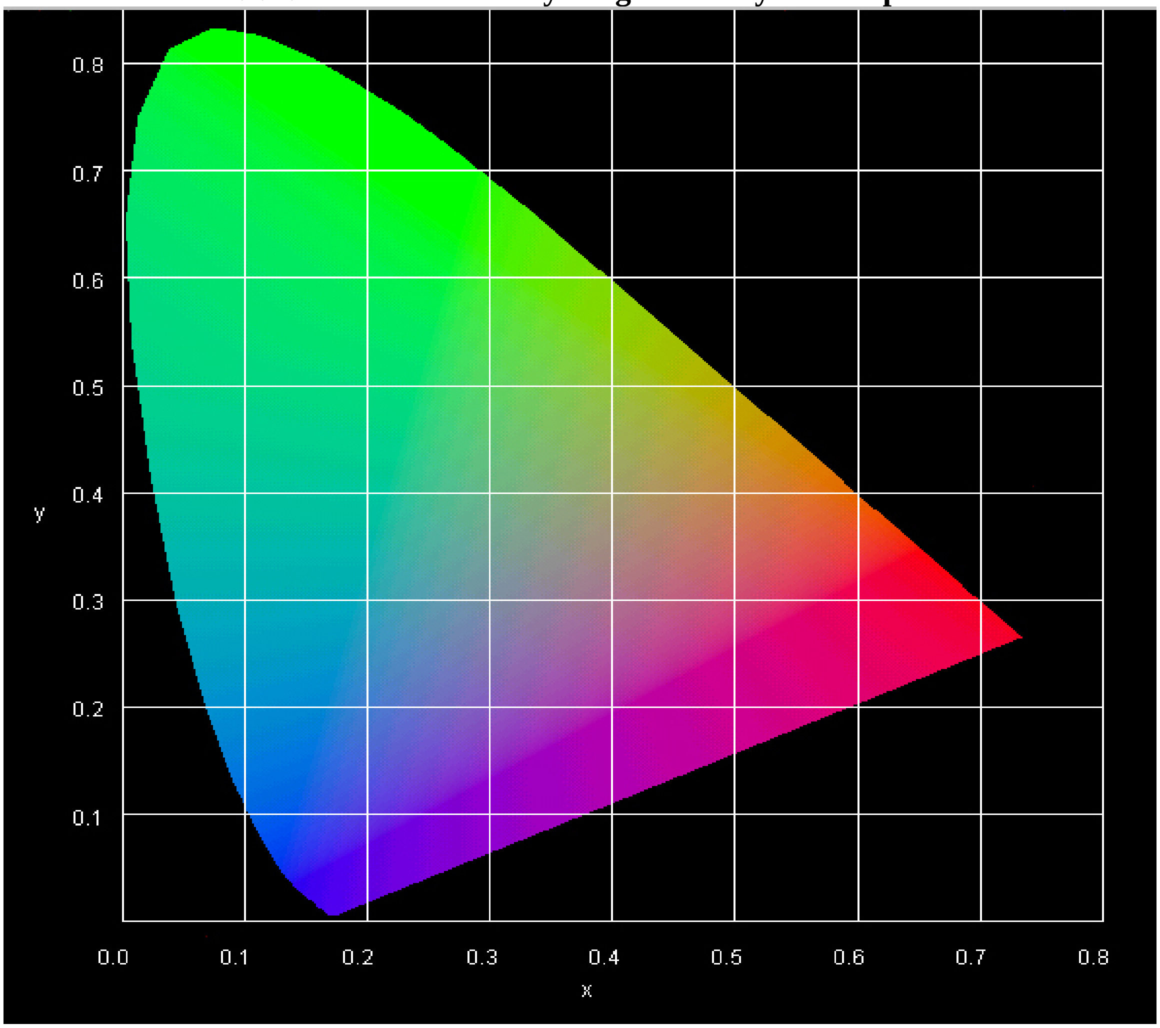

Figure 1. C.I.E. 1931 Chromaticity Diagram

What Colors in the C.I.E. Chromaticity Diagram Can Digital Projectors Display?

The current vintage of digital projectors can only display a small limited percentage of the total available color space in the chromaticity diagram. A simple method to quantitatively compare the color gamut of humans to displays is to compare the area of their color gamuts. The color gamut of the typical human observer is the area of the

Current Vintage Digital Projectors Have Ability (sic) To Display ~25% of Human Observer Color Gamut

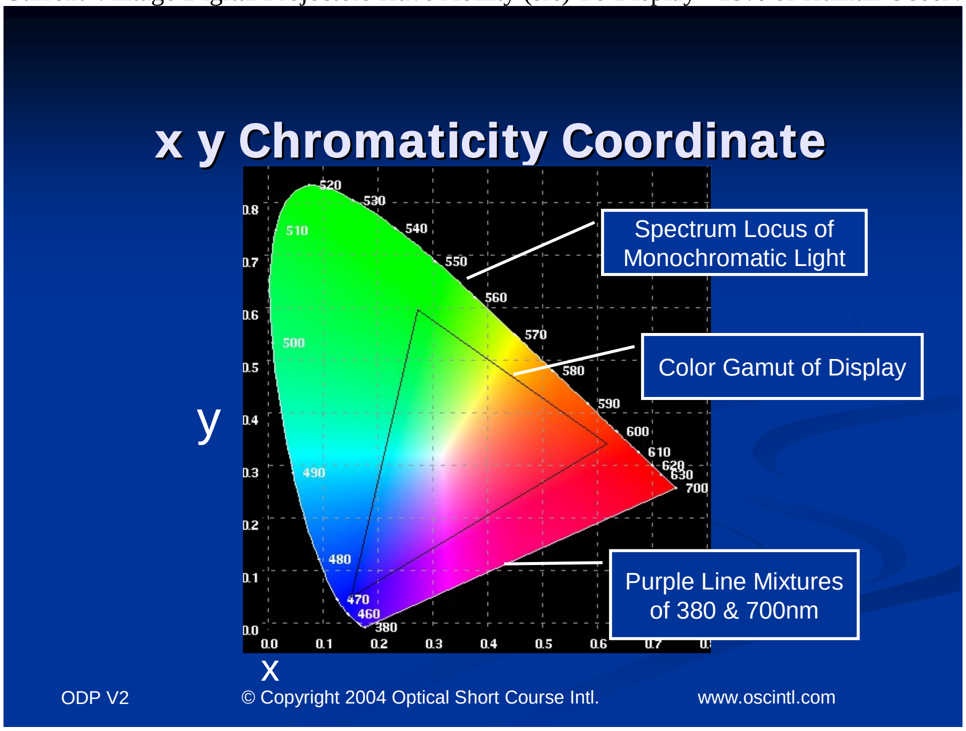

Figure 2. Color Gamut Comparison of Human Eye and Digital Projector
Graphics from our newest DVD course: Color In Digital Projectors
http://www.oscintl.com/prod03.htm

in the chromaticity diagram of Figure 2. This area is called the color gamut of the observer and represents all of the colors that the standard human observer can see if these colors are present in an image. The smaller triangle shown in Figure 2, is the color gamut of a current vintage digital projector. The vertices of the triangle are where the red, green, and blue primary colors are located. In general a display device can display any color within its color gamut or the triangle above by mixing various magnitudes of each of the three primary colors.

We can compare current vintage digital projectors by calculating the area of their color gamut, which is the area of the triangle in Figure 2. The area of the display device can be related to the area or color gamut of the standard human observer. A comparison of the color gamut areas from Figure 2 shows that the current vintage digital projector technology can only display about 25% of the visible colors that one can see with the human eye. The human eye can see or detect all of the colors within the chromaticity diagram.

What parts of the digital projectors limit the color gamut to only 25% of the standard viewer?

The color gamut of a digital projector depends upon the interplay of a large number of the components in the image color chain. Last week we talked about these various parameter that affect the color which a digital projector can display.

- Digital Image Color Content
- Light Source
- Color Filters in Color Wheel
- Optical System Spectral Transmission
- Projection Image
- Projection Screen Spectral Transmission/Reflection
- Viewing Environment
- Human Visual System

We will focus on the mercury light source this week and its ability to display a large color gamut of the digital content. There are several types of light sources used in digital projector light engines and they are mercury, xenon, and LED sources. Each of these light sources has a different amount of power in each of the wavelengths or colors and therefore has a different ability to display true colors. If we look at the power spectral distribution of these lamps we will see the distribution of power in each of the colors.

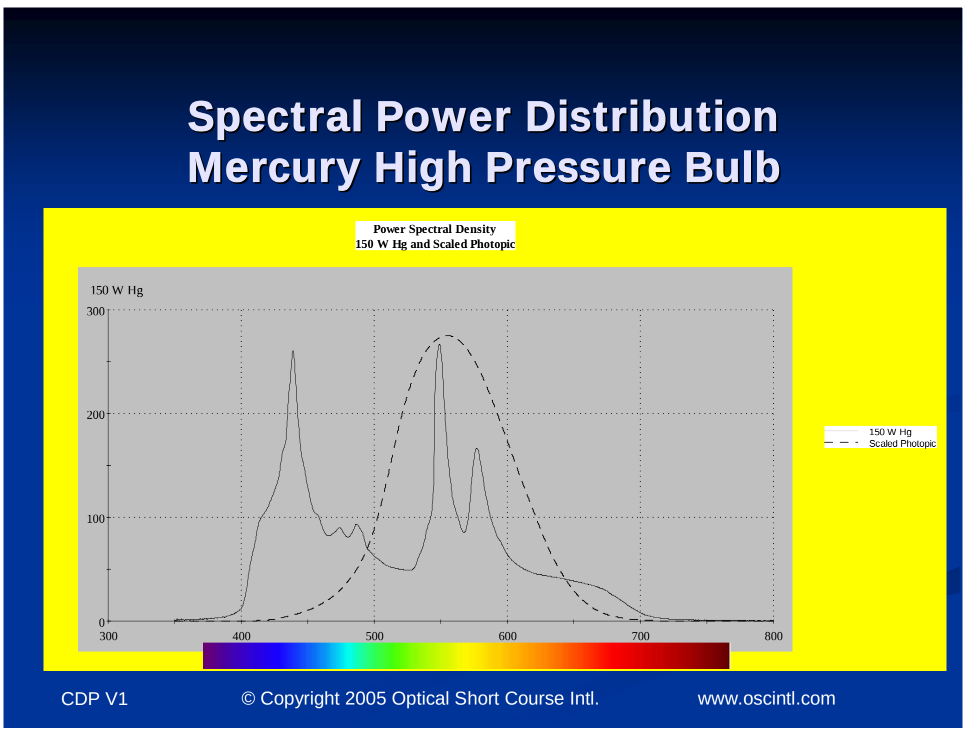

Figure 3. Spectral Power Distribution of Mercury Lamp
Graphics from our DVD course: Optics of Digital Projectors
http://www.oscintl.com/prod01.htm

In Figure 3 above we can see the power spectral distribution of the mercury lamp which shows us how much power is in each of the wavelength bands. We have overlaid the visual response of the human eye with the dotted line and also the visual color spectrum so that you can reference colors to wavelengths in nanometers on the bottom of the chart.

In the mercury lamp spectrum we can see that there are several large color spikes in the power spectral distribution. The first is in the blue at 436nm and there are two more in the yellow-green and yellow at 550 and 575nm approximately. We notice that with mercury there is no power spike in the red. This asymmetry of blue, green, and red power will cause us some color limitations with the mercury lamps in digital projectors.

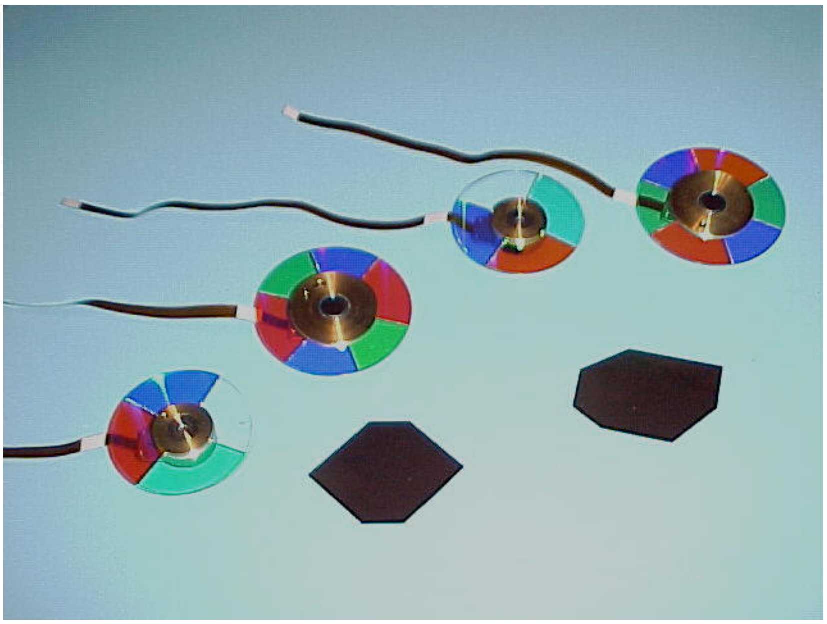

Figure 4. Color Filter Wheel Assemblies RGBW and RGBRGB
Color Filter Wheels Courtesy of Unaxis Optics
http://www.optics.unaxis.com

The color filter segments of red, green, blue, dark green, and white which make up a color filter wheel have their own spectral band pass transmission values. The width of the spectral band determines where the chromaticity value lies for that particular primary color. Recall that a monochromatic color or laser line width will lie on the spectrum locus of the CIE chromaticity diagram, see Figure 2; it is the "D" shape of the diagram where pure colors lie. If we chose a narrow band width to get our green color for example, we would find out that we could not pass much lamp spectral power in the narrow bandwidth of that color filter. So there is a system design tradeoff between narrow band width and spectral power transmission. These tradeoffs result in a larger or smaller color gamut and more or less screen lumens. Typical RGB color filters have a half power bandwidth of between 75 and 150nm, they are chosen during a systems tradeoff analysis.

In Figure 5 below we can see an example of a starting choice of color filter transmission bands for large color gamut. We chose three color bands of about 25nm wide so we can get a large color gamut. Our chosen color band center wavelengths were 435, 525, and 640nm. If we look at the CIE Chromaticity diagram we can see that these three wavelengths will give us a very large color gamut which is good for displaying a large quantity of colors from our digital media. A big color gamut is great but with our choice we will not have very much optical power from the lamp in the green or red, but we will have a large amount from the blue spectral spike at 436nm.

This gives us a system design dilemma with a mercury lamp spectral output, we have to choose between a smaller color gamut or screen lumens. Of course we must first meet the minimum screen lumens so we must move our color filter transmission bands to correspond with the mercury lamp color spikes so we can capture the optical power in these spikes.

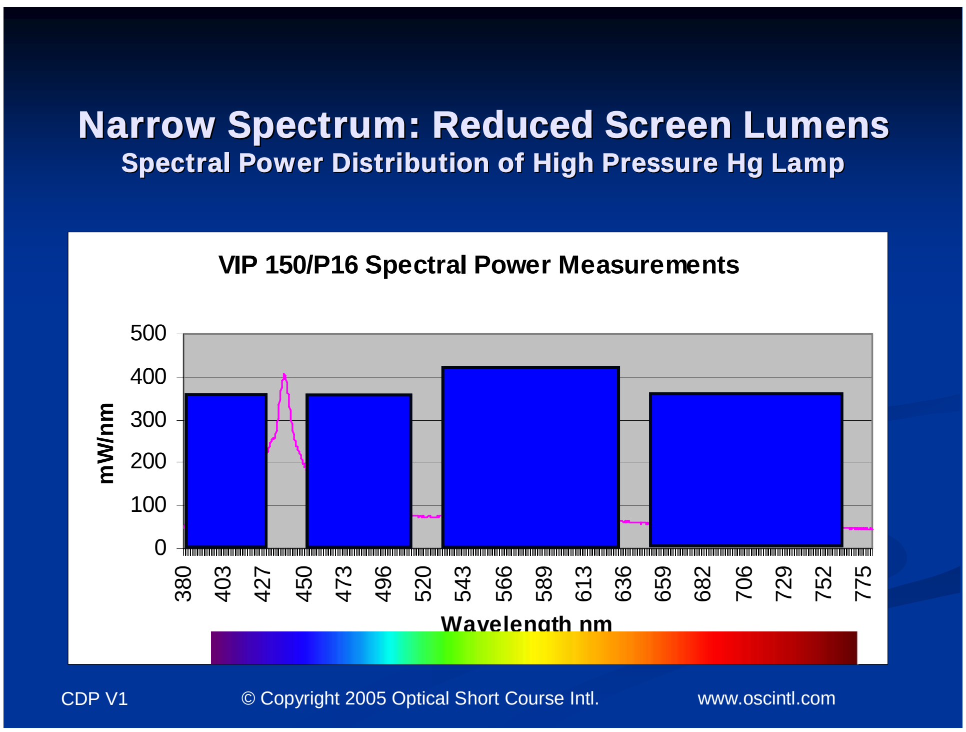

Figure 5. Color Filter Wheel Assemblies Transmission Bands with Mercury Lamp
From OSCI DVD course Color in Digital Projectors
http://www.oscintl.com/prod03.htm

Chromaticity Coordinates of Measured Front Projectors

There are several different methods to measure the chromaticity coordinates of digital projectors. These tests often fall into two categories which are full screen or point measurements. The full screen color tests are done using calibrated CCD cameras and specially designed color measurement filters. The point measurements are typically performed using a spectradiometer with a narrow field of view. The measurements below are taken from Home Theater Magazine from their Test Bench Section, see them at: http://www.hometheatermag.com

BenQ PB6200 DLP Projector
Measured Color Points:
Red Color Point: x=0.616, y=0.369
Green Color Point: x=0.330, y=0.572
Blue Color Point: x=0.145, y=0.071

Mitsubishi HC900 DLP Projector
Measured Color Points:
Red Color Point: x=0.621, y=0.371
Green Color Point: x=0.308, y=0.601
Blue Color Point: x=0.148, y=0.071

JVC HD-70G886 D-ILA HDTV RPTV
Measured Color Points:
Red Color Point: x=0.646, y=0.335
Green Color Point: x=0.285, y=0.695
Blue Color Point: x=0.146, y=0.048

We can see by comparing the chromaticity coordinates that the JVC display has a much deeper red and blue than the two DLP projectors. The Mitsubishi has a larger green position than the BenQ, but the JVC has an even larger green chromaticity coordinate to deliver the largest color gamut. Since RPTV's are typically dimmer than front projectors the better color in the JVC probably was a conscious design tradeoff for better color, larger color gamut, and less screen lumens.

Summary
Mercury lamps have color spikes in the blue and green but not in the red part of the color spectrum. Color filter wheel spectral transmission designs must be centered where these spikes are located to capture the optical power from the lamp and get enough lumens on the screen. Selection of the color filters at these color spike locations reduces the color gamut of the digital projectors in favor of more screen lumens. This tradeoff is a system design result of the mercury lamp spectral color spikes. We also looked at the measured data from three different digital projectors and compared their measured color gamut.

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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