Examining Color Performance Between 3-Chip LCD and 1-Chip DLP Projection Technologies

1. Introduction

Two different technologies are found in the majority of projectors in the marketplace: 3-Chip LCD (or 3LCD) and 1-Chip DLP. There exists considerable confusion and marketing misinformation relating to the color capability and measurement of these different projector systems. This White Paper will use basic color science to help the business user, consumer, and other buyers of projectors, make informed purchasing decisions.

In particular this paper will review:

- The 3LCD based projector systems vs. DLP 1-Chip color sequential systems.*
- A new international projector measurement standard, called Color Light Output also known as, Color Brightness.
- The reluctance of 1-Chip DLP projector manufacturers to provide a Color Light Output measurement for their projectors.
- Credibility issues with marketing used by 1-Chip DLP manufacturers.

2. How Projectors Work

Projectors work by delivering an image onto a screen or other flat, neutral surface such as a wall. Central to all projectors is an imaging system that regulates the amount of light reaching the screen. For the purposes of this paper we will examine two types of imaging systems used in 3LCD and 1-Chip DLP projectors. Projectors can use three primary colors—red, green and blue—and by mixing these together, in differing amounts, projectors are able to create virtually all colors that humans can see.

It is well established in physics and color science, that most colors can be created by the addition of differing amounts of red, green and blue, known as the additive primary colors. Where red, green and blue overlap in a projector system we see this as white. The white has been measured in the past and reported as the "Brightness" level using a measurement scale in units of lumens.

This brightness number has been used by the projector industry as a simple way to express a projector's brightness for marketing and sales purposes. *(Figure 1)* But this form of brightness is a measurement only of white light which does not provide any insight into color performance. In other words, a single brightness number has been measured only where red, green and blue overlap.

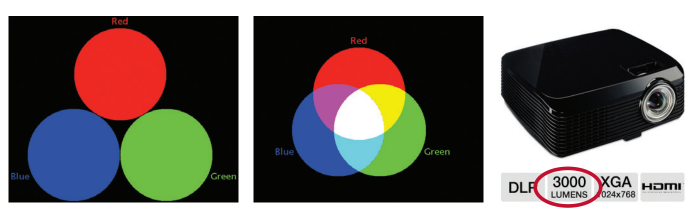

Figure 1: *Projector systems use red, green and blue light to create multiple colors. Where red, green and blue overlap we see this as white. In the past the white has been measured and reported as the "Brightness" level in lumens.*

* There are 1-Chip and 3-Chip DLP systems. This paper focuses on 1-Chip DLP systems. 3-Chip DLP technology is only found in significantly more expensive products used in large theaters vs use in education or business markets.

3. 3LCD and 1-Chip DLP projectors

3LCD technology uses a system of dichroic mirrors and 3 individual LCD chips to control red, green and blue light. This technology is depicted in *Figure 2* and shows the 3 LCD chips that modulate red, green and blue. It is important to note that all three colors are illuminating the screen at the same time—this simultaneous behavior is key to the 3LCD system and is responsible for brighter, more colorful images that can withstand higher levels of ambient room lighting vs 1-Chip DLP.

1-Chip DLP technology works in a totally different way and uses a sequential color wheel that rotates in front of the projector's light source. *(Figure 2)*

The color wheel has red, green and blue filters, and often other segments. The spinning sequential color wheel allows red, green and blue light to pass but not continuously, that is only red or green or blue light is allowed to pass at any one time. When the sequential color wheel rotates quickly the individual colors are usually not seen by the viewer, creating the illusion of a full color image. But there are significant tradeoffs. When the red, green blue are displayed quickly, one after the other, the human brain interprets this as a continuous image (without flicker), so the system works, but the 1-Chip DLP system is not efficient, because while one color of the wheel is projecting light, the other colors are rejected. Thus 1-Chip DLP systems usually produce darker and less colorful images.

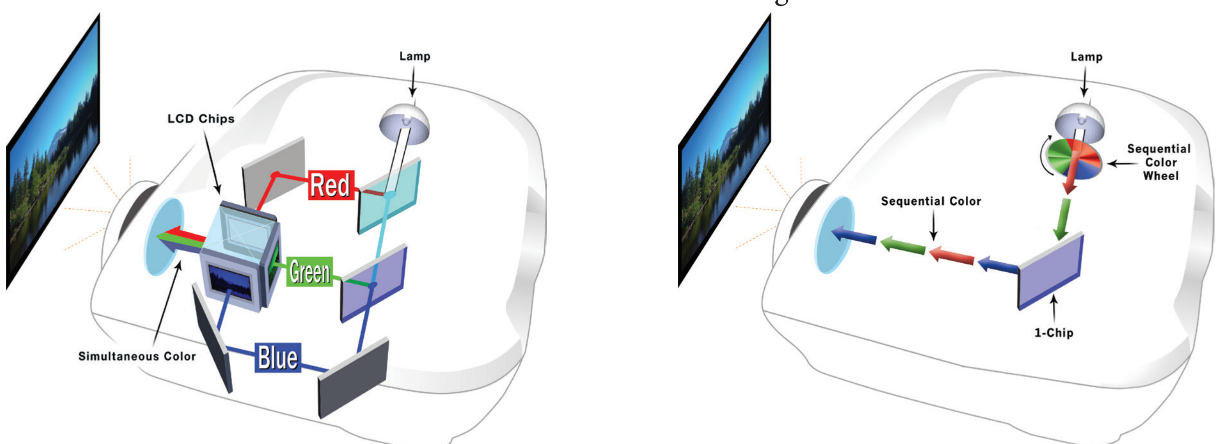

Figure 2: *There are two types of projector systems used by the majority of the market. Both systems use red, green and blue light, but they work in different ways. 3LCD technology (left) uses 3, LCD chips, while the 1-Chip DLP system uses a rotating wheel of sequential colors (right).*

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4. Measuring Color

There are two main color measurement systems used when analyzing projectors. The older system was approved in 1931 and is called the Yxy system. It has a horseshoe shape and is still widely used. A newer system is called the 1976 L*a*b* system. While both systems represent color in a "system independent" scientific manner, it is better to use the newer 1976 L*a*b* system for a number of reasons.

The Yxy diagram is not perceptually uniform and this limits its usage. The newer L*a*b* diagram is better in terms of perceptual uniformity. In the 1931 Yxy diagram the green color takes up a large area, compressing blue and red into smaller corners. *(Figure 3)* Notice in the 1976 L*a*b* diagram, how the colors are more evenly spaced – the green does not occupy the whole top of the diagram and the diagram has a non-distorted, circular shape. In terms of color science, we say the L*a*b* diagram is more "perceptually uniform", so in this White Paper we will use the newer 1976 L*a*b* diagram.

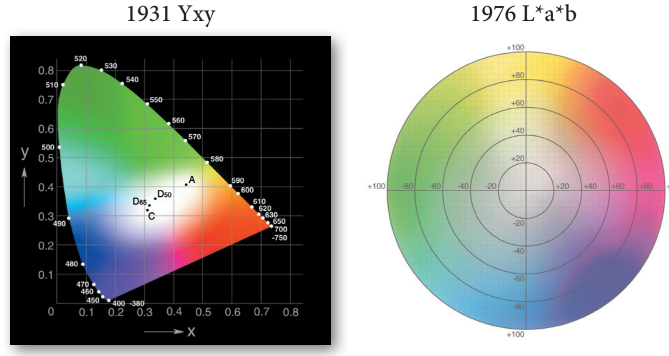

Figure 3: *The 1931 Yxy diagram (left) is horseshoe shaped and has a large area for green colors but compresses blues and reds. The 1976 L*a*b* diagram (right) affords all colors equal spacing. [From Understanding Color Management, Sharma, Thomson, 2004.]*

5. Color in 2D and 3D

The L*a*b diagram can be shown in 2-dimensions, which is easier to plot and often easier to interpret in printed literature. *(Figure 4)* The 3-dimensional L*a*b* diagram *(Figure 4, right)* however, provides a more comprehensive view in that color has 3-dimensions of hue, saturation and lightness. The 3-dimensional diagram as shown here is technically the most suitable system with which to analyze the color output of a projector so we choose to use it in the following analysis.

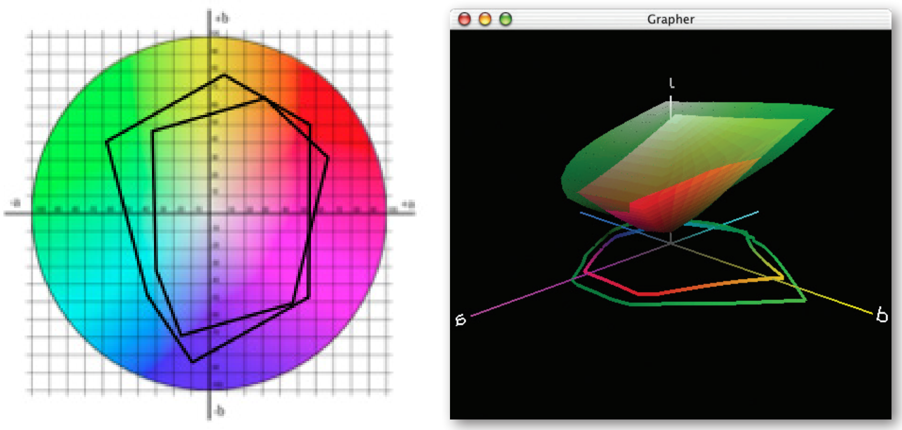

Figure 4: *Color diagrams can be shown as 2-dimensional plots (left), but color is really a 3-dimensional phenomenon and we get more information by displaying the color of a projector in a 3-D L*a*b* plot (right). [From Understanding Color Management, Sharma, Thomson, 2004.]*

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6. Comparing Gamuts of 3LCD and 1-Chip DLP projectors

We are able to plot the color gamut of 3LCD and 1-Chip DLP projection technologies in 3-dimensional L*a*b color space[1], to analyze the color response of the systems.

The 3LCD projector gamut *(Figure 5)* has a fuller volume, while the 1-Chip DLP projector exhibits a smaller, lower overall volume with a sharp, tall steeple. Because 1-Chip DLP projector systems are inefficient due to the sequential color wheel, manufacturers often manipulate the wheel to artificially obtain a higher White Light Output. This is often accomplished by introducing a clear or white segment as seen in *Figure 6*. The white segment artificially boosts white to a sharp point, and it is at this point where the old measurement for "Brightness" is made. So in the 3-dimensional color space diagram we see that the 1-Chip DLP projector does not make a bright white when used in the normal red-green-blue mode. But by adding a white or clear segment to the color wheel, White Light Output extends to a sharp peak allowing a manufacturer to report a higher White Light Output, which is often marketed as a single "Brightness" number.

Viewed on the gamut plot, the addition of the clear white segment results in pulling white up to a sharp point. Gamut maps for different 1-Chip DLP projectors will vary model to model, but in general, 1-Chip DLP projectors will show a similar response as illustrated in *Figure 5*.

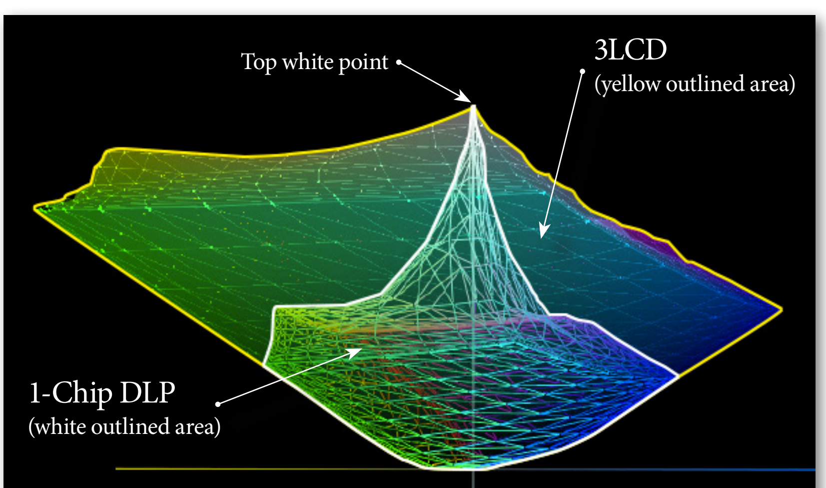

Figure 5: *White Light Output also known as White Brightness is measured only at the top white point. Color Light Output also known as Color Brightness makes multiple measurements that include color. Despite their very different color ability, 3LCD and 1-Chip DLP projectors shown here would have the same White Brightness which can lead to making incorrect assumptions about color performance.*

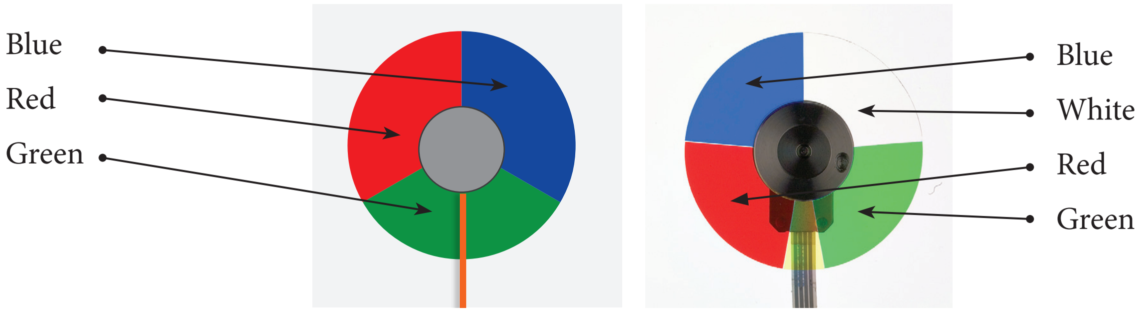

Figure 6: *1-Chip DLP projectors do not make a bright white when used in the normal red-green-blue mode (left), so a manufacturer can add a white segment to the sequential color wheel (right), which artificially increases White Light Output, but at the expense of color. Color wheel shown here is from InFocus IN37 1-Chip DLP projector.*

Figure 6 shows a color wheel from a 1-Chip DLP projector. In addition to the required red, green and blue colors, a white (clear) segment has been added to artificially boost the white point (creating the sharp point in the gamut diagram). As a result, when projecting white only, the screen is bright, and this projector may have a single brightness rating similar to that of a 3LCD projector system. But the 1-Chip DLP and 3LCD projectors are only similar for that very small white point area, and as soon as we start looking at the majority of graphics or images in color that will plot below that peak, a user of the 1-Chip DLP system will, in most cases not get the vivid, bright colors that they expect.

It is relevant to point out that the filter wheel described here is from a single projector from one manufacturer. Different manufacturers employ 1-Chip DLP technology in different ways with different white segment shapes and sizes. Regardless of these manufacturing variations, the only purpose of a white segment is to artificially boost the White Light Output measurement at the expense of color.

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7. Light Output and Color Output

There are two separate and different metrics for projectors:

- White Light Output also known as White Brightness
- Color Light Output also known as Color Brightness

Both metrics, White Light Output and Color Light Output are measured in lumens. "Brightness" only refers to White Light Output and is the number used in the past and currently by most 1-Chip DLP manufacturers for marketing and sales purposes.

Color Light Output is a new international measurement standard, which gives projector buyers a better way to assess a projector's true color and white point capabilities. Let us see how these two metrics are calculated in the case of 3LCD and 1-Chip DLP projector systems.

White Light Output is measured by considering the white point, i.e. the center point in *Figure 5*. The amount of light projected on the screen is measured and has been reported as "Brightness". We can compute the new metric called Color Light Output, and thus calculate Color Light Output in lumens. For 3LCD projector systems using the efficient addition of red-green-blue light, White Light Output and Color Light Output are generally the same number.

In 1-Chip DLP projector systems white is often added to the color wheel to artificially boost White Light Output. But when we compute the Color Light Output we get a dramatically lower number. In most scenarios 1-Chip DLP projectors have a Color Light Output that is 3 times lower than their White Light Output.

The table *(Figure 7)* summarizes a typical comparison between a 3LCD projector and a 1-Chip DLP projector. The data shows that a 3LCD projector has the same rating for White Light Output and Color Light Output, while a 1-Chip DLP projector has a much lower Color Light Output.

While a single brightness number would be convenient for buyers of projectors, white brightness alone is not an effective way to understand the performance of a projector.

	Color Light Output	*White Light Output*
Epson PowerLite 1770W X15 (3LCD)	3000 lumens	3000 lumens
BenQ MX660 (1-Chip DLP)	790 lumens	3000 lumens

Figure 7: *Table above shows comparison between 3LCD and 1-Chip DLP projectors in color and white light output.*

For most users, Color Light Output is critical because in an office or educational environment users will want to faithfully project the color they have built into their presentations to help students grasp key concepts or for an audience to understand key business metrics and see critical details.

It is recommended that all users and buyers of projectors use the new Color Light Output or Color Brightness number which incorporates the true color attributes of any projector.

8. International Standard

The International Committee for Display Metrology (ICDM) recognized the confusion between White Light Output and Color Light Output and addressed the problem. After careful research, the ICDM published a specification[2] for both Light Output and Color Output in June, 2012.

Projector buyers should look for, and request a Color Light Output or Color Brightness number for any projector before making a purchase. The ICDM 2012 standard applies to all displays including projectors for business, education or home use. ***This standard for Color Light Output gives end users a way with which to rank and rate a projector from an independent perspective.*** Leading manufacturers have adopted the standard and report both White Light Output and Color Light Output for their products.

Some manufacturers have elected to not publish the Color Light Output for their projectors. This may be due to a reluctance to show that their products have significantly lower Color Light Output. ***Customers should look for and demand both the White Light Output and Color Light Output numbers and seek projectors with high levels of both numbers. If a manufacturer does not provide both a White Light Output and Color Light Output number, hundreds of projectors have been independently tested for both numbers and results are available at*** **www.colorlightoutput.com**.

9. What is 1-Chip DLP BrilliantColor™?

In order to help end users and buyers understand how projectors work, we investigated a marketing term used in literature and advertisements by 1-Chip DLP Manufacturers called "BrilliantColor with multi-color processing". What is BrilliantColor? What is multi-color processing?

BrilliantColor is a marketing term used by 1-Chip DLP manufacturers. It describes a system where instead of just red-green-blue, white (clear) may be added as well as secondary colors such as cyan, yellow and magenta. *Figure 8* shows photographs of two different 1-Chip DLP color wheels where you can see the incorporation of yellow, cyan and white in addition to red, green and blue. Different 1-Chip DLP manufactures configure the size and number of colors on the wheel in different ways but regardless of the configuration the system is inherently inefficient.

We clearly saw at the start of this paper, that the three primary building blocks for color systems are red-green-blue and that virtually all colors can be made from these three primaries. Cyan can be easily made from a mixture of green and blue (refer back to *Figure 1*). So the green and blue parts of the color wheel can easily make cyan. In this instance why add cyan to the projector system when it can be easily made from green and blue? And look at the yellow, it is included in the wheel in *Figure 8*, but it can be easily made from the green and red parts of the color wheel that are already there. When the wheel is rotating the green and red colors can be seen by the eye as yellow, so there is no need to add a yellow filter segment. Regardless of the size or numbers of colors, a system that uses additional colors outside of red-green-blue has few, if any benefits based on basic color science.

BrilliantColor marketing claims:

"...DLP Projectors with BrilliantColor technology feature multi-color processing to produce stunning, vibrant colors on the screen. Unlike other technologies such as LCD which use just 3 primary colors to produce the image, DLP Technology with BrilliantColor uses up to six separate colors."

It's clear that this statement is made for marketing purposes and not based on basic color science. The statement is also in conflict with the more expensive 3-Chip DLP projectors found in theatres where only 3 colors are used. Due to the inherent inefficiency in a 1-chip DLP system, manufacturers have added a white segment to the color wheel in order to make the projectors competitive on lumens (white light). This technology choice can degrade the color performance of the 1-chip DLP projectors. 1-chip DLP manufacturers attempted to compensate for this degradation in color performance by adding secondary color segments. While users may see a slight improvement in color performance over RGB+white color wheels, the color brightness of so-called "Brilliant Color" projectors still suffer in comparison to any 3-chip system.

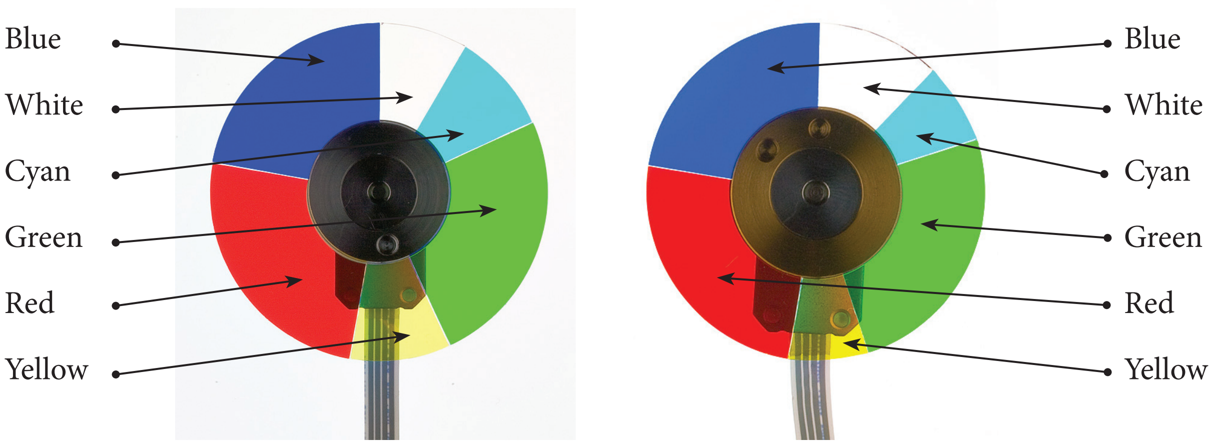

Figure 8: *1-Chip DLP projector color wheels are photographed to show the unnecessary addition of cyan and yellow colors plus the white segment. The white segment can vary in size, directly influencing the White Light Output. Left color wheel is from InFocus IN35 1-Chip DLP projector, right color wheel is from Optoma EP728 1-Chip DLP projector.*

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10. Basic Color Science Established in 1860

From a color science perspective, a sequential system does not need cyan or magenta segments and introducing these can reduce the color gamut of the projector. James Clark Maxwell was a professor at King's College London in the Nineteenth Century. His findings and research established the tri-chromatic (red-green-blue) theory for color systems and provided the foundation for modern color science.

As unrequired colors such as cyan, magenta and yellow are added to the color wheel of a 1-Chip DLP projector, the primary red green blue colors are reduced in size to make room. Since the red-green-blue can do all the work in terms of color science, one should question how a manufacturer could position this technology as "brilliant color" when the actual amount of projected Color is reduced. This is in conflict with fundamental color science principles, discovered and documented by Maxwell at the Royal Society of London in 1860[3].

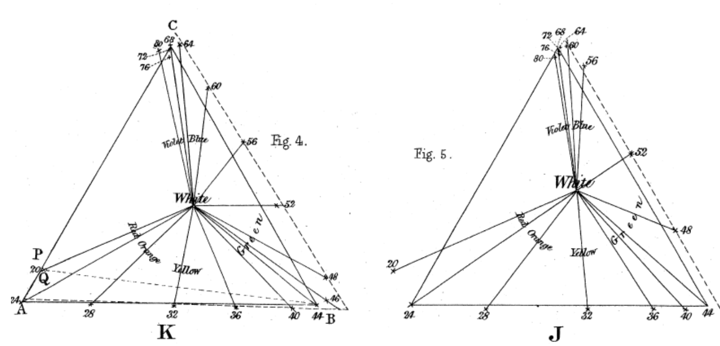

Figure 9: *James Clark Maxwell established the basis for red-green-blue color theory in 1860.*

11. Color Management and Pictorial Images

Using standard color management tools it is possible to evaluate the color response of a projector system. *Figure 10* shows the results obtained using X-Rite i1Profiler with an i1Pro spectrophotometer.

Because of the way these two projector systems work, the 3LCD system creates a wide range of colors as shown here by the larger 3-dimensional color gamut. The size of the attainable color gamut is larger for 3LCD projector systems while 1-Chip DLP is not capable of creating this range of colors due to by its smaller color gamut.

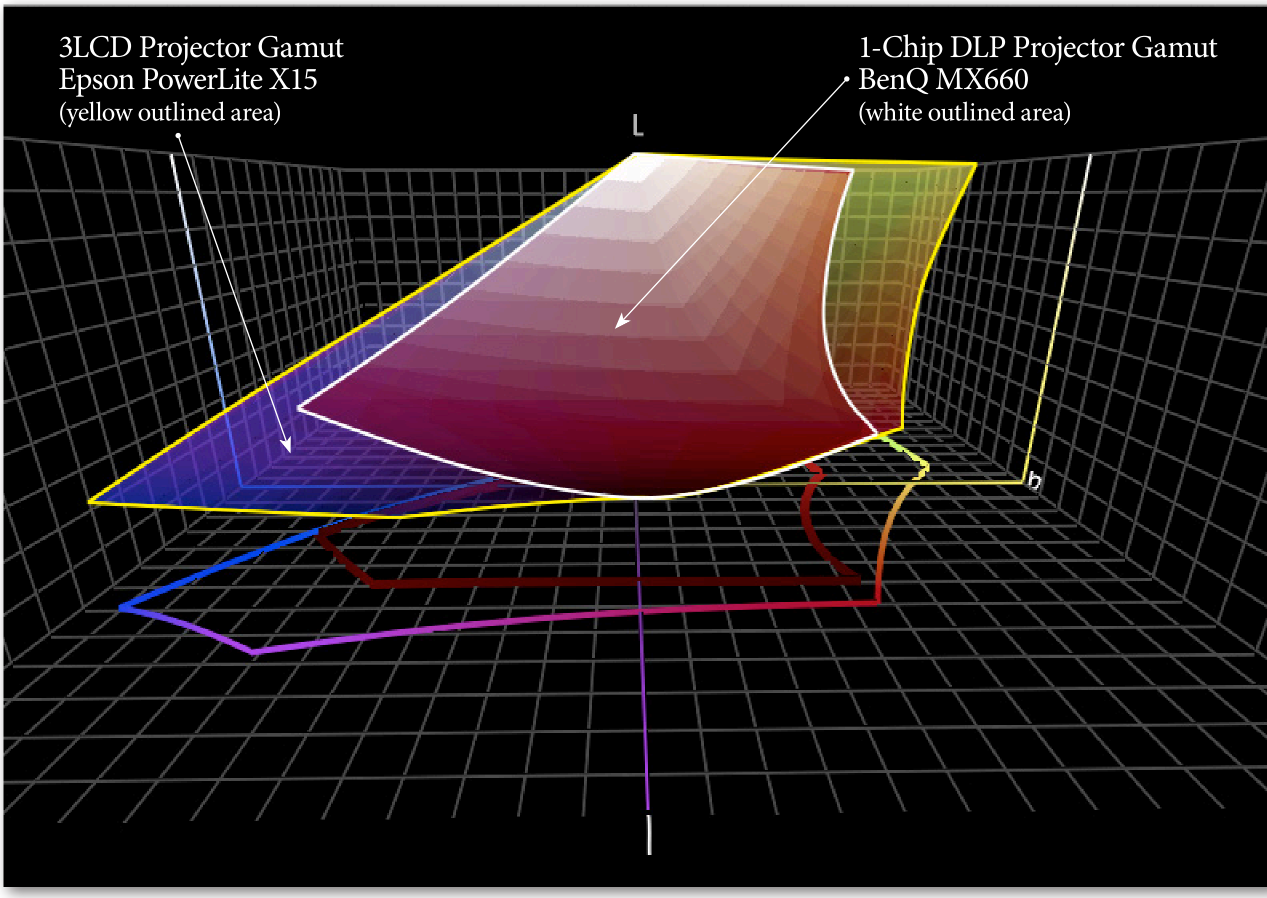

Figure 10: *Standard color management tools were used to evaluate the gamut of a 3LCD and 1-Chip DLP projector. In this L*a*b* diagram we clearly see the smaller shape of the 1-Chip DLP system. These projectors were used in the side-by-side image comparisons shown in Figure 11.*

We clearly see in the side-by-side comparisons the effect of the reduced gamut size of the 1-Chip DLP projector. The darker and duller images 1-Chip DLP examples correlate to the smaller gamut size in *Figure 10*. While the projectors used have a similar White Light Output, only Color Light Output describes the differences seen in these side-by-side comparisons. Thus a single "Brightness" number is misleading and does not describe or predict the color performance of any projector.

3LCD	1-Chip DLP
Color Light Output: 3000 Lumens	Color Light Output: 3000 Lumens
White Light Output: 3000 Lumens	White Light Output: 790 Lumens

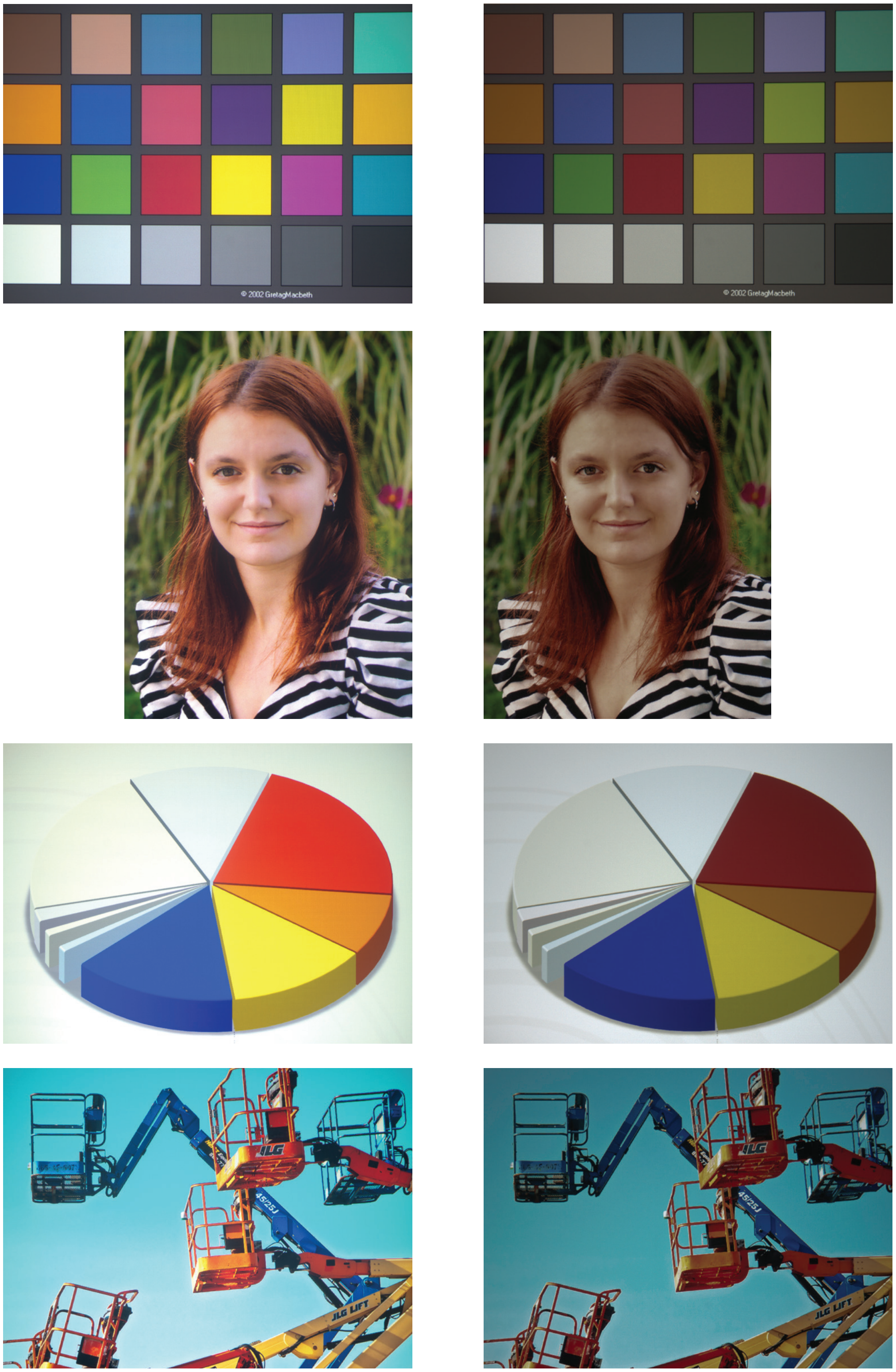

Figure 11: *These side-by-side images were created by projecting images onto a screen and photographing them. A 3LCD (Epson PowerLite X15) projector is compared to a 1-Chip DLP (BenQ MX660P) projector. Both Projectors have a similar White Light Output but a dramatically different Color Light Output.*

Ambient room lighting and projected images

In a meeting room or classroom, ambient light can be a challenge for projectors with low Color Light Output. If the projector has low Color Light Output, projected images and graphs in color will usually appear significantly darker than a projector with high Color Light Output in typical ambient light conditions found in classrooms and conference rooms.

1-Chip DLP manufacturers are bringing to market projectors with White Light Output levels much higher than in the recent past. But beware, in most cases these projectors have Color Light Output numbers that are not only low, but may be going even lower as the White Light Output is artificially boosted at the expense of color.

In most situations presenters and viewers expect projectors to work with reasonable levels of ambient light and only high levels of Color Light Output make this possible. With low Color Light Output, a presenter's ability to communicate using color will be impaired.

Charlie Schuck/Getty Images

Figure 12: *It is important for a projector system to be usable with levels of ambient room lighting found in a typical classroom or conference room. A single "Brightness" number is only a measurement of White Light Output and will not predict how color will project in ambient light levels found in conference rooms and classrooms.*

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12. Summary

- There are two main projector systems used for business and education, 3LCD and 1-Chip DLP. 3LCD projects red-green-blue light simultaneously, 1-Chip DLP uses a rotating color wheel that projects color sequentially.
- Color Light Output is also known as Color Brightness. White Light Output is also known as White Brightness.
- A single "Brightness" number does not provide the information needed to understand a projector's performance. To determine a projector's true performance, look for high values of both Color Brightness and White Brightness.
- Color Light Output is an international scientific standard developed by the International Committee for Display Metrology.

- Basic color science principles clearly show that visible colors can be created by the exclusive use of red-green-blue.
- Adding a clear "white" segment artificially boosts White Light Output at the expense of Color Light Output.
- High Color Light Output is required to successfully project color in typical ambient light found in classrooms and conference rooms.

13. Author's Bio

Dr. Abhay Sharma holds a BS in Electronic Imaging Sciences from the University of Westminster, UK and a PhD from Kings College, London. He has worked as a Senior Research Engineer for Fujifilm Electronic Imaging, UK and was an Associate Professor at Western Michigan University, 2001-2005. Dr. Sharma has served as Chair of the International Color Consortium Working Group and has been on the Advisory Board of CIP4. He has authored many titles in the area of color science including Understanding Color Management, 2004 and co-authored Color Management Handbook, 2008.

14. References

[1] Chromix ColorThink Pro specialist color software

[2] *Information Display Measurements Standard,* version 1.03, June 1, 2012

[3] On *the Theory of Compound Colours* and the Relations of the Colours of the Spectrum, Philosophical Transactions of the Royal Society of London, J. Clerk Maxwell, published 1 January, 1860