Digital Projection Quality

Authored by Jim Sullivan for BOXLIGHT Corporation

About the Author

Jim Sullivan began a partnership with BOXLIGHT Corporation in March 2008 after 34 years at Eastman Kodak Company. Jim spent 20 years as a digital image scientist in all areas of digital color imaging including printing, professional imaging, graphics imaging, medical imaging and government imaging with numerous patents and technical papers. Jim also served as the CTO and COO for the Kodak Theme Park digital system business, the CTO for the Kodak Hollywood Post Production and Special Effects businesses, Cinesite in London and Laser Pacific in Los Angeles, and the COO for the Kodak Digital Cinema business.

Mr. Sullivan's scientific and digital imaging expertise went into the development of BOXLIGHT's proprietary DCI color software. The current DCI software version is loaded onto every Boxlight 3-chip DLP Pro80S3. This leading edge technology makes the Pro80S3 the only projector on the market to adhere to the DCI color standard. DCI is a digital video reproduction standard set by Hollywood; in order to experience the true artistic palette intended by a film's director and production team.

I. Introduction

Digital projectors for professional theaters have become quite affordable in recent years. This is driving homeowners to consider front projection systems for their base broadcast and HD movie rental viewing. Recent consumer electronics reports show home "theaters" are one of the fastest growing home electronics businesses, and digital projectors are approaching a $4B worldwide market. The available home technology is also going through rapid change and now includes the DLP™ technology of high end professional theaters. With these changes the considerations for choosing a projector are broadening beyond just resolution and brightness to include other critical factors; contrast, sharpness, color, digital artifacts, ease of use and ongoing costs. This paper presents some of the overall tradeoffs to aid dealers, professional theater installers and homeowners in their purchase decisions.

BOXLIGHT looks at all factors when integrating solutions, not just one or two numbers as you will see in the Sections below. Our goal is to provide the most compelling and easy to use high end solution in the industry. To BOXLIGHT that means;

- extra bright projectors (greater than 4000 lumens) for audience immersion on 15 foot wide screens and high contrast images even with dim room lighting,
- the sharpest projectors and systems on the market for images that literally jump off the screen,
- providing the first solution with colors that are the same or better than professional theaters to ensure the integrity of the movie's artistic message, and
- ease of use for discerning homeowners.

II. Projector Brightness: Screen Size and the Need for Extra Brightness

The historically accepted standard for specifying the brightness of a projector is ANSI lumens. This is a 9 point area-averaged measurement, center point plus 4 vertices and 4 mid-points of the bounding rectangle, of the visually-weighted, total light falling onto a surface. As noted by various industry providers, lumens can be a misleading standard because it does not take into account the area of the image, the reflectance of the image screen or some of the more subtle timing effects of projectors that change the light level within a frame such as in 1-Chip DLP™. Also many manufacturers will measure the ANSI lumens at the native color temperature that maximizes the measured value, i.e., 9300 K, when indeed they are required to operate at lower color temperatures, i.e., 6500 K, to produce accurate color.

A more viable and understandable brightness specification that is consistent with professional theater standards is Ft-Lamberts. Lumens divided by the area of the projected image in square meters is lux, the visual light intensity per square meter falling onto the screen. The visual light intensity per square foot reflecting from the screen which defines the brightness an audience will see is Ft-Lamberts. If the reflecting screen has a gain of 1.0 meaning that it is a total diffuse reflector and reflects all light to the viewer, then a 1 lumen light source falling onto a 1 square foot area produces 1 Ft-Lambert.

Audiences see the reflected light intensity, i.e., Ft-Lamberts. The professional theater standard for high quality dark viewing is 16 Ft-lamberts. As an example, a 3200 ANSI lumen projector illuminating a 20x10 foot screen (18.58 square meters) with a gain of 1.0 will have a lux value of 161.5 (3000/18.58 sq meters) and a Ft-Lambert value of 16.0 which would meet the accepted standard. The equation is,

Ft-Lamberts = Lumens x Screen Gain / Area in Sq Feet

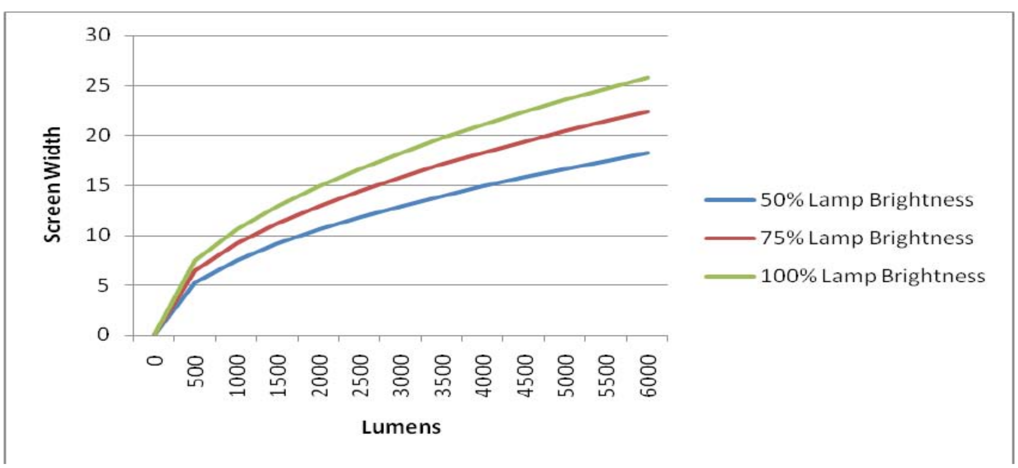
If possible, it is important for buyers to understand that having a projector with extra brightness is a significant advantage. It allows them to, 1) operate at lower wattages to extend lamp life and lower lamp replacement costs, 2) maintain high image quality as the lamp naturally dims over its lifetime, 3) accommodate for variability in manufactured lamp brightness values which can be as high as 20% and 4) allow them to maintain high contrast viewing with dim room lighting (see Section III).

Figure 1 shows the required lumens to achieve 16 Ft-Lamberts for a 16:9 aspect ratio and different screen widths , a screen gain of 1.0 and different levels of % lamp brightness. For a 15 foot screen and lamps at half brightness you need approximately 4250 ANSI lumens to achieve 16 Ft-Lamberts.

Since lamps can have up to 20% lower brightness than the specification due to factory variability and dim up to 20% in their initial 200 hours, it is highly recommended that buyers purchase projectors with extra brightness. For 15 foot wide screens the recommendation is 4250 ANSI lumens or greater.

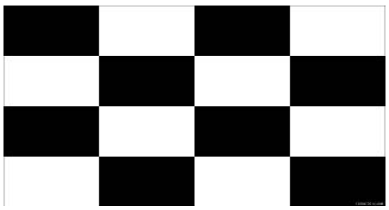
In addition, by lowering the lamp wattage 20%, the lamp life can be increased up to 100% over 4000 usage hours for most DLP™ lamps. That is an increase from 1.5 years to 3 years for a usage of 4 hours a day. With lamp costs up to $600 that can be a savings of $400/year.

Figure 1: ANSI Lumens Required for 16 Ft-Lamberts at Various Lamp Efficiencies



III. Projector Contrast: Vision, Room Lighting, and How Much Contrast and Brightness is Needed

Contrast is a measure of the range between the highest and lowest brightness values a projector can produce. That value can be specified as large area contrast or local area contrast. All measurements are done with no ambient light. For large area contrast the standard is to measure the full screen white point brightness and the full screen lamp off darkness and calculate the ratio. For local area contrast there are various methods. ANSI contrast is defined by measuring a 4x4 checkerboard target illustrated below and calculating the average ratio of white to black.

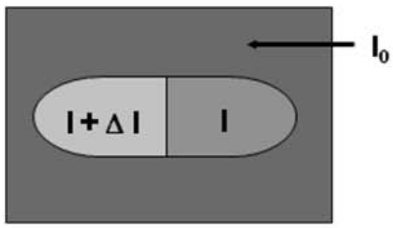


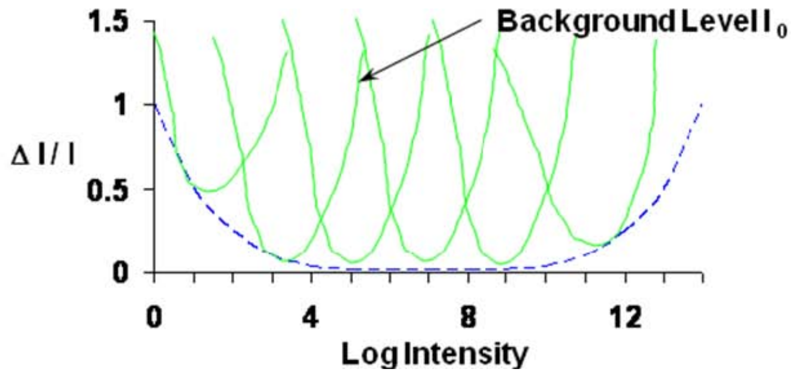
Local area contrast is always lower than large area contrast because light from the bright area “bleeds” over to the dark area all physical projection systems, increasing the dark measurement and lowering the ratio. It is important to know what contrast is being specified, full on/off or ANSI. It is also important to know how the projector was set up for the measurement. Single chip projector manufacturers that employ a filter wheel will measure the full on/off and ANSI contrast values with the “white” filter position in place which inflates the numbers. Both measures are important but for viewing images the local area contrast is the most important because it describes how well the projector will reproduce the image detail.

Human eyes will adapt to a very wide range of brightness values, but there is a limit to the local area contrast where an eye can still see differences. There have been numerous studies that define local area contrast sensitivity. 1, 2, 3 Figure 2 shows a plot of a commonly used local area target and the results from Pratt[1]. The U-shaped curves are at various levels of adapted background brightness, Io. The smallest difference the human eye can see, i.e., the bottom of each U-shaped curve where I = Io, is approximately 0.02 or a 2% difference over a wide range of adaptation levels. As the brightness increases or decreases from this best sensitivity point the eye loses its ability to see differences. The width of these U-shaped curves which is fairly constant at difference brightness levels is a well accepted measure of the contrast range of local adapted vision. You don’t need a contrast range that is larger than this width because the eye cannot see differences anyway. That width is approximately 2.5 logarithmic units or 300:1.

There is some debate about the actual value because it depends on brightness, the exact testing method, how long a person is allowed to look at the test object (local area contrast is much lower for moving objects), age of the viewer and other factors. The data in Figure 2 is for long adaptation and concentration times. The commonly accepted value particularly for moving objects with short concentration intervals is 100:1 or lower.

Figure 2: Contrast Sensitivity Measurements of Human Vision Given that human vision is limited to a contrast range of 100:1 or even 1000:1, there is no justification for the new marketing messages of many projector manufacturers stating that their projectors provide 10,000:1 contrast. You eye simply cannot see that range so it is not worth paying for.



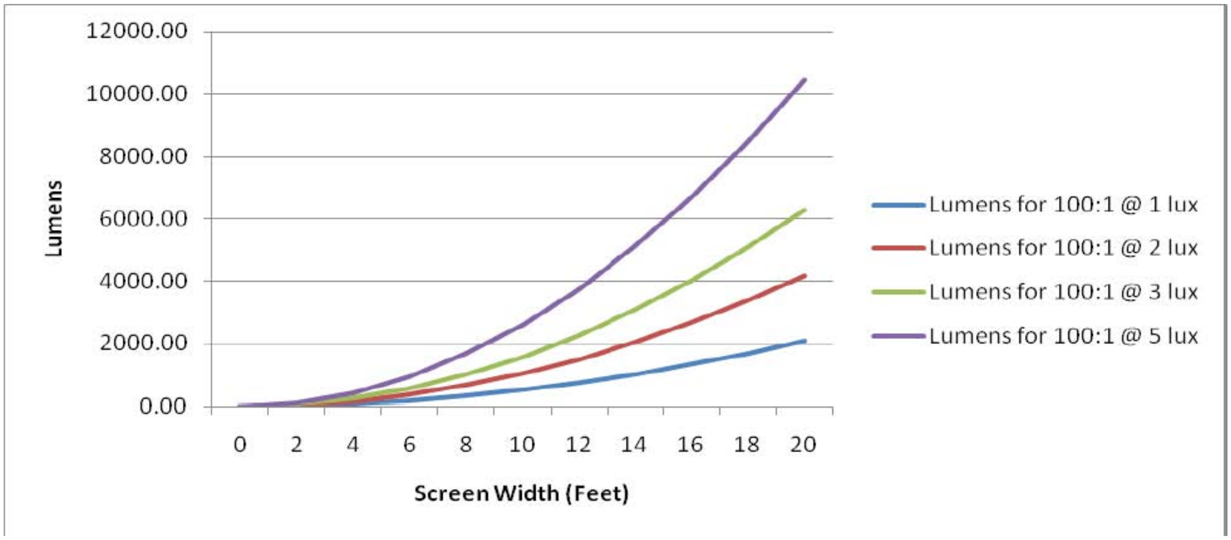


It is very important, however, to recognize that ambient room lighting does have a dramatic effect on the perceived image contrast. Room lights will fill in the dark regions in images and lower the perceived contrast. It is a total misconception that a higher contrast projector will fix this. High contrast projectors will not help because the dark regions will increase significantly due to ambient light whereas the bright regions will only increase slightly making the contrast ratio drop. It doesn't matter how low the dark value of a projector is because the room lights will fill it in anyway.

A single candle in a standard room will add 1 lux of light to the dark regions on the screen. If the screen is 10 foot x 5 foot, i.e., 4.6 sq meters, that is the equivalent of 4.6 lumens. The large area contrast for a 2500 lumen projector will be a maximum of 2500/4.6 or 543:1, no matter how high the contrast ratio of the projector is in total darkness. The only way to increase that contrast is to raise the brightness. Figure 3 shows the required lumens to maintain a large area contrast of 100:1 for different screen widths in feet and a gain of 1.0 at various room light levels. If we use 5 candles, i.e., 5 lux, as our definition of dim room lighting, to maintain 100:1 contrast and not reduce perceived visual contrast for moving objects on a 15 foot wide screen we would need a projector with approximately 5500 lumens.

Again having extra brightness is a significant advantage for high quality viewing in dim lighting. Also, if the projector lamp wattage and brightness can be easily changed by the owner or automatically by measuring the room lighting, then the projector can be adjusted to high brightness to preserve visual contrast with dim room lighting and low brightness in total darkness to preserve lamp life and save cost. Projectors with such flexibility and ease of use provide significant advantages to buyers.

Figure 3: Lumens vs. 1.0 Gain Screen Width for 100:1 Contrast @ Different Ambient Light Levels For ease of use and lamp cost savings as discussed in Section II and the ability to maintain high quality viewing in dim room lighting of this Section, BOXLIGHT will provide the projectors you use in your integrated solutions that have extra brightness without additional cost. The flexibility and continuous delivery of high image quality with that extra brightness are paramount advantages to our customers.

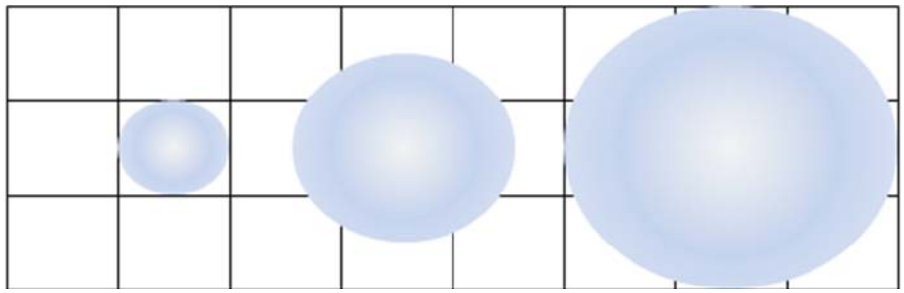


IV. Resolution and Sharpness: What is the Relationship / How do LCD™, Plasma and DLP™ Compare

Resolution or the number of pixels available to create a physical image from a digital record, and image sharpness are not the same. This is a very important concept that is currently ignored by projector manufacturers who do not specify any accepted measure of sharpness leaving buyers open to the often asked question, “I paid more for this higher resolution display or projector, why isn’t it sharper?” If you buy a device with more resolution, i.e., dpi for printers and pixels for projectors and TVs, it must make a better, sharper image, right? The answer is NOT NECESSARILY. We have become so computer literate and focused on bigger numbers that we often forget the basic science of what forms the image. Resolution and sharpness are related but resolution is only one factor of image sharpness that an audience sees. Manufacturers push resolution because it is one number and much easier to control and increase than all of the optical and physical factors that go into creating a sharper image.

Consider the example in Figure 4. The grid represents an array of pixels and the circles represent the brightness values for 3 sizes of image forming light spots created by the optics, electronics and modulation technique of a display or projector.

Figure 4: Representation of 3 Image Light Spots Relative to an Image Pixel Grid



If the image spot is smaller than a pixel as in the first example there is no light overlap with neighboring pixels and there will be unlit or blank areas in the projected image. This will introduced a disturbing grid effect and cause image edges to be heavily jagged and image lines to be wave in and out of existence. In the more sophisticated mathematics of digital imaging this is an extreme case of allowing too much “sample aliasing” to be viewed in converting the digital record into a physical image. This is not a good digital imaging approach. If the image spot is much larger than a pixel as with the third example edges will be blurry and soft. In this case, you might as well have fewer pixels and lower resolution because you cannot see the extra ones anyway. A good image spot is the second one. In this case, the light from the image spots will overlap reasonable well to avoid significant grid effects and aliasing, while maintaining a good match of sharpness and resolution. The spot shape defines the perceived sharpness.

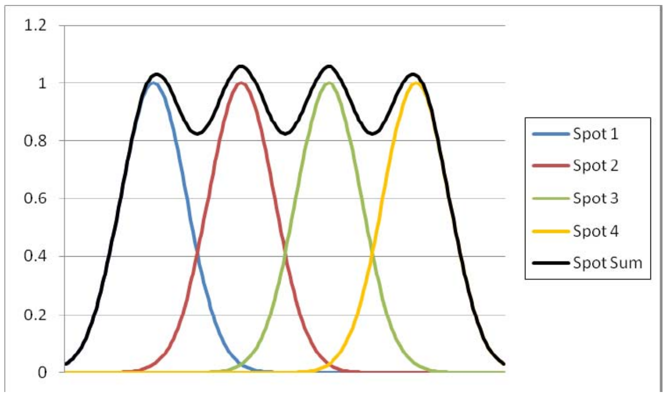
Various studies have been done to define the best spot size relative to the pixel width. In a key study in 1985, Schreiber and Troxel[4] conducted an image quality study of input camera and output display spot sizes with a large number of subjects. He used Gaussian spot shapes and a variety of complex scenes. Optimal image quality occurred when the input and output Gaussian spot shapes had standard deviations of 0.30 and 0.375 of the distance between pixels. The result that the input pixel blur should be less than the output pixel blur or light cross-talk has also been observed in many other visual studies.

The optimal output spot is drawn for four pixels in Figure 5. Note that the adjacent spots do not overlap at their 50% brightness values. Instead they overlap where their brightness is reduced to 41%. This means that you cannot produce a totally constant brightness on the screen as illustrated by the wavy summation of the spots. The Modulation Transfer Function (MTF) of the spot shape is the accepted measure of the sharpness of the output image. A Gaussian spot with a standard deviation of 0.375 of the pixel width produces a system MTF of 0.5 at the Nyquist frequency corresponding to 2 pixels.

Manufacturers measure projector and display MTFs but curiously do not publish them. The reason is perhaps that the predominant projection and display technologies, namely LCD™/plasma/1-chip DLP™ do not have MTFs anywhere near the optimal value of 0.5 at a frequency of 2 pixels. LCD™ and plasmas involve some form of analog process in their image display. Liquid crystal devices whether reflective or transmissive introduce significant blur and color artifacts in the molecular polarization process used for modulation. Plasmas are similar.

Look closely at a white-on-black text image from an LCD™ projector or TV and you will see color fringes and artifacts on what should be pure white text.

Figure 5: Optimal Image Forming Spots from Schreiber and Troxel[4] Study



In a recent article on projector lamps on *Projector.com* entitled “What is the difference between an LCD™ and DLP™ projector lamp?” the quote is made that “As the world’s first 100% digital projection technology, DLP™ stands out of the crowd …”.

The measured MTF values for 3-Chip DLP™ projectors are indeed close to the optimal value 0.5 at a frequency of 2 pixels for all colors. As such, they provide all the available sharpness at the specified resolution without color artifacts. Look closely at a white-on-black text image from a 3-Chip DLP™ projector and see the difference. Step back and the image sharpness will remain apparent from all viewing distances. Images will jump of the screen and have a 3 dimensional depth due to the optimal sharpness.

In a visual image quality study conducted by the author while at Kodak comparing 3-Chip LCD™ and 3-Chip DLP™ projectors at different resolutions with various image types on 30 foot wide screens, it was found that 3-Chip DLP™ at 480P resolution produced overall higher quality images than 3-Chip LCD™ at 720P due to the sharpness loss and lower contrast of 3LCD™. This advantage of DLP™ over LCD™ also extended to higher resolution with 3-Chip DLP™ at 720P producing better images than 3-Chip LCD™ at 1080P. With an increasing larger amount of entertainment content being computer generated, the need for projectors such as DLP™ that produce sharp images is ever increasing. Is it any wonder that virtually all digital projectors currently deployed in professional theaters on screens up to 60 feet wide use 3-Chip DLP™ technology.

BOXLIGHT will demand that the MTFs of its projectors are measured and that they provide the sharpest, most crisp images possible at a given resolution. Today means 3Chip DLP™.

V. Viewing Distance and Resolution: How Much Resolution is Needed, 720P or 1080P

The previous section discussed the relationship between resolution and sharpness. This section discusses the relationship between resolution and viewing distance and what resolution is needed.

Professional theater audiences are viewing digital movies today on 60 foot wide screens with 1,080 lines of resolution. Why do you need 1,080 lines of resolution in your home or commercial installation when your screen is less than 20 feet wide? The answer is not related to screen width but rather to how far you sit from the screen. In a professional theater if the screen is 60 feet wide you are generally sitting at a distance of 60 feet or greater from the screen. In your home or commercial installation, for a 20 foot wide screen, you are closer and generally sitting at a distance of 20 feet or greater from the screen. The ratio of screen width and viewing distance is generally fixed for good full screen viewing with a general rule of thumb that audiences sit at 1.5 times the screen width or greater from the screen.

To understand the resolution needed for audiences sitting 1.5 times the screen width to avoid seeing digital pixels requires an additional understanding of the detailed spatial frequency sensitivity of vision. There have been many studies of the human eyes ability to see image contrast or differences at different spatial frequencies. Figure 6 shows a typical plot[5] for a 10" viewing distance. The Figure is a little complicated with different spatial frequency axes and different measures of contrast sensitivity, but the key point of the Figure is that the eye loses contrast sensitivity at long distances or low frequencies and at short distances or high frequencies. The peak or best contrast sensitivity of the eye represented by the dip in the U-shaped curve at a contrast sensitivity of 0.003 occurs at 0.5 cycles/mm at 10" viewing (scale at the top of the Figure for viewing at 250 mm). At 3.0 cycles/mm the sensitivity is only 10% of the peak. As the viewer moves away from the image, the frequency of peak sensitivity scales directly with the distance. At 100" viewing distance the peak sensitivity is 0.05 cycles/mm. At 1000" viewing distance it is 0.005 cycles/mm and so on.

Figure 6: Contrast Sensitivity of Vision as a Function of Spatial Frequency Figure 7 shows a very interesting plot of the frequency of peak sensitivity of the eye in pixels/foot versus screen width at a viewing distance of 1.5 times the screen width (2 pixels = 1 cycle). The peak visual frequency decreases as the viewing distance increases. The Figure also shows the total number of pixels across the full screen at the peak visual frequency. Since the decrease in peak frequency as the screen widens and the viewer sits further back is exactly compensated by the increased width, the total number of pixels required to equal the peak eye sensitivity is constant. This is a key result, that as long as the audience moves back proportional to the increased screen width, the number of pixels required for good resolution remains constant. For the viewing distance of 1.5 times the screen width the number of pixels required to equal the peak eye sensitivity is approximately 170.

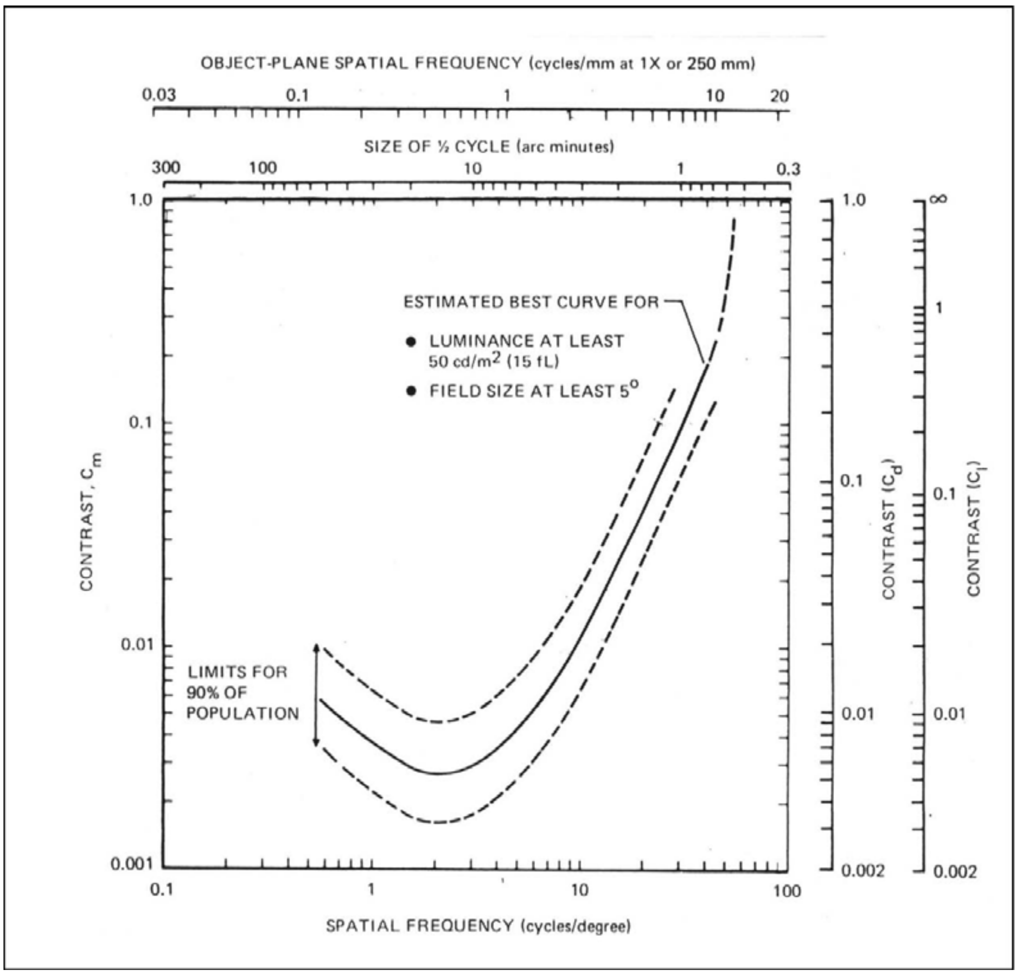
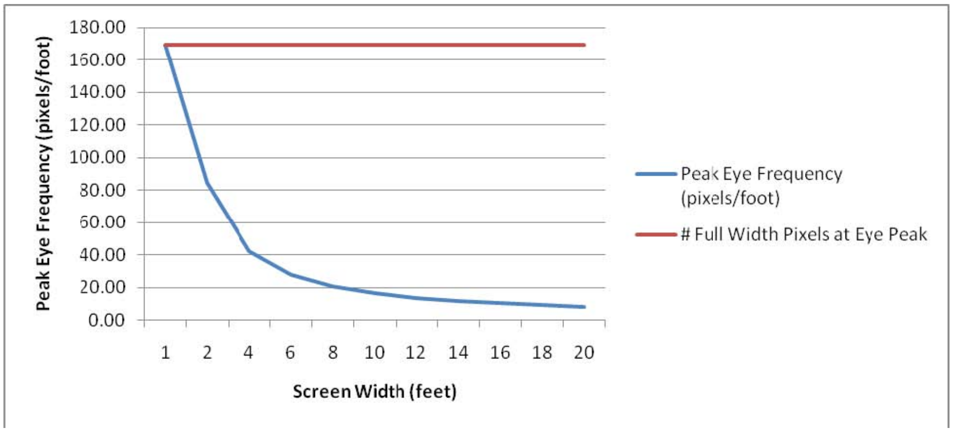


Figure 7: Peak Eye Frequency (pixels/foot) at Viewing Distance of 1.5x Screen Width



Figures 6 and 7 also help answer the question how much resolution is needed. 1280x720 and 1920x1080 have 7.5 times and 11.3 times more pixels respectively across the screen than the 170 pixels of the peak eye sensitivity. Figure 6 shows the visual contrast at 7.5x and 11.3x higher frequencies than the 0.003 peak at 0.5 cycles/mm are 0.04 and 0.07 respectively. Therefore, with 1280 pixels and 1920 pixels across the screen the eye sensitivity is reduced to 7.5% and 4.2% of its peak respectively. Both are significant reductions in an eye's ability to see pixels especially with moving images, meaning that from a resolution perspective the image quality of 1080P and 720P can be similar. The other factors of contrast, brightness and sharpness will be more important to overall quality than resolution.

As mentioned in Section IV, this exact result was observed by the author while at Kodak in a comparison of a 3-Chip DLP™ projector at 720P with a 3-Chip LCD™ projector at 1080P. The higher sharpness and contrast of the 3-Chip DLP™ at a lower resolution produced overall higher image quality. The extra resolution of the 1080P 3-Chip LCD™ was lost by the increased blur. Given 1080P projectors command a premium price; this is why BOXLIGHT considers all imaging factors when offering their projectors.

VI. Color and Creating a Cinema Color Experience

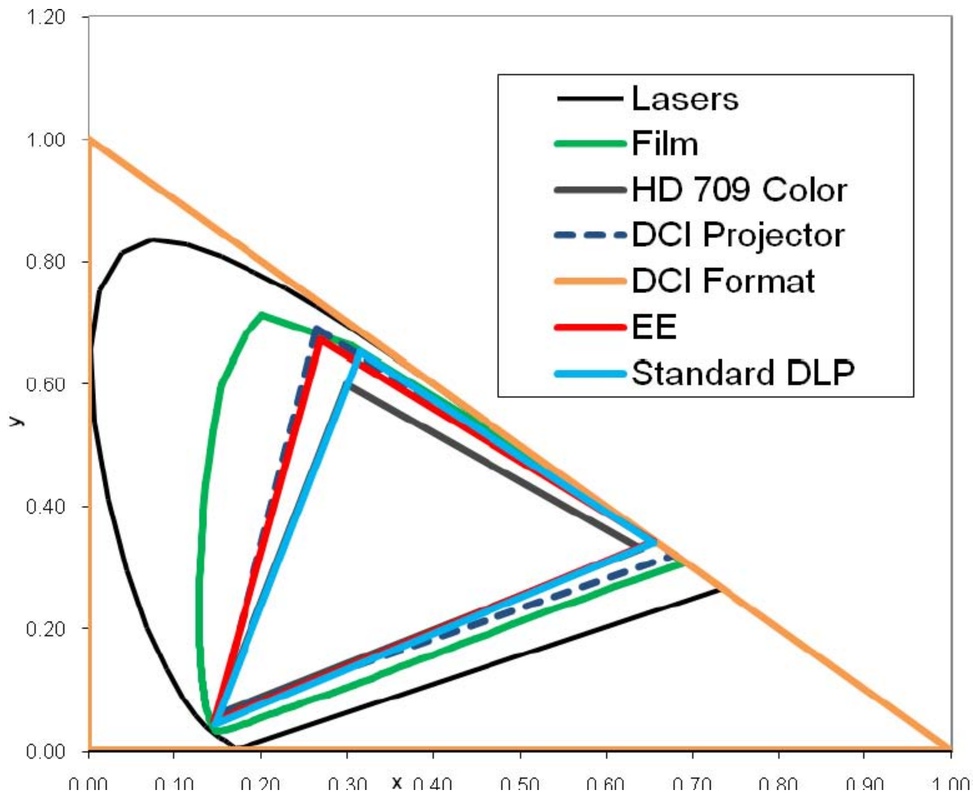
All digital projectors produce colors by adding the red, green and blue primaries together. The number of possible colors a projector can produce is a function of how pure the primary colors are and the overall contrast range of the projector. The purity of the primary colors means how close they are to monochromatic wavelengths or lasers which produce the most pure physical colors. The available color volume is 3-dimensional with planar surface boundaries much like a "diamond". The whitest white is at one vertex, the blackest black is at the opposite vertex, and the color primaries are at mid-brightness vertices out from the central grey axis. With K representing black, the 3-dimensional "diamond" will have 6 bounding planes defined by the 3 vertex points; WGR, WGB, WRB, KGR, KGB, KRB.

The most often used plot of the color capability of a color device is the chromaticity diagram. This is defined by the projection of the red, green and blue tri-stimulus, XYZ, vectors onto the 1, 1, 1 plane of the tri-stimulus vector space. That projection is equivalent to the equations for the chromaticities, xyz,

$$x = X/X + Y + Z \qquad y = Y/X + Y + Z \qquad z = Z/X + Y + Z.$$

Figure 8 shows the chromaticity boundaries of a full range of XYZ values, lasers (spectral locus), Film, Rec 709 for PCs and HDTV, and the native Digital Cinema P3 DLP™ values.

Figure 8: Chromaticity Diagram of Digital Projectors and Film



HD Rec 709, Digital Cinema and XYZ are all linear 3 color systems and therefore the chromaticity boundaries are triangles. As a subtractive CMY color system, film is non-linear so the chromaticity boundary is not a triangle. The laser spectral locus or “horseshoe” represents all wavelengths and therefore contains all the possible physical colors.

Figure 8 shows that the native Digital Cinema P3 DLP™ projector color gamut is larger than Rec 709 for HDTV and computers, but it is smaller than film particularly in the blue-green region. This means that there are no digital projectors today that can exactly produce all the color of film. Can a digital projector produce a good rendition of the film color look so that a home audience has the same experience as the audience in a professional cinema? BOXLIGHT knows how and has the proprietary technology to make it happen with its current projectors.

To illustrate, Figure 9a and 9b show scenes from the movie Narnia rendered in a video Rec 709 color space and in film color space by BOXLIGHT. It is important to understand that this print document cannot reproduce the exact comparison of a video “look” and film “look” on a digital projector, but the images do show the types of differences these disparate “looks” represent. Figure 9b shows that film colors are “softer” with yellowish whites, better shadow detail and higher contrast. These are all due to the non-linearity of film and its subtractive CMY primaries.

Figure 9a: Rec 709 Video Rendering of Scene from Hollywood Movie

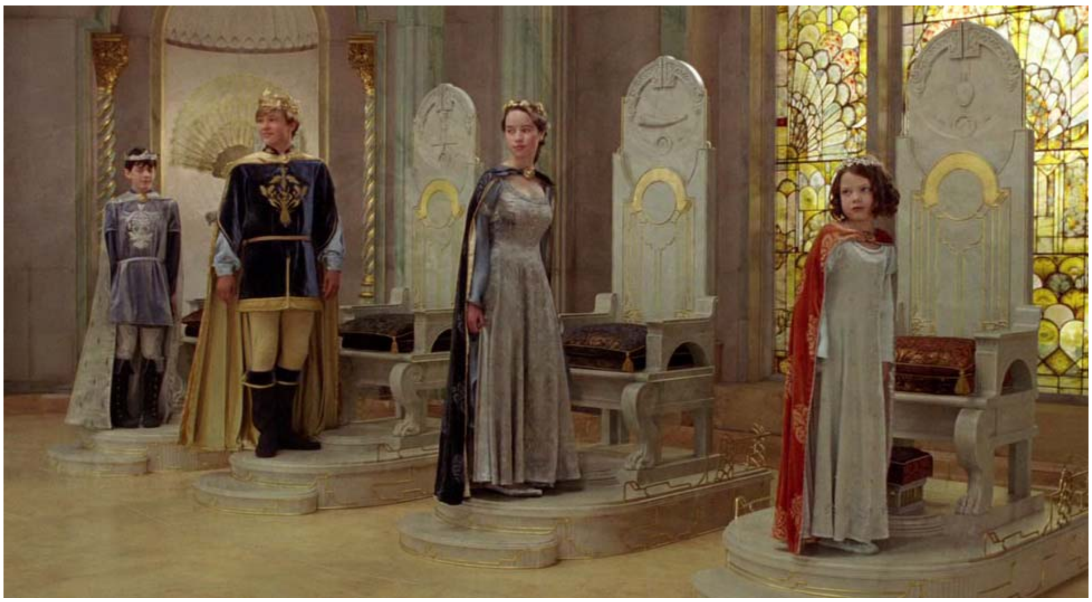


Figure 9b: Film Color Rendering of Scene from Hollywood Movie

BOXLIGHT and its partners understand color; including film color. It is not about white point or calibrating the grey levels of a projector. They are important but those are merely 1 dimensional color calibration. Color is 3-dimensional space and color intent is a 3-dimensional artistic expression. Millions of dollars are spent in post production to set the mood and artistic message of a movie. A movie is not bits any more than a Michelangelo painting is bits. It is art. With its extra bright projector technology that can support extending the chromaticities[6] and knowledge of color, BOXLIGHT projectors will provide the best color match to the professional and artistic intent of the movie in the home cinema industry today and in the future. Guaranteed!

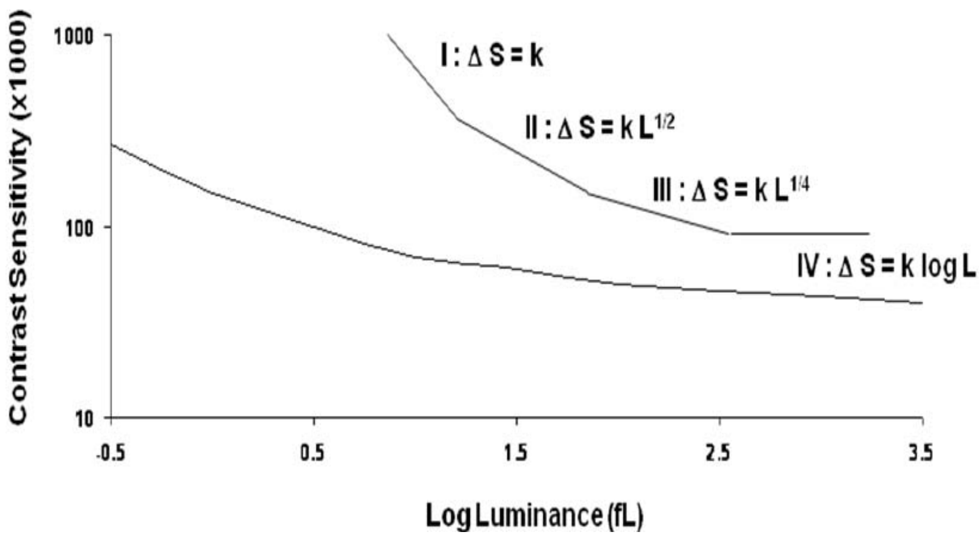
VII. Digital Artifacts

This final Section discusses temporal and spatial artifacts in digital imaging caused by reducing the time and spatial precision of the color data in entertainment content. These are key areas that receive special attention from BOXLIGHT.

There are currently a number of projector manufacturers introducing 1 Chip DLP™ projectors with rotating color filter wheels at 1080P. Considering the fact that a 3 Chip DLP™ at 720P has 33% more color pixels than a 1 Chip DLP™ at 1080P, 3 times the brightness because it projects all colors at once, and does not exhibit disturbing color “rainbow” artifacts on fast moving objects, the buyer needs to aware when choosing a 1 Chip over a 3 Chip DLP™ projector. It is also not clear that there won’t be issues with the mechanical filter wheel as the projectors age. Images are 3-color and a high quality projector should be 3-color. All professional theater projectors are 3-color at all pixels all the time and to achieve a True Color experience in the home theater it must be the same. We have looked at annoying color fringes on the TV weatherman’s checked shirt long enough.

A second key area that can introduce digital artifacts is not having enough bits. If this is the case, the images will exhibit step contours in areas of gradually changing brightness. Systems and projectors must have enough bits at every step of the workflow or contouring will occur. Most system or projector providers use a compressive power law, e.g., 0.45, to encode the image color signals because the human eye is significantly more sensitive to brightness gradations in dark regions and for a given number of bits a compressive power law will make contouring less visible.

One issue with this approach is that the human eye is not exactly a power law and in fact the shape of its non-linear sensitivity varies significantly throughout the eye’s brightness range. This was demonstrated by Blackwell[7] and is shown in Figure 10 along with different functional models that do not match the sensitivity over its full range. Using this sensitivity function, the author[8,9] calculated the number of bits needed to maintain invisible contouring for linear and logarithmic bit usage at a background luminance of 500 Foot-Lamberts and a brightness range of 3000:1 to be 15 and 10 respectively. The author also showed that a power law of approximately 0.20 is near optimal for that viewing environment with a significantly lower visual error than a logarithm or a 0.45 power law. If one is allowed to model the human visual system exactly with a piece-wise linear fit, the author found that it requires 344 linear segments or 8.43 bits to maintain invisible contouring of the 3000:1 range. This is a key result that with a perfect visual model you need 9 bits.



The method for creating the color look-up-tables (LUTs) that map to the non-linear compressive color space is also important. The most common technique is to sample the compressive function, i.e., power law to create the discrete mapping LUTs. It is easy to see, however, that this approach does not use all output bit levels when the compressive function has a high derivative and changes rapidly. Table A shows specific levels for a 12 bit input to 8 bit output LUT using a 0.33 power law and 3.5 logarithmic range. The input levels noted by 0's have no corresponding 0.33 power law output levels. In total 12 of the 256 output levels are lost. The author [8, 9] examined this and alternate methods that use all output levels. In the referenced papers, the author shows that the total visual error can be reduced over 20% by using optimization methods to construct the LUT.

Table A: 12 Bit to 8 Bit LUT for 0.33 Power Law

8 Bit Output Level	12 Bit Input Level Cube Root Power Law
1	1
2	0
3	0
4	0
5	2
6	0
-	
36	27
37	29
38	31
39	32
40	34
-	
254	4026
255	4071
256	4096

BOXLIGHT and its partners understands digital and has introduced proprietary technology in its projectors and systems that take advantage of that knowledge to avoid all digital artifacts and create the highest quality theater experience available.

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