The White Paper: Considerations for Choosing White Point Chromaticity for Digital Cinema

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Abstract

Selection of the white point for digital cinema has been an ongoing debate involving art, technology, and religion. SMPTE 196M specifies color temperature and tolerance for film based movie theatres. This paper examines the actual color differences allowed in this specification, and examines the color differences within a single specified correlated color temperature (CCT) measurement. The emerging digital projection technologies will allow much tighter control of white point chromaticity. This paper recommends the use of more precise chromaticity coordinates instead of CCT to specify white points, and recommends a white point and tolerance applicable to digital cinema projection.

Introduction

The selection of white point impacts most aspects of production and display of cinema. It affects the creative palette, and applies technical design constraints on the projection system.

Digital projection systems have the capability of being accurately tuned to achieve given white points, however, this tuning can detract from important performance aspects– specifically light output and dynamic range.

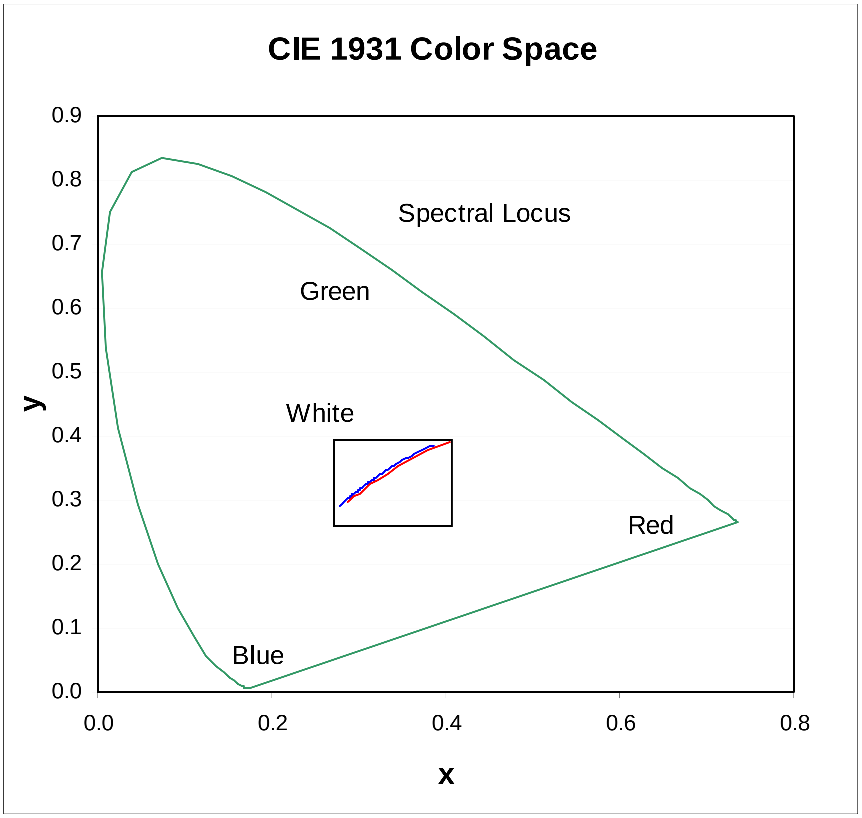
In this paper, we will discuss technical, creative and operational issues that impact the white point selection. Our objective is to point the way toward a white point selection that enables excellent images, accurate reproduction & optimal technical performance in theatres.

Note that the colors in Figures 2a and 2b are intended to represent exact colors, in the CD-ROM version of the proceedings. They have been produced to provide the correct colors on a monitor set for D6500 color temperature, and gamma of 2.5, with Rec. 709 phosphors.

Color Temperature, Correlated Color Temperature and White Point Chromaticity

Color temperature is a term used to describe the color quality of white light. It originates from the color of a black body radiator which has been heated, and the temperature of the radiator in degrees K describes the color of the light produced. A low color temperature appears yellowish or reddish, a high color temperature appears blue. From this point of view, color temperature exactly describes the color of an object.

Running parallel to the black body curve is the D illuminant curve. It is a curve of natural white points measured from daylight illumination in nature, and is slightly offset towards green from the black body curve. Color temperatures such as D-6500 refer to the Daylight curve.



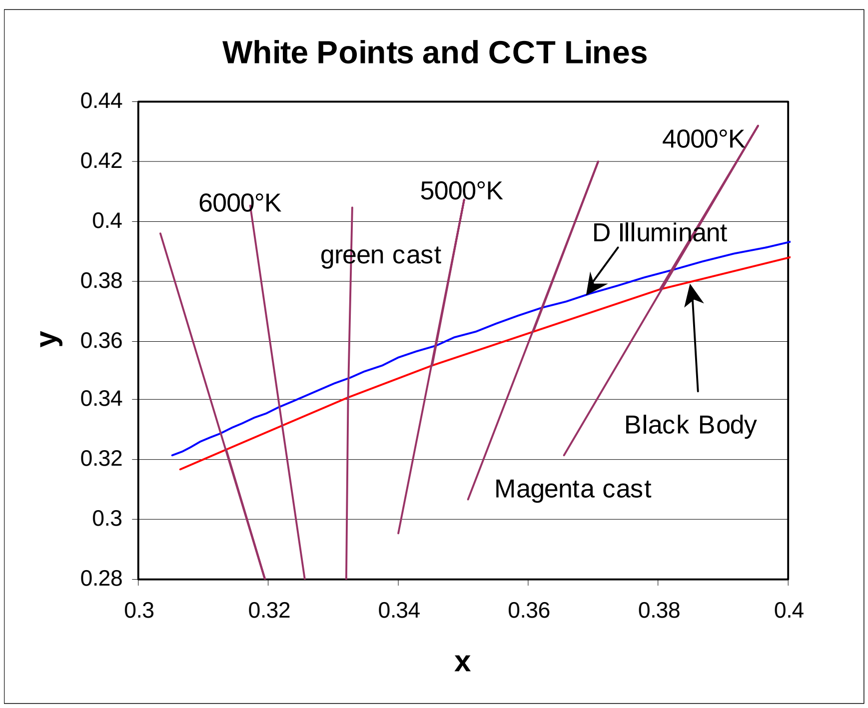


Figure 1: CIE 1931 color space showing spectrum locus, Black Body and D Illuminant curves. Lower diagram is an enlargement of the white area of the color space, showing the isothermal color temperature lines.

In practice, the actual color of white delivered by an illumination source or a movie projector is not on the black body curve, but displaced from the curve, either above it or below it due to spectral response of the illumination system, including the illuminator itself. **Correlated color temperature (CCT)** is used to assign a color temperature number to the color of white projected, using an appearance criterion to match the color to the color temperature on the black body. This definition creates "isothermal" lines (lines of constant color temperature), which cross the black body curve at an oblique angle (see Figure 1). With this definition, it is possible to assign the same color temperature number to a range of colors. This creates large potential differences in the way a white object may look – from neutral (on the black body curve), to magenta (below the curve) to green (above the curve). See figure 2B.

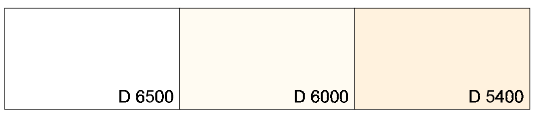


FIG 2A
Color patches showing difference in actual color between 5400, 6000, and 6500°K

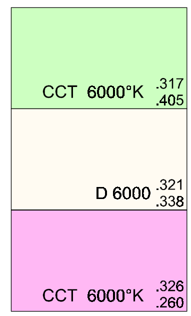


FIG 2B
Color patches showing difference in 3 colors each with a CCT of 6000°K

To avoid the ambiguity of having several colors specified by the same color temperature number, the color can be exactly specified using white point chromaticity coordinates. Note in Figure 2 that the colors with the same CCT have significantly differing hues and chromaticity coordinates. Note in the colors of Figure 2B that color points x=.317,y=.405, x=.321, y=.338, and x=.326, y=.260 have the same color temperature, but are quite different in actual color.

pObviously, systems operating at a specified color temperature can provide significantly differing looks to the resulting picture by being at opposing ends of the isothermal line. For this reason, we need to address the color of white through more precise specification than color temperature.

Choosing a White Point Chromaticity

Perceptual considerations for white point chromaticity

The human visual system is very capable at chromatic adaptation. On the first order, variations in the color of illumination light (or white point) results in colors that continue to appear to be the correct color. Think of observing common objects under tungsten (yellowish light) and daylight conditions. We might remember these as appearing similar from one illumination source to another. An apple looks red under either situation.

When observed more closely, this change in illumination color results in significant alteration to the absolute and relative appearance of colors. The useable color space becomes distorted. When a scene is taken from daylight to tungsten illumination, substantial compression occurs in the yellow – orange area resulting in less visual difference in those colors. This is particularly problematic in skin tones. Luminance of specific colors also varies. For example, dark blue in daylight will appear as black under tungsten illumination.

This variation in relationships will change the tone of an image, and its "look". For this reason, it is important that the material be produced for, and the color relationships balanced for, the color of the ultimate projection display.

Creative Considerations for White Point

Nature provides a range of white points in our normal interactions. Kodak references the color temperature of several sources in their cinematographers' guide (4).

Source	Degrees K
Artificial Light	
Candle Flame	1850
100-Watt Incandescent Tungsten Lamp	2865
3200-Degree Kelvin Tungsten Lamp	3200
White Flame Carbon Arc Lamp	5000
Xenon Arc Lamp	6420
Daylight	
Sunlight: Sunrise or Sunset	2000
Sunlight: One Hour After Sunrise	3500
Sunlight: Early Morning	4300
Sunlight: Late Afternoon	4300
Average Summer Sunlight at Noon (Washington, D.C.)	5400
Direct Mid-Summer Sunlight	5800
Overcast Sky	6000
Average Summer Sunlight (plus blue skylight)	6500
Light Summer Shade	7100
Average Summer Shade	8000
Summer Skylight Will Vary from	9500 to 30000

Cinematographers will choose a white point to create a desired "look" to the picture. Depending on the situation, they may choose a warmer (more yellow) color, cooler (more blue), or even a cyan cast. Currently, this is done by color timing in the film production and post-production processes.

The cinematographer needs a white point which will allow him freedom of artistic expression, and the ability to achieve brightness and contrast within his picture. He needs to properly represent the full intended color range and relationships while delivering the overall "look" needed to tell the story.

It is additionally important to the cinematographer that the white point will be similar in all theatres where the picture is to be shown. (It is interesting to note from the data in figure 3, and the color patches in Figure 2A that this is not available to the cinematographer in today's film theatres.)

Current Film Practice

SMPTE 196M defines the white point for a movie theatre as 5400°K +600° -200°. This gives a range from 5200° to 6000°, and makes no specification of actual chromaticity tolerances. This is intended to be the color of white light on the screen, and is the result of a xenon lamp source modified by the reflector, the projection lens, the port glass, and the screen color. Each of these elements contributes to changing the color of the reflected light from the screen.

In preparation for this paper, we wanted to know how the current film based system performs. For this, we gathered white point chromaticity data from operational theatres. THX and Texas Instruments provided us access to a theatre data measurements made in 1999, 2000 and 2001, and we referenced screening room data published by Berggren in 1997. All measurements were made with Minolta CS-100 colorimeters or with Photo Research PR-650 Spectroradiometers.

The white point chromaticity data was collected from 124 screens. Measurements were of reflected light from the screen, with no film in the gate, and the shutter running. The data is from Berggren(1), and private measurements made in theatres in northern and southern California. The results are shown in figure 3. Note that the color temperature ranges from below 4700°K to greater than 6800°K. Less than 7% of the screens fall below (on the magenta side of) the D-Illuminant curve. The mean of the distribution is x=.326, y=.352. This is significantly on the green side of the D-Illuminant curve.

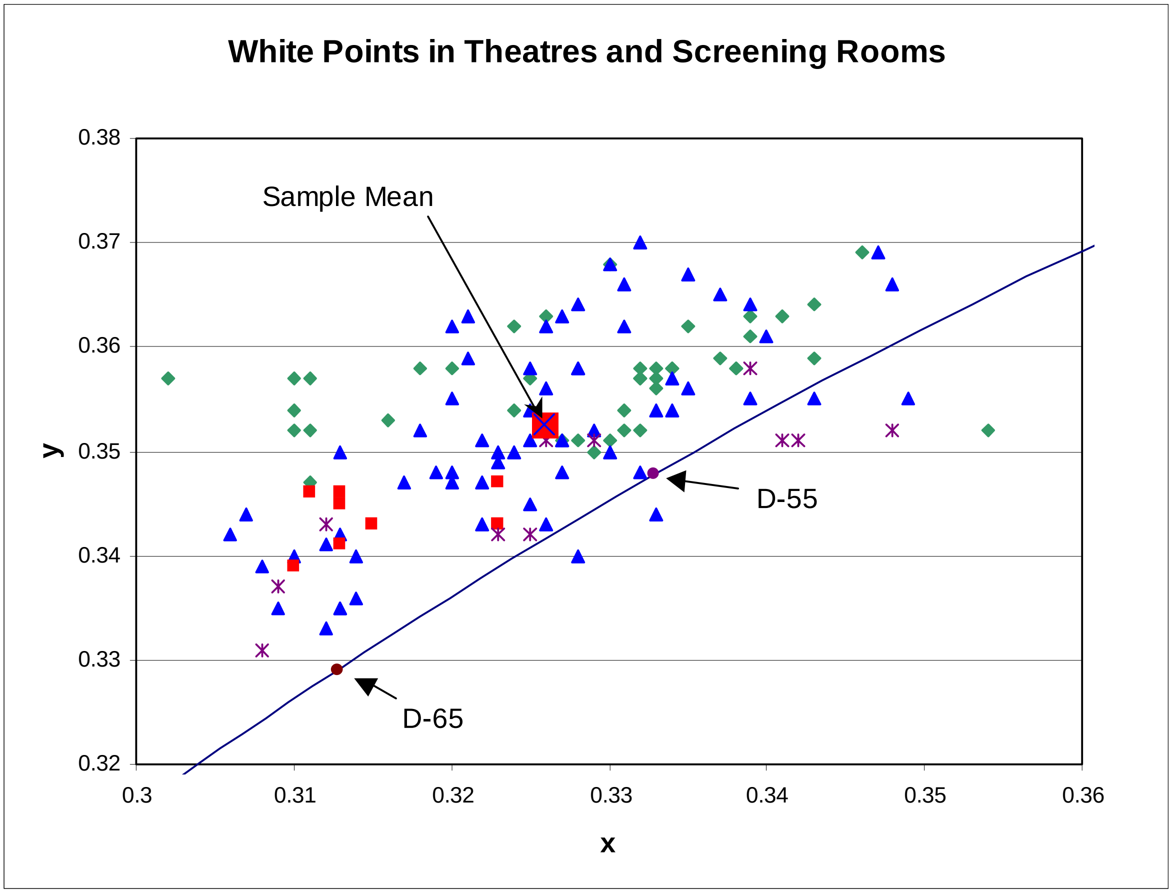


Figure 3: White point chromaticity from measured Film Projection screens in operational movie theatres.

In practice, this means that when a cinematographer creates a picture intended to be shown on a 5400°K projection device, the actual theatre will provide a wide array of differing white point colors for the work, and resulting variability in the look of the projected image. Berggren (1) discovered with his measurements of Hollywood screening rooms and labs that even these locations show a wide variability in white point, spanning a similar range from less than 4800° to more than 6700°. To put this variation into visually significant terms, the color difference across this sample is 48 ΔE* units, or about 16 JND's. This is about one third of the total color difference between D-6500 and bright yellow, effectively eliminating one third of the color variation available between white and yellow. The largest deviation toward green represents 24 ΔE* units in color difference.

Technology Considerations for Digital Cinema White Point

Film projectors use colored film to modulate a single beam of white light. Digital projectors make their images from 3 color components – red, green, and blue. These primaries are modulated and mixed to produce the full range of displayable colors. Included in these is, of course, white. Through electronic modulation of the RGB channels in the projector, we can set the projector to produce virtually any color of white, and as a result we could choose any white point chromaticity.

There is a performance cost to a system, which has variable white point. In an electronic display system, the white point is normally adjusted by changing the contribution of RGB primaries, which are mixed to make white. The most efficient systems will mix all the available R, G, and B to create white. To adjust the white away from that point will require that the contribution of one or two of the components be reduced. Reducing the component contribution will reduce the overall luminance of the display, and thus reduce its light output. This also has the effect of reducing off-to-on contrast ratio, because the black level (in a modulator based display) is fixed. Reducing the maximum light output without reducing the black level light output will cause reduction in contrast ratio. The performance penalty of reducing luminance or dynamic range is very high. To avoid these penalties, the system needs to be designed for a specific and optimal white point with a reasonable tolerance.

The illumination system of a high brightness projector is typically achieved through a high intensity xenon arc lamp. Xenon emits a spectrum which emulates white daylight, with color coordinates of x=.322, y=.320. This is very close to the black body curve. In practice, the lamp is mated with an illumination system, which must eliminate the damaging IR and UV components of the light. These filters will eliminate some visible light in the blue and red ends of the spectrum, leaving the light on the green side of the black body curve. While it is possible to trim the color of the illumination light using dichroic filters in the illumination system, these filters will necessarily reduce the amount of light output, and effect the efficiency of the system. They are therefore not used.

Projector design will be impacted by choice of white point. The highest performance projectors will be achieved with a fixed white point target, which is on the green side of the D illuminant curve.

Practical White Point Management in current Digital Cinema Trials

The ongoing digital cinema trials have several objectives for white point chromaticity

- Provide a useable, neutral white point
- Provide efficient light output, and high contrast
- Provide tight tolerances for a similar look in all theatres
- Ensure that digital masters can be created using existing post production equipment

An additional objective is to achieve a color timing in the digital cinema master which can easily translate to color timing for video release, to allow easy migration from the digital cinema master to the video master.

Tests were done with a limited number of expert subjects to determine a neutral white point for starting. A test screening situation was set up in a digital mastering theatre, using a DLP Cinema™ projector. White points for testing were chosen and programmed into the projector. Test material was played from film through a telecine and DaVinci color corrector. A range of white points was reviewed, bounded by SMPTE 196M specification, and the D-6500 white point. Excursions to the green side of the D illuminant curve were chosen because of practical efficiency issues discussed above.

The subjects were asked to comment on the hue of the white they were seeing. The whites observed ranged from x=.310, y=.329 to x=.330, y=.360., Observers chose colors that appeared relatively neutral, and a target of x=.314, y=.351 was agreed to. The observers developed consensus based on achieving a neutral white appearance, and the ability to achieve a full and broad range of skin tones.

The second part of the experiment was to determine the range of acceptable tolerance for theatrical projection. As we have seen above, significantly different colors are being projected in current theatres, and these change the look of the projected piece. The result was a specification with a central target white point and a specified acceptable tolerance on that white point. These were specified in chromaticity coordinates, not color temperature. (See figure 4)

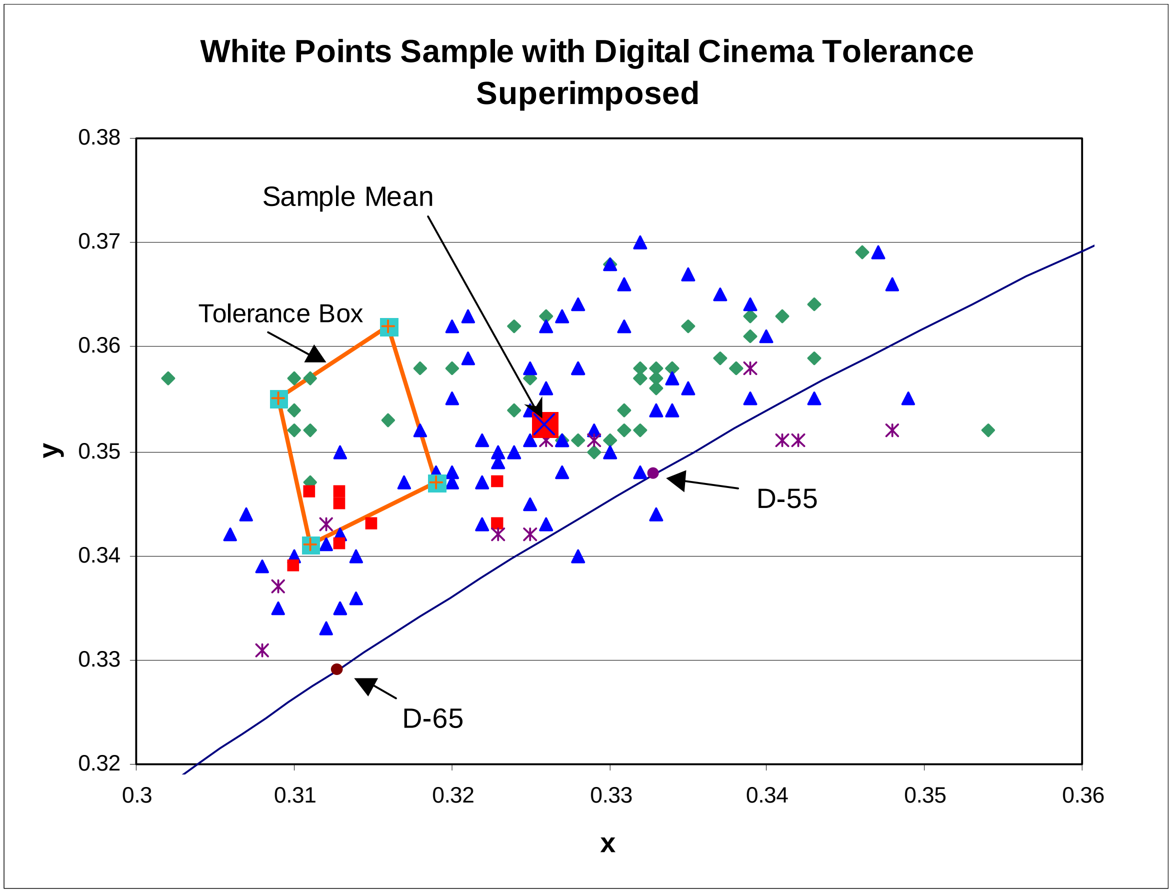


Figure 4: Theatre sample with digital cinema white point tolerance limits superimposed.

In theatrical practice, the digital master is created using a white point set for the target, which is the center of the tolerance box. In the theatre, the digital cinema projector is adjusted to a white point which maximizes projector light output and contrast while staying within tolerance. Tolerance limits were defined around the selected white point, with 7 ΔE* variance across. This tolerance is very tight in color difference terms, and ensures that images will maintain the same look from telecine to theatre.

These tests demonstrated the ability to achieve color balance and relationships on a variety of different materials. Subsequent to the tests, six films have been mastered and released using this white point and tolerance strategy, with good results.

Conclusions

Current practices for white point specification and implementation are inexact.

- White point is current specified by Correlated Color Temperature, a single number which describes a range of colors. This practice should be replaced by using a pair of chromaticity coordinates to exactly specify the desired white point chromaticity

- Current theatres vary widely in white point chromaticity. Digital cinema offers the possibility to significantly tighten the color temperature used in theatres.

Tests have concluded that:
- Choosing a white point of .314, .351 represents the optimization of combined creative, technical and operational requirements
- A moderate tolerance box around the target white point allows the projector to maximize its light output in theatres & assures repeatability from mastering facility to theatre, and among theatres.

Operational experience with digital cinema trials indicate that the white point tolerance can be set up and maintained in theatres.

Acknowledgments

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References

1. Berggren, Glenn, "The Color of Light on the Screen – New Measurements at Studios and Laboratories", SMPTE Journal Vol 106, pp. 156-158, 1997.
2. Poynton, Charles, "A technical introduction to Digital Video", John Wiley and Sons, Inc., Toronto, 1996.
3. Wyszecki and Stiles, "Color Science, Concepts, Methods, Quantitative Data and Formulas", Second Edition, John Wiley and Sons, New York, 1982.
4. Kodak Motion Picture Imaging, "Approximate Correlated Color Temperature for Various Light Sources" http://www.kodak.com/country/US/en/motion/support/h2/temp.shtml