DLPC34xx Controller Image Calibration

Kyle Rakos, Tony Lee, and Susan Ji

ABSTRACT

This application report introduces the basics of image calibration when using TI DLP® Technology. First, a brief background describes the concept of white point and what can affect it. Then various approaches are discussed on how it can be changed. It also discusses the calculations needed to adjust white point using duty cycles. Finally, the method to change white point on the DLPC34xx controller in a production environment is detailed. This method may be useful for both design and production engineers and technicians.

While this application report is intended for systems using DLPC34xx controllers and associated DMDs (digital micromirror devices), it may be partially useful for any system utilizing DLP technology.

Contents

Trademarks

DLP Pico is a trademark of Texas Instruments.
DLP is a registered trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

1 Background

1.1 White Point

White point, or color temperature, is the color reproduced with full brightness from the red, green, and blue primaries [1]. In other words, it is the color that is considered to be white. For example, older incandescent light bulbs produce a *white* light that is *warmer* (more red) compared to newer LED light bulbs which produce a white light that is *cooler* (more blue).

The terms *warmer* and *cooler* refer to the use of temperature to determine white point. A typical white point may be 6500K or 5500K. These temperatures correspond to the color emitted by a theoretical black body at the given temperature. These white point temperature values can be plotted on a standard CIE color space graph as shown in Figure 1.

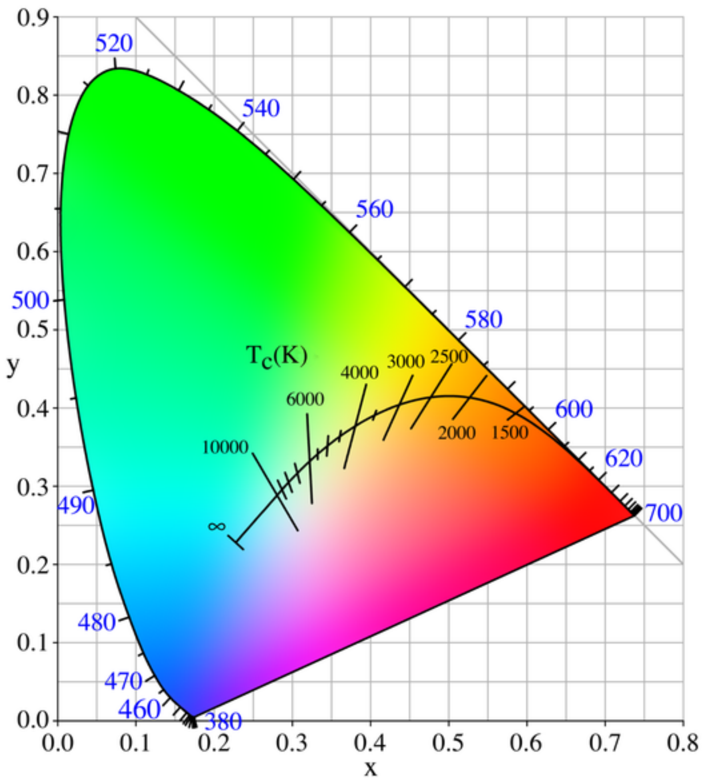

Figure 1. Color Space [2]

1.2 How LED Duty Cycles and Currents Affect White Point

In DLPC34xx systems, colors are reproduced through time sequential illumination synchronized to the DMD mirrors. A simplified example of displaying an all white image frame is discussed.

All DMD mirrors flip into the on position and are illuminated by a red LED, then a green LED, and lastly a blue LED. The human visual system integrates this illumination pattern into a white image. This repeats for each frame. Each illumination period (also referred to as a color's duty cycle) could be divided into equal segments as shown in Figure 2. Assuming a 60-Hz frame rate, each color is shown for (1 / 3) / 60 seconds (5.56 ms). To show a different color, the individual mirrors on the DMD turn off during all, or portions of, an illumination period. For example, yellow can be created by turning on the mirrors for only the red and green illumination time.

Figure 2. Equal Segments

Theoretically, an RGB (red, green, blue) duty cycle of 33.33, 33.33, 33.33 can be used (as described above). Often a duty cycle closer to RGB 30, 50, 20 is used in order to achieve the desired white point. In other words, 30% of the time is allocated for red, 50% for green, and 20% for blue as shown in Figure 3. By changing the duty cycles one can therefore change the white point. For example, a higher red duty cycle will shift the white point warmer.

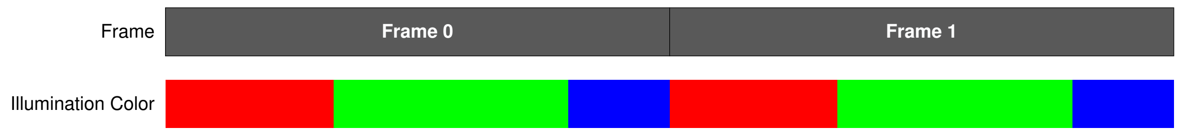

Figure 3. Nominal Segments

In addition to changing duty cycles, the current of individual LEDs can be varied. As an example, let us assume the nominal LED current is set to 5 A but we desire to create a warmer white point. We could increase the red LED current to 6 A while leaving the green and blue LED current at 5 A (assuming of course 6 A remains within the LED specification). This higher current outputs more red light per unit time and therefore shifts the white point to a warmer level.

1.3 Looks

In DLPC34xx systems, various *looks* can be created which can each have a target white point. A system may have different target white points for various situations (such as a cinema mode and a vivid mode). Each look has a specific duty cycle associated with it that corresponds to the desired white point. Additionally, looks may be further optimized for different situations (such as looks for 2D and looks for 3D).

1.4 Color Coordinate Adjustment (CCA)

Digital images are composed of pixels which can be represented by a 24-bit RGB value. Each color is therefore represented by 8-bits and is 0 (full off), 255 (full on), or somewhere in-between. Therefore, to input an all-red pixel to the DLPC34xx system, send a value of (255,0,0). When the DMD recreates this pixel on a DMD mirror, the mirror is on and reflecting light only during the red illumination period. While this behavior can generally be assumed, there are times where it may be desirable to change this behavior.

For example, there may be a situation where an input pixel value of RGB (255,0,0) is desired to be transformed into a value of (255,15,0). This enables one to change the white point of the projector through relatively easy firmware settings. However, the CCA is done in nonlinear space and therefore this is not generally a suggested approach.

1.5 Gamma

As previously mentioned, digital images are composed of pixels which can be represented by a 24-bit RGB value. Each color is therefore either 0 (full off), 255 (full on), or somewhere in-between. While one may expect a pixel value of 128 to correspond to a human eye perceived brightness of 50% and a light energy output of 50%, in reality the human eye perceived brightness and light energy output are not the same. Gamma encoding takes into account this non-linear relationship between light energy and human eye perceived brightness.

A pixel value of RGB (128,128,128) that uses standard gamma-encoding will appears to the human eye as 50% of full brightness. However, before being displayed, a gamma decoding function (sometimes called a degamma function) is used to change the light energy output to 22% of maximum brightness. Therefore, the DLPC34xx controller takes the gamma encoded value and applies a gamma decoding function to the value before display on the DMD.

The below equation takes a gamma encoded decimal value ($V_{encoded}$) between 0 and 1 and outputs a decoded decimal value ($V_{display}$) for display between 0 and 1. This can be scaled for any input and output value range (such as 0 to 255) [3].

$$V_{display} = V_{encoded}{}^{\gamma}$$

A typical degamma curve has γ = 2.2 as shown in Figure 4. Different values of γ can be used for different gamma encoding schemes. Additionally, various degamma curves can be created for specialized use cases and system optimization.

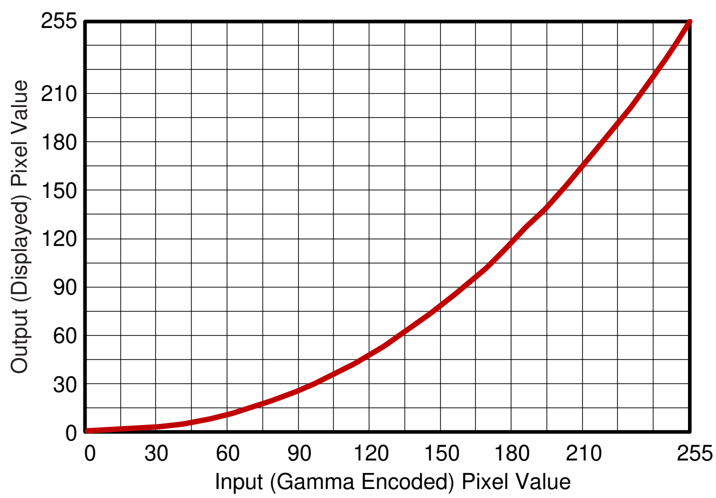

Figure 4. Typical Degamma Curve (γ = 2.2)

1.6 Color Science

Colors are often measured using three numbers referred to as tristimulus values. These three coordinates have amplitudes proportional to intensity [4]. A wide variety of coordinate systems exist. The RGB system uses straightforward red, green, and blue (RGB) values. Each color is composed as a certain amount of each RGB color. If using 8-bit color values, each color is between 0 and 255. An example image is shown below consisting of the indicated RGB colors.

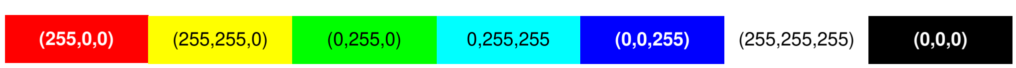

Figure 5. Example RGB Colors

However, a more often used color space in color science is the CIE (Commission Internationalle de L'Éclairage) 1931 color space. This color space uses XYZ tristimulus values where XYZ are imaginary primaries that are useful in avoiding negative values that would arise in the RGB color space.

Y is proportional to luminance in the CIE 1931 system. However, the luminance component can be removed by normalizing the XYZ value to two chromaticity values x and y (z is defined but it is redundant).

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z} = 1 - x - y$$

To use the chromaticity values along with luminance, xyY values can be used. If needed, the X and Z tristimulus values can be calculated back from the chromaticity values x, y and the Y value:

$$X = \left(\frac{x}{y}\right) \times Y \qquad Z = \left(\frac{(1 - x - y)}{y}\right) \times Y$$

The x, y chromaticity values are useful as this is often how a white point is specified. Additionally, standards such as CIE D65 can be defined as CIE 1931 (x, y) = (0.313, 0.329).

This very brief introduction to color science hopefully provides enough background about the CIE 1931 color space to understand the following sections related to white point correction. For more information, a variety of sources exist both online and in textbooks in the field of color science.

2 Approaches for White Point Correction

Generally one of the most important image calibration aspects in a projector is that of white point correction (WPC). Due to the tolerances of the various optical components in a typical DLP Pico™ projector, there is some variance in the final color performance of the product. Light source and optics tolerances primarily drive this variation. These variations can include:

- LED to LED intensity (lumens) variations
- LED to LED wavelength variations
- LED current variation due to LED driver circuit component tolerances
- Optical transmission variations for different wavelengths
- Individual color differences in optical engines due to optical alignment

Consequently, calibration of the projector white point is needed in the factory to achieve the targeted white points and ensure consistency between individual projectors. Some users are more sensitive to projector white point than projector brightness. There are multiple ways to implement white point corrections which are categorized into three domains discussed below.

2.1 Hardware Domain

The variation in the LED manufacturing process can be reduced through effective binning. However, binning is typically cost prohibitive for most high volume consumer products.

2.2 Software Image Processing Domain

Data processing software is commonly used by a variety of display products. In a typical projector, there are two primary components which can be adjusted to achieve a specific white point.

- Front-end electronics can be modified to adjust white point variances. Many display products follow this technique. While this modification is possible to do with DLP projectors, it is generally not recommended. This is because front-end electronics do not take into account TI's specialized color processing algorithms that are optimized for the unique nature of the DMD. In some situations, front-end approaches to white point correct may introduce nonlinearity display issues or even affect the red, green, blue, and secondary color accuracy. Additionally, front-end approaches will reduce dynamic range.
- The Color Coordinate Adjustment (CCA) algorithm in the DLPC34xx controller allows white point adjustments. These adjustments require different DLPC34xx controller settings for each projector.

Adjusting software in the front-end electronics or using the CCA algorithm are both in the data processing domain. Even though this approach is easy to implement and usable in end-products, there are certain issues that can occur. Adjustments purely in the data processing domain will reduce the color dynamic range. In other words, an 8-bit input value, after adjustment, no longer utilizes the full 8-bit range (0 to 255 value). For example, the maximum range may be reduced to 200.

Additionally, due to the effects of the degamma processing, CCA changes occur in nonlinear space. Therefore, if not careful, CCA adjustments may introduce digital artifacts and non-linearity issues. It is generally not a recommended solution in most situations.

2.3 Light Processing Domain

A unique advantage is offered through time sequentially illuminating the RGB LEDs in regard to adjusting the white point accurately and efficiently without reducing the dynamic range. The two main implementation techniques are as follows:

- Change the RGB duty cycle (the time each RGB color is displayed)
- Change each RGB LED current

While either or both techniques can be used, there are some benefits of adjusting only the LED duty cycle. The first benefit is that adjusting the LED duty cycle instead of LED current allows more precise control on the total current consumption of LEDs. LED current may be critical to portable applications if the LED current needs to be pre-defined and fixed. The second benefit is for applications that set LED current to its maximum allowed value to achieve the highest brightness possible. Finally, LED variation in the light output versus current characteristics may make calibration through current changes difficult. In any case, a fixed current helps enable relatively stable thermal conditions in the projector.

Due to the advantages of adjusting RGB duty cycles, the following sections primarily focus on this technique. The discussed technique provides a method that can be implemented and automated in a production line to potentially achieve white point accuracy and consistency at (x, y) tolerance <0.01 level.

2.3.1 Real Time White Point Correction

While setting the desired RGB duty cycles is generally done only during factory calibration, the white point may drift even after initial calibration due to a variety of time dependent changes. For example, LED aging and thermal conditions are time variant parameters. To compensate for these errors requires installing a color sensor in the optical system to sense the LED stray light to perform real-time color management as shown in Figure 6. Real time white point correction ensures the desired color temperature over time and over various operating conditions.

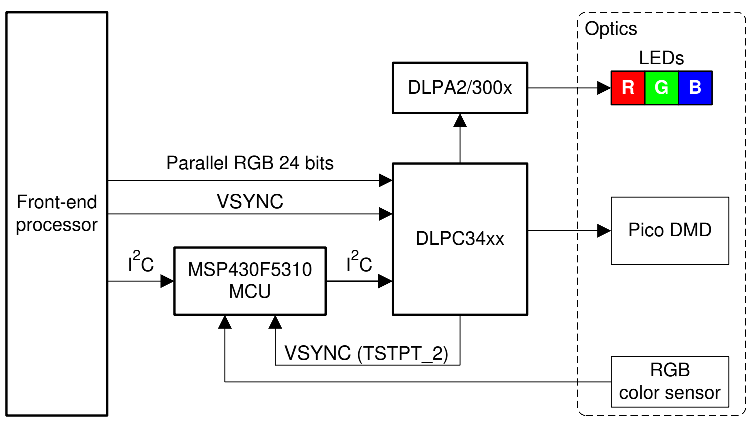

Figure 6. Real Time White Point Correction Functional Block Diagram

The details of the real-time white point correction design is available on Ti.com and through the links below:

- Real-Time Color Management for DLPC343x Application Note
- Real-time Color Management Reference Design

The real-time white point correction system requires additional cost for the color sensor and microcontroller. While this technique can provide great performance, cost and size constraints may limit the ability to implement the solution. Therefore, the remainder of this document focuses on discussing white point calibration in the factory by calculating optimal duty cycles.

3 Calculate the Optimal LED Duty Cycle

3.1 Technique

In order to determine the optimal LED duty cycle needed to achieve the desired white point, display one LED color at a time and measure the individual X, Y, Z tristimulus values. Record the values shown below using the setup indicated in Figure 7.

Red LED: X_R, Y_R, Z_R

Green LED: X_G, Y_G, Z_G

Blue LED: X_B, Y_B, Z_B

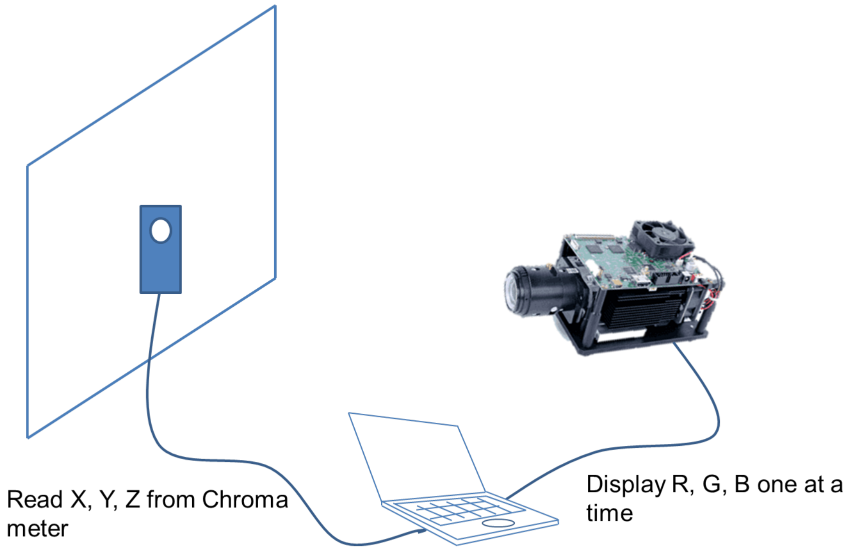

Figure 7. Color Calibration Setup

The white appearance is the sum of the X, Y, Z tristimulus from each R, G, and B LED. This can be expressed as:

$$X_W = X_R + X_G + X_B$$

$$Y_W = Y_R + Y_G + Y_B$$

$$Z_W = Z_R + Z_G + Z_B$$

However, the actual projector system's white point is generated with a default duty cycle of $RDC_{default}$, $GDC_{default}$, and $BDC_{default}$. The duty cycle is a time factor, and the sum of the RGB duty cycles always equal 100. In order to eliminate the time factor, the white appearance with unit duty cycle becomes:

$$X_{W\,unit} = \frac{X_R}{RDC_{default}} + \frac{X_G}{GDC_{default}} + \frac{X_B}{BDC_{default}}$$

$$Y_{W\,unit} = \frac{Y_R}{RDC_{default}} + \frac{Y_G}{GDC_{default}} + \frac{Y_B}{BDC_{default}}$$

$$Z_{W\,unit} = \frac{Z_R}{RDC_{default}} + \frac{Z_G}{GDC_{default}} + \frac{Z_B}{BDC_{default}}$$

$RDC_{desired}$, $GDC_{desired}$, and $BDC_{desired}$ are defined as the R, G, and B duty cycles needed to achieve the desired white point. The desired $X_{Wdesired}$,$Y_{Wdesired}$, $Z_{Wdesired}$ are calculated as:

$$X_{W\,desired} = \left(\frac{X_R}{RDC_{default}} \times RDC_{desired}\right) + \left(\frac{X_G}{GDC_{default}} \times GDC_{desired}\right) + \left(\frac{X_B}{BDC_{default}} \times BDC_{desired}\right)$$

$$Y_{W\,desired} = \left(\frac{Y_R}{RDC_{default}} \times RDC_{desired}\right) + \left(\frac{Y_G}{GDC_{default}} \times GDC_{desired}\right) + \left(\frac{Y_B}{BDC_{default}} \times BDC_{desired}\right)$$

$$Z_{W\,desired} = \left(\frac{Z_R}{RDC_{default}} \times RDC_{desired}\right) + \left(\frac{Z_G}{GDC_{default}} \times GDC_{desired}\right) + \left(\frac{Z_B}{BDC_{default}} \times BDC_{desired}\right)$$

Expressed as a 3 × 3 matrix:

$$\begin{bmatrix} X_{Wdesired} \\ Y_{Wdesired} \\ Z_{Wdesired} \end{bmatrix} = \begin{bmatrix} \frac{X_R}{RDC_{default}} & \frac{X_G}{GDC_{default}} & \frac{X_B}{BDC_{default}} \\ \frac{Y_R}{RDC_{default}} & \frac{Y_G}{GDC_{default}} & \frac{Y_B}{BDC_{default}} \\ \frac{Z_R}{RDC_{default}} & \frac{Z_G}{GDC_{default}} & \frac{Y_B}{BDC_{default}} \end{bmatrix} \times \begin{bmatrix} RDC_{desired} \\ GDC_{desired} \\ BDC_{desired} \end{bmatrix}$$

Inverse the matrix:

$$\begin{bmatrix} RDC_{desired} \\ GDC_{desired} \\ BDC_{desired} \end{bmatrix} = \begin{bmatrix} \frac{X_R}{RDC_{default}} & \frac{X_G}{GDC_{default}} & \frac{X_B}{BDC_{default}} \\ \frac{Y_R}{RDC_{default}} & \frac{Y_G}{GDC_{default}} & \frac{Y_B}{BDC_{default}} \\ \frac{Z_R}{RDC_{default}} & \frac{Z_G}{GDC_{default}} & \frac{Y_B}{BDC_{default}} \end{bmatrix}^{-1} \times \begin{bmatrix} X_{W\,desired} \\ Y_{W\,desired} \\ Z_{W\,desired} \end{bmatrix}$$

As white points are often specified using the CIE 1931 xyY color space, the equation can then make the following substitutions:

$$X = \left(\frac{x}{y}\right) \times Y \qquad\qquad Z = \left(\frac{(1 - x - y)}{y}\right) \times Y$$

Which results in the following the matrix:

$$\begin{bmatrix} RDC_{desired} \\ GDC_{desired} \\ BDC_{desired} \end{bmatrix} = \begin{bmatrix} \frac{X_R}{RDC_{default}} & \frac{X_G}{GDC_{default}} & \frac{X_B}{BDC_{default}} \\ \frac{Y_R}{RDC_{default}} & \frac{Y_G}{GDC_{default}} & \frac{Y_B}{BDC_{default}} \\ \frac{Z_R}{RDC_{default}} & \frac{Z_G}{GDC_{default}} & \frac{Y_B}{BDC_{default}} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{x}{y} \times Y_{W\,desired} \\ Y_{W\,desired} \\ \frac{(1-x-y)}{y} \times Y_{W\,desired} \end{bmatrix}$$

3.2 Example

Given a projection system with the preinstalled default duty cycles of $RDC_{default}$ = 37%, $GDC_{default}$ = 35%, and $BDC_{default}$ = 28%, the following RGB tristimulus values are obtained for each color.

Table 1. Example RGB Tristimulus Readings

	X	Y	Z
Red LED	X_R = 2141.9	Y_R = 928	Z_R =1.87
Green LED	X_G = 871.8	Y_G = 3548	Z_G = 344
Blue LED	X_B = 1472.9	Y_B = 220	Z_B = 8783.2

If a white point of x, y = (0.313, 0.329) is desired, the optimal duty cycles can then be calculated using the above information and the fact that RDC + GDC + BDC = 100. Specifically the following 3 x 3 matrix is established:

$$\begin{bmatrix} RDC_{desired} \\ GDC_{desired} \\ BDC_{desired} \end{bmatrix} = \begin{bmatrix} \frac{2141.9}{37} & \frac{871.8}{35} & \frac{1472.9}{28} \\ \frac{928}{37} & \frac{3548}{35} & \frac{220}{28} \\ \frac{1.87}{37} & \frac{344}{35} & \frac{8783.2}{28} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{0.313}{0.329} \times Y_{Wdesired} \\ Y_{Wdesired} \\ \frac{(1-0.313-0.329)}{0.329} \times Y_{Wdesired} \end{bmatrix}$$

Solving the matrix using straightforward algebra produces these results:

- $RDC_{desired}$ = 50.5%
- $GDC_{desired}$ = 33.8%
- $BDC_{desired}$ = 15.7%
- a luminance corresponding to $Y_{Wdesired}$ = 4823

These desired duty cycles can then be programmed into the projector.

4 How to Perform Factory White Point Correction using LED Duty Cycles

The following general steps are given in order to calibrate each unit. Detailed information follows.

1. Determine target white point(s).
2. Create a default firmware image with fixed LED current and default duty cycles and program the projector.
3. Measure the projector white point with the default duty cycles.
4. Calculate the new duty cycles needed to achieve the target white point.
5. Update the projector's firmware with the new duty cycles to achieve the desired white point.
6. Program the new firmware onto the projector.

4.1 Factory Tools Required for White Point Calibration

In order to individually white point correct each unit, the following tools and environment will be needed.

- Factory Floor Utilities, a TI tool
- Duty cycle database, a database of various duty cycles that can be provided by TI
- A dark room to do Chroma meter measurement
- Hardware to do measurements and update the flash image for each projector
  - Chroma meter (Konica Minolta CL200 or equivalent) that can measure the color coordinates and brightness level
  - Cable to connect the Chroma meter with the factory computer (such as RS232 or USB)
  - Programming tool that allows downloading (or partially downloading) of the firmware to the SPI flash on the projector or optical engine; this could be a Cypress USB to SPI integrated circuit or equivalent SPI programing tool; generally, a DeVaSys USB to I^2C device is used to control the projector over I^2C and a SPI programming tool is used to quickly update the DLPC34xx flash image from the factory computer
- Customer developed software to use on the production line with a factory computer in order to automate the process; the Factory Floor Utilities provide the core components of this software
  - A software program which can trigger a Chroma meter for the measurement and read back the data (the Chroma meter supplier usually provides an API to control the meter and record the measurement)
  - A software program which calculates the target duty cycle based on known condition using the formulas described in Section 3
  - A software program that incorporates the TI dpp343x_build_flash.exe command line utility to select sequences on the fly
  - A software program that incorporates the TI provided dpp343x_flashdownload.exe that can overwrite the flash on the DLPC34xx system with the newly built firmware image

4.2 Steps for Adjusting White Point with RGB Duty Cycle Adjustment

The following process is followed in order to update the white point:

1. Determine the target white point(s) that are desired for the final product (such as CIE D65 which is x, y = 0.313, 0.329). Third party online tools can be used to convert color temperatures to (x, y) coordinates.
2. Create the default firmware image with fixed LED current and default duty cycles.
   - Select the default DLPC34xx firmware image with a default duty cycle (this image will be used in step 3). Each look can have a unique duty cycle.
   - Select a fixed current for each LED. Each LED current must be selected based on the overall product specification and design constraints. For example, it could be set to achieve the best lumen output under certain power limits, or it could be set to limit LED power to achieve a known thermal condition. This decision requires knowledge on the specific LEDs, knowledge of the thermal design of the projector, and testing.
3. Measure a projector's white point after the system reaches thermal equilibrium. This is done by determining a projector's characteristic by measuring full-on R, G, and B color points (x, y) and the system luminance, Y_W, using a known duty cycle under predefined LED current and stable thermal conditions.
4. Calculate the new duty cycles needed to achieve the target white point. Use the formulas in Section 3 to calculate the new duty cycles needed to achieve the target white point based on the measured values. The input of the formula is the measured RGB X, Y, Z values under a known duty cycle along with the desired white point. The output is the needed duty cycle of R, G, and B to achieve the desired white point.
5. Update the projector's firmware with the new white point.
   - Use the sequence database provided by TI. It is a .zip file consisting of a large number of binary files, each of which covers a certain duty cycle combination for R, G, and B with step of 1%. An example of duty cycle range is red from 10% to 50%, green from 20% to 60%, and blue from 10%

to 40%. The binary files are named with specific RGB duty cycle combinations, frame rate, gamma and sequence type to indicate the individual build condition, as shown below.

cmt_bdp_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	2 KB
cmt_ben_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_del_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	2 KB
cmt_den_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_dgd_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_igm_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_lpd_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_R57G33B10_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_ags_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_bdp_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	2 KB
cmt_ben_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_del_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	2 KB
cmt_den_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_dgd_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_igm_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_lpd_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_R57G33B10_63Hz_enhanced_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_ags_R57G32B11_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB
cmt_bdp_R57G32B11_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	2 KB
cmt_ben_R57G32B11_63Hz_Powerlaw2p2_Standard_24.bin	11/15/2018 4:24 AM	BIN File	1 KB

Figure 8. Example Sequence Database

- Note: There is a mandatory minimum R, G, and B duty cycle. A sequence database is built assuming a specific illuminator definition, degamma, frame rate(s), sequence type, etc. If the default database does not meet the desired projector configuration, a custom sequence database may be needed. Examples of changes that would require a custom sequence database are illuminators with significant delays, non-standard degamma curves, or non-standard frame rates.
- A command line tool (dpp343x_build_flash.exe) is provided as part of the Factory Floor Utilities. This tool enables fast building of new firmware with the desired sequences that were selected based off of the duty cycle calculations. A text file including build configurations is also needed which contains duty cycle information, gamma selection, etc.

6. Program the new firmware onto the projector.
   - A command line tool (dpp343x_flashdownload.exe) is also provided as part of the Factory Floor Utilities. This tool enables easy programing of the DLPC34xx controller of the newly created firmware image. This tool's source code is also made available in order to enable easy implementation of this tool within ones production environment.

4.3 Example Files

The following is an example of an input .txt file with comments for each instruction. This .txt file is an input for the dpp343x_build_flash.exe tool.

 # Note: comments start with '#'

 # First, define the frame rates to support. Up to 4 may be specified, each requires specific database support

Rate 63

Rate 123

 # Next, define degamma curves to support (also requires database support)

Degamma enhanced

Degamma PowerLaw2p2

 # The duty cycle to override; R G B numbers should be integers with 2D look defaults

Duty-Cycle 39 40 21

 # The base flash image

Flash-File dpp343x_7.4.2.img

 # The sequence database provided by TI that contains supported sequences and LUTs

Database-File dpp3432_63_123_database.zip

 # The output flash image filename created by the dpp343x_build_flash.exe tool

Output-File dpp343x-output.img

The batch file can be called in the Windows command as indicated:

dpp343x_build_flash /allow-sequence-fail example-build-input.txt

After executing the above batch file, a new image file, dpp343x-output.img is created in the same folder along with the output log file. Review the output log file to see if any error message occurred. If an error message is reported, the output image file is still generated, but the content will be the same as the base image file. Additionally, the log file reports the desired duty cycle and the actual duty cycle utilized in the new image file. In some cases the *Input Settings* and *Matched from Database* values may not be exactly equal because dpp343x_build_flash.exe automatically select the closest duty cycle from the database. An example output log is shown in Figure 9.

```
Matched Duty Cycles (* marks differences):
+-----------------------------------+-----------------------------------+
|          Input Settings           |        Matched from Database      |
+--------+--------+--------+--------+--------+--------+--------+--------+
|    Red |  Green |   Blue |  Total |    Red |  Green |   Blue |  Total |
+--------+--------+--------+--------+--------+--------+--------+--------+
|  39.00 |  40.00 |  21.00 | 100.00 |  39.00 |  40.00 |  21.00 | 100.00 |
+--------+--------+--------+--------+--------+--------+--------+--------+
```

Figure 9. Output Log File Example

5 References

1. White Point In Color Definitions on Barco
2. Planckian Locus
3. What every coder should know about gamma
4. *Digital Video and HDTV: Algorithms and Interfaces* by Charles Poynton (Morgan Kaufmann, 2003; ISBN 1-55860-792-7).