Long-Term Data Projector Color Performance Test

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Introduction

A study was undertaken to evaluate the long term performance of a series of data projectors. The test involved measuring color performance data and gathering imagery of the projector displays with the goal of reaching 5000 runtime hours. The objective of the experiment was to determine the various modes of color and image degradation that each projector exhibited over time.

The test parameters were selected as a direct result of a previous study.[1] That work involved five Liquid Crystal Display (LCD) projectors and two projectors based on Digital Light Processing™ technology. The sample size for this test was increased to seven LCD projectors and nine DLP™ projectors. Like the previous work, this study was supported by Texas Instruments Incorporated (TI). TI personnel were responsible for selecting the models of the data projectors. Also as before, the specific projector models are not identified in this report. To demonstrate the range of projectors used, some specifications are included in Table III at the end of this report.

All projectors are available for consumer purchase in the same configuration as tested here. Except for brightness and contrast adjustments, described below, all units were operated exactly as shipped from the manufacturer.

Overview of Experiment

The colorimetric measurements were made as specified in the relevant ANSI standard[2]. All measurements were made with a hand-held Minolta CL-200 colorimeter. These measurements included:

- ANSI (checkerboard) contrast
- Full on/full off contrast
- Full screen colorimetric and luminance uniformity

These measurements were made on white, red, green, and blue separations. After the colorimetric analysis, the same set of images were observed, pictures captured with a digital camera, and visual observations were made and logged. The goal of these observations was to note anything that might be too subtle to otherwise capture with the camera or colorimetric measurements.

The ANSI document provides specific guidelines for adjusting the contrast and brightness setting of the displays. This procedure was followed for all projectors.

The goal of the test was to achieve a total runtime of 5000 hours by operating projectors for 24 hours per day, seven days per week. In a few instances, the testing was suspended for vacations or required facility shutdowns. Additionally, testing was suspended for some projectors for non imaging-related repair. In these cases, projectors were factory-repaired and returned to testing as quickly as possible. The test was started in mid-January 2003 and completed in mid-October of the same year.

Maintaining relatively constant and reasonable laboratory temperature was an important consideration for this test. Temperature probes were located on each shelf, with fans positioned so as to keep air flowing over all projectors. Positions are shown schematically in Figure 1.

The laboratory is arranged with the projector shelf about eight feet from a black wall. The other walls and curtains are all black to reduce scattered light. Light from the projectors is blocked by a curtain. Holes were cut in the curtain to allow light from each projector to individually project onto the measurement area. A standard white projection screen is lowered for the digital image capture.

In the previous study[1], lamps were run to end-of-life or the manufacturer's recommendation, whichever came first. To reduce lamp related effects on performance, lamps were changed more frequently and on a regularly scheduled basis, as described below. With few exceptions, all projectors seemed to perform about equivalently before and after lamp changes. This can be seen by examining data points at the same number of hours in Figures 4 and 5. It is possible that running lamps to end-of-life may alter their properties enough to impact the color uniformity performance. The more frequent lamp changes ensure the test quantified the long-term performance of the projector imaging apparatus and not properties of the lamp itself.

Throughout the 5000 hour test, all projectors were displaying a repeating set of various images (a custom screensaver). This was done to protect the units from any burn-in effects or other problems that might occur with a prolonged static image. To ensure that all projectors display identical images, the screensaver was displayed via a set of video distribution boxes. To make measurements of a particular projector, it was disconnected from the distribution box and connected directly to a second computer which displayed a set of measurement images and recorded the data from the colorimeter. With this configuration, projectors not currently being measured continued to receive the screensaver images.

Measurement Procedure

The specific measurements were made in the following steps:

1. Display full white image
2. Measure luminance and chromaticity at points indicated in Figure 2.
3. Display white checkerboard
4. Measure luminance at points indicated in Figure 3.
5. Display full white image and measure center screen luminance.
6. Display full black image and measure center screen luminance.
7. Repeat steps 1-6 for red, green, and blue separations.

For each measurement point, the computer displayed a circle in the appropriate area. The operator then placed the CL-200 in line with the circle and signals to the computer that the device is ready. The computer removed the circle, and the operator pressed the button which sent the data to the computer. Using this procedure, the measurement areas were identical for every round of testing. The placement of the CL-200 could be very reliably placed in the same location. To avoid the accidental measurement of the placement circle, the computer is set to allow a measurement no sooner than one second after the circle is removed. The CL-200 is configured to sample every 0.5 seconds. It was therefore guaranteed that the correct measurement was made.

After the colorimetric measurements were made, the above 9 images (full white, black, red, green, blue, and white, red, green, and blue contrast targets) were imaged with a Fuji 4700 digital camera. The camera was set up for automatic exposure, and hence the images cannot be used for scientific data, although relative information can be gained. The primary purpose of these images was to capture a visual record of the state of each projector.

Notes on ANSI/NAPM IT7-228-1997

The methodology described above deviates in two ways from the recommended practices in the ANSI standard:

First, for signal generation we used the standard video card on a desktop computer. The ANSI standard recommends the use of a dedicated signal generator.

Second, for the first part of the uniformity calculation, determining the average u'v' coordinates, we used all thirteen points shown in Figure 2. The ANSI standard uses only the central nine.

Regarding these deviations, we recognize that a signal generator would undoubtedly provide a more constant signal over time. However, we found several projectors with very constant output over time, and others with severe changes. We conclude that the difference between a signal generator and the video card does not account for any significant fraction of the differences between projectors.

The large-scale blue degradation exhibited in the LCD projectors (shown in the Results section, below) is quite obvious whether we calculate uniformity with the standard ANSI method or if we use our slightly modified method. Either method can quantify the degradation observed and show the variety of degradation modes documented in this report. For example, Table II compares the nine- and thirteen-point calculations for an example LCD projector at four different times. The two methods result in very close uniformity calculations. Both methods show that the degradation is quite large and varies over time. For projectors with poor edge uniformity (exhibiting a fall-off of luminance near the edges), the inclusion of the additional four corner points in the calculation may serve to highlight subtle uniformity differences near the corners. The uniformity data presented below are calculations based on thirteen-point data. These data illustrate the point that the observation of large-scale degradation is not significantly effected by the inclusion of the additional four measurement points.

Testing Schedule

The set of measurements and image capture described in the previous section was repeated every two weeks for the duration of the test. Once per month, the projector lamps were changed after the measurement set, and the set was repeated with the fresh bulbs. During the weeks between measurements, visual observations were made and logged when appropriate. A typical month of testing was completed as follows:

Week 1. Visual observations
Week 2. Measurement set
Week 3. Visual observations
Week 4. Measurement set, lamp change, repeat measurement set.

Results

The following plots show various performance metrics plotted versus time. These are all data taken during the measurements on weeks 2 and 4, as described above. There were two sets of data taken in week 4, and both of these are plotted. Since the runtime between these measurements was essentially zero, these points often appear to nearly overlap on the plots.

Contrast. In general, the contrast for the LCD projectors decreased more than that of the DLP™ projectors over time. The final measurements for most projectors were taken after about 5200 hours of runtime. Some units did not complete the same duration due to unplanned shutdowns or other issues (eg: a supplier problem resulting in a lack of lamps). Figures 4a and 4b show the normalized ANSI contrast for the projectors. All values are normalized to the contrast calculated for the baseline measurements at time=0 hours. The line is fit to the average reading at each measurement point. The LCD units show a greater reduction in contrast than the DLP™ units. One DLP™ unit (shown as circles with crosses) behaved differently than the others.

An important note regarding contrast is that very small changes in the dark measurement can impose large swings in the calculated contrast ratio. For example, assuming a dark measurement of 1.0 lux, a change of 0.1 lux in the dark measurement results in a 10% change in contrast ratio. Projectors with very low dark levels can be expected to exhibit significant noise in their contrast readings.

Colorimetric Uniformity. The white, red, green, and blue uniformity is shown in Figure 5. LCD and DLP™ projectors are shown with open and closed circles, respectively. Note that the scale of the y-axis changes for each plot. Across all plots in Figure 5, the color of the data points is consistent for a given projector. The results are in Δu'v'; that color difference calculation is performed as follows (quoted from the specification[2]):

> Set up white, red, green, and blue colors on the screen and measure the u', v' chromaticity at the center of each of the nine equal rectangles described in [Figure 2].
>
> Calculate the average chromaticity value (u'_0 and v'_0) of the nine measurements for each color. Also measure the u', v' chromaticity at the four corners of the screen. Record the maximum deviation in u' and v' of the 13 measurements from the average value for each color. If u'_1, v'_1 represent the spots with maximum deviation from the average values u'_0, v'_0, then a measure of the color uniformity for each color is given by:

$$\Delta u'v' = \left[\left(u'_1 - u'_0\right)^2 + \left(v'_1 - v'_0\right)^2\right]^{\frac{1}{2}}$$

In all cases, the plots omit a few points of high values. This was to expand the bulk of the data. Note that using this metric, high Δu'v' indicates poor uniformity. If the Δu'v' was zero, the display would be showing perfect uniformity.

The range of the vertical axes of Figure 5 are all quite different. The differences in scale should not necessarily be interpreted to correspond to visual differences. For example, the highest blue values are approximately ten times larger than the highest white values, although the difference in white uniformity may be equally perceptible. The magnitude of equal visual perception in Δu'v' is not constant for all areas of color space. Hence, it is not proper to place a threshold on the plots to indicate a specific visual color difference.

We first note that the DLP™ units in general perform better than the LCD units. The difference is particularly strong for the blue channel, where the LCD projectors tended to show more degradation. Often, we see that the uniformity increases and then decreases over time, as illustrated in Figure 5. This apparently confusing behavior is explained by Figure 6 for one LCD projector. (This unit is shown as red open circles in Figure 5.) The initial uniformity is good. As the blue channel degrades, yellow areas increase in size, decreasing white uniformity. The third image shows a nearly uniform yellow. Additional degradation again reduces uniformity in the final image. A similar progression can be seen in several of the other LCD projectors although all LCD projectors exhibited degradation in the blue channel. The uniformity for the images in Figure 6 are shown in the white plot of Figure 5 as black-filled red circles.

We include Figure 7 as a visual representation of the typical performance over the life of the test. Images are shown for two projectors at four times.

Conclusions

For both contrast and uniformity, the LCD projectors did not perform as well as the DLP™ projectors. The degradation was largely confined to the blue channel.

Tables

Table I. Calculations made from each of the measurements.

Step	Calculations
2 (white)	ANSI lumens, luminance uniformity
2 (R,G,B)	Chromaticity uniformity
4 (all)	ANSI contrast
5 and 6	Full on/Full off contrast

Table II. Uniformity data (Δu'v') for an example projector. Calculations for nine- and thirteen-point uniformity are compared. Data are for white uniformity for an example LCD projector. This projector is shown in Figure 5 as red open circles. Note: this is the same projector and approximately the same testpoints as the images in Figure 6.

Hours	9	13
0	0.006	0.006
2184	0.045	0.042
2856	0.003	0.003
4872	0.037	0.040

Table III. Projector Specifications.

Label	Display type	Panel size (in.)	ANSI Lumens
A	LCD	0.99	3000
B	LCD	0.9	2000
C	DLP™	0.7	2500
D	DLP™	0.7	1050
E	LCD	0.9	2000
F	LCD	0.7	2000
G	DLP™	0.7	1300
H	DLP™	0.7	2000
I	LCD	0.7	1200
J	DLP™	0.55	800
K	LCD	0.7	1800
L	DLP™	0.7	1500
M	DLP™	0.7	1000
N	LCD	0.5	800
O	DLP™	0.7	2000
P	DLP™	0.7	1500

Figures

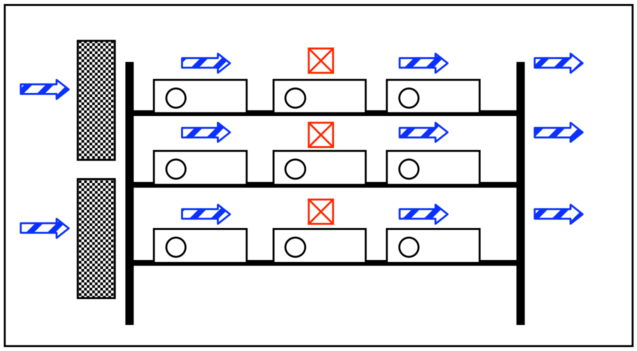


Figure 1. Schematic positioning of projectors, fans (shaded rectangles) and temperature probes (red). Blue arrows indicate airflow.

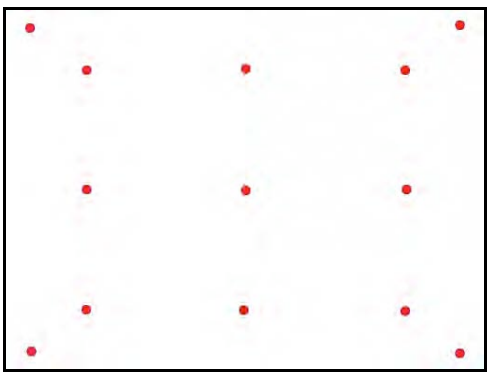


Figure 2. Measurement points for ANSI lumens and luminance and chromaticity uniformity.

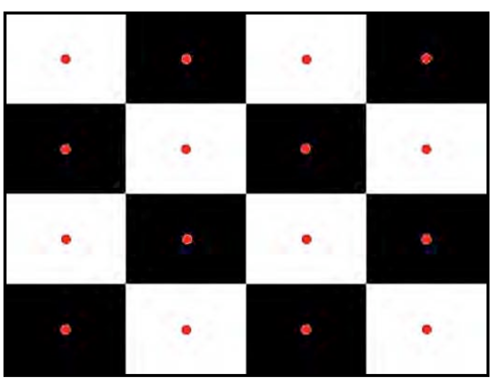


Figure 3. Measurement points for ANSI contrast.

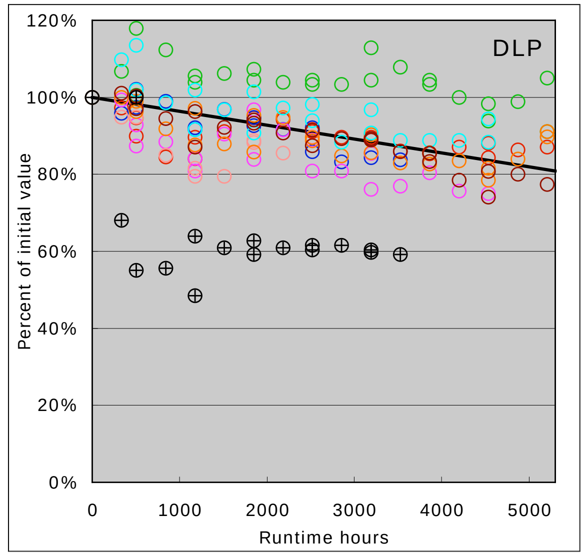


Figure 4a. Normalized ANSI contrast for the set of DLPtm projectors.

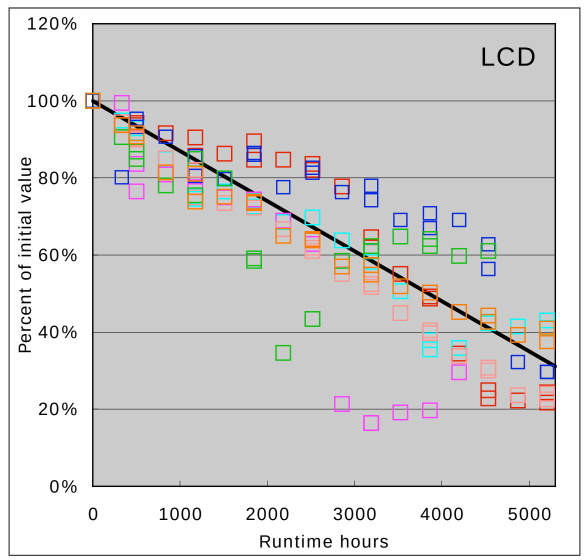


Figure 4b. Normalized ANSI contrast for the set of LCD projectors.

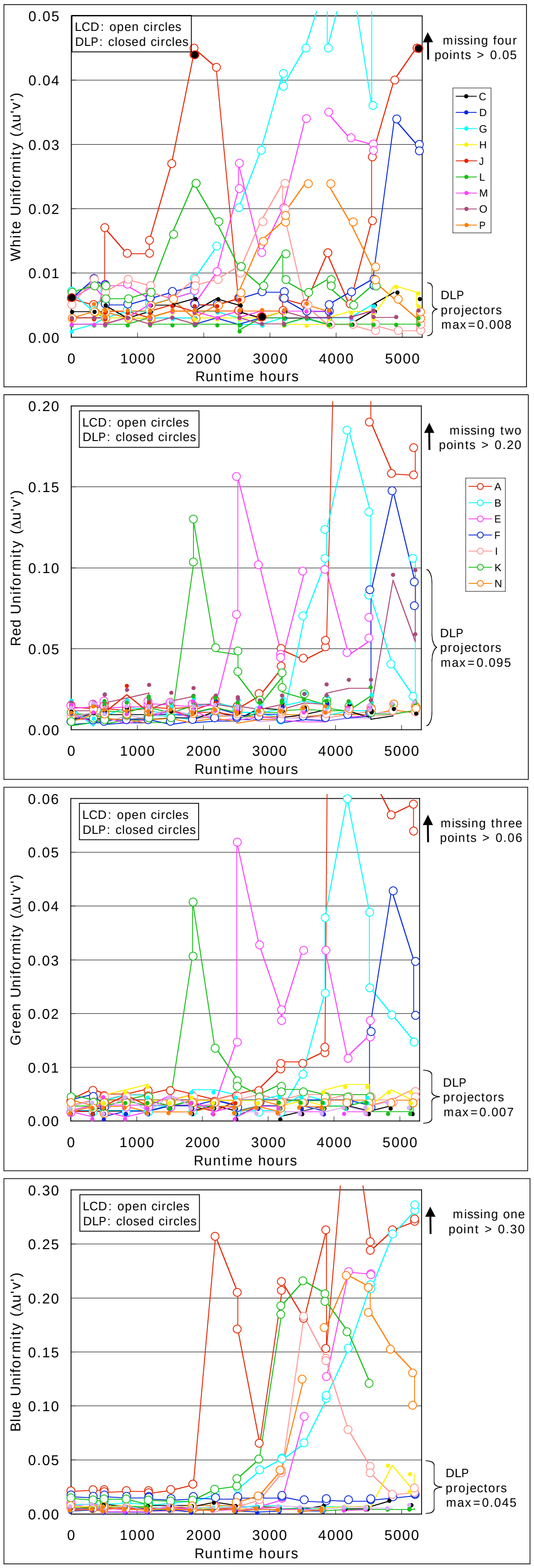


Figure 5. Color uniformity in Δu'v'. Black-filled red circles in the white uniformity plot indicate the points for which images are shown in Figure 6.

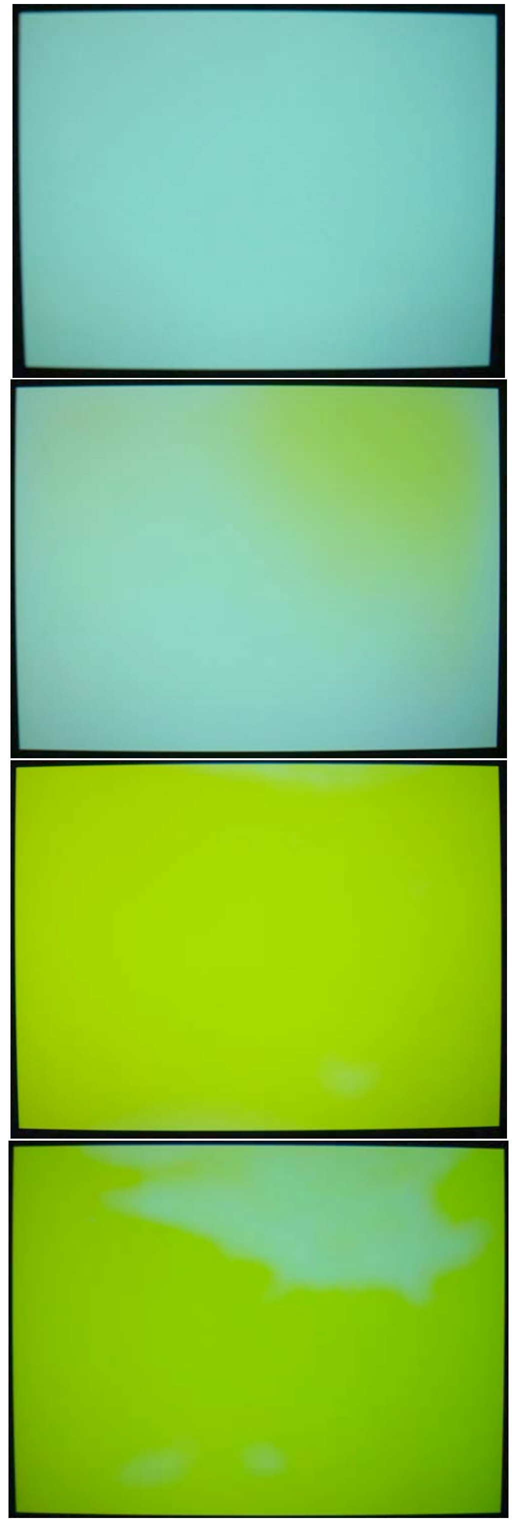


Figure 6. Sequence of example LCD white separation images for times of 0, 1800, 2800, and 5200 hours (top to bottom). This shows how the white uniformity metric can increase (worsen) and then improve over time.

DLP™ Projector #8 @ 1872 hrs

LCD Projector #6 @ 1872 hours

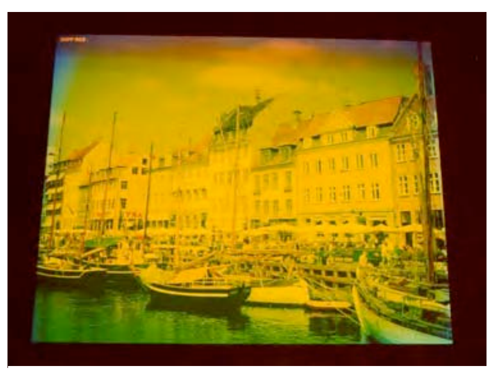
DLP™ Projector #8 @ 2568 hrs

LCD Projector #6 @2568 hours

DLP™ Projector #8 @ 3336 hrs

LCD Projector #6 @ 3336 hours

DLP™ Projector #8 @ 5208 hrs



LCD Projector #6 @ 5208 hours

Figure 7. Sequence of photos comparing actual projected images from a DLP™ projector and an LCD projector. In this example, some loss of blue in the center of the LCD image is apparent at 2568 hours. Image degradation continues through the end of the test.

References

[1] MR Douglass and RW McCall, DMD Field Reliability: A Comparison of Competing Technologies Used in Data Projectors, internal Texas Instruments report.

[2] *Electronic Projection – Fixed Resolution Projectors*, ANSI/NAPM IT7.228-1997. Available from www.ansi.org