

Long Term Data Projector Display Technology & Performance Study Interim White Paper

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Introduction

Intertek, an independent testing organization, was commissioned by Texas Instruments Incorporated (TI) to perform a study on data projectors that involved evaluating the long term effects of two different projector technologies; DLP[®] chip and Liquid Crystal Display Panels (LCD). The intent of the project was to track the changes or shifts in the image quality of the display technologies over time. In order to perform this task, data projectors containing both display technologies were selected by TI, but purchased on the open market and maintained by Intertek. Each of the models chosen were operated on three different duty cycles, and subjected to a number of color and light measurements including light output, light output uniformity, full on / full off contrast ratio, checkerboard contrast ratio, color chromaticity, and color uniformity. All of the data for this study was independently gathered by Intertek. Still picture images were also displayed along with the various test patterns and recorded using a still picture camera throughout the study. This paper will briefly discuss the background for the study, provide a general overview of the methodology and equipment employed, and will provide the current results through December 2nd, 2005.

Background

This study evolved from two previous studies performed by Mr. David Wyble a color scientist at the Rochester Institute of Technology's (RIT) Munsell Color Science Laboratory. During the first study, five LCD and two DLP[®] models were chosen. The second study consisted of seven LCD and nine DLP[®] models. During the first two studies, one sample of each model was evaluated and each sample ran continuously. Both of these studies were commissioned by TI and TI was responsible for selecting the models to be evaluated.

After the release of each of the previous studies certain critiques were advanced. Specifically, it was suggested that the study did not adequately simulate real world conditions because the ambient temperatures of the study sites were not controlled, the samples were run continuously, and only one sample per model was evaluated. Although neither TI nor Intertek concede the validity of these critiques, the study performed by Intertek was designed to address them in the following manner:

1. Ambient Temperature:

- One sample of each model was subjected to an isolated normal temperature test at an average ambient temperature of 75 degrees F. Internal and external temperatures were monitored and used to verify that the ambient temperatures

around the samples in this study were within typical limits (+/- 5 degrees F from ambient room temperature).

2. Continuous Operation:

- Each of the models were run on three different duty cycles and the results from the normal temperature tests were used to set the off time of two and one half hours for the on/off cycle samples. This ensured that all of the on/off cycled display technologies returned to within 5% of ambient before being re-energized. The three duty cycles selected were as follows:
 1. Continuous operation
 2. 5.5 hours on 2.5 hours off
 3. 1.5 hours on 2.5 hours off

3. Sample Size:

- Sixty samples were purchased for this study. Fifty four samples were used in the study; three samples of each of the six models were run on each duty cycle, for a total of nine samples per model. The remaining six samples, one of each model, were purchased for use during the normal temperature test.

Intertek Study

All of the samples for the Intertek study were purchased on the open market by Intertek and remained in the possession of Intertek during the entire study. Samples were not altered from their original condition except for adjustment of the brightness and contrast for base-line measurement purposes.

This study was conducted in three phases. First, temperature data was collected to determine the cooling time needed to return each model to within 5% of ambient. Next the samples were base-lined according to IEC 61947-1:2002, Electronic projection measurement and documentation of key performance criteria, Part 1: Fixed resolution projectors (IEC). Finally, each sample was evaluated.

Phase 1:

Temperature data was collected on one sample of each model using a non-study sample purchased on the open market. The purpose for this test was to determine how long it takes the display components to return to within 5 % of ambient after being on for 24 hours. The longest time recorded during this test was then used to set the off time for all of the display technologies. Additionally, the results obtained during this test were used to validate the placement of the samples during the study. By monitoring the surrounding temperature of the non-study samples and the samples used during the study, a comparison could be made to ensure that the heat from one sample was not acting to heat

the adjacent samples. Upon completion of the normal temperature test the non-study samples were placed in storage.

Phase 2:

In this phase each sample was base-lined. This was accomplished by using a video pattern generator to display the ANSI Grey Scale pattern on a projection screen that was set at the same distance as the measurement device. Once the sample had been on for at least 15 minutes, the brightness and contrast settings were adjusted according to the IEC specification, section 5. The values obtained were then documented and placed on the sample for future reference. This process was then repeated for each sample individually.

Phase 3:

Finally, a thirteen position pattern, as shown in Figure A.2 of the IEC spec, was used to locate the linear actuator for the full screen measurements. First, the pattern was displayed on the projection screen and then the linear actuator was moved into position. The corresponding X and Y coordinates were then recorded and entered into the positional program. This was repeated for a 16 position pattern used when measuring the checkerboard contrast ratio. This procedure was performed on all of the study samples individually. Upon completion the study samples were tested and operated according to their respective duty cycles.

The following test equipment was used during the testing phase of this study. Before the start of this study all equipment requiring calibration was calibrated by an external calibration company to a National Institute of Standards and Technology (NIST) traceable standard.

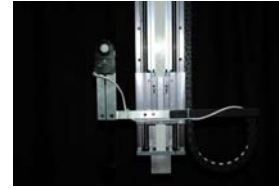
- Konica Minolta CL-200 – Light Meter
- Chroma 2329 – Video Pattern Generator
- Fluke 2686A – Data Logger
- Staco Energy Products Co. MVR-20WCIY045 – Automatic Voltage Regulator
- Fluke - Voltmeter

In order to address repeatability concerns, each sample was pin located on a ¾ inch thick plywood board using the ceiling mount holes located on the bottom of each sample. Each piece of plywood was pre-drilled using a pattern to locate the ceiling mount holes. Furthermore, the plywood was drilled to accept 3 locating pins that were mounted in each test window. This ensured repeatable positioning of the plywood and repeatable positioning of the samples in the test window.

Thermocouples were then placed between each sample and at the exhaust port of the cooling fans. This allowed monitoring of the ambient temperatures around the samples and provided a means for determining if all of the samples cycled properly over night and on weekends.

Cycling was performed by pneumatics and controlled by a Programmable Logic Controller that interfaced to a personal computer running commercially available control software. Pneumatic cylinders were mounted above the on/off buttons of the samples and energized once to turn the samples on and twice to turn the samples off.

The CL-200 light meter was mounted remotely on a linear actuator. The linear actuator incorporated stepper motors and encoders which provided repeatable and accurate positioning of the light meter.



Lamps were replaced at set time intervals corresponding to approximately 1000 hours of operation. Samples were measured before a lamp change took place and after the lamp change was completed. Digital or 35mm film pictures were also taken after the lamp change was completed. In the event of a premature lamp failure, the lamp was replaced and a measurement was performed.

Throughout the study all display technologies received the same image when not under test. This was performed by routing a Microsoft PowerPoint™ presentation slide show set to loop, through several video distribution amplifiers. This was done to protect against image burn-in and to ensure that all of the display technologies received the same image during their respective run times. During the testing phase of this study, the samples were disconnected from the distribution box and connected directly to a video pattern generator using a 15 pin RGB Cable. The pattern order for testing was as follows:

- Full Screen: black, red, blue, green and white
- Checkerboard: white black, red black, blue black, and green black

Daily checks were also made and recorded on log sheets. These checks consisted of verifying the cycling of the samples by looking at the temperature plots at the cooling fan exhaust port. The displays of each of the samples were checked and any noticeable changes in appearance were recorded. Any other anomalies were also recorded.

Failures that were obviously not related to DLP® chip or LCD panels and polarizer were sent back to their respective manufacturers for repair. After repair the sample was set to its original contrast and brightness settings as determined by the original base line measurements and testing continued at the regularly scheduled intervals. Repair information was also acquired from the respective manufacturers to ensure the samples were not altered beyond the original failure.

In the event that a component failure other than an LCD panel and polarizer or DLP® chip is found to have caused the visual and measurable deterioration encountered during this study, the results for that unit will be omitted in the final report. Since, in some cases it is impossible to identify the specific cause of deterioration until that unit is disassembled and evaluated; Intertek felt it was best to run all of the samples that were operational and not obviously linked to a component failure other than LCD panel and

polarizer or DLP[®] chip until the conclusion of the study. It was determined that this course of action would minimize down time and help to ensure that the samples were not altered, damaged, or otherwise rendered useless.

Measurement Procedure

- Disconnect 15-pin cable from distribution amplifier to sample
- Verify operation of cooling fan in measurement window
- Move sample into measurement window
- Connect video pattern generator to sample under test via 15-pin cable
- Place projection screen at same distance as light meter
- Check focus and menu settings to verify contrast and brightness settings
- Remove projection screen
- Verify lights are turned off and close curtain to measurement window
- Load the proper projector grid coordinates into control software
- Press the “Start” button to run the program
- Once completed place projection screen at the same distance as the measurement head and take pictures of the test patterns and two still photos
- Disconnect 15-pin cable from the video pattern generator from projector
- Place Sample back on rack
- Reconnect 15-pin cable from the distribution amplifier to sample
- Repeat for all samples

Sample Identification

Display Technologies:

LCD designation numbers 1, 2, and 4

DLP[®] designation numbers 3, 5, and 6

Duty Cycles:

A, B, C – 1.5 hours on 2.5 hours off

D, E, F – 5.5 hours on 2.5 hours off

G, H, I – 24 hours on 0 hours off

Each sample was provided with a unique identification that consisted of a number and a letter. The number represented the model type and the letter represented a specific duty cycle. Refer to the information above for identification purposes. For example, 5D indicates a DLP[®] technology sample running on a 5.5 hour on and 2.5 hour off duty cycle.

Summary of Interim Results

The following sections of this document represent the detailed results of the study through December 2, 2005. In this study it was found that the LCD panel and polarizer deteriorated after a certain amount of on time, which varies by model. DLP[®] technology maintained a fairly consistent and uniform performance level throughout the study. At this point in the study all of the LCD models running on a 24/7 duty cycle, have shown visual and measurable deterioration. Most of the LCD 5.5/2.5 samples have also shown visual indications of deterioration. One of the 5.5/2.5 models achieved enough on time hours to show measurable deterioration in line with the same model on the 24/7 duty cycle. Additionally, none of the LCD 1.5/2.5 samples indicated visual or measurable deterioration. However, based on the current results one might expect these samples to also show deterioration upon accumulating similar on times to those achieved by the 24/7 and 5.5/2.5 samples. LCD panel and polarizer deterioration was visibly different from model to model. For example, some LCD models initially showed a blue shaded area on portions of the display, while others initially showed yellow areas on portions of the display.

24/7 Duty Cycle:

DLP[®] technology showed no significant visual or measurable change in DMD chip performance. The LCD technology showed significant measurable deterioration between 2000 and 4000 hours of on time. The LCD technology started to show initial signs of visual deterioration between 1700 and 3000 hours of on time. To date this duty cycle has accumulated an average of 3789 out of 4000 hours of on time.

5.5/2.5 Duty Cycle:

Again, DLP[®] technology has shown no significant visual or measurable change to date. Most of the LCD technology in this duty cycle started to show signs of visual deterioration between 1700 and 3000 hours of on time. To date this duty cycle has accumulated an average of 2677 out of 4000 hours of on time.

1.5/2.5 Duty Cycle:

None of the samples running on this duty cycle are showing significant display technology deterioration at this time. To date this duty cycle has only accumulated an average of 1366 out of 4000 hours of on time.

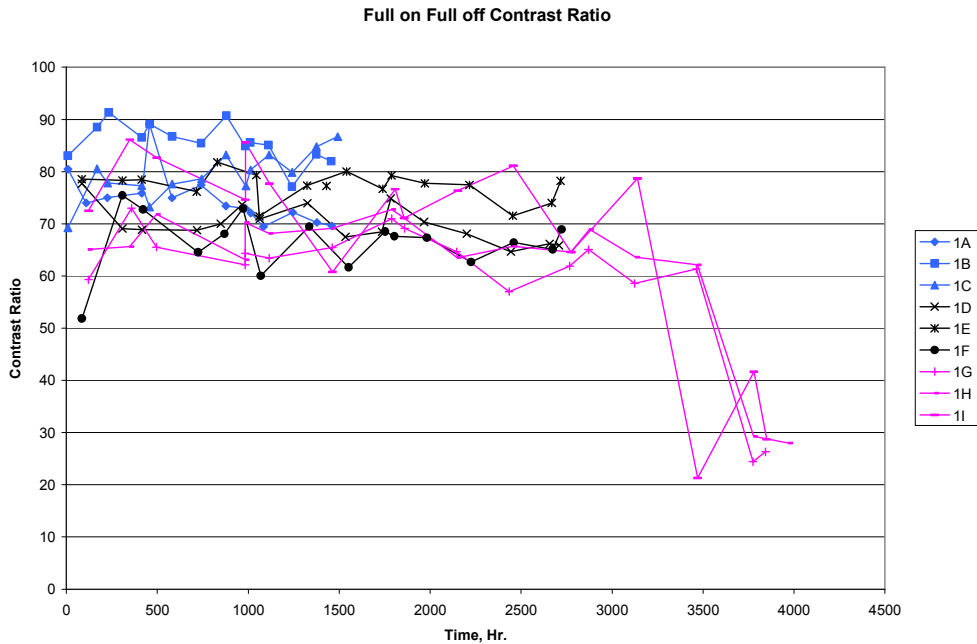
LCD Model 1 Summary

For model 1 LCD's running on a 24/7 duty cycle, significant visual and measurable signs of LCD panel and polarizer deteriorations were noted on or before 3213 hours of on time. This was first noted as a slight yellowing and bluing of the screen at 2773 hours of on time. The 5.5/2.5 duty cycle samples 1D and 1E also showed visual signs of LCD panel and polarizer decay around 2700 hours of on time as indicated by the pictures of sample 1E on page 15. Upon completion of 4000 hours of run time each sample will be evaluated for component failures. Signs of panel and polarizer deterioration have been found in the model 1 samples running on a 24/7 duty cycle, please reference the pictures at the bottom of page 15 for visual examples.

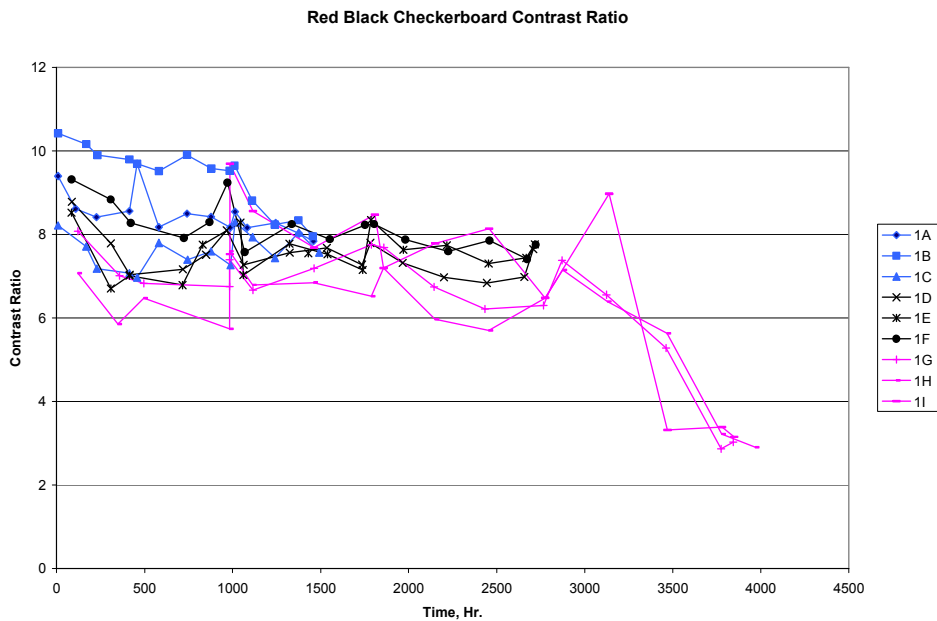
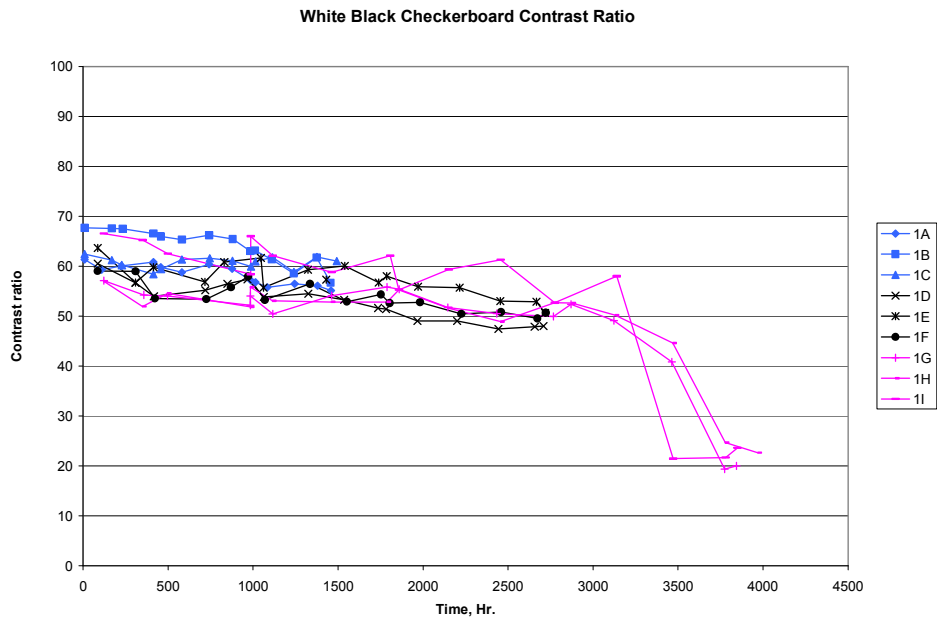
Model 1 Graphs

The graphs below are plotted with all of the samples for this model. The blue lines represent the 1.5 on 2.5 off duty cycle, black lines represent the 5.5 on 2.5 off duty cycle, and the red lines represent the continuous duty cycle.

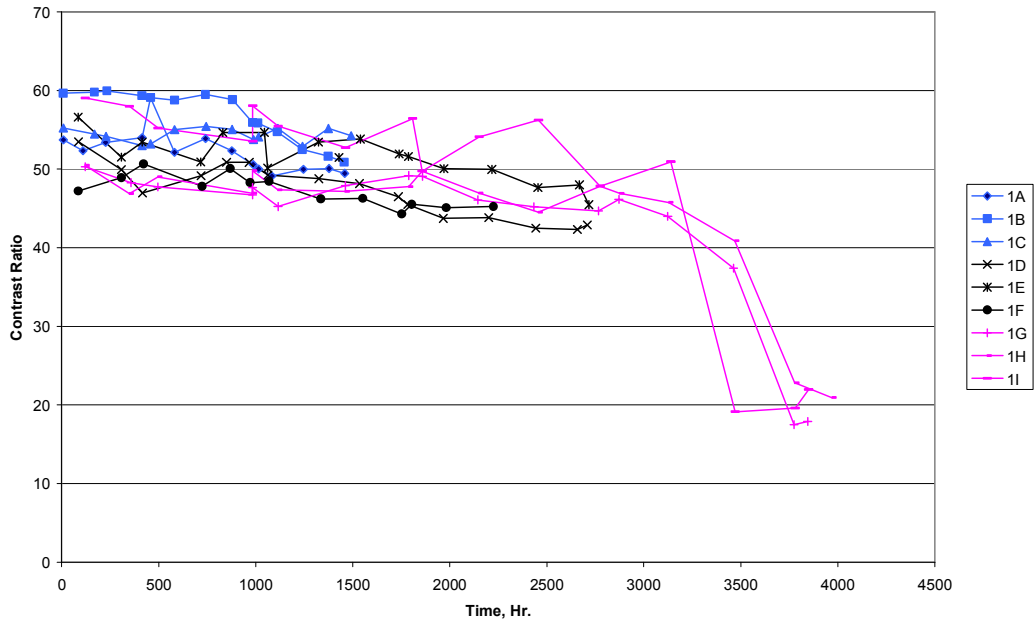
The full on full off contrast ratio measurement is performed by displaying a completely black screen and a completely white screen through the sample under test. Then a brightness measurement is recorded at the center of each of the projected images. The white measurement result is then divided by the black measurement result. This value when referenced to 1 is the contrast ratio (value:1). For this graph the (value) is plotted as a function of time. All of the models are plotted in this fashion.



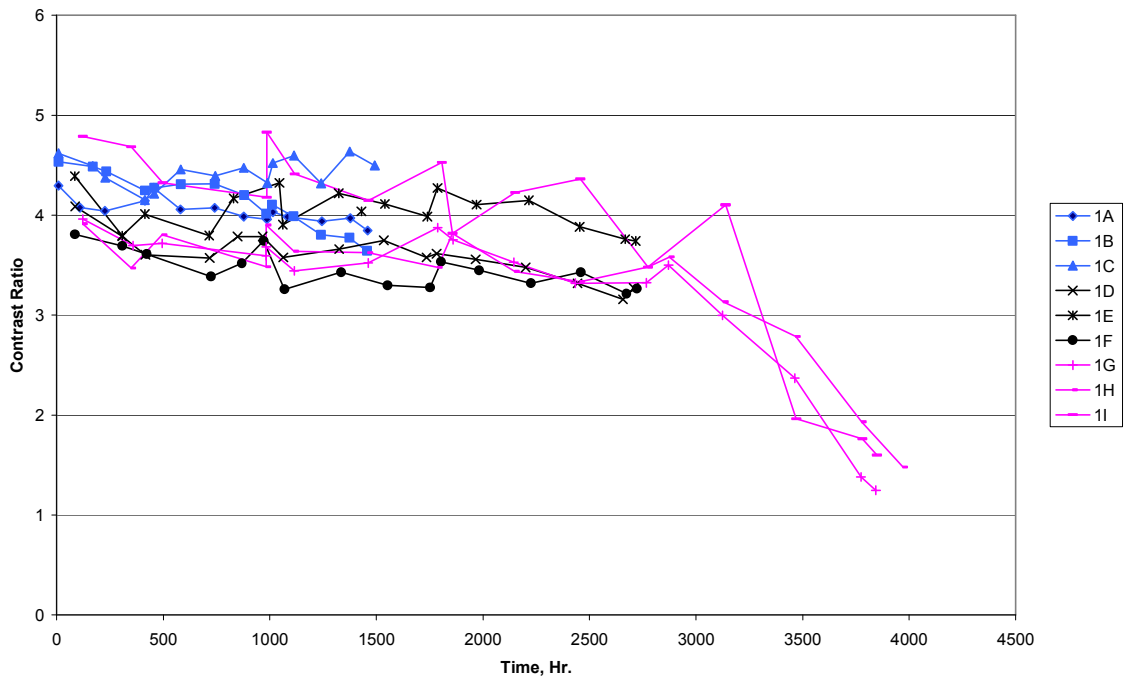
The white black checkerboard contrast ratio is similar to the full on full off contrast ratio but only one image is displayed; a 4X4 checkerboard pattern consisting of alternating white black rectangles. Each of these rectangles is measured at the center and the measured results for the white areas are averaged together and divided by the averaged black areas to arrive at the contrast ratio. This procedure was used for all of the colored checkerboard contrast ratio measurements. Pictures of the white black checkerboard image are provided on page 14 for one sample in each of the duty cycles.



Green Black Checkerboard Contrast Ratio



Blue Black Checkerboard Contrast Ratio

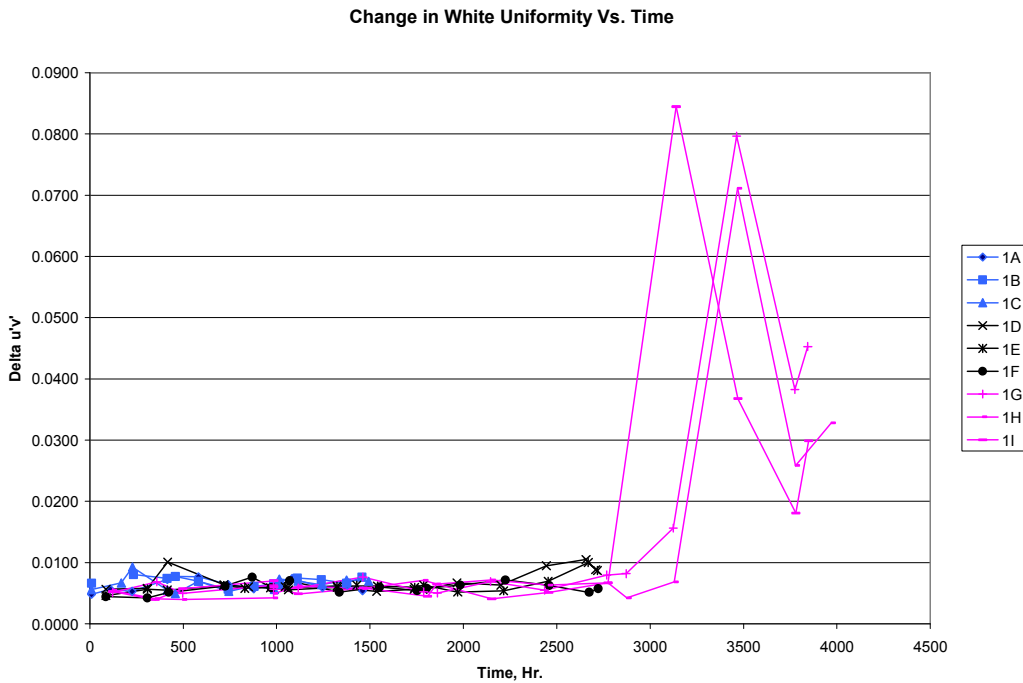


Color uniformity is a measure of how uniform the projected image is across the entire screen. The results are obtained by taking the 9 center readings from a 13 position pattern and averaging the results for the $u' v'$ measurements. Then all the values for the 13 position pattern are used to determine the maximum deviation from the average values. The measure of color uniformity is then calculated from the equation below. In this equation the subscript 0 represents the average value and the subscript 1 represents the maximum deviation from the average values.

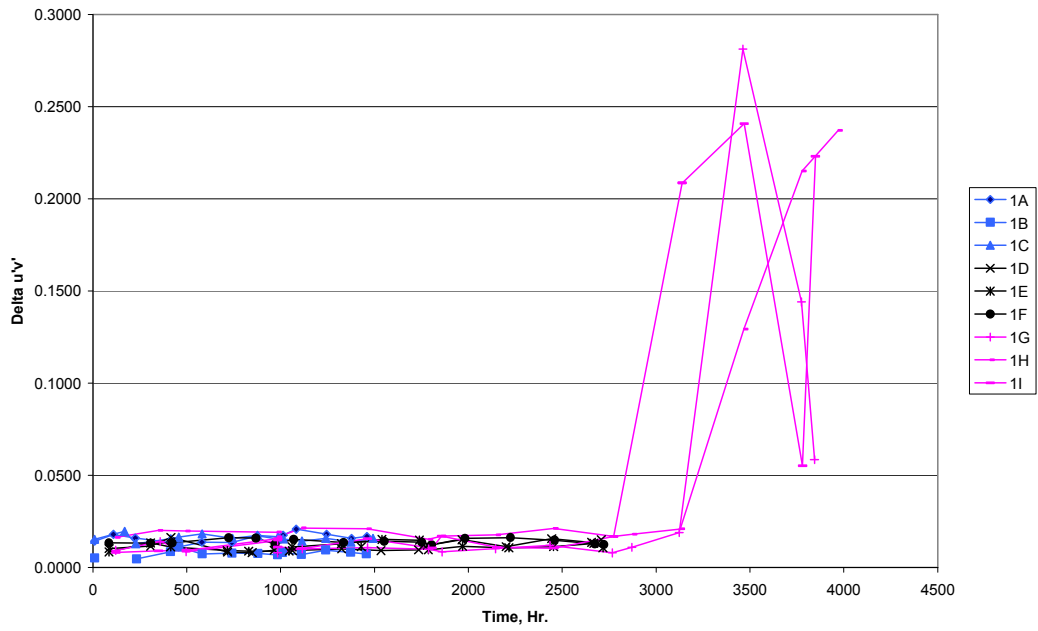
$$\Delta u'v' = \sqrt{(u'_1 - u'_0)^2 + (v'_1 - v'_0)^2}$$

Although color uniformity calculations utilize chromaticity measurements, color uniformity does not take into account what color the image is at the time of the test. It only indicates how uniform that average color is, based on the 9 center measurements. With that in mind one might look at the graphs below and conclude that the white screen discolors and then becomes white again, but that is not the case. What really is taking place is that the projected white image begins to change colors in certain areas. Then, that change in color spreads through the entire projected image. This can be seen best in the pictures on page 15.

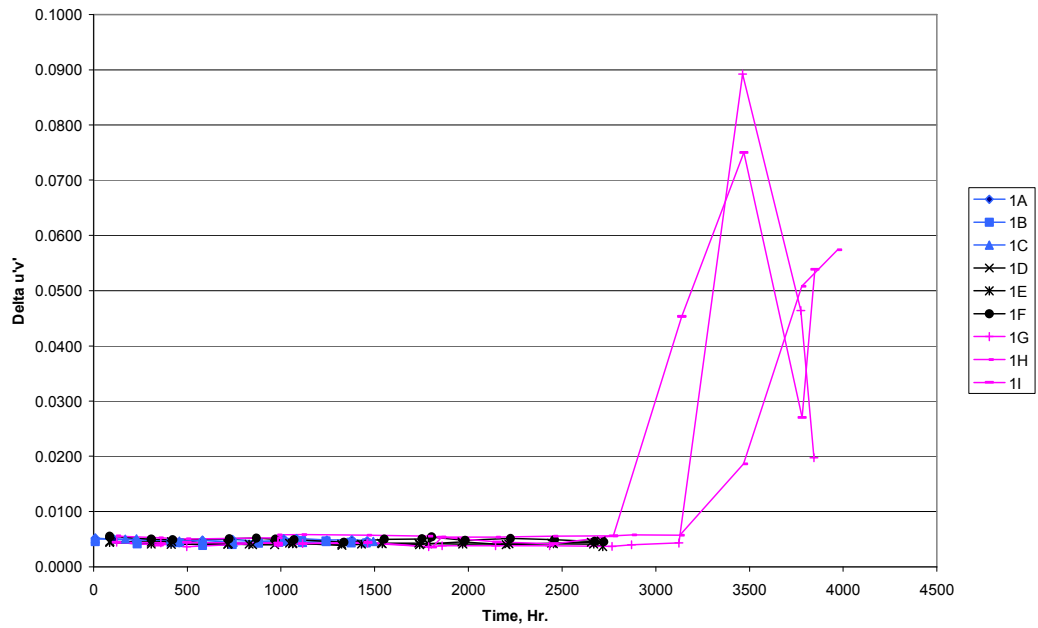
The color uniformity measurements in this study all follow the same principles, only the color being displayed changes.



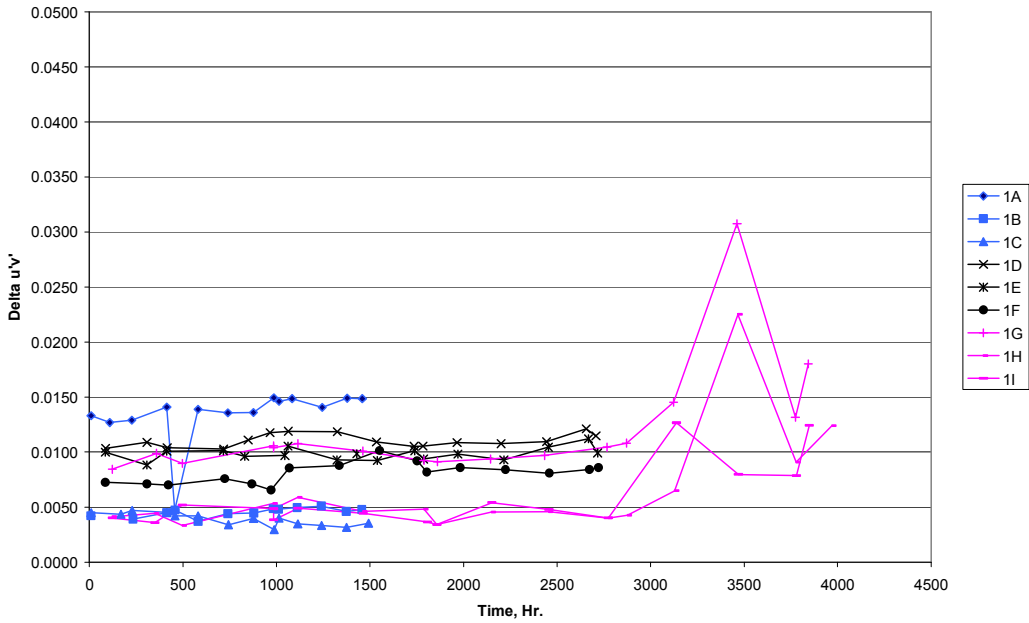
Change in Red Uniformity Over Time



Change in Green Uniformity Over Time

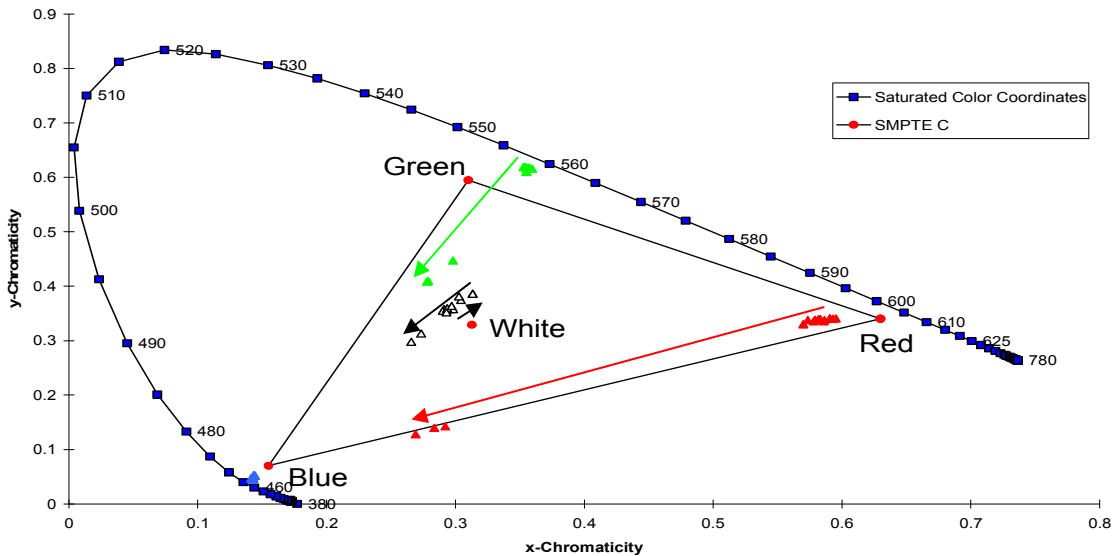


Change in Blue Uniformity Over Time



The chromaticity diagram displayed below is used to show the change in projected image color over time. It is comprised of white, red, green, and blue color chromaticity measurements x, y . The most notable changes are in the white, red, and green measurements. The first shift in color happens in the white measurements, in which the white image shifts up and right into the yellow green region of color space. Then as the screen begins to blue, the white, red, and green measurements begin to shift in the lower left direction toward blue. Only sample 1I is shown below for clarity. However, this trend is evident in the other 24/7 samples, as well.

CIE 1931 CHROMATICITY DIAGRAM
Sample 1I



Model 1 Pictures

The pictures located in this section were taken with a digital camera and are included to assist the reader in understanding the graphs and to provide a visual example of the display technology deterioration that takes place. Pictures of the fruit are provided as a visual example of what a color image looks like before and after the display technology deteriorates. However, due to the limitations of the camera and the type of images being captured, one should not look at the pictures alone to make determinations about the display technology performance.



Sample 1I 122 hours



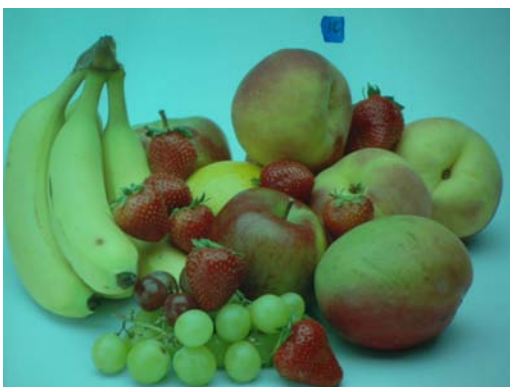
Sample 1I 3470 hours



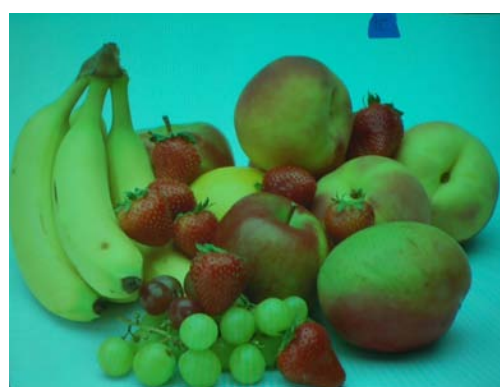
Sample 1F 308 hours



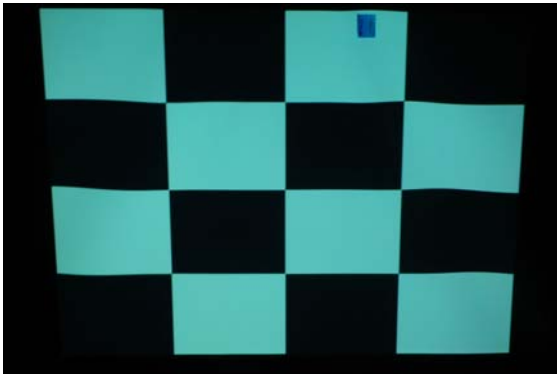
Sample 1F 2459 hours



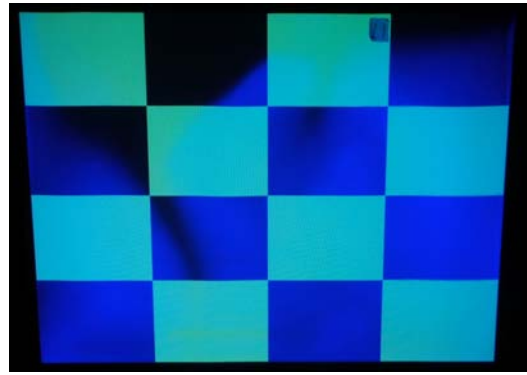
Sample 1C 169 hours



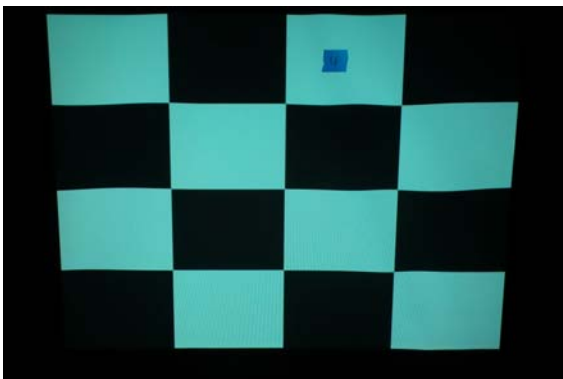
Sample 1C 1375 hours



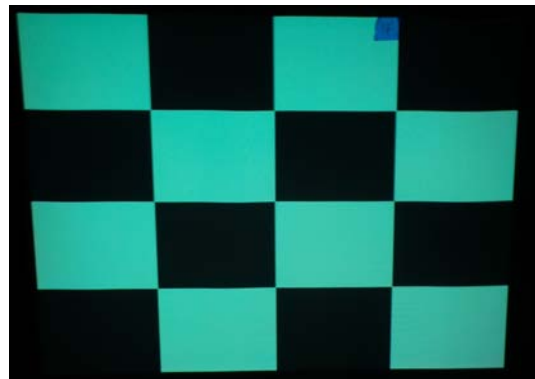
Sample 1I 122 hours



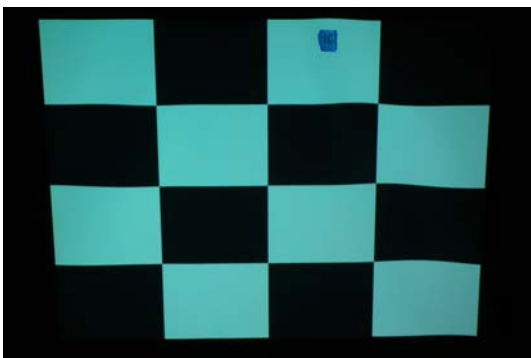
Sample 1I 3470 hours



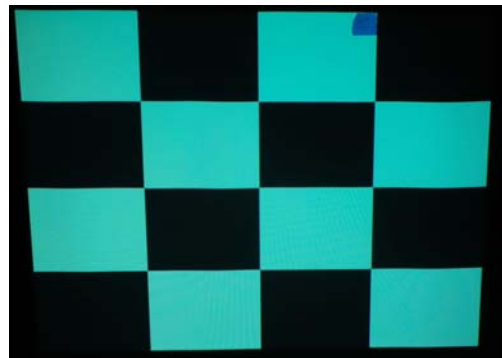
Sample 1F 308 hours



Sample 1F 2459 hours



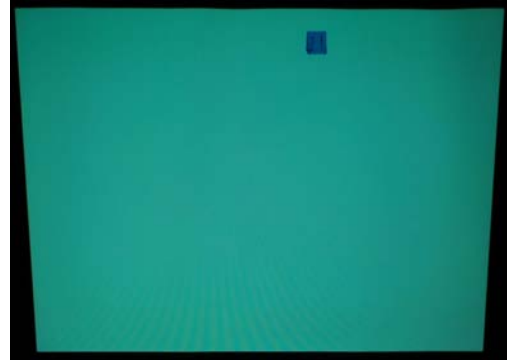
Sample 1C 169 hours



Sample 1C 1375 hours



Sample 1I 122 hours



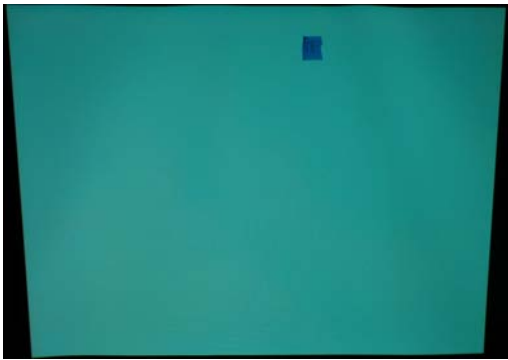
Sample 1I 2151 hours



Sample 1I 2774 hours



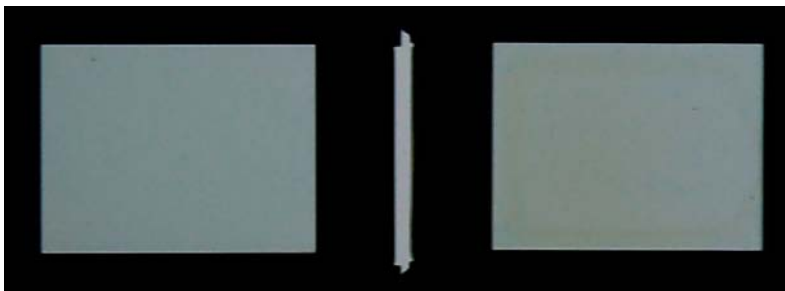
Sample 1I 3470 hours



Sample 1E 85 hours

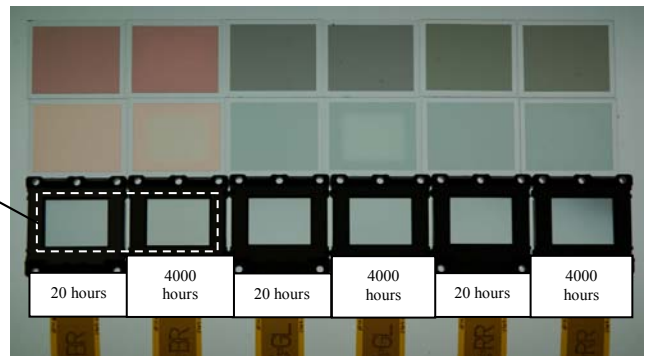


Sample 1E 2717 hours



LCD panel after 20
Hours of on time

LCD panel after 4000
Hours of on time



Side by side comparison of LCD panel and polarizer

LCD Model 2 Summary

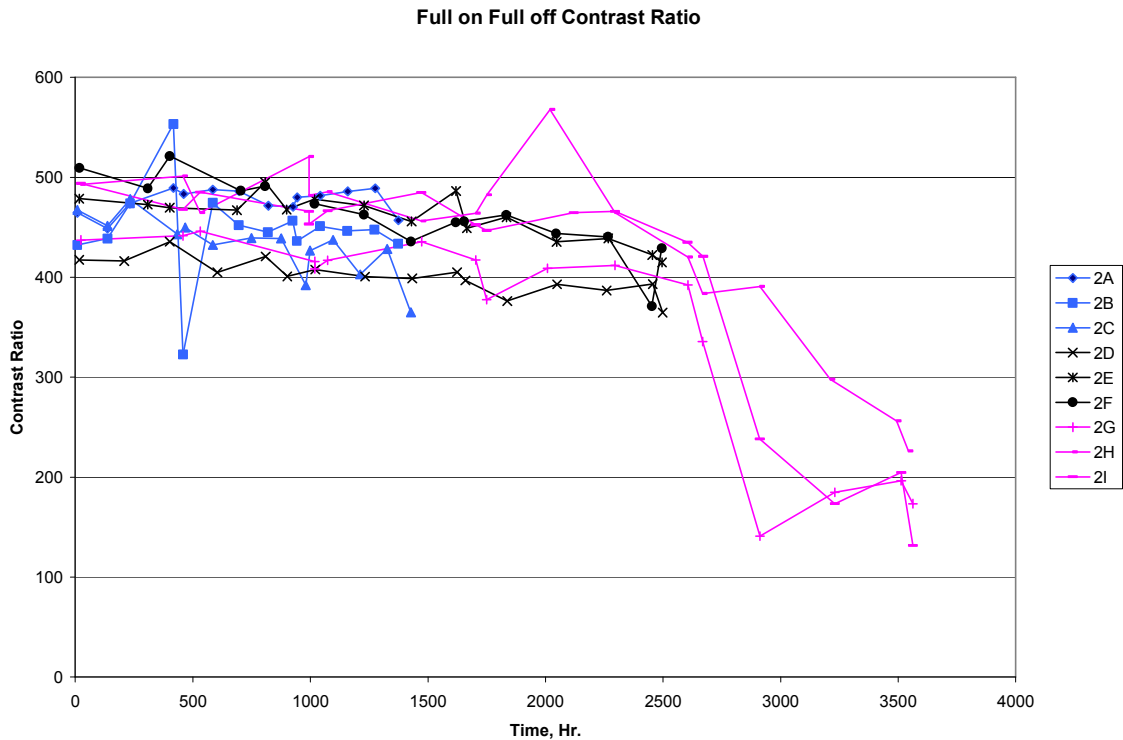
For model 2 LCD's running on a 24/7 duty cycle, significant visual and measurable signs of LCD panel and polarizer deterioration were noted on or before 3500 hours of on time. The first visual indication of LCD technology decay was noted as a slight bluing of the screen around 2000 hours of on time. The 5.5/2.5 duty cycle samples also showed visual signs of LCD panel and polarizer decay at 2000 hours of on time. The graphs to date also indicate similar trends in measured results regardless of duty cycle.

Model 2 Graphs

The graphs below are plotted with all of the samples for this model. The blue lines represent the 1.5 on 2.5 off duty cycle, black lines represent the 5.5 on 2.5 off duty cycle, and the red lines represent the continuous duty cycle.

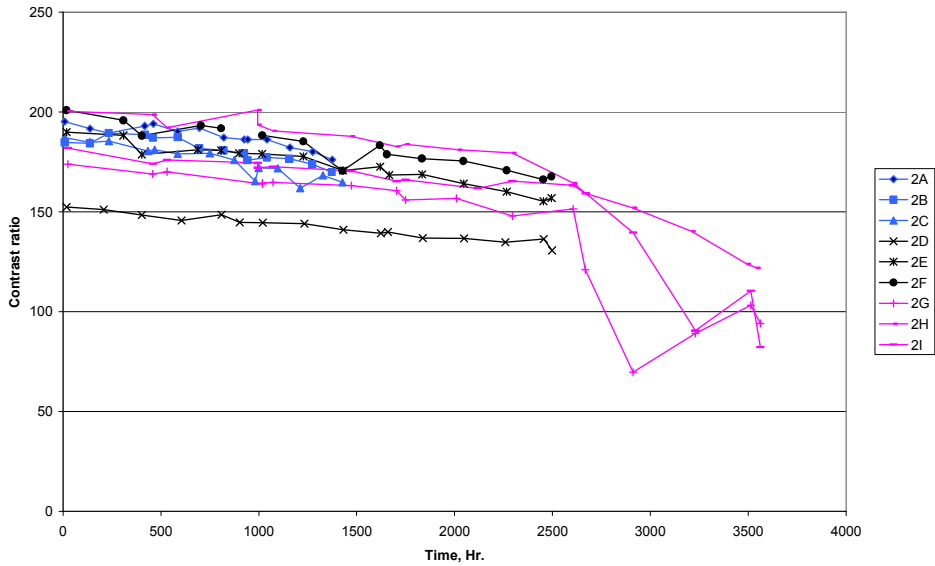
The graph below indicates that there is significant drop in contrast ratio around 2700 hours on time. This is primarily due to LCD technology deterioration.

(Refer to Model 1 Graphs for definitions of color measurements)

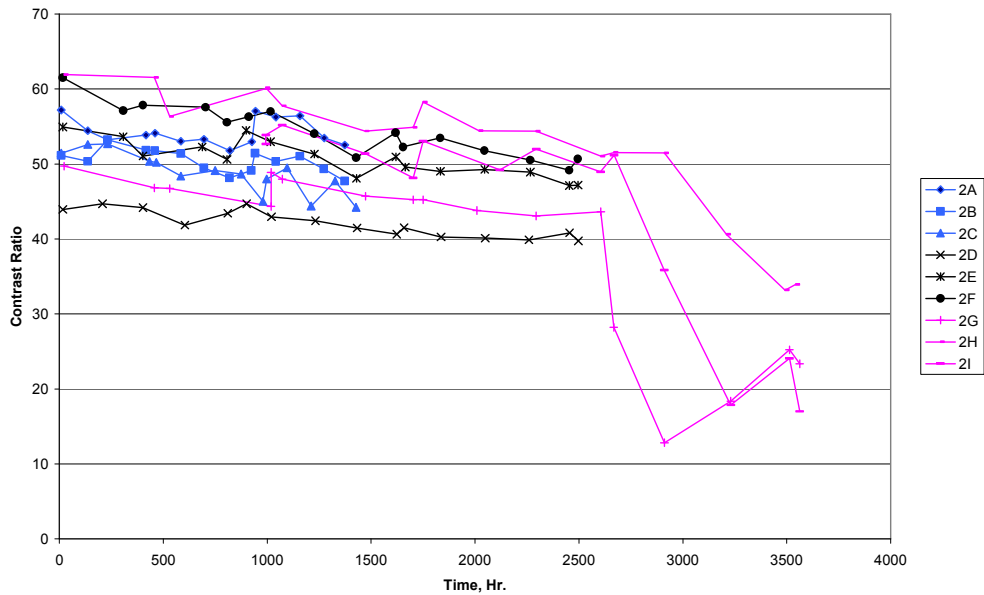


Page 23 shows detailed pictures of the white black, red black, green black, and blue black checkerboard contrast ratio decay for 2G a 24/7 duty cycle sample. Again, the pictures and graphs clearly show significant signs of LCD technology decay. This is seen in the pictures as blue light bleeding through the image and in the graphs as a rapid decay in measured contrast ratio around 2700 hours of on time. Sample 2H was the last sample in this duty cycle to show significant visual and measurable changes in LCD technology decay at 3500 hours of on time.

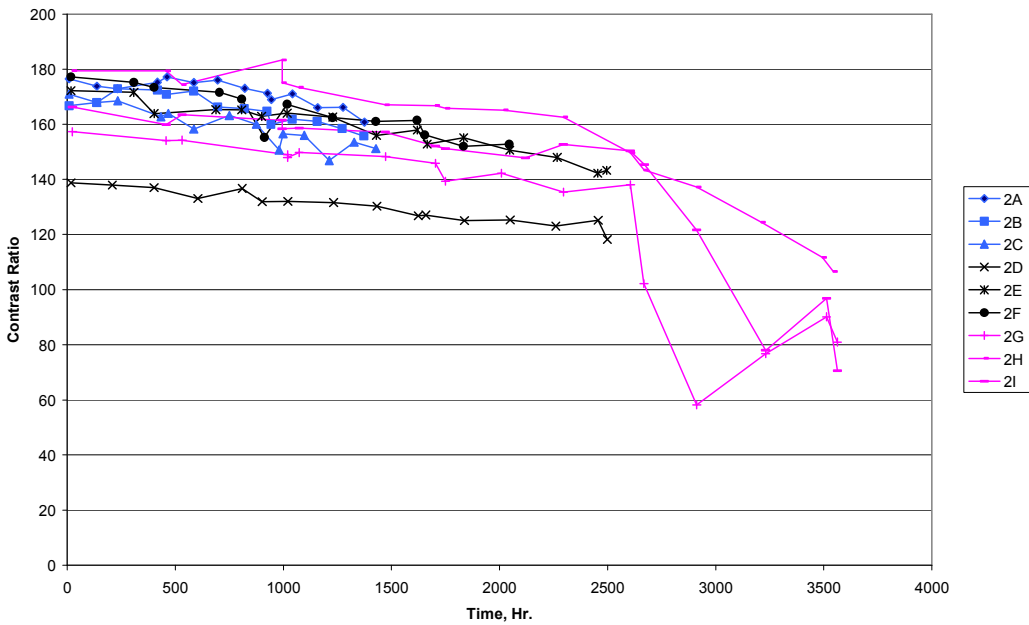
White Black Checkerboard Contrast Ratio



Red Black Checkerboard Contrast Ratio

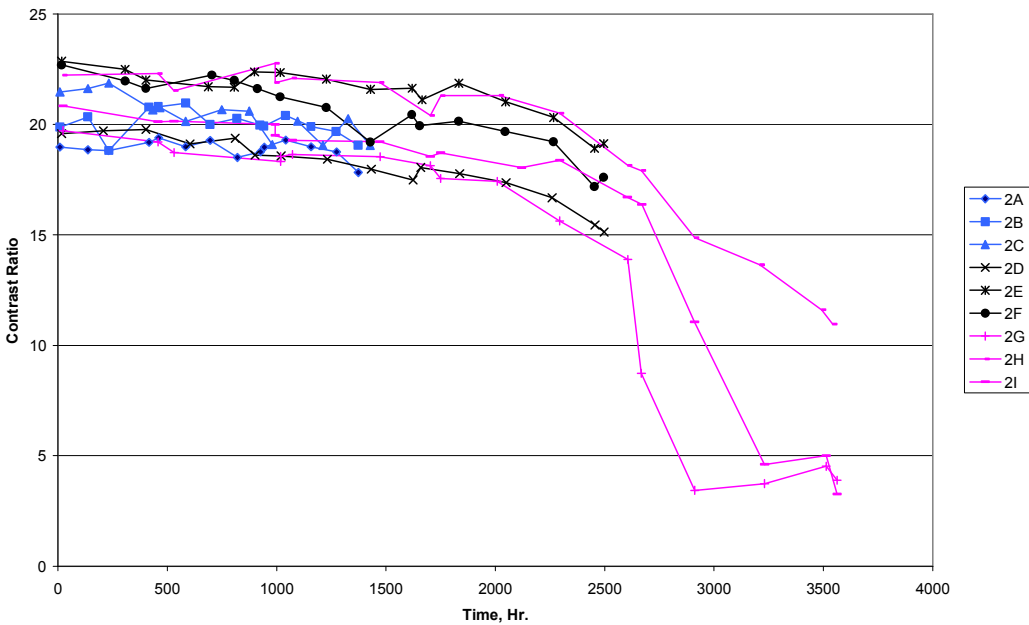


Green Black Checkerboard Contrast Ratio



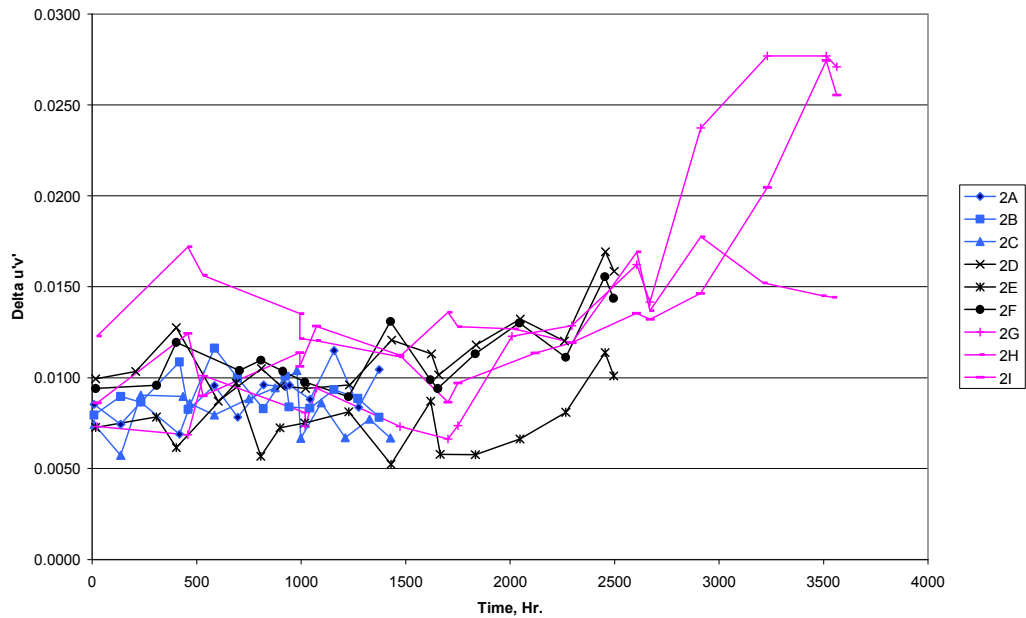
Although, all of the graphs to date suggest the blue LCD technology decays as a function of on time regardless of the duty cycle, the blue black checkerboard contrast ratio graph shows it best. This deterioration appears to be linked primarily to the blue LCD panel and polarizer deteriorating and effecting the measurements taken for the non-blue pattern measurements.

Blue Black Checkerboard Contrast Ratio

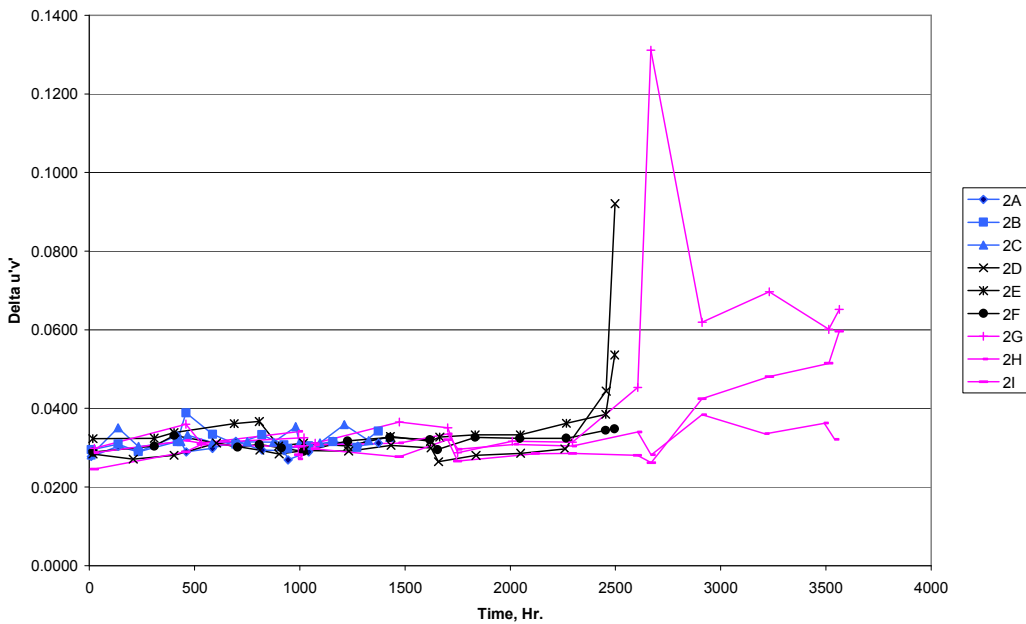


Color uniformity for LCD model 2 was very similar to model 1 in that the measurements show a dramatic change in screen uniformity that eventually levels off and even appears to get better. However, as indicated previously this is due to the LCD technology becoming more evenly deteriorated across the active display and not an improvement in LCD technology operation. This is best seen in the pictures on page 24.

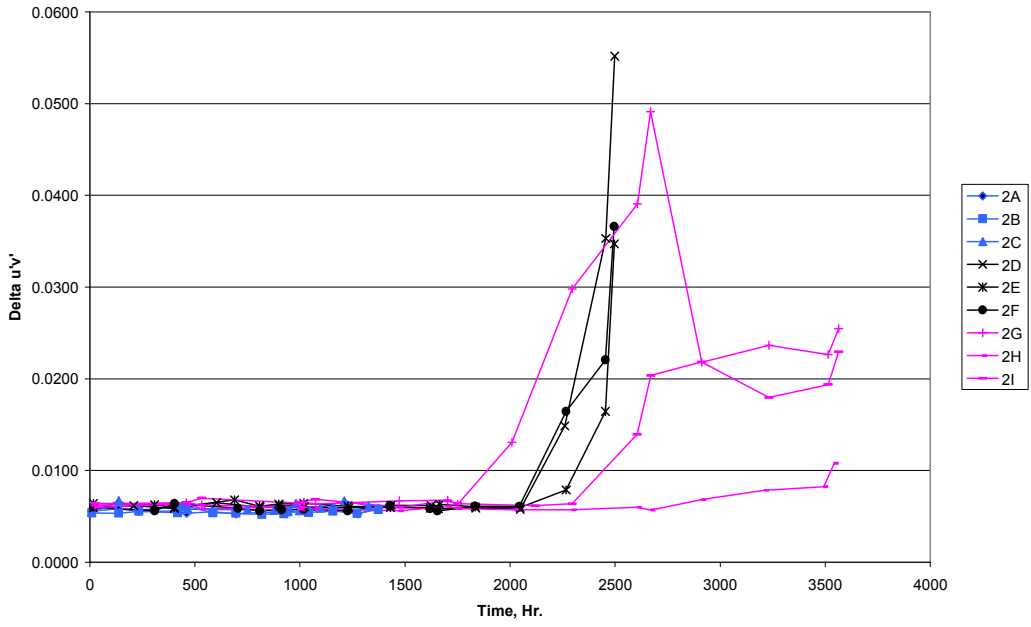
Change in White Uniformity Vs. Time



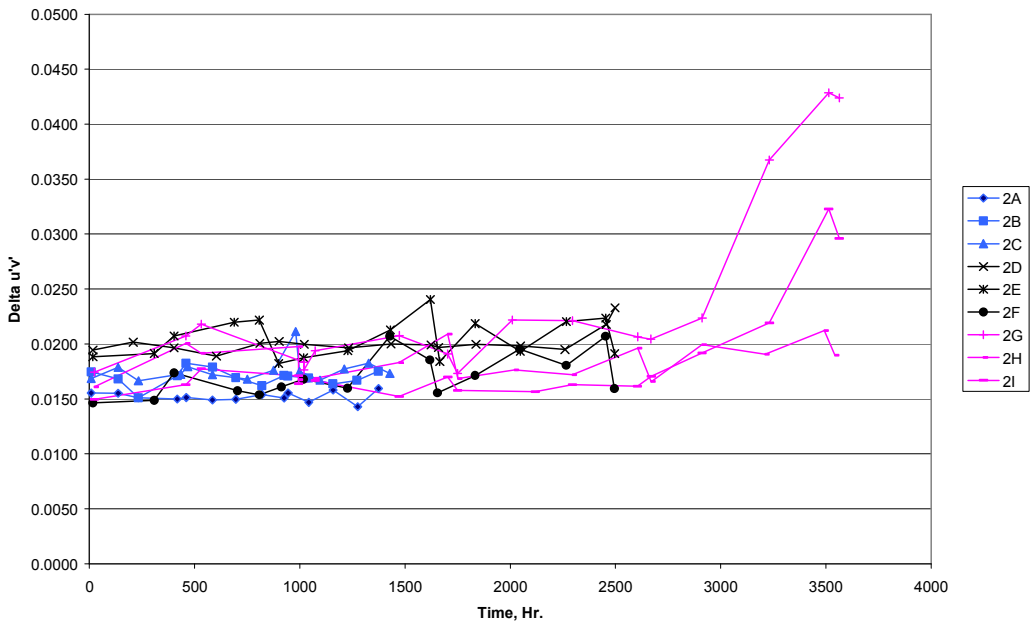
Change in Red Uniformity Over Time



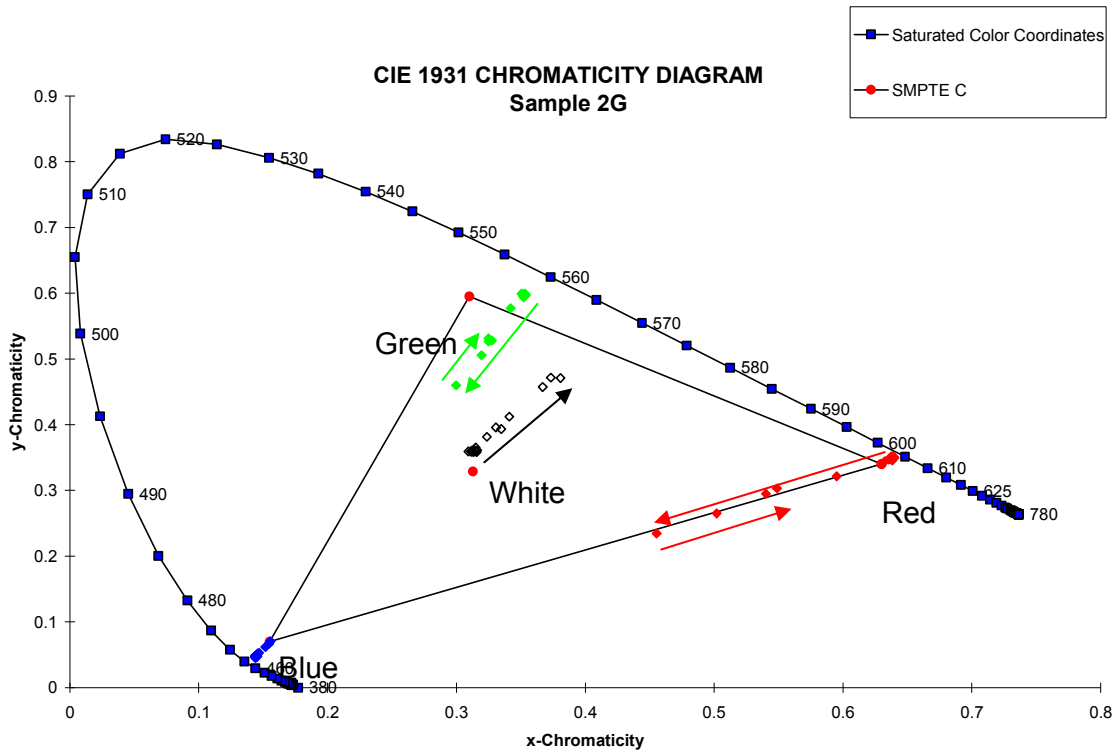
Change in Green Uniformity Over Time



Change in Blue Uniformity Over Time



Again, the most noticeable changes on the Chromaticity diagram are in the white, red, and green measurements. For this model the first significant shift in color happens in the white measurements, in which the white image shifts up and right into the yellow green region of color space. Then the red and green measurements begin to shift in the lower left direction toward blue and then back again. Only sample 1I is shown below, however, this trend is evident in the other 24/7 duty cycle samples.



Model 2 pictures



Sample 2G 458 hours



Sample 2G 3231 hours



Sample 2D 308 hours



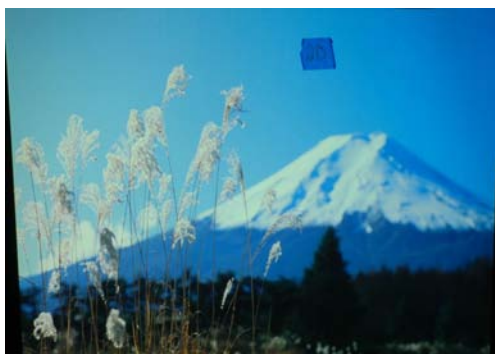
Sample 2D 2260 hours



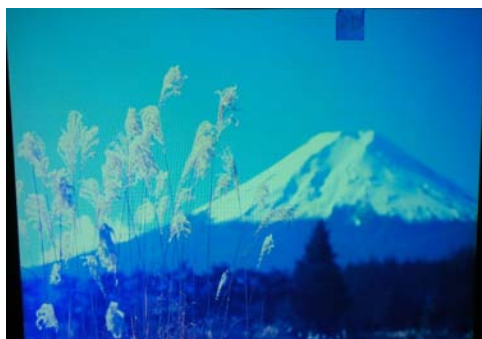
Sample 2G 458 hours



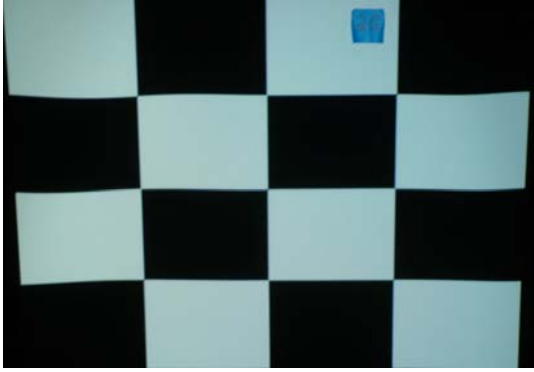
Sample 2G 3231 hours



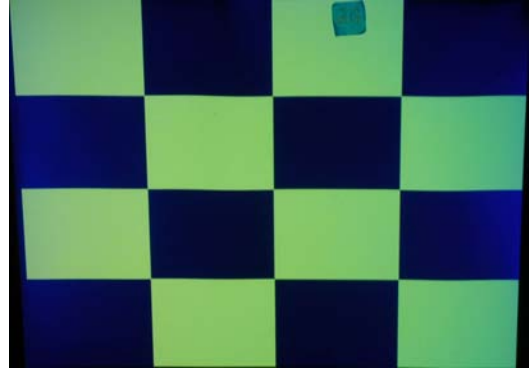
Sample 2D 208 hours



Sample 2D 2862 hours



Sample 2G 458 hours



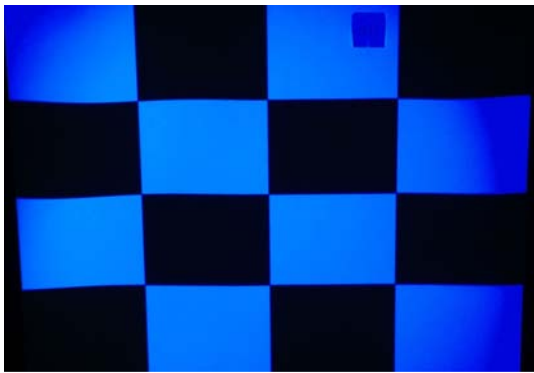
Sample 2G 3231 hours



Sample 2G 458 hours



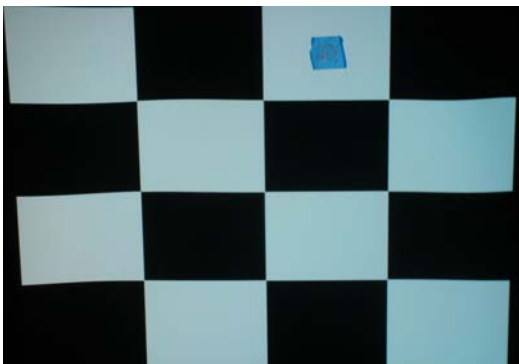
Sample 2G 3231 hours



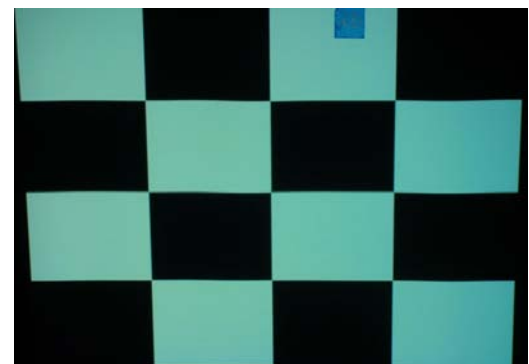
Sample 2G 458 hours



Sample 2G 3231 hours



Sample 2D 458 hours



Sample 2D 1837 hours



Sample 2G 458 hours



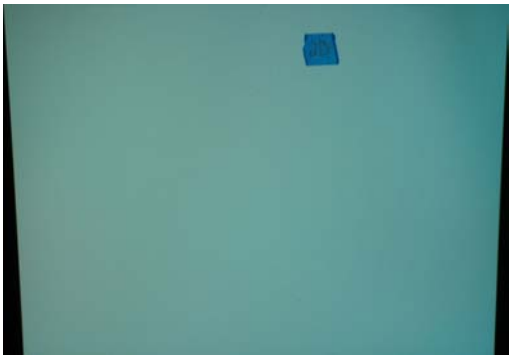
Sample 2G 1473



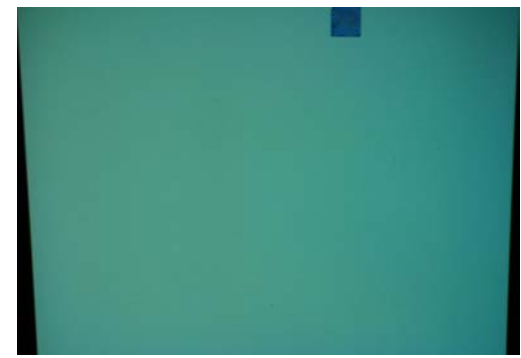
Sample 2G 2668 hours



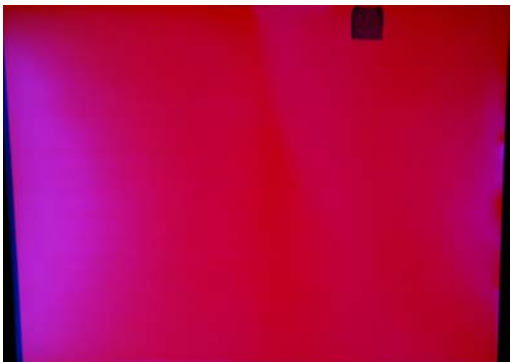
Sample 2G 3231 hours



Sample 2D 208 hours



Sample 2D 2260 hours



Sample 2G_2668 hours



Sample 2G 3231 hours

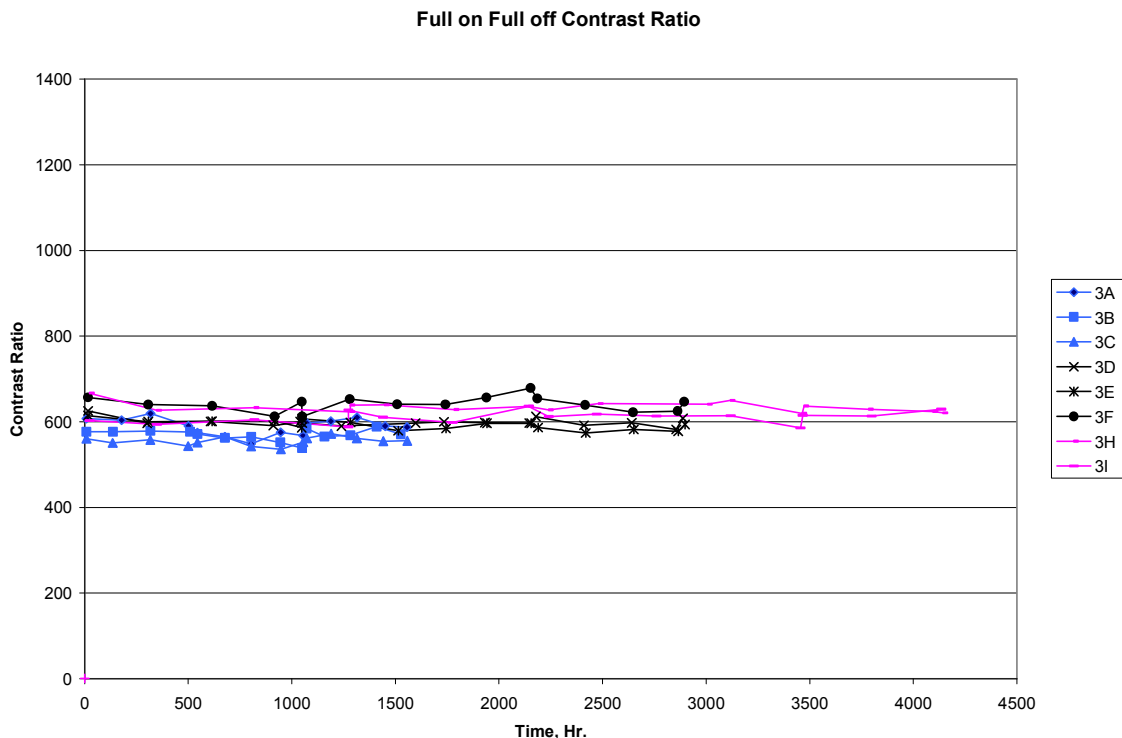
DLP® Model 3 Summary

DLP® model 3 samples have shown no significant visible or measurable change in DMD chip performance to date. Upon completion of 4000 hours of run time each sample will be evaluated for component failures.

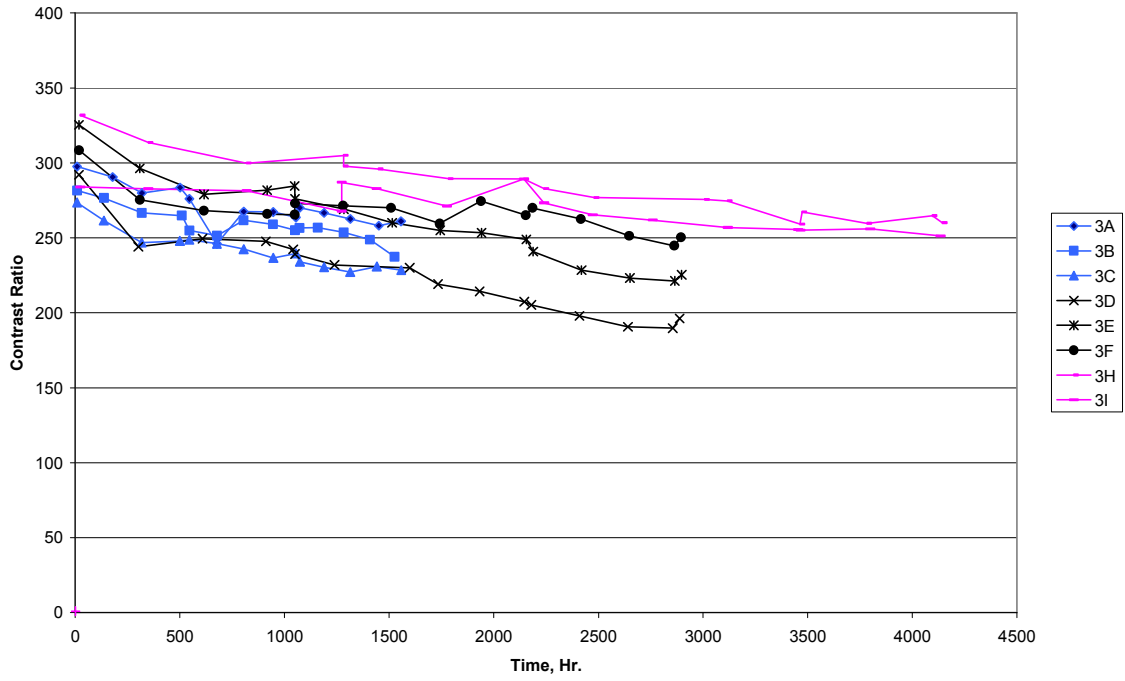
Model 3 Graphs

The graphs below are plotted with all of the samples for this model except 3G. Sample 3G developed a yellow spot at the center of the screen and was disassembled after reaching 4000 hours of run time. It was determined by Intertek that the mirror located directly across from the color wheel showed visible signs of contamination. Although the exact cause for this contamination is unknown, it appears to be an isolated manufacturing flaw. Since this was not related to a failure of the DMD chip the results for this unit have been omitted. Reference the bottom of page 34 for pictures of the 3G screen and component failure. The blue lines represent the 1.5 on 2.5 off duty cycle, black lines represent the 5.5 on 2.5 off duty cycle, and the red lines represent the continuous duty cycle.

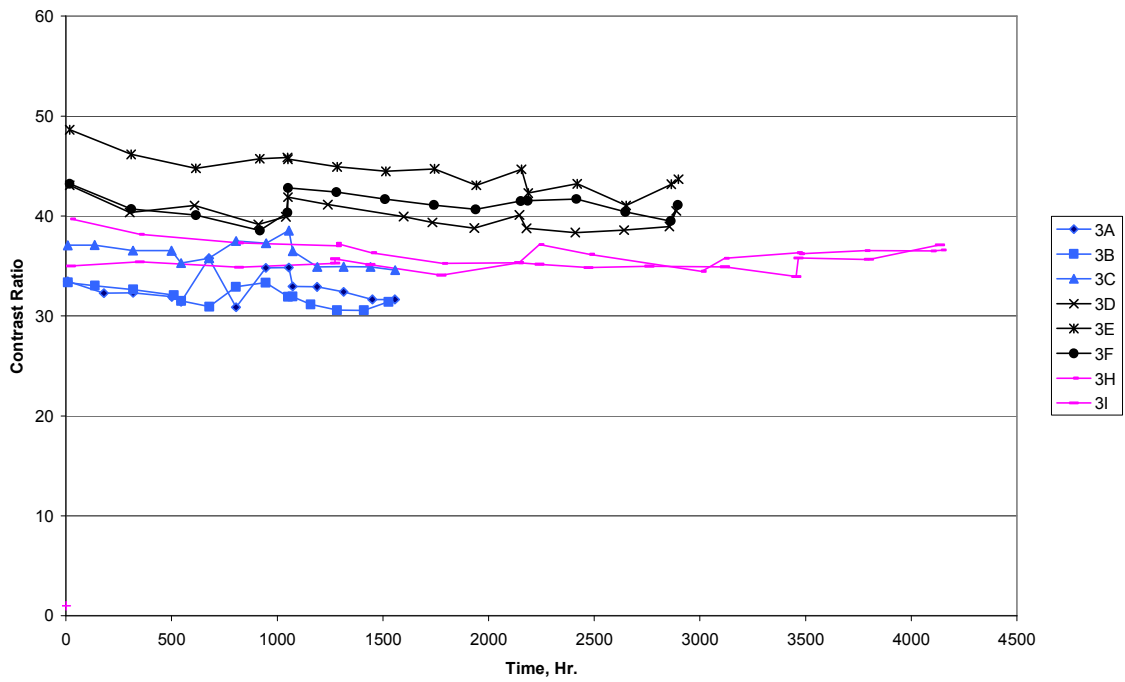
The graphs for the contrast ratio measurements indicate a linear trend in performance. The full on full off, red black checkerboard, and blue black checkerboard contrast ratios are fairly flat and the white black, and green black checkerboard contrast ratios show a slight decrease over time.



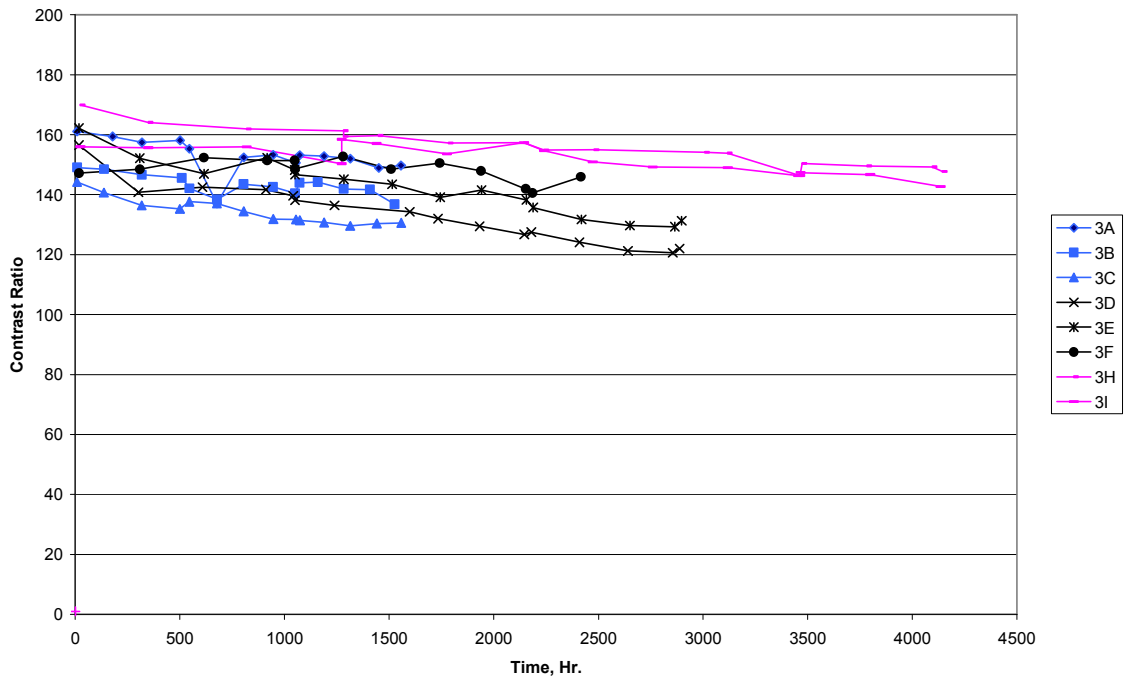
White Black Checkerboard Contrast Ratio



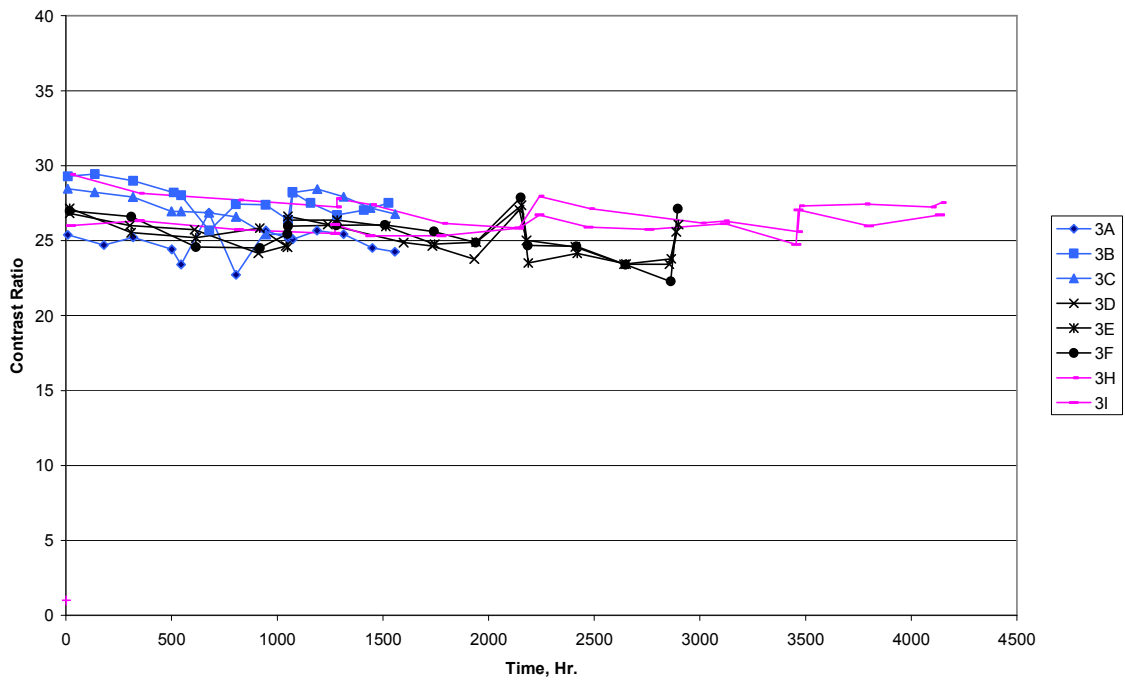
Red Black Checkerboard Contrast Ratio



Green Black Checkerboard Contrast Ratio

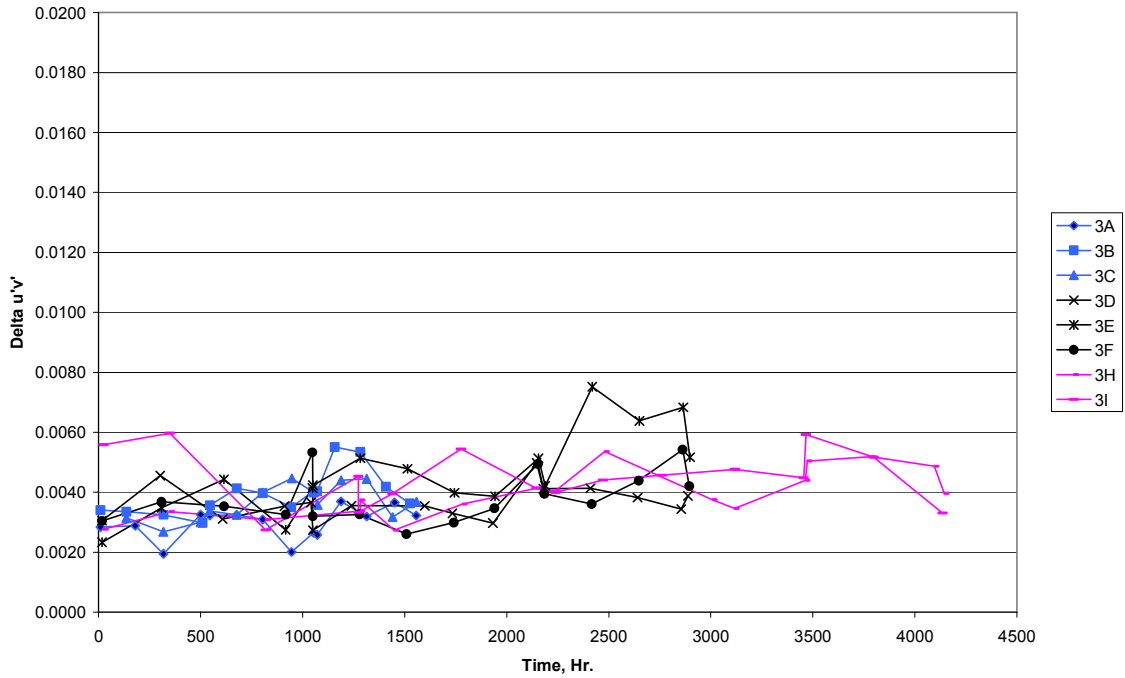


Blue Black Checkerboard Contrast Ratio

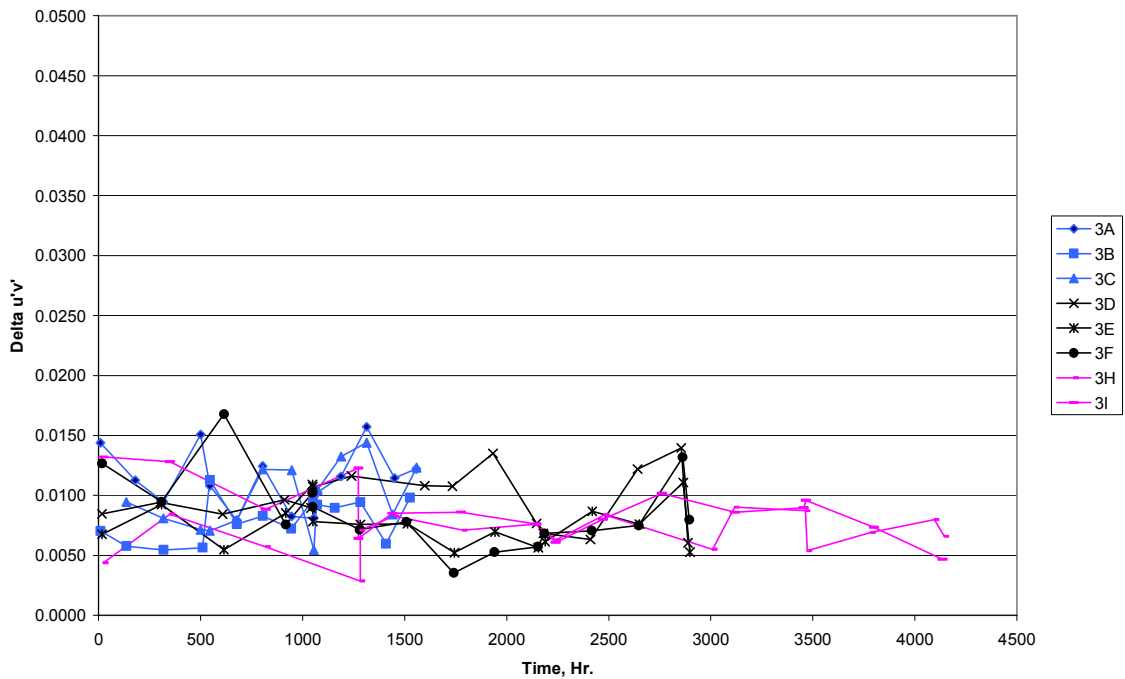


DMD chip technology used in the DLP[®] model 3 samples also shows a fairly consistent measurement in all of the color uniformity graphs.

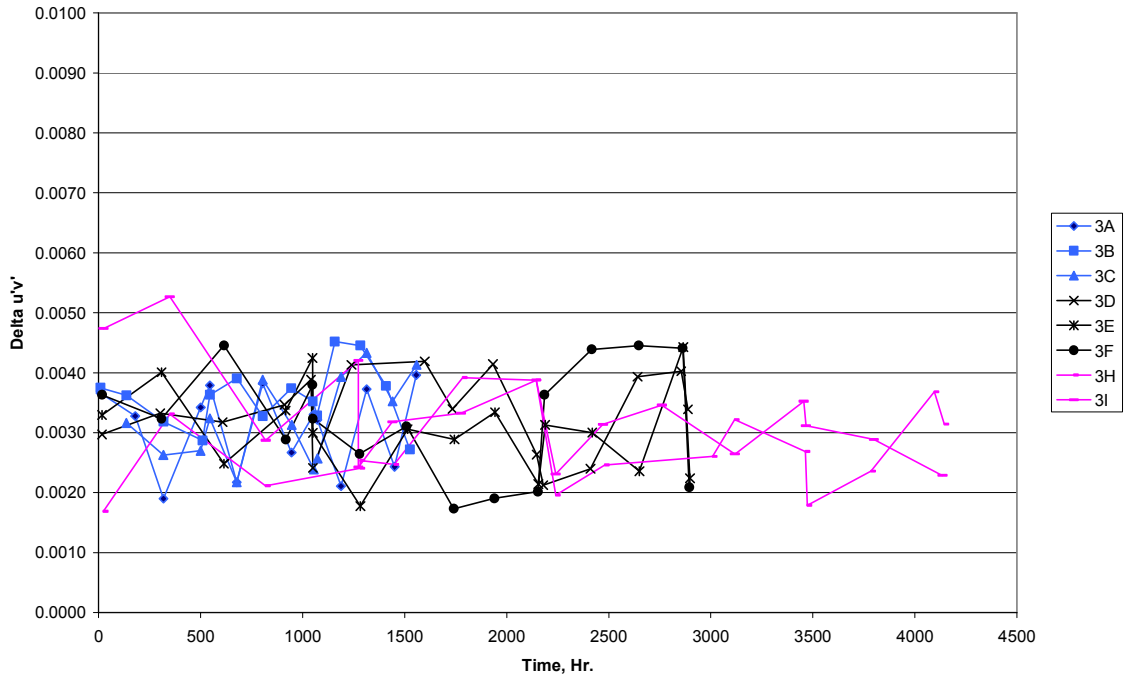
Change in White Uniformity Vs. Time



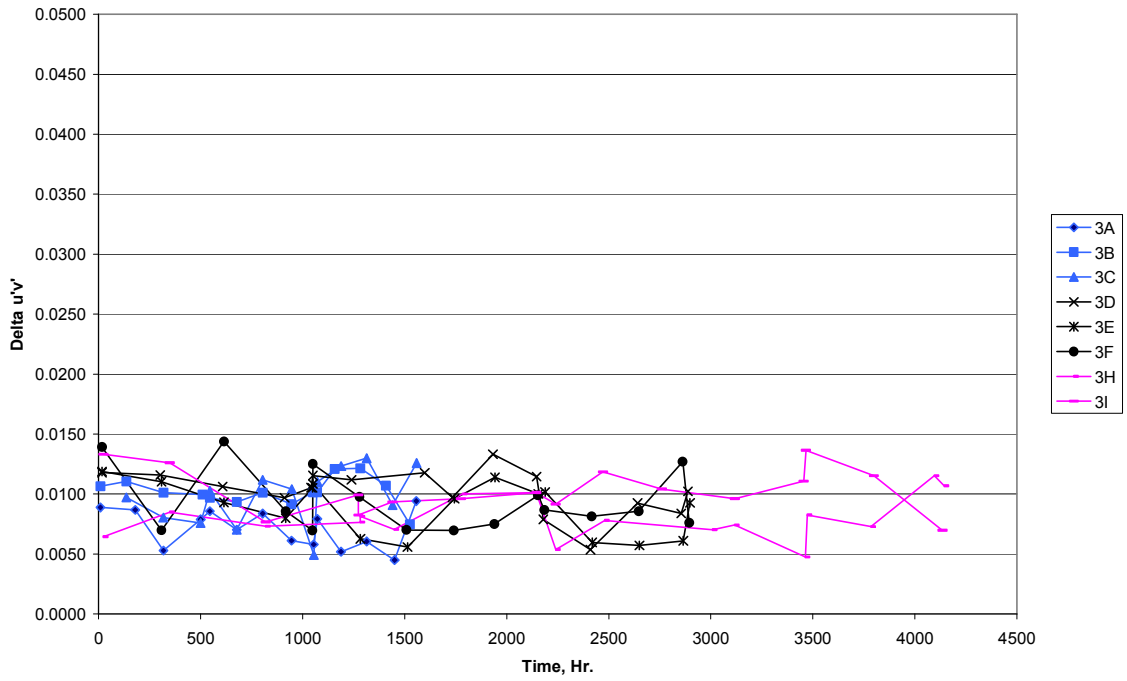
Change in Red Uniformity Over Time



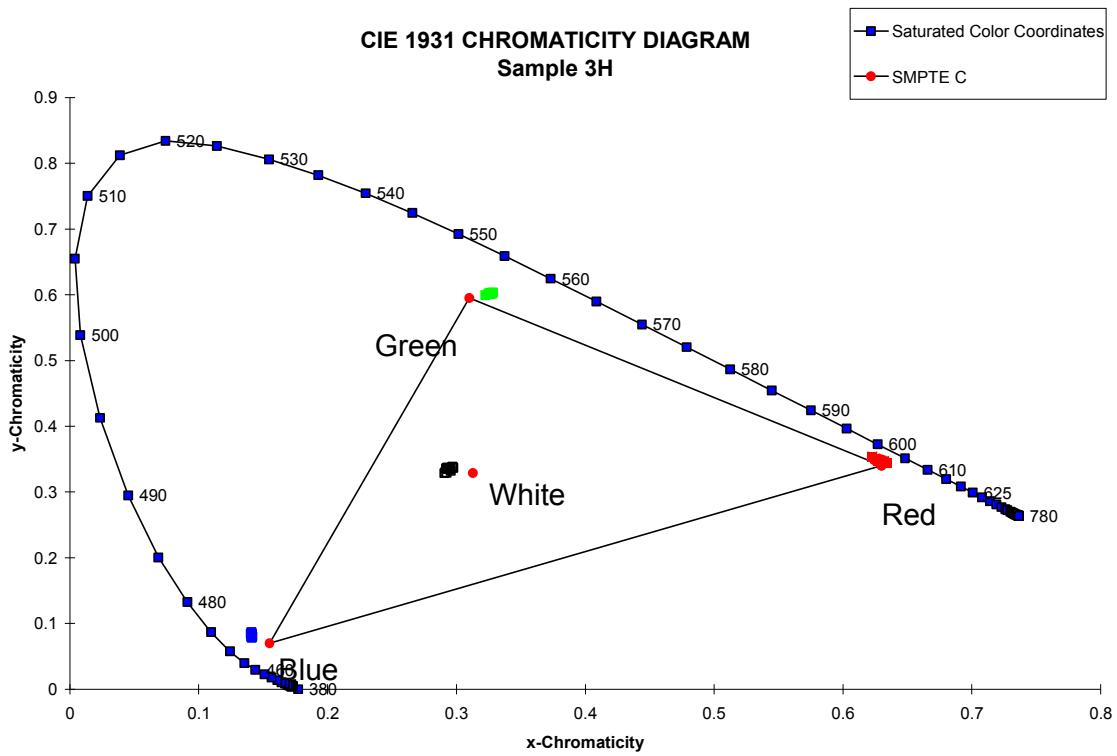
Change in Green Uniformity Over Time



Change in Blue Uniformity Over Time



DMD chip technology has shown little to no change in color reproduction as indicated graphically below.



Model 3 Pictures



Sample 3H 25 hours



Sample 3H 3719 hours



Sample 3E 308 hours



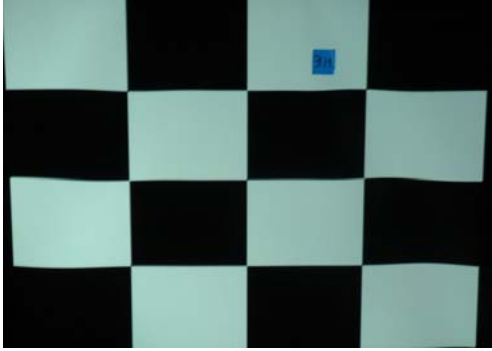
Sample 3E 2650 hours



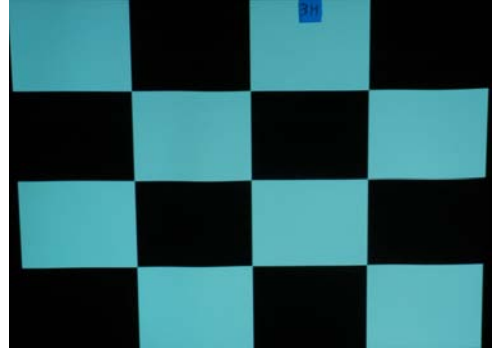
Sample 3B 137 hours



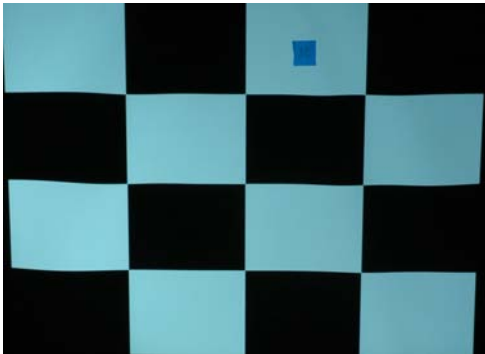
Sample 3B 1409 hours



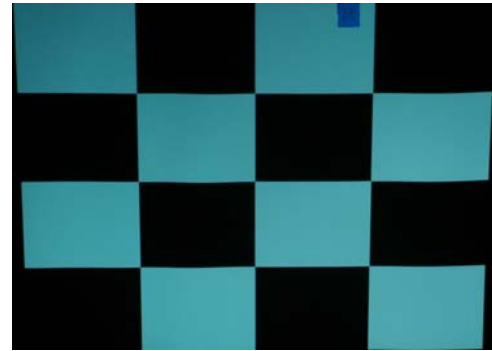
Sample 3H 25 hours



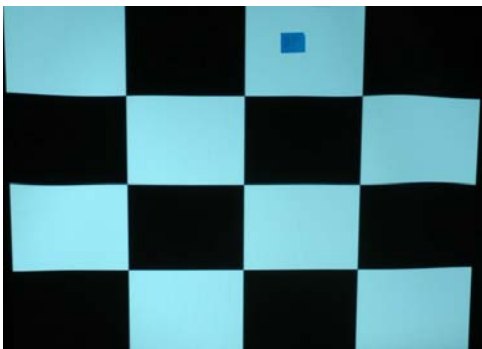
Sample 3H 3719 hours



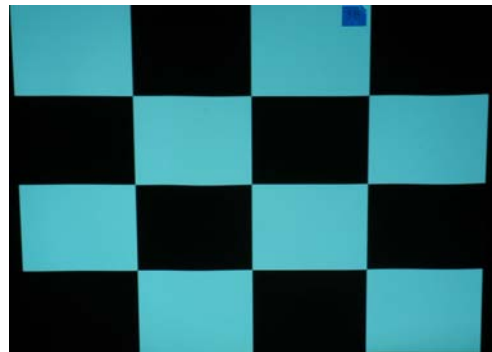
Sample 3E 308 hours



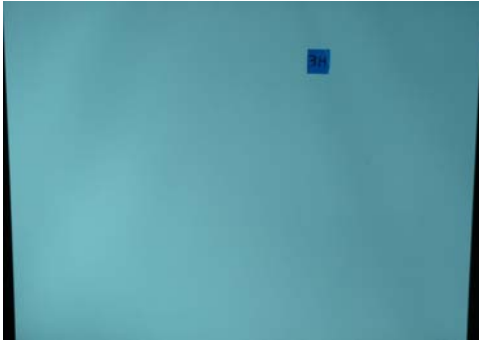
Sample 3E 2650 hours



Sample 3B 137 hours



Sample 3B 1409 hours



Sample 3H 349 hours



Sample 3H 3720 hours



Sample 3E 308 hours



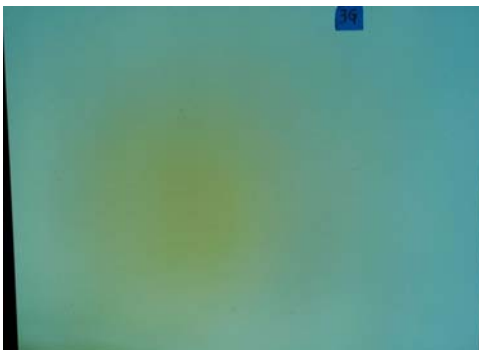
Sample 3E 2650 hours



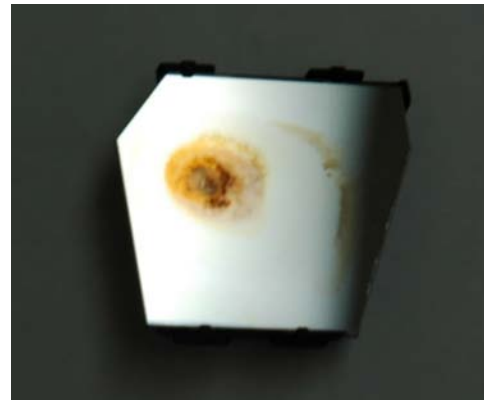
Sample 3B 137 hours



Sample 3B 1409 hours



3G Screen End of Study



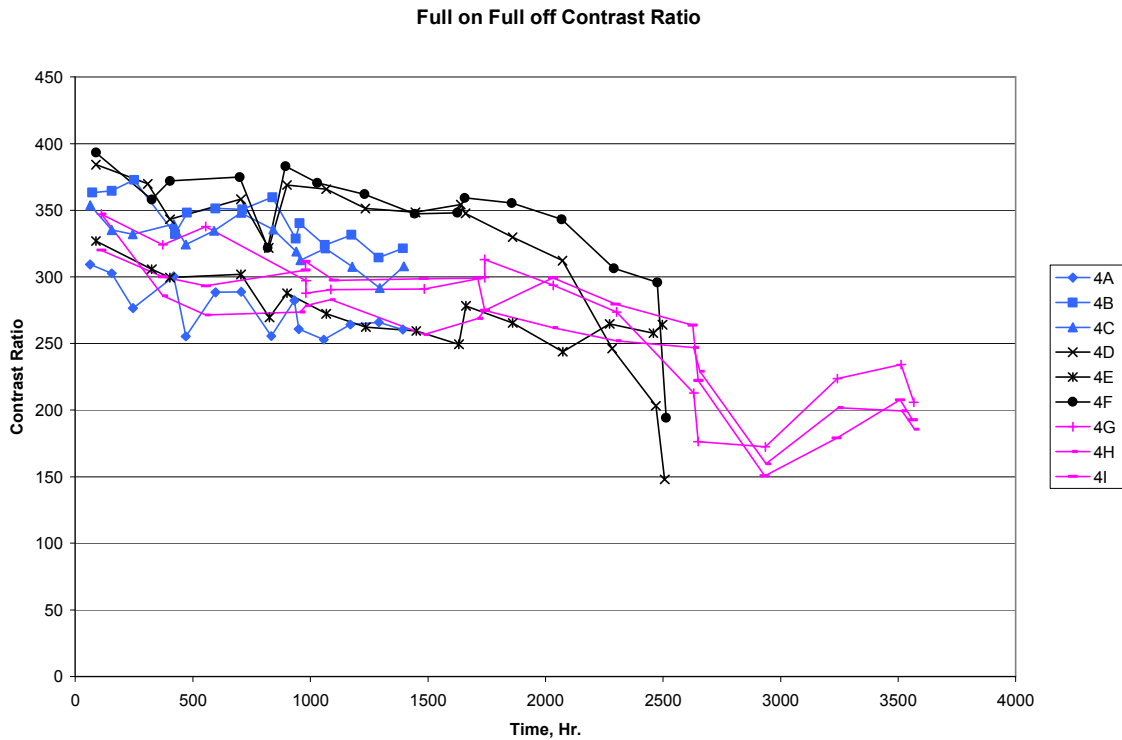
3G Reflective Mirror

LCD Model 4 Summary

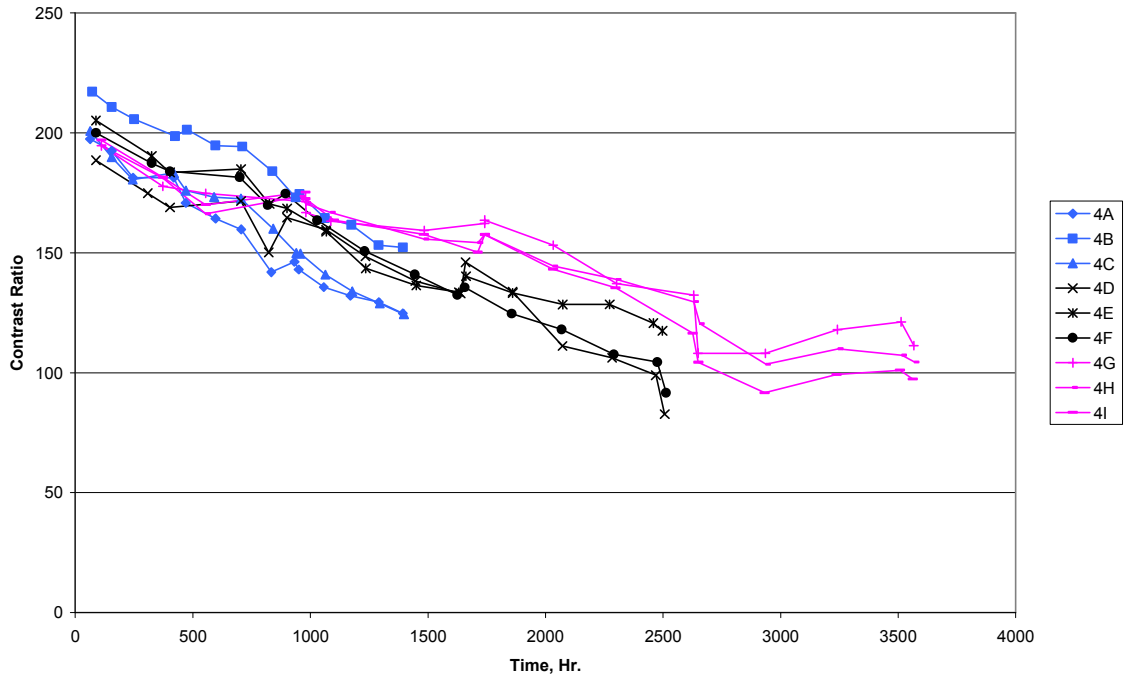
As indicated by the pictures on page 40, all of the LCD model 4 samples showed significant signs of LCD panel and polarizer decay at 3246 hours of on time. Display technology deterioration was first noticed in LCD model 4G at 1771 hours of on time. The slight yellowing noted at 1771 hours later progressed to cover the entire screen. A second anomaly was also noticed in which the images began to show blue in portions of the screen regardless of the projected image. This resulted in a significant drop in contrast ratio as shown in the graphs on page 34 through 36.

Model 4 Graphs

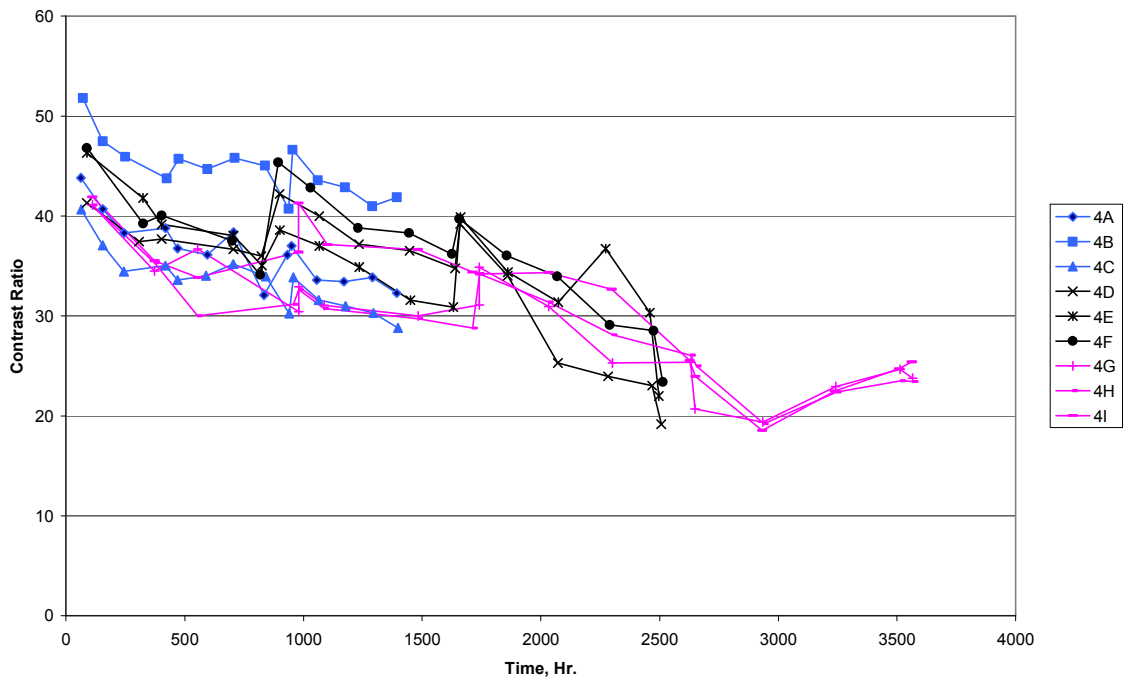
LCD technology, used in the model 4 samples showed significant signs of deterioration after 2700 hours of on time as indicted by the graphs below. The model 4 samples were also the first LCD technology to show visual signs of deterioration.



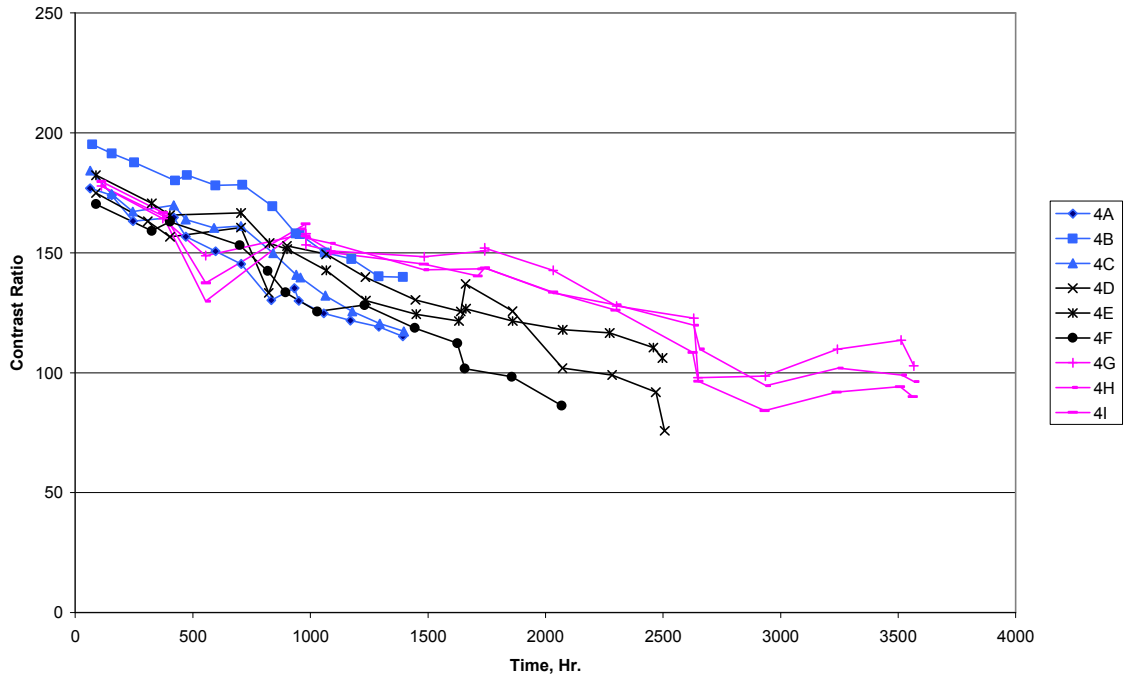
White Black Checkerboard Contrast Ratio



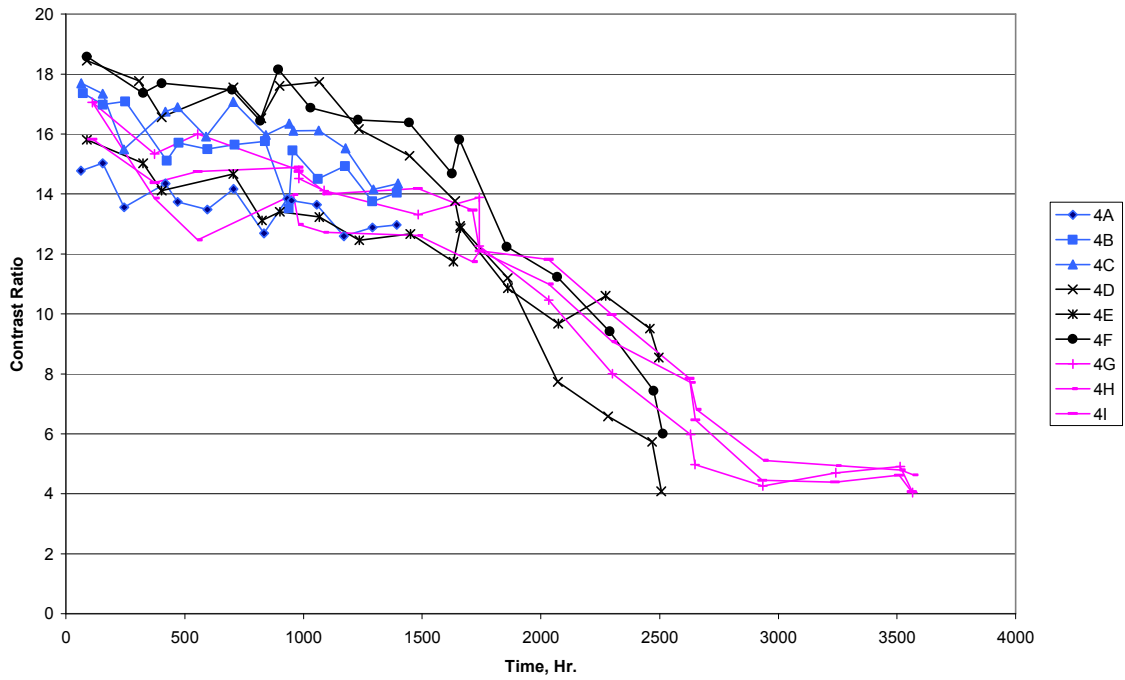
Red Black Checkerboard Contrast Ratio



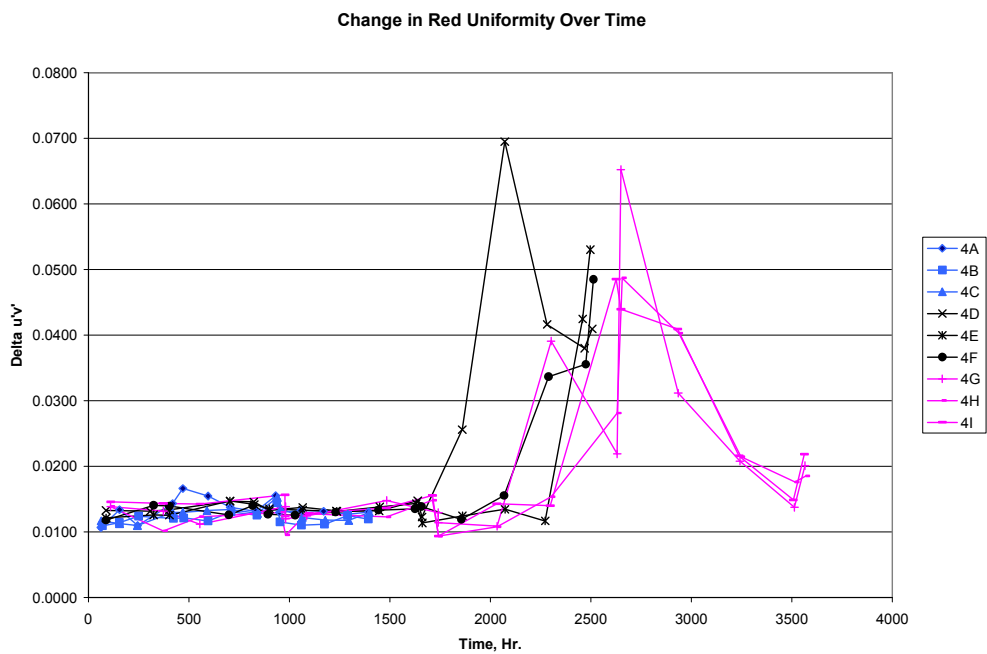
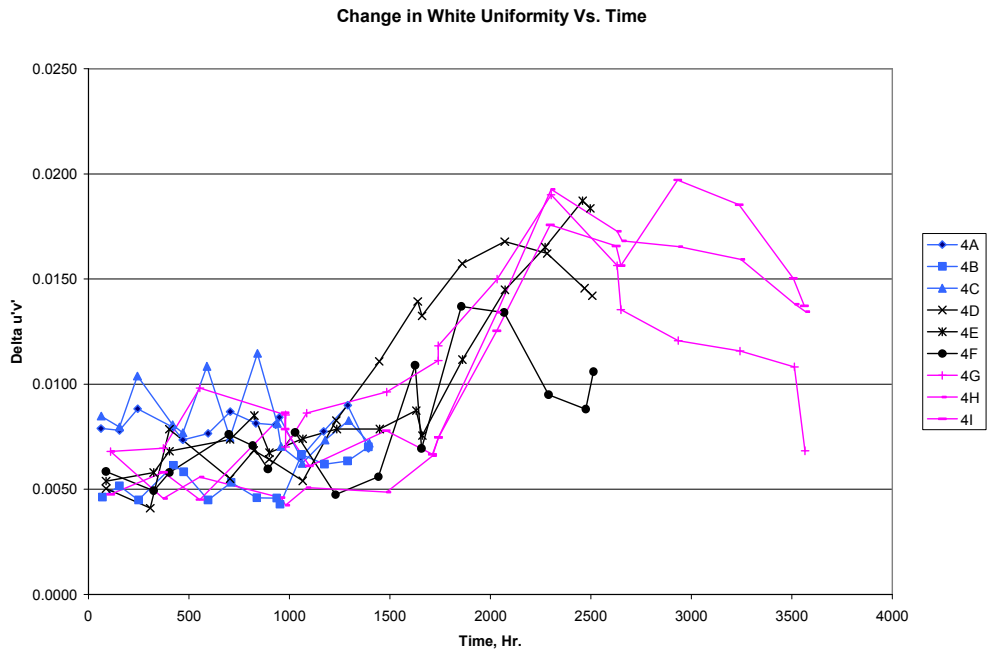
Green Black Checkerboard Contrast Ratio



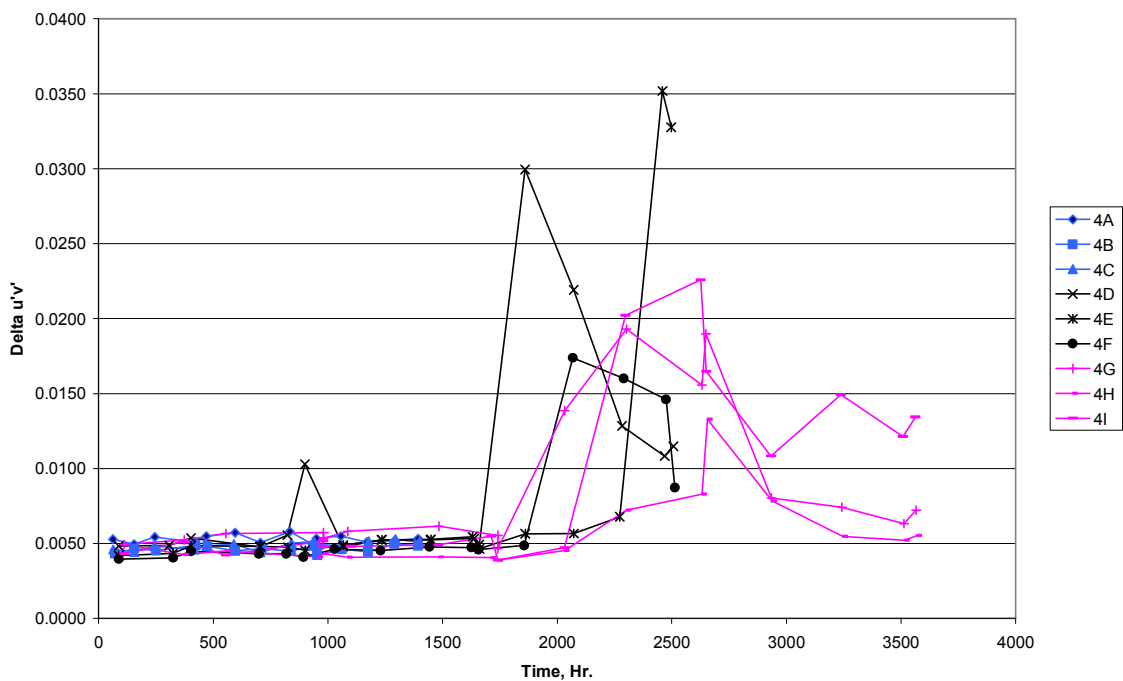
Blue Black Checkerboard Contrast Ratio



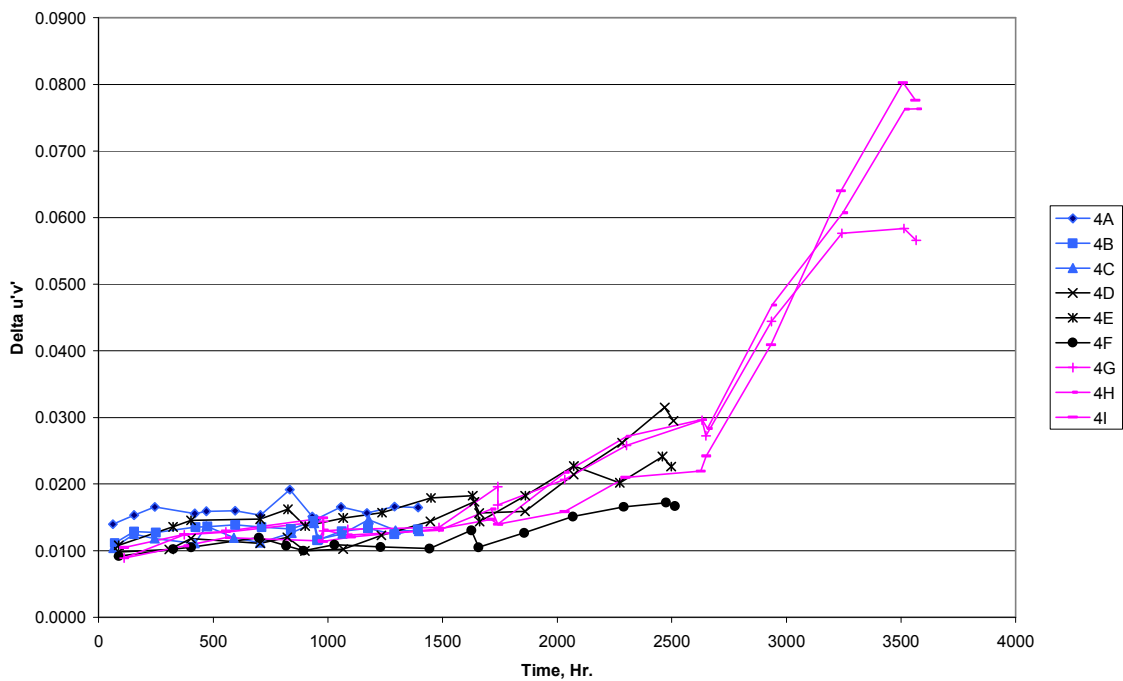
LCD technology decay can be seen in the graphs for color uniformity as a rise in measured values that eventually decline. Again the decline is not so much a return to the original color as it is a more uniformly deteriorated image. Evidence of this can be seen in the pictures provided on page 42.



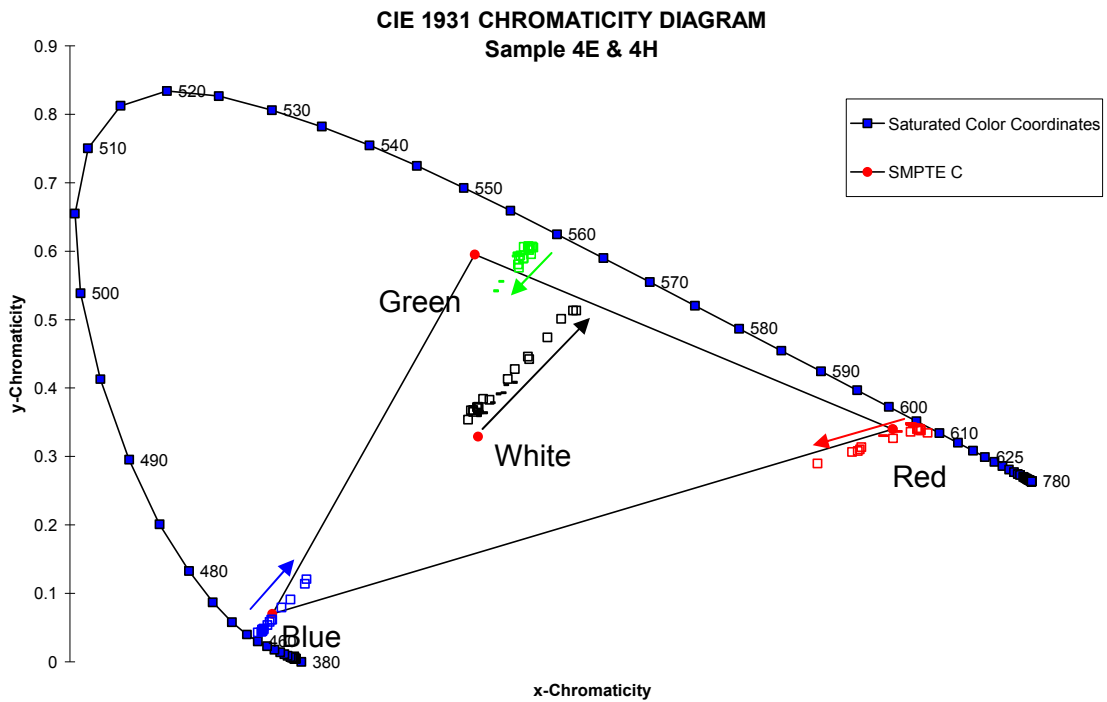
Change in Green Uniformity Over Time



Change in Blue Uniformity Over Time



Unlike the other chromaticity diagrams which show only one model, this diagram includes both 4E (5.5/2.5 sample) and 4H (24/7 sample). Model 4 samples showed the earliest indications of deterioration, and the data collected for 4E indicates a similar trend to that collected for 4H. This is especially clear in the graphs above as 4D-4F (5.5/2.5) samples closely follow that of the 4G-4H (24/7) samples and in some cases even deteriorate faster than their 24/7 counterparts.



Model 4 pictures



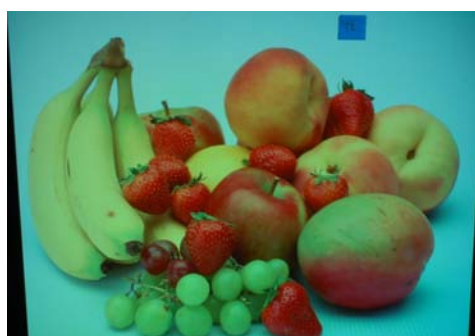
Sample 4H 374 hours



Sample 4H 3246 hours



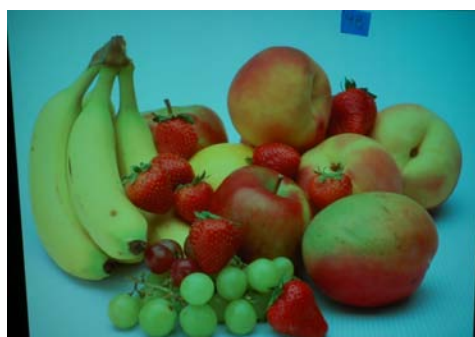
Sample 4E 88 hours



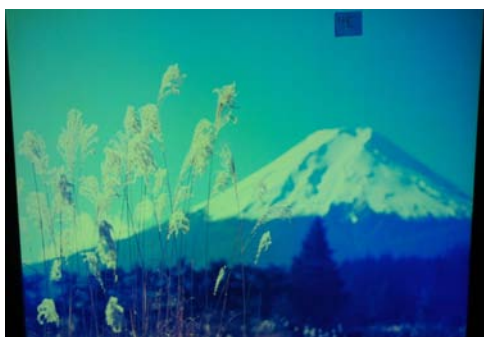
Sample 4E 2273 hours



Sample 4B 71 hours



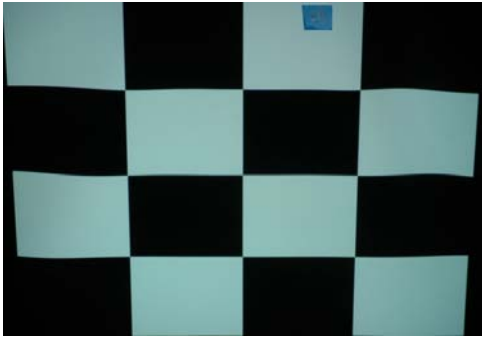
Sample 4B 1290 hours



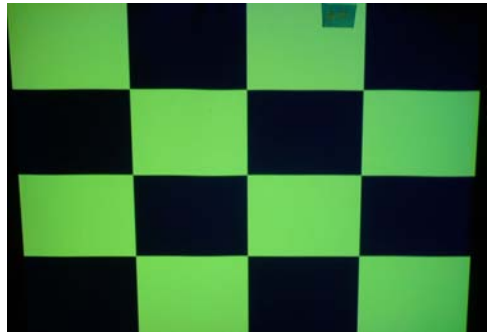
Sample 4E 2857 hours



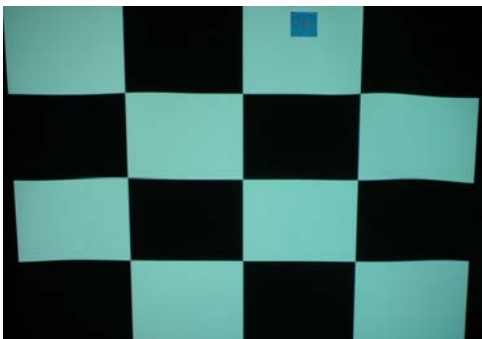
Sample 4H 3246 hours



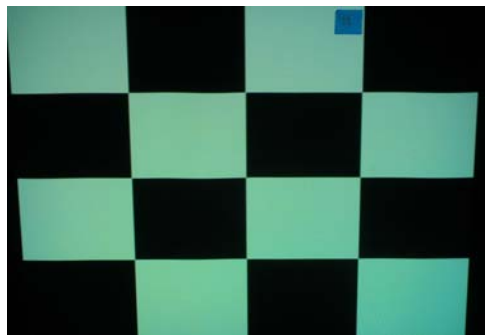
Sample 4H 374 hours



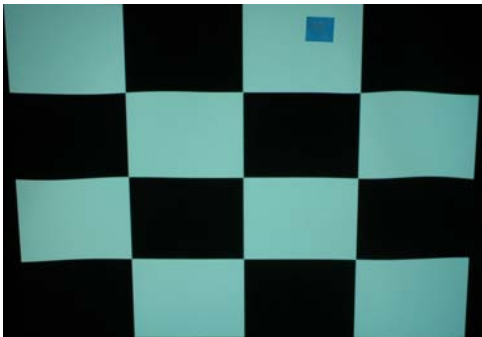
Sample 4H 3246 hours



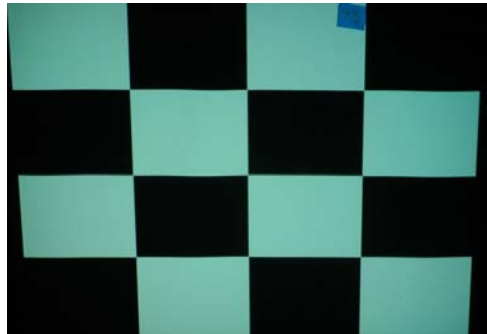
Sample 4E 88 hours



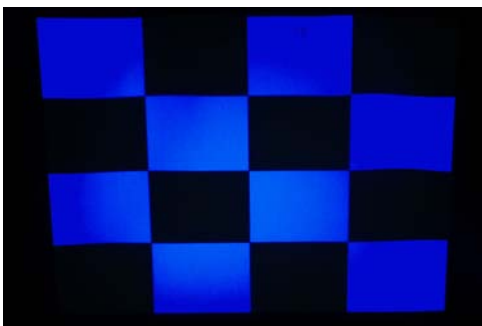
Sample 4E 2273 hours



Sample 4B 71 hours



Sample 4B 1290 hours



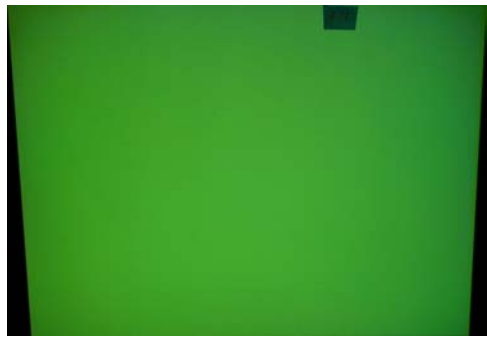
Sample 4H 374 hours



Sample 4H 3246 hours



Sample 4H 374 hours



Sample 4H 3246 hours



Sample 4H 374 hours



Sample 4H 3246 hours



Sample 4H 374 hours



Sample 4H 3246 hours



Sample 4H 374 hours



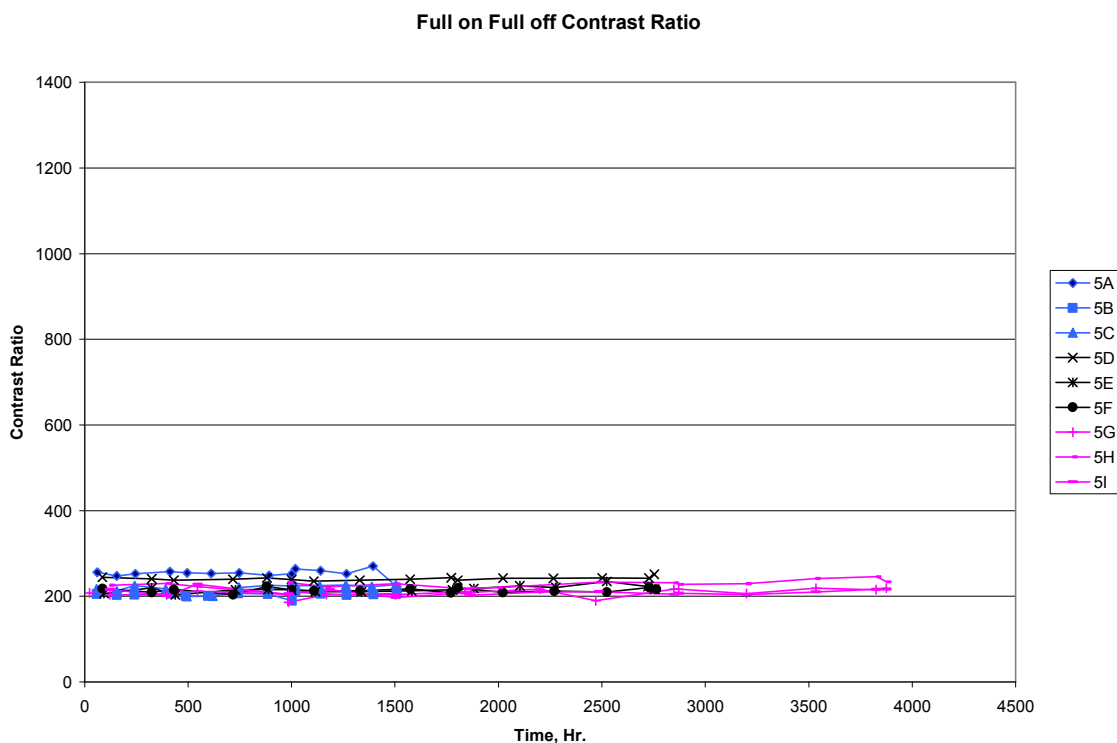
Sample 4H 3246 hours

DLP[®] Model 5 Summary

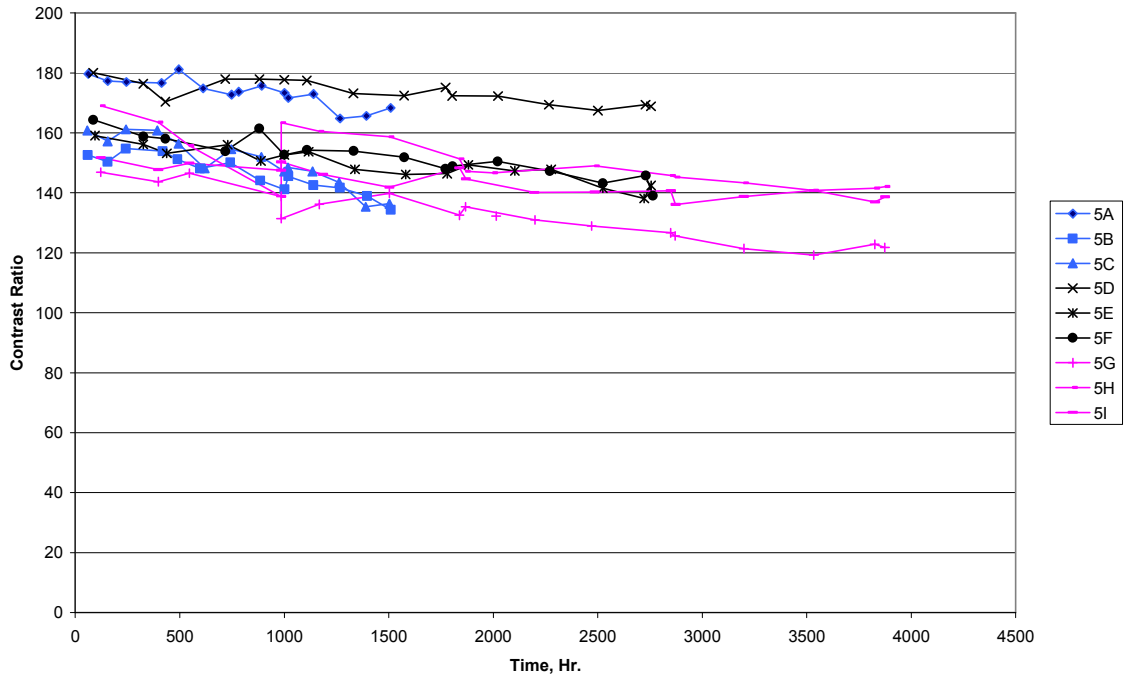
DLP[®] model 5 samples have shown no significant visible or measurable change in DMD chip performance to date.

Model 5 Graphs

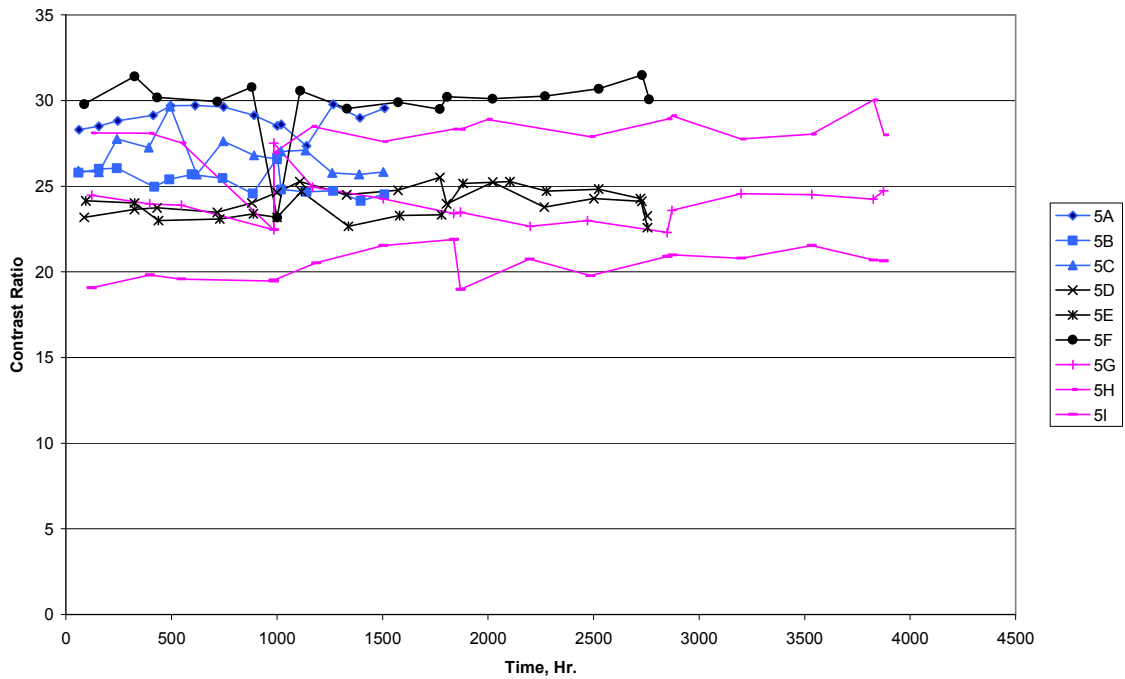
DMD chip technology again shows little to no change in their respective contrast ratio measurements. A slight decrease in values has been noted in both the white and green checkerboard contrast ratios, however, when compared against the LCD technology this change is not significant. The pictures at the end of this section also do not indicate any major changes in visual quality.



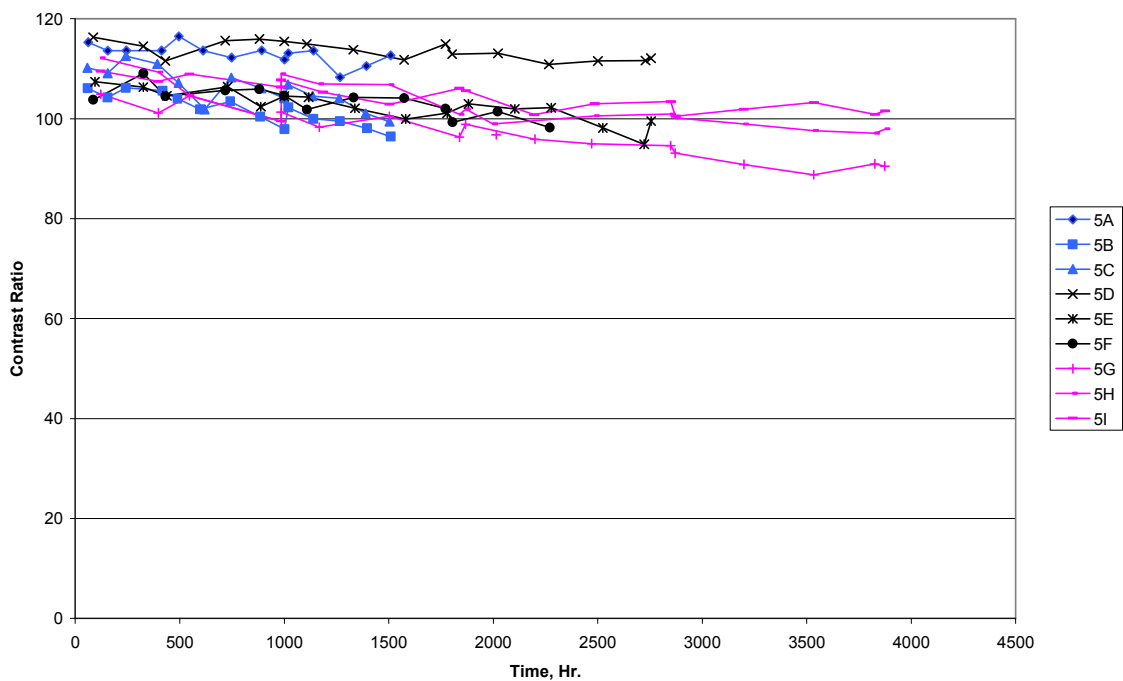
White Black Checkerboard Contrast Ratio



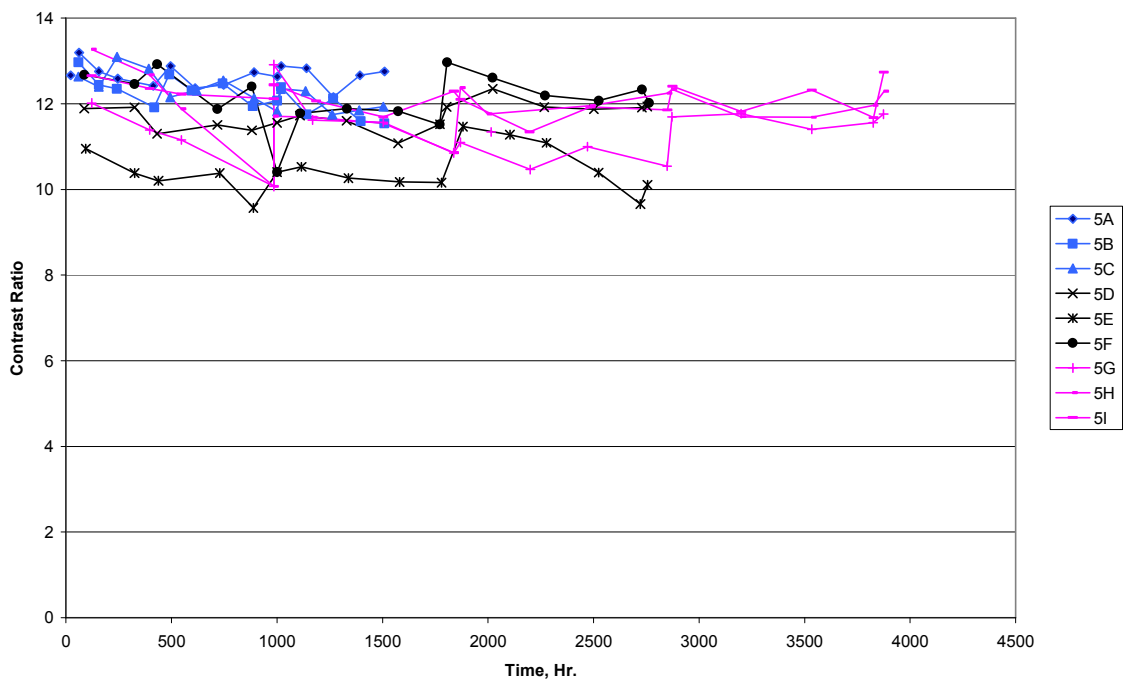
Red Black Checkerboard Contrast Ratio



Green Black Checkerboard Contrast Ratio

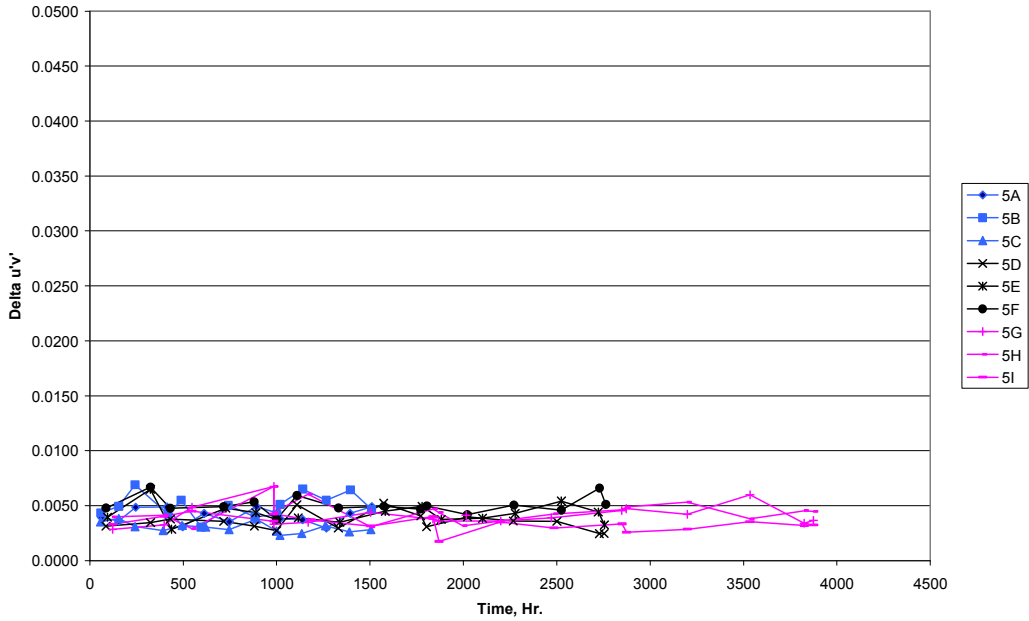


Blue Black Checkerboard Contrast Ratio

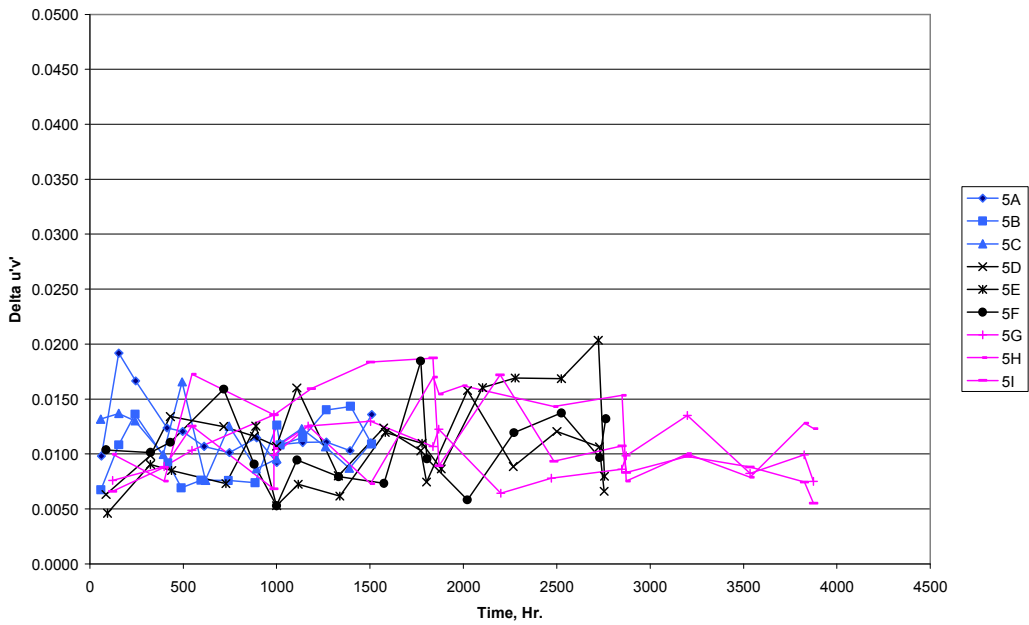


All of the color uniformity measurements for the DLP[®] model 5 samples have shown no significant changes in measured values, as indicated by the graphs below.

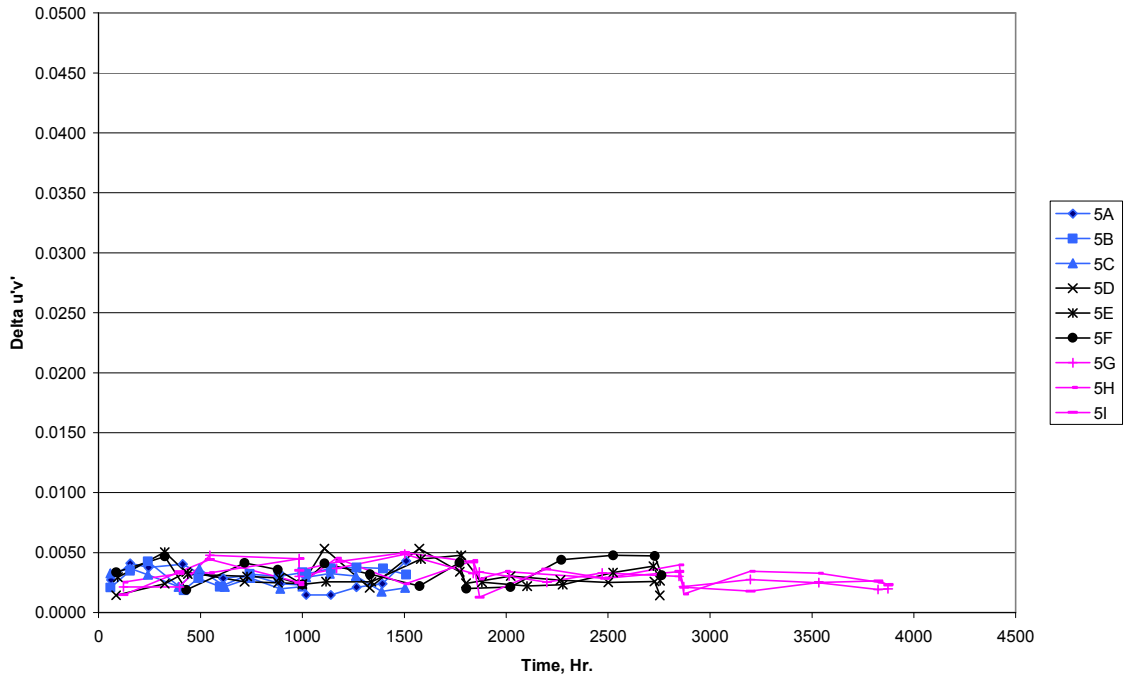
Change in White Uniformity Vs. Time



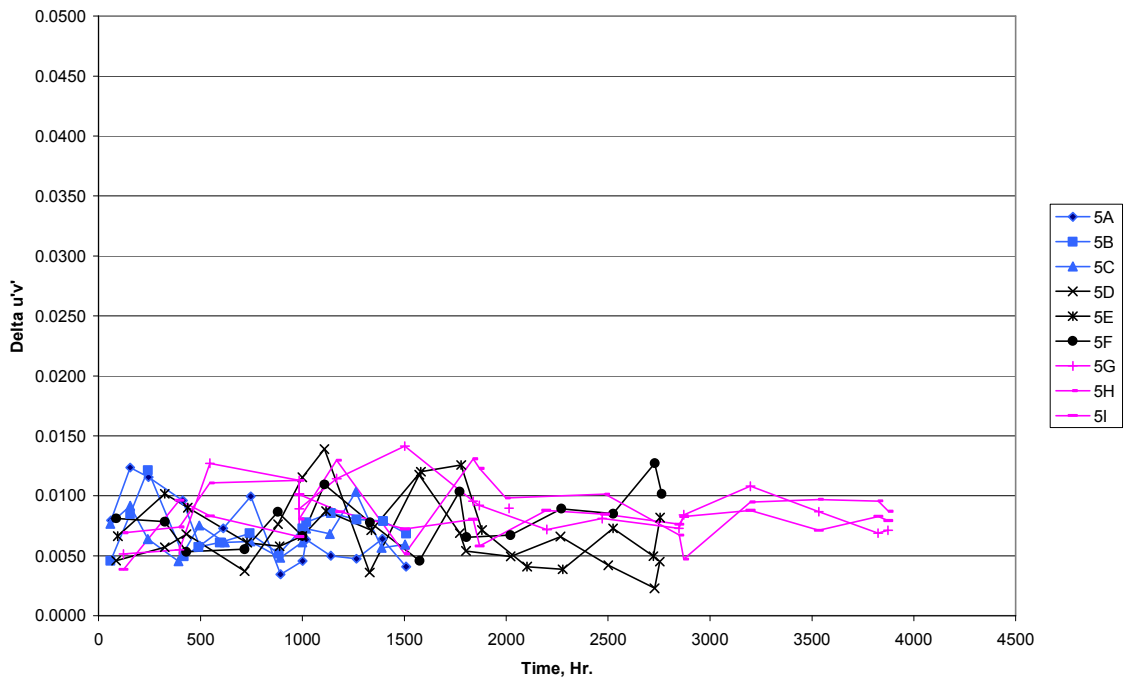
Change in Red Uniformity Over Time



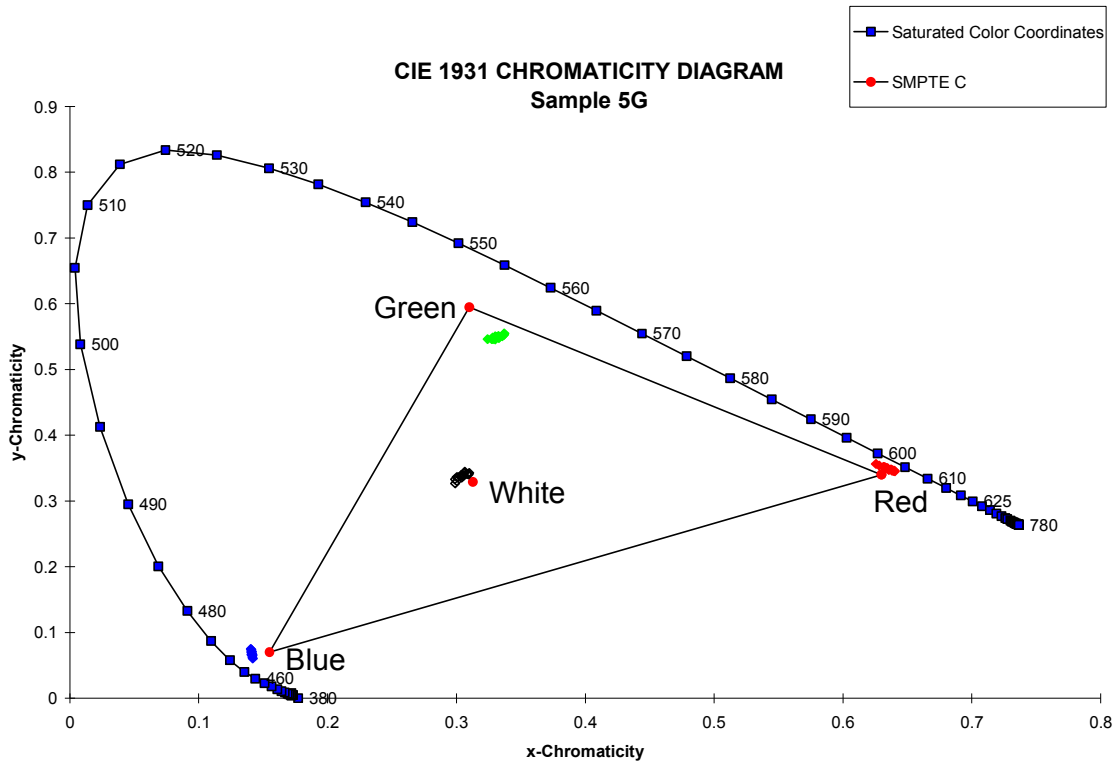
Change in Green Uniformity Over Time



Change in Blue Uniformity Over Time



The chromaticity diagram for sample 5G clearly shows that little to no change in color reproduction has occurred with the DMD chip.



Model 5 Pictures



Sample 5I 122 hours



Sample 5I 3534 hours



Sample 5F 86 hours



Sample 5F 2524 hours



Sample 5C 58 hours



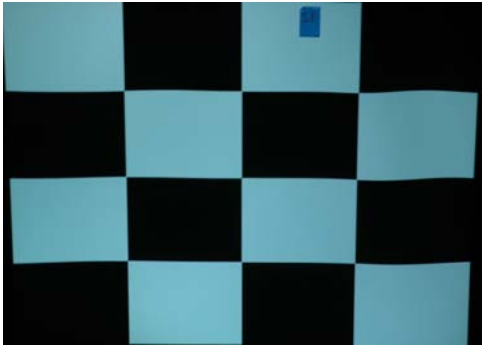
Sample 5C 1389 hours



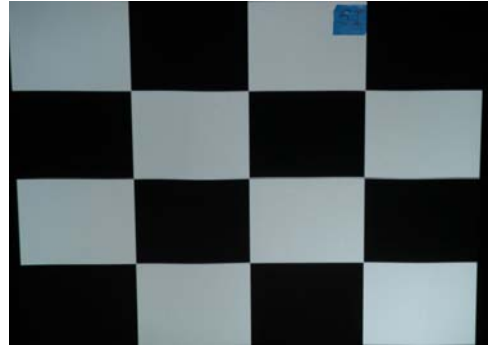
Sample 5I 122 hours



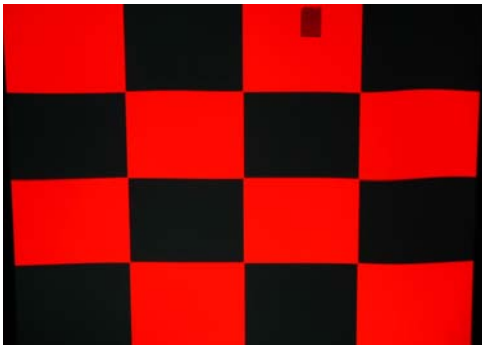
Sample 5I 3534 hours



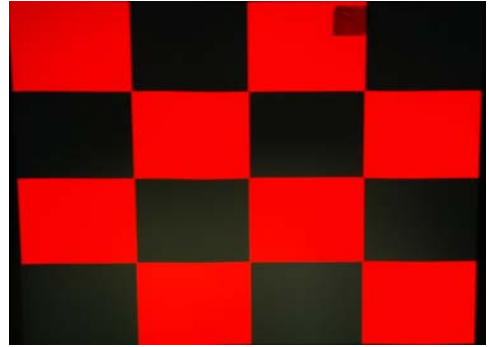
Sample 5I 122 hours



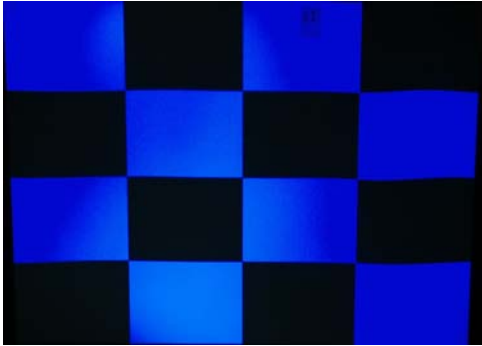
Sample 5I 3534 hours



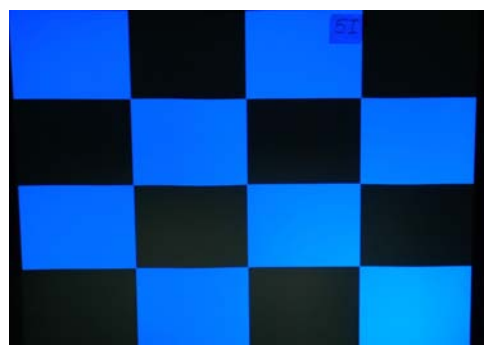
Sample 5I 122 hours



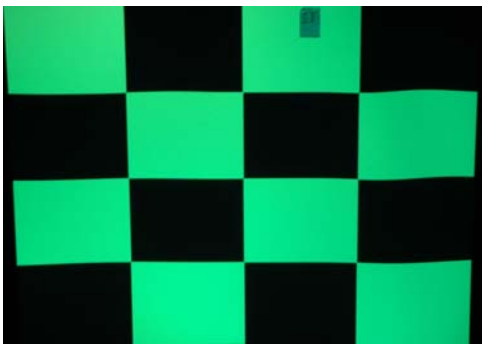
Sample 5I 3534 hours



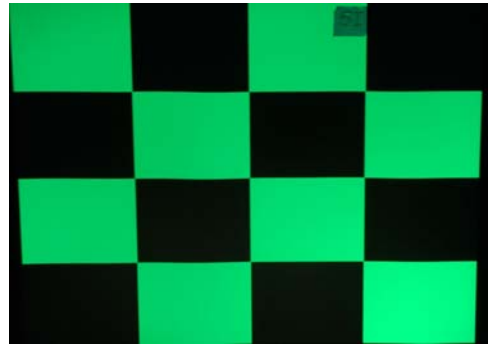
Sample 5I 122 hours



Sample 5I 3534 hours



Sample 5I 122 hours



Sample 5I 3534 hours



Sample 5I 122 hours



Sample 5I 3534 hours



Sample 5F 86 hours



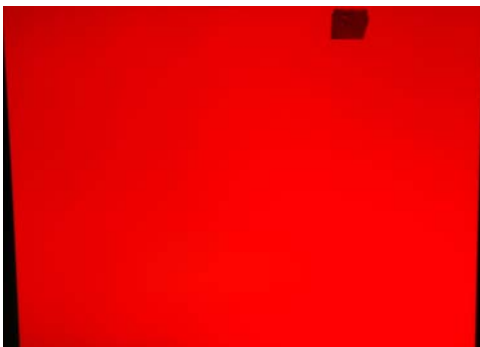
Sample 5F 2524 hours



Sample 5C 58 hours



Sample 5C 1389 hours



Sample 5I 122 hours



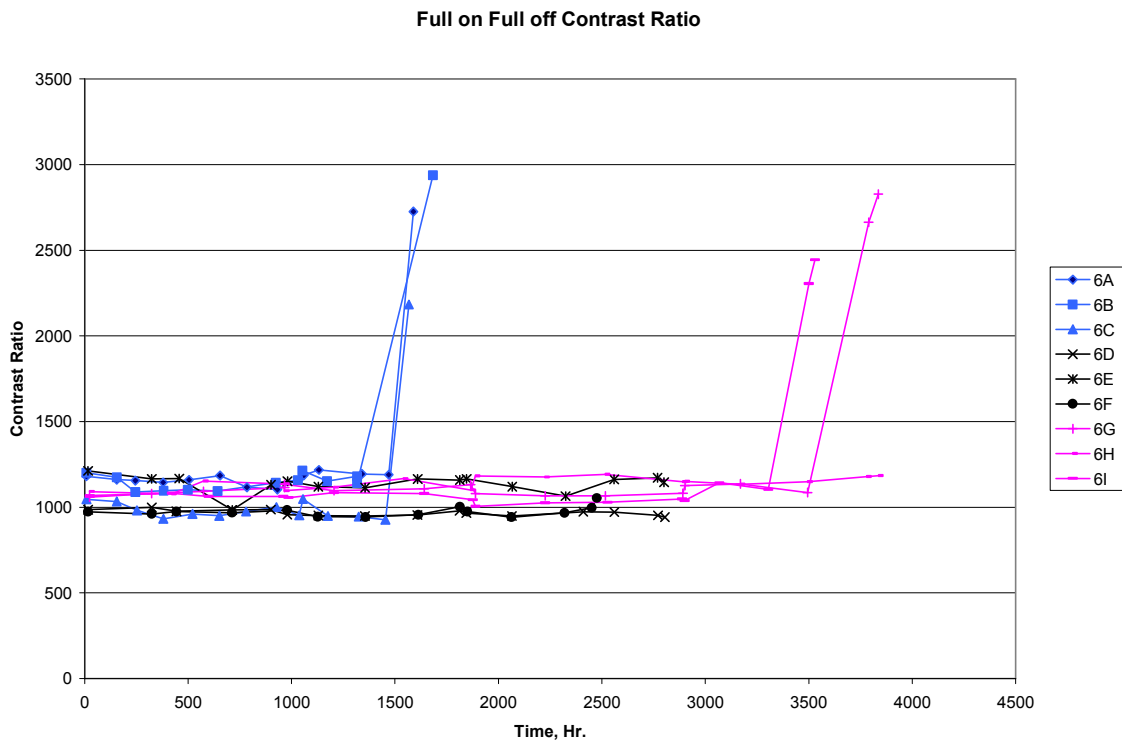
Sample 5I 3534 hours

DLP[®] Model 6 Summary

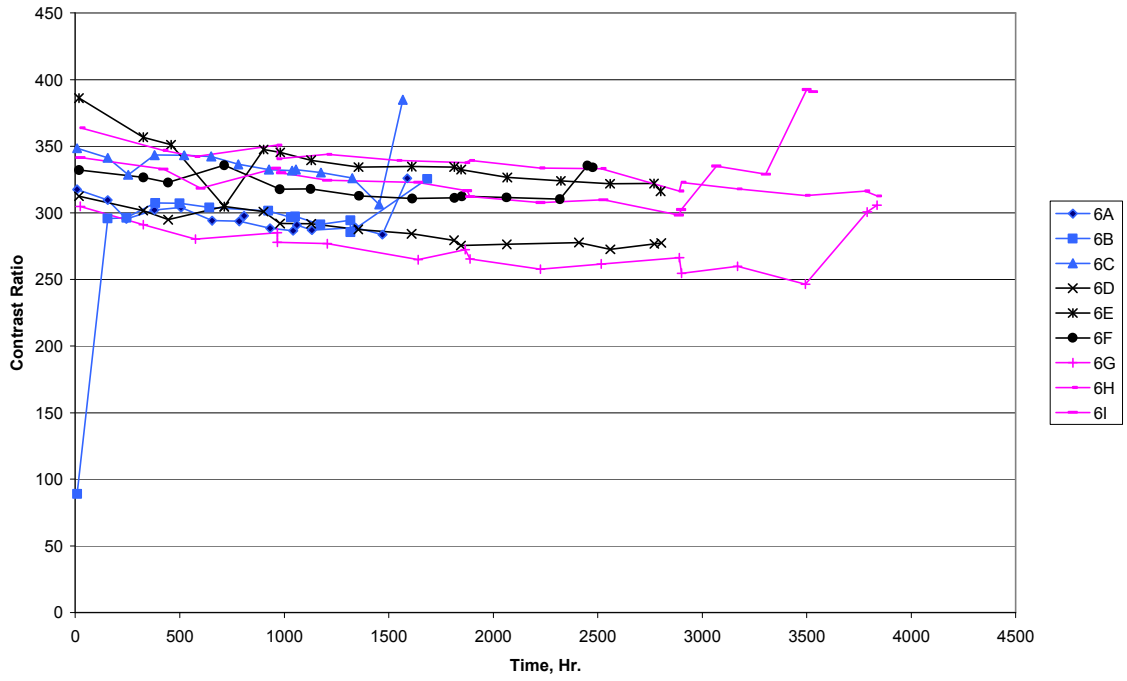
DLP[®] model 6 samples have shown no significant visible or measurable change in DMD chip performance to date. It has been seen, however, that the Model 6 samples for the 1.5/2.5 duty cycle and 2 samples running on the 24/7 duty cycle have undergone a major improvement in their contrast ratio measurements. After further investigation it was determined that this was due to the contrast and brightness controls internal to the unit. An investigation is under way to pinpoint the exact cause and any additional information gathered will be supplied at the end of this study.

Model 6 Graphs

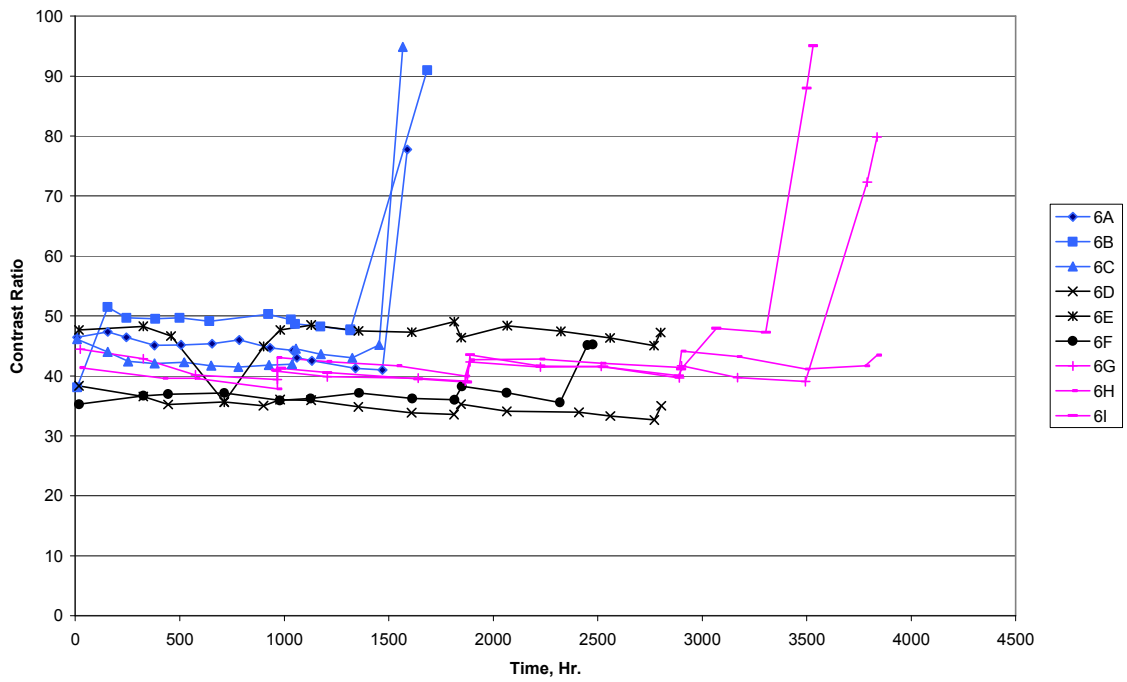
A significant increase in contrast ratio was noticed during the last 2 measurements for samples 6A,B,C,G,I in all of the contrast ratio measurements, except for the white black checkerboard pattern.



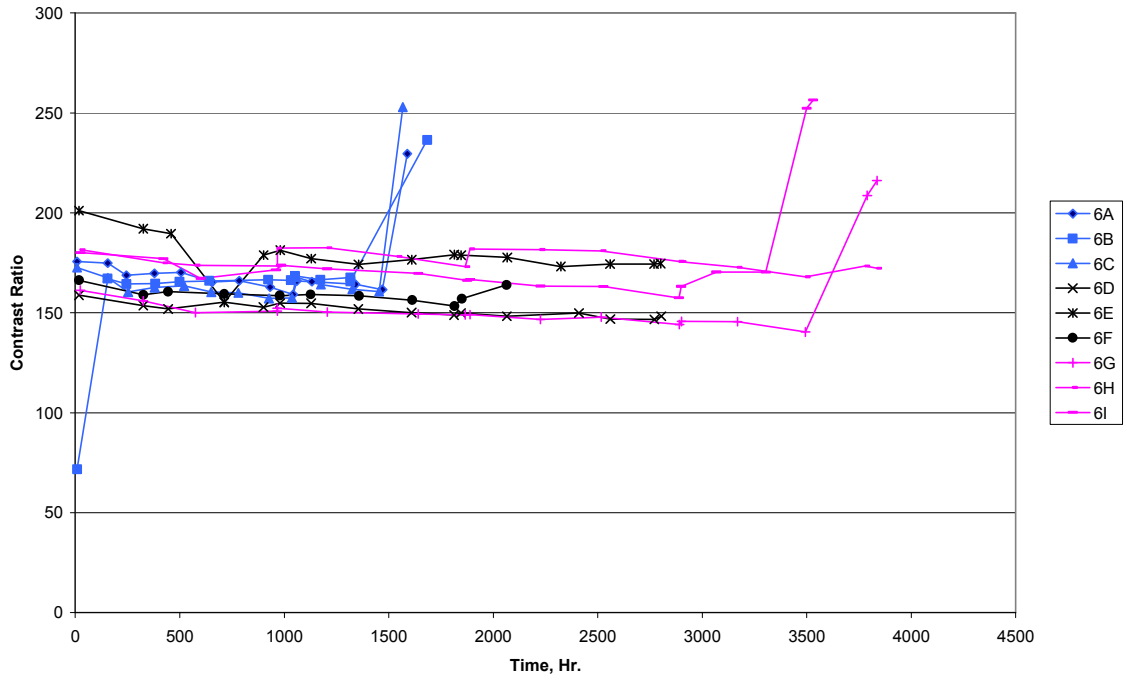
White Black Checkerboard Contrast Ratio



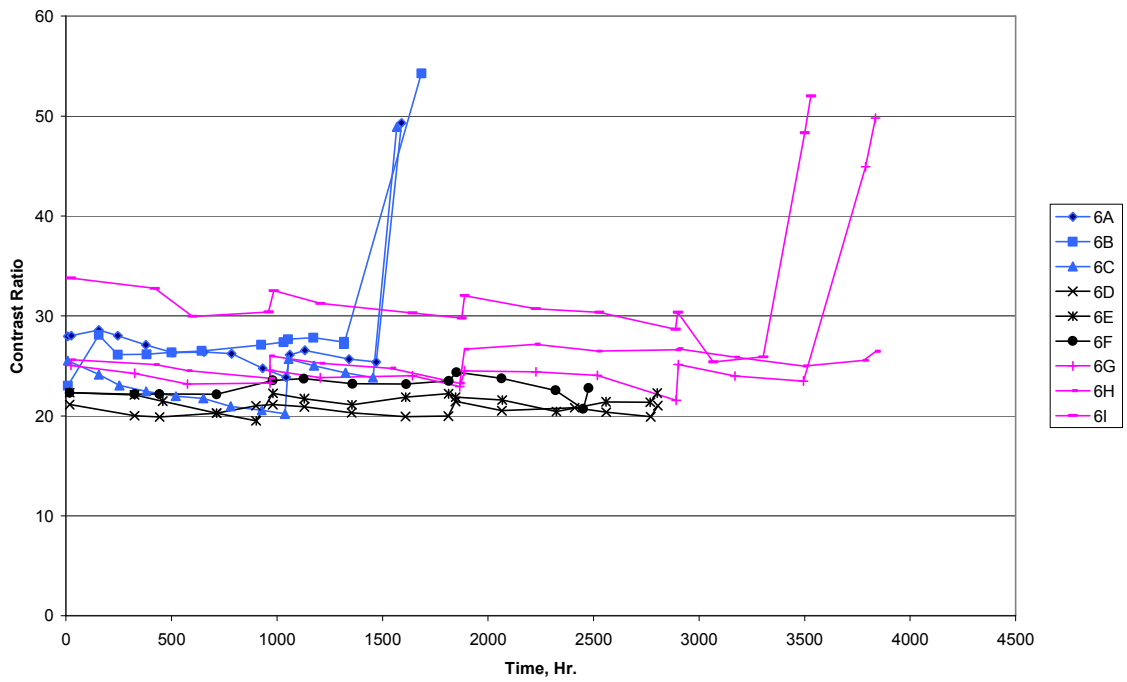
Red Black Checkerboard Contrast Ratio



Green Black Checkerboard Contrast Ratio

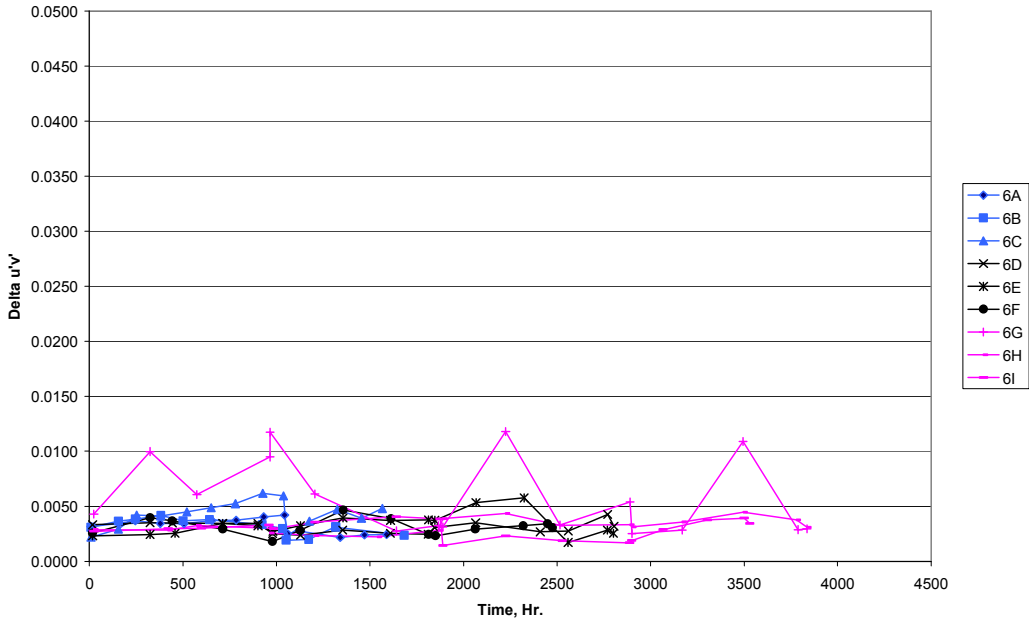


Blue Black Checkerboard Contrast Ratio

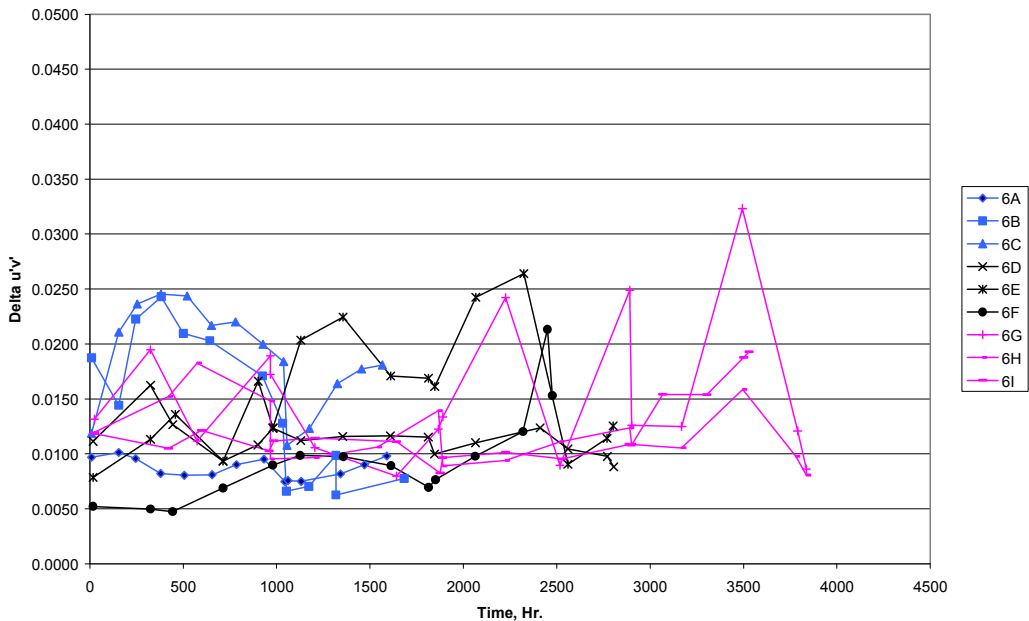


DMD chip technology shows little to no change in color uniformity, as indicated in the graphs below. Although some minor changes exist between test measurements, the overall trend is flat. The pictures located at the end of this section serve to reinforce this.

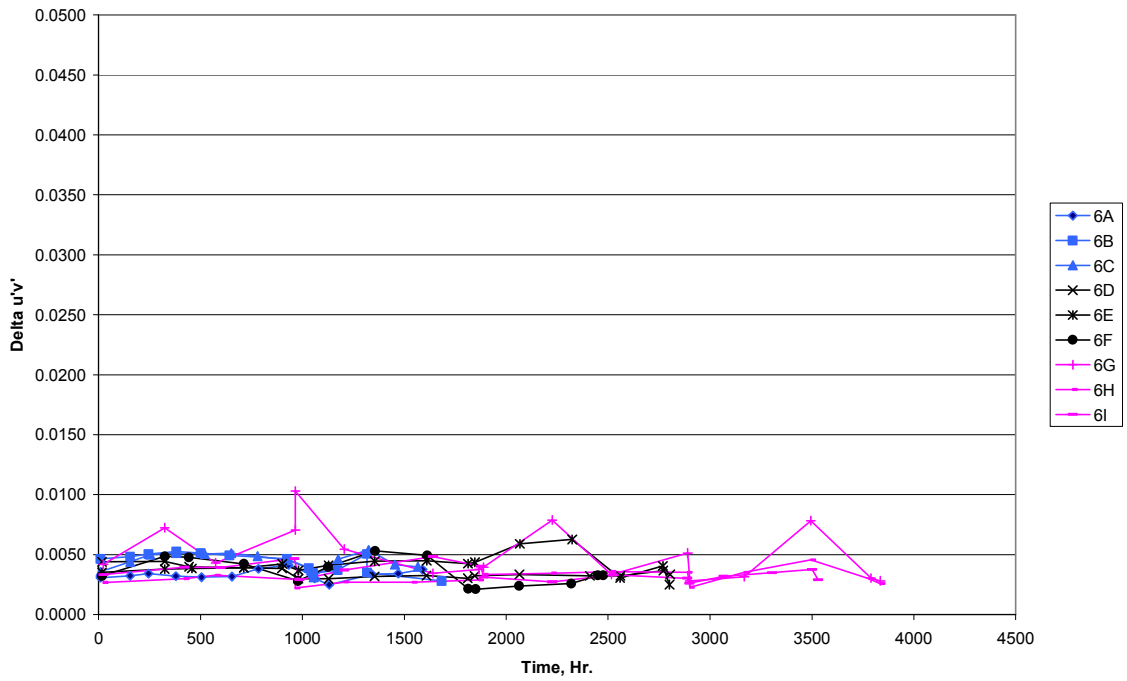
Change in White Uniformity Vs. Time



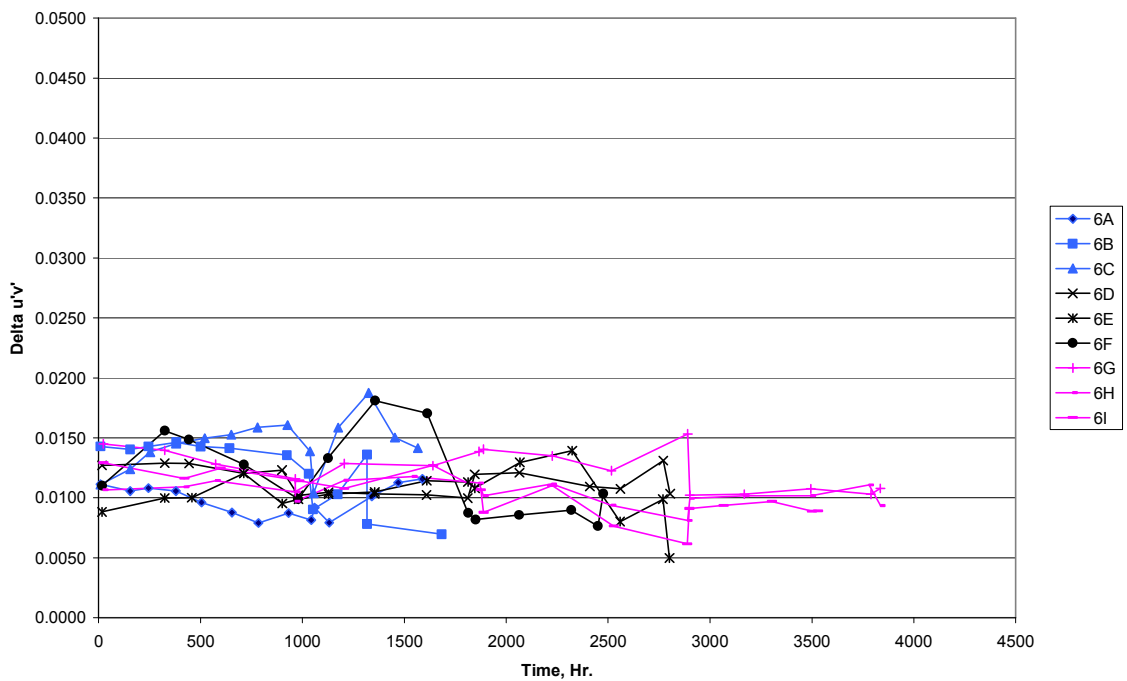
Change in Red Uniformity Over Time



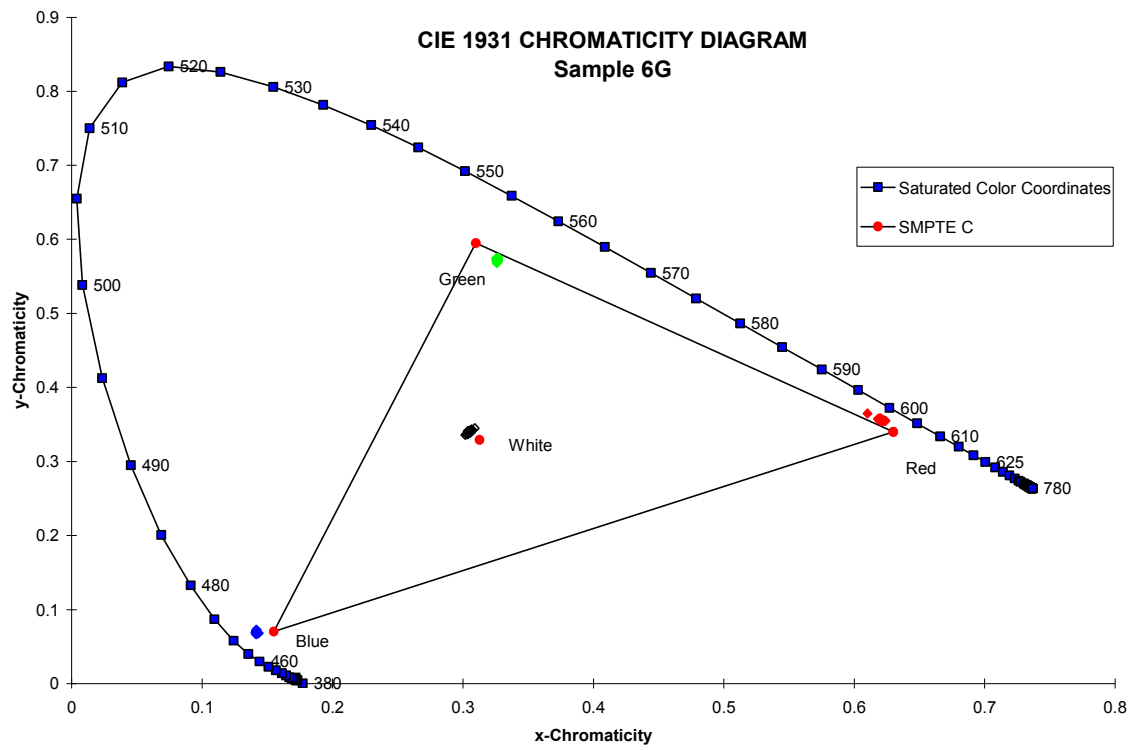
Change in Green Uniformity Over Time



Change in Blue Uniformity Over Time



The chromaticity diagram for 6G also indicates little to no change in the ability of the DMD chip to reproduce a color image.



Model 6 Pictures



Sample 6G 24 hours



Sample 6G 3494 hours



Sample 6D 17 hours



Sample 6D 2560 hours



Sample 6A 9 hours



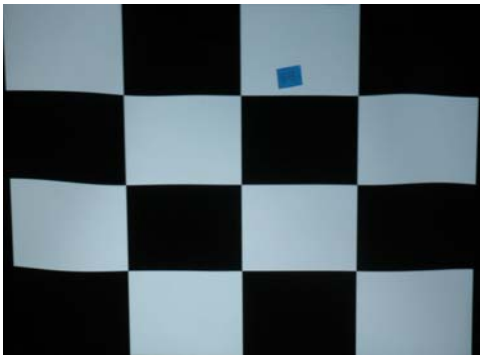
Sample 6A 1470 hours



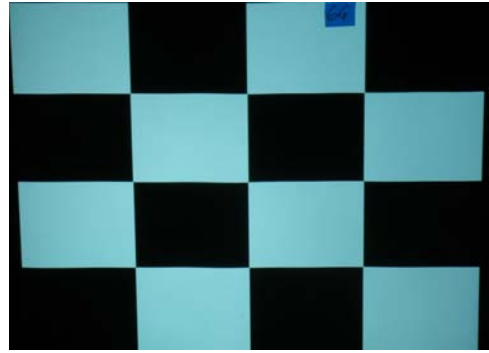
Sample 6G 24 hours



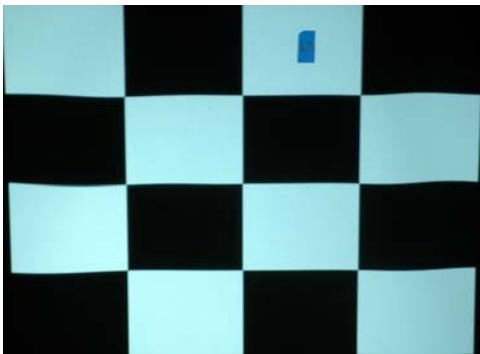
Sample 6G 3494 hours



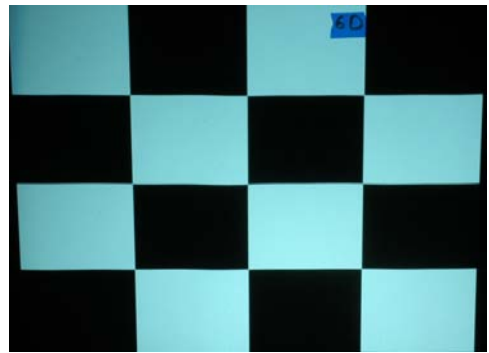
Sample 6G 24 hours



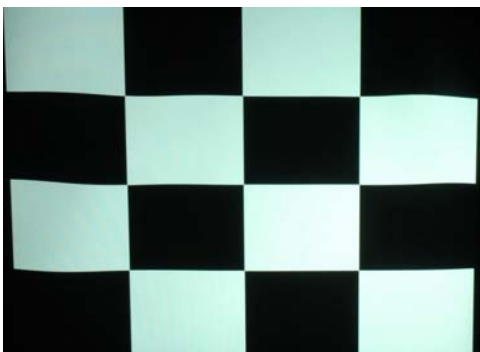
Sample 6G 3494 hours



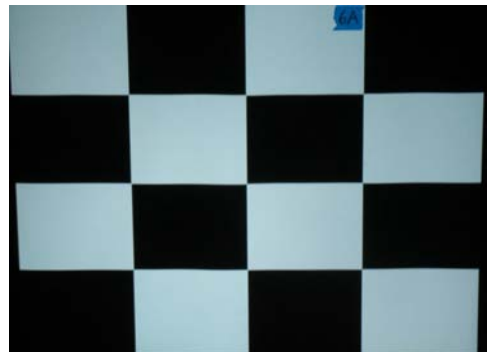
Sample 6D 17 hours



Sample 6D 2560 hours



Sample 6A 9 hours



Sample 6A 1470 hours



Sample 6G 24 hours



Sample 6G 3494 hours



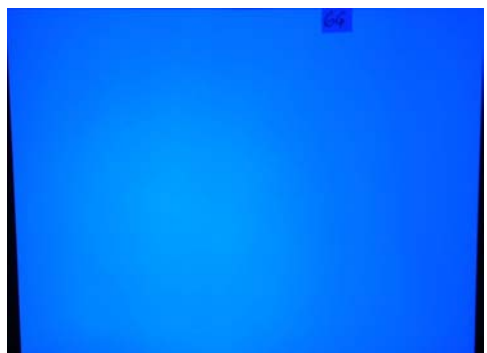
Sample 6G 24 hours



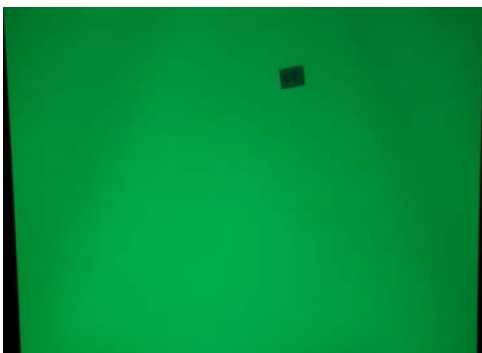
Sample 6G 3494 hours



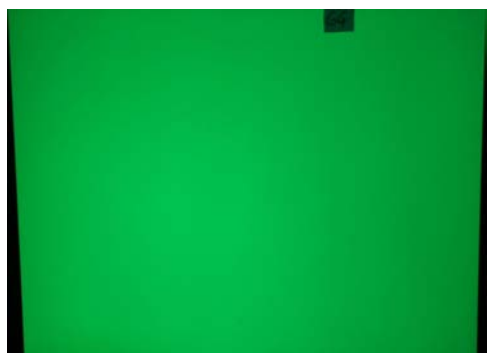
Sample 6G 24 hours



Sample 6G 3494 hours



Sample 6G 24 hours



Sample 6G 3494 hours

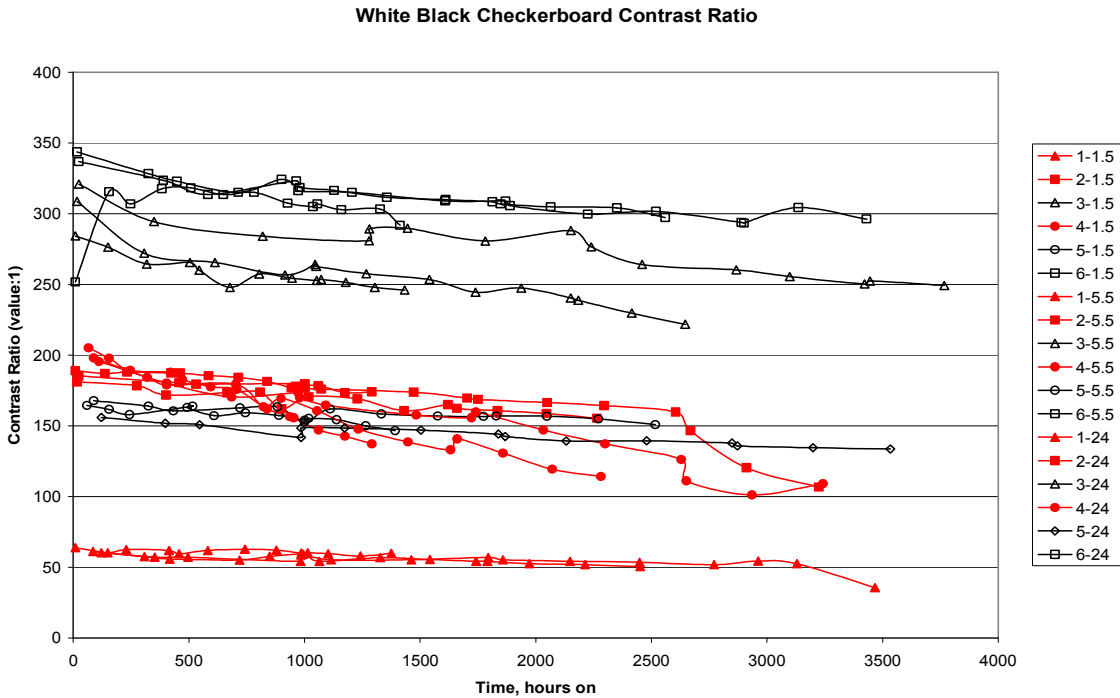
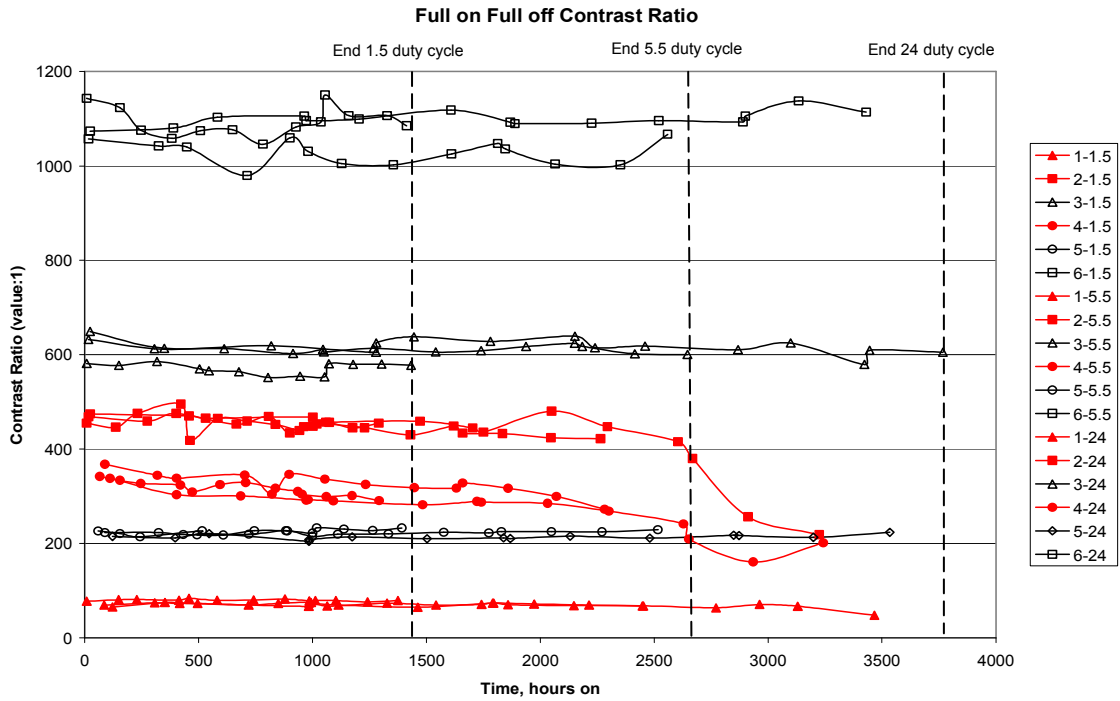
Conclusion

All of the LCD models in this study that have reached a certain number of on time hours have shown visual and measurable deterioration in display characteristics. Although the exact amount of time before deterioration varies, it generally appears to fall within the 2000 to 4000 hours of on time operation. This change appears to be related to the blue LCD panel and the blue and green polarizer. Further investigation will be performed at the end of this study in an attempt to gain more understanding of the failure mode. If, at the end of this study, there is any indication that the LCD panel and polarizer were not the primary contributor to the display deterioration, a revision to this document will be issued.

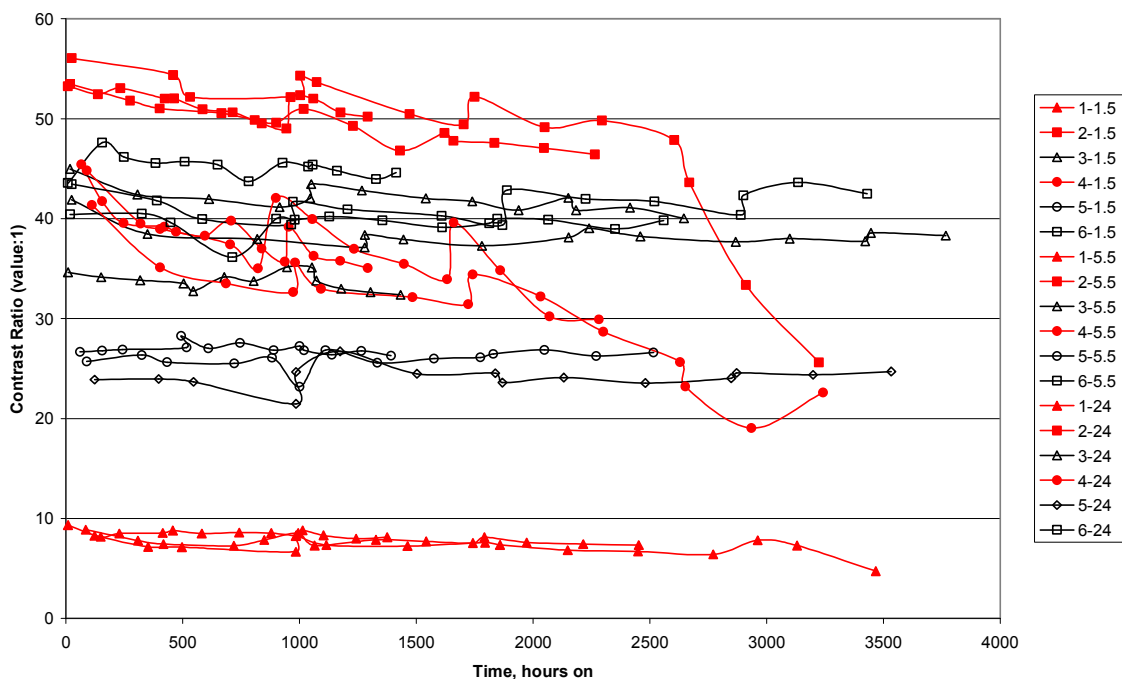
All of the DLP[®] models have shown no significant visual or measurable deterioration in DMD chip display characteristics.

Additional Graphical Data

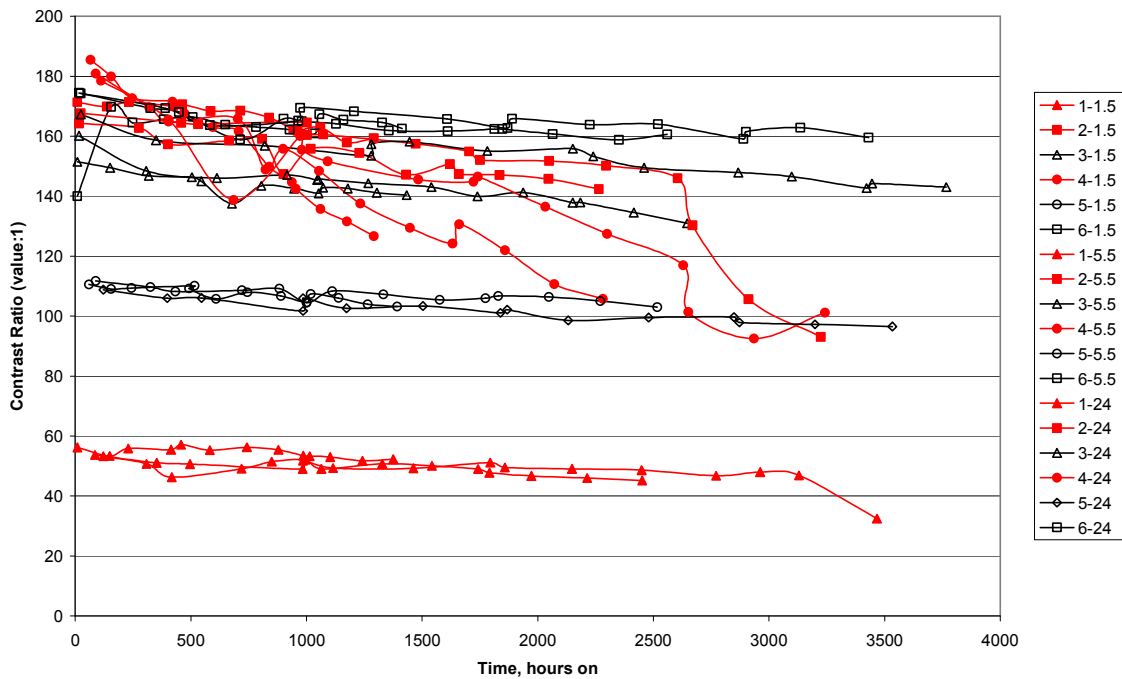
The graphical data supplied in this section represents each model with the average of the 3 samples for each duty cycle within that model category. The black lines and symbols represent DLP® models while the red lines and symbols represent LCD models.



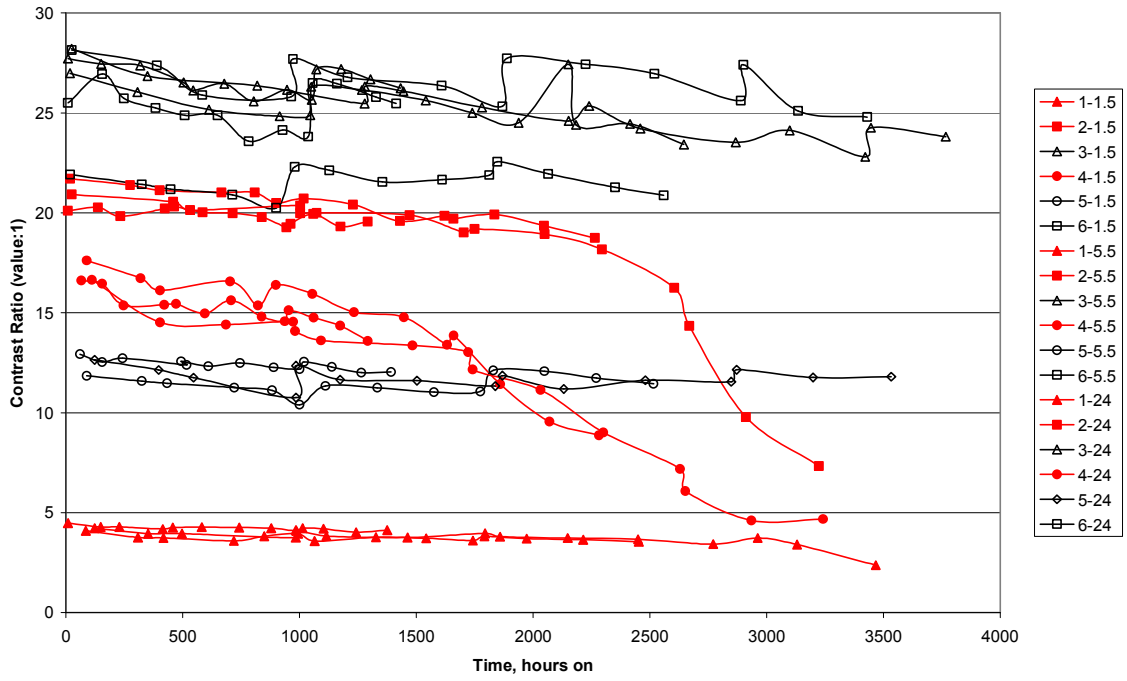
Red Black Checkerboard Contrast Ratio



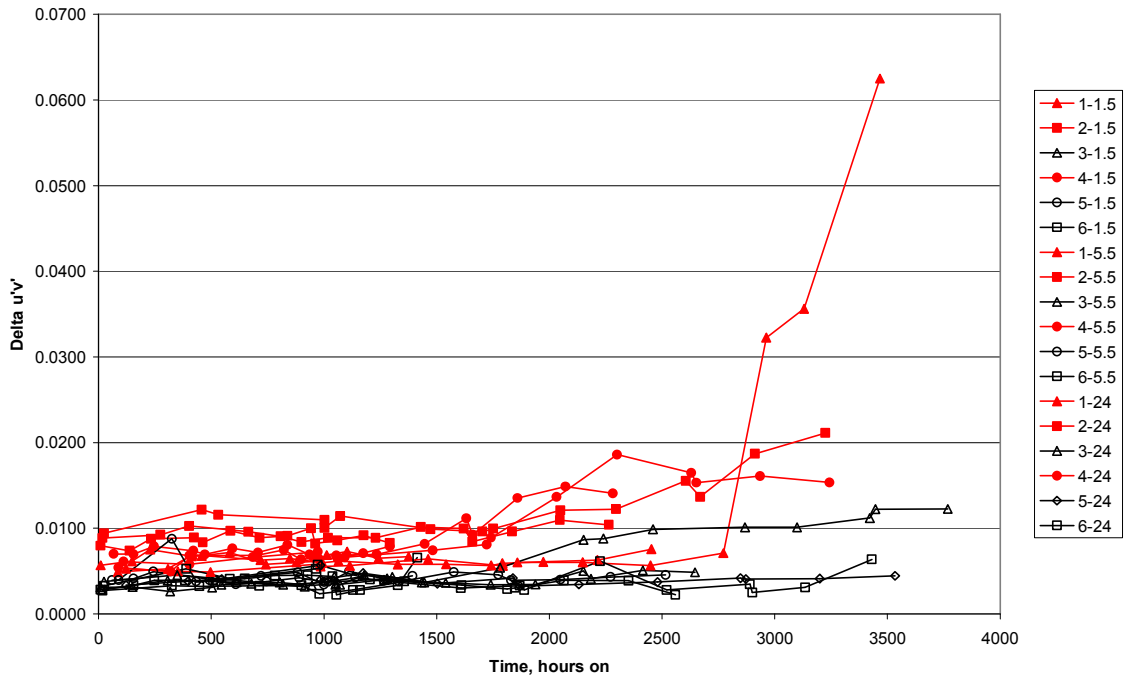
Green Black Checkerboard Contrast Ratio



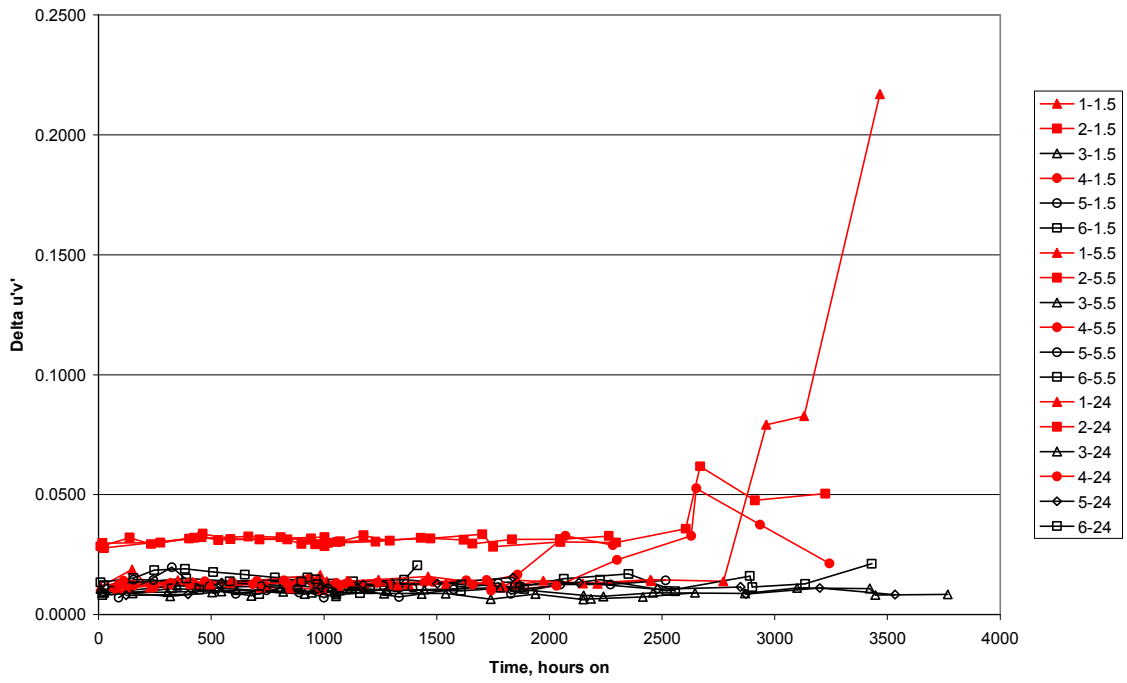
Blue Black Checkerboard Contrast Ratio



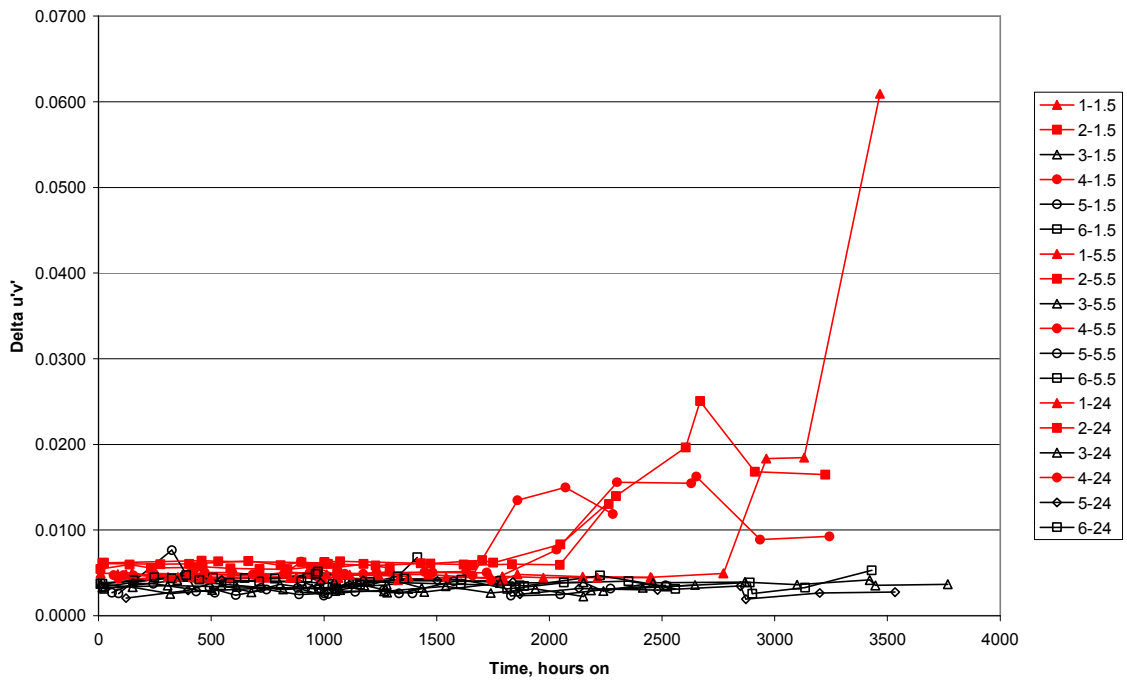
White Uniformity



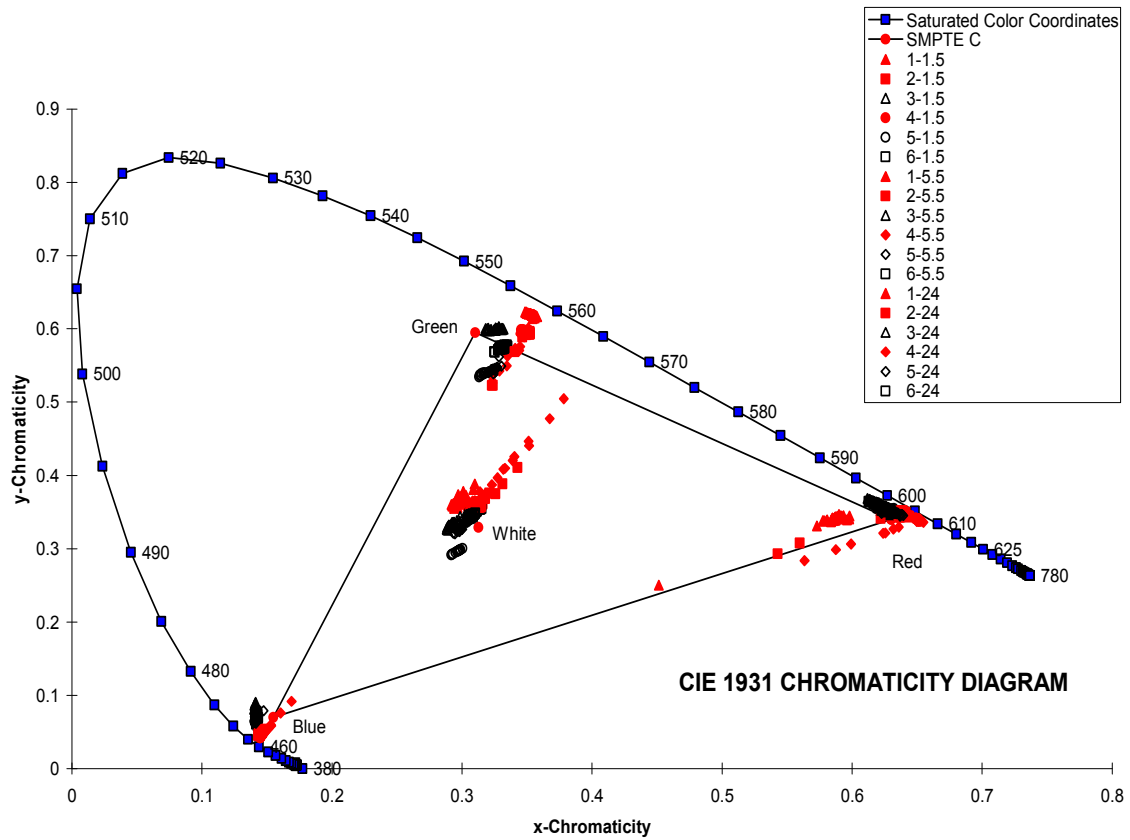
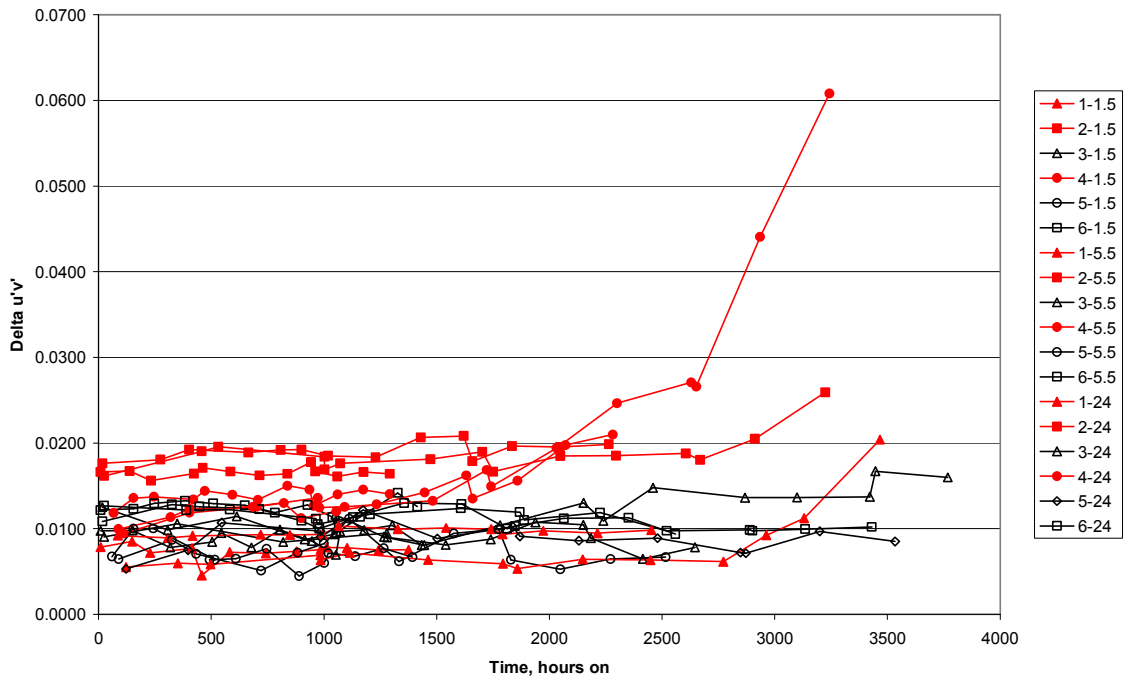
Red Uniformity



Green Uniformity



Blue Uniformity



GLOSSARY

Contrast – The difference in brightness between the light and dark areas of an image.

Checkerboard Contrast Ratio – The average brightness of the light areas of a checkerboard pattern divided by the average brightness of the dark areas of a checkerboard pattern

Full on Full off Contrast Ratio – The brightness of a full white image at the center divided by the brightness of a full black image at the center.

Color Uniformity – The projected image uniformity as a measure of the Chromaticity values $u' v'$. Results are comprised of taking the 9 center readings from a 13 position pattern and averaging the results for the $u' v'$ measurements. These values are then labeled u'_0 and v'_0 . Then all the values for the 13 position template are used to determine the maximum deviation from the average values and are labeled u'_1 and v'_1 . The measure of color uniformity is then calculated from the following equation.

$$\Delta u'v' = \sqrt{(u'_1 - u'_0)^2 + (v'_1 - v'_0)^2}$$

DLP[®] Chip – Refers directly to the Digital Micromirror Device.

DLP[®] Technology – Refers directly to the Digital Micromirror Device and associated electronics required to operate the device.

LCD Panel – Refers directly to the Liquid Crystal Display Panel.

LCD Technology – Refers directly to the Liquid Crystal Display, polarizer, and associated electronics required to operate the device.

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