Using Natural Graphite Heat Spreaders to Increase CCFL LCD Operating Temperatures

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Keywords: flexible graphite, luminance, heat, spreader, sticking

Abstract

A natural graphite heat spreader increased the upper operating temperature limit of a CCFL backlit LCD television. A 0-80W heat source was used to simulate additional electronics. Without the heat spreader, internal circuitry shut-down at ~30; no shut-down occurred above 80W with a heat spreader. Additionally, brightness, temperature uniformity, and operating ranges were improved, verified by environmental chamber performance testing at various ambient conditions.

1. Introduction

The temperature/luminance relationship of a commercially available 40” Samsung LN-4095D LCD display was investigated. The thermal load contributed by the different components and the LCD temperature differences contributed by the chassis electronics were assessed. One objective was to determine the effect of utilizing an eGRAF® SPREADERSHIELD™ SS500 natural graphite heat spreader [1],(commercially available from Advanced Energy Technology, Inc.) which has an in-plane thermal conductivity of 500 W/mK and a through thickness thermal conductivity of ~3 W/mK.

The investigation involved extensive luminance measurements, infrared analysis, and transient measurements under standard and enhanced thermal conditions. Kahn [2] has shown that thermal hot spots on the front of flat panel displays are partially due to local heating by rear mounted electronic components. The LCD’s visual and thermal performance, with and without natural graphite, was monitored in an environmental testing chamber.

2. Experimental

Figure 1 shows the rear chassis of the unit with the addition of the SPREADERSHIELD SS500. The LCD was fully illuminated with a white test pattern, reaching thermal steady state in ~2 hours. Temperatures were measured on three vertical planes 1) CCFL bulbs, 2) reflector, and 3) the rear of the chassis. Infrared images from an Infrared Solutions FlexCam determined the LCD panel thermal profile. Luminance was measured with a Konica CA-210 color analyzer.

Fig. 1. Rear View of LCD Chassis With SPREADERSHIELD SS500

Local hot spots on the rear of the chassis were created using 8 inch square polyimide resistance heaters. The heater delivered various wattages using a 120V/4A DC power supply. The natural graphite heat spreader was applied to the rear of the aluminum chassis via its integral pressure-sensitive adhesive, and the tests were repeated.

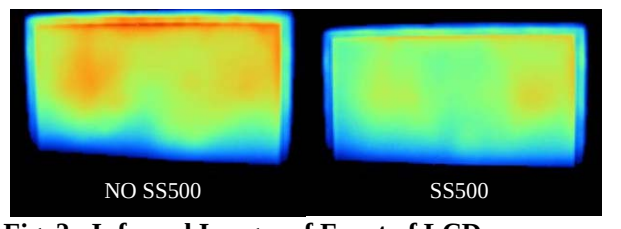

Fig. 2. Infrared Images of Front of LCD, No External Heating on Rear of Chassis

Figure 2 shows thermal images at 0 watts, with/without a thermal solution. Figure 3 shows images at 20 watts, with/without a thermal solution.

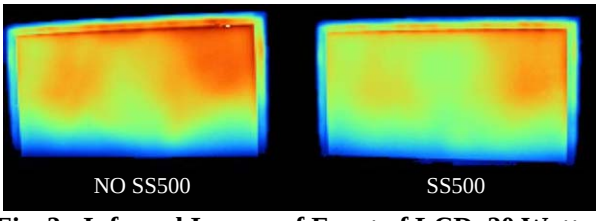

Fig. 3. Infrared Images of Front of LCD, 20 Watt External Heating on Rear of Chassis

The visual performance characteristics of the LCD display, with and without the SPREADERSHIELD SS500, were verified in a 1.22m x 1.22m x 1.22m environmental test chamber (Model GD-64-5-5-WC, Russells Technical Products). The entire set was placed in the chamber, and the front door refitted with clear acrylic to record and monitor visual performance.

3. Results and discussion

This work relates LCD screen thermal uniformity, module thermal uniformity, internal vertical temperature planes, luminance, and image properties. The information should help in developing optimized thermal designs for higher temperature and brightness LCD displays, for both CCFL and LED backlit designs.

The display shut down at local external heater inputs greater than 33 watts when there was no thermal management system used. With the SPREADERSHIELD SS500 attached to the back of the chassis, the unit experienced no thermal shutdown at power levels up to 80 watts. This appears to be a local electronic effect (thermal shutdown, excessive voltages, etc.) of the thermally stressed system, which was mitigated by the heat spreading capabilities of the SS500.

Thermal/Temperatures

SPREADERSHIELD SS500 use resulted in a 2ºC improvement in LCD panel display temperature differentials. Similar results were reported by Norley [3]. A 2.5ºC improvement occurred in CCFL bulb temperature standard deviation, more than at the LCD screen, which should be expected, since the CCFL bulbs are a major source of heat for the LCD panel. This reduction in temperature variation continued even when the external heater was contributing excess heat to the back of the chassis, demonstrating the heat spreading improvements of SPREADERSHIELD SS500.

Luminance

This work demonstrated a temperature relationship of the LCD, the CCFL temperatures, and the chassis electronics. CCFL luminance has been shown by Sanken [4] to vary with temperature. This was verified, as shown by the data plotted in Figure 4. A maximum luminance of 240 cd/m^2 was found at about 40ºC on the LCD screen. In both graphs, the 20 Watt heater is active in order to exaggerate the effects of a local heat source to the back of the chassis.

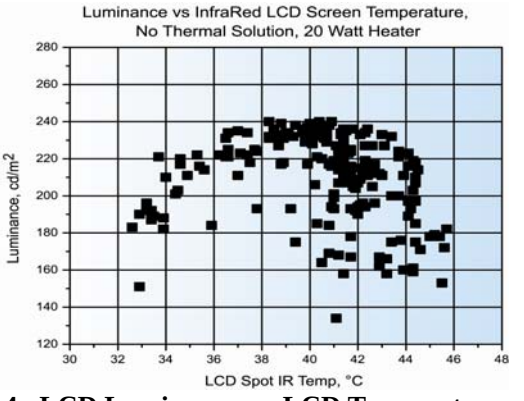

Fig. 4. LCD Luminance vs. LCD Temperature, 20 Watt Heater and No SPREADERSHIELD SS500

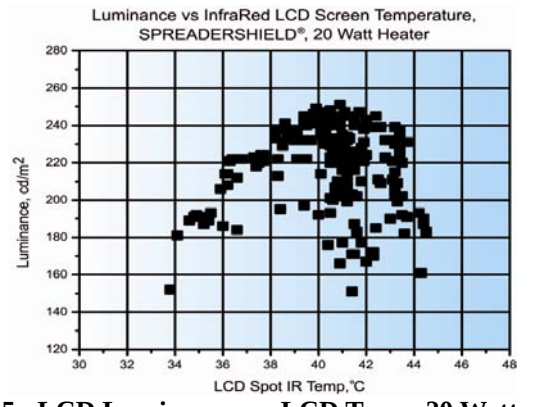

Fig. 5. LCD Luminance vs. LCD Temp, 20 Watt Heater and SPREADERSHIELD SS500

Figure 5 shows the luminance versus temperature relationship after SPREADERSHIELD SS500 was added. The SS500 narrowed the temperature range on the LCD panel, with a 4% luminance improvement. The brightness improvement probably results from the natural graphite's reduction of local hot and cold spots on the CCFL bulbs.

Environmental Chamber Testing

The LCD was then placed in an environmental testing chamber and the temperature was reduced to -10ºC. At stability, the oven was shut off and a non-convecting heat source (not forced air) was turned on. To establish an appropriate temperature range for testing, the chamber was allowed to heat until the clearing temperature of the LCD screen was reached, which was ~70ºC. For each test, ambient temperatures at the top and the bottom of the LCD display were measured and the average of these two temperatures (T_{avg}) is reported here as an onset temperature.

Image Sticking

Image sticking is a phenomenon (5) where a permanent residual image remains after it is statically displayed for an extended period. This process is temperature and time dependent, resulting from the semi-permanent polarization of the liquid crystal. Image sticking was monitored by displaying alternating black spots in the same location for 3 second intervals (i.e. 3 sec. on, 3 sec. off). The point at which the image persisted after being turned off was considered to be the image sticking temperature.

Fig. 6. LCD Image Sticking

Image sticking is shown in Figure 6, with the image remaining after the image is no longer displayed. These tests are at elevated temperatures, but this should occur with longer display times at lower temperatures. With no thermal management solution, the onset of image sticking occurred at T_{avg}= 59.5ºC. With the SPREADERSHIELD SS500, image sticking onset was delayed until T_{avg}= 64.3ºC, a 5.3ºC ambient temperature increase before image sticking was apparent. Image sticking should become more apparent with a high luminance CCFL backlit LCD, displaying static images for extended time periods. This is exactly the case in the area of digital signage, and is exacerbated by the "portrait" orientation of the display where heat will concentrate in the top of the chassis.

Image Distortions

The LCD was monitored for the introduction of the first visible thermally induced artifacts while heated in the environmental chamber. The first thermally induced screen distortions appeared at the top of the LCD panel, consistent with the measurement of the highest temperatures, seen in the hot spots (dark orange regions) at the top of the screen shown in the infrared images of Figures 2 and 3.

Fig. 7. LCD Image Distortion

Figure 7 shows the series of "wavy" distortions in the blue title bar displayed on the LCD display as the oven temperature increases. The distortion onset temperature for the LCD with no thermal solution was T_{avg}= 54.7ºC. This distortion onset was delayed to T_{avg}= 58.3ºC with SPREADERSHIELD SS500, again extending the operating range 3.6ºC over non-thermally managed conditions. This improvement is accomplished by increasing the thermal uniformity of the LCD screen, effectively reducing temperature standard deviation across the LCD and reducing the maximum temperatures seen at the top of the unit.

Moving Images

A series of horizontally and vertically moving spots were animated on an all white background across the LCD in the environmental chamber.

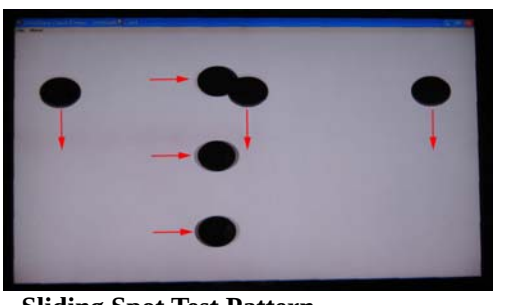

Fig. 8. Sliding Spot Test Pattern

The pattern used for this display is shown in Figure

8, with red arrows indicating the direction of travel of the black spots. The spots moved vertically and horizontally at about 30 cm/sec. Pictures were taken of the spots at various temperatures throughout the heating cycle.

At temperatures below ~10ºC, LCD response times slowed significantly, resulting in the moving images appearing as a blurring or ghosting of the moving spot. Figure 9 shows this low temperature effect on the spot moving in the vertical and horizontal direction. A distinct blur is created in the trailing edges of both spots, due to the slow switching on and off of the LCD. This appears as a tail on moving images at these lower operating temperatures. The effect was similar for the set with and without SS500, indicating that temperature gradients are not significant at these temperatures, and that this slowness of the LCD occurs over a wide temperature range, observed to be at least 20ºC.

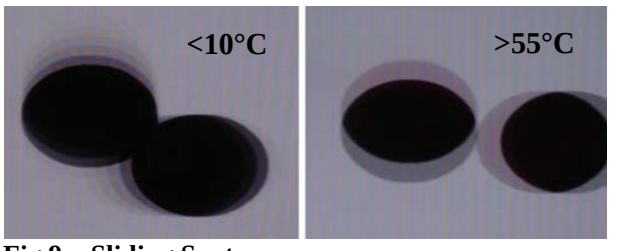

Fig.9. Sliding Spots

The effect at the high end of the temperature range (exceeding 55ºC) is also illustrated in Figure 9. Two motion effects became evident:

1) Leading and trailing edge image ghosting. The darkest black image occurs in the middle of the animated spot, where it has had the longest time to achieve a non-transmission state.

2) A color shift on a moving black image towards the blue-red. Image analysis shows that the green content of the image is lost as the screen temperatures approach the LCD clearing temperature.

Motion artifact onset temperature was extended in the unit with the SS500 installed. Onset temperatures started at T_{avg}= 57.4ºC with no thermal solution, and at 62.4ºC for the display unit with SPREADERSHIELD SS500, which again represented about a 5ºC improvement. Motion blur is a more gradual thermal phenomenon than image persistence and is affected by backlighting.

4. Summary

This paper highlights the effect of temperature and temperature gradients on the thermal, visual, and dynamic performance of the Samsung 4095D CCFL backlit LCD TV. Both CCFL output and the LCD performance were affected by temperature variations. The SPREADERSHIELD SS500 natural graphite heat spreader had a moderating effect on the temperature, reducing the temperature variations experienced in extreme heating situations.

An environmental test chamber exposed the LCD to thermal extremes, verifying that the SPREADERSHIELD SS500 reduced temperature gradients across the chassis, CCFL bulbs, electronic components, and the LCD panel. This increased the effective operating temperature range, allowing visual artifact-free operation at higher temperatures. Note that most improvements can be attributed to the temperature variation reductions enabled through the use of the natural graphite, performing its role as an anisotropic heat spreader. As LCD displays operate at higher temperatures, improved temperature gradients will become increasingly necessary. This is inevitable, as the demand for increased brightness, vertical orientations, and LED back lighting continues.

5. References

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