Sunlight Readable Color LCDs for Outdoor Applications

Introduction

Compared to a CRT display, an LCD has the advantage of being extremely compact in size, having low power consumption, and is free from harmful EM radiation. In addition to the above, LCDs have another distinctive advantage that is not commonly recognized.

The LCD, being a non-emissive display, requires a backlight in order to be visible. The LCD screen luminance (brightness) is directly proportional to the brightness of the backlight. As a result, it is possible to make a very bright LCD by simply using a very bright backlight.

The situation with a CRT is quite different. As the resolution and the display size increase, the brightness of the CRT screen drops rapidly. For example, the screen brightness of a 19" CRT monitor running at 1,280 x 1,024 resolution is about 100 Cd/m^2 (nits). On the other hand, a 19" TV running at a much lower resolution can have a brightness up to 1,000 nits. But, if the size of the CRT in the TV increases to 27", its screen brightness drops off to about 500 nits.

The LCD's brightness advantage has been used very successfully by Landmark Technology to produce sunlight readable LCD modules for outdoor applications, including those under direct sunlight. These LCD modules, with sizes ranging from 6.4" to 20.1" and resolution ranging from VGA (640 x 480) to SXGA (1280 x 1024), can achieve 1,500 to 2,000 nits screen brightness with a very good optical contrast. The power consumption of the very bright backlight in these modules is reasonably low such that the thermal related issues are easily manageable.

The VHB Backlight

For applications in bright outdoor environments, in particular, those under direct sunlight, one of the necessary conditions is that the display must be bright enough in comparison to neighboring objects. As it is described above, the screen luminance of an LCD can be very high if a very bright backlight is used. Thus, the key component in a sunlight readable LCD is a very high brightness (VHB) backlight.

The traditional LCD backlight design using a light pipe edge-lit by one to four cold cathode fluorescent lamps (CCFLs) usually does not provide enough luminance for LCD applications in direct sunlight. However, in relatively small LCDs such as the 6.4" and 10.4", it is possible that an edge-lit backlight can provide an LCD screen luminance beyond 500 nits. At this level, the LCDs can be used for outdoor applications, in particular, if the front surface of the LCD has an anti-reflective coating. However, its optical performance under direct sunlight is somewhat marginal.

Sunlight readable LCDs were initially developed for aerospace and military applications. The typical design of the VHB backight uses a serpentine hot cathode fluorescent lamp (HCFL) as the light source. In addition to that, various bright light sources such as metal halide lamps and special flat fluorescent lamps have also been suggested or used for VHB backlight design.

Landmark Technology introduced a family of 10.4" VHB backlights in 1994 for sunlight readable LCD applications. These backlights use the back-lit design with a number of standard CCFLs in a very thin aluminum box. As a result, the entire thickness of the LCD with the VHB backlight is less than 1 inch. The luminance of these VHB backlights is about 13,000 nits. Since the LCD optical transmission is 6 - 8%, the the LCD screen luminance is about 800 - 1,000 nits, which is adequate for outdoor applications. Since then, the optical performance of our VHB backlights has been drastically improved. As a result, the LCD screen luminance has been increased to about 1,500 nits with no increase in backlight power consumption.

A typical design of our VHB backlight for 10.4" and 12.1" LCDs uses 8 CCFLs laid in the horizontal direction in a thin aluminum box. For l5" LCDs, the number of lamps may increase to 10 or 12. For larger LCDs, more lamps must be used in order to achieve the required LCD screen luminance for sunlight readability.

The construction of a Landmark VHB backlight is illustrated in a very simplified form as shown in Fig. 1. The lamps are supported at their ends by a pair of PC boards (not shown in Fig. 1) which also provide the electric connections to the lamps. The lamp assembly is housed in an aluminum box. Then, a thick white diffuser is used to hide the lamp image. Over the diffuser, some brightness enhancement films (BEF and DBEF) and other films are added for various optical reasons.

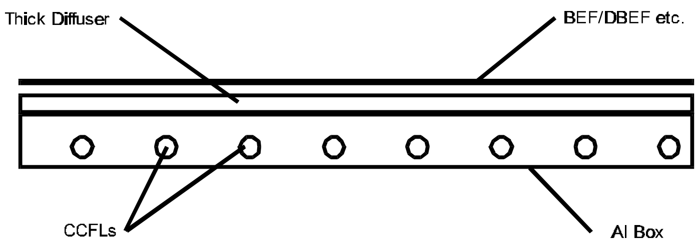

Fig. 1 Simplified Construction of a VHB backlight

The BEF increases the LCD screen luminance by directing more light toward the primary viewing angles of the LCD. The DBEF is a reflective linear polarizer that enhances the screen luminance by allowing more light to transmit through the bottom polarizer of the LCD. The combined effect of the BEF and DBEF provides a factor of 1.8 to 2.4x increase in LCD screen luminance.

Various other features can be designed into our VHB backlights to meet special requirements for certain display applications. For example, the aluminum box and the lamp supports can be reinforced to meet the severe shock and vibration encountered in rugged environments. Internal heaters have been added in the VHB backlights to extend the operating temperature range of the display. Special high temperature diffuser materials and films have been used to meet the high temperature requirements in mil-spec applications. In addition, VHB backlights that are night vision goggle (NVG) compatible have been demonstrated.

Typical Display Optical Performance

Let us use a 12.1" sunlight readable LCD module to illustrate the typical optical performance of these very bright displays. This LCD module uses a Sharp LQ12S41C AMLCD with a Landmark VHB backlight. The optical transmission of the LCD is about 7.9%. The VHB backlight has 8 CCFLs. Using the Landmark BI200A-96 inverter, the LCD screen luminance is 1,500 nits at maximum brightness setting. The power consumption of the VHB backlight at this screen luminance is 19.4 Watts which corresponds to a lamp current of about 5.3 mA (per lamp).

The inherent screen luminance and the display contrast ratio as functions of viewing directions are shown in Fig. 2 and Fig. 3. “Inherent” means that the data is measured in a dark room without any effects caused by the ambient light. The screen luminance is defined as the luminance of the “White” displayed on the LCD. The contrast ratio is the luminance ratio between the “White” and the “Black” displayed on the LCD.

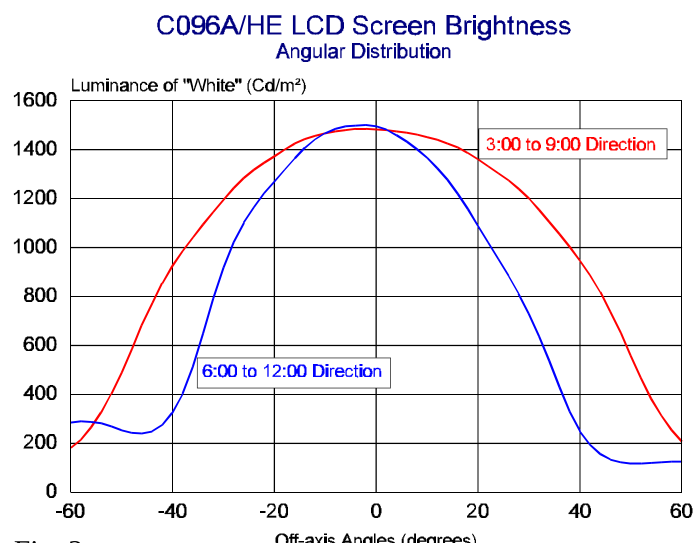

Fig. 2

If we refer to Fig. 2, the LCD screen luminance reaches 1,500 nits (cd/m^2) in the vicinity of the normal direction (0^0 off-axis angles). Along the 3:00 to 9:00 direction, the luminance drops fairly slowly. For example, at $\pm 40^0$, the screen luminance is more than 900 nits. Evan at $\pm 60^0$ off-axis, the luminance is still at 200 nits which is about the luminance of a regular LCD monitor at normal direction. On the other hand, the screen luminance drop along the 6:00 to 12:00 direction is faster, but still maintains a luminance above 200 nits at ±40°.

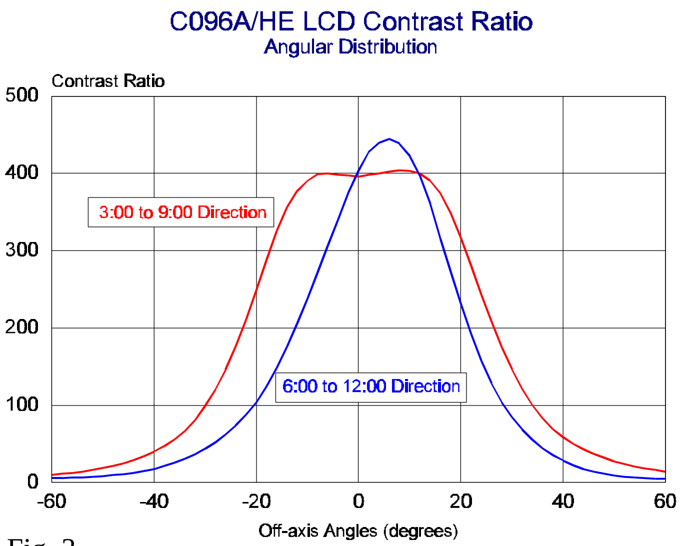

Fig. 3

Referring to Fig. 3, the display contrast ratio at normal direction (0° off axis angle) is very high at 400. Along the 6:00 viewing direction, the LCD contrast ratio reaches 425 at 6o off-axis angle and then drops off quite rapidly. But even at ±40°, the contrast ratio is still beyond 10, which qualifies as a good display. Along the 3:00 to 9:00 direction, the contrast ratio drops similarly but maintains a higher figure than along the 6:00 to 12:00 direction.

In a typical indoor environment, the ambient illumination is less than 100 foot candles. A piece of white paper under this illumination has a luminance of less than 300 nits. The contrast ratio of the black colored text on a well-printed magazine is between 10 to 20. Compared to these figures, the contrast ratio and the screen luminance of the 12.1" sunlight readable LCD are superior to those of the printed magazine for most of the viewing angles over a cone about ±50°.

The very high inherent contrast ratio does not have too much meaning in the bright ambient light encountered in outdoor environments. As the ambient illumination level increases, the “Black” displayed on the LCD becomes less black. This is caused by light reflections and scattering at various surfaces in front of the liquid crystal layer. As a result of this, the luminance of the “Black” increases and the display contrast ratio drops.

Fig. 4 is a typical curve showing the decrease of display contrast ratio at various ambient illumination levels. The display is a 15" sunlight readable module running at 1,500 nits screen luminance. The inherent contrast ratio of the LCD module is about 350. At an ambient illumination level of 1,000 foot candles, which is about the level found in bright outdoor open shade, the LCD contrast ratio drops to about 25. At this level, the display readability is excellent. However, the

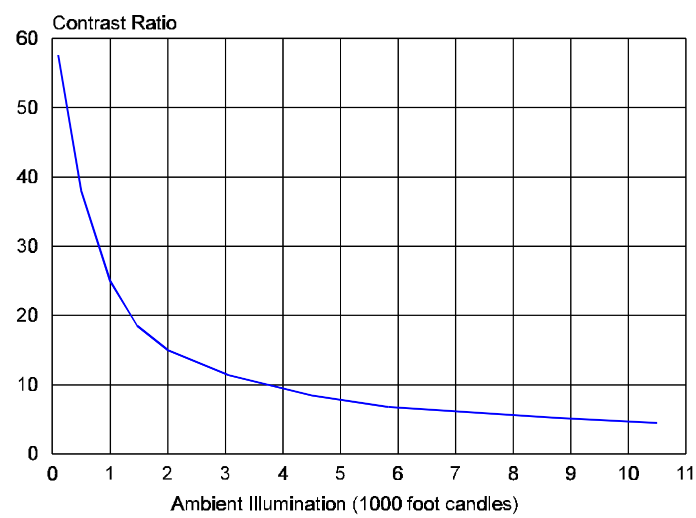

Fig. 4. Contrast Ratio as a function of ambient illumination of a 15" sunlight readable LCD module with an anti-glare front polarizer

contrast ratio drops to 4.5 at an ambient illumination level of 10,500 foot candles. Please note that the noon sunlight illumination level in northern California on a clear day is about 10,000 foot candles. Therefore, this level of illumination represents about the worst situation encountered by a display in outdoor environments. At a contrast ratio of 4.5, the display is readable but not with a good image quality.

The main reason that the contrast ratio of the 15" module drops so much is due to the fact that the front polarizer of this module has an anti-glare coating to diffuse the light reflection. In indoor applications, an anti-glare coating is quite effective in reducing the surface glare problem due to specular light reflections from a white wall, lighted ceiling, or a white shirt. However, in outdoor environments, the anti-glare coating scatters the bright incident light into a cone and forms an overall background glare that greatly reduces the display contrast.

The glare caused by bright ambient illumination can be reduced if the front surface of the LCD has an anti-reflective (AR) coating. Certain LCDs come with an AR coated front polarizer. Also, an AR coated film or glass can be laminated onto the front surface of the LCD. In either case, the surface reflection is reduced and the display contrast can be improved significantly.

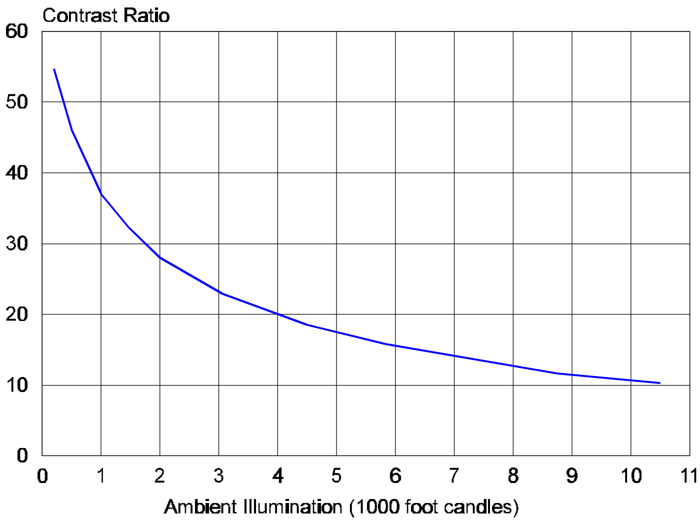

Fig. 5. Contrast Ratio as a function of ambient illumination of a 15" sunlight readable LCD module with an AR coated glass laminated onto the front polarizer.

Fig. 5 shows the measurements made on a 15" sunlight readable LCD module that has an AR coated glass laminated to the front polarizer. Again, the module is running at 1,500 nits screen luminance. As the ambient illumination increases, the display contrast ratio drops, but at a slower rate compared to the LCD without the AR coated glass (Fig. 4). At 1,000 foot candles ambient illumination, the contrast ratio is 37 and at 10,500 foot candles, the contrast ratio is greater than 10 which is quite good for display readability and image quality.

The Thermal Management Issues

The VHB backlight consumes a significant amount of power causing the LCD temperature in a sunlight readable module to be higher than normal. In addition, the front surface of an LCD is a good sunlight absorber. Thus, the LCD temperature can also rise significantly under the direct sunlight illumination.

The exact amount of LCD temperature rise due to these two factors depends on how the LCD module is mounted and also on the heat dissipation design. For example, if the LCD is mounted vertically, a significant portion of the VHB backlight heat will be dissipated into the air without heating up the LCD panel, and as a result, the LCD temperature rise will be low. On the other hand, if the LCD module is mounted horizontally, then almost all of the backlight heat rises to warm up the LCD panel. In addition, if a small fan or a heat sink is mounted onto the VHB backlight, the temperature rise of the LCD panel can be reduced significantly.

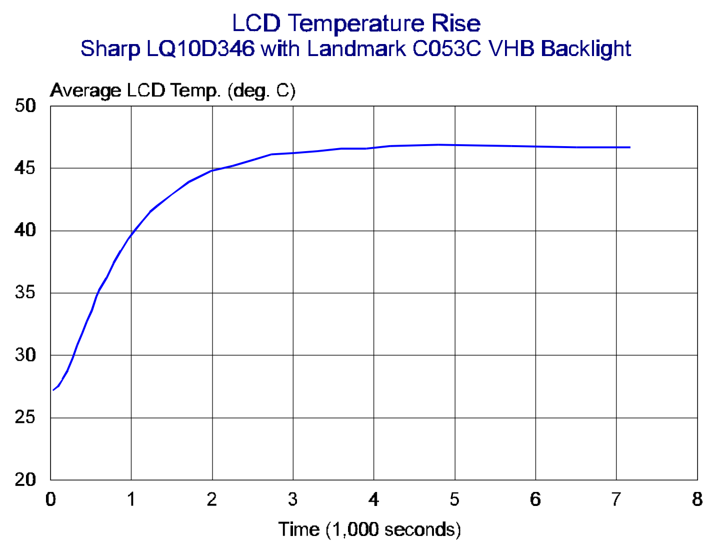

Fig. 6. The temperature rise curve of a 10.4" LCD with C053C VHB backlight.

Fig. 6 shows a typical temperature rise curve of a sunlight readable LCD module. The module is a 10.4" unit operated at 1,500 nits screen luminance with 19 watts backlight power. The LCD is tilted at a 25^{O} angle from the vertical and is operated in still air (i.e., no forced air cooling). There are six thermal sensors to measure the temperature of the LCD panel at various locations. The curve shows the average temperature reading of the LCD as a function of the time. At t = 0 second, the backlight is turned on. Within the first 15 minutes, the

LCD temperature rises about 10^{o}C, and finally settles with a rise of 19.5^{o}C. However, if a small 486 CPU fan is attached to the back of the VHB backlight, the temperature rise reduces to 8^{o}C. A similar reduction of the LCD temperature can also be achieved by attaching a heat sink onto the backside of the VHB backlight. In general, the thermal issues related to the VHB backlight power consumption can be resolved by relatively simple heat dissipation designs.

The second major cause of LCD temperature rise in outdoor applications is the sunlight itself. LCDs are suitable for outdoor uses because they have a very black front surface. On the other hand, a black front surface can absorb nearly all of the incident sunlight and heat up the LCD. This effect severely increases the thermal management problem when the LCD is exposed to strong direct sunlight.

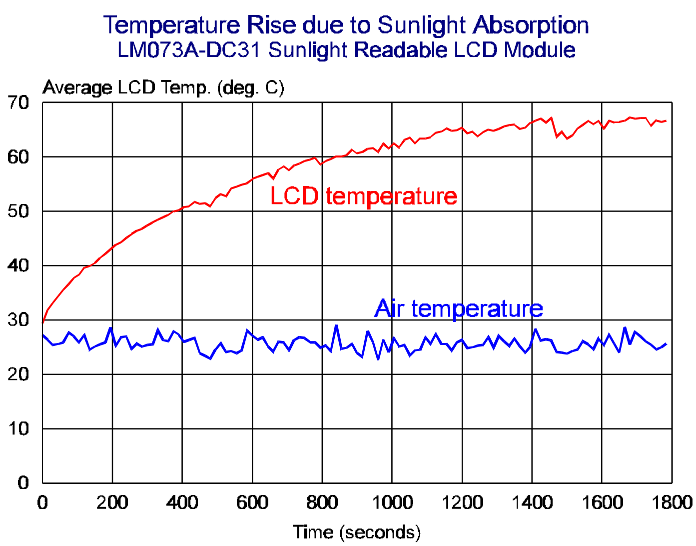

Fig. 7. LCD temperature rise due to sunlight absorption.

Fig. 7 shows a typical LCD temperature rise curve due to direct sunlight exposure. Again, the module is a 10.4" unit. During the test, the VHB backlight was not turned on. So the only heating source is the incident sunlight. On the day this test was conducted, the ambient air temperature was about 26^{o}C. The sunlight illumination was about 10,300 foot candles incident onto the LCD at the normal direction. The large fluctuation of the air temperature shown in the graph was due to wind blowing onto the thermal sensor.

Fig. 7. LCD temperature rise due to sunlight absorption.

The LCD temperature curve indicates that with the absorption of the sunlight, the LCD temperature rises by more than 20^{o}C within the first 5 minutes. After about 30 minutes, the LCD temperature rises by more than 40^{o}C. This is more than twice the temperature rise caused by the VHB backlight heat.

The situation shown in Fig. 7 represents about the worst case where very bright sunlight shines onto the LCD from the normal direction. If the incident angle of the sunlight is not perpendicular to the LCD, then the amount of sunlight power absorbed by the LCD reduces according to the Cosine law. Thus, the temperature rise will not be as serious as in the above case. However, for any outdoor application where the LCD will be subjected to direct sunshine, it is necessary to consider the extra heat due to sunlight absorption and provide additional cooling capability to avoid LCD overheating.

Conclusions

LCDs with screen luminance in the range of 1,000 to 1,500 nits can be used in very bright ambient environments including outdoor conditions under direct sunlight. In order to achieve such a high screen luminance, a very high brightness (VHB) backlight that is 10 to 20 times brighter than a normal backlight must be used.

In order to maintain a good display contrast ratio and image quality in direct sunlight, the front surface of the LCD should be coated with some anti-reflective film. However, for general outdoor applications not subject to strong direct sunlight, a regular LCD module with 1,500 nits screen luminance provides a very good display with contrast ratio greater than 20.

One of the main concerns in using these very bright LCDs is the thermal management issue. In particular, if the LCD faces to direct sunlight illumination, the amount of sunlight power absorbed by the LCD can cause a very severe overheating problem in a relatively short time period.