Energy Reduction in LCD Displays

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Abstract

Low-loss optical films can be used in LCD backlights to improve the display efficiency. Improvements can be used to enhance display performance, increase functionality and reduce energy costs.

1. Introduction

Over the last decade, Liquid Crystal Displays (LCD) have become an increasingly prevalent form of information transfer. Laptop computers, cellular phones, desktop monitors and, most recently, televisions are all dominated by LCDs. These devices are commonly called direct-view LCDs. According to DisplaySearch, the total area of all direct-view displays (LEDs, OLED, plasma, etc) is expected to grow at 15% compounded annually over five years, 2007–2012.[1]

An LCD display itself is an inefficient device with typically less than 10% of the available light passing through the display and less than 1% of the total electrical power to the display emitted as usable optical power.[2]

Recent world events have highlighted an increasing demand for energy which has resulted in rising energy costs. Consumer awareness of energy use is on the increase with energy consumption becoming a purchasing factor for items ranging from automobiles to LCD-TVs. Media coverage of rising energy costs is pervasive. In addition governments and regulatory organizations have issued guidelines for energy consumption of various devices, including LCD displays. For example, the European Union, the Chinese government, and the US government, among others, will be implementing mandatory energy efficiency labels for televisions to ensure that consumers consider energy efficiency as part of their purchasing decisions. A listing of voluntary and mandatory energy regulations can be found at the Asia-Pacific Energy Cooperation website (http://www.apec-esis.org/home.php).

Improving the efficiency of the LCD has been an industry trend for many years. Improved manufacturing of the LC cell and transistors have increased the aperture of each pixel resulting in more light transmitting through the panel; efficacy of light sources such as Cold Cathode Fluorescent Lamps (CCFLs) and light emitting diodes (LEDs) has undergone continual improvement; geometric enhancement films such as prismatic films and gain diffusers move more light toward the viewer; active dimming of LCD backlights with advanced image processing schemes can effectively reduce power consumption and has become more prevalent. 3M offers low-loss reflective polarizers and high efficiency reflector components that work in concert with the aforementioned improvements to further increase the efficiency of the LCD. Examples will be shown for a range of applications.

2. Efficiency Improvement through System Optimization

LCDs are predominantly transmissive devices. A backlight is placed behind the LCD and used to illuminate the image formed by display pixels. A rear display polarizer is used on the LCD panel in order to pre-polarize the light before it enters LC cells. Light emitted from the backlight is absorbed more than half by the rear polarizer if it is non-polarized.

Reflective polarizers, such as Vikuiti™ Dual Brightness Enhancement Film[3] (DBEF), are typically used along with display polarizers to minimize the absorption loss. DBEF are low-loss components that pass one polarization of light and reflect the orthogonal polarization. When aligned with the rear polarizer of the LCD panel, the reflected polarization is recycled in the backlight cavity for further use instead of lost to absorption in the rear display polarizer.

The reflected light needs to be converted to the orthogonal polarization in order to pass the reflective polarizer and to become LCD useful light. General means of polarization conversion in backlights include: scattering by diffuser films or diffuser plates; polarization rotation by material birefringence through transmission or upon reflection. Scattering scrambles the reflected polarization partially or totally depending on the actual backlight components. By comparison, conversion from the reflected polarization to the orthogonal polarization is more efficient since less amount of recycling is needed and it causes less absorption by the backlight components[4].

In direct-lit backlights, which are currently dominant in large size LCDs, diffuser plates provide sufficient polarization scrambling. In edge-lit backlights, which are currently dominant in small and medium-size LCDs, the combination of diffuser films, prism films, and/or white back reflectors provide significant polarization scrambling/rotation as well. For both systems, efficiency improvements of 30-50% can be achieved by using DBEF.

High efficiency reflectors, such as Vikuiti™ Enhanced Specular Reflector (ESR), have high reflectivity over all angles of incidence resulting in low absorption losses. As recycling elements such as geometric enhancement films, reflective polarizers and even diffuser plates are used, the benefit of high efficiency reflectors becomes greater.

The unneeded power of an efficient LCD can be applied to different areas of a device, benefiting other consumer needs. Mobile devices such as cell phones, music players, notebook computers and the like run on batteries that can limit operation of the device. Our measurements indicate 25% or more of the total system power is consumed by the LCD module. Efficiency gains can be used to run the device longer between charges, increase the luminance of the display without additional power consumption, reduce the battery size necessary to meet the display performance requirements or permit the power budget to be redistributed to other device needs.

Plug-in devices such as computer monitors, televisions and digital signs also benefit from more efficient LCDs. The backlight consumes 70% of the power needed to run these devices, which run in continuous operation under a constant power draw. Improvements to display efficiency can be used to increase the luminance without additional power consumption, reduce total power consumption and energy costs with same luminance level, and reduce the heat load of the device.

3. Results

3.1 Mobile Device

The run time of mobile devices can benefit from use of high efficiency reflectors and reflective polarizers. The film stack of a mobile entertainment system was modified to demonstrate the benefits of low loss components. Luminance of the device was measured with the film stacks as listed in Table 1.

The device backlight was further modified to have control of the power to the LED sources and monitor luminance. Luminance as a function of power was mapped for each device in Table 1 with results shown in Figure 1. Each device can now be set to the same luminance level by controlling the power settings for the sources.

Run time was evaluated for a single modification. The display power settings were modified to simulate each film stack. To simulate device#1, the backlight was set to full power. To simulate device#2, the backlight settings were changed to 84% power as this would be the setting if film stack#2 were in the device under test. Similar adjustments were made to simulate devices#3-5. A video was played on continuous loop with the backlight always on. Run time was measured as the time from fully charged battery to when the device shut down from lack of power.

Modification of device#1 to device#2 eliminated one component, modified the diffuser level and added the reflective polarizing capability of Vikuiti™ Multifunctional film BEFRP2-RC (BEFRP2-RC) resulting in a run time increase of 7%. Replacing the silver reflector in device#2 with ESR in device#3 further increased the run time by 12%, or 20% more than device#1. Beginning with device#1 and replacing the silver reflector with ESR and Vikuiti™ Thin Brightness Enhancement Film II (TBEF2-M-i) with BEFRP2-RC improves the reflector and adds a reflective polarizer capability. The resulting run time is improved by 48%.

Table 1. Film stack modifications to a mobile entertainment system and the recorded luminance values and simulated run times. **(L: luminance)**

Device	reflector	film#1	film#2	film#3	L (nits)	Run Time (min)	Run time increase
#1	Silver	diffuser	TBEF2-T-i	TBEF2-M-i	249	232	-
#2	Silver	high haze diffuser	BEFRP2-RC	-	280	249	7%
#3	ESR	high haze diffuser	BEFRP2-RC	-	327	278	20%
#4	Silver	diffuser	TBEF2-T-i	BEFRP2-RC	419	322	39%
#5	ESR	diffuser	TBEF2-T-i	BEFRP2-RC	493	343	48%

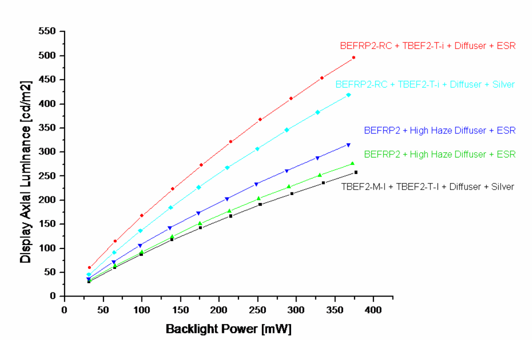

Fig. 1. Luminance as a function of backlight power for the each modification listed in Table 1.

By changing to low-loss components and maintaining the same luminance values the run time of an mobile entertainment system was increased from 232 minutes to 343 minutes (48%).

3.2 Notebook Computer

The power allocation of notebook computers can benefit from use of high efficiency reflectors and reflective polarizers. The film stack of a 15.4 inch notebook computer was modified to demonstrate power savings. The backlight power was regulated by external control. Power and luminance levels were recorded for the film stacks in Figure 2.

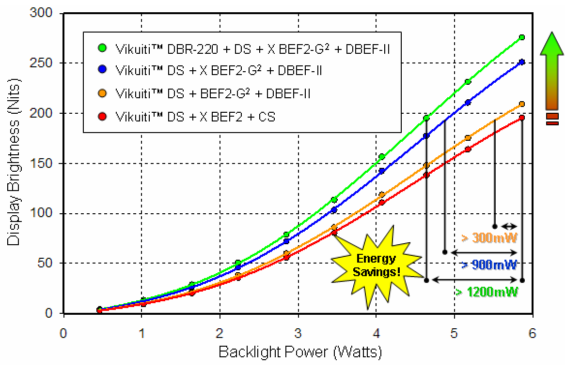

Fig. 2. Luminance as a function of backlight power for the modifications listed in Table 2.

Power to the backlight was modulated to provide 195 nits axial luminance for each film stack configuration. Power draw for the backlight at this luminance and the associated power savings are listed in Table 2. Modifying the enhancement films from crossed Vikuiti™ Brightness Enhancement Film II (BEF2) to Vikuiti™ Brightness Enhancement Film II (BEF2 G2) and Vikuiti™ Dual Brightness Enhancement Film II (DBEF II) allows the removal of the coversheet while adding the reflective polarizer capability. The power required for 195nits luminance decreases by over 300mW (>5%). Further modification to include a second sheet of BEF2 G2 (to obtain a crossed BEF2 G2) and replacing the diffuse white reflector with Vikuiti™ Durable Back Reflector (DBR-220), a modification of ESR for notebook computer, reduces the power consumption of the backlight by over 1.2W (20%).

Table 2. Film stack modifications to a 15.4 inch notebook and the recorded luminance and power consumption for 195nits. **(L: luminance; BL: backlight)**

reflector	film#1	film#2	film#3	film#4	L (nits)	BL power for 195 nits (W)	BL Power decrease (W)
diffuse white	diffuser	BEF2	BEF2	coversheet	195	5.86	-
diffuse white	diffuser	BEF2 G2	DBEF II		209	5.54	0.32
diffuse white	diffuser	BEF2 G2	BEF2 G2	DBEF II	251	4.93	0.93
DBR-220	diffuser	BEF2 G2	BEF2 G2	DBEF II	276	4.66	1.20

Changing the film stack of a notebook computer to include low loss components and maintaining the same luminance decreases the power consumption of the backlight by 1.2W or 20%. This power can be reallocated to add functionality to the computer by increasing the processor performance, adding cameras or adding fingerprint readers to name a few. Alternately the portability of the computer can be improved by reducing the battery size and weight of the computer.

3.3 LCD Monitor

The energy consumption of LCD monitors can benefit from use of high efficiency reflectors and reflective polarizers. Benefits from improving the efficiency of an LCD can result in a reduction of power through a reduction of light source and power supply components.[5]

Two mainstream Lenovo monitors (models L174 and L197w) have demonstrated the power savings. These monitors utilize a reflective polarizer in their backlights, and each monitor uses half the number of CCFLs as their original counterparts (models L171 and L194w). Vikuiti™ Diffuse Reflective Polarizer Film (DRPF2) was added to the L174 model. DBEF II was added to the L197w model. The resulting displays meet luminance specifications while permitting a power savings of 6W, or more than 30%. The addition of a reflective polarizer enables an efficiency boost which results in both energy savings and a reduced number of components, some of which contain mercury. These new Lenovo monitors were able to achieve EPEAT Gold qualified. EPEAT (Electronic Product Environmental Assessment Tool) is one of the most highly sought environmental designations in the tech industry.[5]

3.4 LCD Television

The energy consumption of LCD televisions can benefit from use of reflective polarizers. Benefits from improving the efficiency of an LCD can result in reduction of power consumption, number of light sources and internal temperature of the TV.

The film stack of a standard 40inch LCD television was modified from having a diffuser plate, gain diffuser, Vikuiti™ Brightness Enhancement Film III (BEF3-10T) and gain diffuser to a diffuser plate, crossed BEF2 G2 and Vikuiti™ LED Efficiency Film (LEF-D), a reflective polarizer.

The luminance levels were recorded. Power to the backlight was changed using the TV settings with total power monitored with a plug-in watt meter. Internal temperatures of the TV were also measured using thermal couples located in the backlight cavity. Measurements were made at 19°C ambient temperature.

Table 3. Film stack modifications to a 40 inch TV and recorded luminance, power and internal temperature. **(BL: backlight; temp: temperature)**

Component#1	film#1	film#2	film#3	#CCFLs	L (nits)	BL Power (W)	BL internal temp (°C)
diffuser plate	gain diffuser	BEF3-10T	gain diffuser	20	350	195	44.0
diffuser plate	BEF2 G2	BEF2 G2	LEF-D	12	350	92	34.0

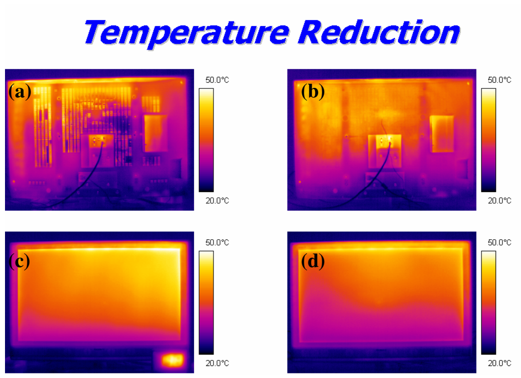

Fig. 3. Thermal images of the front and back of a 40" TV with film stacks listed in Table 3: (a) back with no LEF-D; (b) back with LEF-D; (c) front with no LEF-D; (d) front with LEF-D.

The TV settings were adjusted to best match the luminance levels of the TV in each configuration. The increase in efficiency and luminance due to the prismatic enhancement films and reflective polarizer was enough to remove 8 CCFLs from the backlight without detriment to system uniformity.

The results are listed in Table 3. Thermal images are shown in Figure 3. The use of a reflective polarizer in a television application resulted in a power savings of 103W (53%), CCFL reduction of 8 lamps and 10°C lower internal temperature.

4. Conclusions

Low-loss components in LCD displays can greatly improve system efficiency and help address the need to reduce power consumption. Tests have shown that LCD efficiency can be significantly improved through the use of a reflective polarizer and high efficiency reflectors by up to 50%.

Benefits of the efficiency boost can be used in a variety of ways across the applications of LCD displays. Mobile devices may have extended the battery life. For notebook computers the power budget can be reallocated to improve functionality. Monitors can reduce the power consumption through elimination of light source components. Televisions can reduce the power consumption while simultaneously reducing the heat load of the device.

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