A Green Display for the Internet

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Abstract: In typical use, a liquid crystal display (LCD) with high resolution, brightness and color saturation can consume over half the total system power in a modern mobile device. This paper examines LCD optical transmittance and system electrical design to extend battery run time. By applying a solid understanding of critical optical parameters and complementary system design, a low power "Green" display can be achieved. The LCD in the Pixel Chromebook [1], will be used as a baseline for discussion.

1. Introduction

The advancement of cloud supercomputers and increasingly ubiquitous availability of wireless connections enables users to easily access the internet. Smartphone, tablet and netbook or Chromebook class computers with streamlined peripherals and operating system benefit from this paradigm shift and are gaining in popularity. Our lives have changed drastically with such easy access to information, and the display has assumed a critical role as our optical conduit to the internet. In these modern mobile devices, the display can consume close to 50% of the total system power in normal web browsing operation. This paper discusses ways to both offer a rich interactive experience and to extend mobile device usage time by carefully optimizing display optical and electrical characteristics. The Pixel Chromebook LCD (Pixel LCD module) will be used as an example. This system was designed to delight users with a maximum brightness of 400 Nits, 60% NTSC color gamut, wide viewing angles with IPS technology and a 3:2 aspect ratio to facilitate internet content viewing with minimal scrolling. To eliminate pixelation at laptop viewing distances, the Pixel LCD module pixel density is 239 pixels per inch (PPI).

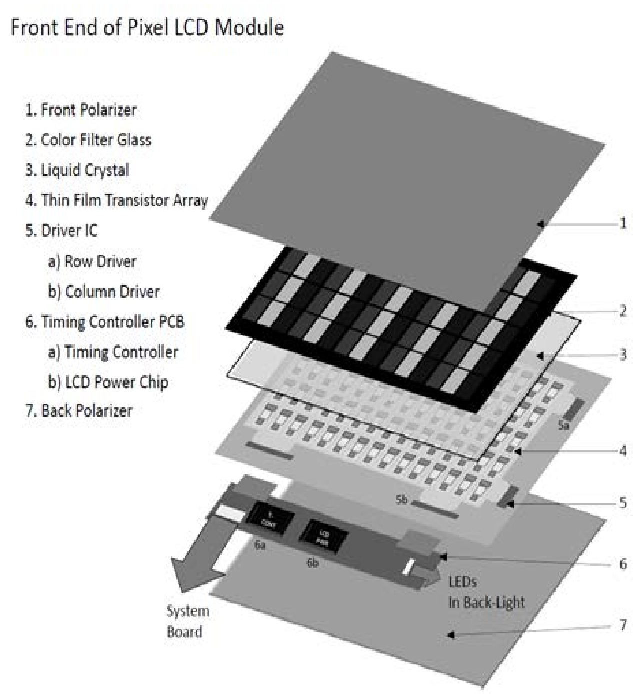

Fig.1: Stack up of the Pixel LCD module front end.

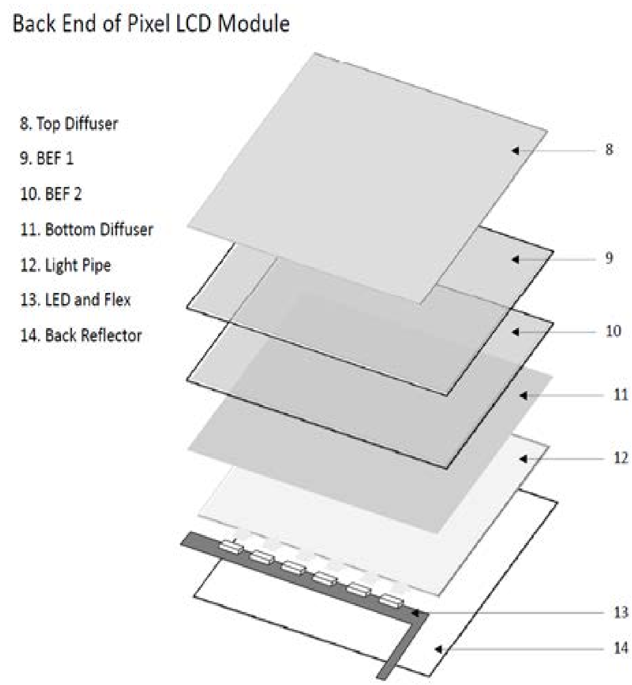

Fig.2: Stack up of the Pixel LCD module back end.

2. The front end

Thin and light mobile devices are desired by consumers, so mechanical requirements are a major consideration in the display design. The Pixel LCD module, conceived in early 2011, has an overall thickness of 2.85mm with a front end thickness of 0.95mm. The stackup of the front end is shown in Fig 1. The optical components of interest are: front and back polarizers, color filter, liquid crystal and thin film transistor (TFT) array. The overall transmittance, $T_{\text{front end}}$, of these optical components is in (1).

$$T_{\text{front end}} = T_{\text{front polarizer}} \times T_{\text{color filter}} \times T_{\text{liquid crystal}} \times T_{\text{TFT array}} \times T_{\text{back polarizer}} \qquad (1)$$

At 60% NTSC color space in CIE 1931 chromaticity diagram, $T_{\text{front end}}$ is approximately 3.7%. The front polarizer acts as a protection film for the Pixel LCD module and the back polarizer is of reflective type with 137% transmittance. Recently, numerous technical advancements have been made in the color filter, liquid crystal and TFT array. Transmittances of $T_{\text{color filter}} \times T_{\text{liquid crystal}} \times T_{\text{TFT array}}$ as high as 50% are reported, resulting from recent improvements in TFT cell and color filter design rules, new liquid crystal materials and novel pixel design. In the near future, $T_{\text{front end}}$ of 5.5% will be achievable for similar mass production LCDs through new technology advancements like photo-alignment [2] and negative dielectric constant liquid crystal materials [3].

3. The back end

The back end has a thickness of 1.75mm. A gap of 0.15mm exists in between the front end and the back end to meet reliability requirements by avoiding mechanical interaction. A typical back end design has four optical films stacked on top of the light pipe, with a pair of brightness enhancement films (BEFs) [4] in the middle, and diffuser films on the top and bottom. The BEFs use pyramidal micro-structures to extract and focus light from the light pipe at the expense of viewing angle. Thoughtful tradeoff of light viewing angle from light pipe and transmittance gain can be realized by selecting BEF appropriately. The diffusers are typically light attenuators, causing some reduction in transmittance while preventing Moiré patterns and helping provide more uniform illumination. The transmittance, $T_{\text{back end}}$, of this optical film stack can be described by (2). The Pixel LCD module was designed so that screen brightness at viewing angle $\theta = \pm 30^{o}$ is 50% of maximum as described in [5], and gain increase of $T_{\text{back end}}$ is approximately 5.8 times.

$$T_{\text{back end}} = T_{\text{diffusers}} \times T_{\text{BEFs}} \qquad (2)$$

The light source comprised of white light emitting diodes (LED) is one of the most critical components in the back end stack. Historically, the luminous flux (Lumens) of LEDs improves roughly 9% per year, and 0.8mm high side-firing LEDs with reported output greater than 9.5 lumens and low V_f at 20mA will be available shortly. The light pipe is designed to provide efficient and uniform light coupling from the LEDs to the film stack while minimizing thickness. Finally, the reflectivity characteristics of the reflector below the light pipe should be chosen to optimally enhance the light recycling from DBEF and BEFs.

4. System electrical design

A well-executed system electrical design will further reduce the LCD module power consumption. Electrical design of both the timing controller PCB and Processor (CPU) board are examined. The timing controller PCB contains the LCD timing controller (T-CON) and LCD power chip. Using video data from the Graphic Processing Unit (GPU) on the CPU board, the LCD T-CON generates all timing signals required by the TFT array. The latest T-CON designs incorporate dynamic backlight control (DBC) [6], and embedded RAM or stack RAM to support panel self-refresh (PSR) [7]. DBC analyzes video data to establish an average luminance level. From an average luminance level computed from video data, gray shades of an image can be altered to compensate a dimmed LED output. Enabling DBC to allow dimmed LED output delivers reported saving of 15% in typical use cases. PSR allows the display to refresh without data from the CPU board. During a static screen image, the GPU is disabled and PSR continues to refresh data to the column drivers. Early investigations suggest that GPU and embedded Display Port™ (eDP) bus shutdowns save about 200 mW. The LCD power chip converts the regulated 3.3V system voltage to the various high voltages required by the TFT array, column and row drivers. While the TFT array consumes a small percentage of the total LCD module power at full brightness, TFT array power becomes a significant term during usage in low light ambient and as the industry continues to increase the display resolution for mobile applications. Alternative TFT fabrication processes such as low temperature poly silicon (LTPS) and Indium Gallium Zinc Oxide (IGZO) TFTs [8], require lower gate threshold voltages than conventional amorphous silicon (a-Si) TFTs, and these advanced processes should be considered to further reduce TFT array power. There are also efforts in the industry to reduce the display refresh rates in the PSR mode. This can significantly help the average display panel electronic power efficiency. Additionally, new features added to eDP 1.4 such as media buffer optimization (MBO) and selective update (SU) can be adopted for future system power improvements.

While most systems place the LED controller on the timing controller PCB, the Pixel system gains power efficiency by locating it on the CPU board. The LED converts the raw battery voltage to drive the LEDs and control dimming. The LEDs consume over 70% of the total LCD module power at full brightness, so the power efficiency of the LED controller is important. While controller efficiency typically ranges from 80% to 90%, it depends on brightness level. Efficiency is also a strong function of the difference between the supply voltage and voltage out to the LED strings. These losses can be reduced by optimizing the string voltage and number of output channels. Efficiency also depends critically on the boost inductor, and by locating the LED controller on the CPU board instead of the timing controller PCB, real estate is available to generously size the inductor. In the case of Pixel Chromebook, the larger inductor allowed an approximately 5% gain in LED controller efficiency.

5. Conclusion

By careful attention to optical and electrical attributes, the Pixel Chromebook LCD module combines high resolution, high color saturation and 400 nit brightness while consuming about 7W, a little over half the total system power. A 40% reduction in total LCD module power is within reach in the near future. Combining such a "Green" display with other expected efficiency improvements, next generation systems will delight users with both a rich internet viewing experience and long battery runtimes.

6. Acknowledgements

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7. References

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