35.5L: *Late-News Paper:* A Direct-View MEMS Display for Mobile Applications

Nesbitt Hagood, Roger Barton, Tim Brosnihan, John Fijol,
Jignesh Gandhi, Mark Halfman*, Richard Payne, and J. Lodewyk Steyn
Pixtronix, Inc., 100 Burtt Road, Suite 123, Andover, MA 01810, USA

Abstract
With the continued proliferation of display intensive applications for portable electronics devices, the need for lower power, higher image quality video displays has never been greater. Pixtronix is uniquely able to meet these requirements through its MEMS (micro-electo-mechanical system) display technology, which enables the development of direct view displays with breakthrough optical transmission over 60%, color gamut over 100% (of NTSC, CIE 1931), 1,000:1 contrast ratio and wide view angles.

1. Introduction

1.1 Market drivers
Display intensive applications, such as mobile TV & video, portable GPS and handheld gaming continue to emerge and are forecast to increase dramatically through the end of this decade. For example, IMS Research forecasts that by the end of 2011, 446 million cellphone users will be watching mobile TV on their cellphone handsets [1]. This represents a compound annual growth rate of approximately 50% for mobile video adoption through 2010. In terms of the corresponding revenue generation, Informa Telecoms and Media forecast worldwide revenues from mobile TV and video services to rise from $2.5B in 2006 to $8.4B in 2011 [2].

A vastly improved end user experience will be necessary if these forecasts are to be achieved. Two critical elements of the end user experience are the image quality of the display and the amount of time the display can be viewed per battery charge. Today's incumbent LCD technology forces mobile consumer electronics OEMs and ODMs to repeatedly make trade offs between power consumption and image quality. Improved image quality can be achieved through various combinations of larger sizes, higher resolutions, higher brightness, and wider color gamut; however implementation of any of these improvements in a liquid crystal based display results in the consumption of significantly higher power – and a corresponding reduction in display "on time" per battery charge. This reduction in available viewing time per battery charge is detrimental to the end user experience and is adverse to the sale of mobile services. Therefore, from an application design perspective, display selection must be balanced between power consumption and performance.

The Pixtronix™ direct-view MEMS display eliminates the need for this power / performance trade off by providing a 10x improvement in optical transmission while also delivering wide color gamut, high brightness, high contrast ratio and wide view angles.

1.2 MEMS display technologies
MEMS technologies have been proven in display applications such as data projectors, HDTVs and digital cinema. In these projection display applications, MEMS are well suited as the spatial light modulator due to their microsecond switching speeds (enabling up to 14 bits of grayscale per color), high optical efficiencies (65%) and high contrast ratios [3]. These MEMS based devices have also been shown to be highly reliable with operating lifetimes in excess of 100,000 hours [4].

Pixtronix has developed a proprietary direct-view MEMS display architecture that takes advantage of the fast switching speeds, high optical efficiencies, high contrast ratios and high reliability of MEMS. Unlike popular MEMS projections display applications that utilize reflective micro mirrors, the Pixtronix display architecture uses MEMS shutters which are digitally actuated between a transmissive (open) or opaque (closed) state. When integrated with a backlight, this forms the basis for a direct-view display.

2. Pixtronix Display

2.1 Overview
The Pixtronix display is a transmissive, field sequential color (FCS) display. Utilizing a tri-color LED backlight, the display provides a full color gamut (105% of NTSC, 1931 CIE) and color depth for a rich and vibrant video experience (contrasted with direct view reflective MEMS displays [5]). It has very low power consumption because

*Corresponding author: mhalfman@pixtronix.com

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of its unique optical train which utilizes light recycling to achieve over 60% optical transmission. The Pixtronix display also has high contrast ratio through a wide viewing angle. The display is based on a proven MEMS shutter design which has fast on and off transitions, enabling a high quality field sequential color implementation that eliminates color breakup and image artifacts.

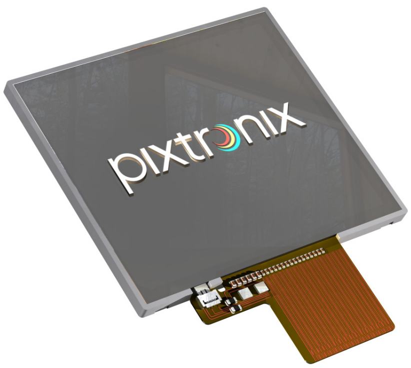

Figure 1: Pixtronix Display Module

2.2 Display module

The Pixtronix display module consists of two joined components: a MEMS module and a backlight. The MEMS module comprises an active backplane with MEMS shutters built over it and a cover glass. The backplane and MEMS are fabricated using standard TFT processing with a simple digital circuit. Cell assembly and module integration are also accomplished using standard LCD processing tools. This allows production of these displays using the large installed base of LCD processing tools and manufacturing infrastructure.

A proprietary optical train is formed by the backlight integration with the MEMS module. The optical train provides highly efficient light recycling through the utilization of a back reflector in the backlight and a highly reflective surface with apertures aligned under the MEMS shutters. Light recycling and the core components of the Pixtronix display are illustrated in Figure 2.

The use of MEMS technology to create an array of high-contrast shutters for a transmissive display configuration has been proposed in the past [6], [7]. However, due to the areas needed for both matrix addressing and lever arms, the optical aperture ratios available in these shutter displays have been considerably less than 10%. To address the issue of aperture ratio, display designers have generally coupled the shutter array to a micro-lens array so that a greater fraction of available light can be focused through each of the relatively small apertures. Micro-lens arrays have in turn required a collimated light source for efficient operation. Therefore, given the constraints of the optical system, shutter arrays have heretofore only been given serious attention for use as projection displays.

The Pixtronix optical train, however, enables optical throughputs as high as 60%-80% even though aperture ratios remain in the range of 10%-20%. These attractive optical efficiencies are achieved using conventional backlights that are thin enough for use in portable electronic modules.

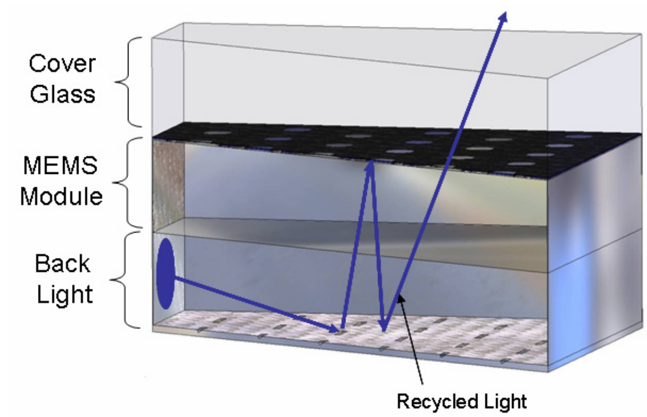

Figure 2: Pixtronix Display Module Illustrating Core Components and Light Recycling

The optical throughput of the display is also improved, relative to LCD, by the absence of color filters and polarizers. Elimination of these layers provides the additional benefit of reducing cost. Manufacturing cost is further reduced due to the decreased manufacturing complexity enabled by the Pixtronix digital display architecture. The digital nature of the display makes possible wide manufacturing tolerances and insensitivities to environmental effects.

An image is formed by synchronously modulating the shutters with the backlight LED illumination in a field sequential method with the red, green and blue LED lamps. The Pixtronix display has a typical color gamut of 105% (of NTSC, CIE 1931) compared to a conventional LCD color gamut of 55% [8]. The effect is a much more saturated color quality and color depth providing superior image quality. Figure 3 shows the Pixtronix color gamut (purple) compared to the LCD color gamut (yellow) and the 100% NTSC color gamut (gray).

The display exhibits very high on-axis contrast and a very wide contrast viewing angle without gray scale inversion at the angles typically observed in an LCD display. The 1,000:1 contrast ratio and wide viewing angle performance of the Pixtronix display is superior to an LCD display requiring complicated LCD modes and/or additional films (also increasing the cost of the LCD display).

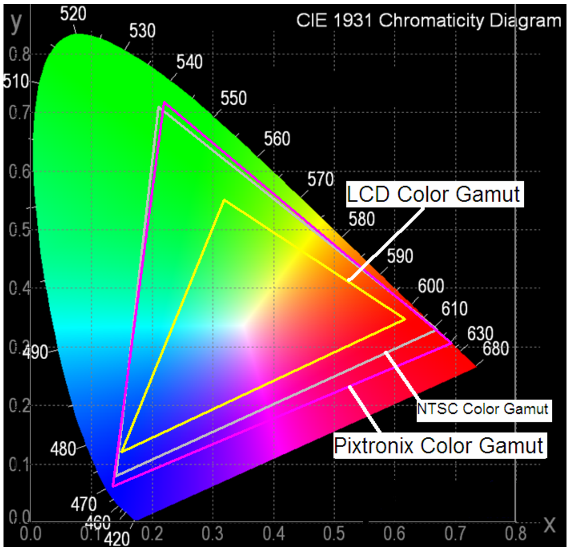

Figure 3: Color Gamut Comparisons

3. Results

3.1 High optical transmission

The proprietary optical train enables display optical throughput of 60%-80% to be achieved with aperture ratios of only 10%-20% (as shown in Figure 4). That is to say that 60%-80% of the light generated by the backlight is transmitted to the viewer (compared to 6%-8% optical throughput in a LCD display [9]). Table 1 illustrates the optical transmission of the Pixtronix display (with a 10% aperture ratio) compared to LCD technologies.

Table 1: Optical Transmission Comparison

Display Technology	Optical Transmission
Conventional LCD	~ 6%
Advanced Mobile LCD	~ 8%
Pixtronix	60%

This translates into a much lower brightness backlight required for generating the same luminance for the viewer. Hence much lower power is consumed in the display. A power consumption reduction by a factor of 5 is achievable with the Pixtronix display when compared to a conventional LCD display.

The data in Figure 4 was measured using a commercial backlight, including 2 white LEDs attached at the side. The luminance of the backlight was compared with and without the insertion of the Pixtronix aperture layer. Five different aperture layers were tested, differing in aperture ratio. The aperture ratio is defined as the open area of the apertures divided by the total area. In the experimental data shown in Figure 4, the aperture ratio was varied from 5% to 20%. The reflectivity of the material between the apertures was 95%. The results show that despite the low aperture ratio (5%-20%), a large percentage (40%-80%) of the optical power is transmitted, due to the highly efficient MEMS shutters and optical recycling.

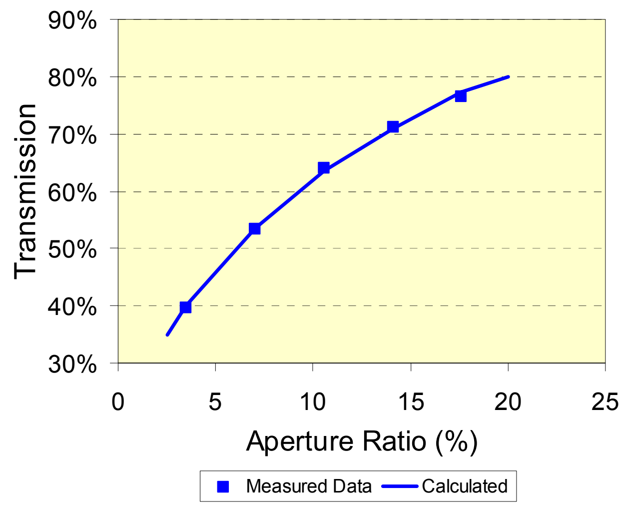

Figure 4: Optical Transmission vs. Aperture Ratio

3.2 High speed MEMS enabled FSC

The MEMS module comprises high speed shutters that take part in forming an image. These pixels are digital; they are either open or closed, with no intermediate positions, and are designed for very low energy consumption between states. A Pixtronix shutter design example is shown in Figure 5 below.

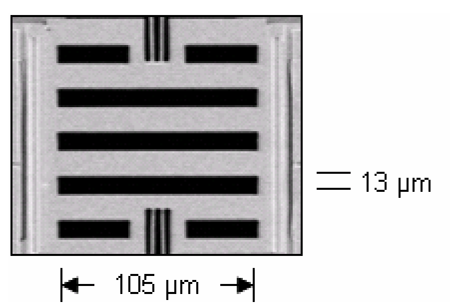

Figure 5: Pixtronix MEMS Shutter

The transition speed of the pixels is less than 100 microseconds. Figure 6 shows the mechanical displacement of the shutters in response to a square wave electrical drive signal. The drive signal provided an on-time of 64 microseconds and an off time of 64 microseconds. In response, the 10%-90% transition widths were less than 54 microseconds.

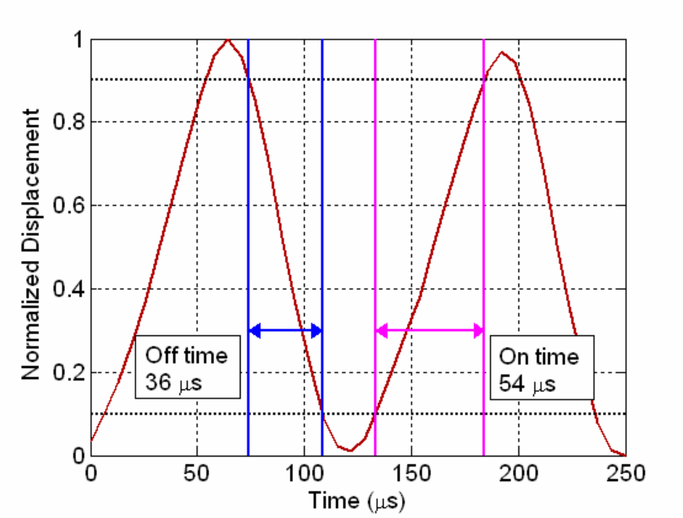

Figure 6: Pixtronix MEMS Shutter Transition Speeds

The Pixtronix proprietary backplane makes use of the fast shutters to provide a high duty cycle image generation mechanism using a field sequential color method. The Pixtronix drive mechanism allows for the display of over 1,400 image fields per second, enabling a high quality image without the color breakup effects or flicker issues seen in FSC LCD implementations. Table 2 illustrates the high color field rate of the Pixtronix display compared to other FSC implementations.

Table 2: FSC Color Field Rate Comparison

FSC Implementation	Color Field Rate
LCD [10]	180 Hz
LCoS [11], [12]	450 Hz - 540 Hz
Pixtronix	1,440 Hz

Experimental results with Pixtronix shutters demonstrate the elimination of perceptible color breakup effects or flicker issues at color field rates of 720 Hz and higher.

4. Summary

The Pixtronix display demonstrates fundamental breakthroughs in the areas of high optical transmission, low power consumption and superior video image quality. Deployment of this technology in display intensive mobile applications will dramatically improve the end user experience and directly contribute to the increased adoption of mobile hardware platforms and services.

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