A

Seminar Presentation Report

On

"Imod (INTERFEROMETRIC MODULAR DISPLAY)"

Submitted To:

Er. Rashi Gupta

(CSE)

Submitted by:

Kartik Barmera

Final Year 8th Sem

DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING

MARWAR ENGINEERING COLLEGE AND RESEARCH CENTER JODHPUR (RAJ.)

ACKNOWLEDGEMENT

We extend our sincere thanks to **Er. Rashi Gupta** In-Charge the Department, Computer Science and Engineering, for providing me his cooperation and guidance in the preparation and presentation of this seminar.

We also extend our sincere thanks to all the faculty members of Electronics and Communication Department for their support and encouragement.

Kartik

Barmera

INTRODUCTION

WHAT IS INTERFEROMETRIC MODULAR DISPLAY TECHNOLOGY?

The Interferometric Modular (iMoD) is an electrically switched light modulator comprising a micro-machined cavity that is switched on and off using driver ICs similar to those used to address LCDs. An iMoD based reflective flat panel display can include hundreds of thousands of individually addressable iMoD elements. iMoD displays represent one of the foremost examples of a micro-electromechanical systems (MEMS) based device.

In one state an iMoD subpixel reflects light at a specific wavelength and gives a pure, bright color at one intensity while in a second state it absorbs incident light and appears black to the viewer. The wing of butterflies employs the same phenomena. When not being addressed, an iMoD display consumes very little power.

The iMoD was invented by Mark W. Miles, a MEMS researcher and founder of Etalon, Inc., and (co-founder) of Iridgim Display Corporation. Qualcomm took over the development of this technology after its acquisition of Iridigm in 2004, and subsequently formed Qualcomm MEMS Technologies (QMT).[4] Qualcomm has allowed commercialization of the technology under the trademarked name "Imod", and this energy-efficient, biomimetic technology sees application and use in mobile phones, etc.

A major breakthrough in display technology, iMoD displays are the next generation of flat-panel displays and promise substantial performance and power-saving benefits over current technologies. Reflect on this: As butterfly wings and peacock feathers create color by causing light to interfere with itself, so do the elements in a QUALCOMM display. This is why we call it an Interferometric Modulator, or iMoD, display.

Overview of IMOD Technology

MEMS-based display technologies have been under development for over a decade, but have only recently started to gain traction. Display systems based on arrays of movable mirrors are now widely available in the consumer marketplace. Deformable mirrors and mechanical shutters are also making use of MEMS-based displays. Their digital nature and fast response make them ideal for display applications. However, their role has been limited to applications with fixed-angle light sources rather than portable direct-view displays, as they are not effective when removed from a fixed-angle light source.

Developed to address these shortcomings, IMOD displays are based on the principle of interference, which is used to determine the color of the reflected light. IMOD pixels are capable of switching speeds on the order of 10 microseconds. Additionally, displays fabricated using IMOD technology have shown reflectivities of greater than 60 percent, contrast ratios greater than 15:1 and drive voltages of as low as 5 volts. Though simple in structure, IMOD display elements provide the functions of modulation, color selection and memory while eliminating active matrices, color filters and polarizers. The result is a high-performance display capable of active-matrix type functionality at passive-matrix cost. IMOD displays are a strong contender in the display industry, with the potential to offer many of the benefits of ink and report

Qualcomm's Imod™ displays are a technology breakthrough that deliver substantial performance benefits over competing display technologies. The reflective displays, based on interferometric modulation (IMOD) technology, offer a significant reduction in power consumption as compared to other display technologies, while extending device battery life and enabling new features. Moreover, these displays require no backlighting and can be viewed in bright sunlight and in a wide range of environments.

Inspired by the simplicity of natural iridescent colors, the Imod display physically manipulates light using micron and sub-micron sized mechanical elements. These simple, elegant structures result in a display that is:

• **Highly Reflective** – provides consistent viewing quality in varied environments ranging from dim indoor lighting to the brightest outdoor sunlight

• **Energy Efficient** – dramatically reduces the energy consumption from the display resulting in increased usage time across every usage models

• **Inspiringly Innovative** – enables increasingly diverse industrial designs and applications while greatly enhancing the potential for carrier revenue.

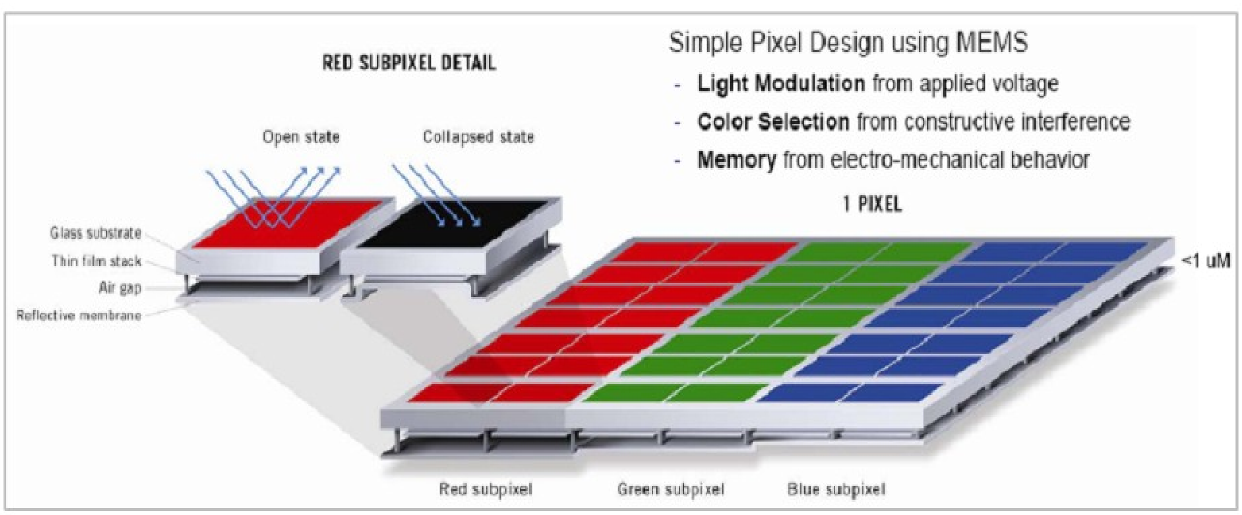
This report will consider current market trends that drive the convergence of multimedia applications onto the cellular phone and the demand this convergence places on the limited battery budget of the typical handset.

Specifically, this discussion will center on the ever increasing gap between the energy available and the energy demands of the handset. Similarly, this reportwill consider the convergence driven market trend of expanding handset use in increasingly diverse viewing environments. Finally, this report will address the solutions Imod display technology offers to these trends. Namely, this report will illustrate the energy savings Imod displays provide, and their ability to enable utilization of the handset throughout the entire range of illumination conditions.

Operational Principles of the Imod Display

As shown in the left-hand side of Figure 1, each pixel within a Imod display is composed of micro-electro-mechanical-system (MEMS) elements. The display is built on a glass substrate, and each MEMS element functions as a resonant optical cavity that strongly reflects a specific portion of the visible spectrum. The related visual color that is created is directly proportional to the cavity's depth. Thin films deposited on the substrate comprise one wall of this cavity, and the other wall is a highly reflective flexible membrane.

When electrostatic force is applied across the cavity, the membrane collapses against the substrate films, the cavity becomes very thin, and the resonant wavelength moves into the ultraviolet spectrum. Consequently, the viewer perceives a collapsed MEMS element as being black or "off." As shown in the right-hand side of Figure 1, color displays are made by composing a single pixel from MEMS elements of different thicknesses. Varying the cavity depth results in variations of resonant wavelengths which yield variations of color. This pixel construction utilizes no color filters, polarizers, or organic compounds. Such simplicity leads to high energy efficiency, brightness, and environmental stability that are the hallmarks of the Imod design.



Overview of Portable Display Technologies

Ink and report are arguably the de facto standard for information display. Developed over 5,000 years ago, today's inks and dyes provide lifelike color imagery. Display technologies, on the other hand, are relatively new. The CRT was developed less than 100 years ago and the increasingly popular flat-panel display less than 40 years ago. For roughly a decade now, engineers have been working to create a display technology capable of providing a report-like reading experience, not only with regards to superior viewability, but also with respect to cost, power and ease of manufacture. Display technologies such as backlit LCDs, reflective LCDs, electroluminescent (EL) displays, organic light-emitting diodes (OLED) and electrophoretic displays (EPD) were all steps in this direction. IMOD displays, based on industry-proven MEMS technology, promise to take the quest for report-like displays to a new level.

A wide variety of display technologies are aiming to capture the key characteristics of ink and report. In this section we will compare them, with particular emphasis on energy consumption and readability.

Emissive/Transmissive Displays

Displays are classified as one of three types: emissive/transmissive, reflective or transflective. A transmissive LCD consists of two transmissive substrates between which the liquid-crystal material resides. By placing a backlight underneath one of the substrates and by applying a voltage to the liquid-crystal material the light reaching the observer can be modulated so as to make the display pixel appear bright or dark. A display can also directly emit light, as in the case of an OLED display, whose active display material emits light. In the case of an LCD, a constant source of power is required to both modulate the liquid-crystal material and to power the backlight. An LCD requires constant refreshing—at least sixty times per second—in order to prevent the liquid-crystal material from transitioning to a different modulation state, resulting in image degradation or flicker. Such is also the case with OLED and EPD—constant power must be provided to the light-emitting materials in order to prevent screen flicker.

Reflective Displays (Continuous refresh type)

In a reflective display, one of the substrates found in a transmissive display is replaced with a reflective substrate. Reflective displays usually employ liquid-crystal material on top of the reflective substrate so as to modulate the ambient light reflecting off the reflective substrate.

Since there is no backlight in reflective displays, they consume substantially less power than emissive displays. However, since the material providing modulation is liquid-crystal, the majority of these types of displays must constantly be refreshed or the displayed image will be lost. So far, most portable devices employing reflective displays are the continuous refresh type..

Reflective Displays (Bistable type)

A bistable display is capable of maintaining one of two states (on or off) without any external influence such as an electric field. A bistable reflective display employing liquid-crystal material for light modulation is in many ways identical to the continuous-refresh reflective display. The key difference is the type of liquid-crystal material that is used. Through proper choice of chemistry, manufacturing and drive schemes, the liquid-crystal material can be locked into one of two states. Once the material has been locked into a certain configuration, it is not necessary for the display to be refreshed. In fact, power can be completely removed from the system and the display will maintain the last image shown.

EPD and IMOD displays are also bistable. EPDs typically consist of charged microcapsules containing dye suspended between two substrates. The microcapsule, generally a sphere, is black on one half and white on the other. Depending on the electric field applied between the two substrates, the microcapsule will flip orientation to position either the black or the white half toward the observer. Depending on the capsule orientation, the ambient light will either be reflected toward the observer or be absorbed.

In an IMOD display, a flexible thin-film mirror is fabricated on a transparent substrate, leaving an air gap of a few hundred nanometers between the thin film and the substrate such that when ambient light enters this cavity and reflects off the thin-film mirror, it interferes with itself, producing a resonant color determined by the height of the cavity. An IMOD display produces iridescent color, similar to what you would observe in a butterfly's wings. Depending on the electric field applied between the substrate and the thin film, the film can be positioned in one of two states. Because IMOD displays are bistable, they don't require a refresh until the image is changed. As a result, they consume very little power, providing extended battery life for the user.

Transflective Displays

Transflective displays are a hybrid of emissive and reflective display technologies. Transflective displays were engineered to overcome the shortcomings of emissive displays, namely the backlight's high power consumption, and the shortcomings of reflective displays, such as poor image quality at low ambient light levels. Transflective displays employ a partially transmissive mirror as the secondary substrate, as well as a traditional backlight. In low light situations, the device operates as a transmissive display, employing the backlight. In high ambient light conditions, the backlight turns off and the display functions as a reflective display.

A transflective display is a compromise and its image quality is generally subpar. In sunlight they are not as bright as purely reflective displays, while indoors they are not as bright as emissive displays. Regardless, they offer a compromise for applications where a wide variety of lighting conditions are seen and transflective displays are widely used in the portable device market.

A Break from the Past

Qualcomm's® Imod™ display is poised to transform the $100 billion* display industry and move beyond the considerable limitations of current display technologies. This next-generation display technology will open new market opportunities for device manufacturers, operators and content developers who are seeking new and compelling products to drive profit and market share.

This report will contrast and compare Imod displays with today's prevailing display technologies: liquid-crystal (LCD), organic light-emitting diodes (OLEDs), electrophoretic (EPD) and cholesteric liquid-crystal (ChLCDs) displays. It will focus primarily on the fast-growing small- to medium-size display arena where the Imod display will have its first application when it goes into production.

Unlike LCD, OLED, EPD or ChLCD displays, Qualcomm's Imod display is based on biomimetics, or technology imitating nature. The natural phenomenon that makes a butterfly's wings or a peacock's feathers shimmer and give off their strikingly rich colors is the same quality that gives Imod displays their color. Microscopic structures on the wings and feathers create vivid colors by causing light to interfere with itself, hence the term interferometric. Using this natural iridescent effect, Qualcomm is creating the next generation of information display technology. It is important to note that the Imod display screen reflects light rather than transmitting it. As the following discussion points out, this has major advantages for users and manufacturers of small portable devices. Qualcomm's Imod display incorporates Interferometic Modulation (IMOD) technology which differs from LCD, OLED, EPD and ChLCD in another important way: it is a micro-electro-mechanical system (MEMS) that requires neither organic materials nor backlighting to operate. As this report will discuss, these two distinctions give Imod displays their greatest competitive advantages—power savings and sunlight viewability.

With demanding new mobile applications, such as full-motion video and animation on the horizon, the display industry has a significant need for a display that will accommodate these applications while consuming less power and providing a convergent user experience.

Displays like the Imod display, based on IMOD technology, stand to gain a share of this market as the technology introduces significant advantages for both consumers and manufacturers in an industry where competitors are under considerable pressure to overcome the limitations of current technologies.

COMPATATIVE DISPLAY TECHNOLOGIES

The Mirasol ™ Display Advantage

Demand for portable electronic devices continues to grow, and new applications encouraging constant usage require components that consume less power than current prevailing technologies can provide. For example, Qualcomm's new MediaFLO™ technology will enable users to watch high-performance video on portable devices – but applications such as this need a display offering superior viewability and frugal power consumption.

Imod displays have the following advantages for the consumer:

• **Low power consumption** –mirasol displays use just a fraction of the power needed by conventional technologies. Imod displays need little or no power-draining illumination in most viewing environments. And because the Imod display does not demand continuous refreshing, once an image has been written to the display, very little power is required to sustain it.

• **Readability** – Imod displays have approximately the same contrast ratio and reflectivity as a newspaper, making it easy to read in almost all lighting situations.

• **Response time** – The fast response time of Imod displays reduces blurring when viewing fast-moving video and gaming animation applications. Imod display's response time is 10 to 1000 times faster than competitive LCD technologies.

• **Thinner and lighter** – The lack of a backlight has the potential to significantly reduce the module size and weight, making it especially useful for mobile applications such as cameras, mobile phones, games, PDAs and GPS units.

• **Scalable** – Once Imod displays are perfected for smaller screens, they will be scalable to larger applications such as TVs and outdoor digital signs.

Imod displays benefit from the following industry advantages:

• Little or no retooling to manufacture – Imod displays can be made on existing FPD (flat-panel display) assembly lines using existing materials.

• **Low-risk** adoption into standard mobile systems due to industry-standard interfaces.

• **Qualcomm's commitment** – The company is making the investment necessary to make IMOD technology a successful competitor in the display industry, including a dedicated MEMS Research and Innovation Center in San Jose, California.

• **New market opportunities** – Now that Imod displays have brought instant access, low-power consumption, an intuitive interface and a smaller form factor to the user experience, manufacturers and content developers can create compelling new ways to help users organize their lives, keep up with news and other interests, play games, watch videos, and so on.

IMOD Technology vs. LCD

A mirasol display's relative simplicity, low power usage and outdoor viewing characteristics make it a compelling replacement for LCDs. In the initial stages the mirasol display will compete primarily with monochromatic (MSTN) and color super twisted nematic (CSTN) displays, used in portable devices.

First brought to light in 1968, LCD technology has rapidly gained a foothold in the display market. Continuous improvements to the chemical mixtures and display-drive electronics, as well as optical films, have overcome the initial problems of the STN-based displays, namely low contrast and low resolution. While scientists continue to work on reducing the power requirements and improving the sunlight readability of the STN- and TFT- type LCDs, limitations inherent in the technology are making it difficult to achieve meaningful improvements.

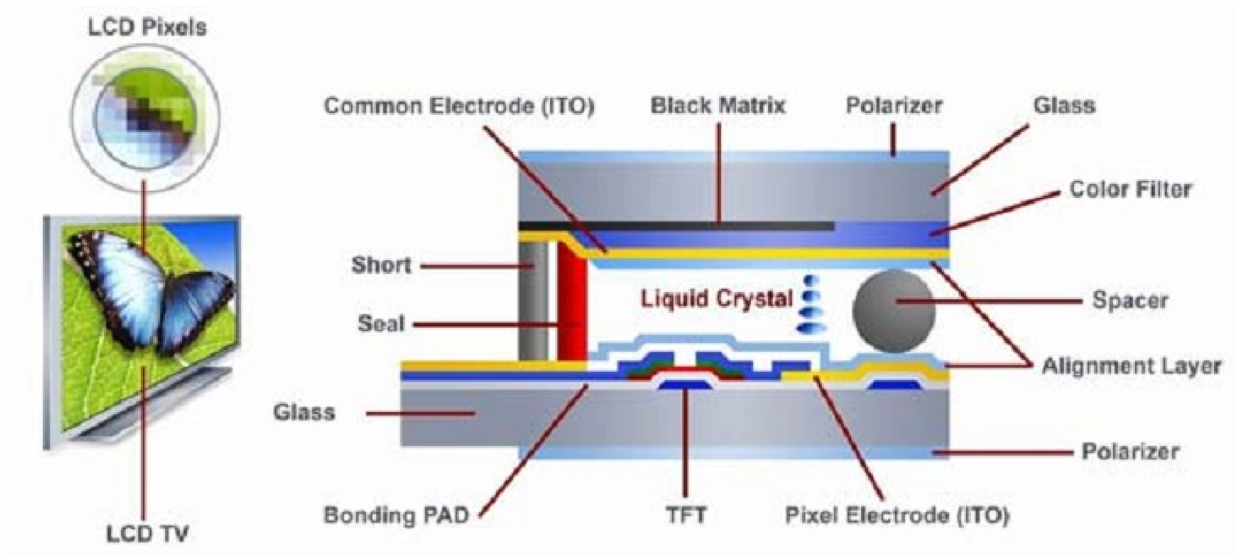


Figure 7. Inner Structure of an LCD Pixel

Figure 7 shows the complexity of an LCD. Note the extensive use of optical films such as polarizers and color filters, as well as the thin film transistor element which itself requires several process steps to fabricate. Since LCDs work with polarized light, the necessity of using a polarizer limits the amount of light that is reflected or transmitted from the display—at least 50% of light is discarded by the polarizer. The additional layers, such as the color filter, reduce light even further—a typical LCD will only transmit six percent of the light it has the potential to use. Consequently, today's LCDs require brighter backlights in order to be readable, whether in total darkness or in the bright sunlight. These brighter backlights lead to greater power consumption. Since a mirasol display operates as a reflective display, powered illumination is only needed when incident light falls below a level that would make reading a newspaper difficult.

Currently, backlighting for LCDs is the single biggest power draw in portable displays. This is especially true in bright environments where the backlight has to be switched to the brightest mode. The fact that mirasol displays do not require extra illumination in these environments gives them a big power-consumption advantage. If supplemental lighting is required, in a dark room for example, mirasol displays would still require only one-half to one-third the power needed by an LCD display.

Given how difficult it is to view a typical transmissive LCD in a sunlit environment, LCD developers have been working diligently on reflective LCDs. Today, there are a number of portable devices using transflective LCDs. The transflective display was invented to improve the performance of the transmissive LCD outdoors, where bright ambient light quickly overpowered the LCD backlight, making the display hard to read. It was also configured to address the shortcomings of a purely reflective LCD in a dark environment. The transflective display employs a reflector that lets some light through from a backlight. Using such an element, the display can be used in the dark where the backlight provides illumination through the partly transmissive reflecting element. In the bright outdoors, the backlight can be switched off to conserve power and the mirrored portion of the reflector allows the LCD to be viewed by making use of the ambient light. Theoretically, the transflective display appears to fix the shortcomings of the purely reflective and transmissive displays. But in reality, this approach is a compromise and offers a rather poor viewing experience.

Qualcomm’s mirasol displays are considerably less complex than LCDs. As described in the previous section, the IMOD element in a mirasol display is bistable and the display can therefore maintain a given image without the need for continuous power. Bistability also leads to a significant amount of power savings when compared to an LCD, which has to be continuously driven as many as 60 times a second in order to prevent the display from losing the image. In addition to the power savings, the mirasol display provides a better viewing experience when compared to the LCD.

Before we define a better viewing experience, we must look at the factors which affect it. A human’s visual perception is strongly related to two elements: luminance and contrast.

Luminance is simply the amount of light reaching the eye. This could include light being emitted or reflected by the display. Contrast is the ratio of the luminance of the bright pixel in a display to the dark pixel. If no light is being emitted from a display, one will not see an image and the contrast ratio will be one. Similarly, if the display is reflecting a lot of light in both the bright and dark state, the contrast ratio will again be poor and the image will again be unreadable.

The problem with LCD displays in bright environments is that the amount of light being transmitted is about the same as the ambient light around it. At the same time, the bright ambient light overpowers the dark pixels, making them appear brighter and reducing the contrast ratio to close to one, thereby making the display unreadable. But in the case of a mirasol display, its pixel is reflective and will reflect all the ambient light when driven to the bright state and in the dark state is able to significantly reduce the reflected light. This provides a contrast ratio very similar to an easily readable black-and-white newspaper—an 8:1 ratio with 60% reflectivity. A mirasol display typically exhibits a contrast ratio of 10:1 with reflectivity on the order of 50%. So while LCDs experience significant viewability issues, a mirasol display’s reflectivity provides an optimum viewing experience for the user.

An additional benefit of the mirasol display is switching speed. If the displayed image is rapidly changing, it is important that the display pixel changes its state from black to white or vice versa on the order of a few milliseconds or faster. If the pixel takes any longer, the human eye will perceive the switch as an effect typically referred to as motion blur. An IMOD pixel in a mirasol display is able to change its state in roughly 10 microseconds, as compared to a STN display pixel which takes roughly 10 milliseconds. The IMOD pixel is approximately 1000 times faster. This translates directly to an improved, sharper-looking image. Qualcomm believes that demand for video applications on portable devices will increase significantly over the next few years. Fast display-response times will be critical for optimum viewability. IMOD technology found in mirasol displays is expected to handle 15 frames per second in the early products and 30 frames per second in the later versions.

Portable devices are subject to environmental extremes that can affect LCDs, which usually operate in the 10- to 30-degree Celsius range and which are limited by changes in viscosity of the liquid-crystal material. Here again, a mirasol display's simplicity gives it an advantage, because it can operate in extremes from minus 30 to plus 70 degrees Celsius. Another advantage mirasol displays have over LCDs are that mirasol displays are impervious to UV exposure.

Additional advantages of mirasol displays compared to current LCD displays include a wider, more symmetric viewing angle, faster video response and a larger operational temperature range

IMOD Technology vs. OLED

Since IMOD components in mirasol displays can be built on a subset of FPD fab lines, the mirasol display's manufacturing costs are expected to ramp quickly downward as volume increases. OLEDs, on the other hand, require completely new fab facilities.

Perhaps the mirasol display's greatest advantage over OLEDs, especially in the battery-powered, small-screen arena is that in order to be visible, the OLED must be powered continuously. OLEDs, then, typically consume around 200mW, compared to 10s of microwatts for mirasol displays without supplemental lighting (display in hold state showing static image).

OLEDs offer several advantages over LCDs. However, the technology has not gained a major foothold for several reasons. The cons will be discussed on the next page while the pros will be reviewed here. The basic OLED cell structure is comprised of a stack of thin organic layers that are sandwiched between a transparent anode and a metallic cathode. When a current passes between the cathode and anode, the organic compounds emit light (see Figure 8.) The obvious advantage is that OLEDs are like tiny light bulbs, so they don't need a backlight or any other external light source. They're less than one-third the bulk of a typical color LCD and about half

the thickness of most black-and-white LCDs. The viewing angle is also wider, about 160 degrees. OLEDs also switch faster than LCD elements, producing a smoother animation. Once initial investments in new facilities are recouped, OLEDs can potentially compete at an equal or lower cost than incumbent LCDs.

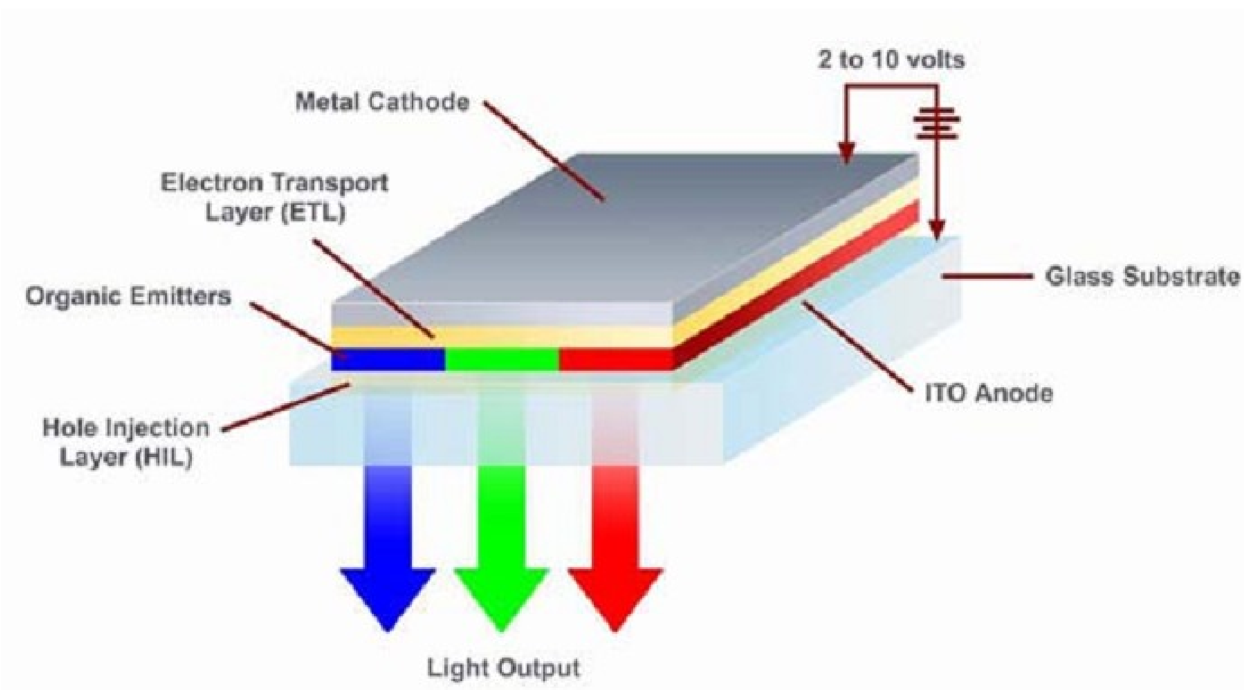
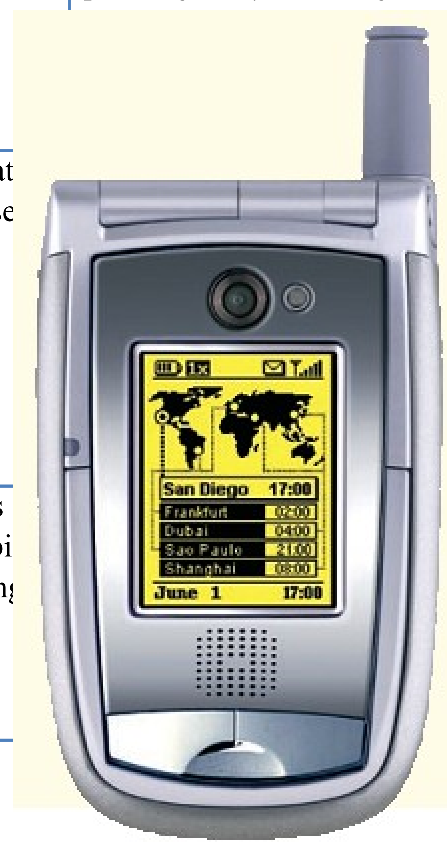


Figure Structure of an OLED Pixel

Despite these advantages, OLEDs have experienced slow acceptance in the industry for a variety of reasons. First, they have a relatively short lifespan and as power/brightness is increased the life is reduced dramatically. This is especially true for the blues, which lose their color balance over time. Low manufacturing yields have also been a problem, keeping the cost of production relatively high. As OLEDs are susceptible to water and oxygen contamination, during manufacturing they need to be encapsulated and sealed against the elements adding significant cost and complexity. In addition, only low resolution OLED displays can use passive matrix backplanes and higher resolutions require active matrices, which need to be highly conductive since OLEDs are current driven. Typically, low temperature poly silicon (LTPS) backplanes are used which adds cost and complexity. These conductors are also highly reflective requiring the

OLED designers to add a circular polarizer on the front of the display reducing the efficiency of the display and increasing the cost. Finally, as is the case with all emissive displays, OLED displays have poor readability in environments such as the bright outdoors.

DISPLAY TECHNOLOGY	ADVANTAGES	DISADVANTAGES
LCD	Inexpensive, widely available, technically simple	High power consumption, poor legibility in sunlight, low ... re ... ng
OLED	Should be inexpensive after fabricat... plants are built, rapid electrical response...	...n, ...nt, ...n, ...nd ...n,
IMOD	Inexpensive, low power usage, always ... rapid electrical response, good readabi... in bright sunlight, wide viewing an... technically simple	...y, ...or



BENEFITS

THE iMoD DISPLAY DIFFERENCE

The Next Generation of Displays

QUALCOMM iMoD technology takes flat-panel mobile displays to a new level—one that today's display technologies cannot match. Our iMoD technology enables an Always-On user experience by combining thin film optics and MEMS structures to create an Always-On display. The extremely low power, high-quality displays are compatible with existing hardware and software architectures, yet deliver ultimate flexibility to designers in image quality and power consumption.

Significant Power Savings

An iMoD display's bistable nature requires very little power, making it much more efficient than LCD technology. An iMoD display's bright reflectivity means it uses ambient light sources. Only in dark environments does it need supplemental lighting—unlike LCD technologies, in which supplemental lighting is the largest consumer of power.

A Display for All Conditions

With their unique reflective light interference quality, iMoD displays achieve a new level of usability that matches that of an age-old display: the printed page.As clear as an image on paper, iMoD displays can be viewed in any lighting condition —including direct sunlight. Two to three times as bright as competitive state-of-the-art technologies, iMoD displays minimize eye strain, and their wide viewing cones are free of the inversion effects that plague polarization-based displays.

True-to-Life Image Quality

An iMoD display's brightness and contrast result in a superior viewing experience for the user. QUALCOMM displays enable saturated colors and high-resolution imagery. Plus, their fast response makes them ideal for artifact-free video and gaming applications.

Robust Functionality—Enhanced Durability

Mechanical structures made from inorganic materials, iMoD displays are more resistant to environmental factors—including UV rays and temperature extremes that diminish the performance of LCDs and other liquid-based displays.

Industry Compatibility

iMoD technology is a fundamentally new approach to displays, but its manufacture is based on that of LCDs. From tools, processes, materials and components to integration into finished modules, iMoD display production is compatible with the current LCD infrastructure. By using existing plants and equipment, QUALCOMM minimizes the time needed to bring iMoD technology to the mass market.

Easy Integration—Low Risk Adoption

QUALCOMM display products are designed to conform to industry standards, ensuring iMoD modules will need no special technological requirements to easily integrate into standard mobile systems.

An iMoD Display's Electrical Interface Features:

- Standard Industry Module Interfaces
  - Serial (SPI, I2C)
  - Parallel (8080 type)
- Standard power supplies supported

Adopting this revolutionary new technology entails minimal risk and effort— making it easy and safe from a business perspective to offer customers a superior viewing experience.

Additional Key Attributes

Speed

Since visible light wavelengths operate on the nanometer scale (i.e., 380nm to 780nm), the deformable IMOD membrane only has to move a short distance—a few hundred nanometers—in order to switch between two colors. This switching happens extremely fast, on the order of tens of microseconds. This switching speed directly translates to a video rate-capable display with no motion-blur effects. Traditional STN- or cholesteric-based passive matrix displays have switching speeds as slow as tens or hundreds of milliseconds. An IMOD element's switching time is 1000 times faster than traditional displays. In addition, switching speed of IMOD displays is maintained across a wide temperature range, unlike organic liquid-crystal-based displays, whose switching speeds decrease as temperatures go into low environmental ranges.

Readability

Humans view the world by sensing the light reflecting from various surfaces. As a result, a reflected image from a newspaper is more appealing and easier to view for the human eye, compared to a backlit image. Based on human perception, there are two critical factors which determine readability: luminance and contrast.

Luminance is the amount of light that reaches the human eye. In the case of a reflective display, it is the amount of ambient light that is reflected from the display, rather than absorbed. The key metric is the reflectivity of the display's white state, which is measured by comparing it to the reflectivity of a standard white source. A white sheet of paper measures between 70 and 90 percent reflectivity, and a newspaper measures on the order of 60 percent reflectivity.

Contrast is the ratio of the display's white state reflectivity to its dark state. This metric dictates whether or not the human eye will be able to perceive transitions between the dark and light areas on the display, which translates to spatial detail. If the contrast is too low, the display will appear washed out and the user will have difficulty perceiving image details. A high contrast ratio makes the image look sharper and improves readability. For reference, a newspaper has a contrast ratio of approximately 4:1.

Comparing the readability of reflective displays to that of emissive displays, it is clear that emissive displays work well at low ambient light levels. The problem with these displays, however, is when ambient light levels increase from room lighting to levels found outdoors on a sunny day, making it difficult for the user to discern spatial detail as shown in Figure 5. This is illustrated by the fact that a user must typically shield their portable-device screen when they are outdoors in bright sunlight. Two factors account for this: first, the increase in light that is reflected from the device pixel in the black state and second, the ambient light exceeding the light levels being emitted from the display. Both of these factors reduce the display's contrast.

Ease of Manufacture

The MEMS elements that constitute an IMOD display have been designed for ease of manufacture. IMOD displays are produced using a process known as surface micro- machining, which is derived from the wafer scale roots of MEMS fabrication. The name refers to the idea of building all of the structure and components of the MEMS device on the surface of the underlying substrate. In the case of IMOD displays, these comprise an array of deposited metal and metal-oxide films which are lithographically patterned to produce a microscopic planar structure. The result is a monolithic electro-optic display which requires fewer process steps to build than the TFT array in a LCD.

The overarching manufacturing benefit of IMOD display production is that the process was engineered to utilize infrastructure already in place in FPD fabs. All of the materials used for IMOD display fabrication currently exist within the FPD palette and, in most cases, substitute materials may be utilized. The end result is a flexible and robust process that enables conversion, with minimal modification, of many FPD fabs into IMOD display foundries, minimizing the time needed to bring IMOD technology to market.

Robustness

The biggest problem with LCD lifetime is the use of organic materials. Both the liquid-crystal material and the alignment material are organic and, as a result, break down over time when exposed to high temperature and light (both artificial and sunlight.) By relying on inorganic materials, IMOD displays are capable of performing over an extended temperature range and at the same time are impervious to high-intensity visible and UV radiation. Additionally, even when exposed to extreme temperatures, an IMOD display's response times are unaffected, and the impact on drive voltages and image content is minimal.

Mechanically, the IMOD element is extremely robust. IMOD displays have demonstrated reliability over 12 billion cycles.

Industry Compatibility

QUALCOMM display products are designed to conform to industry standards, enabling IMOD modules to be "plug-and-play" compatible with standard mobile systems. The IMOD module offers standard industry interfaces, and standard power supplies. This use of industry standards ensures that there is minimal risk to adopting this powerful new technology ensures that there is minimal risk to adopting this powerful new technology will allow for vastly improvedperformance and highly differentiated products to end users.

Sunlight Viewability – The Ultimate Measure of a Display

The mirasol display's remarkable abilities to conserve energy, enable new applications, provide freedom to industrial designers, and enhance revenue streams compliment the display's fundamental ability to be viewed in direct sunlight, indeed to be consistently viewed in almost any environment, without degradation of contrast ratio or color depth.

Emissive displays generate their own illumination, yet the available light output consistently obscures in the face of modest room lighting and is significantly degraded in bright office lighting. Worse, emissive displays become washed out in diffuse sunlight, and are often overpowered in direct sunlight. Consequently, the viewing quality of emissive displays deteriorates to the same extent that the display light emission is washed out.

It should be noted that in very dark environments all displays (including newsprint) will need supplemental lighting, and the mirasol display, because of its high reflectivity, utilizes a very low power front light in extremely dim conditions.

Figure 8 clearly illustrates the consistent viewing quality that would be available from a mirasol display versus the viewing quality expected from a TFTLCD. The results are qualitatively clear to the viewer, but they can be expressed quantitatively by the decreasing JND count indicated below the TFTLCD images and the constant JND count indicated below the mirasol display images.

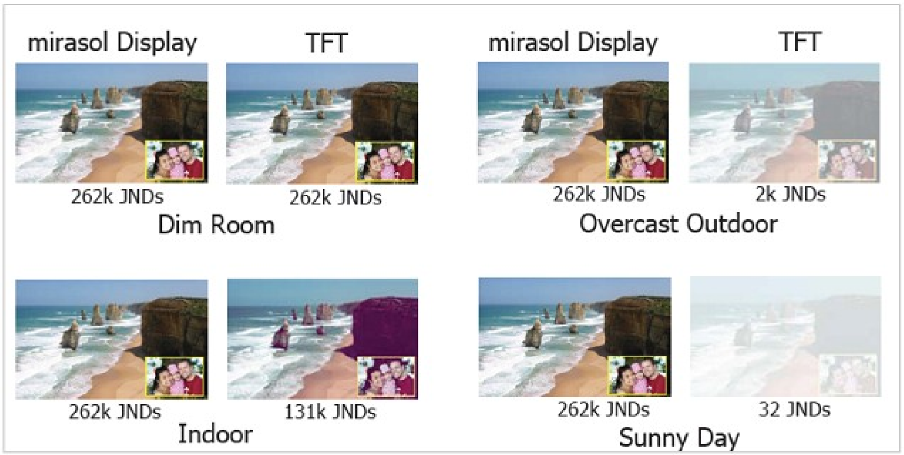


Figure 8: Consistent viewing quality of mirasol display (real world)

JND, or "just noticeable difference", is a recognized method of expressing the number of separately discernable image levels available to the viewer. One can associate the ability to discern small levels of difference in an image with perceiving the image as having high quality. Conversely, a decrease in JND count represents a decrease in the quality level of the viewed image.

Conclusion

Qualcomm's experience in the mobile phone industry, in addition to consumer research, has shown us that consumers will continue to demand and quickly adopt mobile products with an Always-On display, smooth video response, sunlight viewability and extended battery life. Qualcomm's mirasol display will not only replace existing technologies, it will transform the industry by changing user expectations and behavior. Its distinct advantages over LCDs, transmissive technologies and OLEDs emissive technologies, coupled with Qualcomm's commitment to be a major player in portable displays, makes the mirasol display a serious contender in the display space.

For manufacturers of displays and products that use them, mirasol displays present an attractive, low-risk alternative to advanced LCD, OLED and EPD display technologies. Because mirasol displays conform to interconnect standards for most of today's small-display applications, it can be designed efficiently into future products.

The Future

QUALCOMM is aggressively moving forward with the development and commercialization of iMoD technology—including opening a state-of-the-art MEMS Research and Innovation Center in San Jose, California. Currently in development for applications such as wireless phones, GPS units and industrial devices, QUALCOMM's iMoD technology opens up a new world of display innovations and opportunities for exploration.

Potential Applications:

- Gaming devices
- MP3 players
- Laptop and desktop monitors
- Digital TV and DVD player screens
- Medical imaging
- Automotive navigation
- Outdoor TVs
- Outdoor signage
- Digital camera and camcorder screens

Future Capabilities:

- Enhanced image quality
- Increased resolution
- Flexible substrates
- Complete system component integration
- Custom shapes

Summary

The discussion above has illustrated the simple and elegant construction and operation of the mirasol display. The mirasol display is energy efficient, provides greatly extended battery life in handset usage models, and dramatically increases the features available to users, the design space available to developers, and the revenue streams available to operators. Bright, reflective iridescent colors are provided without the use of liquids, polarizers, organics, or semiconductor materials. The lack of these optical enhancers combines with the reflective nature of the display to offer consistent viewing quality across all environments, including bright sunlight.

Additionally, the consistent viewing quality facilitated by the inherent mirasol display design provides a significant advantage to consumers who desire to use their cellular phones anywhere, anytime, and under any viewing conditions. Indeed, the capability of reflective mirasol displays is such that current display metrics cannot adequately convey the value of the viewing experience, and the display industry and technical community are working to introduce to the marketplace new measurement metrics that will enable consumers to easily and appropriately evaluate display view ability.