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Improving Notebook and Tablet Displays

Fujitsu Computer Systems

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THE POSSIBILITIES ARE INFINITE

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Introduction

Today, notebook computers are being used in an increasing number of applications. Consumer oriented models now sport displays up to 17.1" wide and feature TV tuners and DVD writers. Many of these models offer performance rivaling high-end desktop systems and are increasingly being used to play computer games featuring complex 3-D graphics. In commercial applications, especially those involving ultraportable notebooks and Tablet PCs, there are requirements for displays that are viewable in a variety of ambient light environments and have wide viewing angles. This paper will discuss the technologies necessary to meet the demands of these applications and what Fujitsu is doing to meet the varied display requirements of its customers.

Crystal View

Early in 2003, Fujitsu began introducing consumer notebooks into the Japanese retail channel with LCDs that looked dramatically different than the displays people were used to seeing on notebooks. These displays looked more like flat screen CRTs than typical notebook LCDs and had an image clarity that really caught people's attention. These new displays proved to be an instant success and had a dramatic effect on the consumer notebook market first in Japan and then all over the world. So what was it about these displays that made them so special?

A Little Background (the technical part)

We all remember from school that the speed of light in a vacuum is a constant, the "C" in $E=MC^2$. This constant speed is actually 299,792,458 m/s. However, when light is traveling in something other than a vacuum, i.e., air, water, or glass, its speed is not constant; it changes depending on the medium through which it is traveling. For example, when light transitions from traveling in air to traveling in water, it slows down. That causes it to bend or refract. We have all seen this as children when we poked a stick in the water and it looked like it was bent. Of course the stick was not bent, but the light reflecting off the part of the stick that was under the water was bent when it transitioned from water to air on its way to our eyes. You can also think of this in terms of resistance; water has a greater resistance to the passage of light, therefore light travels slower in water than air. Engineers have calculated a number for many materials (called the Refractive Index) which can be used to determine the speed of light through these materials. Here are some sample indices:

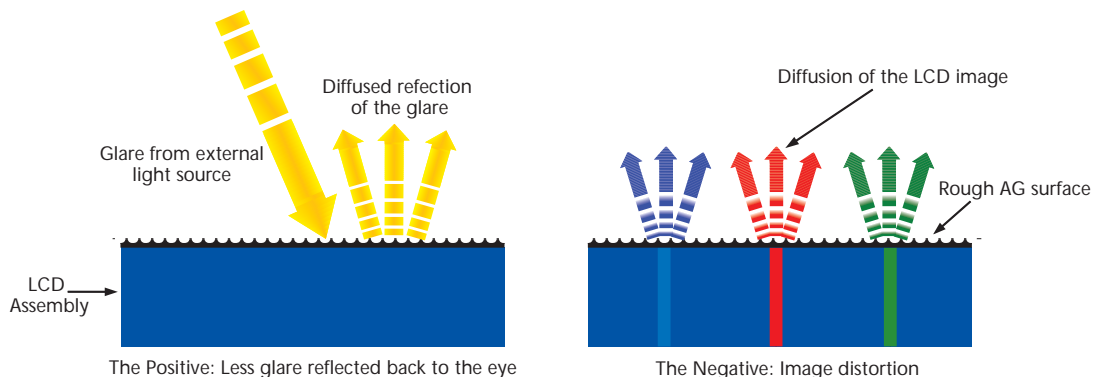| MATERIAL	Index		MATERIAL	Index
Vacuum	1.00000 (exactly)		Polystyrene	1.55
Air (STP)	1.00029		Emerald	1.57
Liquid Carbon Dioxide	1.20		Light Flint Glass	1.575
Ice	1.309		Quartz	1.644
Water (20° C)	1.333		Ruby	1.77
Ethyl Alcohol	1.36		Sapphire	1.77
Sugar Solution (30%)	1.38		Crystal	2.00
Fused Quartz	1.46		Diamond	2.417
Glass	1.5		Iodine Crystal	3.34
Sodium Chloride (Salt)	1.544			

To calculate the speed through any of these materials, simply divide the speed of light in a vacuum (299,792,458 m/s) by the refractive index of that material. When light transitions between materials with different refractive indices you have a condition referred to a "refractive index mismatch." This mismatch creates excessive glare and reflection.

I am sure at this point you are wondering what any of this may have to do with a shiny LCD, but hang in there, you will soon find out.

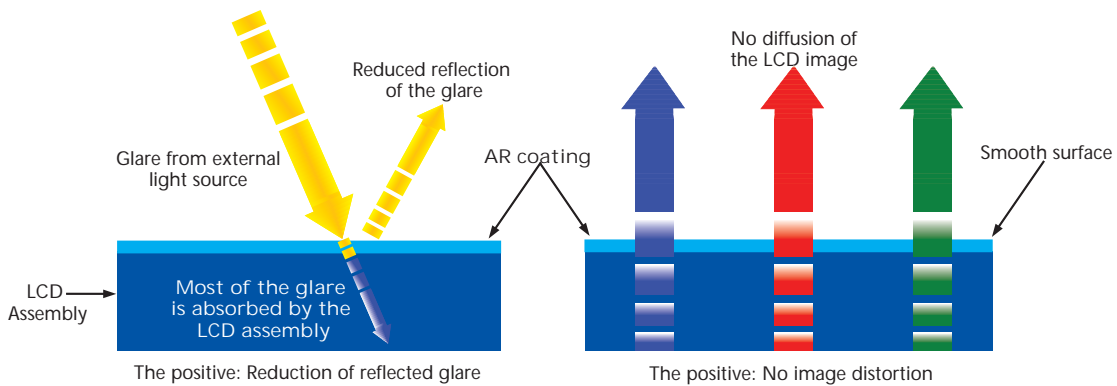## The Difference between a Standard LCD and a Crystal View LCD

Most LCDs have an anti-glare (AG) treatment on their top surface to diffuse the glare from external lighting sources. This is also true of some older CRT monitors. This treatment consists of laminating a matte (rough) surface layer to the LCD. When glare hits this rough surface it bounces off at different angles so that only a small portion of the reflected glare hits your eyes. This is similar to a photograph with a matte finish. Unfortunately this treatment also distorts the image.

Standard LCD with AG Surface Treatment

Diffused refection of the glare

Glare from external light source

LCD Assembly

The Positive: Less glare reflected back to the eye

Diffusion of the LCD image

Rough AG surface

The Negative: Image distortion

A Fujitsu Crystal View LCD does not have a rough AG surface. Instead, it has a coating of an anti-reflective (AR) chemical that actually reduces reflected glare by lowering the Refractive Index of the glass surface of the LCD to a number closer to that of air. This process is known as "index matching". This greatly reduces the refraction of the light as it hits the surface of the LCD. Also, because the surface of a Crystal View LCD is smooth, the image is crystal clear rather than distorted.

LCD with Crystal View Treatment

Reduced reflection of the glare

No diffusion of the LCD image

Glare from external light source

AR coating

Smooth surface

LCD Assembly

Most of the glare is absorbed by the LCD assembly

The positive: Reduction of reflected glare

The positive: No image distortion

LCDs with Wide Viewing Angles

In a number of applications in both the consumer and commercial markets, customers have requirements for notebooks/tablets with displays that need to be seen by more than one person at a time. To meet this demand, Fujitsu has introduced a number of mobile systems with displays supporting wide viewing angles. For our purposes, viewing angle is defined as the number of degrees measured from a line perpendicular to the plane of the display in which the display is readable. This is usually defined as the angle at which the contrast ratio is greater than 10:1. So what is contrast ratio? In terms of LCD technology, it is the measurement of the difference in light intensity between the brightest white pixel and the darkest black pixel.

Perpendicular axis

Total viewing angle = 120°

CR>10

60°   60°

CR<10

LCD surface

Bright white pixel

Dark black pixel
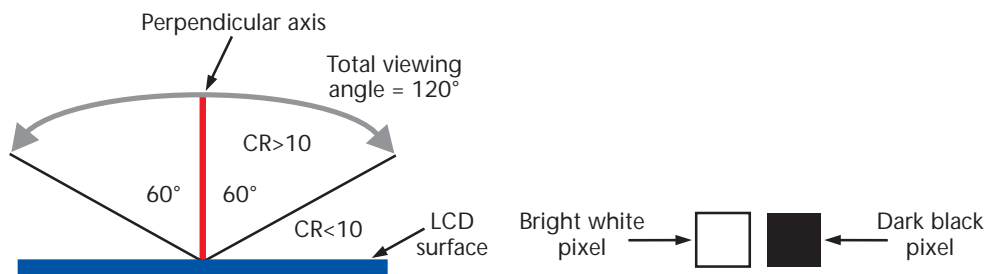
How to make an LCD with a wide viewing angle

1. Start off with an LCD technology that naturally produces a wide viewing angle:
   • Multi-domain Vertical Alignment (Fujitsu)
   • In-Plane Switching (Hitachi/NEC)
   • Fringe Field Switching (BOEHydis)
   • Patterned Vertical Alignment (Samsung)
   • Advanced Super View (Sharp)

2. Add compensation films to a standard technology (Twisted Nematic) LCD

What follows is an article written by Udo Schroeder for Tom's Hardware Guide in June of 1999, so it is a little out of date (some of these technologies did not exist then, but they are really just variants of the existing technologies), but it still serves as a good primer on the different thin-film transistor (TFT) technologies. **Note:** In the illustrations, "on" and "off" refer to voltage being applied to a particular pixel. A pixel acts like a shutter. When it is open, light passes through (white); when it is closed, no light passes through (black). For some technologies, the pixels are naturally open and require the application of voltage to close them. For other technologies, the pixels are naturally closed and require the application of voltage to open them.

TFT Guide - Part 2 - Viewing Angle Technologies

TFT flat panel displays have two decisive disadvantages when you compare them with conventional cathode ray tube monitors:

(1) When you view a TFT display from the side, you will quickly notice a dramatic loss of screen brightness and a characteristic change of displayed colors. Older flat panel displays typically have a viewing angle of 90 degrees, i.e. 45 degrees to each side. As long as there is only one viewer this isn't a problem. As soon as you invite a second viewer, for example a customer you want to show something to, or an additional player for an action game at home - then you won't have to wait too long to hear a complaint about bad display quality.

(2) Quick scene changes, which are commonplace for video playback and games, demand performance that is just too much for today's slow liquid crystals. Slow response times result in distorted or streaked images. Classic examples of streak distortion can be seen when a stock exchange ticker is displayed, or when a jet fighter flies through a valley in an action game.

The flat panel manufacturers are not resting on their laurels and have recently introduced the first models with improved technology to the market. The most important technologies available are TN+Film, IPS (or 'Super-TFT') and MVA, all of which are explained in the following sections of this article.
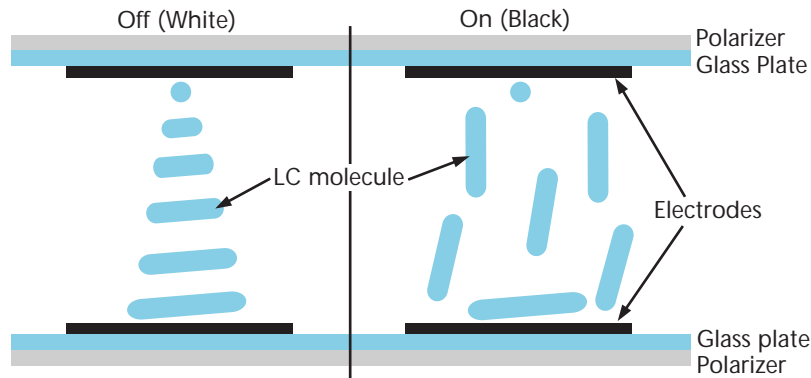
TN+Film

Figure 1: TN+Film displays align their liquid crystals perpendicular to the substrate, in the same way as standard TFTs do. A film on the upper surface increases the viewing angle.

From a technical point of view, the TN+Film solution is the simplest to implement. The flat panel manufacturers use the relatively old standard TFT (Twisted Nematic) technique. A special film (retardation or discotic film) is applied to the top surface of the panel which improves the horizontal viewing angle through the film from about 90 degrees to approximately 140 degrees. However, the poor contrast ratio and the slow response time remain unchanged. The TN+Film method isn't the best solution but it is definitely the most inexpensive as the manufacturing yield is relatively high (virtually identical to that of standard TN displays).
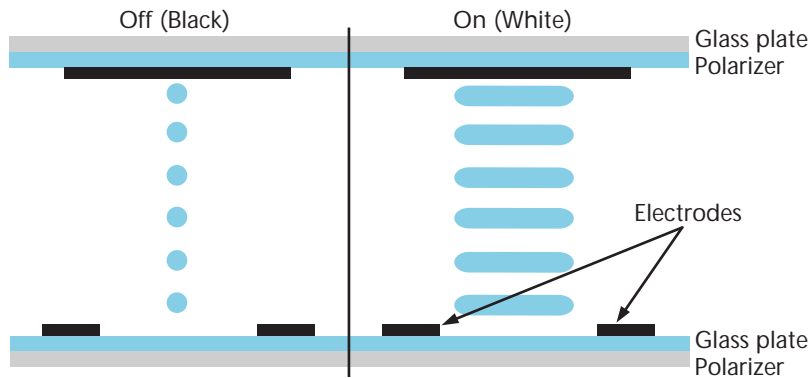
IPS (In-Plane Switching Or Super-TFT)

Figure 2: When a voltage is applied, the molecules are aligned parallel to the substrate.

IPS or 'In-Plane Switching' was originally developed by Hitachi, however NEC and Nokia now also produce displays that use this technology.

The difference to the twisted nematic displays (TN or TN+Film) is that the molecules of the liquid crystal are aligned parallel to the substrate.

Excellent viewing angles up to 170 degrees, such as are known from cathode ray tubes, are attained using IPS or Super-TFT technology. However, the technology also has a disadvantage: due to the parallel alignment of the liquid crystals, the electrodes may not be located on both glass surfaces as with twisted nematic displays. Instead, they must be implemented in a comb-like style on the lower glass surface. This ultimately leads to a reduction of contrast and therefore a stronger backlight is required in order to raise the brightness to the required level again. The response time and contrast are hardly improved in comparison with conventional TFTs.

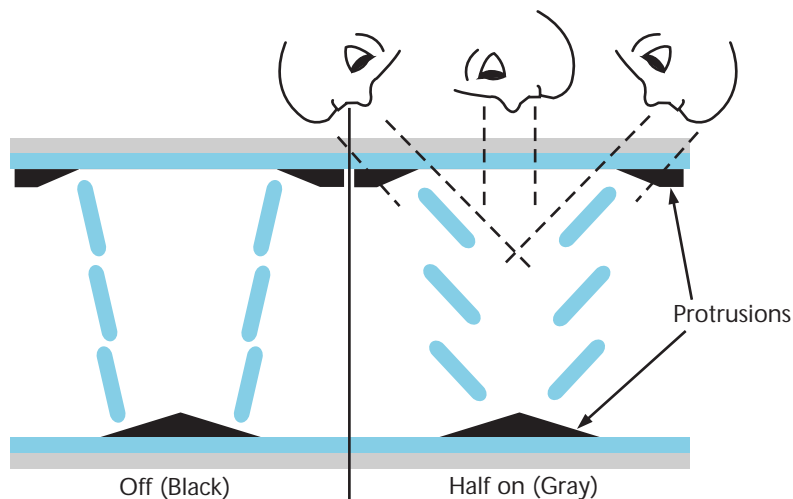## MVA (Multi-Domain Vertical Alignment)

Figure 3: MVA by Fujitsu. From a technical point of view, the best compromise for wide viewing angles and short response times.

In our opinion, Fujitsu has found an ideal compromise. MVA attains viewing angles up to 160 degrees - i.e. still very good - as well as offering high contrast ratios and short response times.

How does MVA work? The letter **M** in MVA stands for 'multi-domains'. These are areas in a color cell. Figure 3 shows multi-domains that are formed by the use of protrusions. Fujitsu currently manufactures panels whose individual cells have up to four such domains.

VA stands for 'vertical alignment' and is a term which is somewhat misleading because the LC molecules (in their static state) are not completely vertically aligned due to the protrusions (see above, Off, i.e. black state). When an electrical field is created by applying a voltage, the

crystals are horizontally aligned and the back light can then pass through the various layers. MVA offers faster response times than IPS and TN+Film technologies which is an important factor for video and game performance. The contrast is generally better, however this can vary somewhat depending on the viewing angle.

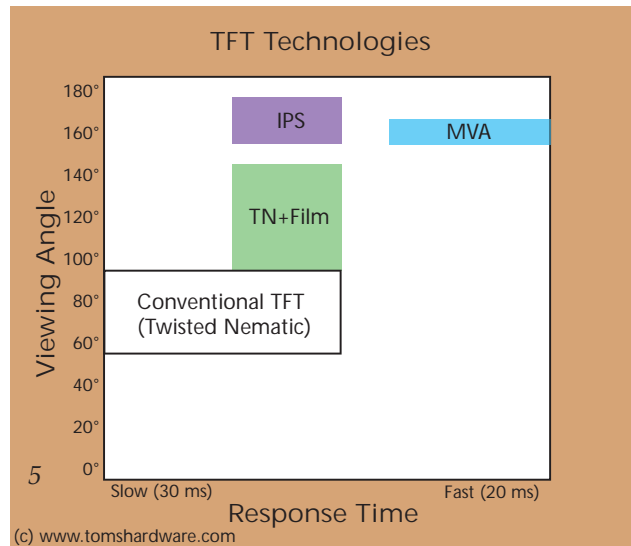# Evaluating Different Viewing Angle Technologies

Figure 4: MVA offers faster response times and very good viewing angles, however, the market share of Fujitsu technology is still quite small.

The **TN+Film** solution does not result in notable improvements in the response time. Having said this, these systems are low-cost, have a high production yield and improve the viewing angle to acceptable values. The market share of these displays will fall back in the long term.

IPS can already claim a high share of the market as there are a number of manufacturers, e.g., Hitachi and NEC, that have backed this technology. Decisive factors for the success of these displays are the high viewing angle up to 170 degrees and the acceptable response times.

From a technical point of view, MVA is the best solution. Viewing angles up to 160 degrees are almost as good as cathode ray tube monitors. The response times of approximately 20 milliseconds are also suitable for video playback. The market share of these displays is still very small but growing[1].

[1]Udo Schroeder, Tom's Hardware Guide, June 1999

Improving Tablet PC Displays

Tablet PCs have special display challenges. First, they are often used in applications where the lighting environment makes viewing an LCD difficult. Second, the shield that sits in front the LCD, to protect it from the Tablet PC stylus, greatly increases glare and reflection while reducing the light coming from the LCD. There are basically two steps a vendor can take to optimize the display of a Tablet PC.

1. Start out with a bright LCD with an excellent viewing angle. Fujitsu uses an LCD with a luminosity (brightness) rating of 180 candela/m2, usually referred to as "nits" and a viewing angle that exceeds 160°.

2. Minimize the optical interference of the LCD shield.

The biggest cause of this optical interference from the LCD shield is the creation of an air gap between the shield and the surface of the LCD. This air gap creates three different refractive index mismatches, which significantly increase glare and decrease transmissivity. See the illustration below.
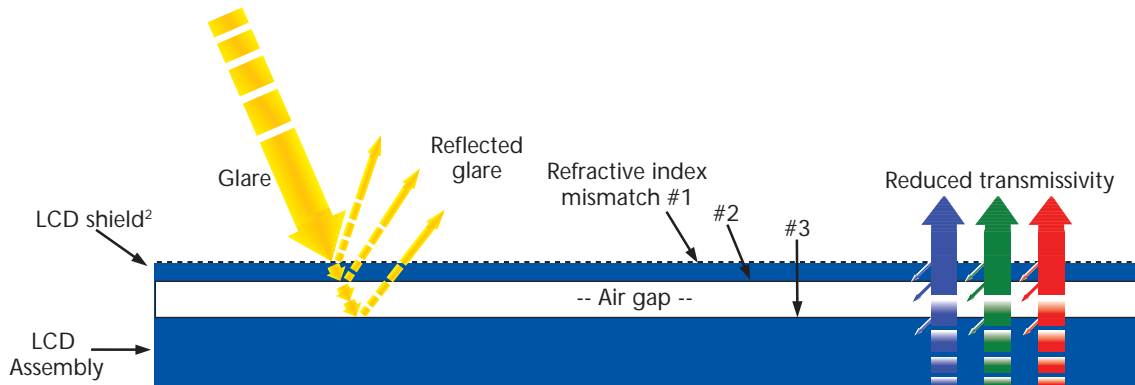

There are essentially three ways you can deal with this problem. The first is to completely eliminate the LCD shield altogether. This can be done if the top surface of the LCD can be made hard enough to withstand the constant tapping and scratching of the stylus. Thus far, no LCD manufacturer had developed an upper polarizer hard enough to meet this requirement. Additionally, even if the upper polarizer were made hard enough to withstand the day-to-day wear and tear of the stylus, if it were to be damaged the entire LCD would have to be replaced, a very expensive proposition.

The second method is to bond the LCD shield directly to the LCD using an index-matching adhesive, either epoxy or silicone. While this technology is commercially available, it is labor intensive and therefore expensive. It also has the same LCD replacement issue as the first method. Because the shield is now permanently bonded to the LCD, if it becomes damaged, the entire assembly (including the LCD) must be replaced.

[2]The upper surface of the LCD shield has a roughened anti-glare (AG) surface to provide friction to the stylus point so that the user gets the proper tactile feedback for accurate digital inking and handwriting recognition.

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The third, and best, method is to coat the three surfaces that are exposed to air with an anti-reflective (AR) chemical (similar to the Crystal View treatment described on Page 3). This does not eliminate the air gap but neutralizes its negative effect. It is also cheaper to implement without LCD replacement should the LCD shield need replacing.
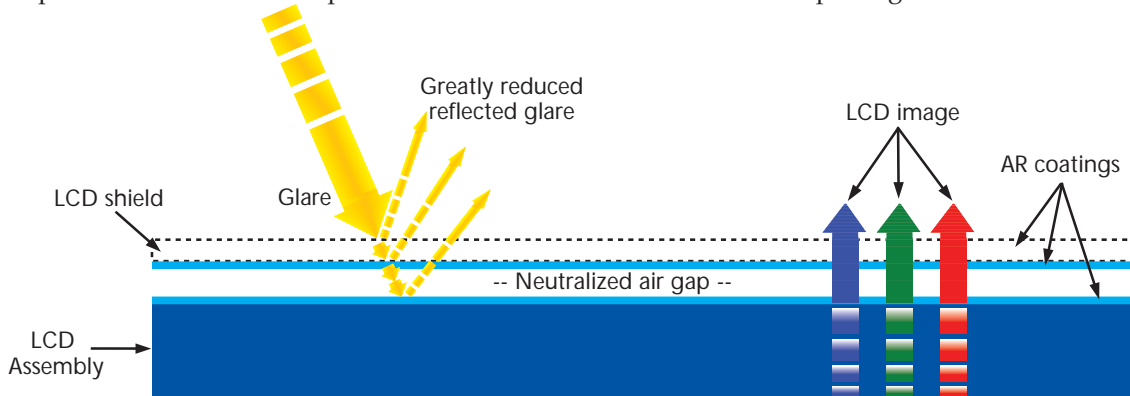

The process described on this page will be offered as an option on both the Fujitsu Stylistic® ST5000 Tablet PC and the LifeBook® T4000 Tablet PC.

A True Outdoor Display

While the Tablet PC display enhancement described earlier will significantly improve the viewability of Tablet PCs in almost any lighting situation, sometimes there is no substitute for a true outdoor display system. To understand the difference between an LCD designed for outdoor usage and a standard (indoor) LCD you have to understand how LCDs are lit.

LCD Lighting Technologies

All LCDs work by projecting light through a layer of liquid crystals which are electronically manipulated to act like a matrix of little shutters called pixels. This light source does not have to be behind the liquid crystal layer. It can be behind it, in front of it, or both. By far, the most popular lighting method is transmissive or backlit. These LCDs use a cold-cathode fluorescent tube with a diffuser or an array of LEDs to light the LCD from behind. Transmissive technology works best in indoor or dim ambient light conditions. It does not work well in bright sunlight. The vast majority of notebooks use transmissive technology, including all Fujitsu LifeBook notebooks.

A Transmissive LCD Assembly

9
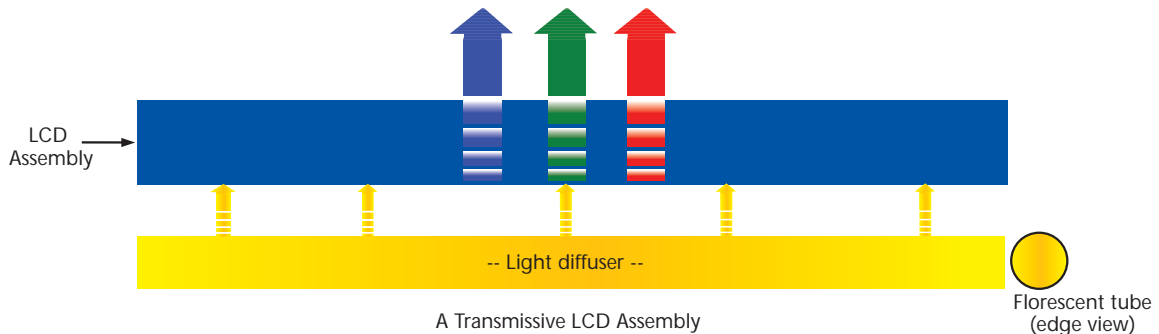
The Reflective LCD

The problem with using a transmissive LCD in bright sunlight is that you are trying to compete with the incredible brightness of the sun with a fluorescent light running on batteries. A reflective LCD, on the other hand, replaces the backlight assembly with a mirror and uses the sun's own light for the LCD, therefore, the brighter the sun, the brighter the display.

A Reflective LCD Assembly
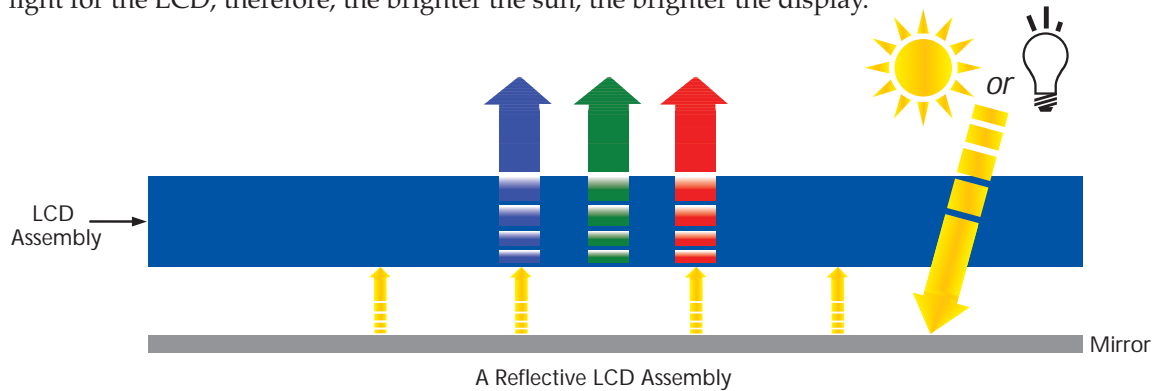
The main drawback of the reflective design is that it is totally dependent on the amount of ambient light available for its brightness. Indoors or at night, it can become totally unusable. Another drawback of the reflective design is that -compared to the transmissive technology - it has a very low contrast ratio. As noted earlier, contrast ratio, is the measurement of the difference in light intensity between the brightest white pixel and the darkest black pixel. Transmissive LCDs generally have contrast ratios between 200:1 and 600:1. Reflective LCDs generally have contrast ratios of about 10:1. Why the huge difference? Remember when we talked about pixels as being little light shutters. A shutter that is fully open will be very bright and one that is fully closed will be dark. Actually, each pixel is composed of three sub-pixels (sub-shutters), one each for the colors: red, green, and blue. As well as being fully open or closed, each sub-pixel can be partially open or closed, usually 64 gradations, allowing the LCD to display 262,144 colors. Because a reflective LCD must get its light from the outside, it can never fully close its shutters. Closed shutters do not let light in. Shutters that are partially open let light in but also let light out. Therefore, the pixels that are supposed to black (closed) can never be completely black, so the difference between the brightest white pixel and the darkest black pixel will be much reduced.

The Reflective LCD with Front Light

As you might guess, this technology is similar to the reflective LCD but adds a front light assembly to supplement the available ambient light.

Transparent light diffuser
Florescent tube (edge view)
LCD Assembly
Mirror
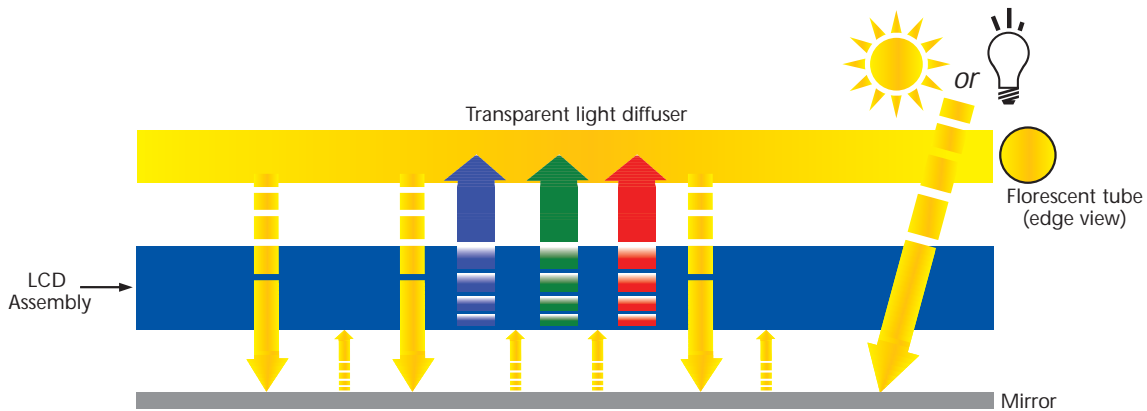
The addition of a front light makes a reflective LCD usable in all lighting situations; however the issue of a low contrast ratio still remains. The Fujitsu Stylistic ST5021 Tablet PC uses this technology. The LCD in this model is designed and manufactured by Fujitsu. It is generally considered to be the best implementation of this technology available today.

The Transflective LCD

This technology is a combination of transmissive and reflective technologies, "transmissive" in that it incorporates a backlight and "reflective" because it also has a mirror. In this case, the mirror is perforated to allow the light from the backlight to shine though.

LCD Assembly
Fluorescent tube (edge view)
Perforated mirror
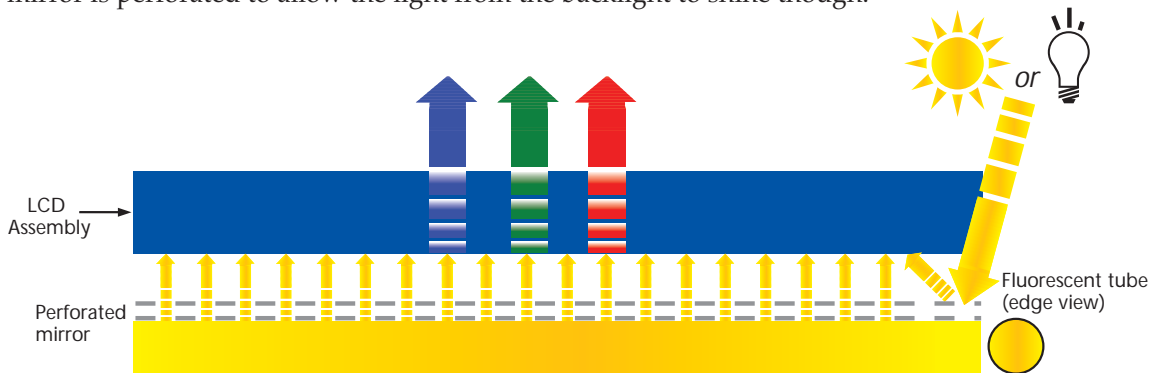
In terms of performance and appropriate use, a transflective LCD is similar to a reflective LCD. They both work very well outdoors in bright sunlight but both have low contrast ratios. Transflective LCD technology is most commonly used in Pocket PCs.

From these descriptions, it should be apparent that there is no one LCD lighting technology that is ideal for all situations. Our goal at Fujitsu is to offer a choice of LCD options to allow you to select the technology that best cmeets your needs.

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Summary

We hope you have found this paper useful in gaining a *basic* understanding of the various display technologies Fujitsu is utilizing in its notebook and tablet products. It is certainly not intended to be an all-inclusive or highly technical document on LCD technology. If you are interested in basic nuts and bolts information on LCD technology, please refer to these articles on the Web:

http://www.pctechguide.com/07panels_LCDs.htm

http://graphics.tomshardware.com/display/19990624/tft1-09.html

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