

Fundamentals of Liquid Crystal Displays – How They Work and What They Do

W H I T E P A P E R

Liquid crystal display technology has enjoyed significant advances in just a few short years. The quality of LCD panels has improved dramatically while at the same time costs have gradually come down. LCDs are now found in products as small as mobile phones and as large as 42-inch flat panel screens.

This white paper identifies the major types of LCDs, describes the technology in detail, shows how it works, and identifies major LCD applications as well as leading global suppliers. The paper also defines and describes Organic Light Emitting Diodes (OLEDs), which represent a powerful new trend. Finally, the paper includes a description of how LCDs are integrated into two important products from Fujitsu: Graphics Display Controllers for vehicles and mobile media processors for consumer electronic devices.

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Fundamentals of Liquid Crystal Displays

The term liquid crystal is used to describe a substance in a state between liquid and solid but which exhibits the properties of both. Molecules in liquid crystals tend to arrange themselves until they all point in the same specific direction.

This arrangement of molecules enables the medium to flow as a liquid. Depending on the temperature and particular nature of a substance, liquid crystals can exist in one of several distinct phases. Liquid crystals in a nematic phase, in which there is no spatial ordering of the molecules, for example, are used in LCD technology.

One important feature of liquid crystals is the fact that an electrical current affects them. A particular sort of nematic liquid crystal, called twisted nematics (TN), is naturally twisted. Applying an electric current to these liquid crystals will untwist them to varying degrees, depending on the current's voltage. LCDs use these liquid crystals because they react predictably to electric current in such a way as to control the passage of light.

The working of a simple LCD is shown in Figure 1. It has a mirror (A) in back, which makes it reflective. There is a piece of glass (B) with a polarizing film on the bottom side, and a common electrode plane (C) made of indium-tin oxide on top. A common electrode plane covers the entire area of the LCD. Above that is the layer of liquid crystal substance (D). Next comes another piece of glass (E) with an electrode in the shape of the rectangle on the bottom and, on top, another polarizing film (F), at a right angle to the first one.

The electrode is hooked up to a power source like a battery. When there is no current, light entering through the front of the LCD will simply hit the mirror and bounce right back out. But when the battery supplies current to the electrodes, the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle untwist and block the light in that region from passing through. That makes the LCD show the rectangle as a black area.

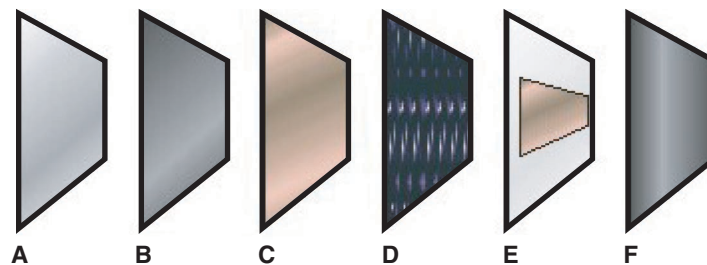


Figure 1

Back Lit and Reflective LCDs

Liquid crystal materials emit no light of their own. Small and inexpensive LCDs are often reflective, which means if they are to display anything, they must reflect the light from external light sources. The numbers in an LCD watch appear where the small electrodes charge the liquid crystals and make the crystals untwist so that the light is not transmitting through the polarized film.

Backlit LCD displays are lit with built-in fluorescent tubes above, beside and sometimes behind the LCD. A white diffusion panel behind the LCD redirects and scatters the light evenly to ensure a uniform display. On its way through liquid crystal layers, filters and electrode layers, more than half of this light is lost such as in LCD displays on personal computers.

In the reflective mode, available light is used to illuminate the display. This is achieved by combining a reflector with the rear polarizer. It works best in an outdoor or well-lighted office environment. Transmissive LCDs have a transparent rear polarizer and do not reflect ambient light. They require a backlight to be visible. They work best in low-light conditions, with the backlight on continuously.

Transflective LCDs are a mixture of the reflective and transmissive types, with the rear polarizer having partial reflectivity. They are combined with backlight for use in all types of lighting conditions. The backlight can be left off where there is sufficient light, conserving power. In darker environments, the backlight can provide a bright display.

Transflective LCDs will not “wash out” when operated in direct sunlight. Another feature of the viewing mode is whether the LCD is a positive or negative image. The standard image is positive, which means a light background with a dark character or dot. This works best in reflective or transflective mode. A negative image is usually combined with a transmissive mode.

This provides a dark background with a light character. A strong backlight must be used to provide good illumination. In most graphic applications, the transmissive negative mode is inverted. This combination provides a light background with dark characters, which offers the user better readability.

Threshold voltage and sharpness of the response are important parameters to characterize the quality of LCDs. The threshold voltage, V_{th} , is the amount of voltage across the pixel that is necessary to produce any response whatsoever. Sharpness' of the response can be calculated by finding the difference in voltage necessary to go from a 10% to a 90% brightness (usually written as $V_{90}-V_{10}$).

Another characteristic of displays that must be dealt with is the switching times of the pixels. These are commonly written as T_{on} and T_{off} , and they correspond to the amount of time between application/removal of the voltage and a 90% brightness/darkness response. Usually T_{off} is slightly larger, because after voltage is removed, the liquid crystal relaxes back into its off state. No force is being applied, unlike when it is being turned on. Switching times can be changed by controlling the amount of orientational viscosity in the crystal, which is the amount of resistance when being forced to change direction.

The contrast of a liquid crystal display is an important issue as well. One way to measure it is to find the difference in brightness between an on and off pixel, divided by the larger of the two values. A more useful value is the *contrast ratio*, which is simply the larger brightness divided by the smaller brightness.

LCD designers want this ratio to be as large as possible in order to obtain "blacker blacks" and "whiter whites." Typical LCDs have contrast ratios between 10 and 40. Unfortunately, the contrast will depend on the angle the display is viewed from since the effects of the liquid crystal are calibrated to work best on light passing through the display perpendicularly. When viewed from an angle, we are not seeing the light coming out perpendicularly from the liquid crystal, so it is common to see a breakdown in the contrast. In some cases it is even possible to see a negative image of the display.

Types of LCDs – Passive Matrix

These LCDs use a simple grid to supply the charge to particular pixels on the display. Passive Matrix LCDs start with two glass layers called the substrates. One substrate is given rows and the other is given the columns, made from a

transparent conductive material. The liquid crystal material is sandwiched between the two glass substrates, and the polarizing film is added to the outer side of each display. To turn on a pixel, the integrated circuit sends a charge down the correct column of one substrate and a ground activated on the correct row of the other. The row and column intersect at a designated pixel, and that delivers the voltage to untwist the liquid crystals at that pixel. As the current required to brighten a pixel increases (for higher brightness displays) and, as the display gets larger, this process becomes more difficult since higher currents have to flow down the control lines. Also, the controlling current must be present whenever the pixel is required to light up. As a result, passive matrix displays tend to be used mainly in applications where inexpensive, simple displays are required.

Direct addressing is a technique mostly used in Passive Matrix Displays in which there is a direct connection to every element in the display, which provides direct control over the pixels. But direct addressing is not good in some instances because in large displays there can be thousands or even millions of pixels that require separate connections.

The method used in the vast majority of large modern displays is *multiplexing*. In this method, all the pixels across each row are connected together on the plate on one side of the liquid crystal film, and all the pixels in each column are connected on the opposite side. The rows are then "addressed" serially by setting all of the column voltages separately for each row and then turning on the row voltages in sequence.

Significantly fewer physical connections must be made when multiplexing is used, but there are also several different challenges to address. If there are N rows, as we cycle through them, the pixels in one row will only be receiving the necessary voltage $1/N$ of the time. When other rows are being addressed, these pixels will be receiving smaller voltages originating only from their column electrodes. Therefore, the pixels never really receive full on or off voltages. They are always somewhere in between, and depending on how close together they are, the contrast of the display can be very low.

A simplified scheme of time multiplexing with passive matrix displays is shown in Figure 2. The pixels are addressed by gated AC voltages (only the envelopes are shown) with a complex temporal structure. A short pulse is applied periodically to the rows as a strobe signal, whereas the columns carry the information signals. A pixel is only selected if a difference in potential (and, therefore, an electrical field) is

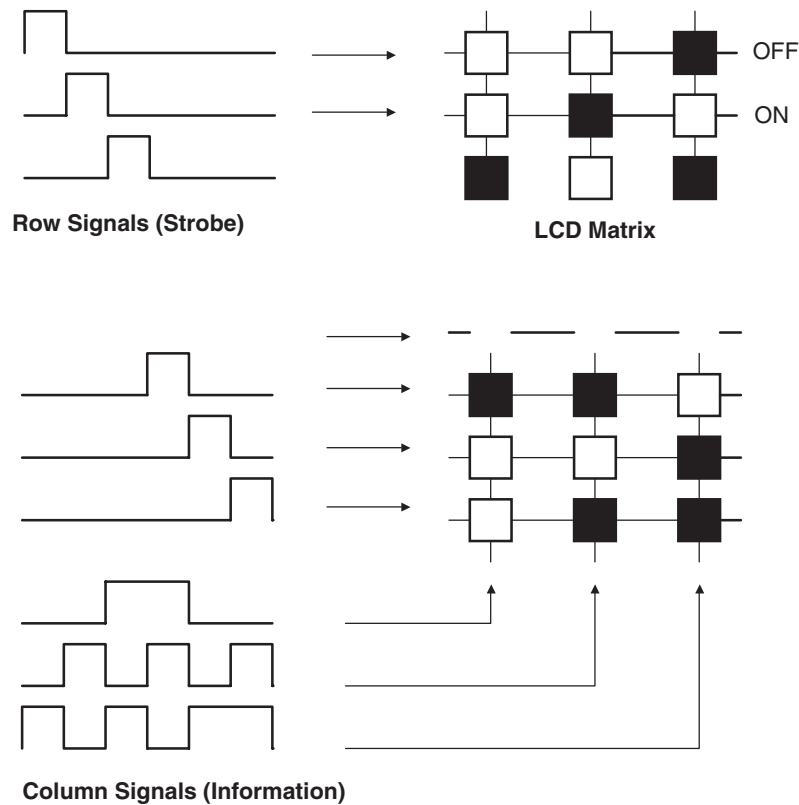


Figure 2

present, that is, only if the row and column are not on a low or high level at the same time. More precisely, the pixel is selected if the RMS voltage is above the threshold for reorientation.

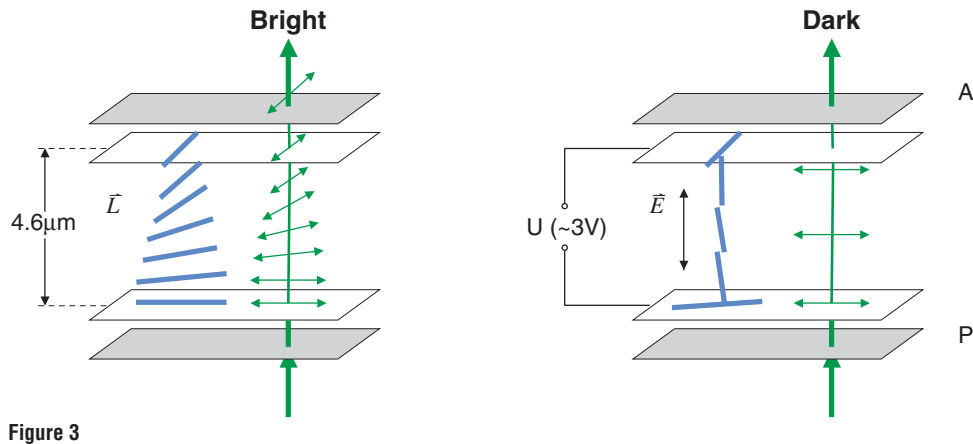
In a passive dual-scan modulator the number of pixel can be doubled without loss in optical contrast by cutting the row stripes in the center of the display and supplying two strobe signals at each half.

In twisted nematic displays the liquid crystal molecules lie parallel to the glass plates, and the glass is specially treated so that the crystal is forced to point a particular direction near one of the plates and perpendicular to that direction near the other plate. This forces the director to twist by 90° from the back to the front of the display, forming a helical structure similar to chiral nematic liquid crystals. In fact, some chiral nematic crystal is added to make sure all of the twists go the same direction.

The thin film of twisted nematic liquid crystal is circularly birefringent. When linearly polarized light passes through, the optical activity of the material causes the polarization of the

light to rotate by a certain angle. The thickness of the film, typically around 6 or 8 micrometers, can be controlled to produce a rotation of the polarization of exactly 90° for visible light. Therefore, when the film is placed between crossed polarizers, this arrangement allows light to pass through. However, when an electric field is applied across the film, the director will want to align with the field. The crystal will lose its twisted structure and, consequently, its circular birefringence.

Therefore, linearly polarized light entering the crystal will not have its polarization rotated (in fact, it is only rotated very slightly), so light will not be able to penetrate through the other polarizer. When the field is turned off, the crystal will relax back into its twisted structure and light will again be able to pass through. In some displays, the polarizers are parallel to each other, thus reversing the on and off states. If the light passes through the two polarized plates, it results in a bright image with dark background. However, if light does not pass through the cross-polarized plates, it results in a dark image with bright background. If red-, green-, and blue-colored filters are used on groups of three pixels, color displays can be created. See Figure 3.



Twisted nematic displays are simple in architecture, cheap and easy to manufacture. The use of polarizers reduces the potential brightness since they allow less than half of the light incident on the display to pass through. The effective viewing angle of the display can be very small because the optical activity and the polarizers are tuned to work best only on light that is propagating perpendicularly to the display. The voltage-brightness response curve is often not very sharp, leading to reduced contrast. The display is also affected by *crosstalk* where voltage meant for a certain pixel can leak through "sneak paths" to nearby pixels, causing a ghosting effect. And finally, the switching speed of the liquid crystal is often not as high as might be desired – typically around 150 milliseconds. Lower switching speeds are necessary when doing multiplexing since we want the crystal to respond to voltages over the whole scanning cycle to reduce flicker. However, such low speeds make passive matrix displays unusable for many applications (such as full motion video, Passive matrix displays are suitable for very low power requirements and only alphanumeric data, like watches and calculators.

An important consequence of passive time multiplexing is that the selection ratio U_{ON}/U_{OFF} approaches unity for large pixel numbers as required with standard VGA computer displays or better. Therefore, liquid crystal modulators with rather steep electro-optical characteristics are required to achieve sufficient optical contrast with weak selection ratios. This was the reason for the development of TN-modulators with larger twist angles than 90° , so-called Super-Twisted-Nematic or STN modulators.

The difference between the ON and OFF voltages in displays with many rows and columns can be very small. For this reason, the TN device is impractical for large information displays with conventional addressing schemes. This problem

was solved in the mid 1980s with the invention of the STN display. In this device, the director rotates through an angle of 270° , compared with the 90° for the TN cell. The effect of twist angle on the electro-optical response curve is shown in Figure 4.

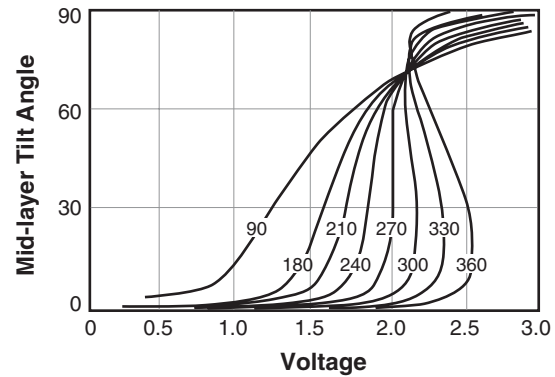


Figure 4

Note that the change in the tilt angle becomes very abrupt as the twist angle is increased. The consequence of this response curve is that the off and on voltages are closer together, as shown in Figure 5.

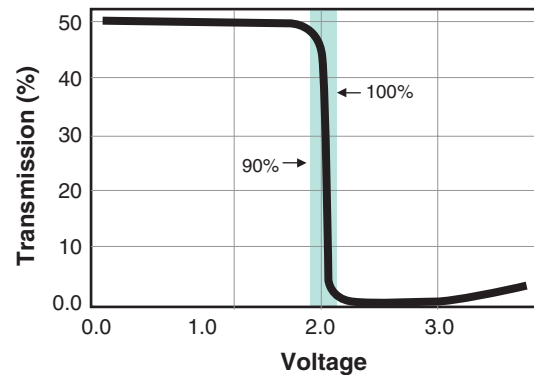


Figure 5

Although it is desirable to obtain a sharp electro-optic transition, grayscale images require intermediate points along the curve. For this reason, many commercial STN displays use a twist angle of 210°. This broadens the transition region enough for grayscale while allowing for conventional addressing. STN displays make use of color filters to come up with color STN displays.

Using STN technology, displays with a better contrast ratio are produced. STN displays can go up to a higher resolution of about 500 rows. STN displays also result in wider viewing angles, high-quality colors and a higher number of gray scale levels as compared to TN displays.

Their response time (the time it takes to go from on to off or off to on) is slower than TNLCs, about 200 milliseconds as opposed to about 60 milliseconds. Also, STN displays are not as bright and are more expensive to manufacture. Another disadvantage of early STN LCDs was that they tended to produce blue and yellow images, rather than black and white ones, due to a small difference in ON and OFF voltages. So STN displays are ideal for regular graphics applications including consumer electronics products like handheld devices, TV screens, computer monitors and digital cameras.

A color STN display has the ability to show full-color character through standard passive matrix LCD technology. Similar to a monochrome LCD, color displays consist of front and rear glass panels, polarizers, glass panels, retardation films and indium tin oxide (ITO). The main differences between passive color cell and monochrome cell is that the segment ITO is now separated into three colors, RGB, and the transmissive layer is moved internally or inside of the glass panels. In addition to these slight changes, a color filter is embedded in the cell to make it a full-color display solution. The color filter is comprised of red, green and blue pigment and is aligned with a particular sub-pixel within the cell.

Three of these sub-pixels – one each for red, green and blue, combine to make one full-color pixel in a display. In each sub-pixel, the color filter transmits only the polarized light of that sub-pixel's color. Through the use of LCD shading for each, a large number of unique colors can be displayed. So a 320 x 240 pixel CSTN display actually contains 960 x 240 individually colored pixels.

These displays are cost-effective compared with color thin film transistor (TFT) displays, with low power, full-color display

resolution, and daylight readability, providing more information content than monochrome displays.

Design is generally customized for the requirements of a specific application, so CSTN LCDs are not available as a standard product. High NRE charges are involved with large volumes.

These displays are best for graphics applications including consumer electronics such as handheld devices, TV screens, computer monitors and digital cameras. It was discovered that placing a second layer of STN LCs above the first, with the STN chains twisted in the opposite direction, produces a true black and white image. The addition of colored filters to these allows a color display to be produced. This type of display with the double layer of STN LCs was given the name "double super twisted nematic LCD" or DSTN LCD. DSTN displays are actually two distinct STN-filled glass cells glued together. The first is an LCD display; the second is a glass cell without electrodes or polarizers filled with LC material for use as a compensator, which increases the contrast and delivers the black-on-white appearance.

This DSTN LCD has a better contrast ratio than STN, and offers automatic contrast compensation with temperature. Response time is significantly enhanced. The DSTN LCD reduces the tendency of a screen to become slightly red, green or blue and has viewing angles wide enough for 6 o'clock and 12 o'clock directions. Operating temperatures from -30°C to 80°C are supported. The storage temperature range is -40°C to 90°C.

One drawback, despite the performance, is that these displays are much thicker, heavier and more expensive to manufacture. However, they are definitely suitable for use in automobiles, industrial facilities and gasoline pumps.

As its name suggests, FSTN (Film Compensated Super Twisted Nematic) uses an additional optical film to compensate for the color effect found in super twisted nematic displays. With a neutral background and virtually a black/dark gray "ON" segment color, the display gives a comfortable "paper feel" viewing.

With true black-and-white display characteristics, exceptional quality, enhanced visibility in dark and bright conditions, and a wide range of operating temperature, FSTN is an excellent choice for high-value handheld devices, navigation equipment such as GPS, mobile phones, or mono-color PDAs.

Active Matrix or TFT (Thin Film Transistor) LCDs

Active matrix displays belong to type of flat-panel display in which the screen is refreshed more frequently than in conventional passive-matrix displays, and which uses individual transistors to control the charges on each cell in the liquid-crystal layer. The most common type of active-matrix display is based on the TFT technology. The two terms, active matrix and TFT, are often used interchangeably. Whereas a passive matrix display uses a simple conductive grid to deliver current to the liquid crystals in the target area, an active matrix display uses a grid of transistors with the ability to hold a charge for a limited period of time, much like a capacitor. Because of the switching action of transistors, only the desired pixel receives a charge, improving image quality over a passive matrix. Because of the thin film transistor's ability to hold a charge, the pixel remains active until the next refresh.

There are three main switch technologies of TFTs: amorphous silicon (a-Si), polycrystalline silicon (p-Si), and single crystal silicon (x-Si). The silicon transistor matrix in a TFT is typically composed of amorphous silicon (a-Si). Amorphous silicon TFT LCDs have become the standard for mass-produced AMLCDs. They have good color, good greyscale reproduction, and fast response.

Because a-Si has inherently low mobility (area/voltage seconds), usually a capacitor must be added at each pixel. The a-Si TFT production process takes only four basic lithography steps, and can have good quality displays up to 14". For color TFT displays, there is one transistor for each color (RGB) of each pixel. These transistors drive the pixels, eliminating at a single stroke the problems of ghosting and slow response speed that affect non-TFT LCDs. The result is screen response times of the order of 25ms, contrast ratios in the region of 200:1 to 400:1, and brightness values between 200 and 250cd/m² (candela per square meter).

TFT screens can be made much thinner than LCDs, making them lighter, and refresh rates now approach those of CRTs as the current runs about ten times faster than on a DSTN screen. VGA screens need 921,000 transistors (640 x 480 x 3), while a resolution of 1024 x 768 needs 2,359,296 transistors and each has to be perfect. The complete matrix of transistors has to be produced on a single, expensive silicon wafer and the presence of more than a couple of impurities means that the whole wafer must be discarded. This leads to a high throwaway rate and is the main reason for the high price of TFT displays. It's also the reason why in any TFT display

there is a liability of a couple of defective pixels where the transistors have failed.

Two phenomena define a defective LCD pixel.

First is a "lit" pixel, which appears as one or several randomly placed red, blue and/or green pixel elements on an all-black background, or a "missing" or "dead" pixel, which appears as a black dot on all-white backgrounds. The former is the more common and is the result of a transistor occasionally shorting on, resulting in a permanently "turned-on" (red, green or blue) pixel. Unfortunately, fixing the transistor itself is not possible after assembly. It is possible to disable an offending transistor using a laser. However, this just creates black dots, which would appear on a white background. Permanently turned-on pixels are fairly common occurrences in LCD manufacturing and LCD manufacturers set limits – based on user feedback and manufacturing cost data – as to how many defective pixels are acceptable for a given LCD panel. The goal in setting these limits is to maintain reasonable product pricing while minimizing the degree of user distraction from defective pixels. For example, consider a 1024 x 768 native resolution panel, containing a total of 2,359,296 (1024 x 768 x 3) pixels. If it has just 20 defective pixels, the pixel defect rate is measured as $(20/2,359,296) \times 100 = 0.0008\%$.

These are thinner and lighter displays as compared to passive matrix LCDs, have faster response times than STN and DSTN displays, can support higher resolutions, have higher contrast ratios with wider viewing angles, have high-quality colors, and low power consumption. But they are also expensive, show lower yield rates, and have a higher probability of defective pixels.

Applications include high-resolution displays, laptop computers, HDTV, healthcare equipment, along with military and industrial applications where high reliability and quality are required.

Future Trends

OLED (Organic Light Emitting Diode) Displays

Organic light emitting diode (OLED) technology uses substances that emit red, green, blue or white light. Without any other source of illumination, OLED materials present bright, clear video and images that are easy to see at almost any angle. OLED displays stack up several thin layers of materials. The displays comprise of dielectric light-emitting phosphor layers sandwiched between two conductive

surfaces. During manufacturing, multiple organic layers are laminated onto the stripes of optically transparent inorganic electrodes. The organic layers comprise of an electron transport layer (ETL) and a hole transport layer (HTL). The layers operate on the attraction between positively and negatively charged particles. When voltage is applied, one layer becomes negatively charged relative to another transparent layer. As energy passes from the negatively charged (cathode or ETL) layer to the other (anode or HTL) layer, it stimulates organic material between the two, which emits light visible through the outermost layer of glass.

Doping or enhancing organic material helps control the brightness and color of light. And manufacturers can choose organic materials' structure – “small” (single) molecules or complex chains of molecules (polymers) – to best suit production facilities.

Active matrix and passive matrix screens are two fundamental types of OLED display assembly. Each type lends itself to different applications.

Active matrix OLED displays stack cathode, organic, and anode layers on top of another layer – or substrate – that contains circuitry. The pixels are defined by the deposition of the organic material in a continuous, discrete “dot” pattern. Each pixel is activated directly: A corresponding circuit delivers voltage to the cathode and anode materials, stimulating the middle organic layer.

AM OLED pixels turn on and off more than three times faster than the speed of conventional motion picture film, making these displays ideal for fluid, full-motion video. The substrate – low-temperature polysilicon (LTPS) technology – transmits electrical current extremely efficiently, and its integrated circuitry cuts down AM OLED displays' weight and cost, too.

Passive matrix OLED displays stack layers in a linear pattern much like a grid, with “columns” of organic and cathode materials superimposed on “rows” of anode material. Each intersection or pixel contains all three substances. External circuitry controls the electrical current passing through the anode “rows” and cathode “columns,” stimulating the organic layer within each pixel. As pixels turn on and off in sequence, pictures form on the screen. PM OLED display function and configuration are well-suited for text and icon displays in dashboard and audio equipment. Comparable to semiconductors in design, PM OLED displays are easily, cost-effectively manufactured with today's production techniques.

Bright, crisp images and video are easy to see from any angle owing to the display's unsurpassed contrast and luminance. OLED screens appear extraordinarily bright because of their unusually high contrast. Unlike LCDs, they have neither backlights nor chemical shutters that must open and close. Instead each pixel illuminates like a light bulb.

Clear, distinct images result from the OLED displays' lifelike color reproduction, vibrancy, and brightness. Unlike LCDs, OLED screens dispense with intervening liquid crystal structures that limit color vibrancy off-angle. OLED pixels turn on and off as fast as any light bulb. Their independent action in an active OLED display produces fluid full-motion video. In fact, active displays can refresh at rates more than three times that required for standard video.

Thin OLED screens are free from the added bulk and weight of backlighting, making them ideal for compact devices. Easier to see in changing ambient light conditions, OLED displays bring an edge to device ergonomics. Bright, clear images and a faster pixel refresh rate – easily better than the standard 60 frames per second – mean fewer compromises in device design and use. OLED displays are more easily viewed than LCDs of comparable size, providing greater utility. You no longer need to position yourself or your device to get a good view.

OLED panels take the same input signals as LCDs, so it is possible to add value to existing product designs and create new ones. The panels are also not power hungry. In typical image and video applications, OLED displays typically use only 25% of their maximum possible power consumption.

But there are some disadvantages. OLED phosphors-built chemistries tend to be damaged by the electrical oxidation-reduction and thermal stress of current driving mechanisms. There is a sharp trade-off between operational lifetime and operating temperature. The higher the operating temperature, the faster an OLED will age and its luminance will fall accordingly. With strong encapsulation, various manufacturers are achieving the goal of 100,000-hour lifetimes at a temperature range of -20°C to 85°C.

Applications of OLED Displays

OLED displays' fundamentally different design is ideal for many applications and electronic devices. Light-emitting layers of just a few microns replace the bulk of liquid crystal sub-section and glass in LCDs. Power, size and weight constraints are minimized. OLED displays' slimmer, lighter form and

energy-efficient adjustability allow consumer electronics manufacturers to optimize other product features and functions. The analyst firm DisplaySearch predicts OLED displays will become prominent in mobile phones, mobile phone sub-displays, PDAs, digital cameras and camcorders in the near future.

In automotive applications, OLED displays work because drivers can focus on the road because OLED displays' 170° viewing angle offers at-a-glance visibility. Currently, OLED displays are being used in car audio, infotainment systems and driver information systems.

The displays are also useful for consumer electronics because consumers see bright, vibrant pictures from almost any angle and share them with OLED displays on digital cameras and camcorders. Because each pixel operates independently, active OLED screens display video at a rate faster than the eye can see, for extremely fluid full-motion effects.

OLED technology's outstanding dynamic range means displays can be tuned to optimal image clarity for medical and scientific research applications, as well as for telecommunications, where thin, bright and highly readable OLED screens emit their own light – so their power consumption is dependent only on the content presented.

The LCD Interface in Fujitsu's Graphic Display Controllers

An RGB type interface is used for LCDs in the graphic display controllers developed by Fujitsu. Data bits for R, G and B (R0–R7, G0–G7, B0–B7), display enable (ENAB), Hsync (HSYNC), Vsync (VSYNC) and data clock (CLK) are the main signals in the RGB interface. The GDC products can support the maximum number of 8 bits per red, green or blue color, thereby supporting the total color depth of 24 bits per pixel.

Using Sharp's LCD with Fujitsu's Coral-P GDC

The LCD module is composed of a TFT LCD panel, driver ICs, control PWB, frame, front-shielding case and backlight panel.

Logical Connections Diagram: A simplified logical connections diagram is Figure 6.

The following issues must be considered while interfacing the LCD and GDC as shown above:

1. The value of Vcc determines the value of the input low-voltage and input high-voltage levels for the LCD. Therefore, the typical value of Vcc for the LCD should be within the acceptable voltage supply for Fujitsu's Coral Graphic Display Controller IO pins..
2. The graphics display controller should be able to provide the required display clock to the LCD for its operation. Coral can provide the display clock from 6.25Mhz to 67Mhz. In the diagram, shown above, the value of required display clock is 6.3 MHz.
3. The values of timing signals including HSYNC and VSYNC depend upon the characteristics of the display. The values for these signals are programmable using the register settings of Coral and should be calculated as explained in the datasheet.
4. If the LCD does not support the maximum color depth (e.g., 24 bits per pixel or 8 bits per each R, G and B color), the most significant bits are connected and rest are left unconnected. In the diagram shown above, LCD can support a color depth up to 18 bits per pixel only, so the R0–R1, B0–B1 and G0–G1 on Coral's side are left unconnected.

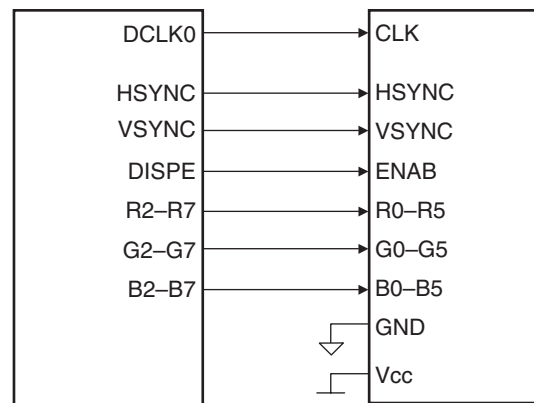


Figure 6

The LCD Interface in Fujitsu's Mobile Multimedia Processors

CPU or memory-type interfaces are used for LCDs in the Mobile Multimedia Processors (MMP) developed by Fujitsu. Data bits for R, G and B (R0–R7, G0–G7, B0–B7), Chip Select (CS), Register Select (RS), Read (RD), Write (WR) and Reset (RS) are the main signals in the CPU-type interface. The Mobile Multimedia Processors can support the maximum color depth of 24 bits per pixel.

Using Sharp's LCD with Fujitsu's MMP

The LCD module is composed of a TFT LCD panel, driver ICs, control PWB, frame, front-shielding case and backlight panel.

Logical Connections Diagram: A simplified logical connections diagram is Figure 7.

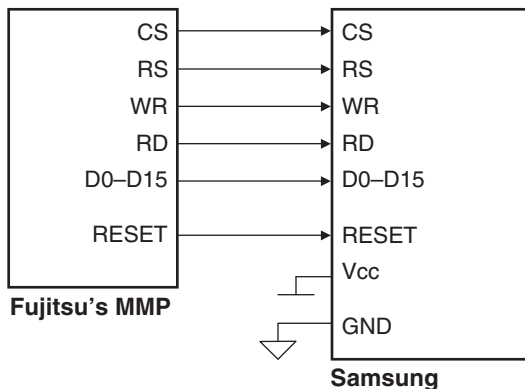


Figure 7

The following issues must be considered while interfacing the LCD and MMP as shown above:

1. The value of Vcc determines the value of input low-voltage and input high-voltage levels for the LCD. Therefore, the typical value of Vcc for the LCD should be within the acceptable IO voltage supply for Fujitsu's MMP. In the above diagram, the maximum acceptable value of Vcc for MMP is 3.6V.
2. If the LCD does not support the maximum color depth (e.g., 24 bits per pixel, 8 bits per each R, G and B color), pins for significant bits are connected. The rest of the pins are left unconnected.

Jasmine Display Controller by Fujitsu

The MB87P2020 "Jasmine" is Fujitsu's Graphics Display Controller, which integrates 8 Mbit embedded SDRAM as graphics memory. The device has the following main functions:

1. Pixel manipulation functions
 - 2d drawing and bitmap functions
 - Pixel memory access functions
2. Layer register for text and bitmap functions
3. Function to copy rectangular areas between the layers
4. Anti-aliasing filter
5. Display functions
 - Bit stream formatter.
 - Programmable display support for:
 - A. Passive matrix displays
 - B. Active matrix (tft) displays
 - C. Electroluminescent displays
 - D. Field emission displays
 - E. TV-compatible output
 - F. Crts
6. Brightness modulation function for displays
7. Direct and indirect physical sdram accesses for non-graphics and graphics data
8. Simultaneous support for digital and analog output, "twin display mode"

No external memory devices are required for the graphic memory. The 8Mbit embedded SDRAM is sufficient, so the package can be reduced to QFP208. Jasmine targets compact automotive or consumer applications required high-functional integration. A new video-input interface, which allows acceptance of more formats (including YUV) and which is compatible to a wider range of video decoder chips, has been developed and added to Jasmine. A new programmable converter matrix (YUV to RGB) allows the device to write these YUV formats to layers and to convert back to RGB for scanning. In addition, a gamma-correction table was added that allows adjusting the picture characteristics according to the connected display requirements. The color look-up table can hold up to 512 entries.

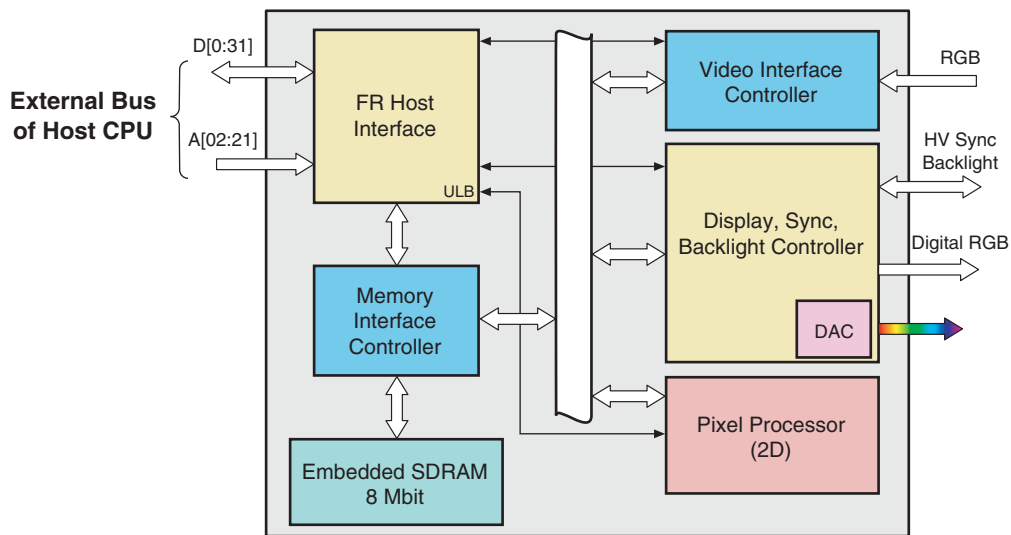


Figure 8

Key features include the following:

1. CMOS 0.25µm technology
2. Flexible display controller for almost all standard LCD panels
3. 4 Layers of overlay display (out of 16 logical layers)
4. RGB analog output (DAC)
5. RGB digital output
6. 2D graphic acceleration functions
7. Gamma correction embedded
8. SDRAM graphic memory 8Mbit (1Mbyte)
9. Digital video input (RGB and YUV formats)
10. Flexible clocking support with on-chip PLL for up to 4 external clocks
11. 16 /32-bits CPU interface (8-, 16- and 32-bit access).
12. Supply voltage 3.3V (I/O), 2.5V (internal)
13. QFP208 package
14. Temperature range -40 to +85 °C

LCD Display Suppliers Information

Optrex

Optrex provides monochrome and color TFT and CSTN-type displays. Analog TFT displays are essentially a transmissive type with a NTSC/PAL interface. Digital TFT displays are available with standard TTL and LVDS interfaces. Both analog and TFT displays are available with an extended temperature range (-30°C to 85°C). These display units are available as standalone units only, as well as a kit containing driver IC board and cables. CSTN displays are transmissive type with normal temperature range (0°C to 50°C). Overall Optrex provides variety of LCD modules, well-suited for consumer electronics as well as for automotive and industrial applications. Resolution of display panels varies from 480 x 234 pixels to 1024 x 768 pixels. For more information: visit <http://www.optrex.com/>

Sharp

Sharp Microelectronics is one of the major suppliers of digital TFT LCDs for handheld and industrial applications. These display units are available as standalone units only as well as a kit containing driver IC board and cables. The resolution of LCDs for handheld applications is QVGA (240 x 320 x 3 pixels). Some of the LCDs for handheld applications are offered with an RGB-type interface (RGB Data, HSync, Vsync, Clock and Enable signals). A separate timing IC is required for most of the LCDs to generate the Vsync and Hsync signals. LCDs for industrial applications are available as VGA (640x480x3 pixels) or SVGA (800 x 600 x 3 pixels) types with 6-bits digital RGB interface. LCDs for handheld and industrial applications have a fairly wide operating temperature range of

0°C to 70°C in general. However, Sharp also offers the LCD modules with extended temperature range for automotive applications. One such module is “LQ038Q5DR01,” which is a transmissive TFT-type LCD with an extended operating temperature range of -30°C to 85°C. The display format is QVGA (320x240x3 pixels) with a 6-bit (each for R, G and B) RGB-type interface. For more information, visit: <http://www.sharpsma.com/productgroup.php?ProductGroupID=51>

Samsung

Samsung offers the active matrix type TFT LCDs for notebook PCs, monitors, LCD TVs and mobile phones. The maximum resolution for the notebook PC segment is Wide UXGA (1920 x 1200 pixels) and the minimum is XGA (1,024 x 768 pixels). The interface for these LCDs is LVDS. The same specifications also apply to the monitor and LCD TV segments. The LCDs for notebook PCs, monitors and LCD TVs are available as finished products with driving circuits built into the housing. A wide range of transfective and transmissive type LCDs is available for mobile phones and car navigation systems. The highest resolution offered is 800 x 600 pixels with 262K colors. The lowest is 128 x 128 pixels with 65K colors, with CPU-type interface (RS, RD.WR, CS and DATA signals). Samsung also offers LCDs for dual-display-type mobile phones. The LCDs for mobile phones and car navigation segments are available as standalone LCDs with flexible cable and connector interfaces. For more information, visit: <http://www.samsung.com/Products/TFTLCD/index.htm>

Kyocera

Kyocera provides monochrome and color STN displays as part of its passive matrix displays lineup and TFT displays as the active matrix product lineup ranging from 3.8" to 10.4". Kyocera also offers LCDs with touch screens and serial interfaces. The LCD lineup is targeted at handheld, industrial and mobile phone applications. 320 x 240 pixels is the lowest and 640 x 480 pixels is the highest resolution in the TFT displays. Touch-screen LCDs are available either as passive matrix STN modules or active matrix TFT LCD modules with the resolution as low as 320 x 240 pixels (1/4 VGA) and as high as 640x480 pixels (VGA). Both transmissive and transfective CSTN LCDs are available. The total number of colors that can be displayed on these LCDs is 65,000. Pulse Width Modulation (PWM) is the drive method used for high quality in these modules. The LCDs for mobile phones are available with a flexible pin cable for connection. The other LCDs are available either with a flexible cable or connector for easy connection on the board. For more information, visit: http://global.kyocera.com/prdct/ios/lcd/38_e.html

Hitachi

Hitachi offers transmissive, transfective and reflective monochrome and color STN displays as part of its passive matrix displays lineup and color TFT displays as the active matrix product line up ranging from 2.6" to 10.4". For color STN displays, 320 x 240 pixels (1/4 VGA) with 3.6" diagonal display is the lowest and 640x480 pixels (VGA) with 7.5" diagonal display is the highest resolution in the TFT displays. For color TFT displays, four different resolutions and display diagonal sizes are available, which are 320 x 240 pixels (1/4 VGA) with a 3.5" diagonal display, 640 x 240 pixels (1/2 VGA) with a 6.5" diagonal display, 640 x 480 pixels (VGA) with a 10.4" diagonal display and 800 x 480 pixels (Wide VGA) with an 8" diagonal display size. For monochrome STN displays, six different resolutions and display diagonal sizes are available, which are 320 x 240 pixels (1/4 VGA) with a 3.8" diagonal display, 640 x 240 pixels (1/2 VGA) with a 6.2" diagonal display, 640x 480 pixels (VGA) with a 9.4" diagonal display, 240 x 128 pixels with a 5.5" diagonal display, and 256 x 64 pixels with a 4.8" diagonal display. The target applications are point of sale, handheld, office automation, industrial, medical, gaming, and consumer electronics. These LCDs are available either with a flex cable or the connector for easy connection on the board. For more information, visit: http://www.hedus.com/sales/lcd_guide.asp

OLED Display Suppliers Information

Kodak

Kodak is the major supplier of OLED displays, called NUVUE displays. The KODAK NUVUE Display AM550L is a 2.2" diagonal (5.5 cm), full-color active matrix OLED display. The AM550L is ideal for bright, clear, highly responsive displays that perform well in variable light conditions. The display power consumption is 400mW and the resolution is 521 x 218 pixels. The operating temperature is from -10°C to 75°C. The module is available with a connector on a flex cable for easy installation. For more information, visit: <http://www.kodak.com>

Samsung

Samsung offers both passive and active matrix OLED displays. For passive OLEDs, seven different resolutions and display diagonal sizes are available, which are 128x128 pixels with a 1.6" diagonal display, 128x96 pixels with a 1.53" diagonal display, 96x64 pixels with a 1.1" diagonal display, 96x96 pixels with a 1.1" diagonal display size, 96x64 pixels with a 1.04" diagonal display size, 96x48 pixels with a 1.03" diagonal display size, and 80x64 pixels with a 1.0" diagonal display size. For more information, visit: <http://www.samsungsdi.co.kr/contents/en/product/oled/oled.html>

Sony

Sony has employed its unique Super Top Emission technology for outstanding brightness and greater color gamut in OLED displays. These translate into image quality and clarity that could previously be viewed only on CRT (cathode ray tube) displays. The new 3.8" (or 9.7cm) screen measures 2.14mm thin, and makes it possible for users to enjoy a variety of high-quality content such as TV programs and digital still images on mobile products. With a wide viewing angle and a contrast ratio as high as 1000:1, high-quality images can be realized on mobile products. The OLED display by Sony has a resolution of 480 x RGB x 320 (HVGA) with 262,144 colors and a contrast ratio of approximately 1000:1. The display has horizontal and vertical viewing angles of 180° and is mainly targeted for handheld applications. For more information, visit: <http://www.sony.net/SonyInfo/News/Press/200409/04-048E/>

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