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TECH WHITEPAPER

Understading Monochrome Display Technology

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INTRODUCTION

With the increasing pervasiveness of smart objects, and product vendors' desires to deliver superior user experiences, more and more embedded devices now integrate some type of display. These can range from small displays in IoT nodes, home appliances or retail technology, to larger sizes in equipment like industrial instrumentation or digital signage.

Choices for designers cover a spectrum from simple passively driven segment displays with icons, monochrome dot matrix character or full graphical LCDs, Passive-Matrix Organic LED displays (PMOLED) to high-resolution active matrix displays such as colour TFT-LCDs or AMOLED. The sheer number of different types can be confusing, so this paper aims to help engineers select the optimum display for their application.

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User Experience Defines Success

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The overall **user experience** is the critical factor that defines the success of any given product's HMI. It can be tempting to believe that today's world demands bright colours and complex graphics or animations. However, both monochrome and colour display categories each have their respective strengths.

There are also various ways to **customise or tailor a solution** to meet specific requirements in relation to the user experience or factors such as environmental performance, cost, power consumption, form factor and time to market.

Part I of this article aims to describe the technologies currently available for **monochrome displays,** highlighting their strengths, limitations, and closest competitors to help you choose the best design approach and display technologies for your applications.

Monochrome Display Technologies

A carefully designed user interface based on a well-chosen monochrome display can be clear, simple, easy to understand and respond quickly to the users's demands. Technical strengths include **low power consumption**, small form factors, easy software design, and **low cost**, relative to full-colour alternatives. For these reasons, monochrome displays continue to offer a viable choice for many high-tech projects, particularly in the industrial and medical sectors.

The ability to selectively enhance some monochrome display technologies using coloured filters or backlights, provides extra opportunities to create a truly outstanding user experience.

Cases when monochrome display technology suits best

Twisted Nematic

LCD Display Technology

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Twisted Nematic (TN), followed by **Super Twisted Nematic (STN) displays,** have been highly influential in the success of popular electronic products such as calculators, DECT phones and pre-smartphones, digital clocks, and industrial control panels. They consist of liquid crystal material sandwiched between two polarising plates which are attached to the outside of two glass plates, one upper and one lower.

The polarisers are fixed to the upper and lower plates of glass with their polarising planes oriented at 90° to each other. When polarisers are arranged in this way they can be described as crossed polarisers. The lower or rear polariser can be **reflective**, **transflective** or **transmissive**.

In a normally white TN display, the inner surfaces of upper and lower glass plates are coated with **indium-tin oxide (ITO)** from which the electrodes within the display cell are formed. The ITO is patterned into suitably shaped segments that will produce the desired display images. These segments may be any combination of simple patterned groups of ITO electrodes to form **7-segment digits**, or a **dot-matrix array** that can create any alphanumeric character, or specific fixed icons or legends like a battery-charge indicator, am/pm indicator, colons, decimal points, etc. The ITO layers previously deposited on the inner surfaces of both the upper and lower glass plates are then coated with a polyimide material to form **PI layers** which are rubbed in orthogonal directions to form microscopic grooves into which the liquid crystal molecules will later anchor when introduced to the stack.

Microscopic spacers are then deposited on the inside of one of the plates of glass before the two plates of glass are finally brought together and sealed to form a cell leaving just a small opening into which the LC material can enter. The microscopic spacers and sealant around the edges of the glass ensure that the upper and lower glass plates never actually come into contact with each other.

When the LCD cell is filled with liquid crystal, the LC molecules anchor themselves parallel to the grooves on the top and bottom PI layers of the glass that were earlier created by the rubbing process and since the directions of the grooves on one plate of

The basics of an Liquid Crystal Display Cell

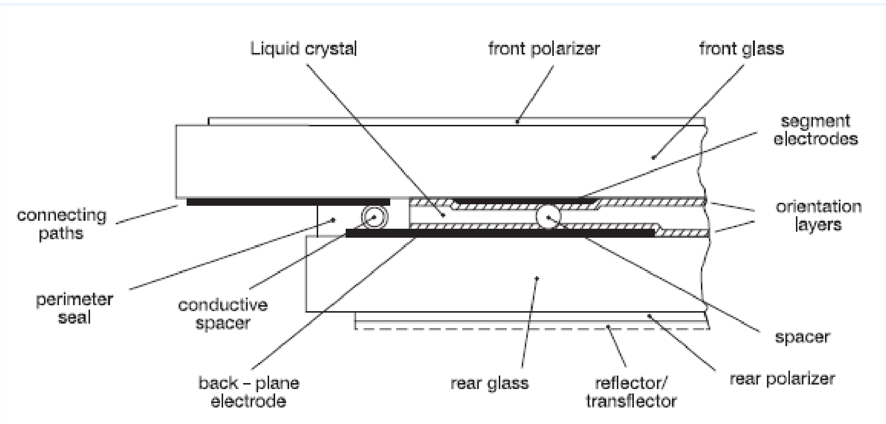

Figure 1. Cross section schematic drawing showing the basic elements of a Liquid Crystal Display.

glass is orthogonal to the grooves on the other plate of glass, the molecules are forced to form a **90° twist arrangement** between the upper and lower ITO electrodes. The LCD cell is then closed off completely using a plug called an end seal. The polarisers can now be attached, one on each glass, with their planes of polarisation oriented 90° to each other.

When a beam of light emitted from a light source **(backlight)** positioned at the rear of the display encounters the first polarising layer, only the portion of the light that matches the polarising plane of the first polariser can pass through it causing the light to be polarised. The rest is absorbed or reflected by the polariser. The polarised beam of light continues through the glass plate, enters the LC layer, and is rotated as it travels through the 90° twisted formation of the liquid crystal molecules.

By the time the beam reaches the boundary that is the second glass plate, the beam of polarised light has undergone rotation of 90° with respect to the first polarising plate. It then makes its way through the second polarising plate, which has its polarising plane oriented at 90° to the first polariser. Because the polarised beam of light that followed the 90° twist arrangement of the LC molecules arrives at the second polariser with its polarisation aligned with the second polarising plate it therefore passes unhindered.

Comparing TN and STN Display Mode

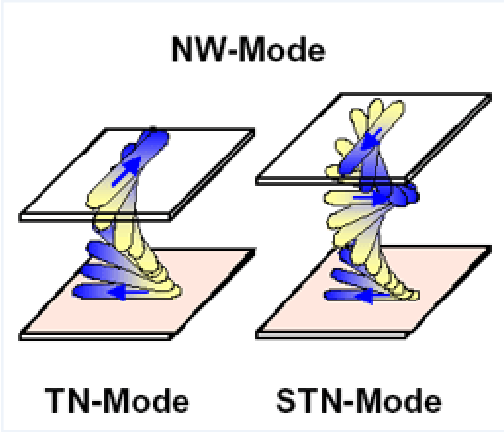

Figure 2. TN cell structure with crossed polarizers and 90-degree angle twist formation of LCD molecules for a normally white mode display.

When a voltage is applied across the upper and lower electrode causing an electric field to be generated in the gap between the upper and lower glass plates, the order of the twisted liquid-crystal molecules is interrupted as the molecules align themselves to the direction of the electric field. This reconditioning of the LC molecules' twisted arrangement prevents the polarised beam of light that exited the first polariser from being aligned to the polarisation of the second polariser and because of this, light is blocked by the second polariser causing the localised area of the display to appear dark.

Better viewing with HTN and STN

TN displays can have certain **viewing angle limitations**, depending on multiplex rates. One way to widen the view angle of TN display is to increase the twist angle from 90° to angles of around 110° for **Highly Twisted Nematic LCD (HTN)** LCD displays or up to 270° for **Super-Twisted Nematic (STN) LCD**.

These types of displays are available at only a small price premium over basic TN units. HTN and STN allows higher multiplex rates, allowing them to support higher resolution. However, response times of the TN based liquid crystal is far too slow to support fast animations or full-frame-rate video.

FSTN, FFSTN, DSTN, ASTN

TN subsequent development of TN technologies has produced further variants, including **FSTN, FFSTN, and DSTN displays**. These are film-compensated displays that contain either one extra layer of compensating film (FSTN) or two layers (FFSTN), in addition to the polarisers, to boost contrast and sharpness. There are potential stability issues when operating in the high end of the display's operating temperature range causing contrast to deteriorate so the **Double Super Twisted Nematic (DSTN)** and **Advanced Super Twisted Nematic (ASTN)** displays were developed to address contrast issues by delivering stable display contrast performance over the entire temperature range of the application; specifically, automotive. Dual-Scan STN displays, introduced a new driving scheme which enabled VGA resolution displays. It did this by dividing the display into two horizontal halves, each of which were scanned simultaneously, effectively doubling the refresh rate resulting in sharper images.

CSTN

Colour STN (CSTN) displays were developed to enable colour graphics. By dividing the pixels into 3 sub-pixels and adding red, green and blue filters the display could produce a variety of colours.

Initially slow display response times and poor image quality hampered CSTN adoption. Although these issues were addressed the arrival of active matrix TFT Displays offered far better performance improvements where colour was desired. Falling prices of active-matrix TFT-LCDs have made these a cost-effective alternative which restricted CSTN growth.

Selecting a TN display for your application

The main criteria for selecting TN displays would be a **low display resolution** requirement, meaning **simple segment displays** through to small, limited icon designs. Other considerations would be **design overheads** in terms of MCU or CPU memory availability and ultimately cost considerations.

Many TN display applications do not require LED backlights, and instead utilise a reflective rear polariser.

Designing with STN/FSTN/FFSTN/ASTN Displays

When considering STN/FSTN/FFSTN displays, the following considerations should be considered: Black and White positive-mode displays are optimised with FSTN; Black and White negative-mode displays are optimised with FFSTN.

For **high-temperature applications** such as automotive-grade LCDs requiring stable contrast performance over the entire specified temperature range, **DSTN and ASTN displays** offer the best contrast performance.

Vertical Alignment Display Technology

As with Twisted Nematic type Liquid Crystal Displays, Vertical Alignment displays rely on changing the orientation of liquid crystal molecules to block or permit the passage of light through the display.

Vertical Alignment (VA) LCDs can deliver excellent performance where a crisp, clear display is required, with high contrast and a deep black background. As with TN-type LCDs, Vertical Alignment displays rely on changing the orientation of liquid crystal molecules to block or permit the passage of light through the display. As the name suggests, when the display is in off-state, the molecules are aligned vertically on specially textured inner surfaces of the two plates of glass, unlike TN mode displays where the LC molecules are aligned parallel to the glass.

This vertically aligned arrangement prevents light from passing. As a result, the display produces a background that is **deep black**, enabling VA displays to achieve very **high contrast ratios** of more than 1000:1, and with sharply delineated characters. **Wide viewing angles** are another important strength of this type of display. Like TN mode displays, the segment forming ITO electrodes are deposited on both upper and lower glass plates.

The ITO layer follows the contours of the textured inner surfaces of the glass plates. When the upper and lower electrodes are energised through the introduction of a voltage, the LC molecules attempt to align themselves horizontally to the plane of glass, allowing light to pass though. When no electric field is applied, the LC molecules revert to being aligned vertically with the glass plates, once again preventing light from passing through the system.

As with many LCD technologies, a backlight is required as the display works only in the transmissive normally black mode. Almost **any backlight colour** can be used to deliver the required visual effect, like cool white for a high visual impact and easy readability. Because the background is dark, and the characters are lit, colour effects work particularly well with VA displays. This can be achieved using a special backlight design or with optical filters, and selective colour is also possible to ensure specific characters such as warning warning symbols, can stand out against other characters to capture the user's attentions. In this way, VA displays can offer a **lower-cost alternative to a full-colour TFT-LCD panel**, benefiting from the presence of colour to improve interaction or enhance the user experience. They are ideal where only one or two areas of colour are needed, and full-colour TFT-LCD would be excessively expensive or power hungry. Like TN types, VA displays can be built to custom specifications cost-effectively and quickly. Anders has proven processes in place for handling the design and offshore manufacture of custom LCD panels including TN and various derivatives, and VA displays.

How VA Display technology works

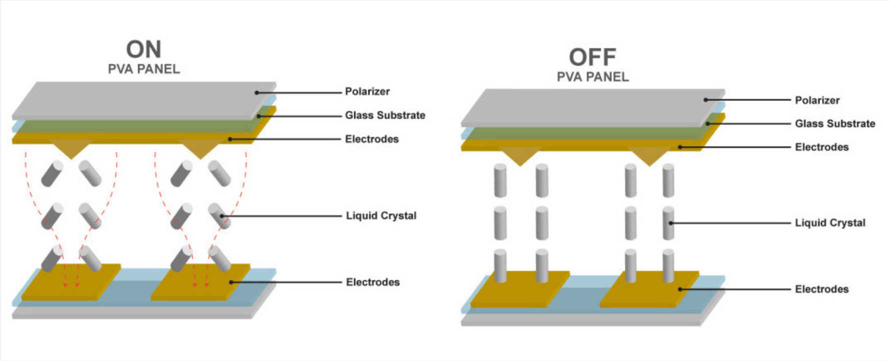

Figure 3. Vertical alignment displays, as TN-type LCDs, rely on changing the orientation of liquid crystal molecules to block or permit the passage of light through the display.

Passive Matrix OLED Display Technology

Organic LED (OLED) displays are emissive displays that require no backlight, unlike LCDs, and so are much thinner. In fact, they can be made so thin that flexible displays are possible.

Organic LED (OLED) displays in general are emissive displays that **require no backlight**, unlike LCDs, and so can be made **thinner than LCDs**. In fact, they can be made so thin that flexible displays are possible. They can also be **more efficient**, since the power required to drive the organic LEDs is lower than that required for a conventional backlight – whether LED or CCFL. Among the types available, the **Passive-Matrix OLED (PMOLED)** operates by driving each line of the display sequentially, one at a time. The display comprises an array of horizontal and vertical conductors. Pixels are formed at the intersections between these conductors, and can be monochrome or – by including red, green and blue sub-pixels - colour.

There is no storage capacitor, but ensuring a bright display demands a **high applied voltage**. This can shorten the lifetime of the PMOLED. Moreover, because the lines are driven one at a time, duty cycle limitations restrict the maximum possible number of lines and hence the overall display size and resolution. For this reason, PMOLED displays are often **applied in smaller sizes, up to about 3-inches**. This makes them well suited to use in **wearable devices**, smart retail shelves, domestic appliances, and industrial control panels.

Summary of Monochrome Display technologies performances

Parameter / relative strenght	Best	OK	Worst
Response time	OLED	VA	TN
Contrast	OLED	VA	TN
Blackness when unlit	OLED	VA	TN
Viewing angle at extreme	OLED	VA	TN
Outdoor readability	TN	-	OLED, VA
Readability in bright ambient light	OLED, VA	TN	-
Readability in low ambient light	OLED, VA	-	TN
Temperature range: Low-temperature performance	OLED	TN	VA
Temperature range: High temperature performance	VA	OLED	TN
Power consumption	OLED	TN	VA
BOM cost	TN	VA	OLED
Size ranges	OLED	TN,VA	-
Hardware design challenges	No distinction	No distinction	No distinction
Software design challenges	TN, VA	-	OLED

Conclusions

Designers must contend with many choices to identify the display most suited to their application. The choice of whether to use a monochrome or colour display, to deliver the required user experience, is one of the first decisions to be made when creating the human-machine interface for any given application. Whichever the chosen route, several options are available, and making the right choice can be based on a variety of criteria.

We hope this paper's aims to help navigate these options and compare their relative strengths has helped you choose the optimum display type to meet the applicable requirements. Getting expert assistance, preferably from an early stage in the project, can help achieve a superior result that is also more cost efficient and faster to market.

ABOUT ANDERS

Anders Electronics is a display and embedded display design specialist, dedicated to making electronic touchscreen technology safer, simpler and more enjoyable to use.

Anders has displayed precision since 1952, and continue to display engineering excellence by focussing our experienced energy into LCD and embedded display technology. As the market leaders, we design, develop, and deliver customised display solutions, for the non-consumer industry, and haven't stopped innovating! Anders features a history of reliability and innovation and lives to solve display engineering challenges.

We harness our expertise in display, embedded computing and touch control technology to help differentiate our customer's products through exceptional design and engineering.

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UK Head Office: Anders Electronics PLC, Kings Studios, 43-45 Kings Terrace, London, NW1 0JR
Call us on: +44 (0)207 388 7171 or email: info@andersdx.com

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