This project includes some basic informations about the LCD technology. LCD stands for “Liquid Crystal Displays”. We will look at different subjects that cover the technology and the physics behind the LCD. Then we will go a step further and discuss the driving forces behind the LCD such as: market expectations, manufacturing capacity, environmental aspects, ergonomical aspects, etc.

Today, LCDs are everywhere we look, but they didn't sprout up over night. It took a long time to get from the discovery of liquid crystals to the multitude of LCD applications we now enjoy. Liquid crystals were first discovered in 1888, by Austrian botanist Friedrich Reinitzer. Reinitzer observed that when he melted a curious cholesterol-like substance (cholesteryl benzoate), it first became a cloudy liquid and then cleared up as its temperature rose. Upon cooling, the liquid turned blue before finally crystallizing. Eighty
years passed before RCA made the first experimental LCD in 1968. Since then, LCD manufacturers have steadily developed ingenious variations and improvements on the technology, taking the LCD to amazing levels of technical complexity. And there is every indication that we will continue to enjoy new LCD developments in the future! LCDs are all around us - in portable computers, digital clocks and watches, microwave ovens, CD players and many other electronic devices. The question is now: why LCDs? LCDs are common because they offer some real advantages over other display technologies. They are thinner and lighter and draw much less power than cathode ray tubes (CRTs) which we know from televisions. Down here one can see an example of a simple LCD calculator.

But what are the Liquid Crystals? The name “liquid crystal” sounds like a contradiction. We think of a crystal as a solid material like quartz, usually as hard as rock, and a liquid is obviously different. How could any material combine the two?

We all learned in school that there are three common states of matter: solid, liquid or gaseous. Solids act the way they do because their molecules always point the same way and stay in the same position with respect to one another. The molecules in liquids are just the opposite: they can point in any direction and move anywhere in the liquid. But there are some substances that can also exist in an odd state that is sort of like a liquid and sort of like a solid. When they are in this state, their molecules tend to point the same way, like the molecules in a solid, but can also move around to different positions, like the molecules in a liquid. This means liquid crystals are neither a solid nor a liquid. That’s how they ended up with their seemingly contradictory name.

So, do liquid crystals act like solids or liquids or something else? It turns out liquid crystals are closer to a liquid state than a solid. It takes a fair amount of heat to change a suitable substance from a solid into a liquid crystal, and it only takes a little more heat to turn that same liquid crystal into a real liquid. This explains why liquid crystals are very sensitive to temperature and why they are used to make thermometers and mood rings. It also explains why a laptop computer’s display may act funny in cold weather or during a hot day at the beach!

Just as there are many varieties of solids and liquids, there is also a variety of liquid crystal substances. Depending on the temperature and particular nature of a substance, liquid crystals can be in one of several distinct phases (see sidebar). In this article, we will discuss liquid crystals in the nematic phase, the liquid crystals that make LCDs possible. As we learned earlier, one feature of liquid crystals is that they’re affected by electric current. 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 light passage.

2) Introduction
2.1) Twisted Nematics (TN)

There are many types of liquid crystal displays, each with unique properties. The most common LCD that is used for everyday items like watches and calculators is called the twisted nematic (TN) display. This device consists of a nematic liquid crystal sandwiched between two plates of glass. A special surface treatment is given to the glass such that the molecules are homeotropic yet the director at the top of the sample is perpendicular to the director ("groove surface") at the bottom. This configuration sets up a 90 degree twist into the bulk of the liquid crystal, hence the name of the display. The twist is visible in the following animation to the left. While to right one can see how the molecules are orientated by the director.

The underlying principle in a TN display is the manipulation of polarized light. When light enters the TN cell, the polarization state twists with the director of the liquid crystal material. For example, consider light polarized parallel to the director at the top of the sample. As it travels through the cell, its polarization rotates with the molecules. When the light emerges, its polarization has rotated 90 degrees from when it entered which can be seen in the picture to the right. As we discussed before the molecules will line up along the director. So when the liquid crystals are sandwiched between upper and lower plates (directors), they line-up with the “grooves” pointing in directions ‘a’ and ‘b,’ respectively as it shown in the upper picture to the right. Where the below picture to the right shows that light passes through liquid crystals, following the direction in which the molecules are arranged. When the molecule arrangement is twisted 90 degrees as shown in the figure, the light also twists 90 degrees as it passes through the liquid crystals.

A schematic of a TN cell is shown in the following animation. The black lines represent crossed polarizers that are attached to the top and bottom of the display. As light enters the cell, its polarization rotates with the molecules. When the light reaches the bottom of the cell, its polarization vector has rotated by 90 degrees, and now can pass through the second polarizer. In a reflecting TN display, a mirror is placed at the bottom of the cell to
reflect the transmitted light. Once again the polarization twists as the light traverses the sample, and is able to emerge from the top of the cell. The following animation to the left shows how light entering the cell twists along the way. The only way which makes light passing through is when voltage is applied to the liquid crystal structure, so the twisted light passes straight through. So the molecules in liquid crystals are easily rearranged by applying voltage or another external force. As we can see from the figure to the right that when voltage is applied, molecules rearrange themselves vertically (along with the electric field) and light passes straight through along the arrangement of molecules.

When voltage is applied to a combination of two polarizing filters and twisted liquid crystal, it becomes a LCD display. Light passes when two polarizing filters are arranged with polarizing axes as shown below, left. Light is blocked when two polarizing filters are arranged with polarizing axes as shown to the right.

A combination of polarizing filters and twisted liquid crystal creates a liquid crystal display. So the conclusion is that when two polarizing filters are arranged along perpendicular polarizing axes, light entering from above is re-directed 90 degrees along the helix arrangement of the liquid crystal molecules so that it passes through the lower filter. When voltage is applied, the liquid crystal molecules straighten out of their helix pattern and stop redirecting the angle of the light, thereby preventing light from passing through the lower filter.

The right figure depicts the principle behind typical twisted nematic (TN) liquid crystal displays. In a TN type LCD, liquid crystals in which the molecules form a 90-degree twisted helix, are sandwiched between two polarizing filters. When no voltage is applied, light passes; when voltage is applied, light is blocked and the screen appears black. In other words, the voltage acts as a trigger causing the liquid crystals to function like the shutter of a camera.

The optical response depends on the field strength, twisted nematic displays can switch between light and dark states, or somewhere in between (grayscale.) How the molecules respond to a voltage is the important characteristic of this type of display. The response of a typical twisted nematic cell to an applied voltage is shown in the following diagram (called an electro-distortional curve). The tilt of the molecules out of the plane of the glass slides is measured as a function of the applied voltage. In the TN display, the electro-distortional response determines the transmission of light through the cell. Percent transmission as a function of voltage is shown in the following diagram. Keep in mind that maximum transmission for a reflective TN device is only 50 percent because polarized light must be used.
The vertical lines represent the voltages at which the cell is OFF or ON. In order to address many pixels with a multiplexing scheme (see Addressing), the differences in the OFF and ON voltages must be very small. This was difficult to achieve with the traditional TN structure. This problem was solved with the invention of the super-twisted nematic (STN) display.

2.2) Super Twisted Nematics (STN)

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 1980’s with the invention of the super-twisted nematic (STN) display. In this device, the director rotates through an angle of 270 degrees, compared with the 90 degrees for the TN cell. The effect of twist angle on the electro-optical response curve is shown in the diagram to the left. 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 much closer together, as is shown in the right figure.

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 degrees. This broadens the transition region enough for grayscale while allowing for conventional addressing. 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 degrees. This broadens the transition region enough for grayscale while allowing for conventional addressing.

Early displays operating in the 210 degree mode suffered from undesirable coloration
resulting from a shifted transmission spectrum of the device. In the ON state, the pixels
tended to be yellow, while the OFF state had a bluish-purple tint. In addition to not being
popular with the consumer, full color displays using filters can only be made with black and
white operation. This problem was solved by adding a second STN layer with the opposite
twist sense to the cell. This type of device is known as the double super-twisted nematic
display (D-STN). In the OFF state, the phase shift resulting from the first layer is
compensated by the second layer. This pixel appears black. The ON state is not affected
by the second STN layer, and white light emerges. Since the two layers consist of the
same liquid crystal material, the behavior is constant over the entire temperature range.

2.3) Display Systems

Addressing is the process by which pixels are turned on and off in order to create an
image. There are two main types of addressing, direct and multiplexing. Direct addressing
is convenient for displays where there are only a few elements that have to be activated.
With direct addressing, each pixel in the display has its own drive circuit. A microprocessor
must individually apply a voltage to each element. A common application of direct
addressing is the traditional seven segment liquid crystal display, found in wristwatches
and similar devices. In multiplex addressing, a larger number of pixels are involved. When
the elements are in a regular order, they can be addressed by their row and column
instead of each element being driven separately. This reduces the complexity of the
circuitry because each pixel no longer needs its own driver circuit. If you have a 10x10
matrix of pixels, with direct addressing, you need 100 individual drivers. However, if you
use multiplex addressing, you only need 20 drivers, one for each row and one for each
column. This is a tremendous advantage, especially as displays become larger and larger.
Down here you can see some of the basic methods to adress a LCD:

1. Segment system
Long display units are arranged to form a figure ‘8’ to display numbers.

2. Dot matrix system (character display)
Display units are arranged in rows and columns to form characters.

3. Dot matrix system (graphics display)
Display units are arranged in rows and columns to depict graphics.

The principle of color displays: A color display is made possible by pla
over each display unit. In dot matrix systems, red, green and blue dots ar
through the use of filters for each of the three primary colors red (R), green
and blue (B). A variety of colors can then be expressed by combining them. The fig
“Structure & Production” section will show how the filter is build in. The Color Displays will
be discussed in details later in this report.
2.4) Structure & Production

Next is a brief description of the structure, liquid crystal materials and production process of a simple matrix LCD. A liquid crystal display is composed of multiple layers. First, a sheet of glass is coated with a transparent metal oxide film (shown as a blue layer in the animation below) which acts as an electrode. This film can be patterned to form the rows and columns of a “passive matrix” display or the individual pixels of an “active matrix” display. These electrodes are used to set up the voltage across the cell necessary for the orientation transition. Next, a polymer alignment layer is applied (shown in red). This layer undergoes a rubbing process which leaves a series of parallel microscopic grooves in the film. These grooves help align the liquid crystal molecules in a preferred direction, with their longitudinal axes parallel to the grooves. This anchors the molecules along the alignment layers and helps force the molecules between the alignment layers to twist.

Two such sheets of glass are prepared and one is coated with a layer of polymer spacer beads (the slightly green glassy layer). These beads maintain a uniform gap between the sheets of glass where the liquid crystals are eventually placed. The two glass sheets are then placed together and the edges are sealed with epoxy. A corner is left unsealed so that the liquid crystal material can be injected under a vacuum. Once the display has been filled with liquid crystals, the corner is sealed and polarizers (the transparent layers with lines) are applied to the exposed glass surfaces. In a TN display (which is shown in the animation below) the alignment layers are positioned with their rubbing directions perpendicular to each other and the polarizers are applied to match the orientation of the alignment layers. In an STN (super-twisted nematic) display the alignment layers are placed with their rubbing directions at a variety of angles to one another to set up a twist from 180 to 270 degrees and the polarizers are not applied parallel to the alignment layers.

So color LCDs have a structure in which their components are formed into a sandwich-like arrangement. Above to the right we show an other more detailed image which shows the layers in an LCD.
2.5) Addressing

There are two ways to address a LCD, either the “Static drive system” or the “Dynamic drive system”. The figure to the left shows the “Static drive system”. Here an upper electrode is connected to each display segment. The figure to the right shows the “Dynamic drive system” with four upper electrodes and two lower electrodes. The display segment to be shown is selected by segment to be shown is selected by combinations of upper and lower electrodes.

A drive system ‘drives’ the LCD by applying voltage to specific electrodes. In the early days of LCD development, a segment systems used a static drive system in which each segment was driven separately. The number of terminals required in this system increases with the number of display units, making it unsuitable for use with large screens. The development of a dynamic drive made it possible to drive displays with fewer terminals.

2.6) Matrix Drive Systems

Passive vs. Active Matrix Displays:

The passive matrix display is addressed by a set of multiplexed transparent electrodes, perpendicular to one another, above and below the liquid crystal layer in a row and column formation as seen below. The electrodes in diagram are colored red and blue so that the structure is apparent. The electrodes are typically constructed of indium tin oxide (ITO) which is a semi-transparent conducting material. The liquid crystal material is colored green in the diagram strictly for structural clarity.

The passive matrix display is addressed by a set of multiplexed transparent electrodes, perpendicular to one another, above and below the liquid crystal layer in a row and column formation as seen below. The electrodes in diagram are colored red and blue so that the structure is apparent. The electrodes are typically constructed of indium tin oxide (ITO) which is a semi-transparent conducting material. The liquid crystal material is colored green in the diagram strictly for structural clarity.
A passive pixel is addressed when there is a sufficient voltage across it to cause the liquid crystal molecules to align parallel to the electric field. A display can have more than one pixel on at any one time because of the response time of the liquid crystal material. When addressed, a pixel has a short turn-on time during which the liquid crystal molecules align in such a way as to make the pixel opaque. When the voltage is removed the pixel behaves similar to a discharging capacitor, slowly turning off as charge dissipates and the molecules return to their undeformed orientation. Because of this response time, a display can scan across the matrix of pixels, turning on the appropriate ones to form an image. As long as the time to scan the entire matrix is shorter than the turn-off time, a multiple pixel image (like the animation below) can be displayed. The time scale of the animation has been stretched so as to see what is normally imperceptible to the human eye. The transparent electrodes momentarily revert to blue and red to signify voltage being applied. The pixel gradually becomes opaque. As the voltage is removed (as shown by the electrodes becoming colorless again) the cell remains opaque briefly before it becomes clear again.

**Active Matrix Displays**

Active matrix displays are currently available in high end laptop computers. In this type of display, the addressing takes place completely behind the liquid crystal film. The front surface of the display is coated with a continuous electrode while the rear surface electrode is patterned into individual pixels. A thin film transistor (TFT) acts as a switch for each pixel. The TFT is shown as the purple square at the corner of the blue electrode in the single pixel animation (below, right.) The TFT is addressed by a set of narrow multiplexed electrodes (gate lines and source lines) running along the gaps between pixels. A pixel is addressed by applying current to a gate line which switches the TFT on and allows charge from the source line to flow on to the rear electrode (shown as the starburst effect in the pixel animation below). This sets up a voltage across the pixel and turns it on. An image is created similar to the passive display as the addressing circuitry scans across the matrix. An active matrix display does not suffer from many of the limitations of the passive display. It can be viewed at an angle of up to 45 degrees and has a contrast of 40:1, meaning that the brightness of an “on” pixel is 40 times greater than an “off” pixel. It does, however, require a more intense back lighting system because the TFT’s and the gate and source lines are not very transparent and therefore block a fraction of the light.
Color Displays:

The techniques discussed so far have only been able to describe a simple two color display. In order to achieve color, it is first necessary to have a display which is black in one state and white in the other. This distinction is made because some displays (early STN displays for example) may have a yellow on blue appearance which will not be able to produce the full range of colors. In a white display, all wavelengths pass through and therefore, all wavelengths can be manipulated to create the desired color. To get full color, each individual pixel is divided into three subpixels: red, green and blue (RGB). That is to say that for each full color pixel, three distinct pixels are employed. These subpixels are created by applying color filters which only allow certain wavelengths to pass through them while absorbing the rest. With a combination of red, blue and green subpixels of various intensities, a pixel can be made to appear any number of different colors. This is analogous to a color cathode ray tube (CRT) like a television or computer monitor in which different phosphors glow red, green or blue when excited by an electron beam. The number of colors that can be made by mixing red, green and blue subpixels depends on the number of distinct gray scales (intensities) that can be achieved by the display.

Display lighting:

In order for a display to show information, it must have a light source. Some displays use only ambient light and employ a reflective surface mounted behind the display—most calculators and watches are like this. These displays are not very bright because the light must pass through multiple polarizers which severely cut down on the intensity of the light, in addition to the various layers of the display which are only semi-transparent. Therefore a more intense source is employed in the form of a back lighting system. Light bulbs mounted behind and at the edges of the display replace the reflected ambient light. This results in brighter displays for two reasons: the light doesn’t have to come in through the display and therefore does not lose part of the intensity, and the lighting system can be made more intense than ambient light. Back lighting has the disadvantage of being very power intensive. Back lighting systems are used in more complex displays such as laptop computer screens.
3) The Driving Forces behind the LCD

3.1) Market Expectations

McDonald's is testing a Digital Menu Board, and United Airlines is using electronic messaging to convey relevant, updated information. Whatever the system, in electronics, there is a strong likelihood a display will be required.

3.2) Manufacturing Capacity

The most popular LCD modules for notebook PCs and desktop monitors are entering a period of oversupply, bringing lower prices for OEMs as the boom-or-bust cycle continues for flat-panel display makers. Flush with cash following more than a year of rising tags, LCD vendors will pour $5 billion into new manufacturing capacity this year, about as much as the industry spent in the past three years combined, according to DisplaySearch Inc., an Austin, Texas-based research house.

DisplaySearch projected a 5% to 10% TFT-LCD surplus into 2001 and lower prices, as suppliers cut tags to maintain high utilization rates at their plants. The main reason for the increase is new capacity coming on line at established suppliers and a concerted market entrance by Taiwanese vendors. In fact, DisplaySearch said that by region, Taiwan will have 35% of the world's LCD manufacturing capacity by 2005, significantly more than Korea and nearly as much as Japan.

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<th>Q4’00 Rank</th>
<th>Q1’01 Rank</th>
<th>Q2’01 Rank</th>
<th>Q4’00 Share</th>
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Tabel 1 4th Quartet 2000 (Q4’00) - 2nd Quarter 2001 (Q2’01) LCD Monitor Supplier Rankings and Market Share.

3.3) Environmental and Ergonomical Aspects

The power required to run an LCD monitor is about 25% of that required for a CRT with the same screen area. In this era of high energy prices and rolling blackouts, this is a significant advantage. Furthermore, the amount of heat generated by an LCD monitor is considerably less than a CRT monitor, resulting in a lower load on air conditioning. If the monitor is used with a system supported by an uninterruptible power supply (UPS), the lower power required by the LCD provides precious extra minutes to store critical data and
shut down gracefully in the event of a power failure. A CRT monitor can be a liability at the end of life due to the amount of lead and mercury in the tube. Special measures must be taken when recycling to prevent hazardous materials from fouling our environment. The LCD uses much less of these materials uses less energy to recycle; thus, it is much more environmentally friendly.

The typical ViewSonic LCD monitor has a brightness of 200 to 250 nits compared with a typical CRT brightness of 100 nits. Thus the LCD can be used in very bright environments that would wash out a CRT monitor. Since an LCD acts like a shutter, it can be made brighter by increasing the brightness of the backlight. When the beam current of a CRT is increased to increase brightness, the beam spot size increases also (an effect called blooming), which lowers effective resolution and yields a soft or fuzzy image. By design, a CRT must be continuously refreshed or rewritten. If this process is not fast enough (> 75Hz), a subtle flicker results that can cause headache and eyestrain. The LCD monitor does not flicker by design and its perfect focus and geometry further reduce fatigue that results from long periods working at the display. This fatigue has come to be known as Computer Vision Syndrome (CVS).

A CRT monitor can generate electric, magnetic and even X-ray emissions due to the high voltage power supply necessary to drive the CRT. Extra circuitry is required to control these emissions to acceptable levels as defined by the Swedish Confederation of Professional Employees (TCO), a global sanctioning organization. The LCD monitor does not require a high voltage supply like the CRT and is essentially emission-free. The smaller size of the LCD monitor permits any shielding required to prevent RFI to be incorporated in the design much less expensively than shielding a CRT monitor. In addition to emitting less radiation, the LCD is less perturbed by external radiation than a CRT monitor. A magnetic field such as might be generated by a nearby speaker or an electric fan will cause severe purity problems with a CRT monitor, while an LCD monitor will be unaffected.

The space saving of an LCD monitor means that it can fit into locations that would be impossible for a CRT monitor. The size and weight of the LCD also permit the unit to be wall or arm mounted easily for essentially zero-footprint installation. The LCD size permits mounting in landscape (normal) and portrait (90-degree rotation) modes to enhance certain applications like word processing and web design. Full pages can be displayed without scrolling resulting in improved usability and throughput. The CRT monitor does not lend itself to rotation by its considerable size and weight. Furthermore, a CRT monitor may develop cooling problems when rotated unless the chassis and cabinet are designed taking rotation into consideration. Finally, effects from the earth's magnetic field will permanently magnetize the CRT shadowmask each time the monitor rotates, mandating a degauss cycle. Until the LCD monitor became generally available, fixed portrait-mode CRT monitors were niche products found primarily on dedicated word processors and on some medical instrumentation.

Although there are still areas in which a CRT monitor has an advantage, such as viewing angle and response speed, the gap has closed to the point where the LCD advantages far outweigh the disadvantages.
3.4) Comparison with other types of FPDs

FED and EL displays are thinner than LCD panels and offer lower power consumption, wider viewing angles and faster response time. Production of FED has started at PixTech in the US, and EL is being manufactured by Pioneer Electronic in Japan. Two new flat panel displays—field emission displays (FED) and organic electroluminescent displays (EL)—are ramping up for volume production. The new displays may offer performance beyond that of LCD, because they improve its three major drawbacks: the viewing angle, response speed and power consumption. The FED offers a light emission efficiency superior to that of the LCD, with color panels already developed in the 10 to 15 lm/W range, roughly double the four to six lm/W range of existing thin-film transistor (TFT) LCD. As a result, power consumption is roughly halved. The light emission efficiency of organic EL displays is about the same as that of LCD, but while the LCD requires a constant backlight, the organic EL display generates its own light. Only the necessary pixels are lit, lowering actual power consumption.

FED manufacturers plan to challenge the color TFT-LCD market monopoly head-on with 6-inch color panels for use in car navigation systems and similar applications, and 10-inch and larger panels for notebook PCs and desktop monitors. FED performance has the potential to beat TFT-LCDs (Table 2), because it totally eliminates the major problems of narrow viewing angles and the slow response speed now faced by color TFT-LCDs. The viewing angle of an FED is 160° in both up-down and left-right directions, and the response time is fast enough (several µs) to handle motion video images. Another advantage is the wider operating temperature range. Because the FED is completely solid state, it will operate across a temperature range from -45°C to +85°C.

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<th>FED</th>
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<td>Viewing angle</td>
<td>Left-right 50°, up/down 50°</td>
<td>Left-right 160°, up/down 160°</td>
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<td>Screen brightness</td>
<td>70cd/m²</td>
<td>70cd/m²</td>
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<tr>
<td>Emission efficiency</td>
<td>4 to 6 lm/W</td>
<td>4 to 6 lm/W (10 to 15 lm/W also developed)</td>
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<tr>
<td>Response time</td>
<td>Several dozen ms</td>
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<td>Contrast ratio</td>
<td>100:1</td>
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<td>Power consumption</td>
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<td>Panel thickness</td>
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<td>Operating temperature range</td>
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<td>Screen size</td>
<td>Max 22 inches</td>
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<td>Price</td>
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Table 2 FED vs Color TFT-LCD
4) Conclusion
## 5) References

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