AN658

LCD Fundamentals and the LCD Driver Module of 8-Bit PIC® Microcontrollers

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INTRODUCTION

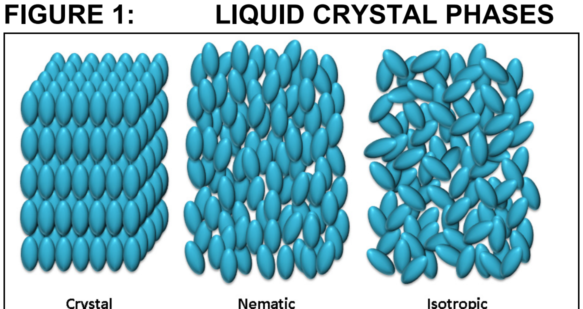
This application note provides an introduction to the basics of the Liquid Crystal Display (LCD); its construction, physics behind its operation, and the different factors affecting its properties and performance. Moreover, 8-bit PIC® microcontrollers with integrated LCD controllers are also introduced. Prominent features of the LCD Driver module of these MCU families are discussed, including contrast control, drive waveforms, biasing methods, power modes, and other LCD circuit design considerations. Lastly, the code samples for a 1-Hour Countdown Timer application for both the PIC16 and PIC18 devices are presented. The application uses the segmented and dot matrix LCD for the two families, respectively.

LIQUID CRYSTALS

Liquid Crystals (LCs) exist in a state between isotropic (liquid) and crystalline (solid), and exhibit the properties of both, as shown in Figure 1. Nematic phase, which is the simplest of the LC phases, is the one employed in the LCD technology.

LCs are affected by electric current and when a voltage is applied, they react and may change order and arrangement. This unique behavior of LCs allows them to play a significant role in electro-optic devices, such as the LCD.

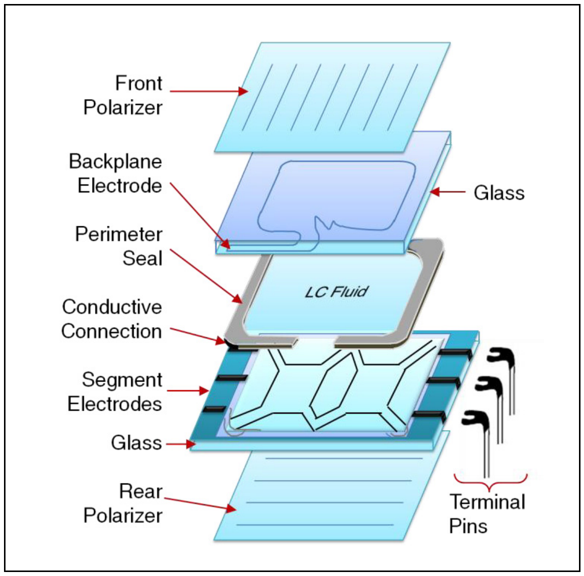
FIGURE 1: LIQUID CRYSTAL PHASES



BASIC COMPONENTS OF AN LCD PANEL

An LCD panel, or more commonly known as a piece of "glass", is constructed of many layers. Figure 2 shows all the layers that are typically present in LCD panels. For this application, it is assumed that the LCD employs a Twisted Nematic (TN) display, unless otherwise stated. TN displays, as well as the other display technologies are discussed in detail in the **Section "LCD Technologies"**.

FIGURE 2: BASIC LCD COMPONENTS

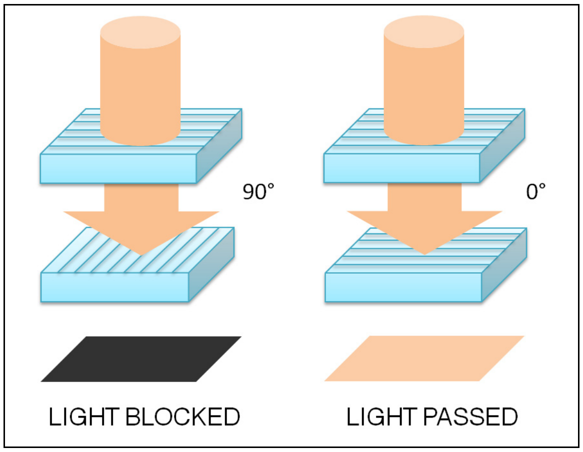


FRONT POLARIZER

Polarization is the process or state in which rays of light exhibit different properties in different directions, especially the state in which all the vibration takes place in one plane. Essentially, a polarizer passes light only in one plane. As shown in Figure 3, if light is polarized in one plane, by passing through a polarizer, it cannot pass through a second polarizer if its plane is 90° out of phase to the first.

The front polarizer is applied to the outside surface of the top piece of glass. The top layer of glass also provides structural support for the LCD panel.

FIGURE 3: OUT OF PHASE AND IN-PHASE POLARIZERS



BACKPLANE ELECTRODE

A transparent coating of Indium Tin Oxide (ITO) is applied to the bottom side of the top layer of glass. ITO is conductive and forms the backplane or the common electrodes of the LCD panel. The patterns of the backplane and segment ITO form the numbers, letters, symbols, icons, etc.

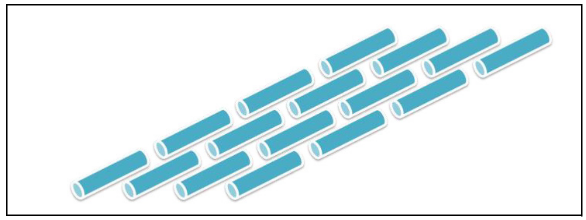
After the ITO has been applied to the glass, a thin polyimide coating is applied to the ITO. The polyimide is “rubbed” in a single direction that matches the polarization plane of the front polarizer. The action of “rubbing” the polyimide causes the Liquid Crystal (LC) molecules in the outermost plane to align themselves in the same direction.

LIQUID CRYSTAL LAYER

The next layer is a reservoir of LC. The LC fluid has many planes of molecules.

LC molecules are long and cylindrical. On any plane within the LC fluid, the molecules align themselves such that the major axis of each molecule is parallel to all others, as shown in Figure 4. The outermost planes of the LC molecules will align themselves on the same axis that the polyimide is “rubbed”. The direction of “rubbing” of the polyimide on the bottom glass is perpendicular to that of the polyimide on the top glass. This orientation creates the twist in the LC fluid.

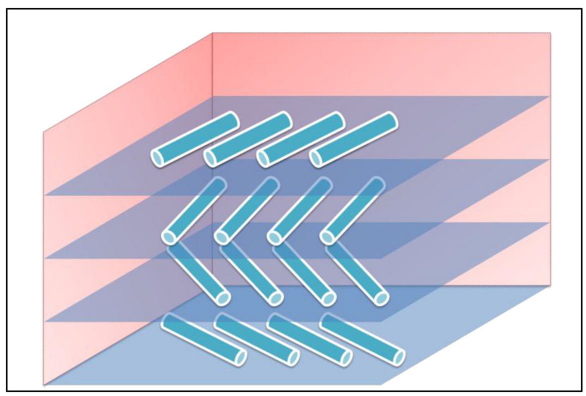
FIGURE 4: LC MOLECULES IN ALIGNMENT



A consequence of this alignment is that each intermediate plane of LC molecules will have a slightly different orientation from the plane above or below as seen in Figure 5.

The twisting of the planes causes the polarization of the light to twist as it passes through the LC fluid. The twisting of the LC planes is critical to the operation of the LCD panel as will be shown in the next section.

FIGURE 5: LC MOLECULES PLANE ORIENTATION



CONDUCTIVE CONNECTION AND ITO SEGMENT ELECTRODES

The next layer is the polymide coating on the bottom glass followed by the ITO segment electrodes. The bottom glass also supplies structural integrity for the LCD panel as well as mounting surface for the electrode connections. Applied to the external surface of the bottom glass is the rear polarizer. Depending on the type of viewing mode employed by the LCD panel, the axis of polarization may be the same as the front polarizer or phase shifted by 90 degrees from the front polarizer.

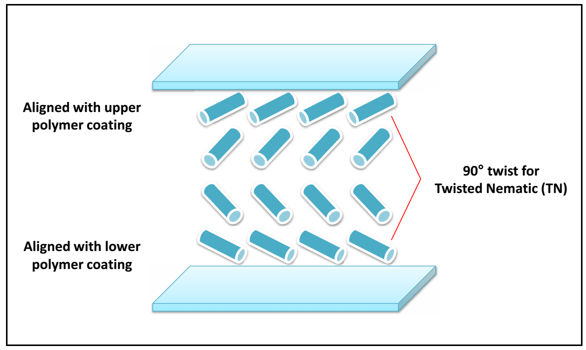
HOW AN LCD WORKS

As explained in the previous section, the twist created in the LC fluid is the basis of how the panel operates. An LCD basically produces an output display by the switching of segments or pixels between ON or OFF. A pixel is considered to be ON when enough electric potential is applied between the segment and common electrodes, resulting to a dark pixel on the display. On the contrary, a pixel is considered to be in the OFF state when insufficient electric potential is applied between the electrodes, creating a clear pixel on the display.

OFF Pixel

Figure 6 shows how an LCD panel creates a pixel that is OFF. For this example, the LC fluid is not energized (i.e., there is 0 VRMS potential between the common and the segment electrodes).

FIGURE 6: LC ORIENTATION WITH NO ELECTRIC FIELD



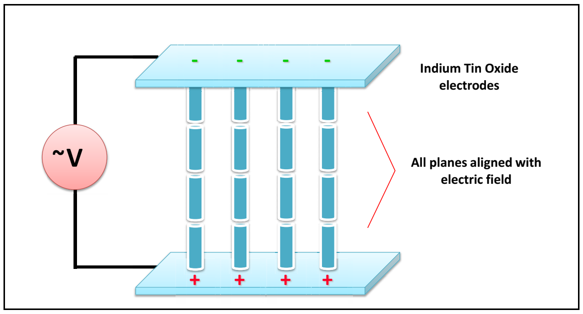
The following is a step-by-step description of the path light takes through the LCD panel. The illustrative representation of the process is shown in Figure 8.

- Light enters the panel through the rear polarizer. At this point, light becomes polarized to the vertical plane.
- The polarized light passes unobstructed through the transparent common electrode.
- As the polarized light passes through the LC fluid, it gets twisted into the horizontal plane.
- The polarized light passes unobstructed through the transparent segment electrode.
- Since the light is now polarized in the horizontal plane, it passes unobstructed through the front polarizer which has a horizontal polarization.
- Since the light has passed through unobstructed, the pixel appears in the OFF state to the observer.

ON Pixel

If a potential is applied across the common and segment electrodes, the LC fluid becomes energized. The LC molecule planes will now align themselves such that they are parallel to the electrical field generated by the potential difference. This removes the twisting effect of the LC fluid. Figure 7 shows how a pixel that is ON, or more specifically energized, is created.

FIGURE 7: LC ORIENTATION WITH ELECTRIC FIELD



The following is a step-by-step description of the path that the light takes through this LCD panel. Refer to Figure 9 for the illustrative representation.

- Light enters the panel through the rear polarizer. At this point, the light becomes polarized to the vertical plane.
- The polarized light passes unobstructed through the transparent common electrode.
- As the polarized light passes through the LC fluid, it does not twist and remains in the vertical plane.
- The polarized light passes unobstructed through the transparent segment electrode.
- Since the light is still polarized in the vertical plane, it is obstructed by the front polarizer which has a horizontal polarization.
- The observer detects that the pixel is ON because the light has been obstructed and creates a dark image on the panel.

FIGURE 8: PATH OF LIGHT FOR OFF PIXEL (POSITIVE IMAGE)

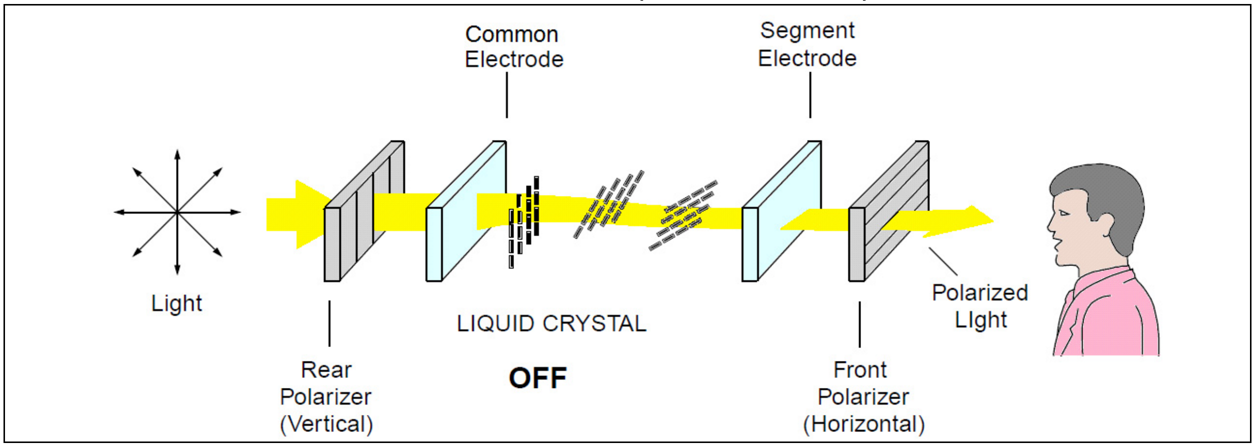
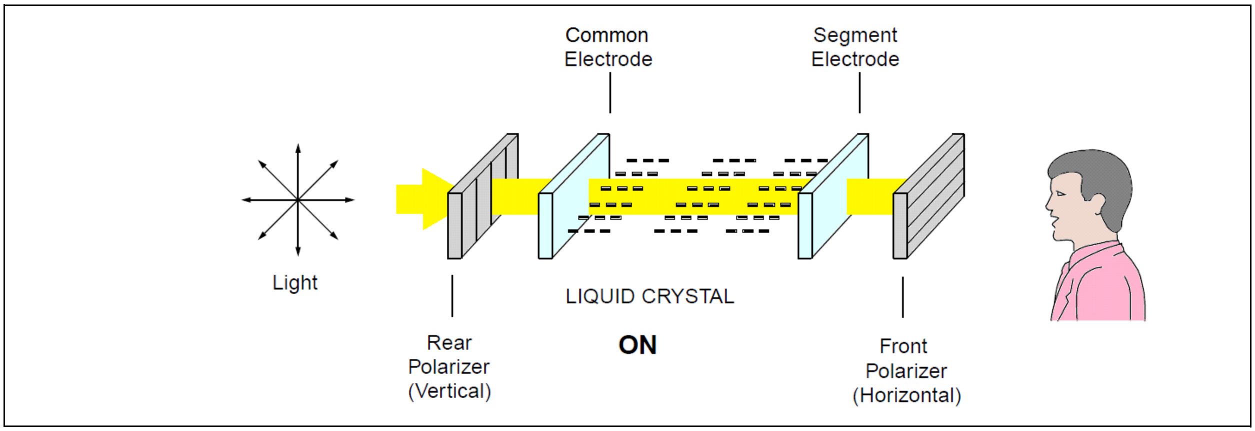


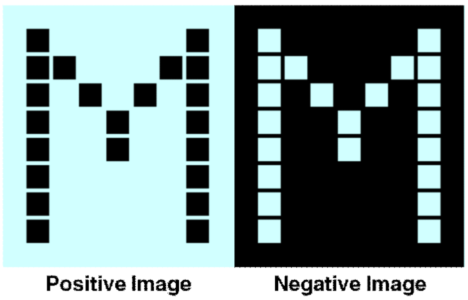
FIGURE 9: PATH OF LIGHT FOR ON PIXEL



LCD IMAGES

LCDs have the capability to produce both positive and negative images. The selection of the type of image is based on the requirements of the application.

FIGURE 10: POSITIVE AND NEGATIVE IMAGE



Positive Image

A positive image is defined to be a dark image on a light background, as shown in Figure 10. In a positive image display, the front and rear polarizers are perpendicular to each other. Unenergized pixels and the background transmit the light and energized pixels obstruct the light creating dark images on the light background. Positive images are usually used in applications where ambient light is high and it is also capable of multiple background colors.

Negative Image

Unlike a positive image, a negative image is a light image on a dark background (see Figure 10). In this type of display, the front and rear polarizers are aligned to each other. Unenergized pixels and the background inhibit light from passing through the display. Energized pixels allow the light to pass creating a light image on a dark background. Typically, negative images are employed in backlit LCDs with medium to dim ambient lighting conditions. The display is also capable of multiple pixel colors.

LCD Viewing Modes

There are essentially three types of viewing modes for an LCD: reflective, transmissive, and transflective.

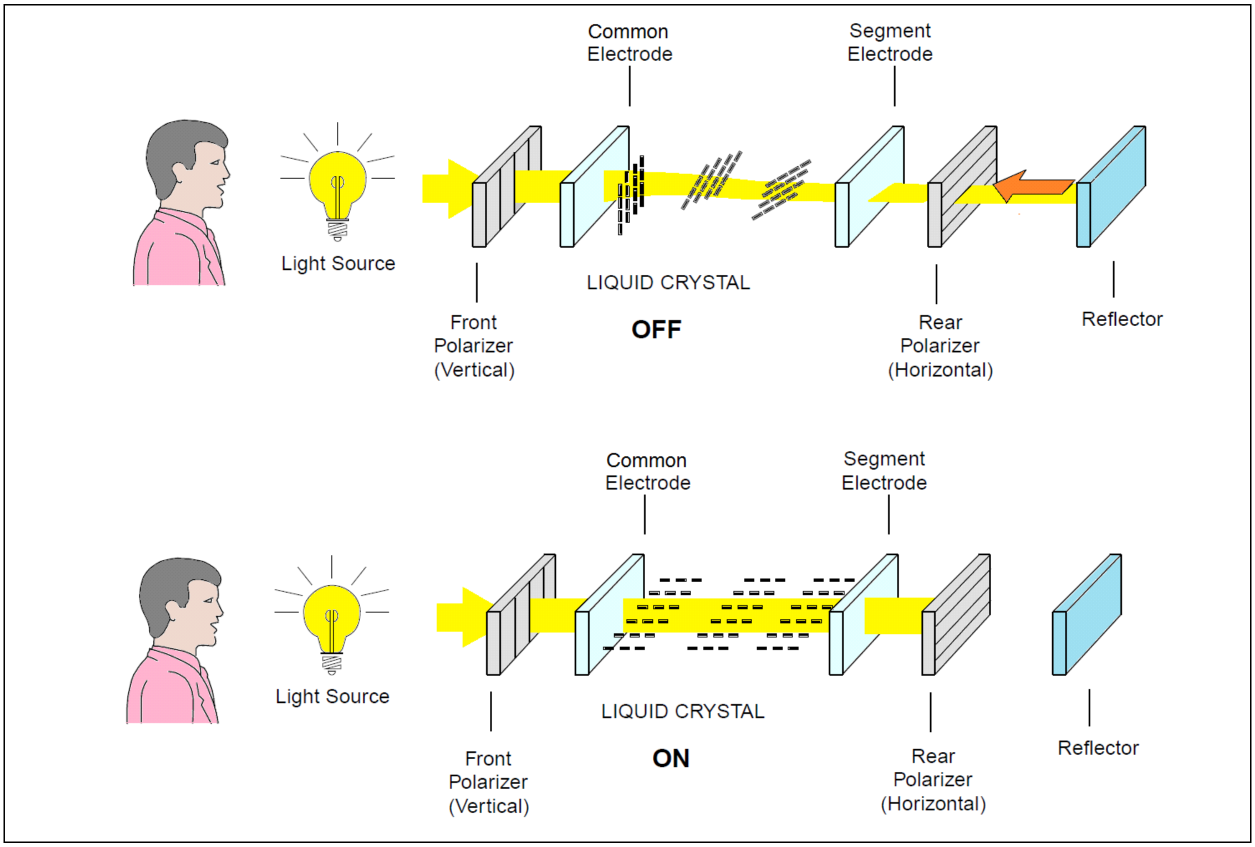
Reflective Displays

Typically, reflective displays use only positive images. The front and rear polarizers are perpendicular to each other. The LCD panel will have an additional layer added to the bottom of the display, a reflector. Figure 11 shows the diagrams for pixels that are ON and OFF for reflective displays. The path that light takes is described below in a step-by-step fashion for a pixel that is OFF in a positive image display.

- Light enters the panel through the front polarizer. At this point, the light becomes polarized to the vertical plane.
- The polarized light passes unobstructed through the transparent common electrode.
- As the polarized light passes through the LC fluid, it gets twisted into the horizontal plane.
- The polarized light passes unobstructed through the transparent segment electrode.
- Since the light is now polarized in the horizontal plane, it passes unobstructed through the rear polarizer which has a horizontal polarization.
- The reflector behind the rear polarizer reflects the incoming light back on the same path.
- The observer sees the pixel in an OFF state, because the light was reflected back.

A pixel that is ON follows the same basic steps except that the light never reaches the reflector and therefore does not return to the observer. Reflective displays lend themselves to battery-powered applications because the images are created using ambient light sources. These displays are very bright under proper lighting conditions, exhibit excellent contrast, and have a wide viewing angle.

FIGURE 11: REFLECTIVE LCD PATH OF LIGHT



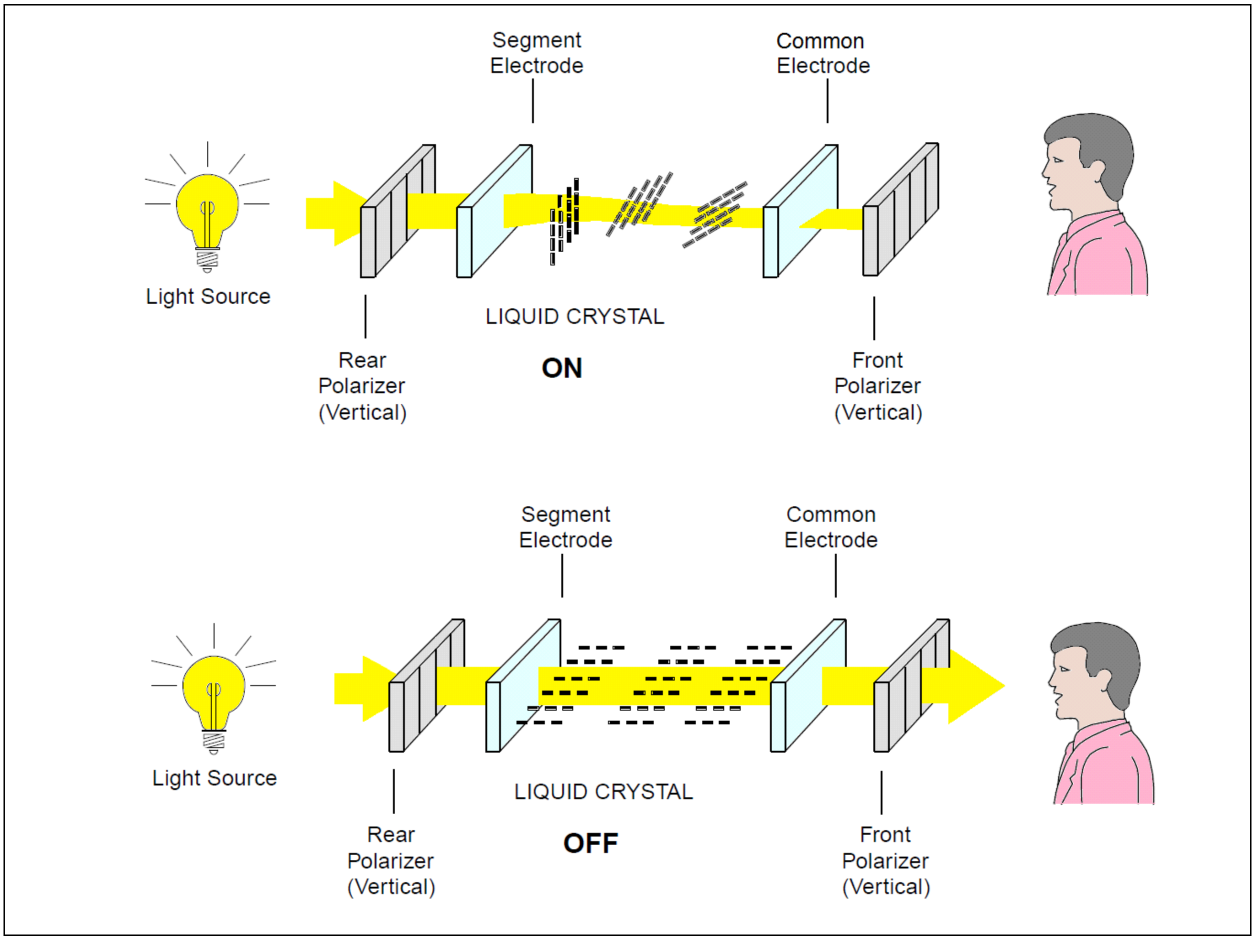
Transmissive Displays

Transmissive displays do not reflect light back to the observer. Instead, they rely upon a light source behind the panel to create images. A transmissive display has front and rear polarizers that are in phase to each other. Figure 12 shows the ON and OFF diagrams for a transmissive display. The path of light is described below for the ON state only in a negative image display.

- Light enters the panel through the rear polarizer. At this point, the light becomes polarized to the vertical plane.
- The polarized light passes unobstructed through the transparent segment electrode.
- As the polarized light passes through the LC fluid it gets twisted into the horizontal plane.
- The polarized light passes unobstructed through the transparent common electrode.
- Since the light is now polarized in the horizontal plane, it is obstructed by the front polarizer which has a vertical polarization. Very little light passes through the front polarizer.
- The observer detects that the pixel is ON because the light was obstructed.

An OFF pixel would allow the light to pass through the display unobstructed because the polarization does not get twisted by the LC fluid. These displays are very good for very low light level conditions. They are very poor when used in direct sunlight because the sunlight swamps out the backlighting.

FIGURE 12: TRANSMISSIVE LCD PATH OF LIGHT



Transflective Displays

The third type of display is called transflective. As what the name implies, it is a combination of reflective and transmissive. It reflects some of the ambient light back to the observer while also allowing backlighting. Transflective displays are very good for applications such as gas pumps.

The type of LCD that an application requires is largely dependent on the ambient light available. Table 1 gives some guidelines for selecting a display according to the lighting conditions.

TABLE 1: LIGHTING CONDITION REFERENCE

Viewing Mode	Display Description	Application Comments	Direct Sunlight	Office Light	Very Low Light
Reflective (Positive)	Dark images on light background	No backlighting. Gives best contrast and environmental stability.	Excellent	Very good	Unusable
Transflective (Positive)	Dark images on gray background	Can be viewed with both ambient light and backlighting	Excellent (no backlight)	Good (no backlight)	Very Good (backlight)
Transflective (Negative)	Light gray images on dark background	Requires high ambient light or backlighting	Good (no backlight)	Fair (no backlight)	Very Good (backlight)
Transmissive (Negative)	Backlight images on dark background	Cannot be viewed by reflection	Poor (backlight)	Good (backlight)	Excellent (backlight)
Transmissive (Positive)	Dark images on a backlight background	Good for very low-light conditions	Poor (backlight)	Good (backlight)	Excellent (backlight)

LCD BACKLIGHTING

An LCD is considered a passive device since it does not emit light by itself to produce the output display, but simply alters the light passing through it. For this reason, it needs illumination or light from external sources to produce a visible image. LCDs use a source of light coming from the rear of the display, or what is commonly known as the backlight.

In choosing the best backlighting for a specific application, it is necessary to consider several factors, such as cost, features and appearance. Backlighting has a significant effect on the contrast, brightness, and other display properties of an LCD. Each method has its own advantages and disadvantages. This section provides a brief discussion on the different backlighting methods and some of their common applications. Table 2 shows a comparison between the features of these backlighting methods.

TABLE 2: BACKLIGHTING FEATURES COMPARISON

Feature	LED	Incandescent	Electroluminescent	CCFL	Fiber Optic
Brightness	Medium-High	High	Low-Medium	High	Medium-High
Color	Many	White	White	White	Many
Size	Small	Small-Medium	Thin	Small-Medium	Thin
Voltage	3.6 VDC-12 VDC	1.5 VDC-28 VDC	2 VDC-7 VDC (requires inverter)	5 VDC-28 VDC (requires inverter)	2.2 VDC-3.6 VDC
Current @5V/sq. in	1 mA-30 mA	20 mA	1 mA-10 mA	5 mA-10 mA	10-30 mA
Temperature	Warm	Hot	Cool	Warm	Cool
Shock Tolerance	Excellent	Fragile	Excellent	Good	Excellent
Life (hours)	100,000	150-10,000	500-15,000	10,000-60,000	100,000

LED Backlight

A Light Emitting Diode (LED) is a semiconductor device that emits light when electric current passes through it. It is an excellent light source in terms of operational voltage, cost, intensity control, and some LEDs can even have a life span of almost 100,000 hours. LED has become the most popular backlighting for small and medium LCDs. LED backlighting also comes in a variety of colors. It has two basic configurations: Edge-lit and Array-lit.

As the name implies, the light source comes from the edge(s) in an edge-lit configuration. The light is then diffused into the screen through a light guide or light pipe. Edge-lit LCDs are often extremely thin, cheap, and power efficient. One drawback of edge-lit LCDs is that light distribution is not always equal which affects the image quality.

In an array-lit configuration, several rows of LEDs are mounted uniformly behind the entire display area. Unlike edge-lit, array-lit provides a more even, uniform, and brighter lighting. It can also implement “local dimming”, in which the LEDs are grouped and can be individually turned on and off independently, which means that some areas can be dimmed while others remain illuminated. Local dimming helps improve the dynamic contrast ratio of the display by dimming the parts that should be dark, while illuminating the parts that should be bright.

Incandescent Backlight

An incandescent lamp emits light when its filament is heated to a high temperature by an electric current passing through it. This backlighting method is rarely used except on applications where cost is a major consideration. This is due to its unsatisfactory performance in terms of display, life span, ruggedness, and power.

Electroluminiscent Backlight

Electroluminescence is the conversion of electrical energy into light energy by the flow of electrons, without any thermal energy or heat involved. Electroluminescent Lamps (EL) typically come in some type of panel arrangement, have the characteristics of being thin, lightweight, and can provide even light and high contrast. EL is basically a capacitor with an inorganic phosphor sandwiched between the electrodes. Since it is an AC device, it requires an inverter for power conversion. It is particularly implemented in applications using panels that have been segmented during the manufacturing process which can display static or animated images or logos.

Cold Cathode Fluorescent Lamp (CCFL)

CCFL backlight is usually implemented in medium-sized to large-sized LCD. It is a lighting system that uses both electron discharge and fluorescence. CCFL is a gas discharge lamp which uses a phosphor material, typically mercury vapor, to emit ultraviolet light, which in turn causes the fluorescent coating or phosphor to emit visible light. CCFL offers low-power consumption and very bright full spectrum white light. It is usually employed in applications requiring high brightness and high contrast. One of its major disadvantages is poor performance in low-temperature environments.

Fiber Optic Backlight

Fiber Optic Backlighting uses bulbs which are usually mounted away from the LCD panel. The type of bulb can be either incandescent lamp or LED, with the latter being the most common. The bulb provides illumination to sheets of fiber cloth to create the backlight of desired shapes, sizes and configurations. A few of the main advantages of fiber optic backlighting are more uniform light distribution, lower power consumption, and a wide range of color choices.

LCD TECHNOLOGIES

Based on technology implementation, LCD is classified into two types: Passive and Active LCDs. This section provides a comparison between these two types and a brief discussion on their subtypes. Table 3 provides a comparison between the features of Passive Matrix and Active Matrix LCDs.

TABLE 3: PASSIVE VS. ACTIVE LCD

Feature	Passive	Active
Response Time	Slower	Faster
Contrast	Poor	High
Viewing Angle	Limited	Better
Resolution	Lower	Higher
Cost	Cheap	Expensive
Hardware Implementation	Simple	Complex

Passive Matrix LCD

A passive matrix LCD uses a grid of conductive material to supply charge to a particular pixel on the display. This type of display has the same basic construction with the one in Figure 2. For the two glasses, one has rows of electrodes while the other has columns of electrodes. The intersection of these rows and columns forms a pixel. A pixel is ON when both row and column lines corresponding to this particular pixel are energized and OFF when both control lines are de-energized. When voltage is applied between these two points, the liquid crystal realigns which varies the direction of light propagation through the liquid crystal, resulting to a dark or ON pixel. Likewise, when there is no voltage between the two points, the liquid crystal return to its twisted state, resulting to a clear or OFF pixel.

One particular kind of nematic LCs is the **Twisted Nematic (TN)**, in which the rubbing directions in the two glass substrates are perpendicular to each other, creating a 90° twist of director from one substrate to the other (see Figure 3). The crossed polarizers' orientations are always parallel to the direction in which the polyimide is rubbed. When a voltage is applied, molecules align along the electric field and untwist to varying degrees, and with enough high field, the twist is removed and the light is completely blocked by the second polarizer, producing an ON pixel. When there is no voltage across the electrodes, the light passes unobstructed through the two polarizers, creating an OFF pixel.

The gray scale is achieved in TN displays by applying field strength somewhere in between the completely ON and completely OFF state. TN is primarily dependent on the response of the LC molecules to the applied voltage.

The optical performance of highly multiplexed TN LCDs has become impractical for large information displays due to its poor contrast, low brightness, and very strong viewing angle dependency. These requirements, however, were fulfilled with the invention of the **Super Twisted Nematic (STN)** LCDs. In this type of display, the molecules are twisted from 180° to 270°, producing a much steeper electro-optical threshold curves which put the ON and OFF voltages closer to each other. Steeper thresholds mean a significant increase in multiplex rates that can be achieved.

The **Film Compensated STN** is an enhanced version of the STN which was developed to produce sharper images, better contrast, and a wider viewing angle. In this type of display, a film optical filter is added between the STN display and the outer polarized filter. This technology is commonly utilized in early laptops, cellular phones, and other hand-held devices.

In contrast with the optical film used in the FSTN, **Double STN** technology utilizes two distinct STN filled glass cells to compensate light dispersion. The first glass is the LCD and the second is an inactive glass cell having no electrodes or polarizers, but only filled with LC. When this extra cell is activated, two distinct images can be produced and this technology is referred to as the **Double Active STN**. The response time of DSTN is significantly enhanced and it offers high brightness and contrast ratio, as compared with the STN and FSTN. It also has an extended operating temperature range of -30°C to 85°C, making it suitable for advanced automotive displays and some industrial applications.

Another type of passive matrix LCD is the **Color STN**, which is essentially a STN using a white backlight and red, green, and blue filters to produce a color display. Modern CSTN displays offer faster pixel response time, a larger viewing angle, and high quality color. It is also a viable alternative to active matrix LCDs when cost is a major consideration.

Active Matrix

Active matrix LCDs basically depend on the Thin Film Transistor (TFT) technology. Tiny switching transistors and capacitors are arranged in a matrix on the display glass. To activate a particular pixel, the appropriate row is turned on while a charge is transmitted along the correct column. The capacitor on the designated pixel holds the charge until the next refresh cycle. Transistors allow the pixels to be switched ON and OFF at a very fast rate. TFTs also allow a precise control of voltage to create different levels of brightness per pixel. Time dependency in multiplexed displays is also eliminated since one transistor is allocated for each pixel. Many modern television sets, laptops, mobile phones, and other high-end displays make use of this technology.

CONTRAST

The contrast of an LCD is dependent upon the amplitude of the driver voltages and the available ambient light. Overdriving the glass can result in a condition called **ghosting**, in which pixels that are supposed to be OFF appear to be ON. This usually occurs when too high drive voltage electric field influences adjacent pixels. Ghosting can also be caused by insufficient discrimination ratio and high viewing angle. High temperature is another factor which causes the LC to assume random orientation.

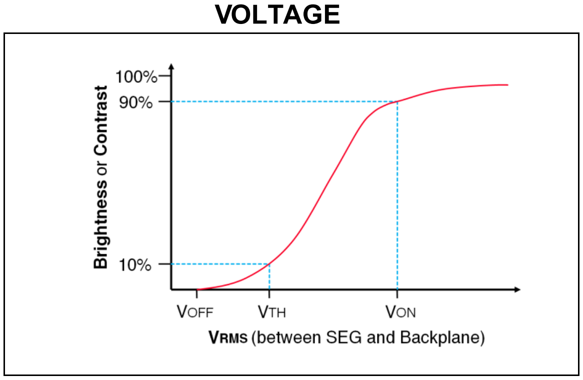
Sometimes, pixels that should be ON become barely visible. These **faint pixels** can be caused by insufficient discrimination ratio, too low drive voltage, and very low temperature. Hence, it is important to check the specifications provided by the LCD glass manufacturer to prevent damaging the glass.

DRIVER VOLTAGES

The number one cause of LCD damage is having a DC voltage applied to it. A DC voltage will deteriorate the LC fluid such that it cannot be energized. The LCD driver waveforms are designed to create a 0 VDC potential across all pixels. The specifications for an LCD panel will include some RMS voltages such as VOFF and VON. A third voltage is VTH which is the RMS voltage across an LCD pixel when contrast reaches a 10% level. Often, this voltage is used as VOFF. VON is defined as the RMS voltage applied by the LCD driver to the segment electrode that creates an ON pixel which is typically at the 90% contrast level.

Figure 13 graphically represents the voltage potential versus the contrast across a pixel. Another specification for an LCD panel is the discrimination ratio which identifies what type of contrast levels the LCD panel will be able to achieve. Examples of discrimination ratio calculations are given in the **Section "Discrimination Ratio"**.

FIGURE 13: CONTRAST vs. RMS VOLTAGE

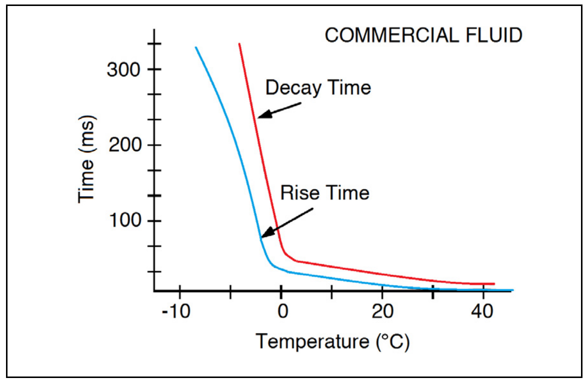


RESPONSE TIME

An LCD panel will have a typical ON and OFF response time. The ON time parameter refers to the time for an OFF pixel to become visible after the appropriate voltages have been applied. The OFF time parameter specifies the time for an ON segment to disappear. Sometimes, these parameters are called "rise" and "decay", respectively. Typically, the OFF time is somewhat larger than the ON time because the LC takes time to return to its untwisted state, unlike when it is being turned ON in which a force is being applied.

Temperature plays a key role in the response time of an LCD panel. Figure 14 shows the response time versus temperature for commercial type LC fluid. LCD panels are usually incorporated with heaters in very cold locations due to the significant increase in response time as the temperature drops below 0°C. Displays with heaters, however, have the disadvantage of consuming more power.

FIGURE 14: RESPONSE TIME vs. TEMPERATURE



TEMPERATURE EFFECTS

As previously shown, temperature has a large impact on the performance of the LCD panel. Not only is the LC fluid affected, but the internal coatings begin to deteriorate. All LC fluids have well defined operating temperature limits. If an LCD is operated above its fluid limits, the LC molecules begin to assume random orientations. The pixels on a positive image display will become completely dark, while pixels on a negative image display will become completely transparent. An LCD can recover from these conditions if the exposure is kept short. However, temperatures above 110°C will cause the ITO and polyimide coatings to deteriorate.

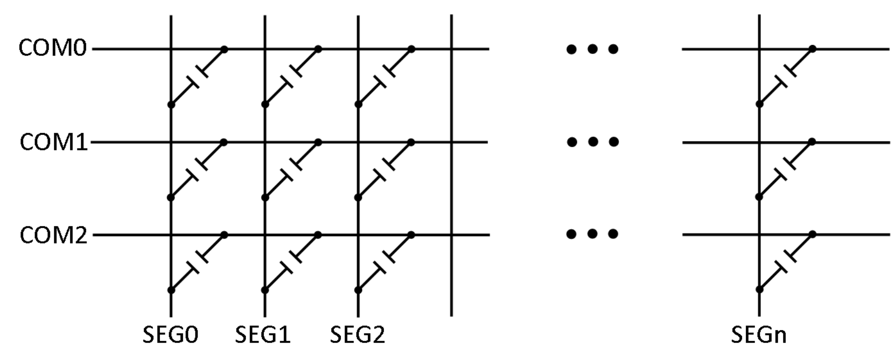
On the low end of the temperature spectrum, response time increases because the viscosity of the LC fluid increases. At very low temperatures, typically –60°C, the LC fluid transitions into a crystalline state. Usually, the LC fluid can recover from the effects of low temperature. Many different types of LC fluid are available, which allows the LCD panel to be tailored to the expected operating conditions. As mentioned in the previous section, heaters can combat the effects of low temperature.

CAPACITANCE

The LCD panel can be modeled as a lossy, non-linear capacitor. The area of the pixel, and therefore the size of the LCD panel, has a direct impact on the value of the capacitance that a common or segment driver must be able to drive. Typical values of capacitance are in the range of 1000 - 1500 pF/cm^2. Figure 15 shows an example of an LCD panel with a 1/3 multiplex ratio. LCD multiplexing is covered in more detail in **Section "Static vs. Multiplex Drive"**. The common driver must be capable of driving significantly higher capacitances than the segment driver.

Care must be taken when designing a system such that the LCD driver is capable of driving the capacitance on the segment and common. Otherwise, the LCD panel may be damaged due to a DC offset voltage generated by overloaded segment and common drivers.

FIGURE 15: 1/3 MUX EQUIVALENT CIRCUIT



STATIC vs. MULTIPLEX DRIVE

LCD panels come in many varieties depending on the application and the operating environment. LCDs can be classified in two ways. First of all, LCDs come in direct drive or multiplex drive variations. Direct drive, otherwise known as static, means that each pixel of the LCD panel has an independent driver. The LCD panel also has only one common. A static drive panel also has static bias. Bias is defined as the number of voltage levels the LCD driver uses to create images on the screen. The number of voltage levels is equivalent to 1 + 1/bias. Static bias refers to two voltage levels which create a square wave: ground and VDD. Static drive panels also have the best contrast ratios over the widest temperature range.

Multiplex drive panels reduce the overall amount of interconnections between the LCD and the drive. By utilizing more than one common, a multiplex LCD driver produces an amplitude-varying, time synchronized waveform for both the segment and commons. These waveforms allow access to one pixel on each of the commons. This significantly increases the complexity of the driver. The number of commons a panel has is referred to as the multiplexing ratio or the "MUX" of the panel. MUX also refers to duty cycle. For instance, a 1/3 MUX panel has three commons. The bias for multiplex panels is at least 1/2—1/5 for segment type drivers and from 1/8—1/33 for dot matrix. Table 4 illustrates the advantage of multiplex panels.

TABLE 4: STATIC VS. MULTIPLEX PIN COUNT

LCD Panel	Pins		
	Commons	Segments	Total
3 -1/2 Digit	1	23	24
	2	12	14
8 Digits	1	64	65
	4	16	20
2 x 16 Character Dot Matrix, 5 x 7 Characters	1	1280	1281
	8	160	168
128 x 240 Graphic Display	16	80	96
	64	480	544
	128	240	368

Table A-1 of **Appendix A: "8-Bit MCU with Integrated LCD Controllers"** shows the drive capabilities of different 8-bit PIC MCUs with integrated LCD controllers. The multiplex type and bias depend upon the LCD glass specifications provided by the manufacturer. For example, the PICDEM™ LCD 2 glass should be driven with 1/4 MUX and 1/3 Bias, while the LCD Explorer Glass should be driven with 1/8 MUX and 1/3 Bias.

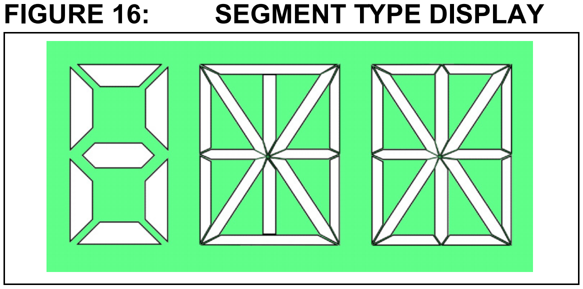
TYPES OF DISPLAY NOTATION

The other method of classifying LCD panels is the type of display notation used.

Segment Displays

Segment Displays are usually the 7-segment, 14-segment, or 16-segment ("British Flag") types used to create numbers and letters. Segment displays are typically static driven, which results in improved contrast and readability in sunlight. Figure 16 illustrates the different types of segment displays previously mentioned. Typical applications of segment displays are in calculators, digital clocks, gas station pump readouts, and other displays which do not require much detail.

FIGURE 16: SEGMENT TYPE DISPLAY



Dot Matrix

Dot matrix displays are always multiplex type displays due to the increased number of pixels required and the pin limitations of most LCD drivers. The higher number of pixels available on a dot matrix display can create more natural letters, numbers, or even custom graphic symbols. Figure 17 shows a typical 5x7 dot matrix character set.

Function Indicator or Icon

The third type of display is most commonly used in conjunction with both segmented displays and dot matrix displays. A function indicator or icon provides status information about the system, and they are only capable of being turned on or off. An example of an application that may use function indicators or icons is a digital multimeter. Digital multimeter devices typically have three 1/2 digits, which are 7-segment type and also various icons for volts, amps, ohms and the ranges for m, μ, K, and M.

Microchip's PICDEM™ LCD 2 Demonstration Board has a built-in LCD glass which can display both segment and functional displays. Figure 18 shows the display layout of this custom-made glass manufactured by the Varitronix Corporation that is part of the PICDEM LCD 2 Demonstration Board. Refer to Table 4 for the LCD glass specifications.

The LCD Explorer Development Board, Microchip's latest 8-Common LCD board for evaluation of the PIC24F, PIC18F and PIC16F LCD devices, includes an 8-Common LCD glass that displays both the dot matrix and various function indicators, as shown in Figure 19.

FIGURE 17: 5 x 7 DOT MATRIX DISPLAY

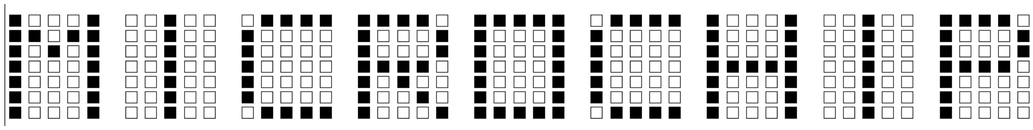


FIGURE 18: PICDEM™ LCD 2 DEMONSTRATION BOARD GLASS DISPLAY

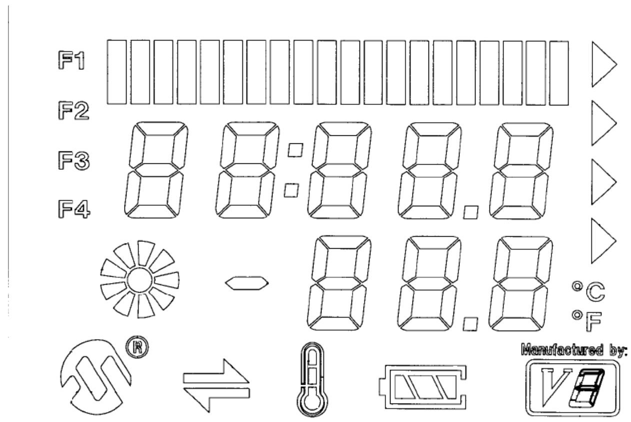
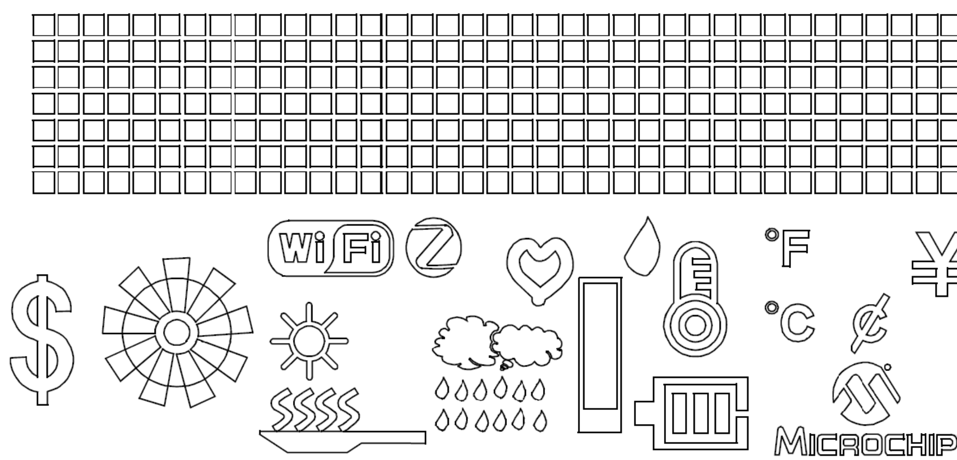


FIGURE 19: LCD EXPLORER DEMONSTRATION BOARD GLASS DISPLAY



LCD VIEWING ANGLE

The LCD viewing angle is usually specified in the glass manufacturer's data sheet. It is a term used frequently when referring to an LCD display, but its definition is often confused with the meaning of bias angle. Bias angle is the angle from the perpendicular from which the display is best viewed, and is always set during the manufacturing process. Its orientation is usually specified with reference to a clock face. An offset above the display is referred to as "12:00" or "top" view, whereas an offset below the display is referred to as "6:00" or "bottom" view. Viewing angle, on the other hand, is the angle formed on either side of the bias angle, in which the contrast of the display is still considered acceptable.

FIGURE 20: LCD VIEWING ANGLE

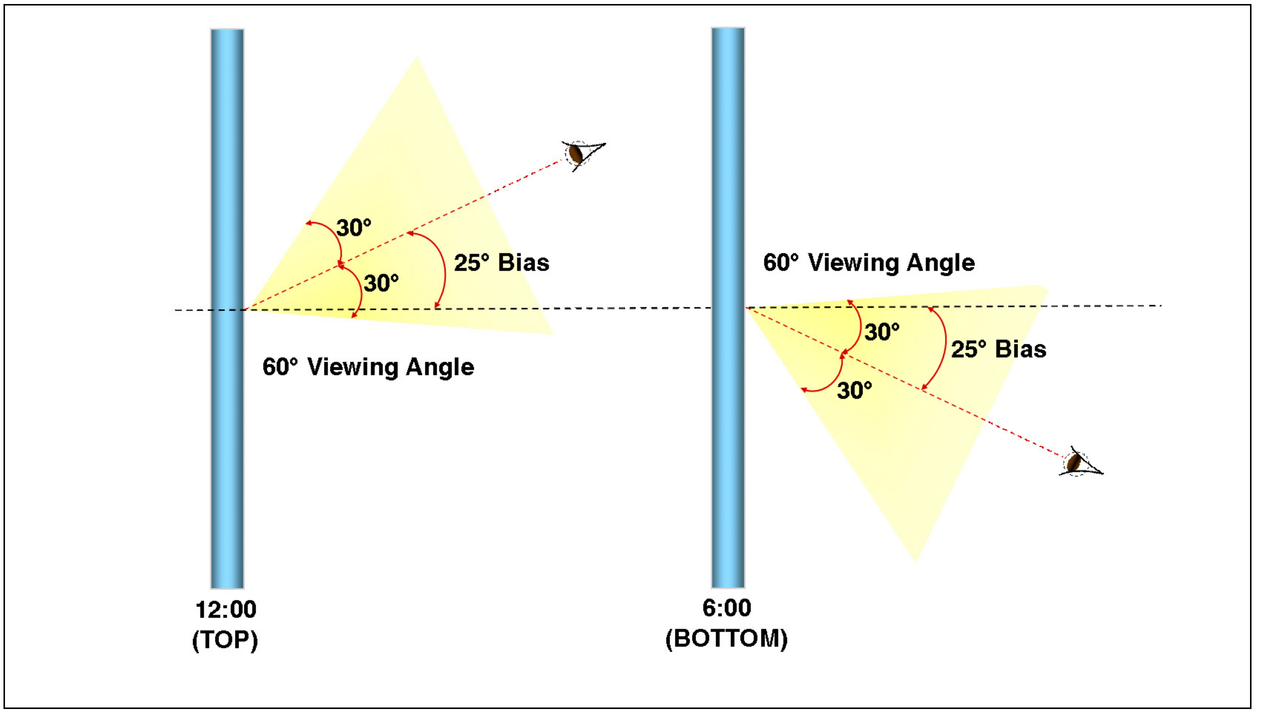


Figure 20 illustrates the LCD viewing angles for both the 12:00 and 6:00 views. For the 12:00 view, the observer can view the best contrast when looking towards the display at 25° above the horizontal, which is the bias angle. When moving the eye further 30° above or below this reference, the display can still be viewed, however, with reduced contrast. Moving the eye any further exceeding the 60° viewing angle will reduce the contrast to an undesirable level. This same basic principle applies for a display at 6:00 view, in which the bias angle is below the horizontal.

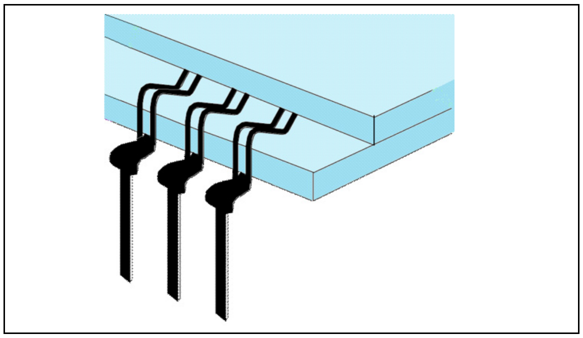
The choice of viewing position depends upon the application of the LCD. Devices that rest on the tabletop, such as calculators are usually viewed from below. A 6:00 module should be employed for such applications. For displays that are usually viewed from the top, such as the ones installed on the dashboard of a vehicle, a 12:00 module is more preferable.

CONNECTION METHODS

Dual In-Line Pins

The earliest method of connecting the LCD panel to external interface was the dual-in-line pin shown in Figure 21. These pins provide excellent protection from harsh environments, vibration or shock. The LCD panel is either soldered directly to the printed circuit board (PCB) or inserted into headers.

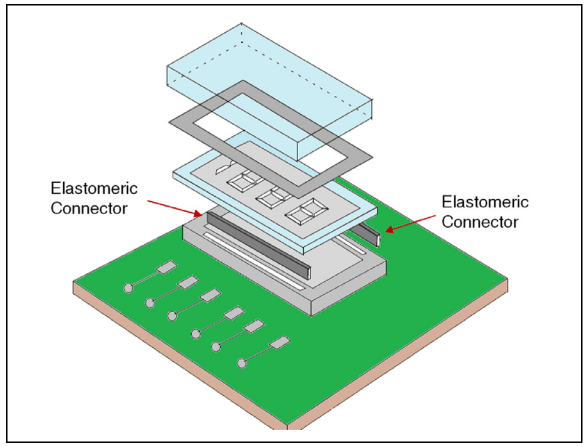
FIGURE 21: DUAL IN-LINE PINS



Elastomeric Connectors

This method allows fast assembly/disassembly without having to solder the LCD panel. Elastomeric connectors are used on small applications where space is a concern. These connectors are relatively resistant to shock and vibration, but special consideration must be used when the panel will be exposed to harsh environments. Figure 22 shows an assembly drawing of an elastomeric connector.

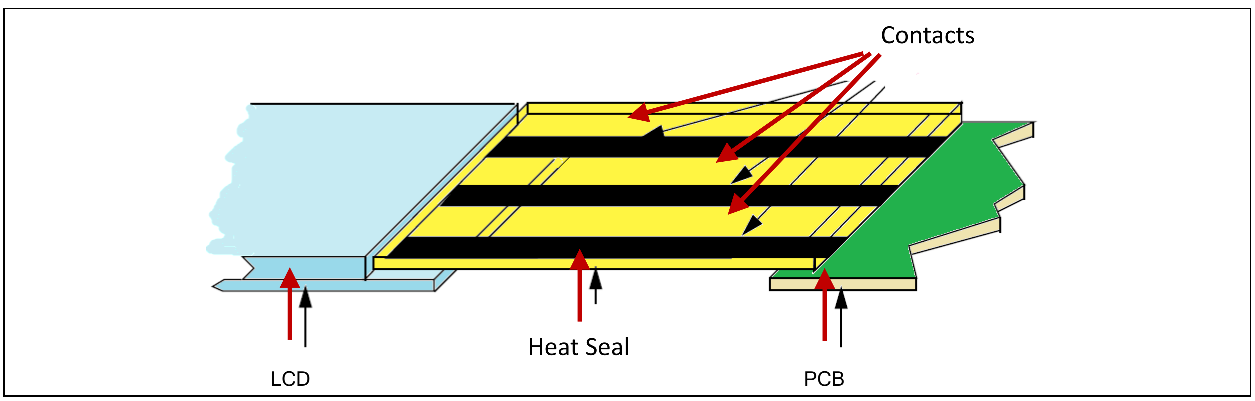
FIGURE 22: ELASTOMERIC CONNECTORS



Flex Connectors

In this method, a PCB and the LCD panel are connected by a flexible cable using a heat seal process. The flexible cable is typically an anisotropic connective film that is applied to the PCB and the LCD panel using heat and pressure. These connectors were designed for harsh environments where the connector must be flexible enough to prevent breakage during stress. These connectors are becoming more popular with large or remotely mounted LCD panels. Figure 23 shows a typical application.

FIGURE 23: FLEX CONNECTORS



THE LCD DRIVER MODULE

Microchip offers a wide range of 8-bit PIC microcontrollers with integrated LCD controllers. These devices can directly drive segmented displays with letters, numbers, characters, and icons, and are developed to meet the low-power design requirements of many LCD applications. Available in 28-, 40-, 64-, 80-, and 100-pin packages, PIC microcontrollers offer not only flexibility and ease in LCD interfacing and control, but also cut design cost by eliminating the need for several external hardware components.

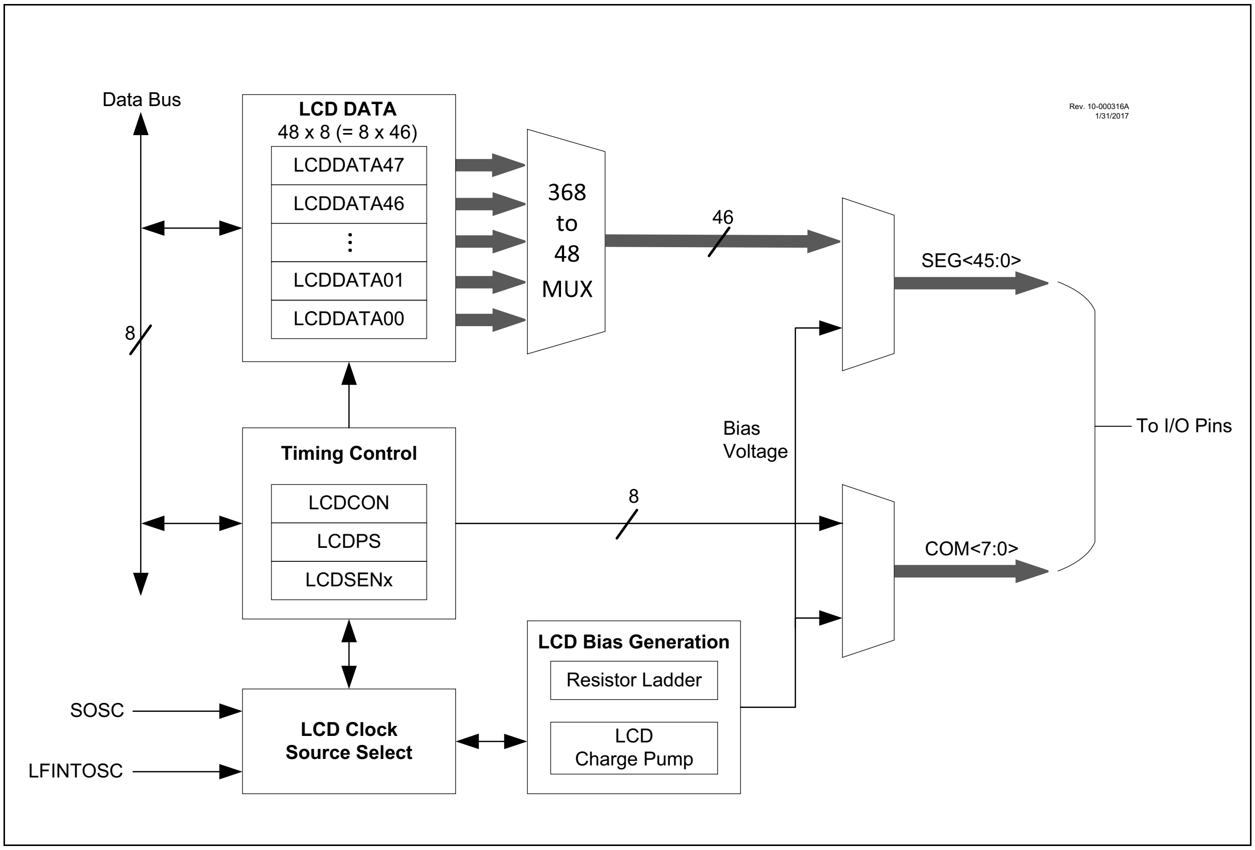
The most recent family of 8-bit PIC microcontroller devices with integrated LCD driver module including the PIC16F19197 supports:

- Direct driving of LCD panel
- Two LCD clock sources with selectable prescaler
- Up to eight commons:
  - Static (One common)
  - 1/2 Multiplex (two commons)
  - 1/3 Multiplex (three commons)
  - 1/4 Multiplex (four commons)
  - 1/5 Multiplex (five commons)
  - 1/6 Multiplex (six commons)
  - 1/7 Multiplex (seven commons)
  - 1/8 Multiplex (eight commons)
- Static, 1/2 (1/2 Multiplex only) or 1/3 LCD bias (1/3 Multiplex and higher)
- On-chip bias generator with dedicated charge pump to support a range of fixed and variable bias options
- Internal resistors for bias voltage generation
- Software contrast control through internal biasing

Table A-1 of **Appendix A: "8-Bit MCU with Integrated LCD Controllers"** provides a summary of the features of the LCD driver module of some common 8-bit PIC MCUs. In the following sections, register names will be based upon the PIC16(L)F19197 devices, unless otherwise stated.

The LCD driver modules that can be found on several families of 8-bit PIC microcontrollers are capable of generating the timing control required to drive a static or multiplexed LCD panel with support for up to 46 segments multiplexed with up to eight commons (1/8 Multiplex) for the PIC16F19197 device. Figure 24 shows the block diagram of the LCD module built into the PIC16F19197 device.

FIGURE 24: PIC16F19197 LCD CONTROLLER MODULE BLOCK DIAGRAM



LCD REGISTERS

The number of LCD registers varies depending upon the maximum number of commons and segments that can be driven by the specific device used. The web links for the data sheets of PIC devices mentioned in this application note are provided on Table C-1 of **Appendix C: "References and Related Documents"** for easy reference. To avoid complexity, this section explains the different LCD registers block by block from the PIC16F19197, as shown in Figure 24. Some of the blocks present in Figure 24 only apply to the PIC16F19197, and may not be present in older parts.

Timing Control Block

As shown in Figure 24, the Timing Control block is composed of the following registers:

- LCD Control Register (LCDCON)
- LCD Phase Register (LCDPS)
- LCD Segment Enable Registers (LCDSEx)

The LCDCON register controls the overall operation of the module. Once the module has been configured, the LCD Enable bit (LCDEN) is used to enable or disable the LCD module. The LCD panel can also operate during Sleep by clearing the LCD Display Sleep-Enabled bit (SLPEN). The Clock Source Select bit (CS) determines the LCD clock source, which is discussed in more detail in **Section "LCD Clock Sources"**. The LMUX bits of the LCDCON register are used to define the number of commons used in the application. The configuration settings of the LCDCON register must comply with the LCD glass driving scheme specifications that has been provided by the manufacturer.

The LCD Phase Register (LCDPS) is used to configure the LCD clock source prescaler and to define the type of wave-form (Type A or Type B). The LCD Prescaler Select bits (LP) of the LCDPS register determine the LCD clock source prescaler and can be configured at different values ranging from 1:1 to 1:16. The Prescaler Select (LP) bits have a direct effect on the LCD frame frequency, so it must be set accordingly to avoid ghosting or flickering of the display. **Section "LCD Frame Frequency"** provides more information regarding frame frequency limits and computation. The Waveform Type Select bit (WFT) is used to determine the type of LCD drive waveform; Type A (WFT = `0`) or Type B (WFT = `1`). An in-depth discussion between these two waveforms is presented in the section **Section "LCD Waveforms"**.

The LCD Segment Enable registers (LCDSEx) are used to configure the functions of the port pins. Setting the segment enable bit for a particular segment configures that pin as an LCD driver. Likewise, clearing the segment enable bit allows the pin to function as an I/O port. For the LCD driver found on the PIC16F19197 device, any bit set in the LCDSEx registers overrides any bit settings in the corresponding TRIS registers and all PPS options along with all other non-LCD pin functions. The number of LCDSEx registers varies per device. The PIC16F19197 has six LCDSEx registers and can drive up to 46 segments. Table 5 shows the corresponding segments that can be set by each bit of the LCDSEx registers (LCDSE5:LCDSE0).

TABLE 5: PIC16F19197 LCDSEx REGISTERS AND ASSOCIATED SEGMENTS

Register	n	Segment							
		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
		SE(n+7)	SE(n+6)	SE(n+5)	SE(n+4)	SE(n+3)	SE(n+2)	SE(n+1)	SE(n)
LCDSE0	0	7	6	5	4	3	2	1	0
LCDSE1	8	15	14	13	12	11	10	9	8
LCDSE2	16	23	22	21	20	19	18	17	16
LCDSE3	24	31	30	29	28	27	26	25	24
LCDSE4	32	39	38	37	36	35	34	33	32
LCDSE5	40	—	—	45	44	43	42	41	40

LCD Data Block

Like the Timing Control block, the LCD DATA block in Figure 24 is also present in all PIC microcontroller LCD modules. It is composed of the LCDDATAx registers. Once the LCD module has been initialized for a particular LCD panel, the individual bits of the LCDDATAx registers are cleared or set to represent a clear or dark pixel on the glass, respectively. Specific sets of LCDDATA registers are used with specific segments and common signals. Each bit of the LCDDATAx registers represents a unique combination of a specific segment connected to a specific common.

Individual bits of the LCDDATAx registers are named by the convention, "SxxCy" where "xx" signifies the segment number and "y" signifies the common number. An example of SEG and COM combinations for the PIC16F19197 device is shown in Table 7. The PIC16F19197 devices have 46 LCDDATA registers (LCDDATA45:LCDDATA0). For a complete detailed listing of the bits associated with the LCDDATAx registers, refer to the device data sheets.

To understand more about these common and segments combination, a simple example is presented in the **Section "LCD Segment Mapping"**.

TABLE 6: PIC16F19197 LCDDATAX REGISTERS FOR SEGMENT AND COMMON COMBINATIONS

COM Lines	Segments					
	0 to 7	8 to 15	16 to 23	24 to 31	32 to 39	40 to 45
0	LCDDATA0 S00C0:S07C0	LCDDATA1 S08C0:S15C0	LCDDATA2 S16C0:S23C0	LCDDATA3 S24C0:S31C0	LCDDATA4 S32C0:S39C0	LCDDATA5 S40C0:S45C0
1	LCDDATA6 S00C1:S07C1	LCDDATA7 S08C1:S15C1	LCDDATA8 S16C1:S23C1	LCDDATA9 S24C1:S31C1	LCDDATA10 S32C1:S39C1	LCDDATA11 S40C1:S45C1
2	LCDDATA12 S00C2:S07C2	LCDDATA13 S08C2:S15C2	LCDDATA14 S16C2:S23C2	LCDDATA15 S24C2:S31C2	LCDDATA16 S32C2:S39C2	LCDDATA17 S40C2:S45C2
3	LCDDATA18 S00C3:S07C3	LCDDATA19 S08C3:S15C3	LCDDATA20 S16C3:S23C3	LCDDATA21 S24C3:S31C3	LCDDATA22 S32C3:S39C3	LCDDATA23 S40C3:S45C3
4	LCDDATA24 S00C4:S07C4	LCDDATA25 S08C4:S15C4	LCDDATA26 S16C4:S23C4	LCDDATA27 S24C4:S31C4	LCDDAT28 S32C4:S39C4	LCDDATA29 S40C4:S45C4
5	LCDDATA30 S00C5:S07C5	LCDDATA31 S08C5:S15C5	LCDDATA32 S16C5:S23C5	LCDDATA33 S24C5:S31C5	LCDDATA34 S32C5:S39C5	LCDDATA35 S40C5:S45C5
6	LCDDATA36 S00C6:S07C6	LCDDATA37 S08C6:S15C6	LCDDATA38 S16C6:S23C6	LCDDATA39 S24C6:S31C6	LCDDATA40 S32C6:S39C6	LCDDATA41 S40C6:S45C6
7	LCDDATA42 S00C7:S07C7	LCDDATA43 S08C7:S15C7	LCDDATA44 S16C7:S23C7	LCDDATA45 S24C7:S31C7	LCDDATA46 S32C7:S39C7	LCDDATA47 S40C7:S45C7

LCD Bias Generation Block

There are generally two methods of generating the bias voltages required to drive different types of LCD glass: resistor ladder and charge pump. Each of these two methods can either be externally or internally supported by the PIC16F19197 device. These devices can support both and additional methods.

The PIC16F19197 device offers eight distinct circuit configurations for LCD Bias Generation:

- LCD voltage supplied from External Resistor Ladder
- LCD voltage supplied from Charge Pump + Internal Resistor Ladder
- LCD voltage supplied from Charge Pump Only (no Resistor ladder)
- LCD voltage supplied from Internal Resistor Ladder + External Capacitors + VDD for VLCD3
- LCD voltage supplied from Internal Resistor Ladder + External Capacitors + External VLCD3
- LCD voltage supplied from Internal Resistor Ladder + FVR for VLCD3
- LCD voltage supplied from Internal Resistor Ladder + VDD for VLCD3
- LCD voltage supplied from Internal Resistor Ladder + External VLCD3

LCD Bias Generation Configuration

The LCD Voltage Source Control bits (LCDVSRC) of the LCDVCON2 register determines what type of resistor biasing is used: external or internal. Setting the corresponding LCDVSRC<3:0> bits enable internal biasing. When selecting internal resistor ladder, the bias voltage source is also selected. The bias voltage can be derived from VDD, the LCD charge pump, the 3x FVR, or it can be supplied externally depending on the configuration of the LCDVSRC<3:0> bits. Refer to the device data sheet for more information regarding the different LCD Voltage Source Control bits.

If internal biasing and references are enabled in the LCDVCON2 register, contrast can be software controlled by configuring the LCD Contrast Control bits LCDCST<2:0> in the LCDREF register. The power source of the contrast control can also be selected through the LCDVSRC<3:0> bits of the LCDVCON2 register.

The **Section "LCD Biasing Methods"** provides more information on the pros and cons of external and internal biasing. The LCD Internal Reference Ladder Control (LCDRL) register provides control for the different ladder power modes, as well as the time interval for each power mode. These power modes are discussed in more detail in the **Section "Power Modes"**.

In order to use the internal charge pump on the PIC16F19197, the LCDPEN bit in Configuration Word 1 must be enabled. In the LCDVCON2 register, one of the charge pump modes needs to be selected using the LCDVSRC<3:0> bits. Once a charge pump mode is selected, the LCDVCON1 register can be used to set the Low Power mode (LPEN bit), set the voltage range (EN5V bit), and the bias voltage generated by the charge pump (BIAS<2:0>). The charge pump supports static, 1/2, and 1/3 biasing by configuring the LMUX<3:0> bits of the LCDCON register.

LCD FRAME FREQUENCY

The LCD frame frequency is the rate at which the common and segment outputs change. Table 8 shows the typical frame frequency formulas of 8-bit PIC MCUs for each multiplex type. Older devices only have three selection bits for LMUX.

The clock source depends upon the configured Clock Source Select bits CS of the LCDCON register on the specific device being used. The PIC16F19197 device is configurable for two clock source choices, while some older devices have three clock source options to drive the LCD. This will be discussed in more detail in the **Section "LCD Clock Sources"**.

The range of frame frequencies is from 25 to 250 Hz with the most common being between 50 to 150 Hz. Frequencies above 25 Hz result in higher power consumption from the LCD and present the possibility of ghosting, while lower frequencies below 25 Hz can cause visual flicker in the images displayed on the LCD panel.

TABLE 7: PIC16F19197 LCD FRAME FREQUENCY

Multiplex	LMUX<3:0>	Frame Frequency =
Static	'0001'	Clock Source/(4 x 1 x (LP<3:0> + 1))
1/2	'0010'	Clock Source/(2 x 2 x (LP<3:0> + 1))
1/3	'0011'	Clock Source/(1 x 3 x (LP<3:0> + 1))
1/4	'0100'	Clock Source/(1 x 4 x (LP<3:0> + 1))
1/5	'0110'	Clock Source/(1 x 5 x (LP<3:0> + 1))
1/6	'0111'	Clock Source/(1 x 6 x (LP<3:0> + 1))
1/7	'0111'	Clock Source/(1 x 7 x (LP<3:0> + 1))
1/8	'1000'	Clock Source/(1 x 8 x (LP<3:0> + 1))

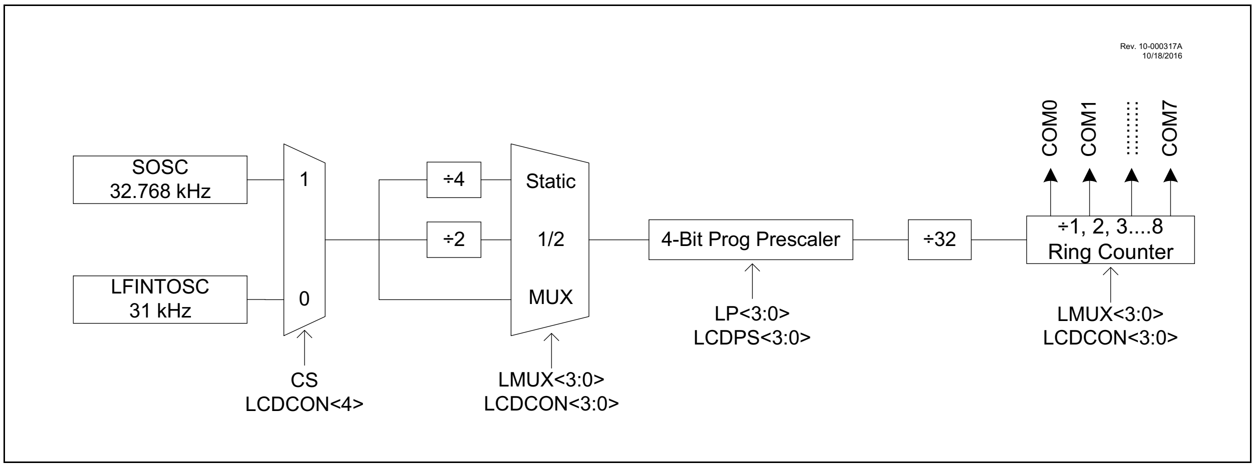
LCD CLOCK SOURCES

The LCD module found in the PIC16F19197 device offers two clock source configurations: the Low Frequency Internal RC Oscillator (LFINTOSC) or the Secondary Oscillator (SOSC). Figure 25 shows a typical diagram that illustrates how a clock is being generated for the LCD peripheral. For more information regarding clock generation, refer to the device data sheet.

The two clock sources available on the PIC16F19197 LCD module utilize a fixed divider ratio to provide an LCD clock signal of approximately 1 kHz. For example, when using LFINTOSC to drive the LCD module, the signal needs to be divided by 32 to produce a clock of approximately 1 kHz. The fixed divider ratio used to generate the 1 kHz clock signal is not software programmable. Instead, the LCD prescaler bits (LP) of the LCD Phase (LCDPS) register are used to set the frame clock rate. These bits determine the prescaler assignment and ratio.

Table B-1 of **Appendix B: "LCD Clock Sources"** shows a summary of the LCD clock sources and divider ratios, as well as the Sleep mode operation of these clock sources. Some of the available clock sources may be used discretely to continue running the LCD while the processor is in Sleep. As previously mentioned, these clock sources are selected through the Clock Selection (CS) bits of the LCDCON register.

FIGURE 25: PIC16F19197 LCD CLOCK GENERATION



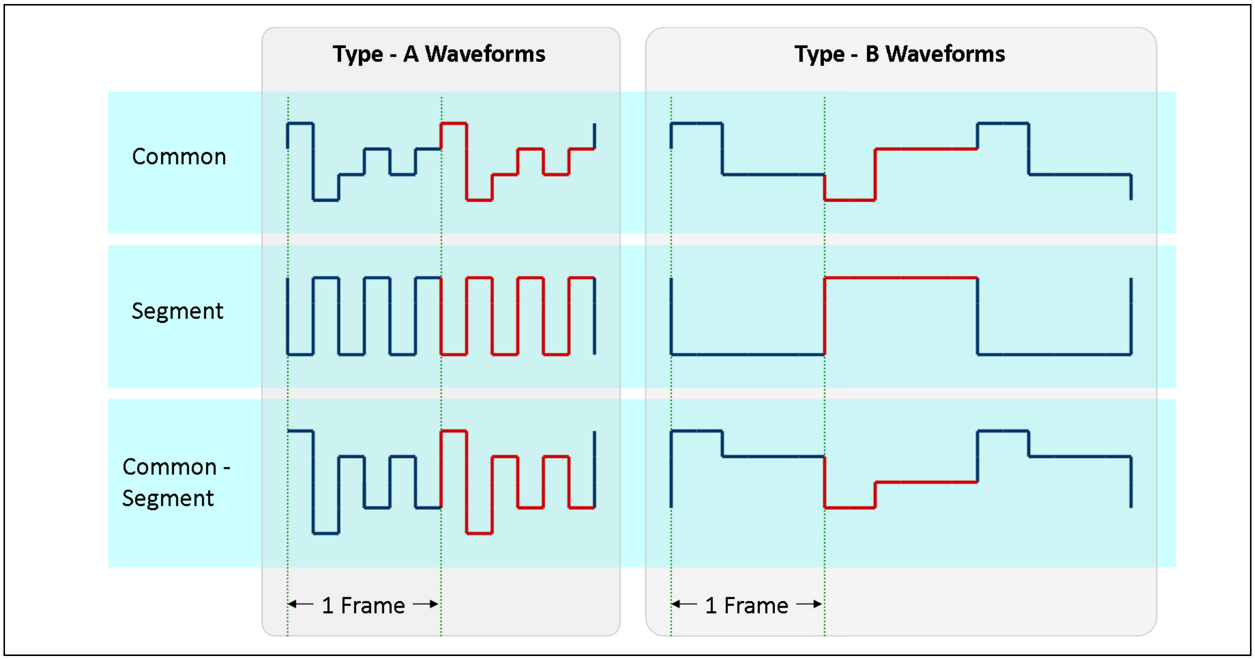
LCD WAVEFORMS

An LCD can be characterized by the MUX ratio and bias, but another important piece of information is still yet to be covered: Drive Waveforms. LCD waveforms are generated so that the net AC voltage across the dark pixel should be maximized and the net AC voltage across the clear pixel should be minimized. As mentioned earlier, the net DC voltage across any pixel should be zero to prevent damage to the LCD panel over time.

LCDs can be driven by two types of waveforms: Type A or Type B. When driving an LCD panel with a Type-A waveform, the phase changes within each common type. When driving an LCD panel with a Type-B waveform, the phase changes on each frame boundary. This means that Type-A waveforms maintain 0 VDC over a single frame, while Type-B waveforms need two frames to maintain 0 VDC.

The LCD module found on the PIC16F19197 devices support both Type-A and Type-B waveforms. Refer to the specifications of your specific LCD panel for more information about the specific drive requirements. Figure 26 illustrates both Type-A and Type-B waveforms for 1/3 Multiplex and 1/3 Bias.

FIGURE 26: TYPE-A vs. TYPE-B WAVEFORMS



The voltage applied across a particular pixel is the voltage on the COM pin minus the voltage on the SEG pin COMx-SEGx. When the resulting voltage is at or above the VON threshold, the pixel becomes visible. If the voltage is at or below the VOFF threshold, then the pixel will not be visible. This formula is used for all drive/bias methods.

The PIC16F19197 microcontroller has 8-commons and also supports both Type-A and Type-B waveforms. The PIC16F19197 is used for the examples to follow in this application note. Figure 27, Figure 28, and Figure 29 provide waveforms for static, Type-A 1/8 MUX, and Type-B 1/8 MUX, respectively. Type-A and Type-B waveforms are the same in static drive, as shown in Figure 27. They also have two voltage levels that alternate within a single frame.

Figure 28 is an example of a Type-A waveform in 1/8 MUX, 1/3 Bias Drive. For this waveform, a single frame consists of 16 time slices that correspond to twice the multiplex number. Since the waveform is a 1/3 bias drive, four voltage levels are possible for each time slice. See Table 10 for the number of voltage levels for each bias type.

A Type-B waveform in 1/8 MUX, 1/3 Bias Drive is shown in Figure 29. For this example, a single frame consists of eight time slices which is equal to the multiplex number. Each time slice also has four possible voltage levels. The differences between these LCD waveforms in terms of display contrast will be discussed in the next section.

FIGURE 27: TYPE-A/TYPE-B WAVEFORMS IN STATIC DRIVE

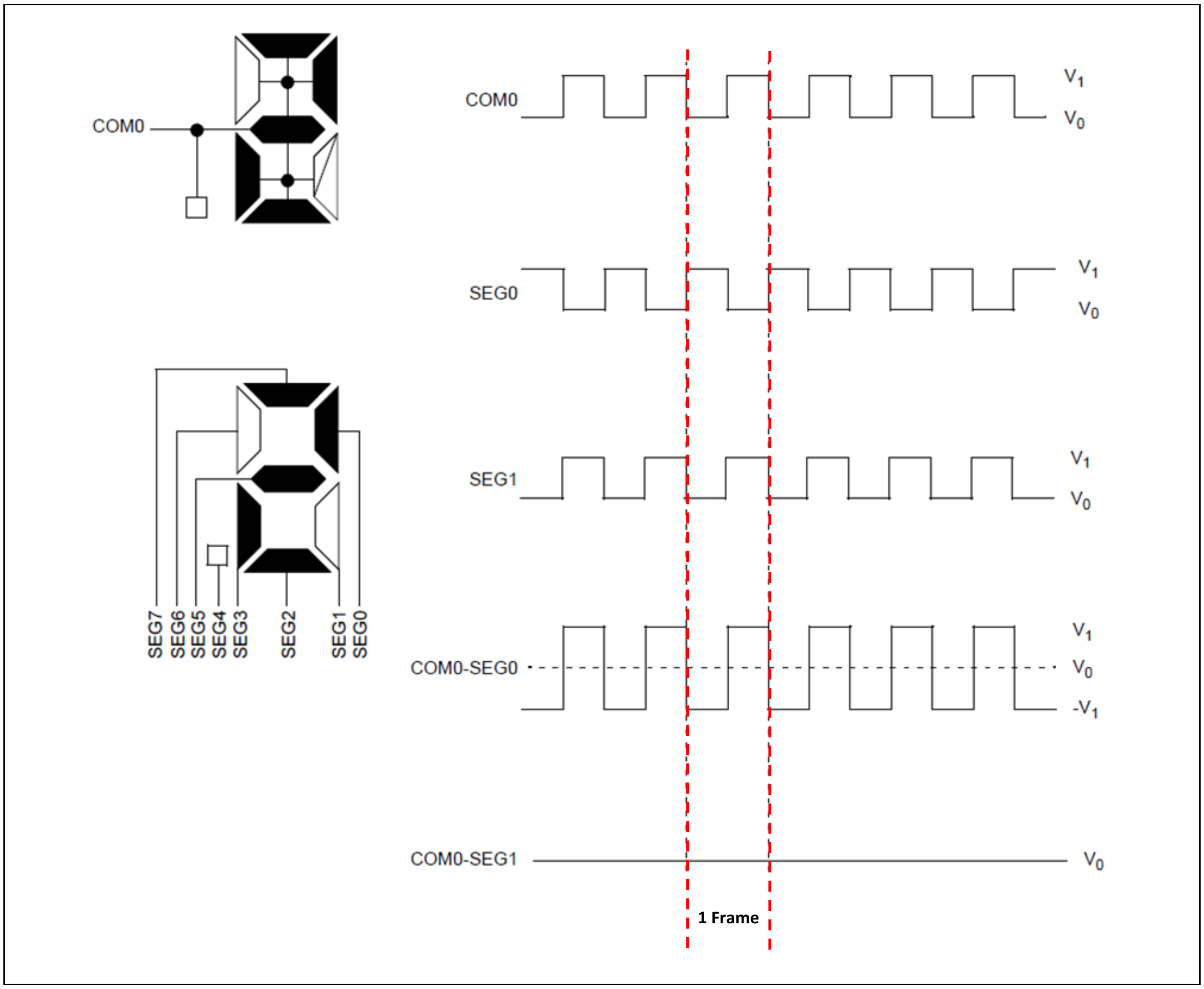


FIGURE 28: TYPE-A WAVEFORMS IN 1/8 MUX, 1/3 BIAS DRIVE

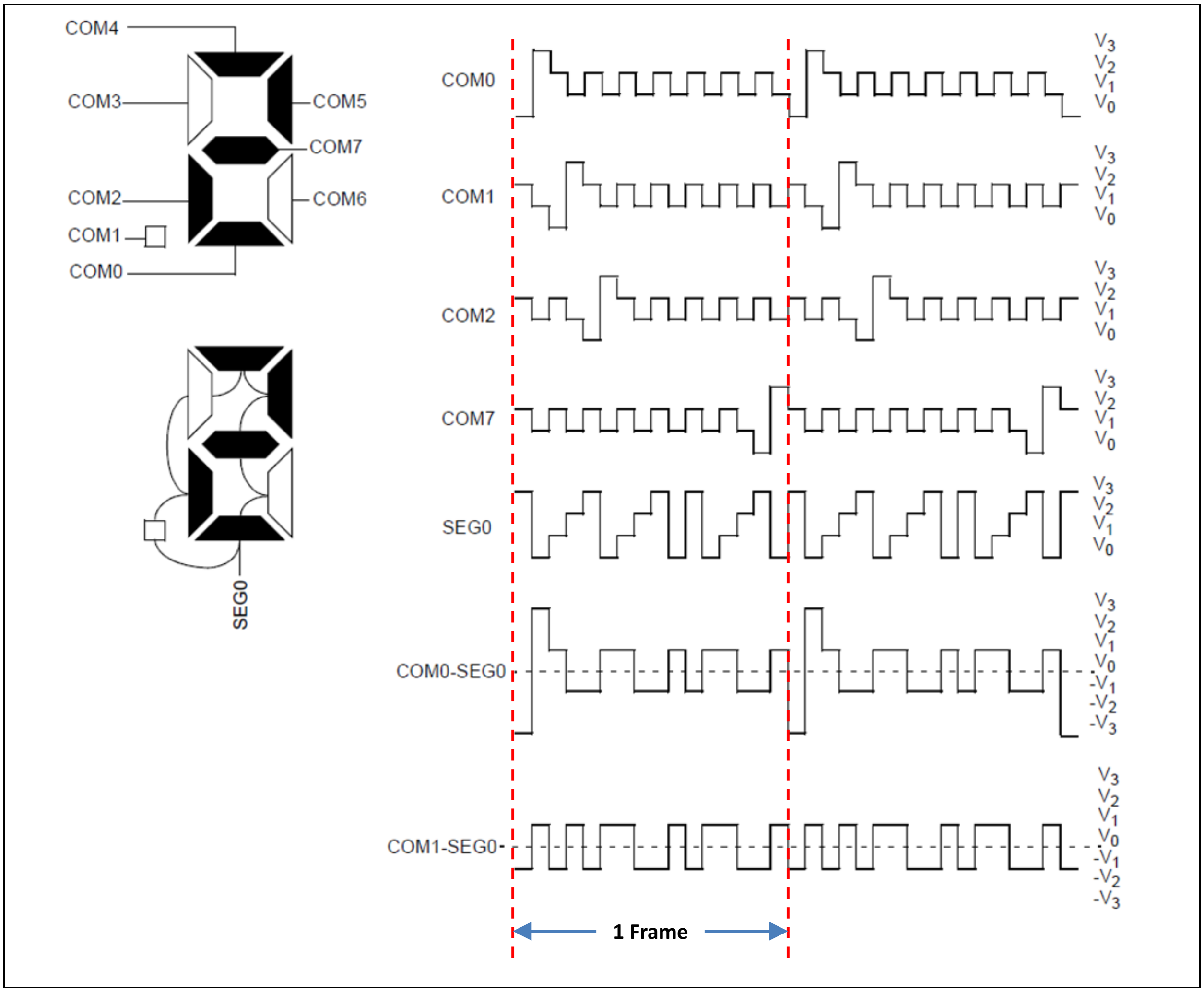
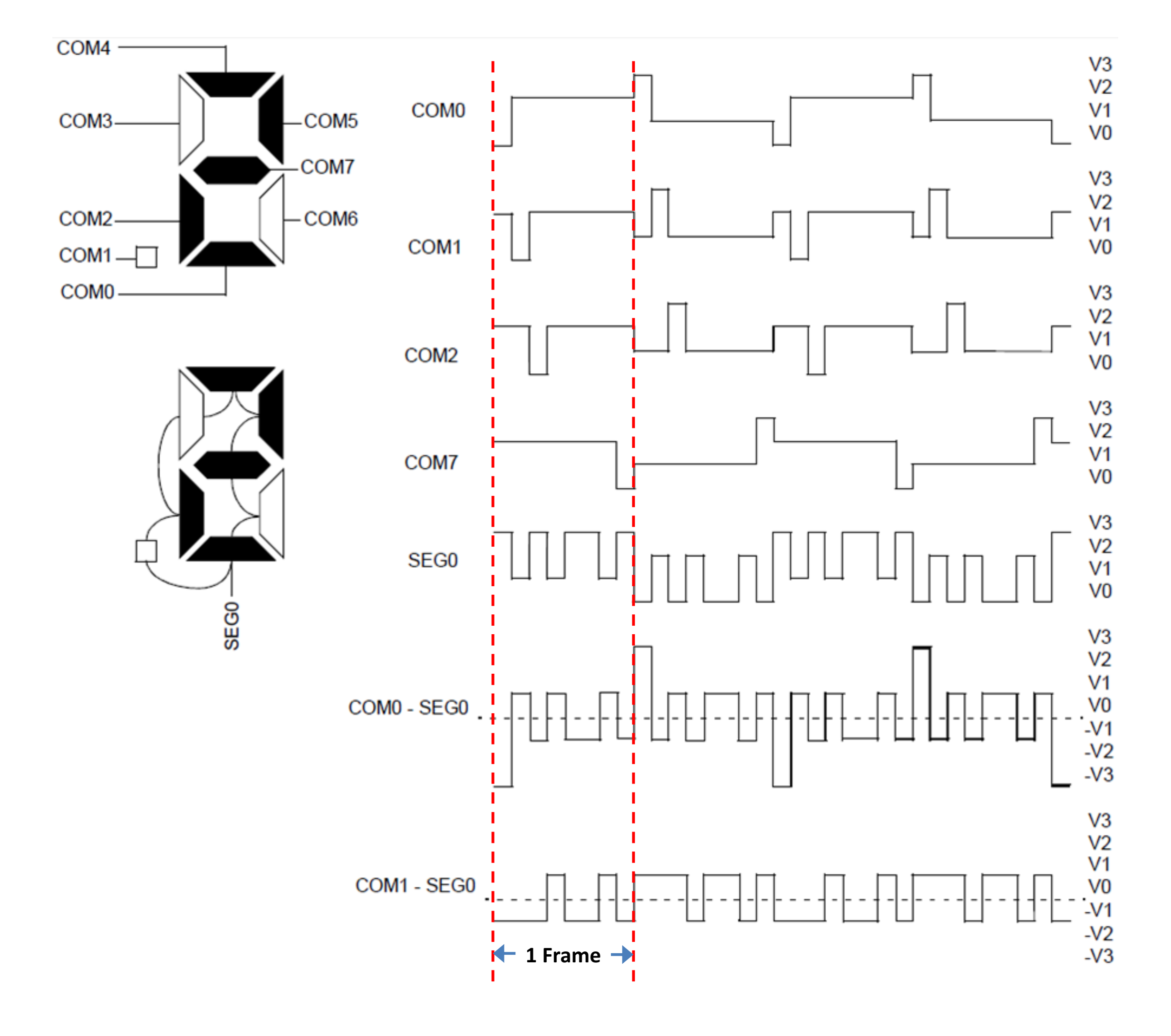


FIGURE 29: TYPE-B WAVEFORMS IN 1/8 MUX, 1/3 BIAS DRIVE



DISCRIMINATION RATIO

The contrast of an LCD can be determined by calculating the discrimination ratio. Discrimination ratio (D) is the ratio between the RMS voltage of an ON pixel with the RMS voltage of an OFF pixel, as defined by Equation 1.

EQUATION 1: DISCRIMINATION RATIO EQUATION

$$D = \frac{V_{RMS}[ON]}{V_{RMS}[OFF]}$$

The first example is the static waveform from Figure 27. The voltages V1 and V0 will be assigned values of 1 and 0, respectively. The next step is to construct a matrix for one frame to help visualize the DC and RMS voltages present on an individual pixel when it is ON and when it is OFF. Example 1 shows the calculation of the DC, RMS, and discrimination ratio.

EXAMPLE 1: DISCRIMINATION RATIO CALCULATION FOR STATIC MUX

COMx	0	1	
SEGx	1	0	ON
	0	1	OFF

$$\mathrm{COMx - SEGx\,[ON]} = -1 + 1, \quad \mathrm{V_{DC}} = 0$$
$$\mathrm{COMx - SEGx\,[OFF]} = 0 + 0, \quad \mathrm{V_{DC}} = 0$$

$$\mathrm{V_{RMS}[ON]} = \Delta\mathrm{V}\sqrt{\frac{(-1)^2 + (1)^2}{2}} = 1\Delta\mathrm{V}$$

$$\mathrm{V_{RMS}[OFF]} = \Delta\mathrm{V}\sqrt{\frac{(0)^2 + (0)^2}{2}} = 0\Delta\mathrm{V}$$

$$\mathrm{D} = \frac{\mathrm{V_{RMS}[ON]}}{\mathrm{V_{RMS}[OFF]}} = \frac{1\Delta\mathrm{V}}{0\Delta\mathrm{V}} = \infty$$

The next examples are for Figure 28 which is a Type-A, 1/8 MUX, 1/3 Bias waveform, and for Figure 29 which is a Type-B, 1/8 MUX, 1/3 Bias waveform. For these examples, the values 3, 2, 1, and 0 will be assigned to V_3, V_2, V_1, and V_0, respectively. The frame matrix, DC voltage, RMS voltage and discrimination ratio calculations for the two waveforms are shown in Example 2 and Example 3, respectively.

EXAMPLE 2: DISCRIMINATION RATIO CALCULATION FOR TYPE-A 1/8 MUX, 1/3 BIAS

COM0	0	3	2	1	2	1	2	1	2	1	2	1	2	1	2	1	
COM1	2	1	0	3	2	1	2	1	2	1	2	1	2	1	2	1	
COM2	2	1	2	1	0	3	2	1	2	1	2	1	2	1	2	1	
COM3	2	1	2	1	2	1	0	3	2	1	2	1	2	1	2	1	
COM4	2	1	2	1	2	1	2	1	0	3	2	1	2	1	2	1	
COM5	2	1	2	1	2	1	2	1	2	1	0	3	2	1	2	1	
COM6	2	1	2	1	2	1	2	1	2	1	2	1	0	3	2	1	
COM7	2	1	2	1	2	1	2	1	2	1	2	1	2	1	0	3	
SEGx	3	0	3	0	3	0	3	0	3	0	3	0	3	0	3	0	ON
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	OFF

$$\mathrm{COM0} - \mathrm{SEGx}\,[\mathrm{ON}] = -3 + 3 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1, \quad V_{DC} = 0$$

$$\mathrm{COM0} - \mathrm{SEGx}\,[\mathrm{OFF}] = -1 + 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1, \quad V_{DC} = 0$$

$$V_{RMS}[\mathrm{ON}] = \Delta V \sqrt{\frac{(-3)^2 + (3)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2}{16}}$$

$$V_{RMS}[\mathrm{ON}] = \sqrt{2}\Delta V$$

$$V_{RMS}[\mathrm{OFF}] = \Delta V \sqrt{\frac{(-1)^2 + (1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2 + (1)^2 + (-1)^2}{16}}$$

$$V_{RMS}[\mathrm{OFF}] = 1\Delta V$$

$$D = \frac{V_{RMS}[\mathrm{ON}]}{V_{RMS}[\mathrm{OFF}]} = \frac{\sqrt{2}\Delta V}{1\Delta V} = 1.414$$

EXAMPLE 3: DISCRIMINATION RATIO CALCULATION FOR TYPE-B 1/8 MUX, 1/3 BIAS

COM0	0	2	2	2	2	2	2	2	3	1	1	1	1	1	1	1	
COM1	2	0	2	2	2	2	2	2	1	3	1	1	1	1	1	1	
COM2	2	2	0	2	2	2	2	2	1	1	3	1	1	1	1	1	
COM3	2	2	2	0	2	2	2	2	1	1	1	3	1	1	1	1	
COM4	2	2	2	2	0	2	2	2	1	1	1	1	3	1	1	1	
COM5	2	2	2	2	2	0	2	2	1	1	1	1	1	3	1	1	
COM6	2	2	2	2	2	2	0	2	1	1	1	1	1	1	3	1	
COM7	2	2	2	2	2	2	2	0	1	1	1	1	1	1	1	3	
SEGx	3	3	3	3	3	3	3	3	0	0	0	0	0	0	0	0	ON
	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	OFF

2 Frames

$$\mathrm{COM0} - \mathrm{SEGx}\,[\mathrm{ON}] = -3-1-1-1-1-1-1-1+3+1+1+1+1+1+1+1, \qquad V_{DC} = 0$$

$$\mathrm{COM0} - \mathrm{SEGx}\,[\mathrm{OFF}] = -1+1+1+1+1+1+1+1+1-1-1-1-1-1-1-1, \qquad V_{DC} = 0$$

$$V_{RMS}[\mathrm{ON}] = \Delta V\sqrt{\frac{(-3)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(3)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2}{16}}$$

$$V_{RMS}[\mathrm{ON}] = \sqrt{2}\Delta V$$

$$V_{RMS}[\mathrm{OFF}] = \Delta V\sqrt{\frac{(-1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2+(-1)^2}{16}}$$

$$V_{RMS}[\mathrm{OFF}] = 1\Delta V$$

$$D = \frac{V_{RMS}[\mathrm{ON}]}{V_{RMS}[\mathrm{OFF}]} = \frac{\sqrt{2}\Delta V}{1\Delta V} = 1.414$$

It is important to note that two frames were used for the Type-B waveform in Example 3 since the phase changes on each frame boundary and takes two frames to maintain a 0 VDC. Nevertheless, the two examples resulted into the same value of discrimination ratio.

As shown in these examples, static displays have excellent contrast. Higher multiplex ratios of the LCD result in a lower discrimination ratio, and therefore the lower the contrast of the display.

Table 8 shows the VOFF, VON and discrimination ratios of the various combinations of MUX and bias. This table also shows that as the multiplex of the LCD panel increases, the discrimination ratio decreases and in turn, the contrast of the panel will also decrease. This relationship is shown graphically in Figure 30. In order to provide better contrast in these types of situations, the LCD voltages must be increased to provide greater separation between each level.

LCD SEGMENT MAPPING

Segment mapping provides a simple and organized method in determining which pixels should be ON or OFF. The LCD Explorer Development Board with the PIC16F19197 Plug-In Module (MA160019) is used in the following example. Figure 31 illustrates the glass layout with the pixel name/numbering, and Table 9 shows the COM and SEG combinations corresponding to specific pixels and function indicators in the display.

TABLE 8: DISCRIMINATION RATIO vs. MUX AND BIAS

MUX	1/3 Bias		
	V_{RMS}[OFF]	V_{RMS}[ON]	D
Static	0	1	∞
1/2	0.333	0.745	2.236
1/3	0.333	0.638	1.915
1/4	0.333	0.577	1.732
1/5	0.333	0.537	1.612
1/6	0.333	0.509	1.528
1/7	0.333	0.488	1.464
1/8	0.333	0.471	1.414

FIGURE 30: DISCRIMINATION RATIO vs. MUX

FIGURE 31: LCD EXPLORER GLASS LAYOUT WITH PIXEL NAME/NUMBERING

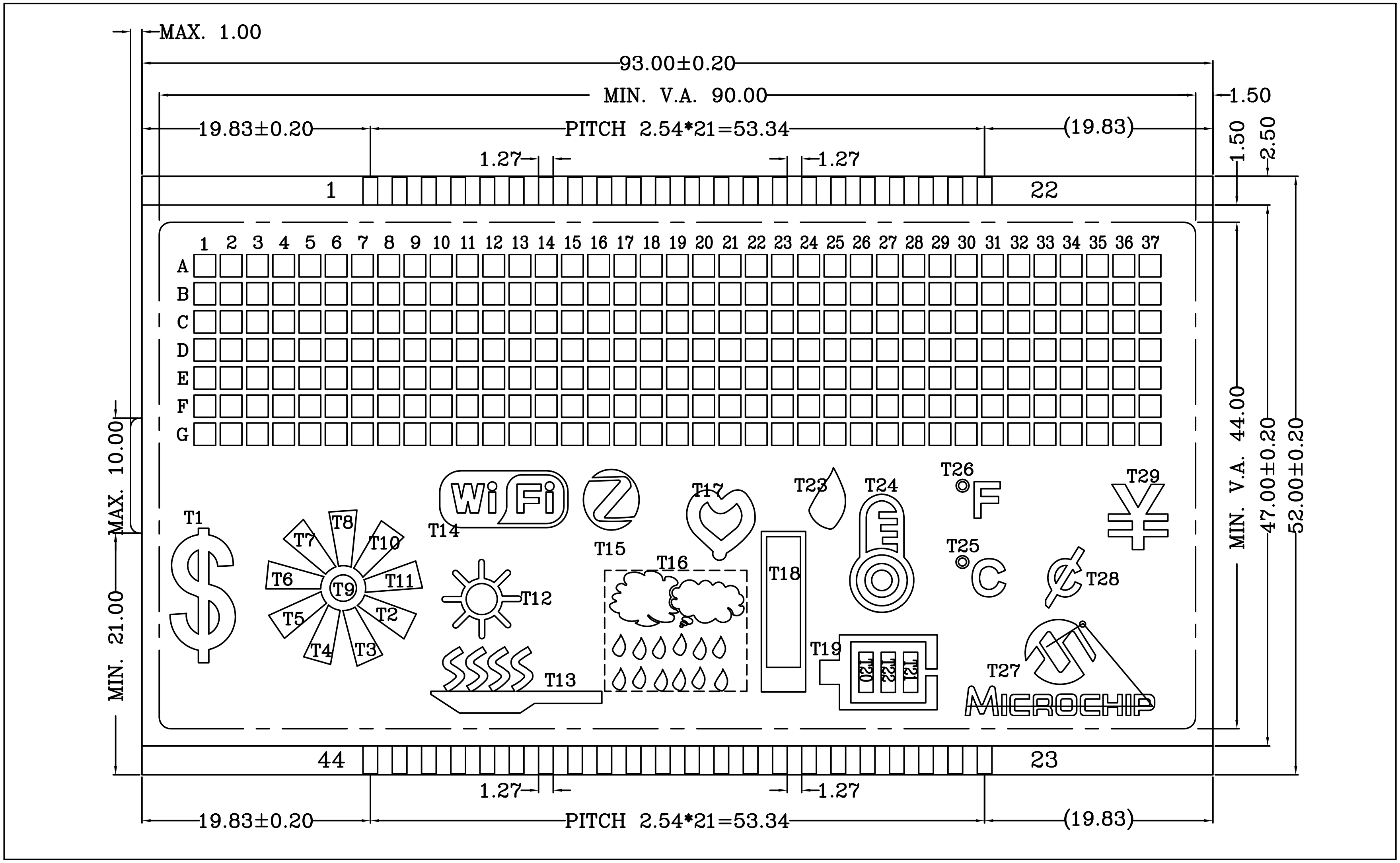


TABLE 9: COM vs. SEGMENT

PIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
COM1	1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	20A	21A	22A	30A	31A	32A	33A	34A	35A	36A	29A	28A	27A	26A	25A	24A	23A	19A	18A	17A	16A	15A	14A	13A	\	\	\	\	\	\	\	COM1
COM2	1B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	20B	21B	22B	30B	31B	32B	33B	34B	35B	36B	29B	28B	27B	26B	25B	24B	23B	19B	18B	17B	16B	15B	14B	13B	\	\	\	\	\	\	COM2	\
COM3	1C	2C	3C	4C	5C	6C	7C	8C	9C	10C	11C	12C	20C	21C	22C	30C	31C	32C	33C	34C	35C	36C	29C	28C	27C	26C	25C	24C	23C	19C	18C	17C	16C	15C	14C	13C	\	\	\	\	\	COM3	\	\
COM4	1D	2D	3D	4D	5D	6D	7D	8D	9D	10D	11D	12D	20D	21D	22D	30D	31D	32D	33D	34D	35D	36D	29D	28D	27D	26D	25D	24D	23D	19D	18D	17D	16D	15D	14D	13D	\	\	\	\	COM4	\	\	\
COM5	1E	2E	3E	4E	5E	6E	7E	8E	9E	10E	11E	12E	20E	21E	22E	30E	31E	32E	33E	34E	35E	36E	29E	28E	27E	26E	25E	24E	23E	19E	18E	17E	16E	15E	14E	13E	\	\	\	COM5	\	\	\	\
COM6	1F	2F	3F	4F	5F	6F	7F	8F	9F	10F	11F	12F	20F	21F	22F	30F	31F	32F	33F	34F	35F	36F	29F	28F	27F	26F	25F	24F	23F	19F	18F	17F	16F	15F	14F	13F	\	\	COM6	\	\	\	\	\
COM7	1G	2G	3G	4G	5G	6G	7G	8G	9G	10G	11G	12G	20G	21G	22G	30G	31G	32G	33G	34G	35G	36G	29G	28G	27G	26G	25G	24G	23G	19G	18G	17G	16G	15G	14G	13G	\	COM7	\	\	\	\	\	\
COM8	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T20	T21	T22	37A	37B	37C	37D	37E	37F	37G	T29	T28	T27	T26	T25	T24	T23	T19	T18	T17	T16	T15	T14	T13	COM8	\	\	\	\	\	\	\

The LCD Explorer Development Board glass requires 288 unique COM and SEG combinations to drive all the pixels and function indicators. The PIC16F19197 is capable of driving up to 360 segments, meaning that when using it to drive the glass on the LCD Explorer Development Board, there should be 72 unused LCD segments, as shown in Table 10. Table 10 makes it apparent that individual pixels are assigned to a specific LCDDATA bit. Unused SEG pins can be configured as digital I/O ports by clearing their respective LCDSEx bits. For example, SEG<10:9> can be configured as digital I/O ports by clearing SE<10:9> (LCDSE1<2:1>) bits.

The LCD Explorer Development Board glass is a 1/8 multiplex type, meaning that the LCD module should be configured for 8-commons (LMUX<3:0> = `1000`) when using the PIC16F19197 plug-In module. Configuring the LCD module in this way limits the glass from driving several segments due to the sharing of some COM and SEG pins. The segments that are affected by this are highlighted in red in Table 10. The computation used to determine the maximum number of pixels is discussed in the next section, **"Numbers of Pixels"**.

NUMBERS OF PIXELS

The maximum number of pixels that can be driven by any PIC microcontroller depends upon the available number of commons and segments. There are instances where a common shares the same pin with a segment which reduces the number of pixels that can be driven by the device, as discussed in the previous section. Equation 2 provides the formula for computing the maximum number of pixels for this scenario.

EQUATION 2: MAXIMUM NUMBER OF PIXELS FOR N COMMONS WITH COM AND SEG SHARED PINS

$$\text{Max No. of Pixels} = (\text{No. of Commons x No. of Segments}) - (\text{No. of Commons x No. of Shared Pins})$$

EXAMPLE 4: MAXIMUM NUMBER OF PIXELS CALCULATION FOR PIC16F19197 USING 8 COMMONS

No. of Segments = 46
No. of Commons Used = 8
No. of Shared Pin Used = 1*

Max No. of Pixels = (No. of Commons x No. of Segments) – (No. of Commons x No. of Shared Pins)
Max No. of Pixels = (8 x 46) – (8 x 1)
Max No. of Pixels = 360

*COM7 shares the same pin as SEG15.

Example 4 shows that 360 pixels can be driven using 8-common multiplexing for the PIC16F19197. The device has a maximum of 8-commons which means that it is capable of driving a total of 360 pixels. Equation 2 can be simplified to compute for the maximum number of pixels with no shared pins. The *No. of Shared Pins* simply becomes zero, and Equation 3 can be obtained.

EQUATION 3: MAXIMUM NUMBER OF PIXELS FOR N COMMONS WITH NO COM AND SEG SHARED PINS

$$\text{Max No. of Pixels} = \text{No. of Commons x No. of Segments}$$

With static drive, only COM0 is used and there are no shared pins. In this instance, the maximum number of pixels is simply the number of segments available on the PIC microcontroller. To know the number of shared pins, refer to the data sheet of the specific device used. Table A-1 of **Appendix A: "8-Bit MCU with Integrated LCD Controllers"** shows the maximum number of pixels for some common 8-bit PIC microcontrollers.

TABLE 10: SEGMENT MAPPING FOR PIC16F19197

PIC® Segment	COM0			COM1			COM2			COM3			COM4			COM5			COM6			COM7		
	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment
SEG0	0	0	15A	6	0	15B	12	0	15C	18	0	15D	24	0	15E	30	0	15F	36	0	15G	42	0	T15
SEG1	0	1	14A	6	1	14B	12	1	14C	18	1	14D	24	1	14E	30	1	14F	36	1	14G	42	1	T14
SEG2	0	2	13A	6	2	13B	12	2	13C	18	2	13D	24	2	13E	30	2	13F	36	2	13G	42	2	T13
SEG3	0	3	12A	6	3	12B	12	3	12C	18	3	12D	24	3	12E	30	3	12F	36	3	12G	42	3	T12
SEG4	0	4	23A	6	4	23B	12	4	23C	18	4	23D	24	4	23E	30	4	23F	36	4	23G	42	4	T23
SEG5	0	5	22A	6	5	22B	12	5	22C	18	5	22D	24	5	22E	30	5	22F	36	5	22G	42	5	T22
SEG6	0	6	11A	6	6	11B	12	6	11C	18	6	11D	24	6	11E	30	6	11F	36	6	11G	42	6	T11
SEG7	0	7	10A	6	7	10B	12	7	10C	18	7	10D	24	7	10E	30	7	10F	36	7	10G	42	7	T10
SEG8	1	0	7A	7	0	7B	13	0	7C	19	0	7D	25	0	7E	31	0	7F	37	0	7G	43	0	T7
SEG9	1	1	6A	7	1	6B	13	1	6C	19	1	6D	25	1	6E	31	1	6F	37	1	6G	43	1	T6
SEG10	1	2	5A	7	2	5B	13	2	5C	19	2	5D	25	2	5E	31	2	5F	37	2	5G	43	2	T5
SEG11	1	3	21A	7	3	21B	13	3	21C	19	3	21D	25	3	21E	31	3	21F	37	3	21G	43	3	T21
SEG12	1	4	30A	7	4	30B	13	4	30C	19	4	30D	25	4	30E	31	4	30F	37	4	30G	43	4	37A
SEG13	1	5	4A	7	5	4B	13	5	4C	19	5	4D	25	5	4E	31	5	4F	37	5	4G	43	5	T4
SEG14	1	6	2A	7	6	2B	13	6	2C	19	6	2D	25	6	2E	31	6	2F	37	6	2G	43	6	T2
SEG15	1	7		7	7		13	7		19	7		25	7		31	7		37	7		43	7	
SEG16	2	0	29A	8	0	29B	14	0	29C	20	0	29D	26	0	29E	32	0	29F	38	0	29G	44	0	T29
SEG17	2	1	3A	8	1	3B	14	1	3C	20	1	3D	26	1	3E	32	1	3F	38	1	3G	44	1	T3
SEG18	2	2	8A	8	2	8B	14	2	8C	20	2	8D	26	2	8E	32	2	8F	38	2	8G	44	2	T8
SEG19	2	3	18A	8	3	18B	14	3	18C	20	3	18D	26	3	18E	32	3	18F	38	3	18G	44	3	T18
SEG20	2	4	24A	8	4	24B	14	4	24C	20	4	24D	26	4	24E	32	4	24F	38	4	24G	44	4	T24
SEG21	2	5		8	5		14	5		20	5		26	5		32	5		38	5		44	5	
SEG22	2	6	17A	8	6	17B	14	6	17C	20	6	17D	26	6	17E	32	6	17F	38	6	17G	44	6	T17
SEG23	2	7	26A	8	7	26B	14	7	26C	20	7	26D	26	7	26E	32	7	26F	38	7	26G	44	7	T26
SEG24	3	0	16A	9	0	16B	15	0	16C	21	0	16D	27	0	16E	33	0	16F	39	0	16G	45	0	T16
SEG25	3	1	25A	9	1	25B	15	1	25C	21	1	25D	27	1	25E	33	1	25F	39	1	25G	45	1	T25
SEG26	3	2	32A	9	2	32B	15	2	32C	21	2	32D	27	2	32E	33	2	32F	39	2	32G	45	2	37C
SEG27	3	3		9	3		15	3		21	3		27	3		33	3		39	3		45	3	
SEG28	3	4		9	4		15	4		21	4		27	4		33	4		39	4		45	4	

TABLE 10: SEGMENT MAPPING FOR PIC16F19197 (CONTINUED)

PIC® Segment	COM0			COM1			COM2			COM3			COM4			COM5			COM6			COM7		
	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment	LCDDATA Address	Bit	LCD Segment
SEG29	3	5	20A	9	5	20B	15	5	20C	21	5	20D	27	5	20E	33	5	20F	39	5	20G	45	5	T20
SEG30	3	6	9A	9	6	9B	15	6	9C	21	6	9D	27	6	9E	33	6	9F	39	6	9G	45	6	T9
SEG31	3	7	31A	9	7	31B	15	7	31C	21	7	31D	27	7	31E	33	7	31F	39	7	31G	45	7	37B
SEG32	4	0		10	0		16	0		22	0		28	0		34	0		40	0		46	0	
SEG33	4	1	1A	10	1	1B	16	1	1C	22	1	1D	28	1	1E	34	1	1F	40	1	1G	46	1	T1
SEG34	4	2	28A	10	2	28B	16	2	28C	22	2	28D	28	2	28E	34	2	28F	40	2	28G	46	2	T28
SEG35	4	3	27A	10	3	27B	16	3	27C	22	3	27D	28	3	27E	34	3	27F	40	3	27G	46	3	T27
SEG36	4	4		10	4		16	4		22	4		28	4		34	4		40	4		46	4	
SEG37	4	5		10	5		16	5		22	5		28	5		34	5		40	5		46	5	
SEG38	4	6		10	6		16	6		22	6		28	6		34	6		40	6		46	6	
SEG39	4	7		10	7		16	7		22	7		28	7		34	7		40	7		46	7	
SEG40	5	0		11	0		17	0		23	0		29	0		35	0		41	0		47	0	
SEG41	5	1	19A	11	1	19B	17	1	19C	23	1	19D	29	1	19E	35	1	19F	41	1	19G	47	1	T19
SEG42	5	2	36A	11	2	36B	17	2	36C	23	2	36D	29	2	36E	35	2	36F	41	2	36G	47	2	37G
SEG43	5	3	35A	11	3	35B	17	3	35C	23	3	35D	29	3	35E	35	3	35F	41	3	35G	47	3	37F
SEG44	5	4	34A	11	4	34B	17	4	34C	23	4	34D	29	4	34E	35	4	34F	41	4	34G	47	4	37E
SEG45	5	5	33A	11	5	33B	17	5	33C	23	5	33D	29	5	33E	35	5	33F	41	5	33G	47	5	37D

LCD BIAS TYPES

The PIC16F19197 device microcontrollers support three bias types:

- Static Bias (two discrete voltage levels: VSS and VDD)
- 1/2 Bias (three discrete voltage levels: VSS, 1/2 VDD and VDD)
- 1/3 Bias (four discrete voltage levels: VSS, 1/3 VDD, 2/3 VDD and VDD

LCD BIASING METHODS

Refer to Table A-1 of **Appendix A: "8-Bit MCU with Integrated LCD Controllers"** for the summary of bias methods supported by different PIC MCUs.

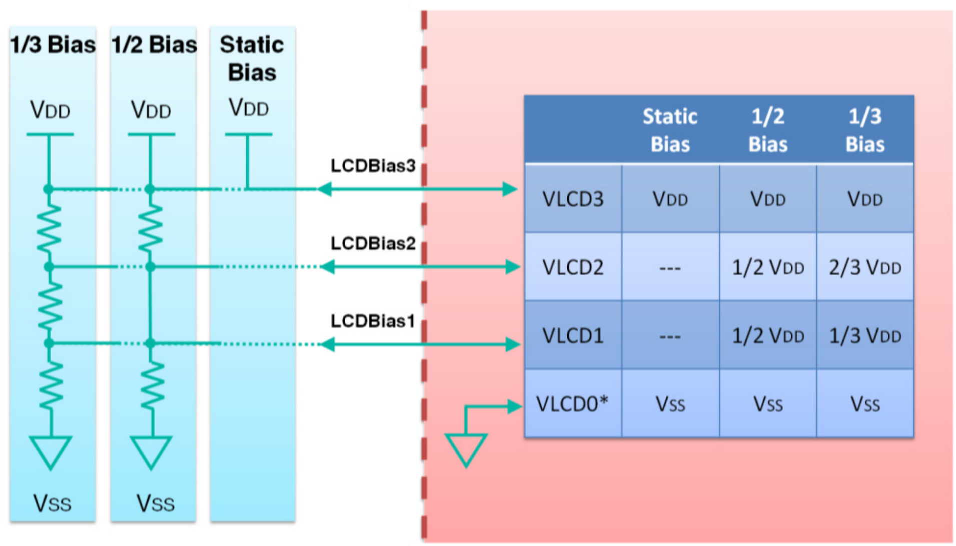
External Resistor Biasing

The resistor ladder method is most commonly used for higher VDD voltages. This method uses inexpensive resistors to create the multilevel LCD voltages. Regardless of the number of pixels that are energized, the current remains constant.

In PIC microcontrollers, the external resistor ladder should be connected to the VLCD1 pin (LCDBias 1), VLCD2 pin (LCDBias 2), VLCD3 pin (LCDBias 3) and VSS. The VLCD3 pin is used to set the highest voltage to the LCD glass and can be connected to VDD or a lower voltage.

Figure 32 shows the proper way to connect the external resistor ladder to the Bias pins.

FIGURE 32: EXTERNAL RESISTOR LADDER

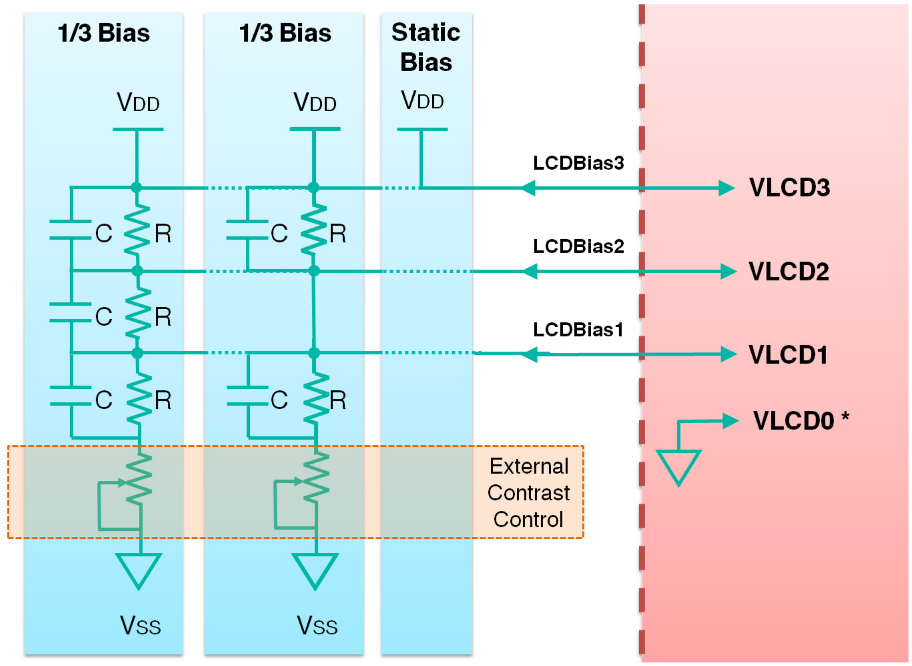


* Internal connection.

The resistance values are determined by two factors: display quality and power consumption. Display quality is a function of the LCD drive waveforms. Since the LCD panel is a capacitive load, the waveform is distorted due to the charging and discharging currents. This distortion can be reduced by decreasing the value of resistance. However, it is important to note that decreasing the resistance value will increase the current flow through the resistors. This will lead to an overall increase in power consumption. As the LCD panel increases in size, the resistance value must be decreased to maintain the image quality of the display.

Sometimes, the addition of capacitors in parallel to the resistance can reduce the distortion caused by charging/discharging currents (see Figure 33). This effect is limited since at some point, a large resistor and large capacitor cause a voltage level shift which negatively impacts the display quality. The addition of a potentiometer permits external contrast control. In general, R is 1 kΩ to 50 kΩ and the potentiometer is 5 kΩ to 200 kΩ.

FIGURE 33: EXTERNAL RESISTOR LADDER WITH PARALLEL CAPACITORS



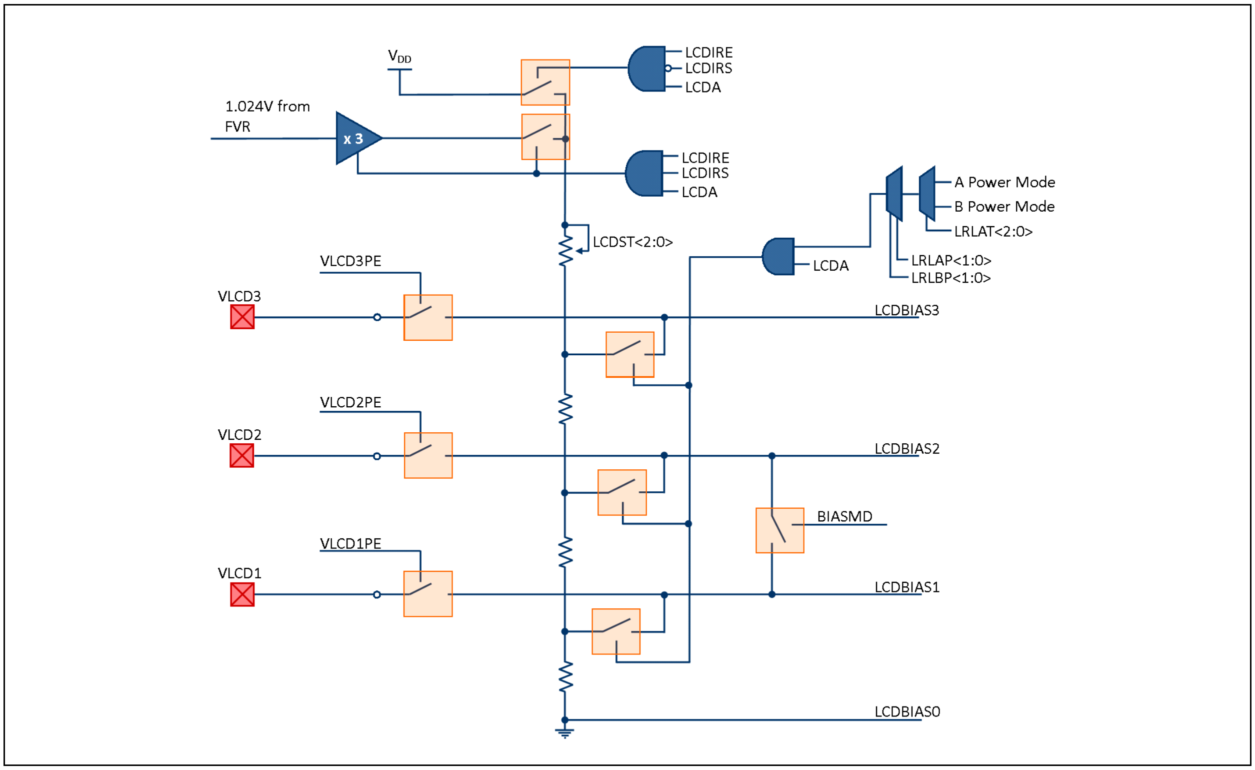
* Internal connection.

Internal Resistor Biasing

The PIC16F19197 devices, along with other newer 8-bit microcontroller devices, allow the user to perform bias generation and contrast control by utilizing internal resistor ladders to generate the LCD bias levels required to drive different panels. Utilizing the internal resistor ladder for bias generation removes the need for additional external components in LCD applications, and allows the user to save up to three pins that would have otherwise been implemented for voltage generation. This mode does not use external resistors, but instead uses internal resistor ladders that are user configured to generate the appropriate bias voltages. These features may be used in conjunction with the external VLCD<3:1> pins, to provide maximum flexibility.

The internal reference ladder can be used to divide the LCD bias voltage to two or three equally spaced voltages that will be supplied to the LCD segment pins. To create this, the reference ladder consists of three matched resistors, as shown if Figure 34.

FIGURE 34: INTERNAL RESISTOR LADDER CONNECTION DIAGRAM



When operating in 1/2 Bias mode, the middle resistor of the ladder is shorted out so that only two voltages are generated. This mode reduces the ladder resistance, thus increasing current consumption.

Figure 34 is only applicable for PIC16 devices. For PIC18 devices, the internal reference ladder consists of three separate ladders for the three power modes. The contrast control is also tied to each ladder. All other reference ladder features are more or less the same, including the internal ladder resistance and current values for the different power modes.

Disabling the internal reference ladder disconnects all of the ladders, allowing external voltages to be supplied. This can be done by configuring the appropriate LCDVRSC<3:0> bits of the LCDVCON2 register. Refer to the specific device data sheet for more details about the different configuration settings for the LCD voltage source control bits.

Power Modes

Depending on the total resistance of the resistor ladders, the biasing can be classified as low, medium or high power. This allows the user to trade off LCD contrast for power consumption in the specific application. On larger LCD panels, more capacitance is present on the physical LCD segments, requiring more current to maintain the same contrast level.

Table 11 shows the nominal resistance and nominal supply current (IDD) for each power mode of the ladder. The internal resistor ladder can be configured for bias generation and contrast control on the PIC16F19197 devices by setting the following registers:

- LCDVCON1 - LCD Voltage Control 1 bits
- LCDVCON2 - LCD Voltage Control 2 bits
- LCDRL - LCD Internal Reference Ladder Control Register
- LCDREF - LCD Reference Voltage / Contrast Control Register.

TABLE 11: INTERNAL RESISTANCE LADDER POWER MODES

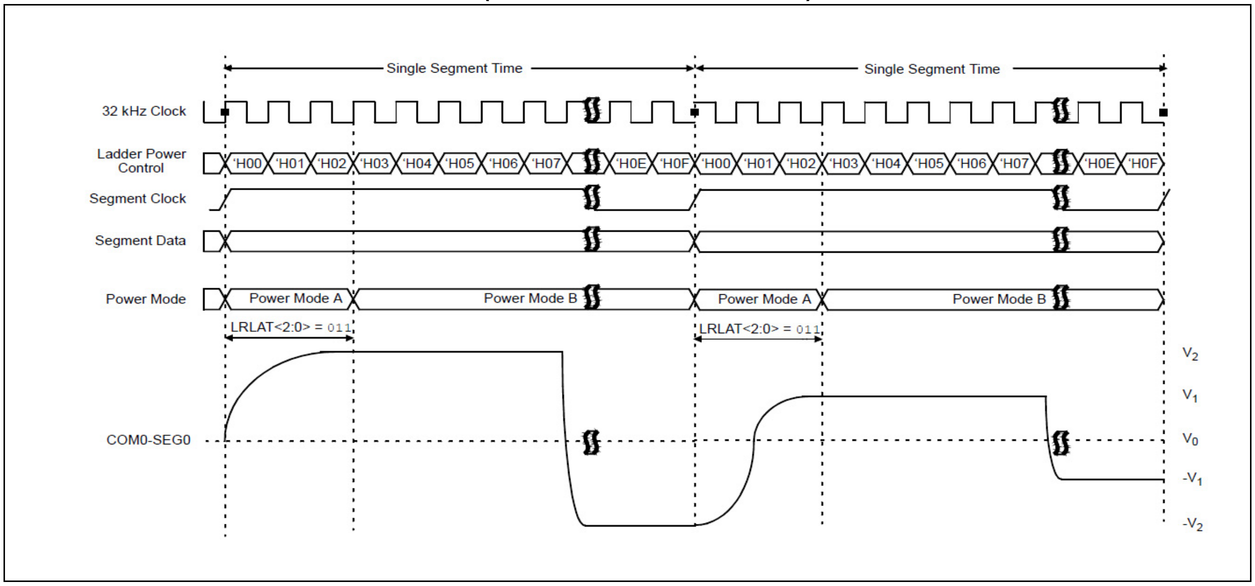
Power Mode	Nominal Resistance of Entire Ladder	I_{DD}
Low	3 MΩ	1 µA
Medium	300 kΩ	10 µA
High	30 kΩ	100 µA

As mentioned earlier, the LCD segment is electrically only a capacitor. Operating the internal reference ladder in different current modes can reduce the total device current. The LCD module supports automatic power mode switching to optimize the power consumption for a given contrast. The LCD Internal Reference Ladder Control Register (LCDRL) allows the user to configure the internal reference ladder power modes to meet the needs of the application.

There are two power modes, designated as “Mode A” and “Mode B”. Mode A is the power mode during Time Interval A and Mode B is the power mode during Time Interval B. They are selected through the LRLAP<1:0> and LRLBP<1:0> bits, respectively. Mode A is active during the time when the LCD segments transition, while Mode B is active for the remaining time before the segments or commons change again.

The LRLAT<2:0> bits are used to select how long the internal reference ladder is in each power mode. There are 32 counts in a single segment time. Mode A can be chosen during the time when the waveform is in transition, whereas Mode B can be used when the clock is stable or not in transition. Figure 35 illustrates an example of a power mode switching diagram for Type A Waveform in 1/2 MUX, 1/2 Bias with LRLAT<2:0> = `011`.

FIGURE 35: LCD INTERNAL REFERENCE LADDER POWER MODE SWITCHING DIAGRAM – TYPE A WAVEFORM (1/2 MUX, 1/2 BIAS DRIVE)

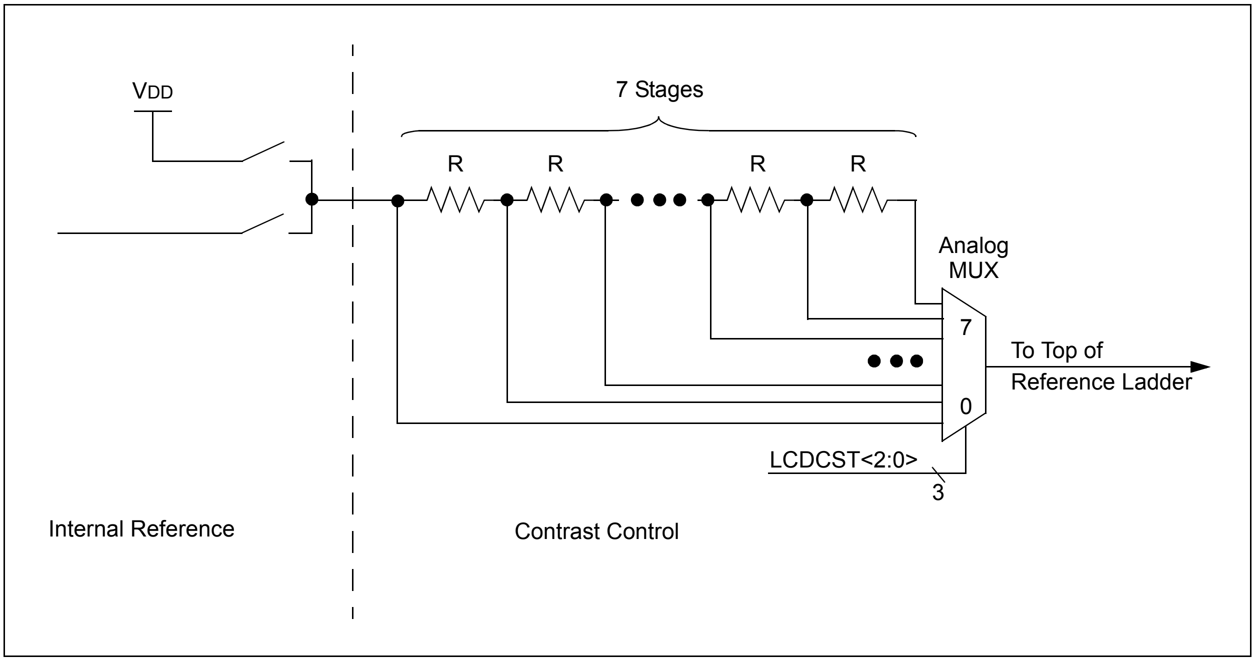


Internal Reference and Contrast Control

As shown in Figure 36, the internal contrast control circuit consists of a 7-tap resistor ladder, controlled by the LCDCST<2:0> bits of the LCDREF register.

An internal reference for the LCD bias voltages can be enabled through firmware. When enabled, the source of this voltage can be VDD. Other microcontrollers, such as the PIC16F19197 devices, have multiple options including three times FVR, VDD, External VLCD3 Voltage, or Charge Pump. When no internal reference is selected, the LCD contrast control circuit is disabled and LCD bias must be provided externally.

FIGURE 36: INTERNAL REFERENCE AND CONTRAST CONTROL BLOCK DIAGRAM



Charge Pump

Another method of generating bias voltages is through a charge pump. A charge pump is ideal for low-voltage battery operation because the VDD voltage can be boosted up to drive the LCD panel. The charge pump on the PIC16F19197 devices requires a charging capacitor and filter capacitor for each of the LCD voltage (VLCDx) pins. These capacitors are typically polyester, polypropylene, or polystyrene material. Another feature that makes the charge pump ideal for battery applications is that the current consumption is proportional to the number of pixels that are energized. The LCD charge pump feature is enabled on the PIC16F19197 by setting the LCDPEN bit in Configuration Word 1. Operation of the charge pump is controlled through bits in the LCDVCON1 register. Setting and clearing the appropriate LCDVSRC<3:0> bits in the LCDVCON2 register determine the voltage source and resistor ladder for the LCD. Using the correct settings can allow the bias voltage to be boosted above VDD or operate at a constant voltage below VDD.

Bias Configurations

There are eight distinct configurations for the LCD bias generation on PIC16(L)F19197 devices:

- M0: External Resistor Ladder
- M1: Charge Pump with Internal Resistor Ladder
- M2: Charge Pump Only
- M3: Internal Resistor Ladder with External Capacitors and VDD for VLCD3
- M4: Internal Resistor Ladder with External Capacitors and External VLCD3
- M5: Internal Resistor Ladder and 3x FVR for VLCD3
- M6: Internal Resistor Ladder and VDD for VLCD3
- M7: Internal Resistor Ladder and External VLCD3

Charge Pump Design Considerations

When using the PIC16F19197 LCD Bias M1 or M2 configuration, refer to the device data sheets for the associated diagrams and specifications. The following factors must be considered: the dynamic current and RMS (static) current of the display, and what the charge pump can actually deliver. The dynamic and static current can be determined by using Equation 4.

Example 5 and Example 6 show computations for both the dynamic and RMS current using Equation 4.

EQUATION 4: LCD DISPLAY STATIC AND DYNAMIC CURRENT EQUATION

$$I = C \times \frac{dV}{dt}$$

For dynamic current,

C = value of the capacitors attached to LCDBIAS3 and LCDBIAS2
dV = voltage drop allowed on C3 and C2 during voltage switch on the LCD
dt = duration of the transient current after a clock pulse

For RMS current,

$C = C_{FLY}$
dV = voltage across V_{LCAP1} and V_{LCAP2}
dt = regulator clock period

EXAMPLE 5: DYNAMIC CURRENT COMPUTATION

For practical design purposes, C = 0.047 µF
dV = 0.1 V
dt = 1 µs

$$I_{DYNAMIC} = 0.047\ \mu F \times \frac{0.1\ V}{1\ \mu s}$$

$$I_{DYNAMIC} = 4.7\ mA$$

EXAMPLE 6: RMS CURRENT COMPUTATION

For practical design purposes, C = 0.047 µF
dV = 1.02 V
dt = 30 µs

$$I_{RMS} = 0.047\ \mu F \times \frac{1.02\ V}{30\ \mu s}$$

$$I_{RMS} = 1.8\ mA$$

Based upon Example 5 and Example 6, the maximum theoretical static current is approximately equal to 1.8 mA. Since the charge pump must charge five capacitors, the maximum RMS current becomes 360 µA that will yield a 180 µA for 50% real-world efficiency. Users should always compare the calculated current capacity against the requirements of the LCD. While *dV* and *dt* are relatively fixed by device design, the values of C_{FLY} and the capacitors on the LCDBIAS pins can be changed to vary the current. It is always important to take note that changes should be evaluated on the actual circuit for their effect on the application.

TABLE 12: PIC16F19197 LCD BIAS CONFIGURATIONS

Bias Configuration	Charge Pump	LCDPEN	Max Bias Voltage	Bias Voltage Control	Contrast Control	Bias Types	Clock Source	CLKSEL	Application
M0 (External Resistor Ladder)	Disabled	0	VDD	External Resistor Ladder	—	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where the LCD’s current requirements exceed the capacity of the charge pump and software contrast control is not needed.
M1 (Charge Pump and Internal Resistor Ladder)	Enabled	1	+3.6 V +5.0 V	BIAS<2:0>	LCDCST<2:0>	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where the voltage requirements of the LCD are higher than the microcontroller's VDD.
M2 (Charge Pump Only)	Enabled	1	+3.6 V +5.0 V	BIAS<2:0>	LCDCST<2:0>	Static 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where the voltage requirements of the LCD are higher than the microcontroller's VDD.
M3 (Internal Resistor Ladder with External Capacitors and VDD for VLCD3)	Disabled	0	VDD	—	LCDCST<2:0>	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where VDD is expected to never drop below a level that can provide adequate contrast for the LCD.
M4 (Internal Resistor Ladder with External Capacitors and External VLCD3)	Disabled	0	VLCD3	—	LCDCST<2:0>	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where VLCD3 is expected to never drop below a level that can provide adequate contrast for the LCD.
M5 (Internal Resistor Ladder with FVR for VLCD3)	Disabled	0	3x FVR	—	LCDCST<2:0>	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where 3x FVR is expected to never drop below a level that can provide adequate contrast for the LCD.
M6 (Internal Resistor Ladder with VDD for VLCD3)	Disabled	0	VDD	—	LCDCST<2:0>	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where VDD is expected to never drop below a level that can provide adequate contrast for the LCD.
M7 (Internal Resistor Ladder with External VLCD3)	Disabled	0	VLCD3	—	LCDCST<2:0>	Static 1/2 1/3	31 kHz LFINTOSC SOSC	0 1	Used in cases where VLCD3 is expected to never drop below a level that can provide adequate contrast for the LCD.

SAMPLE INITIALIZATION CODE

Included in this application note is a multi-function example that uses the PIC16F19197 PIM attached to the LCD Explorer Development Board. The example application includes a scrolling introduction banner, voltage divider, battery voltage, and temperature reading displayed on the LCD panel. A sample initialization code for the PIC16F19197 is presented in Example 7. This example application code uses the internal LCD charge pump to power the LCD panel found on the LCD Explorer Development Board. The PIC16F19197 uses the internal LCD charge pump to generate the necessary bias voltages to drive the display and to control the contrast in this application.

When using this sample code the LCD glass will turn on all segments of the display for two seconds during initialization to verify the functionality of the LCD and the PIM, once this is complete the example code will transition into the next state. From here the LCD glass will display a rolling message that lists the features of the PIC16(L)F19197 family of devices until push button RG5 is pressed. Once RG5 has been detected the LCD glass will display the potentiometer reference voltage. Pressing RG5 again will move the example into the next state and display the voltage of the two batteries that are used to power the board. Once RG5 has been detected the example will move into the next state which will display the temperature in both Celsius and Fahrenheit on the LCD panel. The complete application firmware for this example can be found on www.microchip.com.

EXAMPLE 7: INITIALIZATION CODE FOR THE PIC16F19197

```
LCDCONbits.LCDEN = 0;  // Disable module before configuring
LCDPS = 0x02;          // LP 1:3; WFT Type-A waveform;
LCDREF = 0x00;         // LCDCST Max contrast (Min Resistance);
LCDRL = 0x00;          // LRLAP disabled; LCDIRI disabled; LRLAT Always B Power mode;
LCDVCON1 = 0x03;       // BIAS 3.10V; EN5V disabled; LPEN disabled;
LCDVCON2 = 0x86;       // CPWDT disabled; LCDVSRC Charge Pump only;

//Enable used segments
LCDSE0 = 0xFF;
LCDSE1 = 0x7F;
LCDSE2 = 0xDF;
LCDSE3 = 0xE7;
LCDSE4 = 0x0E;
LCDSE5 = 0x3E;

// CS LFINTOSC; SLPEN disabled; LMUX 1/8 COM(7:0); LCDEN enabled;
LCDCON = 0xC8;
```

CONCLUSION

Regardless of the type of LCD being implemented on any application and despite the rapid advancements on its technology, the fundamental principles of Liquid Crystal Displays remain unchanged. Everything is based on the polarization of light and the unique behavior of liquid crystals.

This application note employs a progressive approach for the designer not only to learn how an LCD operates and the different factors affecting its performance, but also to provide a brief reference on which devices to use for specific applications.

Microchip offers a wide variety of MCUs with LCD controllers that provide design flexibility and straightforward methods of driving the LCD glass. The internal biasing, contrast control and power-saving features incorporated within the module eliminate the trouble of extra hardware. This application note serves as a guide on how the designer would be able to maximize these features while maintaining the quality of the display.

APPENDIX A: 8-BIT MCU WITH INTEGRATED LCD CONTROLLERS

TABLE A-1: 8-BIT MCU LCD MODULE FEATURE COMPARISON

8-bit MCU	Max No. of Commons	Segments	Number of Pixels per Multiplex Type								No. of Clock Source Options	Bias Voltage Generator	Software Contrast Control	LCD Bias		
			Static	1/2	1/3	1/4	1/5	1/6	1/7	1/8				Static	1/2	1/3
PIC18F97J94	8	64	64	128	192	256	315*	372*	427*	480*	3	Internal Resistor Ladder Internal Voltage Reference Charge Pump	√	√	√	√
PIC18F8xJ90	4	48	48	96	144	192	—	—	—	—	3	Internal Voltage Reference Charge Pump	√	√	√	√
PIC18F6xJ90	4	33	33	66	99	132	—	—	—	—	3	Internal Voltage Reference Charge Pump	√	√	√	√
PIC18F8xK90	4	48	48	96	144	192	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√
PIC18F6xK90	4	33	33	66	99	132	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√
PIC18F8x90	4	48	48	96	144	192	—	—	—	—	3	External Resistor Ladder	—	√	√	√
PIC18F6x90	4	32	32	64	96	128	—	—	—	—	3	External Resistor Ladder	—	√	√	√
PIC16(L)F19195/6/7	8	46	46	92	138	184	230	276	322	360*	2	External Resistor Ladder Internal Resistor Ladder Internal Voltage Reference Charge Pump	√	√	√	√
PIC16(L)F19185/86	8	38	38	74*	108*	140*	170*	198*	224*	248*	2	External Resistor Ladder Internal Resistor Ladder Internal Voltage Reference Charge Pump	√	√	√	√
PIC16(L)F19175/76	8	30	30	58*	84*	108*	130*	150*	168*	184*	2	External Resistor Ladder Internal Resistor Ladder Internal Voltage Reference Charge Pump	√	√	√	√
PIC16(L)F19155/56	8	19	19	36*	51*	64*	75*	84*	91*	96*	2	External Resistor Ladder Internal Resistor Ladder Internal Voltage Reference Charge Pump	√	√	√	√
PIC16(L)F1946/47	4	46	46	92	138	184	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√
PIC16(L)F1939	4	24	24	48	72	96	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√
PIC16(L)F1938	4	16	16	32	48	60*	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√
PIC16LF1904/7	4	29	29	58	87	116	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√

TABLE A-1: 8-BIT MCU LCD MODULE FEATURE COMPARISON (CONTINUED)

8-bit MCU	Max No. of Commons	Segments	Number of Pixels per Multiplex Type								No. of Clock Source Options	Bias Voltage Generator	Software Contrast Control	LCD Bias		
			Static	1/2	1/3	1/4	1/5	1/6	1/7	1/8				Static	1/2	1/3
PIC16LF1906	4	19	19	38	57	72*	—	—	—	—	3	Internal Resistor Ladder	√	√	√	√
PIC16F946	4	42	42	84	126	168	—	—	—	—	3	External Resistor Ladder	—	√	√	√
PIC16F914/917	4	24	24	48	72	96	—	—	—	—	3	External Resistor Ladder	—	√	√	√
PIC16F913/916	4	16	16	32	48	60*	—	—	—	—	3	External Resistor Ladder	—	√	√	√

*On these devices, some commons and segments share the same pin.

APPENDIX B: LCD CLOCK SOURCES

TABLE B-1: 8-BIT MCU FAMILIES LCD CLOCK SOURCE SELECTION

8-Bit MCU Family	Clock Source	Divider Ratio	CS<1:0>	SLPEN	Operation during Sleep?
PIC16F91x	F_{OSC} (8 MHz)	8192	00	0	No
				1	No
	T1OSC Crystal Oscillator (32.768 kHz)	32	01	0	Yes
				1	No
	LFINTOSC Nominal = (31 kHz)	32	1x	0	Yes
				1	No
PIC16F190x	F_{OSC}/256	32	00	0	No
				1	No
	T1OSC Crystal Oscillator (32.768 kHz)	32	01	0	Yes
				1	No
	LFINTOSC Nominal = 31 kHz	32	1x	0	Yes
				1	No
PIC16F193x	F_{OSC}/256	32	00	0	No
				1	No
	T1OSC Crystal Oscillator (32.768 kHz)	32	01	0	Yes
				1	No
	LFINTOSC Nominal = 31 kHz	32	1x	0	Yes
				1	No
PIC16F194x	F_{OSC}/256	32	00	0	No
				1	No
	T1OSC Crystal Oscillator (32.768 kHz)	32	01	0	Yes
				1	No
	LFINTOSC Nominal = 31 kHz	32	1x	0	Yes
				1	No
PIC16F1915x/7x/8x	SOSC (32.768 kHz)	32	1	0	Yes
				1	No
	LFINTOSC Nominal = 31 kHz	32	0	0	Yes
				1	No
PIC16F1919x	SOSC (32.768 kHz)	32	1	0	Yes
				1	No
	LFINTOSC Nominal = 31 kHz	32	0	0	Yes
				1	No
PIC18F8x90	F_{OSC}/4 (8 MHz)	8192	00	0	No
				1	No
	T13CK1 Crystal Oscillator (32.768 kHz)	32	01	0	Yes
				1	No
	INTRC (31.25 kHz)	32	1x	0	Yes
				1	No
PIC18F8xJ90	(F_{OSC}/4) = 8 MHz	8192	00	0	No
				1	No
	T13CK1 Crystal Oscillator (32.768 kHz)	32	01	0	Yes
				1	No
	INTRC (31.25 kHz)	32	1x	0	Yes
				1	No

TABLE B-1: 8-BIT MCU FAMILIES LCD CLOCK SOURCE SELECTION (CONTINUED)

PIC18F8xK90	F_{OSC}/4 (8 MHz)	8192	00	0	No
				1	No
	SOSC (32.768 kHz)	32	01	0	Yes
				1	No
	INTRC (31.25 kHz)	32	1x	0	Yes
				1	No
PIC18F9xJ94	F_{OSC}/4 (8 MHz)	8192	00	0	No
				1	No
	SOSC (32.768 kHz)	32	01	0	Yes
				1	No
	INTRC (31.25 kHz)	32	1x	0	Yes
				1	No

APPENDIX C: REFERENCES AND RELATED DOCUMENTS

TABLE C-1: DATA SHEETS

PIC18F9XJ94	DS30575	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC18F97J94
PIC18F8XK90	DS39957	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC18F87K90
PIC18F8XJ90	DS39933	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC18F87J90
PIC18F8X90	DS39629	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC18F8490
PIC16F194X	DS41414	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC16F1947
PIC16F193X	DS40001574	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC16F1939
PIC16F190X	DS41569	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC16LF1907
PIC16F91X	DS41250	http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC16F917
PIC16F1919X	DS40001873	http://www.microchip.com/wwwproducts/en/PIC16F19197
PIC16F191XX	DS40001923	http://www.microchip.com/wwwproducts/en/PIC16F19155

A complete list of PIC MCUs with Integrated LCD Controller can be found on the Microchip website.

PIC® MCUs with Integrated LCD Controller Product Family:

http://www.microchip.com/pagehandler/en-us/technology/lcd/products/integrated-segment-lcd-drivers.html#Jump2Grid).

User Guides:

1. *LCD PICmicro® Tips 'n Tricks* (DS41261)
2. *PICDEM LCD 2 User's Guide* (DS51662)
3. *Introducing the LCD Explorer Demonstration Board* (DS52026)
4. *AN1428 – LCD Biasing and Contrast Control Methods* (DS01428)
5. *AN1354 – Implementing an LCD Using the PIC16F1947 Microcontroller* (DS01354)
6. *AN649 – Yet Another Clock Featuring the PIC16C924* (DS00649)
7. *TB1098 – Low-Power Techniques for LCD Applications* (DS91098)
8. *TB084 – Contrast Control Circuits for the PIC16F91X* (DS1084)
9. *PIC18FX7J94 Plug-In Module User's Guide* (DS41687)

ISBN: 978-1-5224-3605-8

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Tel: 852-2943-5100

China - Nanjing
Tel: 86-25-8473-2460

China - Qingdao
Tel: 86-532-8502-7355

China - Shanghai
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China - Shenyang
Tel: 86-24-2334-2829

China - Shenzhen
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China - Suzhou
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China - Wuhan
Tel: 86-27-5980-5300

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Tel: 86-592-2388138

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Tel: 86-756-3210040

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Japan - Tokyo
Tel: 81-3-6880- 3770

Korea - Daegu
Tel: 82-53-744-4301

Korea - Seoul
Tel: 82-2-554-7200

Malaysia - Kuala Lumpur
Tel: 60-3-7651-7906

Malaysia - Penang
Tel: 60-4-227-8870

Philippines - Manila
Tel: 63-2-634-9065

Singapore
Tel: 65-6334-8870

Taiwan - Hsin Chu
Tel: 886-3-577-8366

Taiwan - Kaohsiung
Tel: 886-7-213-7830

Taiwan - Taipei
Tel: 886-2-2508-8600

Thailand - Bangkok
Tel: 66-2-694-1351

Vietnam - Ho Chi Minh
Tel: 84-28-5448-2100

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Fax: 43-7242-2244-393

Denmark - Copenhagen
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Fax: 45-4485-2829

Finland - Espoo
Tel: 358-9-4520-820

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