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

LIGHT BLOCKED LIGHT PASSED

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.

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

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.
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.
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.
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**

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

**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.

**Electroluminescent 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>
<thead>
<tr>
<th>Feature</th>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time</td>
<td>Slower</td>
<td>Faster</td>
</tr>
<tr>
<td>Contrast</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>Viewing Angle</td>
<td>Limited</td>
<td>Better</td>
</tr>
<tr>
<td>Resolution</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Cost</td>
<td>Cheap</td>
<td>Expensive</td>
</tr>
<tr>
<td>Hardware Implementation</td>
<td>Simple</td>
<td>Complex</td>
</tr>
</tbody>
</table>

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 curve 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

COMMERCIAL FLUID

Decay Time

Rise Time
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.

FIGURE 15: 1/3 MUX EQUIVALENT CIRCUIT

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/cm². 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.

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 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.

#### 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 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 DATA
48 x 8 (≥ 8 x 46)
LCDDATA47
LCDDATA46
...
LCDDATA01
LCDDATA00

Timing Control
LCDCON
LCDPS
LCDSENx

LCD Clock Source Select
SOSC
LFINTOSC

368 to 48 MUX

SEG<45:0>

Bias Voltage

COM<7:0>

To I/O Pins

Data Bus
8

8

LCD Bias Generation
Resistor Ladder
LCD
Charge Pump

LCDDATA48 x 8 (= 8 x 46)
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 Frame Frequency”. 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>
<thead>
<tr>
<th>TABLE 5: PIC16F19197 LCDSEx REGISTERS AND ASSOCIATED SEGMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Register</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>LCDSE0</td>
</tr>
<tr>
<td>LCDSE1</td>
</tr>
<tr>
<td>LCDSE2</td>
</tr>
<tr>
<td>LCDSE3</td>
</tr>
<tr>
<td>LCDSE4</td>
</tr>
<tr>
<td>LCDSE5</td>
</tr>
</tbody>
</table>
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 LCD-DATA 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

<table>
<thead>
<tr>
<th>COM Lines</th>
<th>Segments</th>
<th>Segments</th>
<th>Segments</th>
<th>Segments</th>
<th>Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 7</td>
<td>8 to 15</td>
<td>16 to 23</td>
<td>24 to 31</td>
<td>32 to 39</td>
</tr>
<tr>
<td>0</td>
<td>LCDDATA0</td>
<td>LCDDATA1</td>
<td>LCDDATA2</td>
<td>LCDDATA3</td>
<td>LCDDATA4</td>
</tr>
<tr>
<td></td>
<td>S00C0:S07C0</td>
<td>S08C0:S15C0</td>
<td>S16C0:S23C0</td>
<td>S24C0:S31C0</td>
<td>S32C0:S39C0</td>
</tr>
<tr>
<td>1</td>
<td>LCDDATA6</td>
<td>LCDDATA7</td>
<td>LCDDATA8</td>
<td>LCDDATA9</td>
<td>LCDDATA10</td>
</tr>
<tr>
<td></td>
<td>S00C1:S07C1</td>
<td>S08C1:S15C1</td>
<td>S16C1:S23C1</td>
<td>S24C1:S31C1</td>
<td>S32C1:S39C1</td>
</tr>
<tr>
<td>2</td>
<td>LCDDATA12</td>
<td>LCDDATA13</td>
<td>LCDDATA14</td>
<td>LCDDATA15</td>
<td>LCDDATA16</td>
</tr>
<tr>
<td>3</td>
<td>LCDDATA18</td>
<td>LCDDATA19</td>
<td>LCDDATA20</td>
<td>LCDDATA21</td>
<td>LCDDATA22</td>
</tr>
<tr>
<td></td>
<td>S00C3:S07C3</td>
<td>S08C3:S15C3</td>
<td>S16C3:S23C3</td>
<td>S24C3:S31C3</td>
<td>S32C3:S39C3</td>
</tr>
<tr>
<td>4</td>
<td>LCDDATA24</td>
<td>LCDDATA25</td>
<td>LCDDATA26</td>
<td>LCDDATA27</td>
<td>LCDDATA28</td>
</tr>
<tr>
<td></td>
<td>S00C4:S07C4</td>
<td>S08C4:S15C4</td>
<td>S16C4:S23C4</td>
<td>S24C4:S31C4</td>
<td>S32C4:S39C4</td>
</tr>
<tr>
<td>5</td>
<td>LCDDATA30</td>
<td>LCDDATA31</td>
<td>LCDDATA32</td>
<td>LCDDATA33</td>
<td>LCDDATA34</td>
</tr>
<tr>
<td></td>
<td>S00C5:S07C5</td>
<td>S08C5:S15C5</td>
<td>S16C5:S23C5</td>
<td>S24C5:S31C5</td>
<td>S32C5:S39C5</td>
</tr>
<tr>
<td>6</td>
<td>LCDDATA36</td>
<td>LCDDATA37</td>
<td>LCDDATA38</td>
<td>LCDDATA39</td>
<td>LCDDATA40</td>
</tr>
<tr>
<td>7</td>
<td>LCDDATA42</td>
<td>LCDDATA43</td>
<td>LCDDATA44</td>
<td>LCDDATA45</td>
<td>LCDDATA46</td>
</tr>
<tr>
<td></td>
<td>S00C7:S07C7</td>
<td>S08C7:S15C7</td>
<td>S16C7:S23C7</td>
<td>S24C7:S31C7</td>
<td>S32C7:S39C7</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Multiplex</th>
<th>LMUX&lt;3:0&gt;</th>
<th>Frame Frequency =</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>'0001'</td>
<td>Clock Source/(4 x 1 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/2</td>
<td>'0010'</td>
<td>Clock Source/(2 x 2 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/3</td>
<td>'0011'</td>
<td>Clock Source/(1 x 3 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/4</td>
<td>'0100'</td>
<td>Clock Source/(1 x 4 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/5</td>
<td>'0110'</td>
<td>Clock Source/(1 x 5 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/6</td>
<td>'0111'</td>
<td>Clock Source/(1 x 6 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/7</td>
<td>'0111'</td>
<td>Clock Source/(1 x 7 x (LP&lt;3:0&gt; + 1))</td>
</tr>
<tr>
<td>1/8</td>
<td>'1000'</td>
<td>Clock Source/(1 x 8 x (LP&lt;3:0&gt; + 1))</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Type - A Waveforms</th>
<th>Type - B Waveforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td></td>
</tr>
<tr>
<td>Segment</td>
<td></td>
</tr>
<tr>
<td>Common - Segment</td>
<td></td>
</tr>
</tbody>
</table>

← 1 Frame →
The voltage applied across a particular pixel is the voltage on the COM pin minus the voltage on the SEG pin COM<sub>x</sub>-SEG<sub>x</sub>. When the resulting voltage is at or above the V<sub>ON</sub> threshold, the pixel becomes visible. If the voltage is at or below the V<sub>OFF</sub> 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 27: TYPE-A/TYPE-B WAVEFORMS IN STATIC DRIVE**

---

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 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

1 Frame
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**

<table>
<thead>
<tr>
<th>COMx</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEGx</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

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

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

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

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

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 V3, V2, V1, and V0, 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

<table>
<thead>
<tr>
<th>COM0</th>
<th>COM1</th>
<th>COM2</th>
<th>COM3</th>
<th>COM4</th>
<th>COM5</th>
<th>COM6</th>
<th>COM7</th>
<th>SEGx</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>OFF</td>
</tr>
</tbody>
</table>

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

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

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

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

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

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

\[ D = \frac{V_{RMS[ON]}}{V_{RMS[OFF]}} = \frac{\sqrt{2} \Delta V}{1 \Delta V} = 1.414 \]
### 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 |
| SEG x| 3 3 3 3 3 3 3 3 | 0 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 2 OFF |

2 Frames

\[
\begin{align*}
\text{COM0} - \text{SEGx}[\text{ON}] &= -3 -1 -1 -1 -1 -1 -1 +3 +1 +1 +1 +1 +1 +1 , \quad V_{\text{DC}} = 0 \\
\text{COM0} - \text{SEGx}[\text{OFF}] &= -1 +1 +1 +1 +1 +1 +1 -1 -1 -1 -1 -1 -1 , \quad V_{\text{DC}} = 0
\end{align*}
\]

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

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

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

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

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

<table>
<thead>
<tr>
<th>MUX</th>
<th>V_{R MS}[OFF]</th>
<th>V_{R MS}[ON]</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>0</td>
<td>1</td>
<td>∞</td>
</tr>
<tr>
<td>1/2</td>
<td>0.333</td>
<td>0.745</td>
<td>2.236</td>
</tr>
<tr>
<td>1/3</td>
<td>0.333</td>
<td>0.638</td>
<td>1.915</td>
</tr>
<tr>
<td>1/4</td>
<td>0.333</td>
<td>0.577</td>
<td>1.732</td>
</tr>
<tr>
<td>1/5</td>
<td>0.333</td>
<td>0.537</td>
<td>1.612</td>
</tr>
<tr>
<td>1/6</td>
<td>0.333</td>
<td>0.509</td>
<td>1.528</td>
</tr>
<tr>
<td>1/7</td>
<td>0.333</td>
<td>0.488</td>
<td>1.464</td>
</tr>
<tr>
<td>1/8</td>
<td>0.333</td>
<td>0.471</td>
<td>1.414</td>
</tr>
</tbody>
</table>

### FIGURE 30: DISCRIMINATION RATIO vs. MUX
FIGURE 31: LCD EXPLORER GLASS LAYOUT WITH PIXEL NAME/NUMBERING
| 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 |
|-----|---|---|---|---|---|---|---|---|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|

**TABLE 9: COM vs. SEGMENT**
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 LCDSEEx 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.

\[
\text{Max No. of Pixels} = (\text{No. of Commons} \times \text{No. of Segments}) - (\text{No. of Commons} \times \text{No. of Shared Pins})
\]

**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*

\[
\text{Max No. of Pixels} = (\text{No. of Commons} \times \text{No. of Segments}) - (\text{No. of Commons} \times \text{No. of Shared Pins})
\]

\[
\text{Max No. of Pixels} = (8 \times 46) - (8 \times 1)
\]

\[
\text{Max No. of Pixels} = 360
\]

*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

\[
\text{Max No. of Pixels} = \text{No. of Commons} \times \text{No. of Segments}
\]

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

<table>
<thead>
<tr>
<th>PIC® Segment</th>
<th>COM0</th>
<th>COM1</th>
<th>COM2</th>
<th>COM3</th>
<th>COM4</th>
<th>COM5</th>
<th>COM6</th>
<th>COM7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
<td>LCD DATA Address</td>
</tr>
<tr>
<td>SEG0</td>
<td>0</td>
<td>0</td>
<td>15A</td>
<td>6</td>
<td>0</td>
<td>15B</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>SEG1</td>
<td>0</td>
<td>1</td>
<td>14A</td>
<td>6</td>
<td>1</td>
<td>14B</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>SEG2</td>
<td>0</td>
<td>2</td>
<td>13A</td>
<td>6</td>
<td>2</td>
<td>13B</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>SEG3</td>
<td>0</td>
<td>3</td>
<td>12A</td>
<td>6</td>
<td>3</td>
<td>12B</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>SEG4</td>
<td>0</td>
<td>4</td>
<td>23A</td>
<td>6</td>
<td>4</td>
<td>23B</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>SEG5</td>
<td>0</td>
<td>5</td>
<td>22A</td>
<td>6</td>
<td>5</td>
<td>22B</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>SEG6</td>
<td>0</td>
<td>6</td>
<td>11A</td>
<td>6</td>
<td>6</td>
<td>11B</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>SEG7</td>
<td>0</td>
<td>7</td>
<td>10A</td>
<td>6</td>
<td>7</td>
<td>10B</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>SEG8</td>
<td>1</td>
<td>0</td>
<td>7A</td>
<td>7</td>
<td>0</td>
<td>7B</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>SEG9</td>
<td>1</td>
<td>1</td>
<td>6A</td>
<td>7</td>
<td>1</td>
<td>6B</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>SEG10</td>
<td>1</td>
<td>2</td>
<td>5A</td>
<td>7</td>
<td>2</td>
<td>5B</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>SEG11</td>
<td>1</td>
<td>3</td>
<td>21A</td>
<td>7</td>
<td>3</td>
<td>21B</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>SEG12</td>
<td>1</td>
<td>4</td>
<td>30A</td>
<td>7</td>
<td>4</td>
<td>30B</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>SEG13</td>
<td>1</td>
<td>5</td>
<td>4A</td>
<td>7</td>
<td>5</td>
<td>4B</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>SEG14</td>
<td>1</td>
<td>6</td>
<td>2A</td>
<td>7</td>
<td>6</td>
<td>2B</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>SEG15</td>
<td>1</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>SEG16</td>
<td>2</td>
<td>0</td>
<td>29A</td>
<td>8</td>
<td>0</td>
<td>29B</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>SEG17</td>
<td>2</td>
<td>1</td>
<td>3A</td>
<td>8</td>
<td>1</td>
<td>3B</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>SEG18</td>
<td>2</td>
<td>2</td>
<td>8A</td>
<td>8</td>
<td>2</td>
<td>8B</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>SEG19</td>
<td>2</td>
<td>3</td>
<td>18A</td>
<td>8</td>
<td>3</td>
<td>18B</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>SEG20</td>
<td>2</td>
<td>4</td>
<td>24A</td>
<td>8</td>
<td>4</td>
<td>24B</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>SEG21</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>14</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>SEG22</td>
<td>2</td>
<td>6</td>
<td>17A</td>
<td>8</td>
<td>6</td>
<td>17B</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>SEG23</td>
<td>2</td>
<td>7</td>
<td>26A</td>
<td>8</td>
<td>7</td>
<td>26B</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>SEG24</td>
<td>3</td>
<td>0</td>
<td>16A</td>
<td>9</td>
<td>0</td>
<td>16B</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>SEG25</td>
<td>3</td>
<td>1</td>
<td>25A</td>
<td>9</td>
<td>1</td>
<td>25B</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>SEG26</td>
<td>3</td>
<td>2</td>
<td>32A</td>
<td>9</td>
<td>2</td>
<td>32B</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>SEG27</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>15</td>
<td>3</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>SEG28</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>4</td>
<td>15</td>
<td>4</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>PIC Segment</td>
<td>COM0</td>
<td>COM1</td>
<td>COM2</td>
<td>COM3</td>
<td>COM4</td>
<td>COM5</td>
<td>COM6</td>
<td>COM7</td>
</tr>
<tr>
<td>-------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>SEG29</td>
<td>3</td>
<td>5</td>
<td>20A</td>
<td>9</td>
<td>5</td>
<td>20B</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>SEG30</td>
<td>3</td>
<td>6</td>
<td>9A</td>
<td>9</td>
<td>6</td>
<td>9B</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>SEG31</td>
<td>3</td>
<td>7</td>
<td>31A</td>
<td>9</td>
<td>7</td>
<td>31B</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>SEG32</td>
<td>4</td>
<td>0</td>
<td></td>
<td>10</td>
<td>0</td>
<td></td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>SEG33</td>
<td>4</td>
<td>1</td>
<td>1A</td>
<td>10</td>
<td>1</td>
<td>1B</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>SEG34</td>
<td>4</td>
<td>2</td>
<td>28A</td>
<td>10</td>
<td>2</td>
<td>28B</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>SEG35</td>
<td>4</td>
<td>3</td>
<td>27A</td>
<td>10</td>
<td>3</td>
<td>27B</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>SEG36</td>
<td>4</td>
<td>4</td>
<td></td>
<td>10</td>
<td>4</td>
<td></td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>SEG37</td>
<td>4</td>
<td>5</td>
<td></td>
<td>10</td>
<td>5</td>
<td></td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>SEG38</td>
<td>4</td>
<td>6</td>
<td></td>
<td>10</td>
<td>6</td>
<td></td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>SEG39</td>
<td>4</td>
<td>7</td>
<td></td>
<td>10</td>
<td>7</td>
<td></td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>SEG40</td>
<td>5</td>
<td>0</td>
<td></td>
<td>11</td>
<td>0</td>
<td></td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>SEG41</td>
<td>5</td>
<td>1</td>
<td>19A</td>
<td>11</td>
<td>1</td>
<td>19B</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>SEG42</td>
<td>5</td>
<td>2</td>
<td>36A</td>
<td>11</td>
<td>2</td>
<td>36B</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>SEG43</td>
<td>5</td>
<td>3</td>
<td>35A</td>
<td>11</td>
<td>3</td>
<td>35B</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>SEG44</td>
<td>5</td>
<td>4</td>
<td>34A</td>
<td>11</td>
<td>4</td>
<td>34B</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>SEG45</td>
<td>5</td>
<td>5</td>
<td>33A</td>
<td>11</td>
<td>5</td>
<td>33B</td>
<td>17</td>
<td>5</td>
</tr>
</tbody>
</table>
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

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.
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.
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.
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)**

### TABLE 11: INTERNAL RESISTANCE LADDER POWER MODES

<table>
<thead>
<tr>
<th>Power Mode</th>
<th>Nominal Resistance of Entire Ladder</th>
<th>IDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>3 MΩ</td>
<td>1 µA</td>
</tr>
<tr>
<td>Medium</td>
<td>300 kΩ</td>
<td>10 µA</td>
</tr>
<tr>
<td>High</td>
<td>30 kΩ</td>
<td>100 µA</td>
</tr>
</tbody>
</table>

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.

**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 VLC3 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 \( V_{L\text{CAP}1} \) and \( V_{L\text{CAP}2} \)
- \( dt \) = regulator clock period
EXAMPLE 5: DYNAMIC CURRENT COMPUTATION

For practical design purposes,

\[ C = 0.047 \, \mu F \]
\[ dV = 0.1 \, V \]
\[ dt = 1 \, \mu s \]

\[ I_{DYNAMIC} = 0.047 \, \mu F \times \frac{0.1 \, V}{1 \, \mu s} \]

\[ I_{DYNAMIC} = 4.7 \, mA \]

EXAMPLE 6: RMS CURRENT COMPUTATION

For practical design purposes,

\[ C = 0.047 \, \mu F \]
\[ dV = 1.02 \, V \]
\[ dt = 30 \, \mu s \]

\[ I_{RMS} = 0.047 \, \mu F \times \frac{1.02 \, V}{30 \, \mu s} \]

\[ I_{RMS} = 1.8 \, mA \]

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

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

```c
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;
LDCVCN1 = 0x03; // BIAS 3.10V; ENSV disabled; LPEN disabled;
LDCVCN2 = 0x86; // CPWDT disabled; LCDVSRC Charge Pump only;

// Enable used segments
LCDSE0 = 0xFF;
LCDSE1 = 0x7F;
LCDSE2 = 0x0F;
LCDSE3 = 0xE7;
LCDSE4 = 0x0E;
LCDSE5 = 0x3E;

// CS LFINTOSC; SLPEN disabled; LMUX 1/8 COM(?):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

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

<table>
<thead>
<tr>
<th>8-bit MCU</th>
<th>Max No. of Commons</th>
<th>Segments</th>
<th>Number of Pixels per Multiplex Type</th>
<th>No. of Clock Source Options</th>
<th>Bias Voltage Generator</th>
<th>Software Contrast Control</th>
<th>LCD Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Static 1/2 1/3 1/4 1/5 1/6 1/7 1/8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIC16LF1906</td>
<td>4</td>
<td>19</td>
<td>19 38 57 72* — — — — — — — — — — —</td>
<td>3 — — — — — — — — — — — — — — — — —</td>
<td>Internal Resistor Ladder</td>
<td>√ √ √ √</td>
<td></td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>8-Bit MCU Family</th>
<th>Clock Source</th>
<th>Divider Ratio</th>
<th>CS&lt;1:0&gt;</th>
<th>SLPEN</th>
<th>Operation during Sleep?</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC16F91x</td>
<td>$F_{OSC}$ (8 MHz)</td>
<td>8192</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$T1$OSC Crystal Oscillator</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>LFINTOSC</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Nominal = (31 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC16F190x</td>
<td>$F_{OSC}$/256</td>
<td>32</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$T1$OSC Crystal Oscillator</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>LFINTOSC</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Nominal = 31 kHz</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC16F193x</td>
<td>$F_{OSC}$/256</td>
<td>32</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$T1$OSC Crystal Oscillator</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>LFINTOSC</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Nominal = 31 kHz</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC16F194x</td>
<td>$F_{OSC}$/256</td>
<td>32</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$T1$OSC Crystal Oscillator</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>LFINTOSC</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Nominal = 31 kHz</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC16F1915x/7x/8x</td>
<td>$SOSC$</td>
<td>32</td>
<td>1</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>LFINTOSC</td>
<td>32</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Nominal = 31 kHz</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC16F1919x</td>
<td>$SOSC$</td>
<td>32</td>
<td>1</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>LFINTOSC</td>
<td>32</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Nominal = 31 kHz</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC18F8x90</td>
<td>$F_{OSC}$/4 (8 MHz)</td>
<td>8192</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$T13$CK1 Crystal Oscillator</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>INTRC</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(31.25 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>PIC18F8xJ90</td>
<td>($F_{OSC}$/4) = 8 MHz</td>
<td>8192</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$T13$CK1 Crystal Oscillator</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(32.768 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>INTRC</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>(31.25 kHz)</td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
</tr>
</tbody>
</table>
### TABLE B-1: 8-BIT MCU FAMILIES LCD CLOCK SOURCE SELECTION (CONTINUED)

<table>
<thead>
<tr>
<th>PIC18F8xK90</th>
<th>FOSC/4 (8 MHz)</th>
<th>8192</th>
<th>00</th>
<th>0</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOSC (32.768 kHz)</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>INTRC (31.25 kHz)</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>PIC18F9xJ94</td>
<td>FOSC/4 (8 MHz)</td>
<td>8192</td>
<td>00</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>SOSC (32.768 kHz)</td>
<td>32</td>
<td>01</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>INTRC (31.25 kHz)</td>
<td>32</td>
<td>1x</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C: REFERENCES AND RELATED DOCUMENTS

TABLE C-1: DATA SHEETS


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:**


**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* (DS91089)
8. *TB084 – Contrast Control Circuits for the PIC16F91X* (DS1084)
Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip’s Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer’s risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights unless otherwise stated.

Trademarks

The Microchip name and logo, the Microchip logo, AnyRate, AVR, AVR logo, AVR Freaks, BitCloud, chipKIT, chipKIT logo, CryptoMemory, CryptoRF, dsPIC, FlashFlex, flexPWR, Heldo, JukeBlox, KeeLoq, Kleer, LANCheck, LINK MD, maxXSylus, maxTouch, MediaLB, megaAVR, MOST, MOST logo, MPLAB, OptoLyzer, PIC, picoPower, PICSTART, PIC32 logo, Prochip Designer, QTouch, SAM-BA, SpyNiC, SST, SST Logo, SuperFlash, tinyAVR, UNI/O, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

ClockWorks, The Embedded Control Solutions Company, EtherSynch, Hyper Speed Control, HyperLight Load, IntelliMOS, mTouch, Precision Edge, and Quiet-Wire are registered trademarks of Microchip Technology Incorporated in the U.S.A.


SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

GestIC is a registered trademark of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2018, Microchip Technology Incorporated, All Rights Reserved.

ISBN: 978-1-5224-3605-8
## Worldwide Sales and Service

### AMERICAS

**Corporate Office**  
2355 West Chandler Blvd.  
Chandler, AZ 85224-6199  
Tel: 480-792-7200  
Fax: 480-792-7277  
Technical Support:  
http://www.microchip.com/support  
Web Address:  
www.microchip.com

**Atlanta**  
Duluth, GA  
Tel: 678-957-9614  
Fax: 678-957-1455

**Austin, TX**  
Tel: 512-257-3370

**Boston**  
Westborough, MA  
Tel: 774-760-0087  
Fax: 774-760-0088

**Chicago**  
Itasca, IL  
Tel: 630-285-0071  
Fax: 630-285-0075

**Dallas**  
Addison, TX  
Tel: 972-818-7423  
Fax: 972-818-2924

**Detroit**  
Novi, MI  
Tel: 248-848-4000

**Houston, TX**  
Tel: 281-894-5983

**Indianapolis**  
Noblesville, IN  
Tel: 317-773-8323  
Fax: 317-773-5453  
Tel: 317-536-2380

**Los Angeles**  
Mission Viejo, CA  
Tel: 949-462-9523  
Fax: 949-462-9608  
Tel: 951-273-7800

**Raleigh, NC**  
Tel: 919-844-7510

**New York, NY**  
Tel: 631-435-6000

**San Jose, CA**  
Tel: 408-735-9110  
Tel: 408-436-4270

**Canada - Toronto**  
Tel: 905-695-1980  
Fax: 905-695-2078

### ASIA/PACIFIC

**Australia - Sydney**  
Tel: 61-2-9888-6733

**China - Beijing**  
Tel: 86-10-8569-7000

**China - Chengdu**  
Tel: 86-28-8665-5511

**China - Chongqing**  
Tel: 86-23-8980-9588

**China - Dongguan**  
Tel: 86-769-8702-9880

**China - Guangzhou**  
Tel: 86-20-8755-0299

**China - Hangzhou**  
Tel: 86-571-8792-8115

**China - Hong Kong SAR**  
Tel: 852-2943-5100

**China - Nanjing**  
Tel: 86-25-8755-0299

**China - Qindao**  
Tel: 86-532-8502-7355

**China - Shanghai**  
Tel: 86-21-3326-8000

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

**China - Shenzhen**  
Tel: 86-755-8864-2200

**China - Suzhou**  
Tel: 86-186-6233-1526

**China - Wuhan**  
Tel: 86-27-5980-5300

**China - Xian**  
Tel: 86-29-8833-7252

**China - Xiamen**  
Tel: 86-592-2386138

**China - Zhuhai**  
Tel: 86-755-8864-2200

**India - Bangalore**  
Tel: 91-80-3090-4444

**India - New Delhi**  
Tel: 91-11-4160-8631

**India - Pune**  
Tel: 91-20-4121-0141

**Japan - Osaka**  
Tel: 81-6-6152-7160

**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: 84-8-5446-2100

### EUROPE

**Austria - Wels**  
Tel: 43-7242-2244-39  
Fax: 43-7242-2244-393

**Denmark - Copenhagen**  
Tel: 45-4450-2828  
Fax: 45-4485-2829

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

**France - Paris**  
Tel: 33-1-69-53-63-20  
Fax: 33-1-69-30-90-79

**Germany - Garching**  
Tel: 49-8931-9700

**Germany - Haan**  
Tel: 49-2129-3766400

**Germany - Heilbronn**  
Tel: 49-7131-67-3636

**Germany - Karlsruhe**  
Tel: 49-721-625370

**Germany - Munich**  
Tel: 49-89-627-144-0  
Fax: 49-89-627-144-44

**Germany - Rosenheim**  
Tel: 49-8031-354-560

**Israel - Ra'anana**  
Tel: 972-9-744-7705

**Italy - Milan**  
Tel: 39-0331-742611  
Fax: 39-0331-466781

**Italy - Padova**  
Tel: 39-049-7625286

**Netherlands - Drunen**  
Tel: 31-416-690399  
Fax: 31-416-690340

**Norway - Trondheim**  
Tel: 47-7288-4388

**Poland - Warsaw**  
Tel: 48-22-3325737

**Romania - Bucharest**  
Tel: 40-21-407-87-50

**Spain - Madrid**  
Tel: 34-91-708-08-90  
Fax: 34-91-708-08-91

**Sweden - Gothenburg**  
Tel: 46-31-704-60-40

**Sweden - Stockholm**  
Tel: 46-8-5090-4654

**UK - Wokingham**  
Tel: 44-118-921-5800  
Fax: 44-118-921-5820