Simple Data Display

Driving LCDs with Microchip and Atmel Micros

Thinking about incorporating an LCD in your next design? It isn't too difficult, especially if all you're looking to do is display your data as a set of numeric digits. Follow along as Fred shows you how Microchip and Atmel can help you drive a simple data display.

Years ago, I wore a Seiko watch that was both analog and digital. The watch had a standard watch face with all of the normal moving hands plus a tiny LCD that displayed the date and did double-duty as a stopwatch. At the time, the good old LED-based watches had been replaced by the newer and fancier LCD watches. By wearing my Seiko, I was opting for the classic look with the new technology feel.

The LCD-in-watch trend is still alive and well. There are numerous watches on the market that are LCD-enabled and tout a boatload of features. I remember when calculator watches were big. These days, calculator watches are a no-brainer. Now you can buy a watch that graphs the phases of the moon and tidal activity in addition to keeping the time and noting when the sun sets and rises. There's even a touch-enabled, LCD-faced watch out there that runs Linux!

This month's column is not about fancy watches; it's all about LCDs. My office telephone, cell phone, and pager have one. My Microchip PRO MATE II device programmer has one. My VOM has one. My SMT rework machine has one. Even my atomic clock (that locks into WWV only when it feels like it) has one.

Have you ever thought about why LCDs are so prevalent? The answer is simple: they're cheaper to incorporate than comparable integrated LCD modules and multiplexed LED display solutions.

I'm willing to bet that you have constructed some sort of a multiple-digit LED display. If you haven't but want to, start by collecting the desired number of individual LED digits, add seven or eight current-limiting resistors for each digit, and select a suitable digit segment driver that can handle the current drawn by the collection of LED segments on each digit. Then, choose a suitable microcontroller to drive the LED/resistor/driver display rig. If you need more than a couple of digits, you're also going to need multiplexing firmware to drive your LED display.

If you don't require huge and bright digits, another approach would be to use a standard LCD module, which includes all of the necessary driver circuitry and LCD glass in a compact package. If you need to see your LCD module's dots in the dark, you can buy an LCD module with an integral backlight. The LCD module is a good choice if you want to easily display multiline text messages; however, the cost rises considerably as you add extra lines of text to the display.

It doesn't matter if you use LEDs or an LCD module because in either case you'll still need a microcontroller to complete the job. LCDs and LED displays both adhere to the first rule of embedded computing: nothing is free.

Let's assume you want to display data as a simple set of between four and eight numeric digits. The optimal solution would be an inexpensive electronic device that includes some smarts and

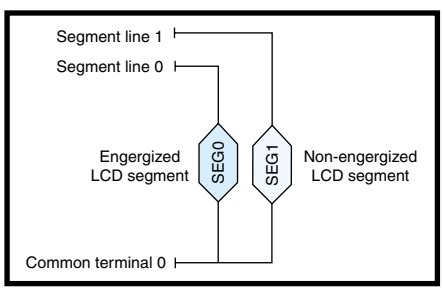

Figure 1—*An LCD operating in Static Duty mode is much like its LED counterpart, because a different segment driver addresses each display segment individually.*

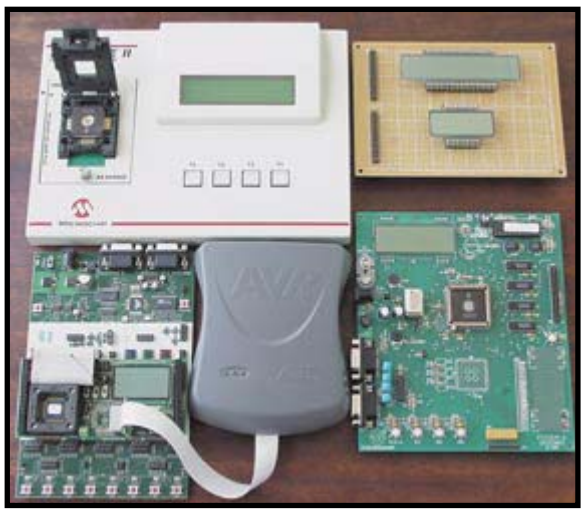

Photo 1—*Although the Microchip PICDEM-3 development board was designed years earlier, both the Atmel and Microchip boards contain similar features. For instance, the boards come equipped with a 32-kHz external oscillator, a thermistor, several general-purpose push buttons, and an external LCD port.*

the circuitry necessary to drive the LCD glass. Fortunately, that technology is already walking the streets.

DRIVING MISS LCD

If you've worked with any of Microchip's PICs or Atmel's AVRs, you've already done the datasheet drill that describes the core functionality of a PIC and an AVR. Because the PIC16C923, PIC16C924, PIC16C925, PIC16C926, and ATmega169 are all about driving LCD segments, it may be a good idea to take a look at what it takes to make a typical LCD work before I dive into the specifics of what it takes to microcontroller-enable an LCD.

The term "LCD glass" refers to two glass plates that contain and support a layer of liquid crystal material. Liquid crystals are rod-shaped molecules that flow as a liquid; they use their electrical and optical properties to actually bend light. The inner surfaces of the glass plates are lined with transparent electrodes, which are patterned to form the images that are to be displayed by the LCD. The outer surfaces of the glass plates are fitted with polarizers, which are placed perpendicular to each other and parallel to the liquid crystal rods.

The liquid crystal material has many layers of molecules. Each glass is rubbed with a polyimide coating that aligns the liquid crystal material closest to the glass with the polarizer. Because the polarizers are 90° out of phase with each other, the layers of liquid crystal material actually twist between the upper and lower glass.

The best way I can explain the polarizer/liquid crystal relationship is to recall a childhood memory. Remember when the first polarized sunglasses came out? No? Well, I do. If you take the polarized lenses and look through them with one lens behind the other, you can rotate one of the lenses until the light is blocked and you can't see through the back-to-back set of lenses. LCDs work in a similar manner.

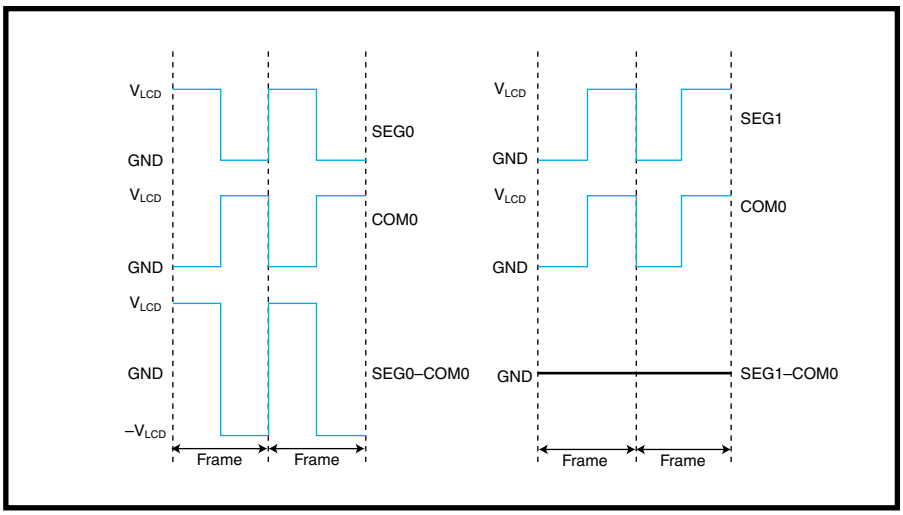

Figure 2—*The resultant voltage across a segment is the difference between the segment voltage and the common terminal voltage. Note that the sum of the voltages across the segment in each frame is equal to zero.*

When the liquid crystals are not excited, they twist the light and allow it to pass unimpeded through the out-of-phase polarizing filters. In the unexcited state, you see the normal background color of the LCD glass. This unexcited state is relative to holding both of the polarized sunglass lenses back-to-back so you can see through them.

If the liquid crystals become excited, or energized, the molecules within the liquid crystals align themselves with the electric field and fail to twist the light. In this case, the polarizers are out-of-phase and the light is not bent. Thus, the light cannot pass through the second polarizer filter. This is analogous to rotating one of the polarized sunglass lenses 90° and bringing the lenses out of phase and blocking the light. The absence of light appears as a darkened spot on the LCD glass.

Unlike standard LED displays, which are driven by applying a DC voltage across each desired digit segment's anode and cathode, LCD glass must be driven by an alternating current. Each segment in an LCD connects to the driver on one side of the segment and to a common terminal on the other side. Applying the AC across the segment driver and the common terminal excites the liquid crystal causing the segment's liquid crystal molecules to twist in such a way as to allow the segment to be visible.

Even for a Cyclops, more than one segment is needed to make a programmable display. So, there has to be a process

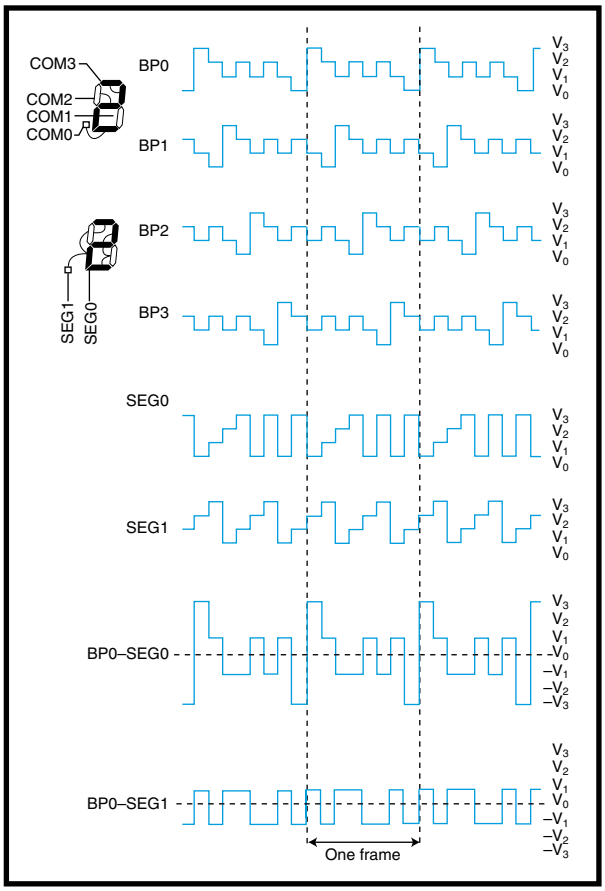

Figure 3—*This particular LCD glass contains four common terminals, which implies four backplanes. Note that only a single segment driver is required to drive up to four segments.*

that determines which segments are visible and at what time. On a typical LCD, the LCD segments must be excited more than 30 times per second to keep you from seeing them flicker. The number of times per second the LCD segments are excited is called the frame rate. LCD segments cannot turn on or turn off instantaneously. So, if the frame rate is too high, the segments will appear to ghost, because the segments aren't given enough time to turn off completely before being excited again. The ghosting usually occurs when the frame rate exceeds 100 frames per second. The theory behind the LCD frame rate is akin to video frames. Both use the human eye and brain image persistence phenomenon to fool you into seeing a bunch of really fast flickers as smooth motion.

There are a couple of ways to drive a collection of LCD segments. If all of the LCD segments are tied to a single common terminal with separate segment driver lines for each individual segment, then you have a static arrangement (see Figure 1).

Each segment must be driven above its threshold voltage to excite the liquid crystal molecules with the highest voltage applied falling equal to or below the maximum voltage specifications set forth for the LCD glass segments. Applying a DC voltage to an LCD segment will either end or shorten the life of the segment, because the DC voltage will eventually cause the liquid crystal material to lose its excitability. For that reason, the LCD driver waveforms are designed to provide a potential across the LCD segments that is as close as possible to 0 VDC.

In a static segment arrangement, square waves are normally used to drive the common terminal and segments. Segments that are excited are driven in opposite phase of the common terminal. If the segment and common drive signals are in phase, the segment is not excited. Figure 2 depicts the segment and common terminal drive signals and how they affect the segments of a statically driven LCD.

A static LCD glass with one common terminal has only a one backplane and runs with a duty cycle of 1/1. Duty cycle is defined as one divided by the number of segments driven by each LCD driver, or one divided by the number of common terminals.

An example of LCD glass capable of running at a one-fourth duty cycle is shown in Figure 3. Each segment driver drives four segments, each of which is driven by a separate backplane (common terminal). To control each segment from a single segment driver, the segment driver must be able to generate multiple voltage levels. The number of voltage levels is associated with the drive bias. Mathematically, drive bias is one divided by the number of voltage levels minus one:

$$\frac{1}{\text{Number of voltage levels} - 1}$$

Therefore, the drive bias for the LCD glass in Figure 3 would be 1/3, and the drive bias for the LCD glass in Figure 1 would be 1/1.

You don't have to guess about how to set the duty and bias parameters. The LCD recommended duty cycle and drive bias settings are normally called out in the LCD's datasheet. Some LCD datasheets also provide a recommended frame rate.

DO THE TWIST

I love my job. In the process of researching and writing this column, I collected a bunch of goodies to play with. I have a Microchip PICDEM-3 PIC16C9*xxx* development board, an Atmel STK502 development module, and an assortment of static and multiplexed LCD glass. The Microchip parts aren't flash memory-based, so I've got to churn and burn when I develop code for the Microchip LCD microcontroller. Thus, I pulled out my fancy UV eraser and obtained a PIC16C9*xx* 68-pin PLCC programmer socket for my PRO MATE II. I hate waiting for UV parts to erase between spins. So, to keep myself busy, I procured a couple of extra PIC16C924/CL and PIC16C925/CL UV erasable devices.

I'm also fully covered on the Atmel side. The ATmega169 is flash memory-based and can be programmed and debugged using the latest version of AVR Studio and JTAG ICE. If I don't run into trouble coding the AVR, I can use the STK500 development board that supports the STK502 to program the ATmega169 firmware spins. I gathered my family of LCD development

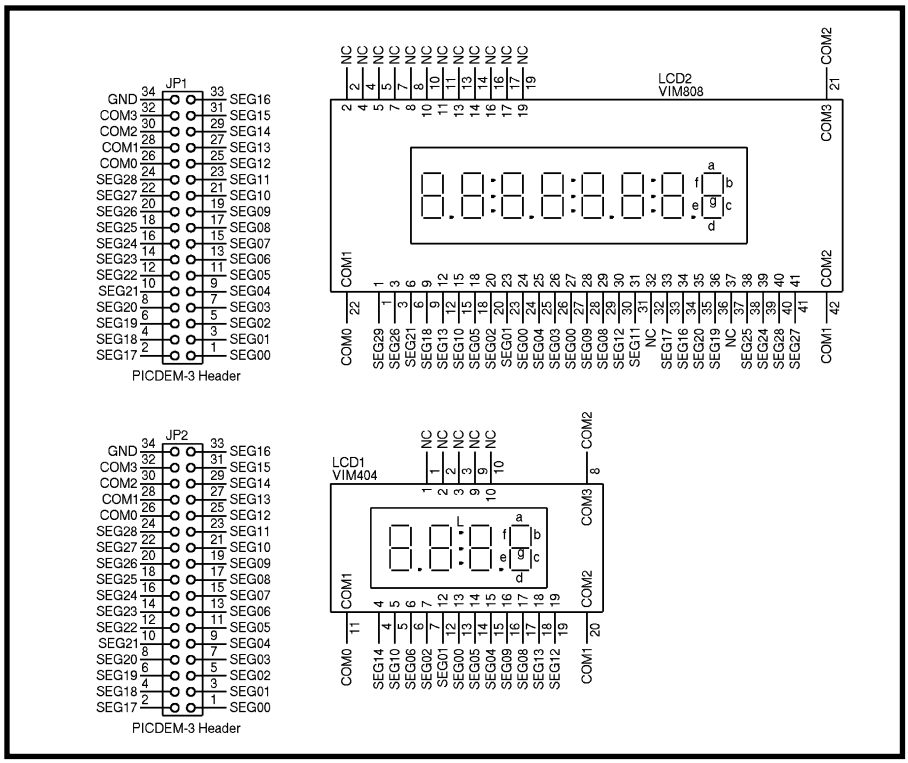

Figure 4—*Although there appears to be a million pins on the headers and LCD glass, after laying out everything on a spreadsheet the process of hooking up everything was simple.*

tools together to produce Photo 1.

The Atmel STK502 and Microchip PICDEM-3 both come with their own specialized LCD glass. You can actually buy the Atmel LCD glass from a company in Norway, but the Microchip PICDEM-3 LCD is not a commercial, off-the-shelf product. Just as LCD glass is common to both development boards, the STK502 and PICDEM-3 are equipped with temperature sensors that are used by demo programs that come with each board. The STK502 holds the ATmega169 in place with the same type of ZIF socket used on the STK501 to hold the Atmega128 microcontroller. A standard through-hole, 68-pin PLCC socket supports the PIC16C924/CL on the PICDEM-3.

As you'd expect, both LCD microcontrollers are filled with demo code and are ready to run right out of the box. In addition, both development kits are supplied with ample example source code that is focused on driving the LCD glass.

An LCD demultiplexer driven by a separate PIC16C73 is an interesting aside to the Microchip LCD board. The extra PIC is programmed to demultiplex the LCD glass signals produced by the on-board PIC16C924 and display them using a special segment versus the common terminal display program that runs on a PC host. Basically, the PC host program/PIC hardware demultiplexer combination tells you which segments are energized on which LCD backplane in real time.

After absorbing the various ATmega169 and Microchip PIC16C92*x* datasheets, application notes, and development board user guides, I was ready to "do the twist." Fortunately, the minds of both the Atmel and Microchip LCD development board designers roll in the same silicon gutter because both boards make provisions for attaching external LCD glass. The Atmel board uses a ribbon cable and headers to connect the ATmega169 to the LCD glass. So, all I have to do is to remove the 34-pin ribbon cable and I've got direct access to the pins of the ATmega169 and the STK502 LCD glass. The PICDEM-3 also provides direct access to its on-board LCD glass and PIC via a 34-pin ribbon cable.

Normally, the shelves in the Florida room have all of the necessary compilers to morph any development kit example code into a real-world application. Although the STK502 source says it can be compiled with either

Listing 1—*Each element in the character table is made up of three 3-bit values. The 3-bit values are mapped into the segment matrix of each digit. The data doesn't actually get to the microcontroller's LCD segment registers until all is well inside the LCD frame interrupt service routine. A detailed look at how the segments map to the character table can be found in the VIMLCD.xls spreadsheet, which you may download from the* Circuit Cellar *ftp site.*

```
//The look-up table is used when converting ASCII to LCD data
//(segment control)
int16 const LCD_character_table[] = //Character definitions table.
{
      0x0257,                       //0
      0x0044,                       //1
      0x0236,                       //2
      0x0266,                       //3
      0x0065,                       //4
      0x0263,                       //5
      0x0273,                       //6
      0x0046,                       //7
      0x0277,                       //8
      0x0267,                       //9
      0x0077,                       //A
      0x0271,                       //b
      0x0213,                       //C
      0x0274,                       //d
      0x0233,                       //E
      0x0033,                       //F
    0x0000                          //Space
};

#int_LCD
LCD_isr()
{
      unsigned char i;
      unsigned char *dest;

      LCD_timer--;
      if( LCD_timer == 0 )
      {
        if( LCD_status.updateRequired == TRUE )
       {
          LCD_timer = LCD_TIMER_SEED;
          LCD_status.updateComplete = TRUE;
//Set the ucLCD_ScrollReady to true.

//Copy the display data buffer to I/O segment registers.
       dest = &LCDD00;
       for(i=0;i<LCD_REGISTER_COUNT;++i)
       {
          *dest++ = LCD_displayData[i];
       }
      }
            else
             {
LCD_timer = 1;    //If the LCD timer allows the updating of the
                  //LCD but the update is blocked by LCD_status.
                  //updateRequired == FALSE, the LCD_timer is pre-
                  //loaded with the smallest timer seed to ensure
                  //fastest LCD update.
LCD_status.updateComplete = FALSE;
//Block for further access to the LCD_displayData until the LCD
//update has been performed.
      }
           }
 }
```

the ICCAVR C compiler or the IAR C compiler, the former choked badly when I tried to compile the raw STK502 source code that is provided with the Atmel development board.

After some investigation, I found that one of the include files was missing from the source code package. The PICDEM-3 files are PIC assembler and would have to be ported to C for use in either the Microchip or Custom Computer Services PIC C compilers. My preference of C over assembler in this case is justified by the easy manipulation of tables and 16-bit values made possible by functions built into the C compiler packages.

The good news is that the suggested code formats and compiler types used by the LCD development kits don't matter, because I've decided to use the best ideas from both of the LCD development board source code libraries to turn on some LCD segments of my own. I knew this project was off to a good start when I opened my flock of LCD glass. There were five LCDs inside an antistatic bag with their pins punched into a piece of Styrofoam. A thin layer of standard foam covered all the LCDs to protect their top glass surfaces. I removed the LCDs from the bag and lifted the foam layer to peek at the devices. As I peeled away the foam, every device turned on the segments to produce a visible one. I was already successfully turning on segments and I hadn't even taken the LCD glass out of the packing material yet!

BENDING LCD CODE

The first order of business is to gather the specifications of the LCD glass and set up the LCD driver devices accordingly. I have static and multiplexed parts made by Varitronix. The static LCD is a VI-422-DP-RC-S and the multiplexed display is identified as VIM-404-DP-RC-S-HV. The "M" following the "VI" denotes that the LCD is multiplexed, which implies multiple common terminals. Both displays are instrument displays (VI) using standard Twist Nematic, or TN, liquid-crystal fluid (S) with commercial reflective polarizers (RC) in a dual inline package (DP). The "HV" parameter in the multiplexed display part number specifies that the LCD is able to operate at a higher typical operating voltage than the static display.

The multiplexed VIM-404 has three common terminals. Applying the duty cycle formula gave me an LCD duty cycle value of one-third. Because there are three common terminals, you know that each segment driver will drive a maximum of three segments; therefore, it will take four voltage levels to drive the three segments.

Applying the drive bias formula generates a resultant bias value of one-third. The Atmel and Microchip LCD microcontrollers support my LCD's required duty cycle and drive bias. The PIC16C924 drives up to 30 segments with three backplanes, and the ATmega169 drives up to 25 segments on three backplanes. The VIM-404 has a total of 33 segments. With each segment driver handling up to three segments, the VIM-404 uses only 12 segment drivers.

Things are a bit different for the VI-422; it too has 33 total segments. The PIC16C924 can drive a maximum of only 32 segments with a single backplane, and the ATmega169 is maxed out at 25 segments, which simply means I cannot exploit the entire segment farm on the VI-422 with either LCD microcontroller. That's not a showstopper. Regardless of how many segments I can or cannot drive, it takes 36 connections to tie in all of the segments of the statically driven VI-422 versus 15 connections for the multiplexed VIM-404. The VI-422 is wired one segment to one LCD driver and doesn't require a lot of thinking to implement. I'll concentrate on showing you how to implement the VIM model.

Photo 2—*Lots of information had to be assimilated to put numbers on the displays. Although the schematic has enough graphical information to allow you to build the display interfaces, a glance at the Excel spreadsheets exposes the logic behind it all.*

The connections from the development board to the external LCD glass hardware are shown in Figure 4. I also created an Excel spreadsheet that details the VIM-404 and VIM-808 pinouts, the PIC16C924 segment memory layouts, the LCD character maps, the VIM segment-to-PIC16C924 segment driver combinations, and the initial LCD module register settings. You may download the spreadsheet from the *Circuit Cellar* ftp site.

Despite some internal and external differences in how the LCD voltages are generated, both LCD driver microcontrollers ultimately do the same job by using a similar internal LCD data register setup. Both microcontrollers have similar LCD register memory maps. This similarity allows me to leverage the Atmel example code on the Microchip and Atmel development boards. The Atmel example code is easy to alter (it's already in C format), so I adapted the existing Atmel example code to drive a four-digit and an eight-digit LCD using the Microchip PICDEM-3 electronics.

The Atmel C example code loads an image of the segment buffer memory into an SRAM buffer and transfers the bit image from the SRAM to the actual segment memory during a frame interrupt. The frame interrupt occurs at the beginning of every frame. There are flags within the frame interrupt service routine that

can be set up to enable or prevent the SRAM-based segment buffer contents to be written to the LCD segment registers during the execution of the interrupt service routine.

The nature of an LCD segment doesn't allow it to bend light instantaneously, and the VIM-404/808 datasheets reflect this by specifying a typical 80-ms response time at room temperature. Obviously, the LCD cannot be updated at every frame interrupt, so a timer routine is used to determine how often the LCD actually gets updated from within the frame interrupt service routine.

In addition to having a similar LCD segment memory map, the PIC16C924 also issues an interrupt at the beginning of a frame. You know where I'm going with this idea. I'm going to use the Atmel code as well as its logic to write the PIC code just as if I were writing the code for the Atmel part. Some of the ported Atmel code is shown in Listing 1. I'll post the entire port on the *Circuit Cellar* ftp site along with the Excel spreadsheet.

CLEARING THE LCD

Although Photo 2 measures my success in numbers, it's time to stop twisting code and light, and wrap up this piece on driving LCDs. Documenting the relationships between the LCD segments, the microcontroller segment drivers, and microcontroller segment memory using a spreadsheet amplified the extent of the well-thought-out logic that went into the design of the LCDs and LCD microcontrollers. By incorporating ideas from a set of LCD development boards, I've proven that driving LCDs isn't complicated, no matter which embedded LCD microcontroller you choose.

Fred Eady has more than 20 years of experience as a systems engineer. He has worked with computers and communication systems large and small, simple and complex. His forte is embedded-systems design and communications. Fred may be reached at fred@edtp.com.

PROJECT FILES

To download the code and spreadsheet, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/159.

SOURCES

STK502 LCD Display
ACTE
www.acte.no

ATmega169, JTAG ICE, STK500 development board, and STK502 LCD demonstration board
Atmel Corp.
www.atmel.com

PIC16C924 Microcontroller, PICDEM-3 LCD demonstration board, and PRO MATE II device programmer
Microchip Technology, Inc.
(480) 792-7200
www.microchip.com

VIM-404 and VIM-808 Displays
Varitronix International
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www.varitronix.com

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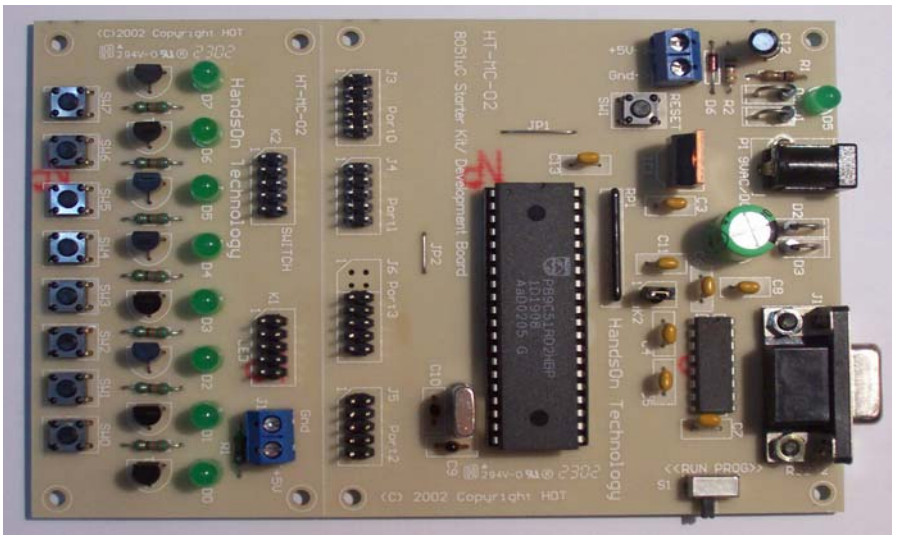

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- Free ***Flash Magic*** Windows software for easy program code down loading.

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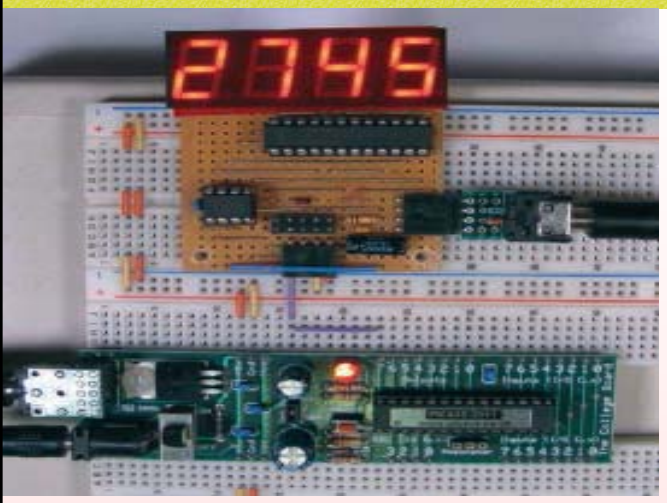

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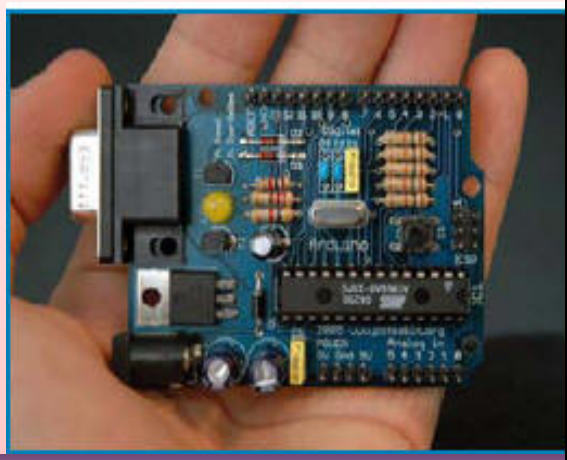

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