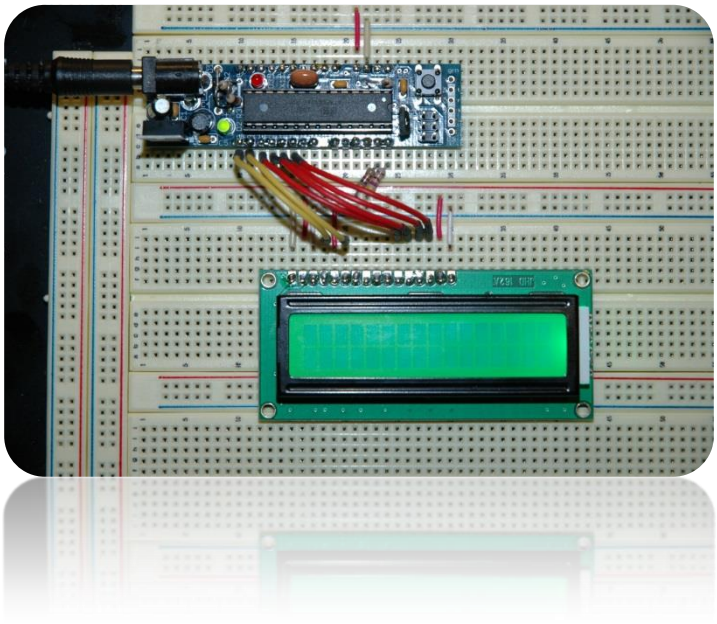


Add an LCD to your AVR microcontroller

Bruce E. Hall, W8BH

There are hundreds, if not *thousands*, of online articles about interfacing HD44780-compatible LCD displays to microprocessors/ microcontrollers. I have contributed one to the pile already, with my write-up on adding LCD displays to the Raspberry Pi. Here is what sets this article apart from the rest:

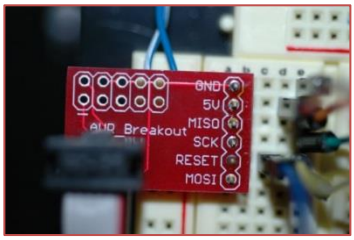
- Breadboard construction
- ATmega328 microcontroller
- Uses C language (AVR studio, AVR-gcc)
- Does not rely on libraries or other code
- Simple, no-nonsense functionality

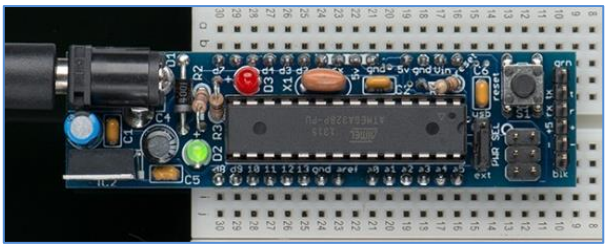
If you have an AVR micro that you'd like to connect to an LCD display, this is for you.

2) THE WIRING AND THE SWITCHES

The centerpiece of this project is the ATmega328 microcontroller by Atmel.

First, you need a way to program the microcontroller. I have the AVRISP II, which costs about $37 from Digikey (or eBay). This unit connects to your computer via USB, and connects to the microcontroller via a 6pin female header. A $1 AVR-breakout board from Sparkfun, shown here, lets you breadboard the output of the AVRISP programmer.





Next, you'll need a suitable 5V power supply for your breadboard. I started to wire up my micro, ISP-header, and power supply when I realized that I have a compact module containing all three: the DC boarduino by adafruit. This compact board contains the power supply, micro, and ISP header; plus a status LED and

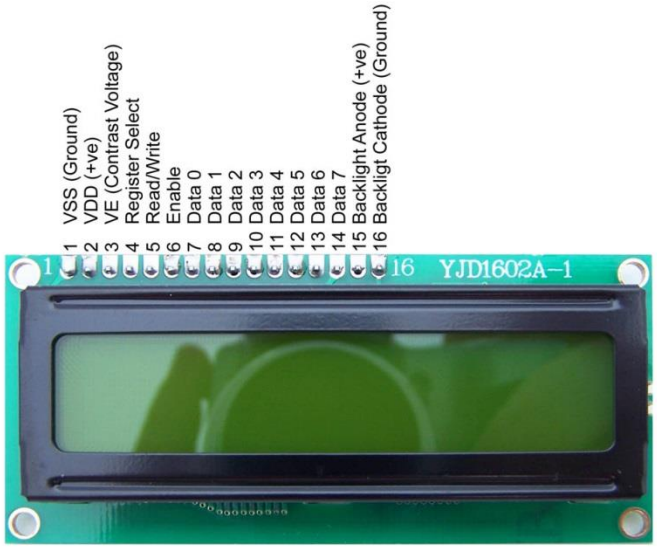
reset switch. For around $17 it's a good way to save breadboard space. I'll use it here.

'328 (boarduino)	LCD Display
PB0 (digital 8)	pin 4
PB1 (digital 9)	pin 6
PB2 (digital 10)	pin 11
PB3 (digital 11)	pin 12
PB4 (digital 12)	pin 13
PB5 (digital 13)	pin 14

The DC boarduino is an arduino-like device, so it uses the same "analog" and "digital" pin numbering. But I am not using it as an arduino. For me, it's just a convenient way to breadboard the ATmega chip. Connect 6 data lines between the boarduino and LCD as indicated here. The first two are control lines, and remaining four are the data lines.

Next, connect the power lines. The +5 and Gnd lines from the boarduino will supply power the rest of the project.

The LCD has a 16-pin interface, as shown here. On the LCD, connect pins 2 & 15 to +5v power and pins 1, 5, and 16 to ground. Pin 3 is the contrast voltage. For some displays, you can connect this directly to ground. For others, a 1K resistor to ground works better.



When everything is hooked up, the LCD will have pins 7-10 disconnected.

Apply power, and you should see the glow of your LCD backlight. If not, unplug and check all power connections. In addition, the top row of the LCD should display a line of solid-block characters. If not, the display contrast may need to be adjusted. Vary the voltage on pin3 to get good display contrast.

Start AVR studio, choose 'Device Programming' from the Tools menu, or press Ctrl-Shift-P. Choose AVRISP II as the Tool, ATmega328P as the Device, and ISP as the Interface. Click Apply. Now click on the Device Signature Read button. A result of '0x1E950F' indicates successful 2-way communication with your microcontroller.

From this device programming window you can also set the microcontroller's fuses. Click on 'Fuses' in the left-hand pane. All the fuses except 'SPIEN' should be unchecked. (You will need to uncheck the CKDIV8 fuse.) Also, the SUT_CKSEL fuse should be set to EXTXOSC_8MHZ_16KCK_14CK_65MS. This will run the chip at 16 MHz, using the external resonator. After checking your values, click the program button. You need to program the fuses only once.

3) CODING

For this project I chose 'C' as my programming language. For me, C is a bit easier to use than assembly language. The complete source code for my project is given at the end of this article. Like many microcontroller projects, the outer shell of the program is very simple:

```
int main (void)
{
        init();
        DoSomething();
}
```

First, init() is called for do-once, initialization steps. Next, DoSomething() is called to create interesting displays on the LCD. This routine is typically set up as an infinite "while(1)" loop, so that the program never ends.

The first initialization job is to set up microcontroller pins as inputs or outputs. We need only outputs for this project. To set a pin as an output, we write a '1' to the ports data direction register. DDRB is the data direction register for port B. Look at this statement:

```
DDRB    =  0x3F;                        // 0011.1111; set B0-B5 as outputs
```

In Port B, we use the lower 6 pins (B5-B0) as outputs, so the corresponding bits are set to logic 1:

B7	B6	B5	B4	B3	B2	B1	B0
0	0	1	1	1	1	1	1

The binary number is 00111111, or hexadecimal 0x3F.

4) NIBBLES & BYTES

Put on your thinking cap, because it's time for the interesting part: sending data to the LCD controller. There are 8 bits to each byte, but we will only send 4 bits at a time. And we have to time them according to the controller's specifications. Check out the datasheet for the specific details. The gist is to send the upper 4 bits of the data, pulse the LCD enable pin, and then send the lower 4 bits. The half-byte chunks are called nibbles.

```
#define LCD_RS      0                   // pin for LCD R/S (eg PB0)
#define LCD_E       1                   // pin for LCD enable
#define DAT4        2                   // pin for data4
#define DAT5        3                   // pin for data5
#define DAT6        4                   // pin for data6
#define DAT7        5                   // pin for data7

void SendNibble(byte data)
{
    PORTB &= 0xC3;                      // 1100.0011 = clear 4 data lines
    if (data & _BV(4))  SetBit(PORTB,DAT4);
    if (data & _BV(5))  SetBit(PORTB,DAT5);
    if (data & _BV(6))  SetBit(PORTB,DAT6);
    if (data & _BV(7))  SetBit(PORTB,DAT7);
}
```

```
void PulseEnableLine ()
{
    SetBit(PORTB,LCD_E);              // take LCD enable line high
    usDelay(40);                      // wait
    ClearBit(PORTB,LCD_E);            // take LCD enable line low
}
```

The SendNibble() routine takes the upper 4 bits of the data and places them on four I/O lines (PB2-PB5). The first line takes all 4 pins to logic 0. SetBit() is an inline macro which sets the value of a port pin to logic 1.

Pulsing the LCD enable line is as simple as taking the line high, waiting, then taking it low again. The data is clocked into the module on the high-to-low transition. A very short waiting period, in microseconds, is specified in the datasheet.

```
void SendByte (byte data)
{
    SendNibble(data);                 // put upper 4 bits on data lines
    PulseEnableLine();                // clock them into controller
    data <<= 4;                       // get lower nibble
    SendNibble(data);                 // put lower 4 bits on data lines
    PulseEnableLine();                // clock them into controller
}
```

Sending a byte to the LCD controller involves two SendNibble operations: send the upper half of the byte first, then send the lower half. A right-sift operation '<< 4' moves the lower four bits into the upper 4 bits.

Bytes can be send to the controller as either data byte (characters) or as commands. The controller uses the input line RS to distinguish the two: anything sent when RS is low is a command, and anything sent when RS is high is a character. We'll create two new routines to account for this requirement.

```
void SendChar (byte ch)
{
    SetBit(PORTB,LCD_RS);             // R/S line 1 = character data
    SendByte(ch);                     // send it
}

void SendCmd (byte cmd)
{
    ClearBit(PORTB,LCD_RS);           // R/S line 0 = command data
    SendByte(cmd);                    // send it
}
```

Now we have routines for sending commands and characters to the display. It would be nice to test them right away, but we can't: we have to initialize the display first. All HD44780-based displays require certain startup commands to specify things like data-length, cursor-mode, etc. These command bytes will set the data-length to 4 bits, turn the cursor off, enable sequential addressing, and clear the display.

```
void InitLCD()
{
    SendCmd(0x33);                    // initialize controller
    SendCmd(0x32);                    // set to 4-bit input mode
    SendCmd(0x28);                    // 2 line, 5x7 matrix
    SendCmd(0x0C);                    // turn cursor off (0x0E to enable)
    SendCmd(0x06);                    // cursor direction = right
```

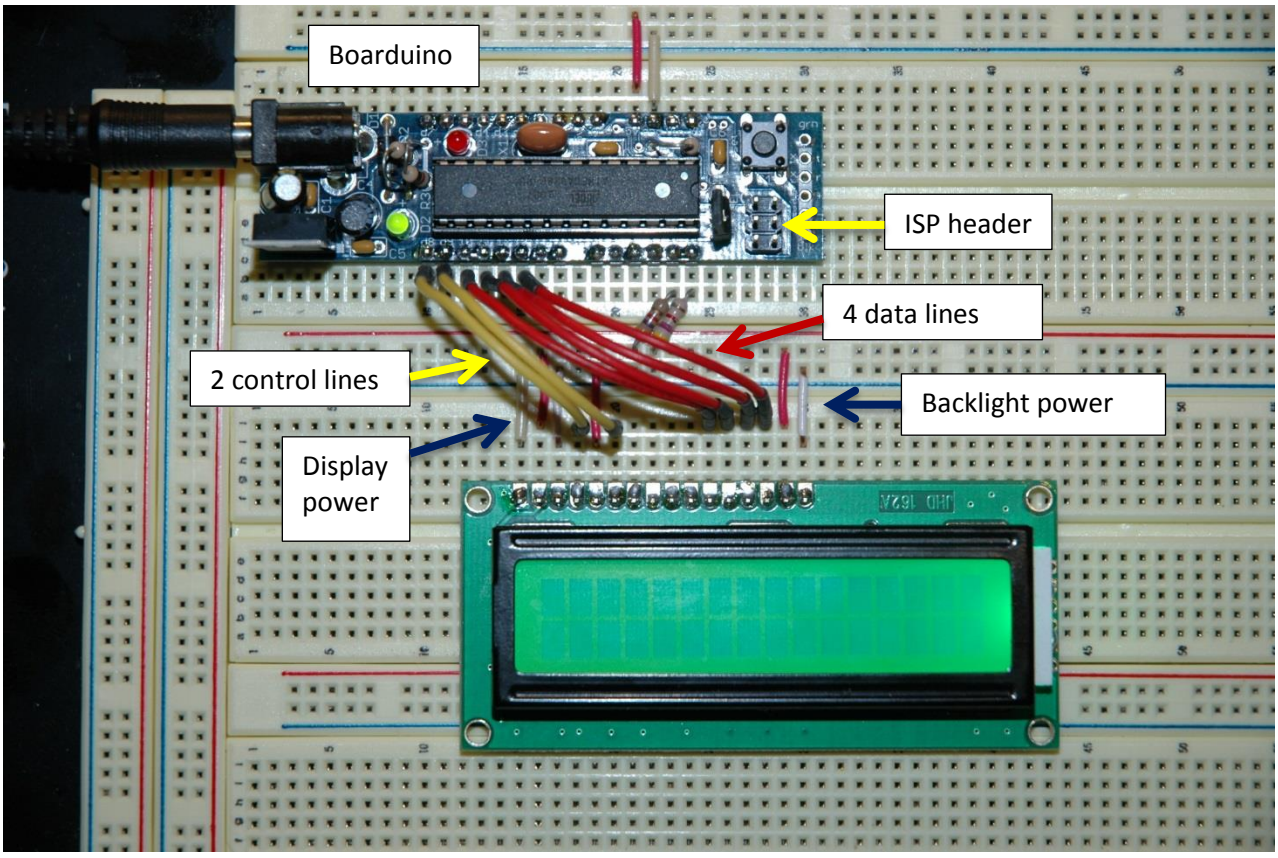
```
    SendCmd(0x01);                      // start with clear display
    msDelay(3);
}
```

It's time to write something on the LCD display, like 'Hello, World'. All we need to do is write each character, one at a time. A simple for-loop would do the trick. But if we want to get fancy, and use the fact that strings in c are null-terminated character arrays, we can use a compact while loop instead:

```
void ShowMessage(const char *text)
{
    while (*text)               // string ends with 0x00
    {
        SendChar(*text++);      // auto-increment the array pointer
    }
}
```

5) PROTOTYPING

Here is my breadboard setup:



There are two control lines (yellow) and four data lines (red) between the PortB pins of the microcontroller and the display. The two resistors are for an I2C bus, not used in this demo.

6) SOURCE CODE:

```
//-------------------------------------------------------------------------
//  lcd01:  Experiments interfacing ATmega328 to an HD44780 LCD display
//
//  Author   :  Bruce E. Hall <bhall66@gmail.com>
//  Website  :  w8bh.net
//  Version  :  1.0
//  Date     :  7 Sep 2013
//  Target   :  ATmega328P microcontroller
//  Language :  C, using AVR studio 6
//  Size     :  836 bytes, using -O1 optimization
//
//  Fuse settings:  8 MHz osc with 65 ms Delay, SPI enable; *NO* clock/8


//      ---------------------------------------------------------------------
//      GLOBAL DEFINES

#define F_CPU  16000000L                // run CPU at 16 MHz
#define LED    5                        // Boarduino LED on PB5
#define ClearBit(x,y) x &= ~_BV(y)      // equivalent to cbi(x,y)
#define SetBit(x,y) x |= _BV(y)         // equivalent to sbi(x,y)

//      ---------------------------------------------------------------------
//      INCLUDES

#include <avr/io.h>                     // deal with port registers
#include <util/delay.h>                 // used for _delay_ms function
#include <string.h>                     // string manipulation routines
#include <stdlib.h>

//      ---------------------------------------------------------------------
//      TYPEDEFS

typedef uint8_t byte;                   // I just like byte & sbyte better
typedef int8_t sbyte;

//      ---------------------------------------------------------------------
//      MISC ROUTINES

void SetupPorts()
{
    DDRB = 0x3F;                        // 0011.1111; set B0-B5 as outputs
    DDRC = 0x00;                        // 0000.0000; set PORTC as inputs
}

void msDelay(int delay)                 // put into a routine
{                                       // to remove code inlining
    for (int i=0;i<delay;i++)           // at cost of timing accuracy
    _delay_ms(1);
}

void FlashLED()
{
    SetBit(PORTB,LED);
    msDelay(250);
    ClearBit(PORTB,LED);
    msDelay(250);
}
```

```
//      ---------------------------------------------------------------------------
//      HD44780-LCD DRIVER ROUTINES
//
//  Routines:
//      LCD_Init     initializes the LCD controller
//      LCD_Cmd      sends LCD controller command
//      LCD_Char     sends single ascii character to display
//      LCD_Clear    clears the LCD display & homes cursor
//      LCD_Home     homes the LCD cursor
//      LCD_Goto     puts cursor at position (x,y)
//      LCD_Line     puts cursor at start of line (x)
//      LCD_Hex      displays a hexadecimal value
//      LCD_Integer  displays an integer value
//      LCD_Message  displays a string
//
//  The LCD module requires 6 I/O pins:  2 control lines & 4 data lines.
//  PortB is used for data communications with the HD44780-controlled LCD.
//  The following defines specify which port pins connect to the controller:


#define LCD_RS      0                   // pin for LCD R/S (eg PB0)
#define LCD_E       1                   // pin for LCD enable
#define DAT4        2                   // pin for d4
#define DAT5        3                   // pin for d5
#define DAT6        4                   // pin for d6
#define DAT7        5                   // pin for d7


//  The following defines are HD44780 controller commands
#define CLEARDISPLAY 0x01
#define SETCURSOR    0x80



void PulseEnableLine ()
{
    SetBit(PORTB,LCD_E);                // take LCD enable line high
    _delay_us(40);                      // wait 40 microseconds
    ClearBit(PORTB,LCD_E);              // take LCD enable line low
}

void SendNibble(byte data)
{
    PORTB &= 0xC3;                      // 1100.0011 = clear 4 data lines
    if (data & _BV(4))  SetBit(PORTB,DAT4);
    if (data & _BV(5))  SetBit(PORTB,DAT5);
    if (data & _BV(6))  SetBit(PORTB,DAT6);
    if (data & _BV(7))  SetBit(PORTB,DAT7);
    PulseEnableLine();                  // clock 4 bits into controller
}

void SendByte (byte data)
{
    SendNibble(data);                   // send upper 4 bits
    SendNibble(data<<4);                // send lower 4 bits
    ClearBit(PORTB,5);                  // turn off boarduino LED
}

void LCD_Cmd (byte cmd)
{
    ClearBit(PORTB,LCD_RS);             // R/S line 0 = command data
    SendByte(cmd);                      // send it
}

void LCD_Char (byte ch)
{
    SetBit(PORTB,LCD_RS);               // R/S line 1 = character data
    SendByte(ch);                       // send it
}
```

```
void LCD_Init()
{
    LCD_Cmd(0x33);                      // initialize controller
    LCD_Cmd(0x32);                      // set to 4-bit input mode
    LCD_Cmd(0x28);                      // 2 line, 5x7 matrix
    LCD_Cmd(0x0C);                      // turn cursor off (0x0E to enable)
    LCD_Cmd(0x06);                      // cursor direction = right
    LCD_Cmd(0x01);                      // start with clear display
    msDelay(3);                         // wait for LCD to initialize
}

void LCD_Clear()                        // clear the LCD display
{
    LCD_Cmd(CLEARDISPLAY);
    msDelay(3);                         // wait for LCD to process command
}

void LCD_Home()                         // home LCD cursor (without clearing)
{
    LCD_Cmd(SETCURSOR);
}

void LCD_Goto(byte x, byte y)           // put LCD cursor on specified line
{
    byte addr = 0;                      // line 0 begins at addr 0x00
    switch (y)
    {
        case 1: addr = 0x40;  break;    // line 1 begins at addr 0x40
        case 2: addr = 0x14;  break;
        case 3: addr = 0x54;  break;
    }
    LCD_Cmd(SETCURSOR+addr+x);          // update cursor with x,y position
}

void LCD_Line(byte row)                 // put cursor on specified line
{
    LCD_Goto(0,row);
}

void LCD_Message(const char *text)      // display string on LCD
{
    while (*text)                       // do until /0 character
        LCD_Char(*text++);              // send char & update char pointer
}

void LCD_Hex(int data)
// displays the hex value of DATA at current LCD cursor position
{
    char st[8] = "";                    // save enough space for result
    itoa(data,st,16);                   // convert to ascii hex
    //LCD_Message("0x");                // add prefix "0x" if desired
    LCD_Message(st);                    // display it on LCD
}

void LCD_Integer(int data)
// displays the integer value of DATA at current LCD cursor position
{
    char st[8] = "";                    // save enough space for result
    itoa(data,st,10);                   // convert to ascii
    LCD_Message(st);                    // display in on LCD
}
```

```
//      ---------------------------------------------------------------------------
//      DEMO FUNCTIONS


void UpdateCursor (byte count)          // helper fn for FillScreen
{
    switch(count)
    {
        case  0: LCD_Line(0); break;
        case 16: LCD_Line(1); break;
        case 32: LCD_Line(2); break;
        case 48: LCD_Line(3); break;
    }
}

char GetNextChar(char ch)               // helper fn for FillScreen
{
    if ((ch<0x20) | (ch>=0xFF))
        return 0x20;
    if ((ch>=0x7F) & (ch<0xA0))
        return 0xA0;
    return ++ch;
}

#define NUMCHARS 64                     // number of characters per screen
void FillScreen ()
// fills LCD screen with ascii characters
// be sure to set NUMCHARS to 32 or 64 characters, depending on the size of your display
// 32 looks good on 16x2 displays; 64 looks good on 20x4 displays.
// four line displays also show an incrementing 1-99 page counter.
{
    char ch = 'A';
    LCD_Clear();
    for (byte count=1;count<100;count++)
    {
        LCD_Goto(18,0);
        LCD_Integer(count);             // show counter (vis on 4-liners only)
        for (byte i=0;i<NUMCHARS;i++)   // do a screenful of characters
        {
            UpdateCursor(i);            // go to next line, if necessary
            LCD_Char(ch);               // show current ascii character
            ch = GetNextChar(ch);       // update to next character
            msDelay(60);                // set animation speed
        }
    }
}



//      ---------------------------------------------------------------------------
//      MAIN PROGRAM

int main(void)
{
    SetupPorts();                       // use PortB for LCD interface
    LCD_Init();                         // initialize LCD controller
    LCD_Message("Ready.");              // welcome message
    msDelay(2000);                      // wait
    while(1)
        FillScreen();                   // fill screen with ASCII characters
}
```