EE 109 Unit 9 – LCD
LCD BOARD
The EE 109 LCD Shield

• The LCD shield is a 16 character by 2 row LCD that mounts on top of the Arduino Uno.
• The shield also contains five buttons that can be used as input sources.
How Do We Use It?

• By sending it data (i.e. ASCII characters one at a time) that it will display for us
• By sending it special commands to do things like:
  – Move the cursor to a specific location
  – Clear the screen contents
  – Upload new fonts/special characters
How Do We Communicate?

• The LCD uses a "parallel" interface (4-bits sent per transfer) to communicate with the µC (Note: µC => microcontroller)
• Data is transferred 4 bits at a time and uses 2 other signals (Register Select and Enable) to control where the 4-bits go and when the LCD should capture them

Uno

Data lines

D7
D6
D5
D4

Register Select

D8
D9

Enable

EE 109 is fun!
Walk your bike!

LCD
Commands and Data

- LCD contains two 8-bit registers which it uses to control its actions: Command and Data
- A Register Select (RS) signal determines which register is the destination of the data we send it (RS acts like an address selector)
  - RS = 0, info goes into the command register
  - RS = 1, info goes into the data register
- To perform operations like clear display, move cursor, turn display on or off, write the command code to the command register.
- To display characters on the screen, write the ASCII code for the character to the data register.

<table>
<thead>
<tr>
<th>Command</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear LCD</td>
<td>0x01</td>
</tr>
<tr>
<td>Curser Home (Upper-Left)</td>
<td>0x02</td>
</tr>
<tr>
<td>Display On</td>
<td>0x0f</td>
</tr>
<tr>
<td>Display Off</td>
<td>0x08</td>
</tr>
<tr>
<td>Move cursor to top row, column i</td>
<td>0x80+i</td>
</tr>
<tr>
<td>Move cursor to bottom row, column i</td>
<td>0xc0+i</td>
</tr>
</tbody>
</table>
How Do We Communicate?

- To transfer data we send it in two groups of 4
  - First the upper 4-bits followed by the lower 4-bits
- \( \text{RS} = 0 \) sets the destination as the command reg.
- \( \text{RS} = 1 \) sets the destination as the data reg.
How Do We Communicate?

- To transfer data we send it in two groups of 4:
  - First the upper 4-bits followed by the lower 4-bits
- RS=0 sets the destination as the command reg.
- RS=1 sets the destination as the data reg.
Another View

- Data from the Uno is transferred by placing four bits on the data lines (PD[7:4]).

- The Register Select (RS) line determines whether the data goes to the LCD’s "Command Register" or "Data Register"
  - RS=0 => Command Register
  - RS=1 => Data Register

- The Enable (E) line acts as a "clock" signal telling the LCD to capture the data and examine the RS bit on the 0-1-0 transition
  - Pulse must be held at 1 for at least 230ns according to LCD datasheet

![Diagram showing data transfer and timing](image)
Another View

- Data from the Uno is transferred by placing four bits on the data lines (PD[7:4]).
- Whether sending info to the "command" or "data" register, the LCD still wants a full byte (8-bits) of data so we must do 2 transfers
  - We always send the upper 4-bits of the desired data first
  - Then we transfer the lower 4-bits

"0000 0101" sent to the **command** register in the LCD

The first 4-bits of a transfer to the **data** register in the LCD

<table>
<thead>
<tr>
<th>(PB0) RS</th>
<th>(PD[7:4]) Data</th>
<th>(PB1) Enable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0000</td>
<td>230 ns</td>
</tr>
<tr>
<td></td>
<td>0101</td>
<td>230 ns</td>
</tr>
<tr>
<td></td>
<td>0110</td>
<td>230 ns</td>
</tr>
</tbody>
</table>
Who's Job Is It?

- So who is producing the values on the RS and Data lines and the 0-1-0 transition on the E line?
- You!! With your digital I/O (setting and clearing PORT bits)

```c
// Turn on bit 0 of PORTD
PORTD |= 0x01

// Delay 1 us > 230ns needed
_delay_us(1);

// Turn off bit 0 of PORTD
PORTD &= ~(0x01)

This code would produce some voltage pattern like this on PD0

(PD0) ___________

Note: The LCD connection doesn't use PD0, you'll need to modify this appropriately to generate the E signal
Other LCD Interface

• Other LCD devices may use
  – Only one signal (a.k.a. serial link) to communicate between the \( \mu \)C and LCD
    • This makes wiring easier but requires more complex software control to "serialize" the 8- or 16-bit numbers used inside the \( \mu \)C
  – 8-data wires plus some other control signals so they can transfer an entire byte
    • This makes writing the software somewhat easier
LCD LAB PREPARATION
Step 1

• Mount the LCD shield on the Uno without destroying the pins
• Download the “test.hex” file and Makefile from the web site, and modify the Makefile to suite your computer.
• Run “make test” to download test program to the Uno+LCD.
• Should see a couple of lines of text on the screen.
Step 2

• Develop a set of functions that will abstract the process of displaying text on the LCD
  – A set of functions to perform specific tasks for a certain module is often known as an **API** (application programming interface)
  – Once the API is written it gives other application coders a nice simple interface to do high-level tasks

• Download the skeleton file and examine the functions outlines on the next slides
LCD API Development Overview

• Write the routines to control the LCD in layers
  – Top level routines that yours or others code can use: write a string to LCD, initialize LCD, etc.
  – Mid level routines: write a byte to the command register, write a byte to the data register
  – Low level routines: controls data lines and E to transfer a nibble to a register

• Goal: Hide the ugly details about how the interface actually works from the user who only wants to put a string on the display.
High Level API Routines

• init_lcd()
  – Does all the steps to initialize the LCD
  – See the lab writeup and follow it exactly as written
  – Uses: writenibble(), writecommand(), delays

• moveto(unsigned char row, unsigned char col)
  – Moves the LCD cursor to “row” (1 or 2) and “col” (1-16)
  – Translates from row/column notation to the format the LCD uses for positioning the cursor (see lab writeup)
  – Uses: writecommand()

• stringout(char *s)
  – Writes a string of character starting at the current cursor position
  – Uses: wriedata()
Mid-Level Functions

• **writecommand(unsigned char x)**
  – Send the 8-bit byte ‘x’ to the LCD as a command
  – Set RS to 0, send data in two nibbles, delay
  – **Uses: writenibble()**

• **writedata(unsigned char x)**
  – Send the 8-bit byte ‘x’ to the LCD as data
  – Set RS to 1, send data in two nibbles, delay
  – **Uses: writenibble()**

• Could do as one function
  – **writebyte(unsigned char x, unsigned char rs)**
Low Level Functions

• writenibble(unsigned char x)
  – Assumes RS is already set appropriately
  – Send four bits from ‘x’ to the LCD
    • Takes 4-bits of x and copies them to PD[7:4] (where we've connected the data lines of the LCD)
    • Produces a 0-1-0 transition on the Enable signal
  – Must be consistent with mid-level routines as to which 4 bits to send, MSB or LSB
  – Uses: logical operations (AND/OR) on the PORT bits
Step 3

• Complete the LCD Lab after first understanding how to use the buttons present on the LCD shield
  – Information about how to use the buttons is presented in the next slides
LCD Shield Buttons

- The LCD shield has 5 buttons.
- However, they do not produce 5 individual signals like you are used to from previous labs.
- They are configured in such a way such that they sum together to produce a single analog voltage which the shield connects to the A0 input of the Arduino.
- If the voltage is in certain range we can infer that a particular button is being pressed.

5 Button Inputs => 1 analog voltage
LCD Shield Buttons

- You can use the Arduino's A-to-D converter to sense when a button is pressed
- Each button produces a certain voltage when pressed and the default value of 5V when no button is pressed
- The table to the right shows the nominal voltages and 10-bit ADC result
  - Note these are nominal and could be different so it would be best to just split the range evenly (e.g. to know the 'Up' button is pressed check if the 10-bit ADC results is between 104 and 308)

<table>
<thead>
<tr>
<th>Button</th>
<th>Volts (V)</th>
<th>Avg. 10-bit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>0 V</td>
<td>0</td>
</tr>
<tr>
<td>Up</td>
<td>1.0 V</td>
<td>208</td>
</tr>
<tr>
<td>Down</td>
<td>2.0 V</td>
<td>408</td>
</tr>
<tr>
<td>Left</td>
<td>3.1 V</td>
<td>624</td>
</tr>
<tr>
<td>Select</td>
<td>4.0 V</td>
<td>816</td>
</tr>
<tr>
<td>None</td>
<td>5V</td>
<td>1023</td>
</tr>
</tbody>
</table>
Ensuring the Enable pulse is long enough

THE DEVIL IN THE DETAILS...
Does your code do the right thing?

- Lab 6 required the program to generate an Enable (E) pulse.
- Example: The writenibble() routine controls the PB1 bit that is connected to the LCD Enable line.
  
  ```
  PORTB |= (1 << PB1);        // Set E to 1
  PORTB &= ~(1 << PB1);       // Clear E to 0
  ```

- Creates a 0→1→0 pulse to clock data/commands into LCD.
- But is it a pulse that will work with the LCD?
- Rumors circulated that the E pulse had to be made longer by putting a delay in the code that generated it.
- Don’t Guess. Time to read the manual, at least a little bit.
Check the LCD controller datasheet

Timing Characteristics

Figure 27  Write Operation

Figure 28  Read Operation

Note: * VOL1 is assumed to be 0.8 V at 2 MHz operation.
Check the generated code

- Can check the code generated by the compiler to see what is happening.
- For the creation of the E pulse the compiler generated this code:
  ```
  SBI  PORTB, 1 ; Set Bit Immediate, PORTB, bit 1
  CBI  PORTB, 1 ; Clear Bit Immediate, PORTB, bit 1
  ```
- According to the manual, the SBI and CBI instructions each take 2 clock cycles
- $16\text{MHz} \Rightarrow 62.5\text{nsec/cycle}$, so pulse will be high for $125\text{nsec}$
Making Things Work Together

Check with the oscilloscope
Making Things Work Together

Extend the pulse

• At 125nsec, the E pulse is not long enough although it might work on some boards.
• Can use _delay_us() or _delay_ms() functions but these are longer than needed since the minimum delay is 1 us (=1000 ns) and we only need 230 ns
• Trick for extending the pulse by a little bit:

  PORTB |= (1 << PB1); // Set E to 1
  PORTB |= (1 << PB1); // Add another 125nsec to the pulse
  PORTB &= ~(1 << PB1); // Clear E to 0
Making Things Work Together

Better looking pulse
Extend the pulse (geek way)

- Use the “asm” compiler directive to embed low level assembly code within the C code.
- The AVR assembly instruction “NOP” does nothing, and takes 1 cycle to do it.

```c
PORTB |= (1 << PB1);       // Set E to 1
asm("nop":::);            // NOP delays another 62.5ns
asm("nop":::);
PORTB &= ~(1 << PB1);     // Clear E to 0
```
Making Things Work Together

Don’t guess that things will work

• When working with a device, make sure you know what types of signals it needs to see
  – Voltage
  – Current
  – Polarity (does 1 mean enable/true or does 0)
  – Duration (how long the signal needs to be valid)
  – Sequence (which transitions comes first, etc.)

• Have the manufacturer’s datasheet for the device available
  – Most of it can be ignored, but some parts are critical
  – Learn how to read it

• When in doubt ➔ follow the acronym used industry-wide: RTFM (read the *!@^-ing manual)