EE 109 Unit 7 – 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

![Diagram of Uno and LCD connections](image-url)
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
• RS=0 sets the destination as the command reg.
• 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

```
(PB0) RS

(PD[7:4]) Data
0000 0101

(PB1) Enable
230 ns 230 ns 230 ns

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

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

(PB0) RS

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

(PD[7:4]) Data

0000 0101 0110

(PB1) Enable

230 ns 230 ns 230 ns

The first 4-bits of a transfer to the data register in the LCD
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 μC and LCD
    • This makes wiring easier but requires more complex software control to "serialize" the 8- or 16-bit numbers used inside the μC
  – 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.
Low Level Functions

- **writtenibble**(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)
    - **SEE NEXT SLIDES ON COPYING BITS**
    - 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
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)
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” (0 or 1) and “col” (0-15)
  - 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: writedata()`
COPYING BITS
Copying Multiple Bits

• Suppose we want to copy a portion of a variable or register into another BUT WITHOUT affecting the other bits

• Example: Copy the lower 4 bits of X into the lower 4-bits of PORTB...but leave the upper 4-bits of PORTB UNAFFECTED

• Assignment doesn't work since it will overwrite ALL bits of PORTB
  – PORTB = x; // changes all bits of PORTB
Copying Into a Register

- Solution...use these steps:
  - Step 1: Define a mask that has 1’s where the bits are to be copied
    ```
    #define MASKBITS 0x0f
    ```
  - Step 2: Clear those bits in the destination register using the MASK
    ```
    PORTB &= ~MASKBITS
    ```
  - Step 3: Mask the appropriate field of x and then OR it with the destination, PORTB
    ```
    PORTB |= (x & MASKBITS);
    ```
Do We Need Step 2...Yes!!!

- Can't we just do step 1 and 3 and OR the bits of x into PORTB
  
  ```c
  #define MASKBITS 0x0f
  PORTB |= (x & MASKBITS);
  ```

- No, because what if the destination (PORTB) already had some 1's where wanted 0's to go...

- ...Just OR'ing wouldn't change the bits to 0

- That's why we need step 2
  
  - Step 2: Clear those bits in the destination register using the MASK
    
    ```c
    PORTB &= ~MASKBITS;
    ```
Copying To Different Bit Locations

• What if the source bits are in a different location than the destination
  – Ex. Copy lower 4 bits of x to upper 4 bits of PORTB

• Step 1: Define a mask that has 1’s where the bits are to be copied
  #define MASKBITS 0xf0

• Step 2: Clear those bits in the destination register using the MASK
  PORTB &= ~MASKBITS

• Step 3: Shift the bits of x to align them appropriately, then perform the regular step 3
  PORTB |= ((x<<4) & MASKBITS);
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
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 8-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 8-bit ADC results is between 26 and 77)

<table>
<thead>
<tr>
<th>Button</th>
<th>Volts (V)</th>
<th>Avg. 8-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>52</td>
</tr>
<tr>
<td>Down</td>
<td>2.0 V</td>
<td>104</td>
</tr>
<tr>
<td>Left</td>
<td>3.1 V</td>
<td>156</td>
</tr>
<tr>
<td>Select</td>
<td>4.0 V</td>
<td>208</td>
</tr>
<tr>
<td>None</td>
<td>5V</td>
<td>255</td>
</tr>
</tbody>
</table>
Ensuring the Enable pulse is long enough

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

- LCD lab 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
- 16MHz ⇒ 62.5nsec/cycle, so pulse will be high for 125nsec
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
Making Things Work Together

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
```
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)
Logical Operations

Transfer Byte

Data

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
a & b & c & d & e & f & g & h \\
\end{array} \]

 Writtenibble

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
a & b & c & d & e & f & g & h \\
\end{array} \]

 Writtenibble

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
e & f & g & h & ? & ? & ? & ? \\
\end{array} \]

Writtenibble

Icdbits

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
\end{array} \]

PORTD

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
\end{array} \]

Bit #

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
\end{array} \]

&

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
\end{array} \]

|

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
\end{array} \]

^ 0 0 0 0 1 1 1 1

\[ \begin{array}{cccccccc}
7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
\end{array} \]