OBJECTIVES

- Learn how to use C (as an alternative to Assembly) in your programs.
- Learn how to control and interface an LCD panel to a microprocessor.
- Learn how to use analog-to-digital conversion (ADC) system on a microcontroller.
- Use the ADC on your XMEGA to sample an analog input, convert the binary value to decimal, and display the value on an LCD. (You are creating a simple voltage meter.)

REQUIRED MATERIALS

- uPAD and Proto Base kit and tools
- DAD (Diligent Analog Discovery) kit
- 1 – Female Header (16-pins) for LCD mounting
- 1 – Male Header (16-pins) for LCD mounting
- 1 – LCD with 8-bit data (16-pins)
- 2 – Potentiometers (pots)
- Spec sheet for Level Shifter (for 5V LCD)
- You WILL need the following documentation:
  - LCD Panel Notes (8-bit data)
- XMEGA documents
  - doc8331: XMEGA Manual
  - doc8032: Analog to Digital (ADC)
  - doc8075: Writing C-code for XMEGA
- Lecture 13 notes for A-to-D pertaining to uPAD
  - uPAD documentation

NOTE: It is assumed you have already soldered your potentiometers and LCD to the board. If you haven’t, refer to the board assembly instructions.

NOTE: All software in this lab should be written in C. If you cannot get your programs working in C, you can write it in Assembly for partial credit.

NOTE: Although the C language has a multitude of built-in functions, you are NOT permitted to use any of them in EEL 3744. For example, you are NOT allowed to use the _delay_ms or _delay_us functions. Also, do not use sprint or any similar functions for this lab.

PART A: LCD DISPLAY

In this section you will add an LCD display to your uPAD Proto Base and send your name to the LCD. The filename should be Lab5_lcd_name.c. The LCD module included in your kit can display 2 lines with up to 16 characters on each line (2x16), has an 8-bit data bus, and can operate in 4- and 8-bit modes. The LCD has 2 registers, command and data, that are used for issuing commands/writing (or reading) characters respectively. Refer to the LCD Panel Notes (8-bit data) document or device datasheet for pin-out and command information.

From a previous lab, you already configured CS0 to 0x4000 to 0x7FFF. For this lab, configure CS1 to enable on addresses 0x37 0000 to 0x37 FFFF, but use additional address decoding to place an LCD at addresses 0x37 A000 to 0x37 AFFF. (We could then use addresses 0x37 0000 to 0x37 9FFF and 0x37 B000 to 0x37 FFFF for other purposes.)

1. Consult the LCD datasheet for pin-out information and an example circuit. You will interface the LCD to the XMEGA pins as follows.

You may have a 3.3V LCD or a 5V LCD. (This is old inventory and future kits, and many this semester, will have a 3.3V LCD.) The 5V LCD PCBs have two rows of headers on opposite edges of the LCD PCB; the 3.3V LCD has only one row of headers. Fortunately, you can still interface the 5V LCD to XMEGA’s 3.3V logic using the provided logic level shifter.

5V LCD instructions:
If you have a 5V LCD, then you should also have received a level shifter chip. Review this specification sheet, especially Figure 1. This is a bi-directional device that will allow the 5V LCD to work with the 3.3V XMEGA bus.

Connect the LCD’s VSS to GND and VDD to 5V. Use the provided logic level shifter to interface this LCD to XMEGA’s 3.3V. The LCD’s VO (labeled C [for contrast] on the bottom of the uPAD Proto Base) should be connected to a 5V potentiometer (pot) for contrast adjustment, as shown below:
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3.3V LCD instructions:
If you have a 3.3V LCD, then no level shifter is necessary. Connect VSS to GND and VDD to 3.3V. Vo (labeled C – for contrast – on the bottom of the uPAD Proto Base) should be connected to a 3.3V potentiometer (pot) for contrast adjustment, as shown below:

2. Unlike the 4-bit LCD modules used in the past, the 8-bit LCD’s timing characteristics are compatible XMEGA’s external data bus (EBI). Aside from CS and address lines, your LCD enable signal (E) also needs to include the /WE and /RE signals from your processor. If you are confused about how to configure the LCD enable signal, look at the reading/writing diagrams for the processor (Appendix A in doc8331, i.e., Figure 36-1) along with the reading/writing diagrams for the LCD (datasheet).

3. RS signal is used to distinguish between LCD commands and characters sent to the LCD. Since RS is attached to the XMEGA’s A0 pin, you can use any even address to set RS to 0 and any odd address to set RS to 1. All addresses must be within LCD enable range.

4. Your LCD runs much slower than the XMEGA. As a result sending instructions too quickly will cause the LCD to malfunction. Poll the LCD’s Busy Flag (BF on DB7) to avoid interfering with the LCD as it processes instructions. After writing a command or character, read the BF using LCD command address (not LCD data) to determine whether the LCD is still processing your last transmission. When the BF becomes false (low), the LCD is ready for the next character/command. Make sure you wait at least two cycles after a write before reading so the LCD has time to turn on its busy flag. The fastest that the (E) signal can be toggled, according the LCD documents, is 1 MHz. Since our board runs at approximately 2 MHz, this constraint is violated. We therefore need a two cycle delay. (One cycle should also work, but we use two cycles just to be sure.) You may insert NOP instructions between a write and read to implement the delay. You can insert a NOP in C with the following instruction.

   asm volatile ("nop");

5. As a simple first test for writing to the LCD, write code to send out your name to the LCD. There is a character output function supplied to you on the examples page of our class website called __far_mem_write(address, data). To access this function you need to include the "ebi_driver.h" header file at the top of your code. Save the above file and place it in the same folder as your program. You will then be able to use the #include to have access to it in the program.

NOTE: It’s STRONGLY suggested that you write functions like subroutines OUT_CHAR and OUT_STRING. The proposed OUT_STRING function should take in as a parameter any string and send it to the LCD, making sure all LCD timing requirements are satisfied. This is almost ESSENTIAL to complete this lab on time. You must initialize your LCD to 8-bit mode first before you can use the BF.

PART B: USING AN A/D TO CREATE A VOLTMETER
In this part of the lab, you will use XMEGA’s ADC to display the voltage from center tap of a second potentiometer on the LCD. The filename should be Lab5_lcd_voltage.c. Carefully read sections 28.1 - 28.6, 28.8, 28.16 - 28.17 in XMEGA doc8331 manual.

1. Connect a potentiometer (as shown below) to any of the four open ADC channels (labeled Analog at jumper J4) on your Proto Base. Note that the channels on J4 of your Proto Base are not conditioned to accept 5V input. In order to reduce noise in the system, place the potentiometer as close to the analog input as possible. Also, locate the 3-by-4 header under the uPAD. Be sure to place a jumper between the center pins and the pins labeled AFE4-7. Those pins connect Port B to the Analog Front End described later.
2. Use the external reference of AREFB in your ADC register initializations. This will set your ADC voltage span to be from 0V to 2.5V. (There is op-amp circuitry on your board to divide the 0 to 5V potentiometer voltage to meet this constraint.)

3. There are several ways to configure the ADC system. For example, you can use 12-bit signed, right adjusted, single-ended mode with no gain, with continuous conversion on channel 0. In this case, bit 11 will be zero and you can use bits 10 to 0 (11 bits) or 10 to 3 (8 bit) for calculations. It is your choice to use signed or unsigned mode. (Do not forget to set the direction of the ADC pin you are using to input and enable the ADC module.)

If you used 12-bit unsigned mode, when the input is ground (0V), the digital value will be approximately 200. (See doc8032, Figure 3-2.)

4. The ADC value will need to be converted into the decimal value voltage that it represents. You will use an algorithmic conversion (mathematical calculations) to find the decimal value from the analog voltage. The alternative is to use a lookup table (LUT), as discussed in the Appendix.

5. You must display the voltage of an ADC input pin as both a decimal number, e.g., 4.37 V, and as a hex number, e.g., 0xDE (if you use unsigned, 8-bit). For example, the LCD might display 2.50V (0x7F) for unsigned, 8-bit. The hex value and its corresponding voltage will vary depending on your implementation. I suggest that you use signed mode for reasons apparent in Figure 3-2 of doc8032.

6. Determine a formula that converts the ADC value (unsigned 8-bit: 0 to 255, unsigned 12-bit: 0 to 4095, signed: 8-bit: -128 to 127, or signed 12-bit: -2048 to 2047). Note that our circuit will only allow positive voltage, e.g., 3.14V. The output 3 digits to the LCD for your decimal voltage, e.g., 3.14 V.

7. The hex values for the ASCII characters for the digits 0 through 9 are 0x30 through 0x39, i.e., just add 0x30 to the digit to find the ASCII representation of a digit. You will also need the hex values for the ASCII equivalents of the decimal point, a space, the letters “V” and “x,” and both the left and right parenthesis.

8. If we assume that the input voltage calculated in part 6 was 3.14V, the below algorithm describes how to send that value to the LCD, one character at a time. Note that using the type casting operation in C is very helpful for this algorithm. Type casting converts a value of one type to a value in another type. For example, if I is an integer equal to 3 and F is a floating point number, then F = (float) 3; will result in F = 3.0. Similarly, if Pi = 3.14159265 (approximately), then I = (int) Pi, with result in I = 3.

   - Pi = 3.14159… //variable holds original value
   - Int1 = (int) Pi = 3 3 is the first digit of Pi
   - Send this Int1 digit to the LCD, then send “.”
   - Pi2 = 10*(Pi - Int1) = 1.4159…
   - Int2 = (int) Pi2 = 1 1 is the second digit of Pi
   - Send this Int2 digit to the LCD
   - Pi3 = 10*(Pi2 – Int2) = 4.159…
   - Int3 = (int) Pi3 = 4 4 is the third digit of Pi
   - Send this Int3 digit to the LCD
   - …

Send a space, then a “V (“ to the LCD. Then send the two or three hex digits corresponding to the ADC value to the LCD, i.e., 2 hex digits if you use 8-bit mode and 3 hex digits if you use 12-bit mode. Finally send a “)“ to the LCD, resulting in something like 3.14 V (0xA0), for an unsigned, 8-bit.

9. Testing: Use your DAD and multimeter to verify that your XMEGA-based voltmeter is functioning properly. Set the potentiometer at five different positions across the entire range of voltages and record the readings from your DAD, your XMEGA-based voltmeter, and your multimeter. The values will not agree perfectly, and may be as much as (5-10%) different.

PART C: SELECTING LCD FUNCTION USING A KEYPAD

In this part of the lab you will use your keypad to select different functions for displaying on your LCD. The filename should be Lab5_lcd_keypad.c. The functions are described as follows:

<table>
<thead>
<tr>
<th>Function</th>
<th>Keypad Keys</th>
<th>LCD Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,1</td>
<td>Display your name on LCD.</td>
</tr>
<tr>
<td>2</td>
<td>2,3</td>
<td>Clear LCD and blink cursor at home</td>
</tr>
<tr>
<td>3</td>
<td>4,5</td>
<td>Toggle display on or off.</td>
</tr>
<tr>
<td>4</td>
<td>6,7</td>
<td>Display the following on 2 lines: May the Schwartz be with you!</td>
</tr>
<tr>
<td>5</td>
<td>*,#</td>
<td>Continuously display the pot tap voltage, e.g., 2.37 V (0x79)</td>
</tr>
<tr>
<td>6</td>
<td>Others</td>
<td>Create your own. Be creative! (worth +3 extra credit points added to this lab’s grade)</td>
</tr>
</tbody>
</table>

- If any key from function 1 is pressed, the LCD should display your name, just like in part A of this lab.
- If any key from function 2 is pressed, clear the LCD, return the cursor to home (the top left element of the LCD) and make it blink.
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- If the user presses a key from function 3, the LCD’s display should turn on or off. You should check the LCD data sheet for a helpful function to do this!
- If a key from function 4 is pressed, the string “May the Schwartz be with you!” should be displayed on the LCD.
- If the user presses any key from function 5, the LCD should display the voltmeter reading in the same format as described in parts 5-8 of this lab; the LCD should constantly update the voltmeter reading until a different key is pressed.
- If any key from function 6 is pressed, the LCD should display anything you want. Note that the better and more original function you create for function 6, the more points you will get (up to 3% of the lab).

PRE-LAB QUESTIONS
1. If you were working on another microcontroller and you wanted to add an 8-bit LCD to it, what is the minimum amount of signals required from the microcontroller to get it working?
2. Assume you wanted a voltage reference range from $-1 \text{ V}$ to 3 V, with a signed 12-bit ADC. What are the voltages if the ADC output is 0xA37 and 0xD42?
3. In this lab our reference range is ideally from 0V to 5V. If the range was 0 to 2.0625V (a possible internal reference) and 12-bit unsigned mode was used, what is the resolution (volts/bit) and what is the digital value for a voltage of 0.73 V.
4. What is the difference in conversion ranges between 12-bit unsigned and signed conversion modes? List both ranges.

PRE-LAB REQUIREMENTS
1. Answer all pre-lab questions
2. Add an LCD panel to your uPAD Proto Base.
3. Use the ADC to sample the analogue voltage and display the results on the LCD.
4. Write an interactive menu, using your keypad, LCD, and ADC. You may use your computer keyboard and your serial port in lieu of your keypad.

IN-LAB REQUIREMENTS
1. Demonstrate parts B and C.
2. If parts B and C do not work, demonstrate part A.

APPENDIX
Part B, number 4 could be accomplished using a Table Look Up (LUT) technique, described below. If there is no division available, then this is a good technique. Since there is no division instruction in assembly language, than this technique would be necessary if you were writing this program in Assembly, unless a division subroutine was created. In C, division is accomplished with the appropriate library included.

4. The ADC value will need to be converted into the decimal value voltage that it represents. You could use algorithmic conversion, however your processor does not have a divide instruction, and you cannot use C-generated division routines. The alternative is to use a lookup table (LUT). An example lookup table (LUT) may look like the following at successive memory locations, where the values are in stored in ASCII:

$0.00 \text{V} \text{ (0x00)}, 0.02 \text{V} \text{ (0x01)}, 0.04 \text{V} \text{ (0x02)}, 0.06 \text{V} \text{ (0x03)}, 0.08 \text{V} \text{ (0x04)}, 0.10 \text{V} \text{ (0x05)}, \ldots$

Note that the actual value corresponding to 0x01 for 8-bit unsigned is 0.0196V. But it is a waste to store the ASCII for the decimal point, the parentheses, and the 0x, since those will always need to be displayed.

A table with the above structure would simplify the lookup process. One only has to calculate the address by using the ADC’s hex value to retrieve the voltage equivalent. There are multiplication assembly instructions which should be used for the lookup process:

$\text{Addr} = \text{SizeOfText} \times \text{ADC\_value} + \text{TableAddr}$