Lab 5: LCD and A/D: Digital Voltmeter

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
- NAD/DAD (NI/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)
- 1- CdS cell
- 1 10kΩ resistor
- Spec sheet for Level Shifter (for 5V LCD)
  - Link on website
- You **WILL** need the following documentation:
  - LCD Panel Notes (8-bit data)
  - Spec sheet for a Orient LCD panel
- 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

YOU WILL NOT BE ALLOWED INTO YOUR LAB SECTION WITHOUT THE REQUIRED PRE-LAB.

PRELAB REQUIREMENTS

You must adhere to the *Lab Rules and* Policies document for **every** lab.

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.

You must also solder the CdS cell and a 10k resistor to the board along with headers. Please see circuit diagram in Part C of this lab.

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 0x8000 to oxBFFF. For this lab, configure CS1 to enable on addresses **0x42** 0000 to **0x42** FFFF, but use additional address decoding to place an LCD at addresses **0x42 2**000 to **0x42 7**FFF. (We could then use addresses 0x42 0000 to 0x42 1FFF and 0x42 8000 to 0x42 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.

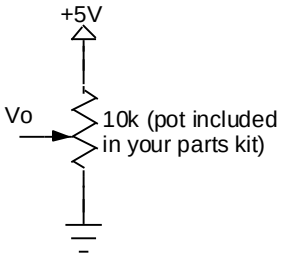
uPAD Proto Base Pins	LCD Pins
RS (A0)	RS
E (CPLD Pin)	E
D7:0	DB7:0
R/~W	R/~W
C (to middle pin on potentiometer)	Vo

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 LDC 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:

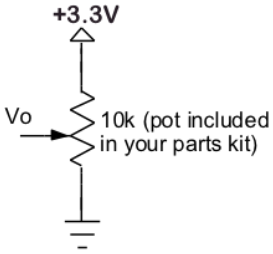
If you have a **5V LCD**, then you should also have received a level shifter chip. Review this specification sheet, especially Figure 1. This is a bi-directional device that will allow the 5V LCD to work with the 3.3V XMEGA bus.

Connect the LCD's V_{SS} to GND and V_{DD} to **5V**. Use the provided logic level shifter to interface this LCD to XMEGA's 3.3V. The LCD's V_O (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:



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**.

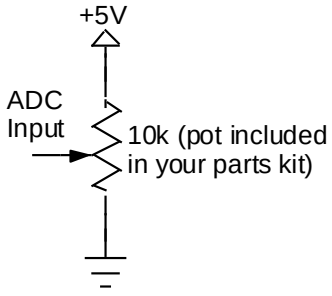
   The syntax for prototypes of the two functions discussed above are as follows:

   void OUT_CHAR(char character)
   void OUT_STRING(char *string)

PART B: SAMPLING AN ANALOG SIGNAL

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`**. You will add to this program in Part C and use it again in Part E. 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 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.)

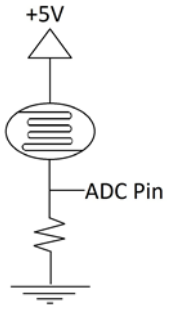
   If you used 12-bit **un**signed mode, when the input is ground (0V), the digital value will be approximately 200. (See doc8032, Figure 3-2.)

4. Test the voltage at the ADC input with your voltmeter (or NAD/DAD) and then compare it with the values that you get with your ADC system. For example, if the voltage at the XMEGA ADC pin is 2.5V (5V at the output of the potentiometer) and you configured the ADC for 8-bit signed mode, then you should read approximately 0x7F with your ADC. If the ADC pin voltage is 1.25V (2.5V at the output of the potentiometer), you should read approximately 0x40.

PART C: USING AN A/D TO SENSE LIGHT

In this part of the lab, you will use XMEGA's ADC to detect light conditions using a CdS cell. CdS (Cadmium Sulfide) cells are a type of photoresistors, electronic components sensitive to incident light. The filename should be `Lab5_lcd_cds.c`.

1. As a CdS sensor is exposed to more light, the resistance decreases. You can use a voltage divider to change the voltage based on light conditions. Build the circuit pictured below using your CdS cell and a 10kΩ resistor.



2. Use any of the remaining open ADC channels (labeled Analog at jumper J4) channels to measure the voltage obtained by your circuit and display it on your LCD in the same format as your voltage display.
3. Observe the voltage change (ADC value) as you change the light conditions (moving your hand over the CdS cell or shining a light on the sensor).
4. Pick an LED and turn it on if the CdS cell detects low light and turn it off otherwise. Low light can be defined as when the cell is partially covered with your hand.

PART D: CREATING A VOLTMETER

1. In this part of the lab you will take the ADC value from Part B into a voltmeter. (Add to the program that you started in Part B called **`Lab5_lcd_voltage.c`**). You need to be convert the ADC value into the decimal value voltage that it represents. You will use an algorithmic conversion (arithmetic calculations) to find the decimal value from the analog voltage. The alternative (not to be used in this lab) is to use a lookup table (LUT), as discussed in the Appendix.

2. 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.

3. 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 singed 12-bit: -2048 to 2047). Note that our circuit will only allow positive input values. Essentially, you are just finding the equation of a line (with the ADC value on the horizontal access and the corresponding voltage on the vertical axis). Output 3 digits to the LCD for your decimal voltage, e.g., 3.14 V.

4. 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.

5. If we assume that the input voltage calculated in part 2 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 Int2 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.

6. Testing: Use your DAD and multimeter to verify that you 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 E: 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, utilizing parts of each of the previous programs that you have written. The filename should be **`Lab5_lcd_keypad.c`**. You will demo only this part to your TA in lab. The functions are described as follows:

Function	Keypad Keys	LCD Function
1	0,1	Display your name on LCD.
2	2,3	Display the following on **2** lines: **`May the Schwartz`** **`be with you!`**
3	4,5	**Continuously** display the pot tap voltage, e.g., **2.37 V (0x79)**
4	6,7	Clear LCD and blink cursor at home and control an LED with the CdS sensor circuit
5	*,#	**Toggle display on or off**
6	Others	Create your own. **Be creative!** (worth +3 extra credit points added to this lab's grade)

- If any key from function 1 is pressed, the LCD should display your name, just like in part A of this lab.
- If a key from function 2 is pressed, the string "**`May the Schwartz be with you!`**" should be displayed on the LCD.
- If the user presses any key from function 3, the LCD should display the voltmeter reading in the same format as described in Part D of this lab; the LCD should constantly update the voltmeter reading until a different key is pressed.
- If any key from function 4 is pressed, clear the LCD, return the cursor to home (the top left element of the LCD) and make it blink. The function 4 should also utilize the CdS sensor circuit to control an LED (as described in Part C).
- If the user presses a key from function 5, the LCD's display should turn on or off. You should check the LCD data sheet for a helpful function to do this! ~~The function 5 should also utilize the CdS sensor circuit to control an LED (as described in Part C).~~
- 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).

Until a new key is pressed, the last function pressed should determine what is shown on the LCD. For instance, if a 3 is pressed, the *Spaceballs* quote (May the Schwartz …) should be displayed on the LCD until a different function is selected on the keypad.

PRE-LAB QUESTIONS

1. What is the difference in conversion ranges between 12-bit unsigned and signed conversion modes? List both ranges.
2. Assume you wanted a voltage reference range from -2 V to 1 V, with a signed 12-bit ADC. What are the voltages if the ADC output is 0xA25 and 0xB42?
3. 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?
4. 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.

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 CdS circuit output and the potentiometer circuit outputs. Turn on/off an LED based on the ADC value of the CdS circuit and display the analog voltage of the potentiometer circuit on the LCD panel.
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 Part E.
2. If Part E does not work, demonstrate as much as you can from Parts A, B, C, and D.

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:

```
0.00V (0x00), 0.02V (0x01), 0.04V (0x02),
0.06V (0x03), 0.08V (0x04), 0.10V (0x05), …
```

   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:

   Addr = SizeOfText*ADC_value + TableAddr