

# **Lab 3**

## **Data Manipulation and the LCD Display**

## Objectives

- Understand the basics of data manipulation
- Initialize a program (i.e. stack, registers, LCD, etc)
- Use indirect addressing with the X, Y, and Z-pointers
- Read data from program memory
- Move data around in data memory
- Setup and successfully call functions and subroutines

## Prelab

The answers to the prelab questions can be found in the AVR Starters Guide and the AVR Instruction Set.

- What is the stack pointer? How is the stack pointer used and how do you initialize it? Provide pseudo-code (NOT actual assembly code) that illustrates how to initialize the stack pointer.
- What does the AVR instruction LPM do and how do you use it? Provide pseudo-code that shows how to use the LPM instruction.
- Look at the definition file *m128def.inc*. What is contained within this definition file? What are the benefits of using this definition file? How would you include it into your AVR Assembly program?

## Introduction

For this lab, you will learn to use the LCD Display on the AVR microcontroller board. In order to use the LCD display, you will need to learn to properly initialize your program. You will also learn how to move data from your program memory into your data memory. This data is what will be displayed on the LCD display. To help you along the way, a project skeleton file will be provided. This file will contain some code and comments directing you to what code to write and where. The file will also give you a basis for writing well-structured code as defined in the AVR Starters Guide.

## Initialization

A program initialization consists of any code that is only run once at the beginning of the program. This code does not belong in the MAIN program, this is why most Assembly programs begin with INIT and not MAIN.

The INIT function is not a function in the classic sense but rather a function that is called at reset (and at power on) and jumps to the main program once it is finished.

There are several things that should be contained in the INIT function. The first and foremost is the initialization of the stack pointer. The stack in AVR operates in a higher to lower address fashion, meaning that newest element on the stack is in a lower address space than the previous element. Therefore the stack should be initialized to the highest data address space available. See the AVR Starters Guide for more information about the stack.

Other things that are initialized within the INIT function are ports, timers, interrupts, and other peripherals. For this lab, you will need to initialize the LCD display. Making a function call to the LCD Initialization Subroutine does the LCD initialization. You will also need to move data from the program memory to data memory in the INIT function.

## LCD Driver User Manual

To successfully use the LCD display for this lab, you will need to properly setup and call the functions in the LCD driver. To do this, you must first include it into your program. Unlike the definition file, the LCD driver contains actual assembly code and thus cannot be included at the beginning of the program file like the definition file. A quick look at the AVR Starters Guide under proper coding structure tells us that any include code file is included at the end of the program, i.e. the last lines. The actual LCD driver file is called *LCDDriver.asm* and can be downloaded from the lab website. There will also be another program file called *LCDTest.asm* that utilizes every function described below. You can download it for a sample of using the LCD.

The following are the LCD driver function definitions. In order for any function call to work, the stack pointer must be initialized prior to the function call.

### LCDInit

This subroutine initializes the serial interface that is used to communicate with the LCD display, initializes the 'Hitachi Display Chips with 8-bit Incremental DD-RAM Pointer with no features,' and sets the display to 2x16 characters.

```
rcall    LCDInit        ; Call LCD Init Subroutine
```

## LCDWrite

This is a generic function that will write out both lines of text to the LCD display. The line data is fetched from the following AVR data memory addresses:

Line 1: \$0100 - \$010F

Line 2: \$0110 - \$011F

In order to use this function you must first put the data (i.e., ASCII string) that you want displayed on the LCD in the appropriate line address in data memory. Then call the function.

```
; Move ASCII string to line addresses $0100-$011F
rcall    LCDWrite      ; Write string to LCD
```

## LCDWrLn1

This function will write the ASCII string in the first line AVR data memory address (\$0100-\$010F) to the first line of the LCD Display.

In order to use this function you must first put the data (i.e., ASCII string) that you want displayed on the LCD display line 1 in the line 1 addresses in the data memory and call the function.

```
; Move ASCII string to line addresses $0100-$010F
rcall    LCDWrLn1      ; Write string to LCD
```

## LCDWrLn2

This function will write the ASCII string in the second line AVR data memory address (\$0110-\$011F) to the second line of the LCD display.

In order to use this function you must first put the data (i.e. ASCII string) that you want displayed on the LCD display line 2 in the line 2 addresses in the data memory and call the function.

```
; Move ASCII string to line addresses $0110-$011F
rcall    LCDWrLn2      ; Write string to LCD
```

## **LCDClear**

This subroutine will clear both lines of the LCD display and the lines in AVR data memory will be cleared to the ASCII value of ' ' (space). No prior setup is required.

```
rcall    LCDClear        ; Clear both lines of LCD
```

## **LCDClrLn1**

This subroutine will clear line 1 of the LCD Display and line 1 in the AVR data memory in the same fashion as LCDClear. No prior setup is required.

```
rcall    LCDClrLn1       ; Clear line 1
```

## **LCDClrLn2**

This subroutine will clear line 2 of the LCD display and line 2 in the AVR data memory in the same fashion as LCDClear. No prior setup is required.

```
rcall    LCDClrLn2       ; Clear line 2
```

## **LCDWriteByte**

This function allows you to write a single ASCII character or byte anywhere on the LCD display. This allows complete control over where things go within the display and does not require the AVR data memory lines as in the previous functions. There are three registers that need to be initialized prior to calling this function.

count – Holds the index value of the line to where the ASCII Char will be written, 0 – 15 (of 39). Indexes 0 – 15 are visible on the display, but can be up to 39, thus indexes 16 – 39 are off screen. If count has a value of 3 then the ASCII char will be written to the 3<sup>rd</sup> element on the LCD display.

line – Holds the line number that the char is going to be written to, 1 or 2.

mpr – Contains the value of the ASCII char to be written, 0-255.

```
; Example of writing 'D' to Line 2 slot 7  
ldi      mpr, 'D'        ; mpr <- 'D'
```

```
ldi        line, 2          ; line <- 2
ldi        count, 7         ; count <- 7
rcall      LCDWriteByte     ; Write Byte to LCD Display
```

## Bin2ASCII

This function will convert an unsigned 8-bit binary number into the numerically equivalent ASCII string, i.e. 186 -> "186". For this function, three registers are needed:

mpr – Contains the 8-bit binary number to be converted.

X-Pointer – Contains the start address to AVR data memory when the ASCII string will be stored.

count – Will contain the number of characters that are written once the function has completed.

This function is useful for printing a number that you don't always know what the value will be (i.e., not a constant value such as a counter). When using this function, be aware that up to three characters could be written. For example, if you had the value 138 in the mpr and the address of \$0112 in the X-pointer, you would get the following after calling this function:

```
DataMem($0112) <- '1'
DataMem($0113) <- '3'
DataMem($0114) <- '8'
count <- 3
```

Here is an example of calling the function described above.

```
ldi        mpr, 138          ; mpr <- 138
ldi        XL, low($0112)    ; X <- $0112
ldi        XH, high($0112)   ; X <- $0112
rcall      Bin2ASCII         ; Call Bin2ASCII
```

There are many other functions within the LCD driver, but they are support functions for those described above and should not be called individually. Modifying any function within the driver is not recommended as it could damage the performance of the function, but feel free to play around if you like. With that said, if you do modify the driver or add another function that improves the performance, let your TA know what you did and how it works or why it is better and we might add it to future versions of the driver.

## Data Manipulation

To be able to move data from one memory to another, you first must understand the memory. The ATmega128 is an 8-bit AVR architecture. This means all data is moved around 8-bits or 1-byte at a time, thus all register and data memory are 8-bit wide. However, the AVR Op-Code is 16 or 32-bits and for efficiency reasons the program memory is 16-bits or 2-bytes wide. This means that when you read from the program memory, you will have to read 2-bytes for every address space in the program memory.

When writing a program, it is often necessary to include data directly into program memory instead of entering it into the data memory each a time a simulation is run. The `.DB` (Data Byte) directive allows data to be written directly to the program memory during compilation. For example, the following code demonstrates how to create data in program space:

```
DATA:
.DB    $05, $F4
```

When the program is compiled, the hex data 0x05 and 0xF4 will be located in the program memory at the address specified by the label `DATA`. To read this data, use the `LPM` (Load Program Memory) instruction.

Note: Since the program memory is 16-bits wide, the data after the `.DB` directive needs to be in multiples of 16-bits. Otherwise, the compiler will insert an extra byte of data, usually `$FF`.

The movement within data memory is accomplished with the different variations of Load and Store commands. There are two main addressing modes to move the data: direct addressing and indirect addressing. Direct addressing is best when you want to move data to and from a single memory location, like an extended I/O register. Indirect addressing uses the X, Y, and Z-pointers and is useful for moving data to multiple areas of data memory. For example, using indirect addressing in conjunction with a while-loop, you could move ‘blocks’ of data around in memory. See the *AVR Starters Guide* for more information on pointers and indirect addressing.

The following is some pseudo-code you can use to properly read a bunch of data from program memory

```
Z <- Beginning Address of string in Program Memory
Y <- Beginning Address in Data Memory for string
do {
    mpr <- ProgMem(Z), Z++
    DataMem(Y) <- mpr, Y++
} while (Z != End Address of string in Prog Memory)
```

## Writing Your Name

You are to write your name on the first line of the LCD Display and a simple phrase, such as “Hello World!” on the second line of the LCD Display. In order to accomplish this, you must have you two strings in program memory using the .DB directive. Then read the data from program memory and store it into the appropriate spots in data memory that are used for Line 1 and Line 2. Then make a simple call to the correct function to display the two lines on the LCD display. You must first correctly initialize your program.

To help you along the process, skeleton code is provided. Use this as a starting point. When you are finished, demonstrate your LCD Display to the TA to get credit. Have them sign below.

TA Signature: \_\_\_\_\_

## Write Up

Write a short summary that details **what you did and why, explain any problems you may have encountered, and answer the questions below**. Submit your write up and code to your TA via email by the beginning of class the week following the lab. NO LATE WORK IS ACCEPTED.

## Additional Questions

1. In this lab, you were asked to manipulate data by moving it around in memory. In fact, the AVR architecture has two different memories, a program memory and data memory. Briefly explain the differences and purposes of these memories within your write up.



2. You also learned how to make function calls. Explain how the function call works, its connection to the memory stack, and why a RET instruction must be called to return from a function. To help you understand, comment out the stack pointer initialization in the beginning of the code and try running the program. Observe and comment on this behavior.

## Challenge

Not being content with displaying a static message, you would like to add some flare by creating a scrolling marquee style message. Your text will scroll across the lines from left to right. When a character is at the end a line, it will be displayed at the beginning of the opposite line, i.e. a character on slot 16 of line 1 will go to slot 1 of line 2 and a character on slot 16 of line 2 will go to slot 1 of line 1. You will also want to add a wait loop after all the characters have moved one slot so that you can read the characters. Below is an example of the display and motion where ' ' signifies a space:

```
1:   Line 1 - "____My_Name_is_"
      Line 2 - "____John_Doe_"
wait(.25sec)
2:   Line 1 - "____My_Name_is"
      Line 2 - "____John_Doe"
wait(.25sec)
3:   Line 1 - "e____My_Name_i"
      Line 2 - "s____John_Do"
wait(.25sec)

4:   Line 1 - "oe____My_Name_"
      Line 2 - "is____John_D"
wait(.25sec)
etc...
```

Use the strings that are required for the lab to scroll. Submit this code with your report. Demonstrate the challenge problem to the TA for credit.