CECS-412-01

Summer 2017

Project # 3

Name	Report (20 Points)	Demo (15 Points)	Quiz (5 Points)
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LAB 3

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ABSTRACT

I/O communications through implemented drivers written in C are studied in this lab. This device onboard the A3BU that is used to accomplish this is through the Universal Synchronous Asynchronous Receiver Transmitted (USART), an I/O Peripheral device that permits serial I/O Communication. First, an RS232C serial interface circuit was built which allowed for asynchronous serial communication between the A3BU and a PC running terminal communication software, and an example driver was flashed onto the board to initialize the USART. If done correctly, ASCII characters would be communicated from the PC terminal to the A3BU, and then echoed back to be displayed on the terminal. Next, LCD synchronous communications were investigated through the PORT D Serial Peripheral Interface (SPI) and the LCD ST7565R MCU. Another example driver was flashed onto the A3BU to initialize the port. This time, lines were first drawn across the screen and then the screen was rolled. Finally, the two example drivers were integrated into one driver called SYSTEM, and a MAIN was written to receive ASCII characters from the keyboard to be displayed on the LCD. Through the successful completion of this lab, basic communication between an MCU and external hardware is understood.

Body

Part 1

The Tera Term software was downloaded for aid in every portion of the lab. Tera Term was used as the chosen terminal program to display procedures that would be carried out to the ATxMEGA256A3BU Xplained board. To interface the A3BU board, a RS232C serial interface circuit (Schematic located in “Schematics” Section) was implemented. The circuit was then assembled and inspected. Once the circuit was set up, the program USART_EXAMPLE was built and stored on the A3BU board. The function of USART was to communicate to the A3BU board by way of TxD and RxD asynchronously (of header J1). Pin PC3 served as the TxD pin and PC2 served as the RxD pin on the A3BU board.

Serial port configuration settings next had to be configured. The number of data bits was set to 8, BAUD RATE to 9600, one stop bit used, and no parity bit was necessary in the C program (Tara Term would also follow these settings).
The program outputted a “Hello World” message on the Tera Term screen. This was possible by the translation of ASCII characters from the terminal back to the terminal by way of Tera Term.

The code was then re-written. The new program allowed for two single digit numbers to be added together. Again, ASCII values were translated, this time to single digit values. Since 0 has an ASCII value of 48, 48 had to be subtracted from the result of the addition of the two digits (any addition would result in a “c” output rather than the true sum value). This displays the true value of the new digit. This is an example of when digits “3” and a “6” are inputted through Tera Term, which results in their sum, 9.

An ASCII table was necessary for reference in part 1:

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH (start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX (start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX (end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT (end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ (enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK (acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL (bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS (backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB (horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF (NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT (vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF (NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR (carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO (shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI (shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE (data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1 (device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2 (device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3 (device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4 (device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK (negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN (synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB (end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN (cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM (end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB (substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC (escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS (file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS (group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS (record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US (unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

The rate at which bits are communicated between the PC and the A3BU is called “BAUD rate.” The RS232 aids by allowing both the PC and A3BU to know when bits are being communicated, and subsequently when this processes is stopping. A higher BAUD rate allows for data to transferred faster, however this comes with risk as data can be misinterpreted. A lower BAUD rate may run at a slower rate, but data is rarely, if ever, misinterpreted.

A chart of the USART registers that were involved in the program:

Register	Purpose
UDR	16-bit USART Data Register. The Transmit Data Buffer Register (TXB) is where UDR received data is stored.
UBRRH	Stands for USART Baud Rate Register High. The first 8 bits of the 16-bit BAUD rate register are stored here.
UBRRL	Stands for USART Baud Rate Register Low. The last 8 bits of the 16-bit BAUD rate register are stored here.
UCSRA	8-bit USART Control and Status Register A. The flag bit is set by the CPU when unread data is in the Receive Buffer, and then cleared by the CPU when the Buffer is empty.
UCSRB	8-bit USART Control and Status Register B. The UCSRB enables interrupts, receiver, transmitter, and third bit character size.

UCSRC	8-bit USART Control and Status register C. Allows for stop bits, Asynchronous or Synchronous mode, parity type, selection of registers, and selection of two bits of character size.

(The USART of the AVR » MaxEmbedded)

Part 2

LCD Synchronous Communication

Part 2 introduces the concept of synchronous communication. This form of communication involves using the system clock rate as a reference to send signals between different devices on the A3BU board. Through using the same clock rate, these devices are considered in-sync. In synchronous communication, a continuous stream of data signals is transferred to the desired device. This allows for a more predictable outcome compared to asynchronous communication. On the A3BU board, the LCD ST7565R MCU is an example of a device that uses synchronous communication to receive data signals.

Serial Peripheral Interface

PORT D on the A3BU board is a Serial Peripheral Interface (SPI) device. SPI is an interface bus that allows the A3BU board to communicate with smaller peripheral devices such as the LCD module used in part 2. The ST7565R example program relates the SPI to the LCD. The SPI device on PORT D of the A3BU is considered the master because it generates the clock signal. The LCD module is considered the slave because it receives these signals. The SPI has registers that are capable of initiating data transfer.

The ST7565R code was rewritten to send and display alphanumeric text/characters. To accomplish this, the LCD module must first be initialized. The initialization code uses seven header files: board.h, sysclk.h, st7565r.h, gfx_mono.h, gfx_mono_text.h, sysfont.h, and gpio.h. The file board.h configures the board by enabling the LCD screen. The file sysclk.h configures the system clock to be used for synchronous communication. The st7565r.h file configures a number of factors of the LCD module. It selects the SPI interface and sets the minimum clock period and the maximum frequency. It also sets the contrast and sets up the registers that will be used to hold information used by the LCD module during clock cycles. The two header files gfx_mono.h, and gfx_mono_text.h initialize gfx functionality which allows the user to write text to the LCD. The gpio.h file enables the backlight on the LCD.

Description of Code

A function called InitializeLcdScreen is created that incorporates these header files to initialize the LCD. This function contains the initialization functions from most of the header files that were incorporated. It also clears the screen and lights it up. The function DrawWord is used to write the word hello on the screen. It takes as an argument a pointer to a string of characters and the length of that string. It then steps through each character in the string and displays it using the gfx function gfx_mono_draw_char to place the char on the screen. The gfx function takes an X and a Y coordinate that defines a location on the screen. After each letter is displayed the X coordinate must be incremented so that the characters are not drawn on top of each other. The string “Hello” was passed into the DrawWord function. The text Hello, properly appeared on the LCD screen.

Part 3

For this part of the project it was necessary to combine the functionalities of the last two parts of the project. A program that receives text sent from the terminal on the computer and displays them on the LCD screen will be written. The serial interface circuit must be able to collect data from the computer and send it along to the ST7565R MCU through the SPI.

Description of Code

The ASF wizard was used to incorporate all of the libraries that were needed to control both the Serial interface and the SPI interface to the LCD display. As in part 2, GFX functions were utilized that made displaying text on the screen very simple. The GFX functions display text in a certain location. An X and a Y coordinate must be passed to the GFX functions. The starting location is X=0 Y=0. After each character was displayed the X coordinate had to be incremented so that the characters were not written on top of each other. Then if the characters filled up a whole line of the LCD screen, the X coordinate was reset to 0 and the y coordinate was incremented. This made a new line of text appear. If the enter key was ever pressed the whole screen had to be cleared and the X and Y coordinates were both set to 0 so that the next characters were displayed at the starting location again. The code can be viewed in the source code section.

Source Code (Software)

Part 1 Source code

```
/* Lab 3 part 1 */

#include <conf_usart_example.h>
#include <asf.h>

// some variables to store simple characters
static uint8_t newLine = '\n';
static uint8_t carriageReturn = '\r';
static uint8_t numberOne = '1';

static uint8_t ConvertToInt(uint8_t numberToConvert) {
	return numberToConvert - '0';
}

static uint8_t ConvertToAscii(uint8_t numberToConvert) {
	return numberToConvert + '0';
}

static void DisplayNumber(uint8_t numberToDisplay_integer) {
	uint8_t numberToDisplay_Ascii;

	// Start a new Line
	usart_putchar(USART_SERIAL_EXAMPLE, newLine);
	// Make sure the cursor is at the beginning of that line
	usart_putchar(USART_SERIAL_EXAMPLE, carriageReturn);

	// If the number is greater than 9 the code needs to display 2 digits
	if (numberToDisplay_integer >= 10) {

		// Convert integer to ASCII
		// Only save the last digit
		// (subtracting 10 removes the first digit)
		numberToDisplay_Ascii = ConvertToAscii(numberToDisplay_integer) -10;

		// Display leading 1 as first digit
		usart_putchar(USART_SERIAL_EXAMPLE, numberOne);

		// Display second digit
		usart_putchar(USART_SERIAL_EXAMPLE, numberToDisplay_Ascii);
	}
	else
	{
		// Convert integer to ASCII
		numberToDisplay_Ascii = ConvertToAscii(numberToDisplay_integer);

		// Display the digit
		usart_putchar(USART_SERIAL_EXAMPLE, numberToDisplay_Ascii);
	}
}

int main(void)
{
```

```
	// variables for storing data at different
	// stages of the conversion process
	uint8_t receivedByte_Asc;
	uint8_t return_num;
	uint8_t convertedNum_prev;
	uint8_t convertedNum_rec;

	/* Initialize the board.
	 * The board-specific conf_board.h file contains the configuration of
	 * the board initialization.
	 */
	board_init();
	sysclk_init();

	// USART options.
	static usart_rs232_options_t USART_SERIAL_OPTIONS = {
		.baudrate = USART_SERIAL_EXAMPLE_BAUDRATE,
		.charlength = USART_SERIAL_CHAR_LENGTH,
		.paritytype = USART_SERIAL_PARITY,
		.stopbits = USART_SERIAL_STOP_BIT
	};

	// Initialize usart driver in RS232 mode
	usart_init_rs232(USART_SERIAL_EXAMPLE, &USART_SERIAL_OPTIONS);

	// This loop runs forever
	while (true) {

		// Receive characters asynchronously from Tera Term
		receivedByte_Asc = usart_getchar(USART_SERIAL_EXAMPLE);

		// Convert ASCII number to an integer
		convertedNum_prev = ConvertToInteger(receivedByte_Asc);

		// If the number is between 0 and 9 then enter the next loop
		if (convertedNum_prev >= 0 && convertedNum_prev <= 9) {

			while(true) {

				// Receive characters asynchronously from Tera Term
				receivedByte_Asc = usart_getchar(USART_SERIAL_EXAMPLE);

				// Convert ASCII number to an integer
				convertedNum_rec = ConvertToInt(receivedByte_Asc);

				// Add the two numbers
				return_num = convertedNum_rec + convertedNum_prev;

				// Display the number on the LCD screen
				DisplayNumber(return_num);

				// After the number has been displayed break
				// out of second loop and enter the top level loop
				break;
			}
		}
	}
}
```

Part 2 Source code

```
/* Lab 3 Part 2 */
#include <board.h>
#include <sysclk.h>
#include <st7565r.h>
#include <gfx_mono.h>
#include <gfx_mono_text.h>
#include <sysfont.h>
#include <gpio.h>

static void ClearLcdScreen(void) {
	// This function clears the screen by writing 0x00 over
	// and over again which turns off every pixel
	for (int page_address = 0; page_address <= 4; page_address++) {
		st7565r_set_page_address(page_address);
		for (int column_address = 0; column_address < 128; column_address++)
{
			st7565r_set_column_address(column_address);
			st7565r_write_data(0x00);
		}
	}
}

static void InitializeLcdScreen(void) {

	// Initialize the board and clock
	board_init();
	sysclk_init();

	// Initialize the interface (SPI), ST7565R LCD controller and LCD
	st7565r_init();

	// Set addresses at beginning of display
	st7565r_set_page_address(0);
	st7565r_set_column_address(0);

	// Initialize gfx functionality
	gfx_mono_init();

	// Turn on backlight
	gpio_set_pin_high(LCD_BACKLIGHT_ENABLE_PIN);

	ClearLcdScreen();
}


static void DrawWord(char *word, int wordLength) {
	// The starting location is (10,10)
	int x = 10;
	int y = 10;

	for (int i = 0; i < wordLength; i++) {
		gfx_mono_draw_char(*word, x, y, &sysfont);

		// Increment the X coord
		x += 7;
```

```
                // Increment the pointer so that it points to the next char
                word = word + 1;
        }
}

int main(void)
{
        InitializeLcdScreen();

        // Declare a the word to display
        char word[5] = {'H','e','l','l','o'};

        // Display the word to the LCD screen
        DrawWord(word, 5);
}
```

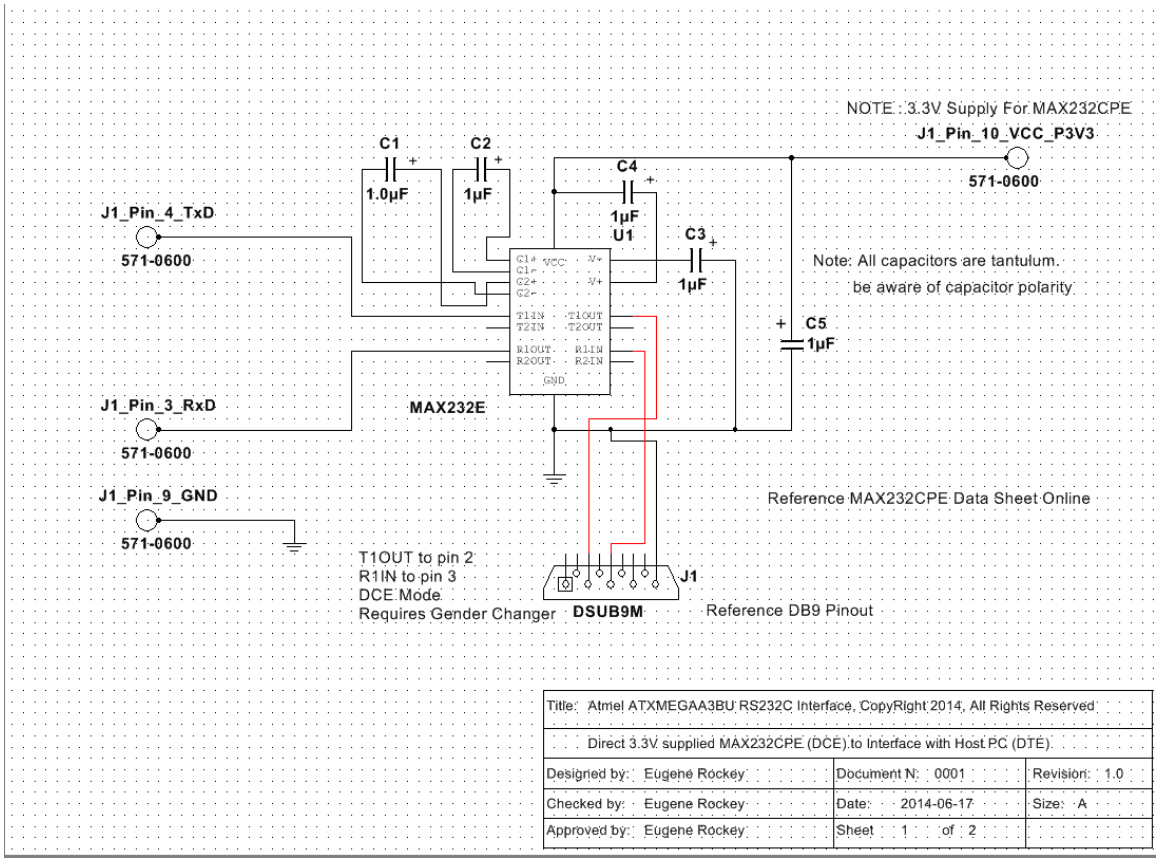
Part 3 Source code

```
/* Lab 3 Part 3 */
#include <board.h>
#include <sysclk.h>
#include <conf_usart_example.h>
#include <st7565r.h>
#include <gfx_mono.h>
#include <gfx_mono_text.h>
#include <sysfont.h>
#include <gpio.h>

static void ClearLcdScreen(void) {
        // This function clears the screen by writing 0x00 over
        // and over again
        for (int page_address = 0; page_address <= 4; page_address++) {
                st7565r_set_page_address(page_address);
                for (int column_address = 0; column_address < 128; column_address++)
{
                        st7565r_set_column_address(column_address);
                        st7565r_write_data(0x00);
                }
        }
}

static void FlashScreen(void) {
        // Turn the backlight off
        gpio_set_pin_low(LCD_BACKLIGHT_ENABLE_PIN);
        // Delay for 4 milliseconds
        delay_ms(4);
        // Turn the backlight back on
        gpio_set_pin_high(LCD_BACKLIGHT_ENABLE_PIN);
}

static void InitializeLcdScreen(void) {

        // initialize the board and clock
        board_init();
        sysclk_init();
```

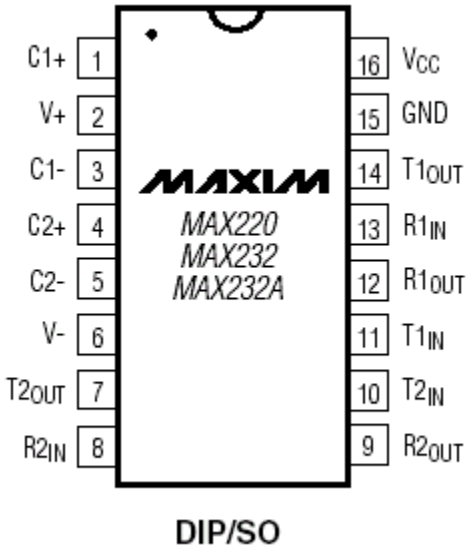
```
	// Initialize the interface (SPI), ST7565R LCD controller and LCD
	st7565r_init();

	// Set addresses at beginning of display
	st7565r_set_page_address(0);
	st7565r_set_column_address(0);

	// Initialize gfx functionality
	gfx_mono_init();

	// Turn on backlight
	gpio_set_pin_high(LCD_BACKLIGHT_ENABLE_PIN);

	ClearLcdScreen();
}

int main(void)
{
	char receivedByte_Ascii;

	InitializeLcdScreen();

	static usart_rs232_options_t USART_SERIAL_OPTIONS = {
		.baudrate = USART_SERIAL_EXAMPLE_BAUDRATE,
		.charlength = USART_SERIAL_CHAR_LENGTH,
		.paritytype = USART_SERIAL_PARITY,
		.stopbits = USART_SERIAL_STOP_BIT
	};

	// Initialize usart driver in RS232 mode
	usart_init_rs232(USART_SERIAL_EXAMPLE, &USART_SERIAL_OPTIONS);

	// The first location for the text to appear
	// is (0,0) or the top left of the LCD screen
	int x = 0;
	int y = 0;

	while (true) {
		// Asynchronously receive ASCII character
		receivedByte_Ascii = usart_getchar(USART_SERIAL_EXAMPLE);

		// Flash the screen once after a character is received
		FlashScreen();

		// If the enter key was pressed then clear the screen
		// and put the location for text back to (0,0)
		if (receivedByte_Ascii == '\r') {
			ClearLcdScreen();
			x=0;
			y=0;
		}
		// If any other key was pressed then display it
		else {
			gfx_mono_draw_char(receivedByte_Ascii, x, y, &sysfont);

			// Then increment x so that there is room
			//for the next character
```

```
                        x += 7;
                }

                // The screen only fits 18 characters
                // So if x gets above 18*7 then go to the next line
                // by incrementing y
                if ( x == 18 * 7)
                {
                        x = 0;
                        y += 8;
                }
        }
}
```

Schematics (Hardware)



This is a schematic of the circuit used to create the MAX232CPE Serial interface



This is a schematic of the chip used in the circuit above.

Analysis

In lab 3 several new capabilities of the A3BU were demonstrated. This lab explored the concepts of Asynchronous and Synchronous serial I/O communication with a PC terminal. The lab also explored communication techniques of SPI with the LCD module. When working with microcontrollers in the field, communication between devices is incredibly important. Systems need to fine tune the type of communication that is used based on the resources, money, and time that are available. This lab introduced a lot of the types of communication and how they work. This knowledge is very helpful in understanding and designing communication frameworks for large embedded systems.

Part 1 introduces asynchronous communication which uses Tx and Rx lines. Through this type of communication there is no control over when the data is sent. As a result, there is no guarantee that both sides of the communication are running at the same rate. This makes the possibilities of errors and packets being lost greater. Part 2 introduces synchronous communication which uses the system clock for timing. This ensures that both sides of the communication are running at the same rate. Part 3 combines both types of communication. Asynchronous communication is used for receiving characters and synchronous communication is used to write these characters on the LCD.

An example of asynchronous communication is a graphical user interface (GUI). A GUI does not know when an input is going to be received so it needs to use asynchronous communication to account for this occurrence. An example of synchronous communication is a phone call when data is needed to be transmitted in real time.

Conclusion

The main purpose of lab 3 was to study I/O communications through implemented drivers written in C. This was accomplished through the Universal Synchronous Asynchronous Receiver Transmitted (USART). The USART is an I/O Peripheral device, found onboard the A3BU, that allows for serial I/O communication. An RS232C serial interface circuit was constructed to allow for asynchronous communication between the A3BU board and a PC running terminal communication software. Next, LCD synchronous communications was used through the PORT D Serial Peripheral Interface (SPI) and the LCD ST7565R MCU. Finally, both parts were combined into one program that receives ASCII characters from the terminal communication software to be displayed on the LCD. Through the successful completion of this lab, basic I/O communication techniques were understood.

References

1. "The USART of the AVR » MaxEmbedded." *MaxEmbedded*. N.p., 04 Nov. 2015. Web. 23 June 2017.
2. "MAX232CPE - MAX232 5V Multichannel RS232 Transceivers Technical Data - Buy MAX232CPE." MAX232CPE - MAX232 Multichannel RS232 Transceivers Technical Data. N.p., n.d. Web. 25 June 2017.