ESE381 Embedded Microprocessor Systems Design II

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Laboratory 07: Asynchronous Serially Controlled Digital Potentiometer with SPI Interface

To be performed the week starting March 10th.

Prerequisite Reading
1 AVR128DB48 Data Sheet Section 28 SPI - Serial Peripheral Interface
2. Maxim MAX5402 Digital Potentiometer Data Sheet.
3. TB3215 Application Note Getting Started with Serial Peripheral Interface (SPI)
4. Cool Term Terminal Emulator

Overview

Serial Peripheral Interface (SPI) is a defacto standard for transmitting serial data between ICs placed on the same printed circuit board. SPI allows high-speed synchronous serial data transfer between two ICs. It was originally defined by Motorola. Microcontrollers from many different manufacturers now have one or more on-chip modules that implement the SPI interface protocol in hardware. Of course you can also implement the SPI protocol in software using GPIO pins, but the transfer rate will be limited and the microcontroller will not be free to do other tasks during SPI transfers.

Using an SPI on-chip module we can eliminate the need to execute a large number of instructions to read or write data bits from or to a compatible SPI device. For maximum flexibility and wide applicability, microcontroller on-chip SPI modules are configurable. Thus, they contain one or more control registers that are written to specify the SPI module's configuration.

While in operation, an SPI on-chip module has one or more status registers that are used to provide information about the current state of the module. On-chip SPI modules are primarily used to transfer or generate data. Accordingly, they have one or more data registers. Writing the data register initiates a data transmission. Reading this same register returns the received data.

A single SPI master module can have multiple slaves connected to it. When SPI is used to communicate with a specific external peripheral IC, the microcontroller's SPI master module must be configured to be compatible with that external peripheral IC's configuration and limitations. If the microcontroller is used as the master with multiple slave external peripheral ICs, its configuration must be changed by its application software to be compatible with each slave before it communicates with that slave. Accordingly, appropriate code must be written to accomplish this.

The AVR128DB48 has 2 separate SPI modules.

One major objective of this laboratory is reinforcing your understanding of the basic SPI protocol and familiarizing you with the use of an AVR128DB48 SPI module to implement SPI serial communications.

Design Task Summary

1. Design Task 1: Designing the Interface Connection and Verifying SPI Writes from the AVR128DB48 SPI0 Module to a MAX5402.
2. Design Task 2: Asynchronous Serial Control of the MAX5402 Digital Potentiometer Using Hexadecimal Values.
3. Design Task 3: Asynchronous Serial Control of the MAX5402 Digital Potentiometer Via an ASCII Decimal Character Command String.

Design Tasks

Design Task 1: Designing the Interface Connection and Verifying SPI Writes from the AVR128DB48 SPI0 Module to a MAX5402.

Your first task is to understand the operation of the MAX5402 and its serial peripheral interface (SPI). You are to use the MAX5402 as a simple potentiometer divider with terminal H connected to +3.3V and terminal L connected to ground. The output of this simple divider is at terminal W.

Note that in your design, the only supply voltage to be used is the 3.3V output voltage from the Curiosity board.

Draw a schematic of the interface of the MAX5402 to an AVR128DB48 using the AVR128DB48's SPI0 module. Use PF2 to drive the MAX5402's chip select ($\overline{\text{CS}}$) input.

Write a function named `MAX5402_SPI0_init` that initializes the AVR128DB48's SPI0 module to communicate with the MAX5402. SPI0 must be configured in the Normal mode (no buffering). Thus, this function must check that the previous transfer is complete after writing each byte of data and then deselect the MAX5402 before returning. Note that there are two definitions (variations) of the INTFLAGS register. One for use in Normal mode and the other for use in Buffered mode. Your serial communication between the AVR128DB48 and the MAX5402 must be configured to be as fast as possible.

The function prototype follows.

```
void MAX5402_SPI0_init(void);
```

Write a second function named `MAX5402_SPI0_write` that is passed an `uint8_t`. This is the value to be sent to the MAX5402 to set the position of the its wiper. It is important that before this function returns, it must deselect the MAX5402. If this is not done, there could be a subsequent SPI bus conflict between the MAX5402 and other (future) SPI devices added to the system.

The function prototype for this function is:

```
void MAX5402_SPI0_write(uint8_t data);
```

Write a verification program named `MAX5402_verify` that uses the previous two functions to verity the operation of the MAX5402. A good verification strategy would be to have the `uint8_t` argument to `MAX5402_SPI0_write` function increment in a loop from 0 to 255. A small delay, say 1 ms, could be inserted between each call of `MAX5402_SPI0_write`. The resulting output should look like a periodic staircase or ramp and can be viewed on your oscilloscope or Saleae logic analyzer.

Submit your schematic, program C source, and program verification strategy as part of your prelab. Make sure that your program includes a program header, a header for each function, and clear comments throughout.

Design Task 2: Asynchronous Serial Control of the MAX5402 Digital Potentiometer Using Hexadecimal Values.

In this design task, you must write a program that allows you to send data from the CoolTerm terminal emulator and have that data control the analog output of the MAX5402. Since you will need to use all 8-bits of the data you send to represent (produce) output voltages over the entire MAX5402's output range, you need to be able to specify the data values as hexadecimal, not ASCII. The basic ASCII code is a 7-bit code and when sent as a byte the most significant bit is always 0.

Write a program named `Terminal_to_MAX5402` that allows you to type single 8-bit hexadecimal values into the terminal emulator and have those values sent to the AVR128DB48's USART3. Use a USART3 RXC interrupt service routine (ISR) to transfer the data to a 16-byte software receive buffer. The code for this receive buffer is the same as for the circular buffer example code. Implement only the receive buffer, the transmit buffer is not needed.

In the main loop of your program use the USART3_Receive function from the circular buffer example code to check whether there is data in the software receive buffer, If there is data in the receive buffer, the main loop should read the data and then write it to SPI0 and, thus, to the MAX5402. Note that you must not check for a pushbutton press before reading from the receive buffer. Just check to make sure there is a byte to read in the buffer. Make maximal reuse of functions that you have written for previous laboratories and for Task 1 of this laboratory.

As you type data in hexadecimal into CoolTerm it will be sent one byte at a time to the receive buffer and then read from the buffer and sent to the MAX5402 by code in your main loop. The Laboratory Task 2 description explains how to configure CoolTerm to send hexadecimal data.

Submit your C source file for this program as part of your prelab. Make sure that your program includes a program header, a header for each function, and clear comments throughout.

Design Task 3: Asynchronous Serial Control of the MAX5402 Digital Potentiometer Via an ASCII Decimal Character Command String.

As you have already seen, in some embedded systems, commands are sent to the system serially in the form of ASCII character strings. The embedded system must interpret (parse) these command strings and if a string is valid carry out the command represented. Command strings are usually parsed by standard C Library string functions or a finite state machine (FSM) executed by the embedded system's microcontroller. Later in this course we will look at a method for implementing an FSM that can handle any situation. For this task you will be provided with an FSM that is adequate for this design and you will have to study its implementation.

In this design task you must control the MAX5402's output serially from the CoolTerm terminal emulator as in Task 2. However, in this case, you must type an ASCII character string into the terminal emulator that represents the desired MAX5402 output voltage in decimal. This command string has the following format:

```
Vddd
```

followed by a carriage return and line feed <CR><LF>.

The `ddd` in the string is the desired output voltage in units of hundreds of a volt. So, a value of 333 means 3.33 V and a value of 162 means 1.62 V.

A receive software buffer is to be used, but no transmit buffer. A USART3 RXC ISR puts the data into the receive buffer. The code in the super loop must read the data from the receive buffer and parse the string. If the string is valid, your code must compute the binary value to be sent to the MAX5402 to output this voltage value. The computed value is then sent to the MAX5402 via the AVR128DB48's SPI0 module. This value is sent as a single hexadecimal character. Do your computations using integer arithmetic only, do not use floating point arithmetic.

Write a program named `ASCII_str_to_MAX5402` that allows you to type a string having the specified format into the terminal emulator and have the value represented sent to the AVR128DB48's USART0. Make maximal reuse of functions that you have written for previous laboratories and for Task 1 and Task 2 of this laboratory.

A switch statement labelled `FSM` is provided to parse the command string. It is available in a file in the Laboratory 07 folder.

Submit your C source file for this program as part of your prelab. Make sure that your program includes a program header, a header for each function, and clear comments throughout. Also submit a state diagram for `FSM` case statement.

Laboratory Activity

Laboratory Task 1: Designing the Interface Connection and Verifying SPI Writes from an AVR128DB48 SPI0 Module to a MAX5402.

Wire the MAX5402's SPI interface to the Curiosity board's SPI0 SPI pins and PF2. Connect and configure the Saleae logic analyzer so you can monitor the data transfer between the AVR128DB48 and MAX5402. **Caution: in your design, the only supply voltage to be used is 3.3V output voltage from the Curiosity board.**

Create a project named `MAX5402_verify` using the program `MAX5402_verify` that you wrote for Task 1. Set the compiler optimization to -Og. Build the program. Place any variables in a watch window to observe their values. Single step through each instruction in the program. Prior to single-stepping each instruction, determine what changes you expect in the values of SPI0's registers and any variables you created.

Run your program and verify that it continually increments the binary value sent to the MAX5402. Use the Saleae logic analyzer to capture the first transaction sent from the microcontroller to the MAX5402. Submit this screen capture with your laboratory.

When your program is working correctly, have a TA verify that it performs as required. Get the TA's signature.

Laboratory Task 2: Asynchronous Serial Control of a MAX5402 Digital Potentiometer Using Hexadecimal Values.

Create a project named `Terminal_to_MAX5402` using the program `Terminal_to_MAX5402` that you wrote for Design Task 2. Set the compiler optimization to -Og. Build the program. Place any variables in a watch window to observe their values. Single step through each instruction in the program. Prior to single-stepping each instruction, determine what changes you expect in the values of the port registers and any variables you created.

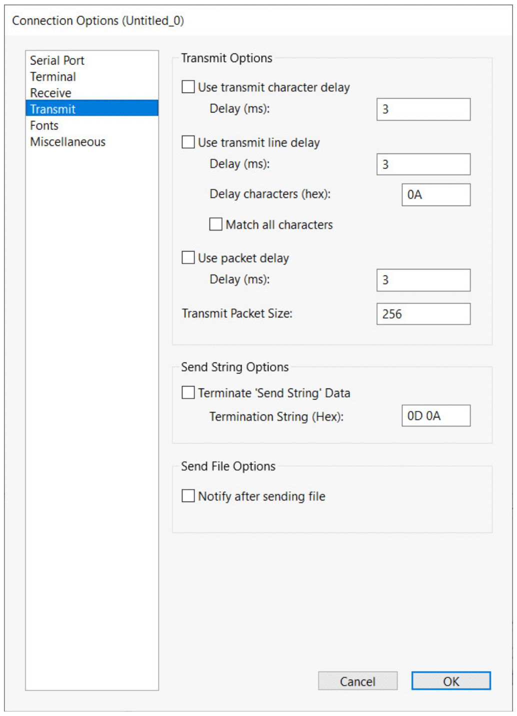
CoolTerm normally focuses on text (ASCII) data, and specifically text that is sent and received as strings terminated with "new-line" characters. However, for this task we want to send and receive non-ASCII bytes as hexadecimal values.

How to Send Hexadecimal Data Using CoolTerm

First note that you have configured USART3 for 9600 baud and 8N1.

You need to configure CoolTerm slightly differently to send and view hexadecimal data. After performing the normal configuration do the following.

Under Options > Transmit > Send String Options make sure the Terminate Send String Data box is unchecked.



Connection Options (Untitled_0)

- Serial Port
- Terminal
- Receive
- Transmit
- Fonts
- Miscellaneous

Transmit Options

- [ ] Use transmit character delay
  - Delay (ms): 3
- [ ] Use transmit line delay
  - Delay (ms): 3
  - Delay characters (hex): 0A
  - [ ] Match all characters
- [ ] Use packet delay
  - Delay (ms): 3
- Transmit Packet Size: 256

Send String Options

- [ ] Terminate 'Send String' Data
  - Termination String (Hex): 0D 0A

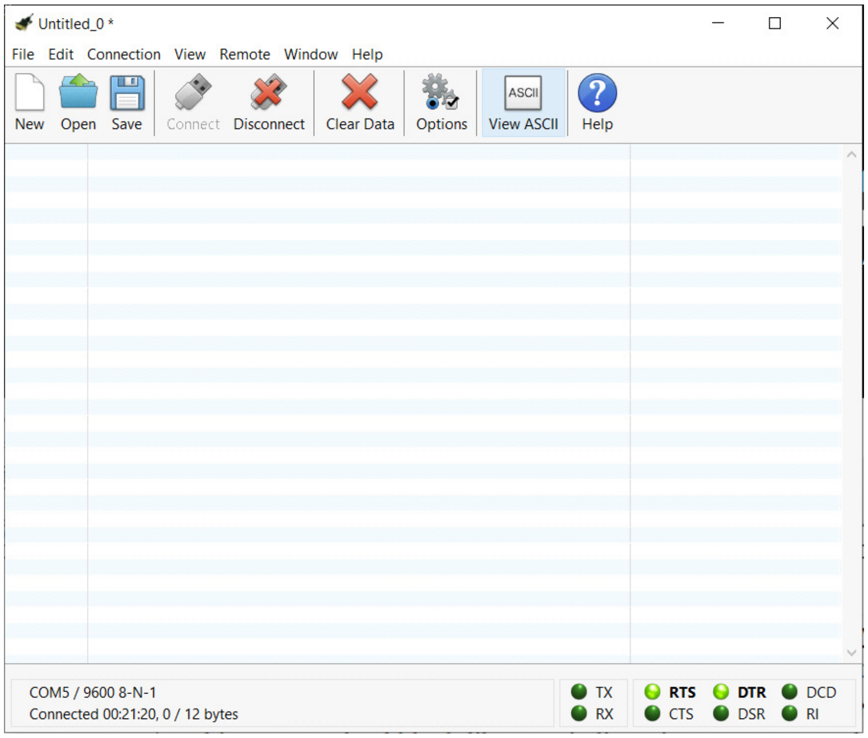
Send File Options

- [ ] Notify after sending file

Cancel OK

Thus, the string you type will be sent without \r\n (0D 0A).

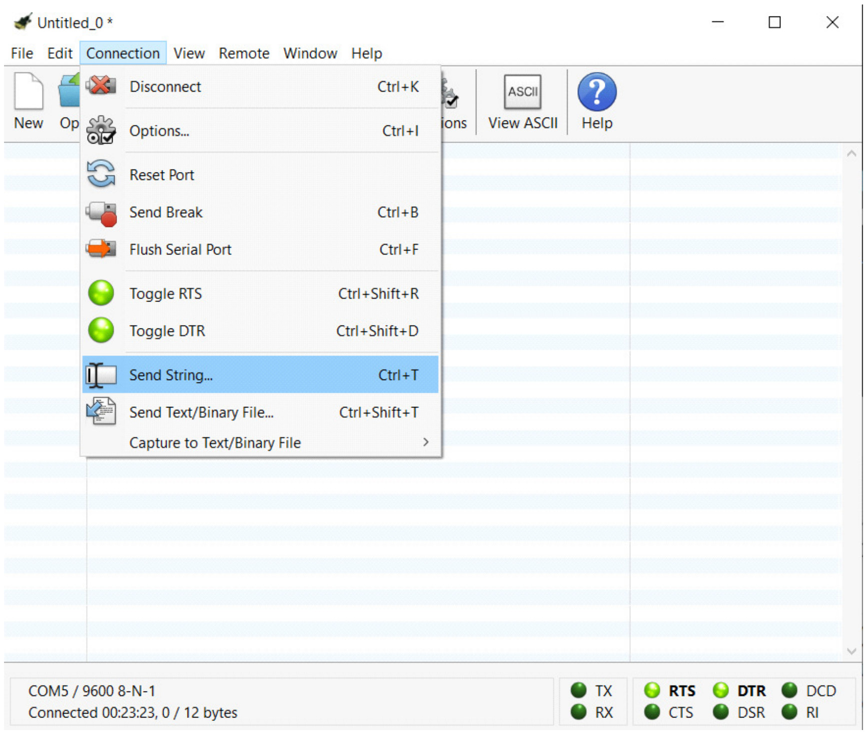
In the Tool bar click on View Hex to change the view to hexadecimal.



Untitled_0 *
File Edit Connection View Remote Window Help
New Open Save Connect Disconnect Clear Data Options View ASCII Help
TX RX RTS CTS DTR DSR DCD RI

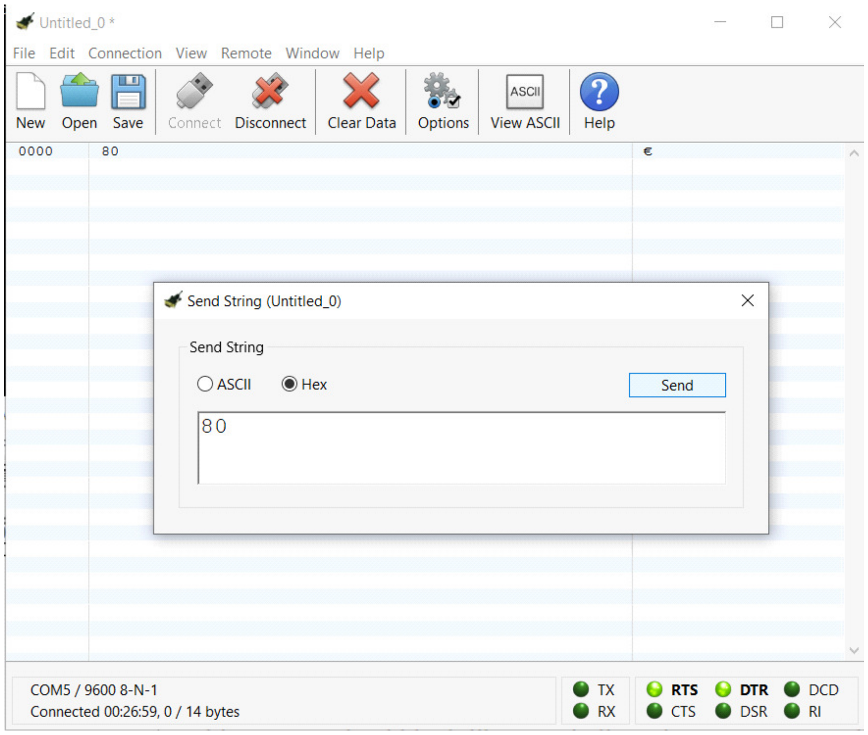
COM5 / 9600 8-N-1
Connected 00:21:20, 0 / 12 bytes

Next using the Connection tab select Send String.



COM5 / 9600 8-N-1
Connected 00:23:23, 0 / 12 bytes

In the Send String pop up window select Hex and type a two digit hexadecimal value into the text box. Press the Send button to send this value.


Untitled_0 *
File Edit Connection View Remote Window Help
New Open Save Connect Disconnect Clear Data Options View ASCII Help
Send String (Untitled_0)
Send String
Send
TX RX RTS CTS DTR DSR DCD RI

```
0000    80                                        €
```

ASCII [✓ Hex]

80

COM5 / 9600 8-N-1
Connected 00:26:59, 0 / 14 bytes

Use the Saleae logic analyzer to capture each frame (transaction) sent from the microcontroller to the MAX5402.

When your program is working correctly, have a TA verify that it performs as required. Get the TA's signature.

Laboratory Task 3: Asynchronous Serial Control of a MAX5402 Digital Potentiometer Via an ASCII Decimal Character Command String.

Create a project named `ASCII_str_to_MAX5402` using the program `ASCII_str_to_MAX5402` that you wrote for Task 3. Set the compiler optimization to -Og. Build the program. Place any variables in a watch window to observe their values. Single step through each instruction in the program. Prior to single-stepping each instruction, determine what changes you expect in the values of the port registers and any variables you created.

When your program is working correctly, have a TA verify that your program performs as required. Get the TA's signature.

Leave the circuit you have constructed on your breadboard, it may be used in later laboratories.

Questions

1. Fill out the logic level compatibility check list (in the laboratory folder) for the AVR128DB48 and the MAX5402. Make the AVR128DB48 device A. Both devices are operated with a supply voltage of 3.3V.

2. What is the maximum SCLK frequency you can have for an SPI transfer from the AVR128DB48 to the MAX5402 and what limits this frequency?

3. What are the required values for CPOL and CPHA for the MAX5402 and how did you determine them?

4. Review C's switch statement. Draw the state diagram for the finite state machine (FSM) implemented by the FSM switch statement you were provided.

5. From your state diagram from Question 4, what happens in Task 3 if you send an invalid command string?

6. Why is the variable `decimal` declared as a `uint32_t`?