ECE 362 Lab Experiment 8: SPI and DMA

Home About References Lecture Homework Labs

Introduction

The Serial Peripheral Interface (SPI) is a widely-used method for communicating with digital devices with an economy of wires and connections. It is possible to control such devices by "bit-banging" the protocol using GPIO, but your microcontroller has high-level support for SPI devices that simplifies the use of such interfaces. This support also allows for the use of Direct Memory Access (DMA) to automatically transfer a region of memory to the device. In this lab, you will gain experience using SPI and DMA with display devices.

Instructional Objectives

- To understand the Serial Peripheral Interface format

- To use and observe an SPI device
- to use DMA to automatically transfer data to an SPI device

Table of Contents

* All the points for this lab depend on proper completion of and submission of your post-lab results.

When you are ready for your lab evaluation, review this checklist.

Step 0: Prelab Exercises:

- Be familiar with lectures up to and including (19) Serial Peripheral Interface.
- Read Chapter 27 of the STM32F0 Family Reference Manual to become familiar with the SPI subsystem.

- Read Chapter 11 of the Family Reference Manual to understand how to configure the proper DMA channel.
- Read Section 22.3 of the textbook
- Read the datasheet for the SOC1602A OLED LCD display.
- Read this entire lab document.
- Leave the devices and wiring you did for Lab 5 in place and add the things described in section 1.5.
- After doing the previous steps, including reading the entire lab document, complete the prelab exercises and submit them **before** attempting the lab experiment.

Step 1: Background

1.1 Serial Peripheral Interface

When communication speed is not high priority, it is helpful to minimize wiring by using a serial communication protocol. It is named so because bits are sent one at a time, one after another. The Serial Peripheral Interface (SPI) is a common way of doing so. SPI turns words into a stream of bits and vice-versa. To send an entire word through the serial output, a programmer need only write the word into the SPI data register, and the hardware takes care of converting into a bit stream.

SPI is a synchronous protocol, so it requires a clock signal to indicate when each bit of data sent should be latched-in to the receiver. SPI defines devices that act in two distinct rôles: A master device is responsible for directing operations by asserting a slave select line, driving the clock, sending data on a MOSI (master out, slave in) pin, and optionally listening to input on a MISO (master in, slave out) pin. A slave device responds to operations when its slave select pin ($\overline{SS}$ or NSS) is asserted, reads data on the MOSI pin, and sends data on the MISO pin on each clock pulse. Because SPI is synchronous, there is no need for devices to agree, in advance, on a particular baud rate to communicate with each other. As long as the master device does not drive the clock at a frequency that is higher than a slave device can tolerate, data will be received correctly.

The SPI driver in the STM32 can be configured for several different modes of operation. For instance, the clock output can be configured to latch data on the rising edge or falling edge. Also, the NSS output can be set to automatically pulse low for each word written, but only when the clock is in a specific configuration. NSS pulse generation is generally not useful in situations where multiple slave devices share the same MOSI, MISO, and SCK pins. For that, you would want to control multiple individual $\overline{SS}$ pins. Since we are using a single device, and since that device demands that NSS go high after every word written to it, we will use the NSSP feature.

The baud rate (another name for the rate at which bits are sent) for an STM32 SPI channel can be set to a fraction of the system clock. The SPIx_CR1 register has a BR field that defines a prescale divisor for the clock. The size of the word to be sent and received by an STM32 SPI channel is set with the SPIx_CR2 DS field. This 4-bit field is unique among other I/O registers in that ‘0000’ is not a legal value. An attempt to clear this field before setting it to something new will result in it being reset to ‘0111’ which defines an 8-bit word size. For this lab experiment, we will connect a SOC1602A OLED LCD display which communicates in bytes with two extra bits to indicate a register selection and read/write selection–10 bits total. To set the DS field to a 10-bit word, it is necessary to write the bit pattern directly without clearing the DS field first. This should be the first thing done to the CR2 register. Thereafter, other bits can be ‘OR’ed to CR2.

1.2 Shift Registers and 7-Segment Display

In Lab 5, you built an eight-character display out of multiplexed 7-segment LED displays. Since then, you have been using it through a *parallel interface* — you need to output 11 bits on Port B at the same time in order to display a character at a particular position. To reduce the number of STM32F091RC pins needed to drive your display, it is possible to use external shift registers as a *serial interface* for it.

Since each 74HC595 shift register in your lab kit only provides 8 output pins, you will need to cascade two together to effectively build a 16-bit shift register. Connect the serial input of one 74HC595 shift reigster to PB15 (MOSI). Connect the serial input of the other shift register to the serial output (Q7') of the first. Tie both shift register clock inputs (SH_CP) together, and connect them to PB13 (SCK). The outputs of the shift registers replace your previous Port B connections.

Note: You may find it useful to place the 74HC595 shift registers on your breadboard upside-down, so the outputs of the shift registers are facing the inputs of the decoder and sink driver.

The output pins of each 74HC595 shift register are gated by an internal *storage register*. In order to update outputs, the storage register must be clocked (by asserting ST_CP). Tie both storage register clock inputs together, and connect them to PB12 (NSS). With SPI, you can simply use NSS as the storage register clock. Since NSS will be deassarted (set HIGH) at the end of every message in pulse mode, the shift registers will output new data.

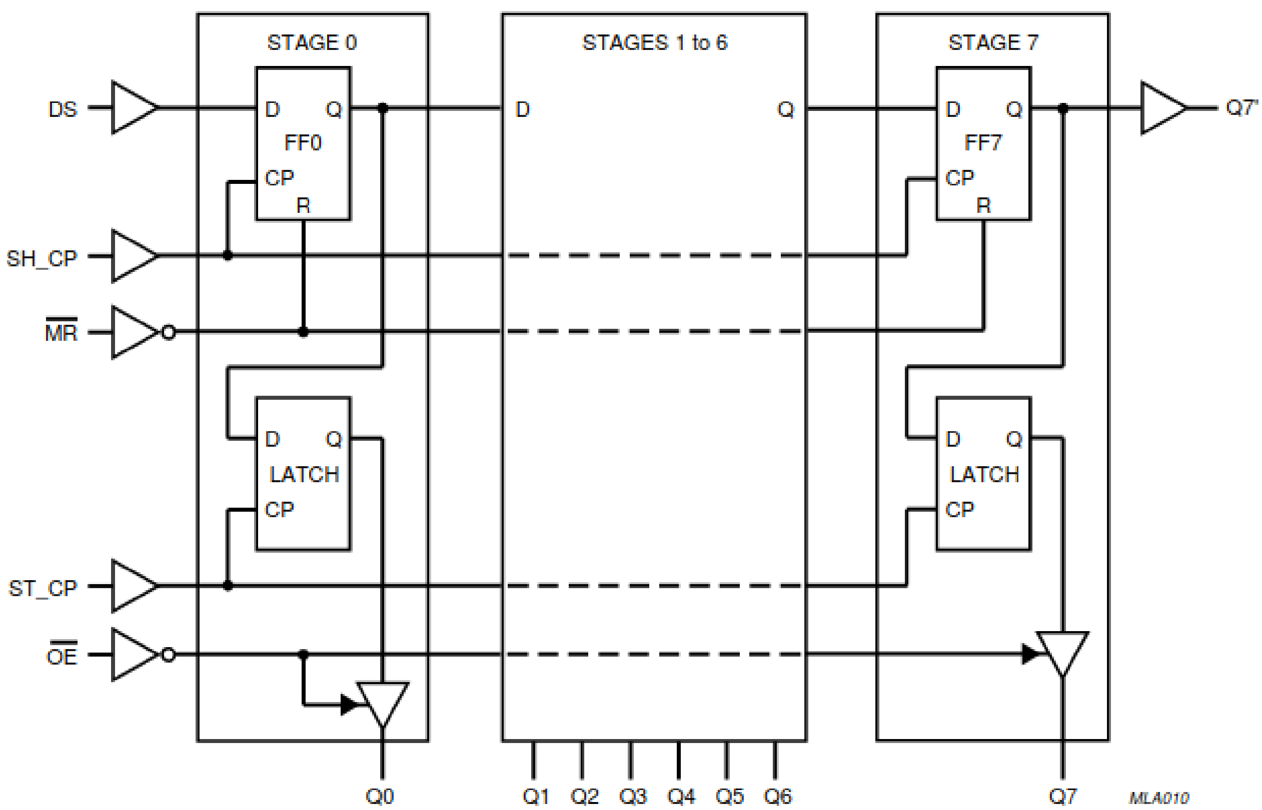


Figure 1: Shift Register Internal Diagram

The schematic for this setup is shown below.

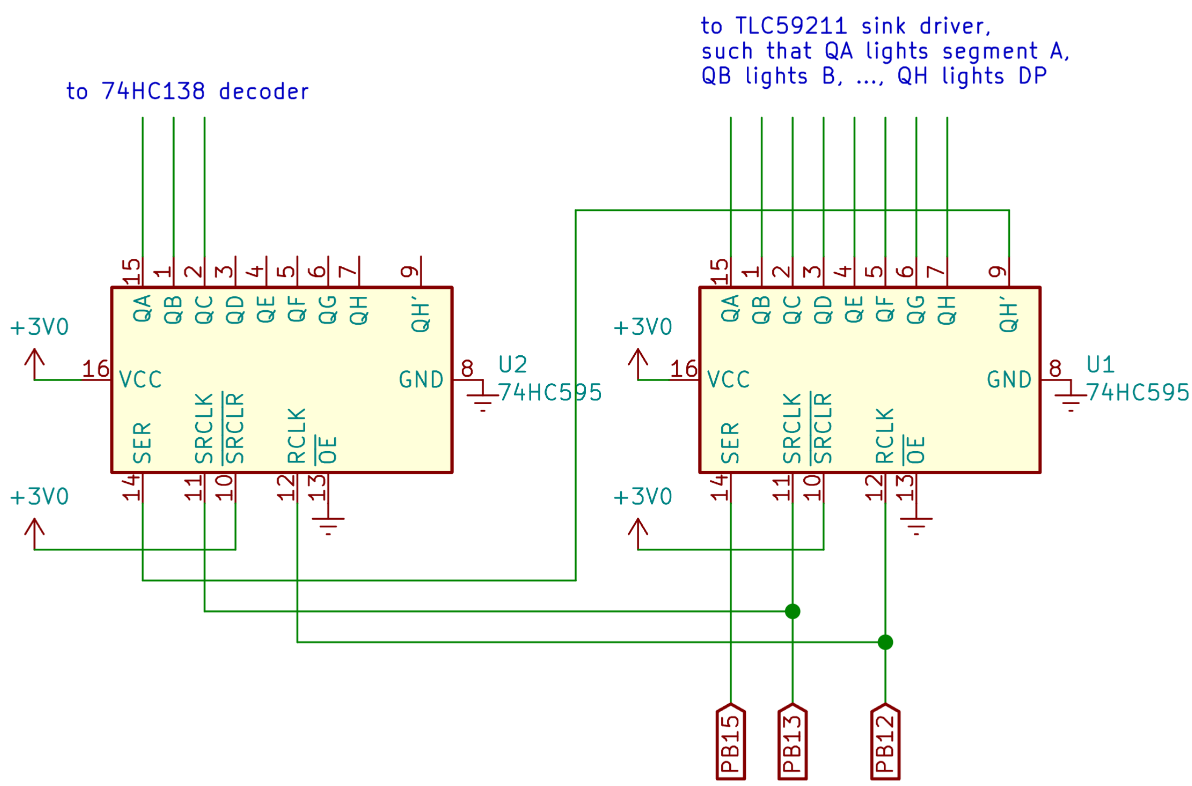
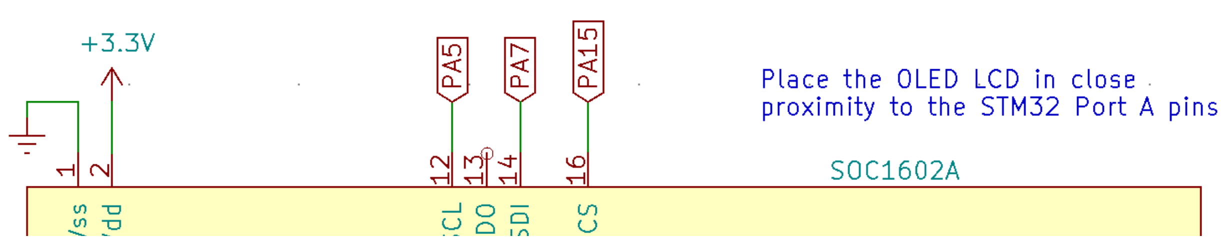


Figure 2: Shift Register Schematic

1.3 OLED Hardware Configuration

Page 4 of the datasheet for the [SOC1602A OLED LCD display]() describes the pins for the serial interfaces. Like many SPI devices, the documented pin names differ from the canonical description of the SPI protocol. Pin 12 (SCL) is the SPI clock. Pin 14 (SDI) is the MOSI signal. Pin 16 (/CS) is a "negated chip select", which is connected to NSS. Figure 3 describes the connection to the STM32F091 development board.



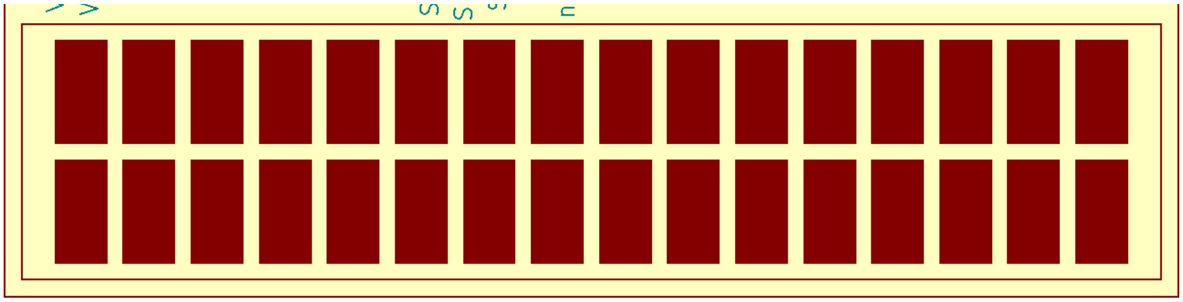


Figure 3: OLED LCD wiring

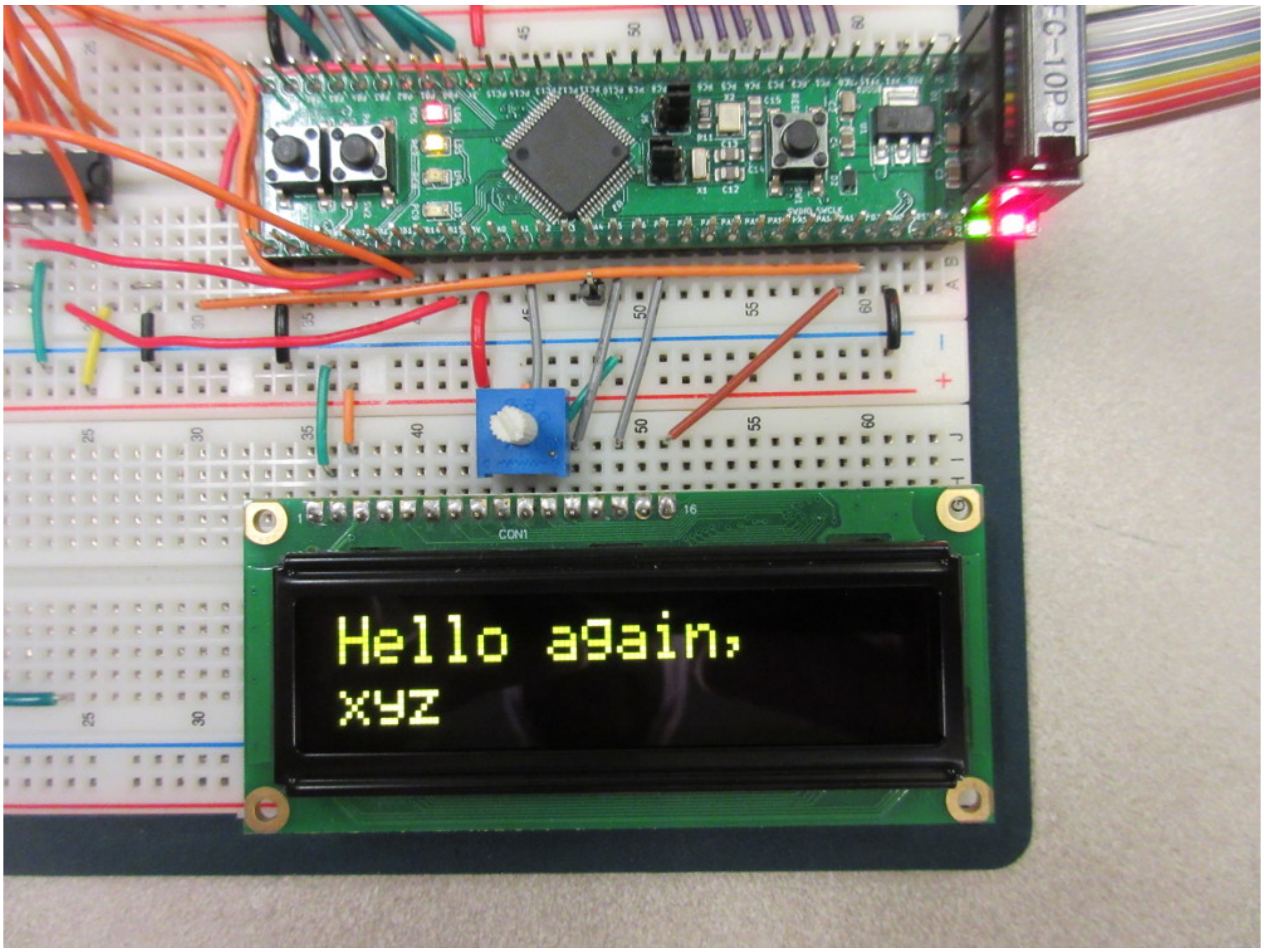


Figure 4: Preferred placement and example wiring of the OLED LCD

1.4 SPI Protocol for OLED LCD Display

A controlling computer uses three pins to send data to the SOC1602A LCD. First, for any communication to take place, the /CS pin must be asserted low. This corresponds to the NSS (negative slave select) line of the STM32. Since we are using only one SPI slave device, the STM32 will be the master device for all SPI protocol operations, and we can use automatic NSS protocol to control the display. Data is sent to the display on its SDI pin, and it is "clocked in" on the rising edge of the signal on the SCL pin. Each transfer must be terminated by deasserting (setting high) the /CS pin.

Most SPI devices use a 4-, 8-, or 16-bit word size. The SOC1602A uses a 2+8-bit word size to send two bits of configuration information plus an 8-bit character on each transfer. The first two bits are, respectively, the register selection and read/$\overline{\text{write}}$. Since we will always be writing data to the display and never reading it, we will always make the second bit a '0'. The register selection determines whether a write is intended as a command or a character to write to the display. Commands are needed to, for instance, initialize the display, configure the communication format, clear the screen, move the cursor to a new position on the screen, etc. The SOC1602A implements an old and well-known LCD protocol. You may see it in many other two-line LCD modules. There are many commands that can be used to implement complex operations on the SOC1602A that we will not use for this lab experiment. For the sake of this lab, we will be concerned only with the initialization sequence, moving the cursor, and writing characters to display.

When the register select bit is zero, the transmission issues an 8-bit command to the display. When the register select bit is one, the transmission represents a character to write to the display.

Page 7 of the SOC1602A datasheet lists the set of possible commands that can be sent to the display. Pay special attention to the column labeled "Max Execution Time". Regardless of how fast data is sent to the display, some operations take significant time to complete. The sender must not start a new command before the previous one has finished. On the next page, details of the instruction format are given. Page 20 lists the initialization sequence (under the header **LNITIALIATION SWUENCE**[*]) that must be used to prepare the display for use. Until each step is properly completed, the display will not show anything. The greatest problem that students have with new hardware (other than poor documentation) is finding the patience to carefully implement each step of the initialization sequence.

The operations to be done are as follows:

- Wait 1ms for the display power to stabilize.
- **Function set:** The reason for issuing this command first is to set the data length for 8-bit operation. This is set by the DL bit in the command description for the 8-bit Function Set operation:

  ```
  0 0 1 DL 1 0 FT1 FT0
  ```

  To set the data length to 8-bit, we use DL=1. The FT[1:0] bits select a font. We'll select 0 0 to use the English/Japanese font. The 8-bit command will be 0x38.

We cannot check the BUSY flag, because we did not connect the MISO pin to the display. Instead, we will simply wait long enough that the display can be guaranteed to finish the command. This command will complete in 600µs, at most. In practice, it will finish much faster.

- **Display OFF:** The recommendation is to turn the display off with the 8-bit command

  ```
  0 0 0 0 1 D C B
  ```

  where D enables the display output, C set the cursor to be visible, and B set the cursor to blink. Turn the display off with the 8-bit code 0x08.
- **Display Clear:** Clear the display. **Note that this command requires 2ms to complete.** Delay for that long before continuing. The 8-bit command is 0x01.
- **Entry Mode Set:** Set the *entry mode* to move the cursor right after each new character is displayed without shifting the display. This is done with the command

  ```
  0 0 0 0 0 1 D S
  ```

  where D represents the direction to advance in, and S configures shifting the display. We'll use the 8-bit command 0x06 to move the cursor left-to-right and not shift the display.
- **Home Command:** This will set the cursor to position zero (the top left corner) of the display. The command

to use is 0x02.

- **Display ON:** Turn the display back on again with the command

```
0 0 0 0 1 D C B
```

  This time, we will set D=1 and leave C=0, B=0. The 8-bit command is 0x0c.

After these initialization steps are complete, the LCD is ready to display characters starting in the upper left corner. Data can be sent with a 10-bit SPI transfer where the first bit is a 1. For instance, the 10-bit word 10 0100 0001 (0x241) would tell the LCD to display the character ‘A’ at the current cursor position. In the C programming language, a character is treated as an 8-bit integer. In general, any character can be sent to the display by adding the character to 0x200 to produce a 16-bit result that can be sent to the SPI transmitter. For instance, to write an ‘A’ to the display after initialization, the following statement could be used:

```
while((SPI2->SR & SPI_SR_TXE) == 0)
    ; // wait for the transmit buffer to be empty
SPI2->DR = 0x200 + 'A';
```

To understand why 0x41 is the same thing as 'A', you should consult the ASCII manual.

2.0 Experiment

For this experiment, you will write the subroutines to write to the shift registers to drive the 7-segment LED displays and to initialize and write to the SOC1602A OLED LCD display through the SPI interface and using DMA.

Create a project in SystemWorkbench called "lab8", and replace the automatically-generated main.c file with the main.c skeleton file provided for you.

2.1 Lab 7 code

Copy the code into the relevant sections from lab7.

2.2 Driving an SPI interface by "bit-banging"

The SPI interface is simple enough that it can be driven by setting individual GPIO pins high and low — a process known as bit-banging. This is a common method for using SPI with most microcontrollers because no specialized hardware is needed to do so. For our first implementation, we will bit bang the SPI protocol for the shift registers connected to the 7 segment LED array.

2.2.1 setup_bb()

Write a C subroutine named **`setup_bb()`** that configures GPIO Port B for bit-banging the 7 segment LED displays. To do so, set pins PB12 (NSS), PB13 (SCK), and PB15 (MOSI) for general purpose output (not an alternate function). Initialize the ODR so that NSS is high and SCK is low. It does not matter what MOSI is set to.

2.2.2 small_delay()

Write a C subroutine named **`small_delay()`** that calls the **`nano_wait()`** subroutine provided for you in main.c. When you are starting out bit-banging an interface, it is helpful to have a uniform small delay that can be made arbitrarily large. The parameter for **`nano_wait()`** is number of nanoseconds to spend spinning in a loop. Having **`small_delay()`** allows you to always call **`nano_wait()`** with the same value. If things do not work, it helps to slow down all elements of the protocol. You can make the value very large so that you can debug it. Start out with a large value like 5000000 (5 ms). In practice, you would gradually reduce it to see what works, but you will find that, when driving the 7-segment LED array with the shift registers, you will not need any delay at all. Once the circuitry and software is working you can comment out the **`nano_wait()`** call in small delay.

Consider what the SPI protocol does. The delays are to be inserted between transitions of NSS-MOSI-SCK-MOSI-SCK-...-NSS. The SPI interface will certainly work at extremely low speeds. When starting to develop any hardware interface, it is helpful to be able to see things happening in slow-motion. Once it works, increase the speed.

2.2.3 bb_write_bit()

Write a C subroutine named **`bb_write_bit()`** that accepts a single integer parameter, which should always be either 0 or non-zero, and does the following steps:

- Set the MOSI pin to low if the value of the parameter is zero. (Otherwise, set it to high.)
- **`small_delay();`**
- Set the SCK pin to high.
- **`small_delay();`**
- Set the SCK pin to low.

2.2.4 bb_write_halfword()

Write a C subroutine named **`bb_write_halfword()`** that accepts a single integer parameter and does the following steps:

- Deassert the NSS pin
- Call **`bb_write_bit()`** with bit 15 of the argument.
- Call **`bb_write_bit()`** with bit 14 of the argument.
- ...
- Call **`bb_write_bit()`** with bit 0 of the argument.
- Assert the NSS pin

If you're new at this, remember that you can use the **`>>`** operator to shift values to the right by an arbitrary amount. Then use the **`&`** operator to AND the result with a 1 to isolate one bit. If you don't feel like expressing this with a loop, you may make sixteen separate calls to **`bb_write_bit()`** in the proper sequence.

2.2.5 init_tim7() and TIM7 ISR

Initialize tim7 in **`init_tim7()`** such that it generates an interrupt at a rate of 1 kHz. In the interrupt handler, it should call `bb_write_halfword` and pass the `msg` element at the current `msg_index`. Then increment the index.

2.2.6 Demonstrate Bit Banging

The display should say "ECE 362", though it will iterate through each display element very slowly. If you reduce the number of nanoseconds that `small_delay` waits, the interrupt frequency of TIM7 will be able to refresh the display without perceptible flashing. Comment out the `nano_wait()` call and use your AD2 to capture a trace of the SPI protocol. To do so,

- Invoke the "Logic Tool" and add a new SPI bus in the signal list.
  - Use DIO 0 for the "Select" (NSS) signal.
  - Use DIO 1 for the "Clock" (SCK) signal.
  - Use DIO 2 for the "Data" (MOSI) signal.
- Click the box in the "SPI" row in the "T" column (see the thick red box in the picture below.) to set a value-based trigger. Set the trigger as follows:
  - Trigger: Value
  - Value: h0079
  - Place: Any
- Click the "Single" button to capture the transaction.

While your program is running, capture a single trace of the protocol transaction that writes the "E" pattern to digit 0 of the display. It should look like the image below.

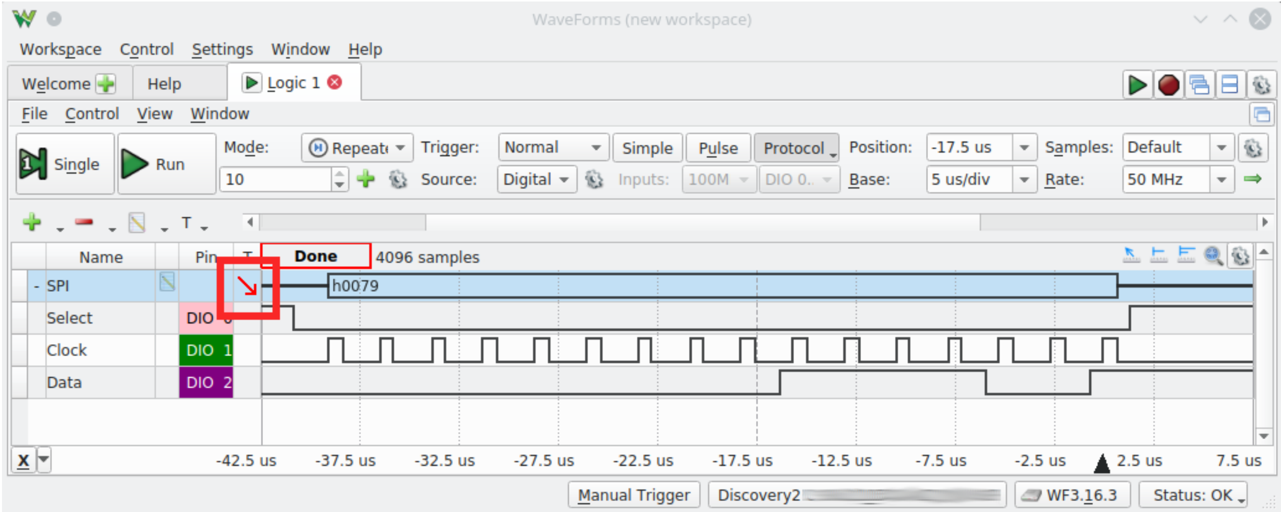


Figure 4: AD2 trace of an SPI protocol transaction

Create a snapshot of the output of the AD2 by clicking **File -> Export** and save it as a PNG file. Ensure that your device, serial number, and creation time are shown in the image. Upload the image into the postlab and restore the `nano_wait()` call for the check off process below.

Have a TA check you off for this step (TA Instructions: Confirm that the bit-bang subroutines are being called in `main()`. Check that display flashes one digit at a time. Ask the student to comment the `nano_wait()` call in `small_delay()` and confirm that the display is smooth. Enter numbers on the keypad, and ensure they are displayed on the 7-segment displays. Confirm that the image uploaded to the postlab shows the proper transaction.)

2.3 Using the hardware SPI channel

The STM32 has two SPI channels that do the work of the subroutines you just wrote in hardware instead of software.

Implement the following subroutines to initialize and use the SPI2 interface.

You should now comment out **`setup_bb()`** and **`init_tim7()`** in the main function. Uncomment the lines below it that call **`setup_spi2_dma()`**, **`enable_spi2_dma()`**, and **`init_spi2()`**.

2.3.1 setup_spi2_dma()

The body of **`setup_spi2_dma()`** and **`enable_spi2_dma()`** should be similar to the body of the similarly named functions in previous labs. Be sure to select the correct channel for SPI2_TX DMA requests (check the table on page 205 of the Family Reference Manual) and to set the CMAR and CPAR appropriately.

2.3.2 init_spi2()

Write a C subroutine named **`init_spi2()`** that initializes the SPI2 subsystem and connects its NSS, SCK, and MOSI signals to pins PB12, PB13, and PB15, respectively. You should set these pins to use the alternate functions to do this.

The subroutine should then configure the SPI2 channel as follows:

- Ensure that the CR1_SPE bit is clear. Many of the bits set in the control registers require that the SPI channel is not enabled.

- Set the baud rate as low as possible (maximum divisor for BR).
- Configure the interface for a 16-bit word size.
- Configure the SPI channel to be in "master mode".
- Set the SS Output enable bit and enable NSSP.
- Set the TXDMAEN bit to enable DMA transfers on transmit buffer empty
- Enable the SPI channel.

It might be helpful to watch the lecture video for slides 15 and 16 of lecture 19 on SPI.

2.3.3 Demonstrate SPI2 and 7-Segment Display

Have a TA check you off for this section (TA Instructions: Check that the correct functions are commented/uncommented in main and that the display and keyboard work normally).

2.4 Using SPI to drive the OLED LCD

We will now use the SPI1 peripheral to drive the LCD OLED display.

2.4.1 setup_spi1()

The configuration for SPI1 is similar to SPI2 from before with a few key differences:

- Configure NSS, SCK, MISO and MOSI signals of SPI1 to pins PA15, PA5, PA6, and PA7, respectively.
- 10-bit word size

- TXDMAEN not needed anymore

In this lab, you will be using pins on Port A for SPI output. This means you will modify the GPIOA_MODER and GPIOA_AFR configuration. Remember that, if you modify the configuration for pins PA13 or PA14, you will lose the ability to debug or even re-program the microcontroller. Double-check your MODER updates to make sure they will not change pins 13 or 14.

When you misconfigure GPIO Port A, remember that you can restore the ability to use the debug/programming interface by:

1. repairing your program,
2. pressing and holding the reset (SW1) button,
3. pressing "Run" on SystemWorkbench to reprogram the microcontroller

Depending on what kind of mistake you made, you might have to hold down the reset button for only one second after pressing "Run". You may also need to reprogram the microcontroller twice before it works again. Be patient. Do not give up. Ask a TA for help with this process.

2.4.2 spi_cmd()

Write a C subroutine named **`spi_cmd()`** that accepts a single integer parameter and does the following:

- Waits until the SPI_SR_TXE bit is set.
- Copies the parameter to the SPI_DR.

That's all you need to do to write 10 bits of data to the SPI channel. The hardware does all the rest.

2.4.3 spi_data()

Write a C subroutine named **`spi_data()`** that accepts a single integer parameter, and does the same thing as **`spi_cmd()`**, except that it ORs the value 0x200 with the parameter before it copies it to the SPI_DR. This will set the RS bit to 1 for the 10-bit word sent. For instance, if you call the subroutine with the argument 0x41, it should send the 10-bit value 0x241 to the SPI_DR. This will perform a character write to the OLED LCD.

2.4.4 init_oled()

Write a C subroutine named **`init_oled()`** that performs each operation of the OLED LCD initialization sequence:

- Use **`nano_wait()`** to wait 1 ms for the display to power up and stabilize.
- **`cmd(0x38); // set for 8-bit operation`**
- **`cmd(0x08); // turn display off`**

- **`cmd(0x01); // clear display`**
- Use **`nano_wait()`** to wait 2 ms for the display to clear.
- **`cmd(0x06); // set the display to scroll`**
- **`cmd(0x02); // move the cursor to the home position`**
- **`cmd(0x0c); // turn the display on`**

2.4.5 display1()

Write a C subroutine named **`display1()`** that accepts a **`const char *`** parameter (also known as a string) and does the following:

- **`cmd(0x02); // move the cursor to the home position`**
- Call **`data() for each non-NUL character of the string.`**

2.4.6 display2()

Write a C subroutine named **`display2()`** that accepts a **`const char *`** parameter (also known as a string) and does the following:

- **`cmd(0xc0); // move the cursor to the lower row (offset 0x40)`**
- Call **`data() for each non-NUL character of the string.`**

The display hardware allows for scroll buffers for each line, so the beginning of the second line is actually position 64

(0x40). That offset is combined with the "Set DDRAM address" command (0x80) to position the cursor.

2.4.7 Demonstrate the SPI OLED Display

At this point, you should be able to uncomment the following calls in **`main()`**:

```
setup_spi1();
spi_init_oled();
spi_display1("Hello again,");
spi_display2(login);
```

Have a TA check you off for this part (TA Instructions: the OLED display should display "Hello again,\n[Their login]")

3 On Your Own

After going through the initialization process for the OLED display, it is able to receive new character data and cursor placement commands at the speed of SPI. Configure SPI1 for DMA. Create an array of 34 16-bit entries. Element 0 of the array should hold the 10-bit command to set the display cursor at position 0 (the beginning of the top line) of the display. This is the "home command" for the display. Element 17 of the array should hold the 10-bit command to set the cursor position to the beginning of the second line.

Configure every other element of the array to be the 10-bit representation of a <space> character (ASCII value 32).

Remember that each character must be sent with the 0x200 prefix.

Once the array is set up, use circular DMA triggered by SPI1_TX to write it as a circular buffer. Thereafter, the display is effectively "memory-mapped". As characters are written to the array values, they are quickly copied to the display. This allows you to easily create very complicated patterns and animations on the display.

4 Submit your postlab results

You must also submit the program that you wrote in the postlab so that it can be checked by the course staff. Either upload the file or copy it from SystemWorkbench and paste it into the text box. Make sure that your entire program is shown there.

Lab Evaluation Checklist

Normally, we'll have a checklist of things that you should review before going into your evaluation. There will be no evaluation for this lab experiment.

- [ ] Do your bit-bang subroutines work with and without a delay?
- [ ] Is your AD2 SPI protocol transaction capture in the postlab?
- [ ] Do the SPI2 functions properly drive the 7-segment display?
- [ ] Does the OLED display initialize correctly and display

- [ ] the requested text? Does it update if the login is changed and the program is rerun?