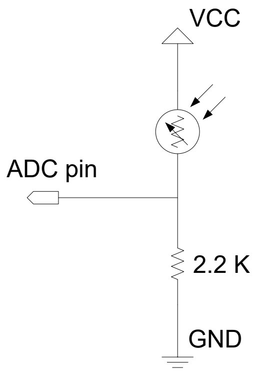
SE 423 Mechatronics Homework Assignment #2
Spring 2024, Due In Lecture February 21st. The Microcontroller Demonstration Check-Off for Question 2 is due 5pm Tuesday February 13th. Check-Offs for Questions 3 and 4 are due by 5PM Tuesday February 20th.

Exercise 1:

Solder your breakout board to add the photo resistor circuit connected to ADCINA4 which is Pin 69 of the red board. Also solder the 5 pin female header connector for your Joystick. See the Demo Board in Lab as a guide on what to solder to your board.



Exercise 2: Vary the intensity of an LED connected to a PWM output

Create a new CCS project from HWstarter project found in your repository and rename it HW2<yourinitials>. Use this same project for all the below exercises. Each exercise builds on the next one.

As discussed in lecture, the EPWM peripheral has many more options than we will need for SE423 this semester. We are only going to need to focus on the basic features of this peripheral. I have created a condensed version of the EPWM chapter of the F28379D technical reference guide. The condensed version can be found here http://coecsl.ece.illinois.edu/SE423/EPWM_Peripheral.pdf. The full technical reference guide can be found here http://coecsl.ece.illinois.edu/SE423/tms320f28379D_TechRefi.pdf.

To setup the PWM peripheral and its output channels, you will need to program the PWM peripheral registers through the “bitfield” unions TI defined. Let’s look at the definition of the bitfields for the registers TBCTL and AQCTLA. (Note: you can find these definitions in Code Composer Studio also by typing in EPwm12Regs and then right clicking and selecting “Open Declaration.” Then do that one more time on the TBCTL_REG union.)

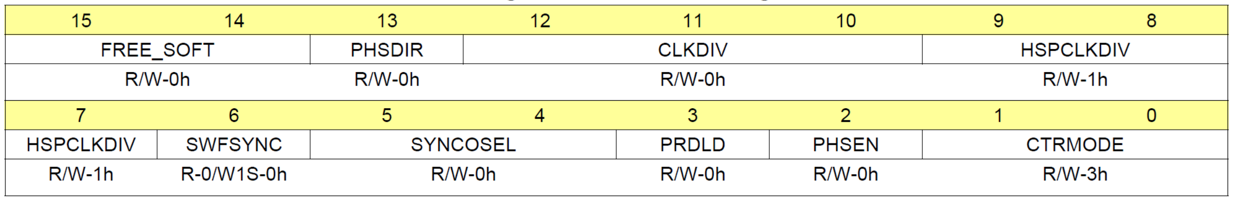
```
struct TBCTL_BITS {                         // bits description
    Uint16 CTRMODE:2;                       // 1:0 Counter Mode
    Uint16 PHSEN:1;                         // 2 Phase Load Enable
    Uint16 PRDLD:1;                         // 3 Active Period Load
    Uint16 SYNCOSEL:2;                      // 5:4 Sync Output Select
    Uint16 SWFSYNC:1;                       // 6 Software Force Sync Pulse
    Uint16 HSPCLKDIV:3;                     // 9:7 High Speed TBCLK Pre-scaler
    Uint16 CLKDIV:3;                        // 12:10 Time Base Clock Pre-scaler
    Uint16 PHSDIR:1;                        // 13 Phase Direction Bit
    Uint16 FREE_SOFT:2;                     // 15:14 Emulation Mode Bits
};
union TBCTL_REG {
    Uint16  all;
    struct  TBCTL_BITS  bit;
};

struct AQCTLA_BITS {                        // bits description
    Uint16 ZRO:2;                           // 1:0 Action Counter = Zero
    Uint16 PRD:2;                           // 3:2 Action Counter = Period
    Uint16 CAU:2;                           // 5:4 Action Counter = Compare A Up
    Uint16 CAD:2;                           // 7:6 Action Counter = Compare A Down
    Uint16 CBU:2;                           // 9:8 Action Counter = Compare B Up
    Uint16 CBD:2;                           // 11:10 Action Counter = Compare B Down
    Uint16 rsvd1:4;                         // 15:12 Reserved
};

union AQCTLA_REG {
    Uint16  all;
    struct  AQCTLA_BITS  bit;
};
```

Looking at these bitfields notice the :1, :2 or :3 after PHSEN, CTRMODE, CLKDIV respectively. This is telling how many bits this portion of the bitfield uses. If you add up all the numbers after the colons, you see that it adds to 16, which is the size of both the TBCTL and AQCTLA registers. So each bit of the register can be assigned by this bitfield. To make this a bit more clear, look at the definition of TBCTL and AQCTLA from TI's technical reference guide:

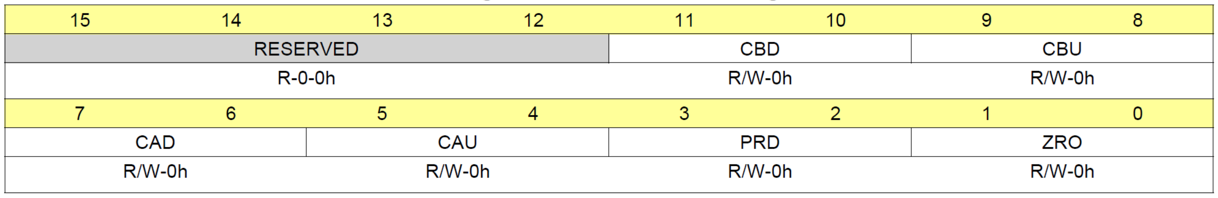
Figure 15-93. TBCTL Register



15	14	13	12	11	10	9	8
FREE_SOFT		PHSDIR	CLKDIV			HSPCLKDIV	
R/W-0h		R/W-0h	R/W-0h			R/W-1h	
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
HSPCLKDIV	SWFSYNC	SYNCOSEL		PRDLD	PHSEN	CTRMODE	
R/W-1h	R-0/W1S-0h	R/W-0h		R/W-0h	R/W-0h	R/W-3h	

and

Figure 15-115. AQCTLA Register



15	14	13	12	11	10	9	8
RESERVED				CBD		CBU	
R-0-0h				R/W-0h		R/W-0h	
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
CAD		CAU		PRD		ZRO	
R/W-0h		R/W-0h		R/W-0h		R/W-0h	

Notice how CLKDIV takes up 3 bits of the TBCTL register. CAU takes up 2 bits of the AQCTLA register. So what the bitfield unions allow us to do in our program is to just assign the value of the three bits that are CLKDIV and not touch/change the other bits of the register. So you could code:

EPwm12Regs.TBCTL.bit.CLKDIV = 3;

and that would set bit 10 to 1, bit 11 to 1 and bit 12 to 0 in the TBCTL register and leave all the other bits the way they were. Since CLKDIV takes up 3 bits, the smallest number you could set it to is zero. What is the largest number you could set it to? *(Technically you could set it to any number in your code but only the bottom 3 bits of the number are looked at in the assignment.)* The answer is 7 or binary 111, all three bits set to 1.

So given that introduction to register bitfield assignments, write some code in the main() function to setup EPWM12A which can drive LED1. *If I do not list an option that you see defined in a register, then that means you should not set that option and it will be kept as the default. I may tell you an option that is already the default, but to make it clear to the reader of your code that this option is set, I would like you to assign it the default value even though that line of code is not necessary.* Set the following options in the EPWM registers for EPWM12A:

With TBCTL: Set all these options: (1) Count up Mode, (2) Free Soft emulation mode to Free Run so that the PWM continues when you set a break point in your code, (3) Do not load the time-base counter from the time-base phase register, (4) set clock divide to divide by 1.

With TBCTR: Start the timer at zero.

With TBPRD: Set the period (carrier frequency) of the PWM signal to 5KHz which is a period of 200 microseconds. Remember the clock source that the TBCTR register is counting has a frequency of 50MHz or a period of 1/50000000 seconds.

With CMPA initially start the duty cycle at 0%.

With AQCTLA set it up such that the PWM12A output pin is set low when CMPA is reached. Have the pin be set high when the TBCTR register is zero.

With TBPHS set the phase to zero, i.e. EPwm12Regs.TBPHS.bit.TBPHS =0; I am not sure if this setting is necessary but I have seen it in a number of TI examples so I am just being safe here.

You also need to set the PinMux so EPWM12A is used instead of GPIO22. Use the PinMux table for the F28379D Launchpad to help you here. Use the function GPIO_SetupPinMux to change the PinMux such that GPIO22 is instead set as EPWM12A output pin. For example the below line of code sets GPIO158 as GPIO158:

```
GPIO_SetupPinMux(158, GPIO_MUX_CPU1, 0); //GPIO PinName, CPU, Mux Index
```

Looking at the PinMux table, this below line of code sets GPIO40 to be instead the SDAB pin:

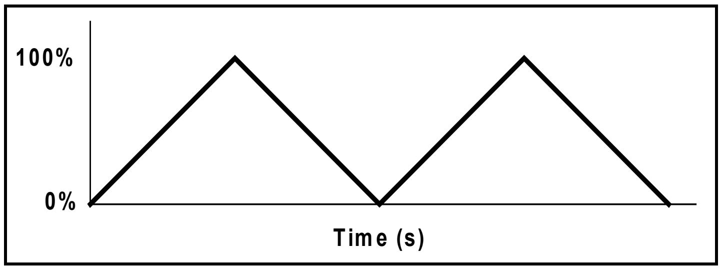
```
GPIO_SetupPinMux(40, GPIO_MUX_CPU1, 6); //GPIO PinName, CPU, Mux Index
```

Finally, it seems from a number of TI examples that it is a good idea to disable the pull-up resistor when an I/O pin is set as a PWM output pin for power consumption reasons. Add these lines of code after your above initializations.

```
EALLOW;  // Below are protected registers
GpioCtrlRegs.GPAPUD.bit.GPIO22 = 1; // For EPWM12A
EDIS;
```

Compile your code and fix any compiler errors that you have. So that you can see LED1 dimming and brightening, go to CPU Timer 0's interrupt function and comment out the call to the displayLEDletter() function. When ready, download this code to your Launchpad. When you run your code the EPWM12A signal driving LED1 is 0% duty cycle so the LED should be off. You are going to change the duty cycle of EPWM12A by manually changing its CMPA register in Code Composer Studio. In CCS, select the menu View->Registers and the Registers tab should show. There are a bunch of registers so you will have to scroll down until you see the "EPwm12Regs" register. Click the ">" to expand the register. Scroll down until you find the TBPRD register and the CMPA register. Note the value in TBPRD. Expand the CMPA register and see that it is a 32bit register with two 16bit parts CMPA and CMPAHR. Leave CMPAHR at 0 and just change CMPA. First, try setting CMPA to half the value of TBPRD. What happens to the intensity of LED1? Change CMPA to the same value as TBPRD to see the maximum brightness (100% duty cycle). Play with other values for CMPA to see the brightness change. Note: Code Composer Studio may not display your EPWM12 registers correctly due to very little code running on your F28379D processor and also due to the large number of registers to display in the register view. Once you click on the Registers tab, you will see in the tab two icons that have yellow arrows pointing towards each other. These are Refresh and Continuous Refresh. When you enter in a value for CMPA, try clicking Refresh and Continuous Refresh to see of CCS will refresh the value in CMPA. If the Refresh icons do not work try one more thing. In your initializations you set EPwm12Regs.TBPRD = to a value that made the carrier frequency of the PWM signal 5Khz. Copy that one line of code and paste it into one of your timer interrupts. This way your code is now communicating continuously with one EPWM12 register. Run this code and go back to changing CMPA in the Register view. Hopefully now by pressing the Refresh icon you should see the value of CMPA change and as change it to a new value. MAKE SURE if you did need to add this "EPwm12Regs.TBPRD = your value" statement in one of your timer interrupts, make sure to delete that line of code before you go on. You will not need it below as you will be writing every 1ms to CMPA below.

Now that you see CMPA changes the brightness of LED1, initialize CPU Timer 2 so that its interrupt function is called every 1ms. Then write code in CPU Timer2's interrupt function to increase, by one, the value of EPWM12's CMPA register every one millisecond. Then when CMPA's value reaches the value in TBPRD, change the state of your code to decease the value of CMPA, by one, each millisecond. Then when CMPA reaches 0 start increasing CMPA, by one, again each millisecond. This way your code will change the duty cycle of the PWM driving LED1 and make it get brighter and then dimmer and keep on repeating this process. The easiest way to code this is to create a global variable int16_t updown. When updown is equal to 1 count up when updown is 0 count down. When up counting, check for CMPA to reach the value of TBPRD and switch to down counting. While down counting, check if CMPA equals zero to switch back to up counting.



Ramped LED1 Brightness Pattern

Exercise 3: Using ADCA to read the voltage drop across a photo resistor:

These documents will be helpful to understand how to use the ADC peripheral. Find the full chapter 11 discussing the F28379D's ADC peripheral in the TMS320F28379D Technical Reference Guide just in case you need some extra detail. Also in this document, read through sections 3.4 through 3.4.5 which discuss Hardware Interrupt events on the F28379D. Table 3-2 is important when setting up Hardware Interrupts (HWI) so I have created a separate file with that table only. I have created a condensed version of the ADC peripheral that should explain the majority of the topics we need for this homework. ADC Condensed Technical Reference Guide These included sections and register descriptions, should give you an introduction to the ADC peripheral. The EPWM4 peripheral will be used to signal the ADC when to convert instead of driving a duty cycle varying square wave so I am including another link here to the EPWM reference. EPWM Condensed Technical Reference Guide.

Each of the TMS320F28379D processor's ADC peripherals can generate an interrupt when its sequence of samples have been converted and stored in the results registers of the ADC peripheral. When the ADC conversion is complete, the F28379D will automatically stop the code it is currently processing and jump to the interrupt service routine (ISR) specified for the ADC. On completion of the ISR code, the program counter (PC) will automatically jump back to the code that was interrupted and resume processing.

There are four ADC peripherals in the F28379D, ADCA, ADCB, ADCC and ADCD. For this first exercise with the ADC we will use ADCA and its channel ADCINA4 which you have soldered to the output of the photo resistor.

Input pins, or channels, ADCINA0, ADCINA1, ADCINA2, ADCINA3, ADCINA4, ADCINA5 are brought through a multiplexer inside the F28379D processor into the ADCA peripheral. The ADCA peripheral can only sample one of these voltage input pins at a time. So the multiplexer allows the ADCA sequencer to sample one channel and then when finished, the sequencer can change the multiplexer so that the next channel can be converted. The sequencer can schedule up to 16 conversions each trigger. At first you are only going to setup one conversion, ADCINA4. But in the next exercise you will add channels in order to sample the voltage of your attached Joystick.

We will initialize ADCA to perform 12 bit ADC conversions. The range of input voltage for this ADC is 0 volts to 3.0 volts. So, a 12 bit result equaling 0(decimal) indicates that 0.0 volts is on the ADC input pin. The maximum value of a 12 bit ADC result, 4095, indicates that 3.0 volts is on the ADC input pin. Hence, there is a linear interpolation between 0 and 4095 covering all the voltages from 0.0 to 3.0 volts with steps of 3.0V/4095 = .73mv.

We will command ADCA to sample channel ADCINA4 which will be a one channel sequence. (As I stated above, in the next exercise you will also sample the two voltages of the Joystick and use a three channel sequence.) We will setup Start of Conversion 0 (SOC0) to convert ADCINA4. When SOC0 is finished converting the input voltage to its corresponding 12 bit value, hardware interrupt ADCA1 will be flagged for execution. You will write the hardware interrupt function that is called when ADCA1 is flagged. The conversion results will be stored in registers AdcaResultRegs.ADCRESULT0.

There are quite a number of things to setup so I am giving you most of the code. You will need refer to the register descriptions to fill in the blanks. I also give you some commented out code that will help you in the next exercise.

We would like to command the ADCA peripheral to sample ADCINA4. There are a few ways to accomplish this, but for this HW we are going to use EPWM4 as just a timer (no duty cycle output) to trigger the ADCA conversion sequence. In main() after the init_serial function, add the following code and fill in the ??? blanks by studying the EPWM reference. Don’t forget to copy EALLOW and EDIS.

```
EALLOW;
EPwm4Regs.ETSEL.bit.SOCAEN = 0; // Disable SOC on A group
EPwm4Regs.TBCTL.bit.CTRMODE = 3; // freeze counter
EPwm4Regs.ETSEL.bit.SOCASEL = ???; // Select Event when counter equal to PRD
EPwm4Regs.ETPS.bit.SOCAPRD = ???; // Generate pulse on 1st event (“pulse” is the same as “trigger”)
EPwm4Regs.TBCTR = 0x0; // Clear counter
EPwm4Regs.TBPHS.bit.TBPHS = 0x0000; // Phase is 0
EPwm4Regs.TBCTL.bit.PHSEN = 0; // Disable phase loading
EPwm4Regs.TBCTL.bit.CLKDIV = 0; // divide by 1  50Mhz Clock
EPwm4Regs.TBPRD = ???;  // Set Period to 1ms sample.  Input clock is 50MHz.
// Notice here that we are not setting CMPA or CMPB because we are not using the PWM signal
EPwm4Regs.ETSEL.bit.SOCAEN = 1; //enable SOCA
EPwm4Regs.TBCTL.bit.CTRMODE = ???; //unfreeze, and enter up count mode
EDIS;
```

Next, we would like to setup ADCA so that it uses 1 of its 16 SOCs (Start of Conversions). These SOCs are used by the ADC sequencer to sample the ADC channels in any desired order and if necessary, assign priority to certain SOCs. It can be very confusing for the first time user of this peripheral, but if we stick to the basics it is pretty straightforward. We are going to trigger SOC0 with the EPWM PRD time event. When triggered, SOC0 will sample/convert its assigned channel. Assign channel ADCINA4 to SOC0. These below initializations setup ADCA to flag an interrupt when SOC0 is finished converting.

Some of the given code I found in an ADC example. It retrieves the default calibration values for the ADCA in the F28379D's read only memory (ROM). Add the following to main() after the init_serial functions, filling in the appropriate blanks (???). Note that the lines of C code that are commented out will be used in the next exercise when you also convert the Joystick channels.

```
EALLOW;

//write configurations for  ADCA
AdcaRegs.ADCCTL2.bit.PRESCALE = 6; //set ADCCLK divider to /4
AdcSetMode(ADC_ADCA, ADC_RESOLUTION_12BIT, ADC_SIGNALMODE_SINGLE);  //read calibration
settings
//Set pulse positions to late
AdcaRegs.ADCCTL1.bit.INTPULSEPOS = 1;
//power up the ADCs
AdcaRegs.ADCCTL1.bit.ADCPWDNZ = 1;
//delay for 1ms to allow ADC time to power up
DELAY_US(1000);

//Select the channels to convert and end of conversion flag
//ADCA
AdcaRegs.ADCSOC0CTL.bit.CHSEL = ???;//SOC0 will convert Channel you choose Does not have to be A0
AdcaRegs.ADCSOC0CTL.bit.ACQPS = 99; //sample window is acqps + 1 SYSCLK cycles = 500ns
AdcaRegs.ADCSOC0CTL.bit.TRIGSEL = ???;// EPWM4 ADCSOCA

//AdcaRegs.ADCSOC1CTL.bit.CHSEL = ???;//SOC1 will conv Channel you choose Does not have to be A1
//AdcaRegs.ADCSOC1CTL.bit.ACQPS = 99; //sample window is acqps + 1 SYSCLK cycles = 500ns
//AdcaRegs.ADCSOC1CTL.bit.TRIGSEL = ???;// EPWM4 ADCSOCA

//AdcaRegs.ADCSOC2CTL.bit.CHSEL = ???;//SOC2 will conv Channel you choose Does not have to be A2
//AdcaRegs.ADCSOC2CTL.bit.ACQPS = 99; //sample window is acqps + 1 SYSCLK cycles = 500ns
//AdcaRegs.ADCSOC2CTL.bit.TRIGSEL = ???;// EPWM4 ADCSOCA

AdcaRegs.ADCINTSEL1N2.bit.INT1SEL=???;//set to last or only SOC that is converted and it will set INT1
flag ADCA1
AdcaRegs.ADCINTSEL1N2.bit.INT1E = 1;   //enable INT1 flag
AdcaRegs.ADCINTFLGCLR.bit.ADCINT1 = 1; //make sure INT1 flag is cleared

EDIS;
```

Add your ADCA1 hardware interrupt function. A shell function definition is given below. *Note: The naming can get confusing here. There are ADCA inputs channels labeled ADCINA0, ADCINA1,* *ADCINA2, ADCINA3, ADCINA4, ADCINA5 and there are also four ADCA interrupts labeled ADCA1, ADCA2, ADCA3 and ADCA4. In the above code the ADCA1 interrupt is setup to be called when one channel ADCINA4 is finished converting.* You will be adding most of the remainder of your code for this exercise inside this ADCA1 hardware interrupt function. Perform the following steps:

- Create your interrupt function as a global function with "void" parameters and of type "__interrupt void" for example __interrupt void ADCA_ISR(void) { (See shell below)
- Put a predefinition of your ISR function at the top of your C file in the same area as the predefinitions of the CPU Timer ISRs.
- Now inside main() find the PieVectTable assignments. This is how you tell the F28379D processor to call your defined functions when certain interrupt events occur. Looking at Table 3-2 in the F28379d Technical Reference find ADCA1. You should see that it is PIE interrupt 1.1. Since TI labels this interrupt ADCA1, there is a PieVectTable field named ADCA1_INT. So inside the EALLOW and EDIS statement assign PieVectTable.ADCA1_INT to the memory address location of your ISR function. For example &ADCA_ISR.
- Next step is to enable the PIE interrupt 1.1 that the F28379D associated with ADCA1. A little further down in the main() code, find the section of code of "IER |=" statements. This code is enabling the base interrupt for the multiple PIE interrupts. Since ADCA1 is a part of interrupt INT1, INT1 needs to be enabled. Timer 0's interrupt is also a part of interrupt 1. So, the code we need is already there "IER |= M_INT1;". You do though need to enable the 1st interrupt source of interrupt 1. Below the "IER |=" statements you should see the enabling of TINT0 which is PIEIER1.bit.INTx7. Do the same line of code but enable PIE interrupt 1.1.
- Now with everything setup to generate the ADCA1 interrupt, put code in your ADCA1 interrupt function to read the value of the ADCINA4. ADCINA4 is setup to convert the input voltage on their corresponding pin to a 12 bit integer. The range of the ADC inputs can be from 0.0V to 3.0V. So the 12 bit conversion value, which has a value between 0 to 4095, linearly represents the input voltage from 0.0V to 3.0V. The 12 bit conversion value is stored in the results register, see given code below. Create a global int16_t result variable to store ADCINA4's "raw" reading. Create one global float variable to store the scaled (0V-3V) voltage value of ADCINA4. Write code to converted the ADCINA4 12 bit integer result value to voltage and store it in this global float variable.

- Set UARTPrint = 1 every 100ms and change the code in the main() while loop so that your ADC voltage value is printed to TeraTerm. Make sure to create your own int32_t count variable for this ADA1 interrupt function. It is normally not a good idea to use a count variable from a different timer function.
- As a final step, clear the interrupt source flag and the PIE peripheral so that processor will wait for the next interrupt flag before the ADC ISR is called again. The below code has many of these steps.

```
//adca1 pie interrupt
__interrupt void ADCA_ISR (void)
{
   Adca4result = AdcaResultRegs.ADCRESULT0;


   // Here covert ADCINA4 to volts

   // Print ADCINA4's voltage value to TeraTerm every 100ms by setting UARTPrint to one
every 100th time in this function.

   AdcaRegs.ADCINTFLGCLR.bit.ADCINT1 = 1;  //clear interrupt flag
   PieCtrlRegs.PIEACK.all = PIEACK_GROUP1;

}
```

Put your hand over the photo resistor and use a flashlight to see the voltage output of your photo resistor circuit changing. In addition, write code set EPWM12A's CMPA register to a scaled value of the photo resistor's reading. When the photo resistor is not seeing much light the LED1 should be dim. As the photo resistor sees more light, LED1 should get brighter due to the duty cycle change.

Demonstrate these items working for your check off.

Exercise 4: Also sample the Joystick voltages

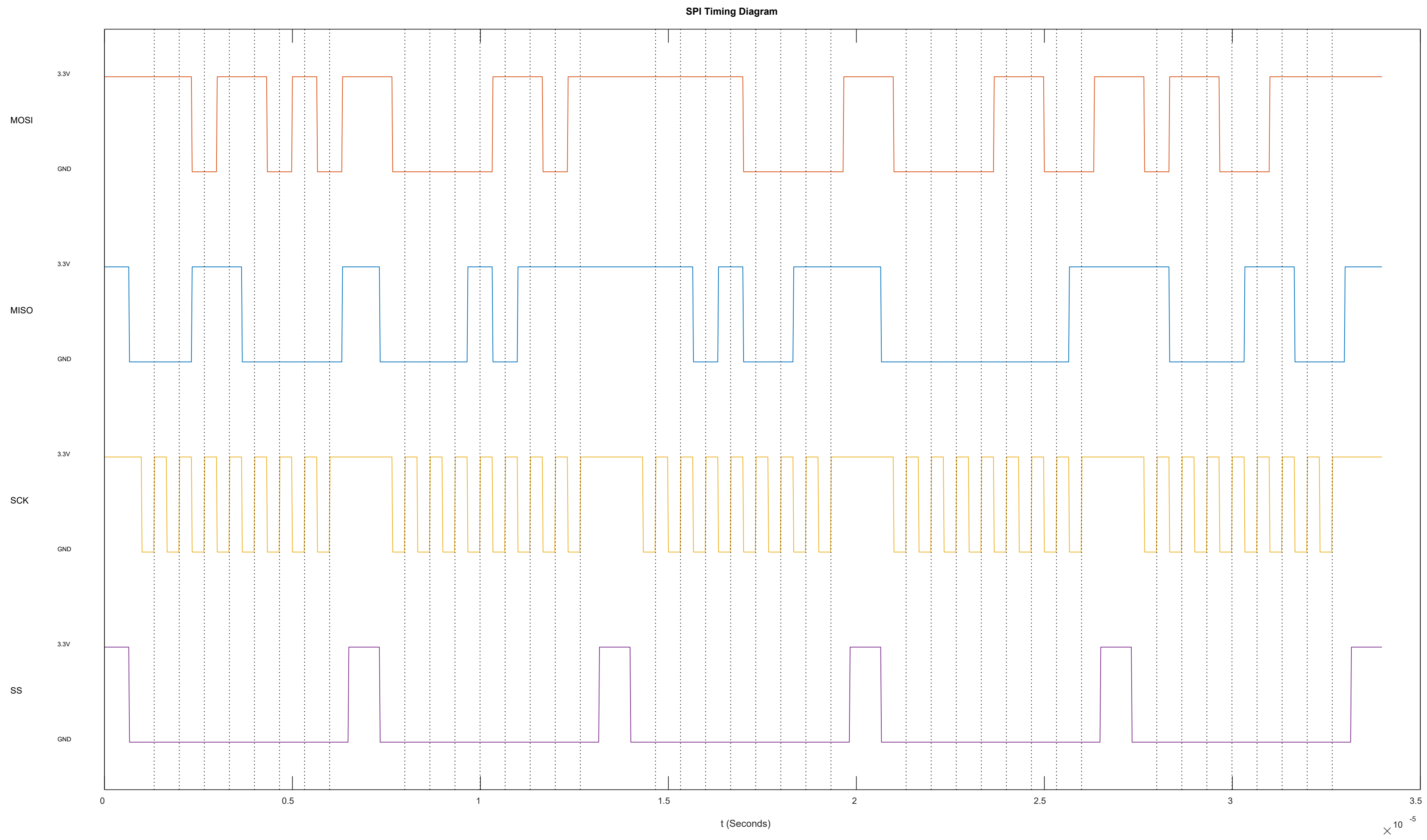
In this exercise I would like you to add to the ADCA sequence of conversions sampling the X and Y axis voltage of the Joystick. The Joystick X axis is connected to ADCINA2 and the Y axis is connected to ADCINA3. You will only have to make a few changes to Exercise 3's code to make these additional samples occur. Leave SOC0 setup to sample ADCINA4 and triggered by EPWM4. Setup SOC1 to sample ADCINA2 and triggered by EPWM4 and SOC2 to sample ADCINA3 and triggered by EPWM4. Also make sure to change the interrupt select so that SOC2 is the last sampled conversion and causes the ADCA1 interrupt function to be called. Then inside the ADCA1 interrupt function sample all three results and convert each to a voltage value between 0V and 3V and every 100ms print these three values to Tera Term.

Using the readings of the Joystick X and Y, write code to update LEDs to kind of point in the direction you have moved the Joystick. If Joystick X is in the center position turn on only LED8. If Joystick X is moved past a threshold and pointing towards the buzzer then turn on only LED6. If Joystick X is moved past another threshold and pointing away from the buzzer then turn on only LED10. Then similarly, if Joystick Y is in the center position turn on only LED8. If Joystick Y is moved past a threshold and pointing down turn on only LED13. If Joystick Y is moved past a threshold and pointing up turn on only LED3. Demonstrate these items working for your check off.

Exercise 5:

Answer the following questions about the SPI timing diagram on the next page. Remember that SPI both sends data and receives data at the same time.

1. How many bytes are sent? How many bytes are received? What are the values of the bytes sent from the master to the slave? What are the values of the bytes received into the master from the slave?
2. Approximate the bit rate (baud rate) by looking at the X axis time divisions.
3. Look at Figure 18-7 and Figure 18-11 in the SPI Condensed Reference. What SPI mode is being used in the below timing diagram: CLOCK_POLARITY = ?, CLOCK_PHASE = ?. So this means that the master reads in each bit on the rising edge of the clock (SCK) or the falling edge of SCK?


SPI Timing Diagram
MOSI
MISO
SCK
SS
3.3V
GND
t (Seconds)
0
0.5
1
1.5
2
2.5
3
3.5
×10 -5