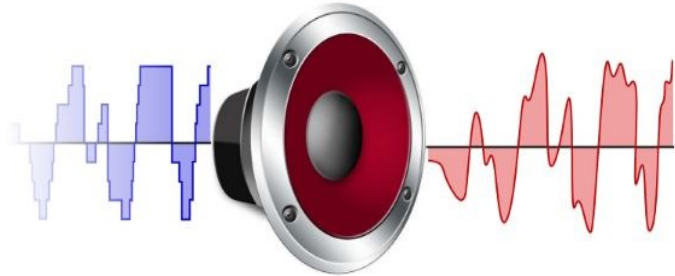




**Microprocessor Interfacing
of
A/D Converters**



Experiment 7 - Analog to Digital Converter

Objectives

The TM4C is equipped with an analog-to-digital (ATD) conversion system that samples an analog (continuous) signal at regular intervals and then converts each of these analog samples into its corresponding binary value using the successive approximation technique. While doing this lab, you will learn,

- How to program the TM4C ATD converter system.
- How to display the ATD converted analog signal on the termite.

1 Background Information

The TM4C analog-to-digital (ATD) conversion system:

The TM4C ATD conversion system consists of a 12-channel, 12-bit, multiplexed input analog-to-digital converter block. Like many peripherals, in order to use the ATD feature, you must first “power up” one of the ATD modules. To do this, we again use the Run Clock Gate Control register like in Lab 4, only this time for the ATD (RCGCADC at address 0x400F.E638). Set bit 0 of the RCGCADCA register to 1 in order to use ATD module 0 (ADC0). Since the ATD module will need access to the external signal being sampled, a GPIO port must be configured to “connect” an external pin to the ATD. Therefore, we must also “power up” the GPIO peripheral just like in Lab 4 using the RCGCGPIO register. Each of the ATD input channels are associated with a pin on the board. For this lab, we will use pin PE3. Figure 1 shows the assignment of each channel.

Every sample, or sequence of samples, is controlled by a sequencer. There are 4 sequencers total that can control every channel. This allows for greater flexibility and ability to work for many applications. Each sequencer also has its own set of attributes that may make it better for one application than another. As seen in Figure 2, each sequencer will take a different number of samples, and has an equivalent size of FIFO buffer. The FIFO buffer is where the results of each sample is stored.

Pin Name	Pin Number	Pin Mux / Pin Assignment	Pin Type	Buffer Type ^a	Description
AIN0	6	PE3	I	Analog	Analog-to-digital converter input 0.
AIN1	7	PE2	I	Analog	Analog-to-digital converter input 1.
AIN2	8	PE1	I	Analog	Analog-to-digital converter input 2.
AIN3	9	PE0	I	Analog	Analog-to-digital converter input 3.
AIN4	64	PD3	I	Analog	Analog-to-digital converter input 4.
AIN5	63	PD2	I	Analog	Analog-to-digital converter input 5.
AIN6	62	PD1	I	Analog	Analog-to-digital converter input 6.
AIN7	61	PD0	I	Analog	Analog-to-digital converter input 7.
AIN8	60	PE5	I	Analog	Analog-to-digital converter input 8.
AIN9	59	PE4	I	Analog	Analog-to-digital converter input 9.
AIN10	58	PB4	I	Analog	Analog-to-digital converter input 10.
AIN11	57	PB5	I	Analog	Analog-to-digital converter input 11.

Figure 1: ATD channel – pin assignments (Table 13-1 of the datasheet)

Sequencer	Number of Samples	Depth of FIFO
SS3	1	1
SS2	4	4
SS1	4	4
SS0	8	8

Figure 2: ATD channel – pin assignments (ATD Sequencer list (Table 13-2 of the datasheet))

Since this lab will be fairly straight forward in that there is only one signal to sample at a relatively slow sample rate, sequencer 3 (SS3) will work perfectly.

GPIO Setup

As mentioned before, the ATD needs access to the outside world via the GPIO port, so it is a good idea to set this up first. We need to configure the GPIO port so that it can receive a signal (input), and then send that signal to the ATD for sampling. (Refer to Lab 4 or datasheet for a reminder of GPIO registers). After the RCGCGPIO register has been configured to enable port E (by setting bit 4), the Alternate Function register (AFSEL) will need to be set for pin 3. The Alternate Function register tells the TM4C that we will not be using PE3 as a simple on/off switch like we did in Lab 4. Instead, enabling the AFSEL register tells the TM4C that we would like to “connect” the associated pin with some other peripheral in the TM4C. Since we are using PE3 (pin 3 of port E), set bit 3 in the AFSEL register associated with port E. When using an alternate function, the next step is normally to configure the PCTL register to tell the TM4C which of the many peripherals available we would like to use as the alternate function. However, in this case, AIN0 happens to be the default for PE3. Next, set the direction of PE3 to input by setting bit 3 to 1 in the DIR register. Since we will be measuring a continuous (analog) signal, we must enable analog on PE3 by setting bit 3 to 1 in the AMSEL register.

ATD Setup

The base address for the ADC0 configuration registers is 0x4003.8000, and the following configuration registers will be referenced by their offset instead of their full address. Changes to the ATD configuration should only be made while the ATD is disabled! Controlling the ATD is done by controlling its associated “sequencer”. The sequencers control when a sample should be taken, and which sequencer is activated is controlled by the ADC Active Sample Sequencer register (ADCACTSS, offset 0x000). For this lab we will be using sequencer 3, therefore, in order to disable sequencer 3, clear bit 3 of the ADCACTSS.

ADC Active Sample Sequencer (ADCACTSS)

ADC0 base: 0x4003.8000
 ADC1 base: 0x4003.9000
 Offset 0x000
 Type RW, reset 0x0000.0000

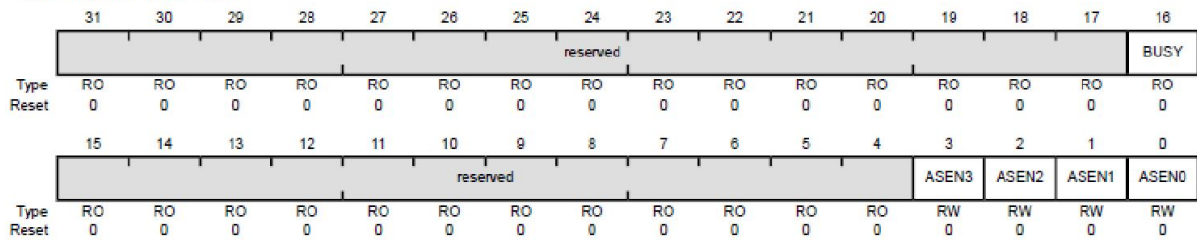


Figure 3: The ADC Active Sample Sequencer register

ADC Sample Sequence Control 3 (ADCSSCTL3)

ADC0 base: 0x4003.8000
 ADC1 base: 0x4003.9000
 Offset 0x0A4
 Type RW, reset 0x0000.0000

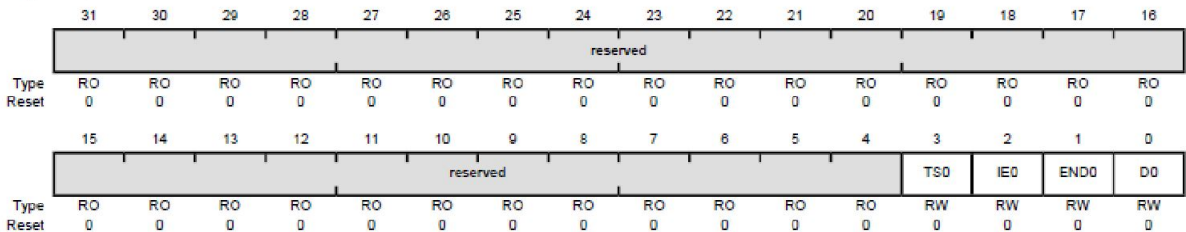


Figure 4: ADC Sample Sequence Control 3 register

Next, we will use a polling method in order to know when a sample is ready. To do this we monitor the interrupt flags in the RIS register. However, in order to tell the TM4C to set flags in the RIS register, we must set the IE0 bit in the ADC Sample Sequence Control register (ADCSSCTL3, offset 0x0A4). (Note that we are using SSCTL3 because we are using sequencer 3.) We also need to set the END0 bit to tell the sequencer to stop sampling after one sample. This seems redundant since sequencer 3 only takes one sample, but it is required. Note, that if you were using a different sequencer that had the capability to take many samples, the appropriate SSCTL register is where you would specify the number of samples desired.

The TM4C has the capability to trigger a sample based on a variety of signals. For instance, a sample can start on the edge of a square wave, by software, or from the timer module. Again, like the interrupts, the trigger to start an ATD conversion is sequencer specific. What triggers the sequencer is configured using the ADC Event Multiplexer Select register (ADCEMUX, offset 0x014). We will be triggering each sample in software for this lab, therefore, bits 15:12 need to be cleared.

So far we have told the TM4C that we need to create an input through GPIO to be used to receive our signal to be sampled, we have told which ATD module and which sequencer to use. However, we have not told the ATD module which channel to use. To do this, clear bits 15:12 of the ADC Sample Sequence Input Multiplexer Select 0 register (ADCSSMUX0, offset 0x040) to select channel AIN0.

ATD sampling rate is controlled by the ADC Peripheral Configuration register (ADCPC, offset 0xFC4). The ATD can sample at 125 kilo-samples per second (ksps), 250 ksps, 500 ksps, and 1 Mega-samples per second (Msps). Since we are triggering via software, and doing so on a relatively slow interval, we can choose a sample rate of 125 ksps. Set bits 3:0 to 0x01 in the ADCPC register to select 125 ksps.

The ATD system is now configured and can be enabled. Once enabled, (by setting bit 3 of the ADCACTSS register) the ATD system is ready to start sampling on your trigger.

ADC Event Multiplexer Select (ADCEMUX)

ADC0 base: 0x4003.8000
 ADC1 base: 0x4003.9000
 Offset 0x014
 Type RW, reset 0x0000.0000

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	EM3				EM2				EM1				EM0			
Type	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5: ADC Event Multiplexer Select register

ADC Sample Sequence Input Multiplexer Select 0 (ADCSSMUX0)

ADC0 base: 0x4003.8000
 ADC1 base: 0x4003.9000
 Offset 0x040
 Type RW, reset 0x0000.0000

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	MUX7				MUX6				MUX5				MUX4			
Type	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	MUX3				MUX2				MUX1				MUX0			
Type	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6: ADC Sample Sequence Input Multiplexer Select 0 register

ADC Peripheral Configuration (ADCPC)

ADC0 base: 0x4003.8000
 ADC1 base: 0x4003.9000
 Offset 0xFC4
 Type RW, reset 0x0000.0007

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved												SR			
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RW	RW	RW	RW
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

Figure 7: ADC Peripheral Configuration register

ADC Processor Sample Sequence Initiate (ADCPSSI)

ADC0 base: 0x4003.8000

ADC1 base: 0x4003.9000

Offset 0x028

Type RW, reset -

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	GSYNC	reserved			SYNCWAIT	reserved										
Type	RW	RO	RO	RO	RW	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved												SS3	SS2	SS1	SS0
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	WO	WO	WO	WO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-

Figure 8: ADC Processor Sample Sequence register

ADC Raw Interrupt Status (ADCRIS)

ADC0 base: 0x4003.8000

ADC1 base: 0x4003.9000

Offset 0x004

Type RO, reset 0x0000.0000

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															INRDC
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved												INR3	INR2	INR1	INR0
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 9: ADC Raw Interrupt Status register

Sampling

Since we set the ATD module up to initiate a sample from a software trigger, the program needs to tell the ATD module (specifically, the sequencer we are using) to start sampling. This is done using the ADC Processor Sample Sequence Initiate register (ADCPSSI, offset 0x028). Bits 3:0 represent each sequencer. Since we are using sequencer 3, setting bit 3 to 1 tells the sequencer to start sampling.

A sampling sequence will take a few clock cycles, so we have to monitor when the sequence is complete. The ADC Raw Interrupt Status register (ADCRIS, offset 0x004) contains flags corresponding to each sequencer (bits 3:0) that are set to 1 when a sequence has completed. In our case, checking bit 3 monitors if / when sequencer 3 is done sampling.

Each sequencer stores its results in its own FIFO buffer register (ADCSSFIFO_n). Address offset: ADCSSFIFO0 0x048 ADCSSFIFO1 0x068 ADCSSFIFO2 0x088 ADCSSFIFO3 0x0A8 Once sampling is complete on sequencer 3, the value of the oldest sample will be in ADC Sample Sequence Result FIFO 3 (ADCSSFIFO3, offset 0x0A8).

The ADC lets us know a sample value is ready for us by setting the appropriate bit in the ISR, then it waits for us to load the sample from the FIFO register. Therefore, we need to tell the ADC we are ready for it to continue sampling. To do this, we set bit 3 (for sequencer 3) of the Interrupt Status and Clear Register (ADCISC, offset 0x00C).

ADC Sample Sequence Result FIFO n (ADCSSFIFOn)

ADC0 base: 0x4003.8000

ADC1 base: 0x4003.9000

Offset 0x048

Type RO, reset -

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved															
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved				DATA											
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-

Figure 10: ADC Sample Sequence Result FIFO n register

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	reserved												DCINSS3	DCINSS2	DCINSS1	DCINSS0
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	reserved												IN3	IN2	IN1	IN0
Type	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RO	RW1C	RW1C	RW1C	RW1C
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 11: ADC Interrupt Status and Clear register

2 Preliminary Work

You will present your preliminary work to TAs at the beginning of the lab.

1. Draw a flowchart of the program you will write to convert an analog input applied to pin PE3 to its digital value and show it on the termite with decimal numbers.
2. Program the ATD conversion system on the board to convert the analog signal to a 12-bit number between 0x000 and 0xFFF. The output value should be stored in an available register of your choice.
3. Convert the above mentioned value to a BCD number with three digits (X.YZ) between 3.30 and 0.00. 3.30 is the maximum voltage value which can be get from the GPIO ports of the board.
4. Output the converted value on termite if a change greater than 0.05 volts happens. If all the converted values of ATD system are shown on the screen, it will cause flooding numbers on termite, which seems like an unstable state even if the applied voltage is kept unchanged (because of voltage fluctuation on the ports).

3 Experimental Work

1. Build and run the program in Step 2. Show your work to TA and answer the questions.
2. Complete all the steps and test your program with a potentiometer. Show your work to TA and answer the questions.

!!! Important Notice !!!

When using DEES in your experiments, **DO NOT CONNECT VCC (Pins +3.3V & VBUS) of TM4C123G Board** to DEES's VCC terminal. Also, to make a common voltage reference, CONNECT

GND of TM4C123G Board to DEES's GND terminal. Please make sure that you turn all supplies OFF while making any connection throughout laboratory work.

4 Parts List

Potentiometer

References

- [1] TI, "TivaTM c series tm4c123g launchpad evaluation board user's guide." <http://www.ti.com/lit/ug/spmu296/spmu296.pdf>.
- [2] TI, "TivaTM tm4c123gh6pm microcontroller data sheet." <http://www.ti.com/lit/ds/spms376e/spms376e.pdf>.