ECEN 3213:
Computer Based Systems in Engineering
Lab 3: Analog to Digital and Digital to Analog Conversions

Ex #	Max Points	Points Earned	Grading Criteria	Instructor Initial
1	**5**		Circuit is wired correctly. (1.0) ______ Program written correctly, compiles, and runs. (4.0) ______	
2	**3**		Circuit is wired correctly. (1.0) ______ Program written correctly, compiles, and runs. (2.0) ______	
3	**6**		Circuit is wired correctly. (2.0) ______ Program written correctly, compiles, and runs. (3.0) ______ Fill the table correctly and obtain the screenshots. (1.0) ______	
4	**3**		Circuit is wired correctly. (2.0) ______ Fill the table correctly and obtain the screenshots. (1.0) ______	
Doc	**3**		Supplemental Questions (3.0) ______	
TOTAL:				

Team Members:	**TA Observations:**
______________________________	______________________________
______________________________	______________________________

OBJECTIVE

This lab aims to introduce students the basics of analog input and output using Raspberry Pi. Upon completion of this lab, you will obtain hands-on experience in analog to digital and digital to analog conversions. You will also learn how to use I2C communication in Raspberry Pi.

INTRODUCTION

In this lab you will construct a circuit that will generate a variable analog voltage. This will be given as an analog input to the external ADC (analog to digital converter) which will convert the analog signal into a digital signal using ADS1015. You will first use the single-ended measurement mode of ADS1015 in Exercise 1. Then you will use the differential measurement mode of ADS1015 in Exercise 2. Next you will build an R-2R ladder circuit to achieve digital to analog conversion in Exercise 3. Finally, you will use a voltage follower to improve the output of the R-2R ladder in Exercise 4. This lab involves the use of I2C serial communication.

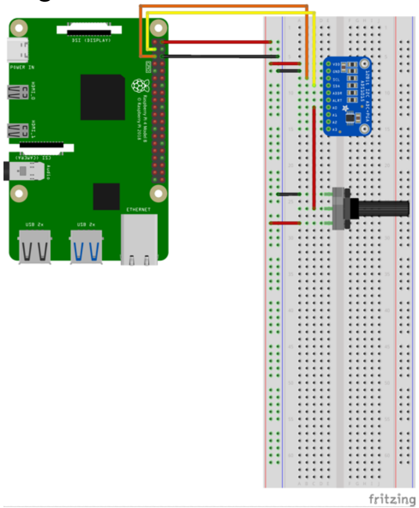
Warning! Consult the lab TA before you connect the power to the RPi or any external hardware.

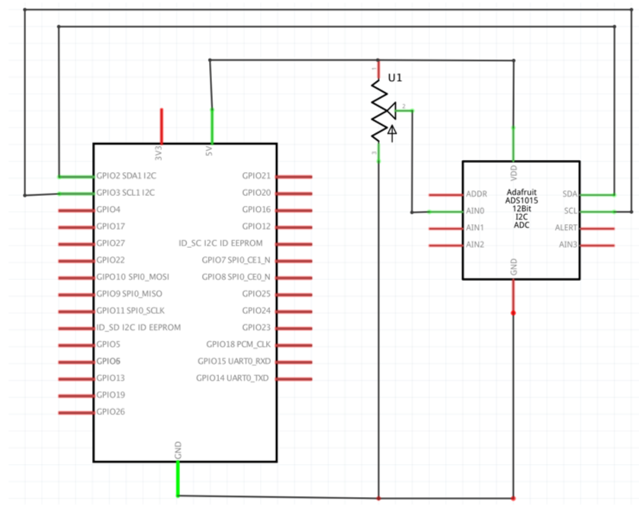
LIST OF DOCUMENTS USED IN THIS LAB

1. *ads1015.pdf*
2. *I2C Library _ Wiring Pi.pdf*
3. *I2CProtocol.pdf*
4. *lm358-n.pdf*

Exercise 1

1. On the breadboard, construct the following circuit. In this exercise, the ADS1015 uses the single-ended measurement mode.

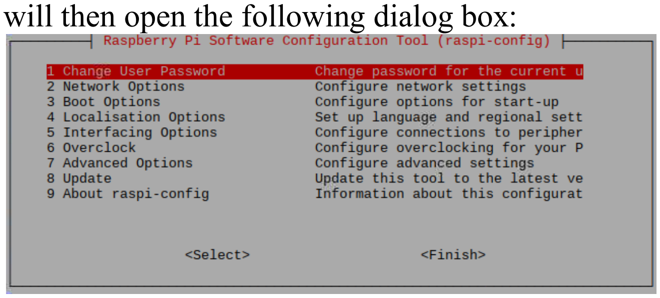




2. Use sudo i2cdetect -y 1 to get the i2c address of ADS1015. If you cannot find the address, type command in the Terminal:

   sudo raspi-config

   This command will then open the following dialog box:



   Choose "Interfacing Options" then "I2C" then "Yes" and then "Finish" in this order and restart your RPi. The I2C module will then be started.

3. Complete the code in Lab3EX1.cpp to read the analog voltage available at the input pin AIN0 of the ADS1015. Use the I2C protocol to read this measured value to Raspberry Pi (which is in volts) and display the following string on the Monitor "The Analog input voltage is X.XXX". Vary the potentiometer and check for the maximum and minimum voltages that can be obtained. Consult the lab supplements ads1015.pdf, I2CProtocol.pdf and I2C Library_Wiring Pi.pdf for more information on the ADS1015 and I2C protocol. Consult the lab supplement the page 24 of ads1015.pdf for how to choose the configuration parameters of ADS1015.

4. Knowing that the full-scale range of the **ADS1015** used in this exercise is set to [0, 6.144] (volts), use the equation below to calculate the voltage in millivolts, add the

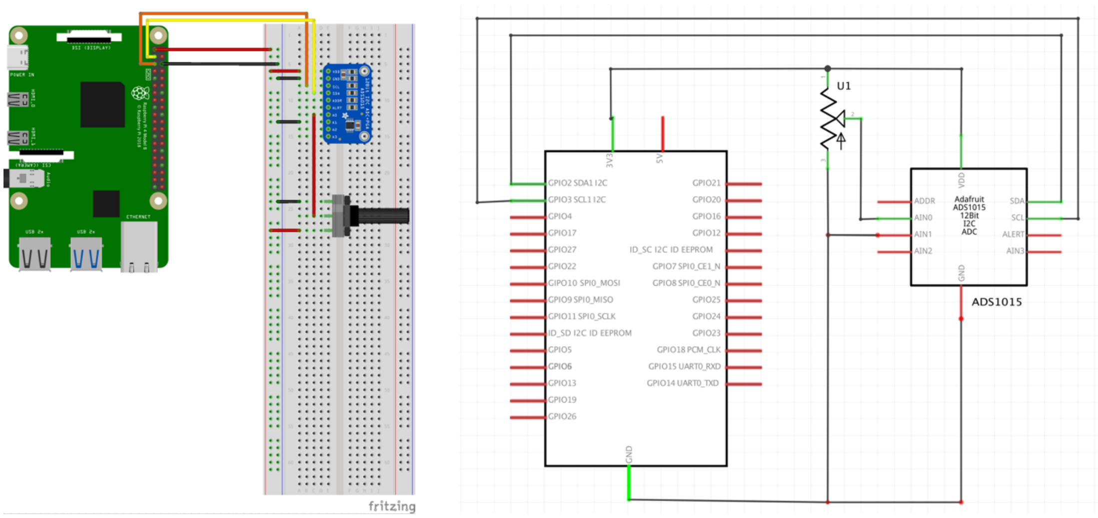
function to your program to calculate the voltage and assign it to the variable you declared to store the value of the voltage.

$$Actual\ Voltage = \frac{Measured\ Digital\ Value}{2047} * 6144\ mV$$

5. Make sure your code is well documented. Save your program.
6. Demonstrate your program to the lab instructor.
7. Thoroughly comment your code. Make sure your name and the exercise number clearly appear in the comments.

Exercise 2

1. On the breadboard, construct the following circuit. In this exercise, the ADS1015 uses the differential measurement mode.



2. Complete the code in Lab3EX2.cpp to read the analog voltage available at the input pins AIN0 and AIN1 of the ADS1015.

3. Set the full-scale range of the ADS1015 to be [-4.096, 4.096] (volts) and enable the differential measurement of the ADS1015. Consult the lab supplement the page 24 of ads1015.pdf for how to choose the configuration parameters of ADS1015. Use the equation below to calculate the voltage in millivolts, add the function to your program calculate the voltage and assign it to the variable you declared to store the value of the voltage.

$$Actual\ Voltage = \frac{Measured\ Digital\ Value}{2047} * 4096\ mV$$

4. Vary the potentiometer and check for the maximum and minimum voltages that can be obtained.

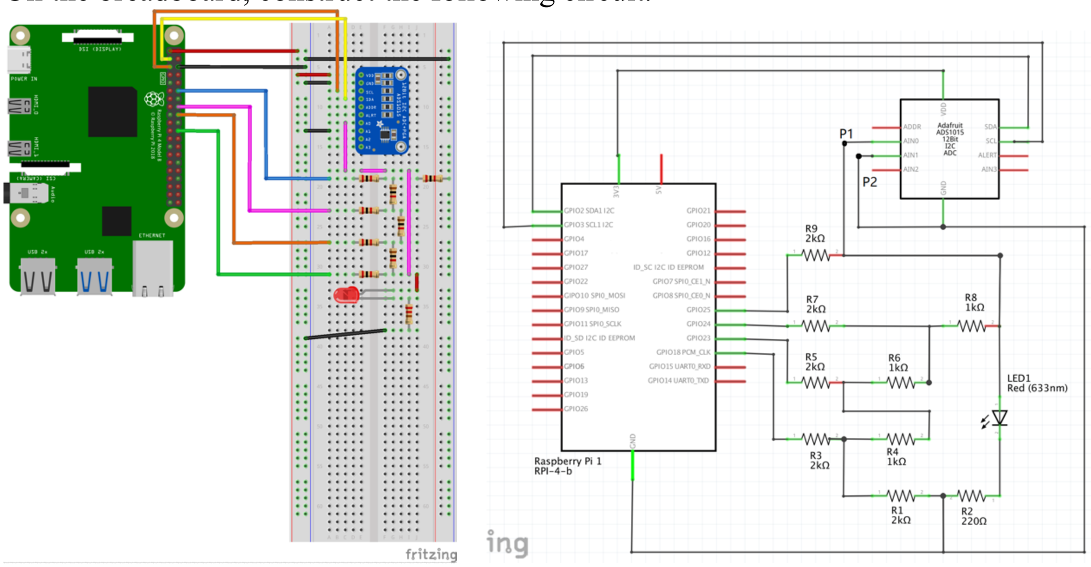
5. Switch the two inputs to Pin AIN0 and AIN1 shown in the above figure. Vary the potentiometer again and check for the maximum and minimum voltages that can be

obtained.

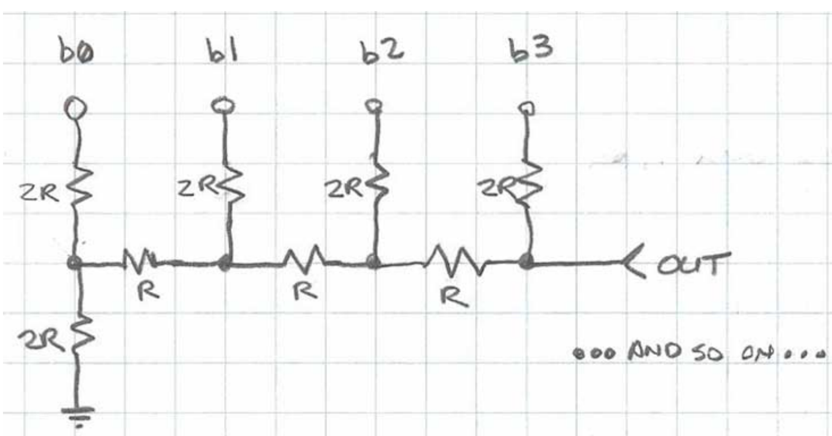
6. Make sure your code is well documented. Save your program.
7. Demonstrate your program to the lab instructor.
8. Thoroughly comment your code. Make sure your name and the exercise number clearly appear in the comments.

Exercise 3

1. On the breadboard, construct the following circuit.



This is actually the implementation of the R-2R Ladder for DAC.



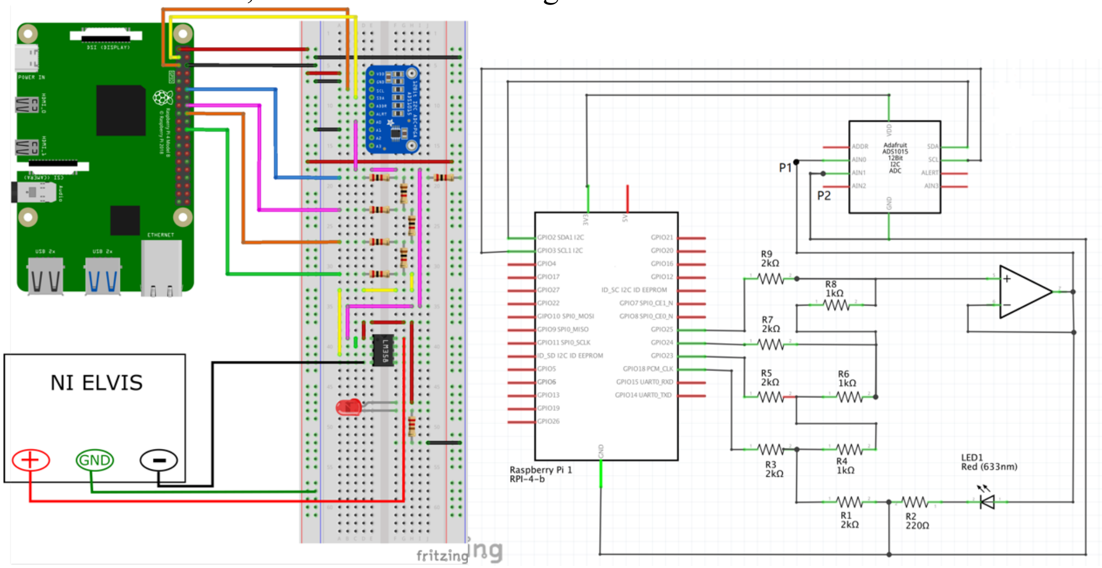
2. PIN18, PIN23, PIN24, and PIN25 are the output pins on RPi and they serve as the digital inputs to the DAC circuit.
3. The analog output of the DAC is given as an input to the ADS1015. Use the same configuration of the ADS1015 used in Exercise 2 to convert the analog signal back to digital signal.
4. Complete the code in Lab3EX3.cpp to generate 16 binary numbers from ‘0000’ to ‘1111’ across the output pins in the order ‘PIN18 PIN23 PIN24 PIN25’ with each number lasting 1 second.

5. For each input from ‘0000’ to ‘1111’ display the following on the Monitor:
   “The converted analog voltage for the binary input XXXX to R-2R ladder is X.XXX”.
6. Measure the analog voltage between P1 and P2 using the Digital Multimeter. Capture the screenshots as needed.
7. Fill the table at the end of the exercise.
8. Demonstrate your program to the lab instructor.
9. Thoroughly comment your code. Make sure your name and the exercise number clearly appear in the comments.

Decimal	Binary	Analog Voltage	ELVIS III Reading
00	0000	2107.03mV	2.097V
01	0001	2036.99mV	2.0356V
02	0010	1998.98mV	1.9929v
03	0011	1924.94mV	1.9364V
04	0100	1908.93mV	1.8874v
05	0101	1824.09mV	1.8264v
06	0110	1780.87mV	1.7810v
07	0111	1640.80mV	1.6409V
08	1000	1622.79mV	1.5976V
09	1001	1326.65mV	1.3381V
10	1010	1170.57mV	1.3278V
11	1011	856.418mV	0.8570V
12	1100	786.384mV	0.7877V
13	1101	856.418mV	0.8570V
14	1110	316.154mV	0.31595V
15	1111	0mV	-0.046V

Exercise 4

1. On the breadboard, construct the following circuit.



2. Consult the lab supplement lm358-n.pdf for more information about the operational amplifier. Connect the Variable Power Supplies' probes to the VCC+ and VCC- pins of LM358N and the ground line of the breadboard. Configure the Positive (+) and Negative (-) of Variable Power Supplies to be +5V and -5V. Refer to the Appendix for more information.

3. Run your code Lab3EX3.cpp completed in Exercise 3. Use Digital Multimeter to measure the analog voltage between P1 and P2 in the schematic. Capture the screenshots as needed.

4. Fill the table at the end of the exercise.

Decimal	Binary	Analog Voltage	ELVIS III Reading
00	0000	0	-0.372
01	0001	0.156076	0.156
02	0010	0.810396	0.812
03	0011	0.546267	0.546
04	0100	0.812397	0.811
05	0101	0.964471	0.967
06	0110	1.19859	1.199
07	0111	1.34866	1.366
08	1000	1.6328	1.635
09	1001	1.78887	1.791
10	1010	2.02099	2.023
11	1011	2.17706	2.178
12	1100	2.44119	2.443
13	1101	2.58926	2.596
14	1110	2.82938	2.831
15	1111	2.98546	2.986

Supplemental Questions

1. Briefly summarize what you learned from this lab.
2. Derive the voltage output expression of the four-bit R-2R ladder DAC and compare it with your experimental results.
3. The following code has been given to you in Ex2 and Ex3 when you read the ADS1015 data and convert that to a measured voltage. Explain the function of this code.

```
a.     low = (data & 0xFF00) >> 8;
b.     high = (data & 0x00FF) << 8;
c.     value = (high | low)>>4;
d.     if (value > 0x07FF)
e.         {
f.             value |= 0xF000;
g.         }
```

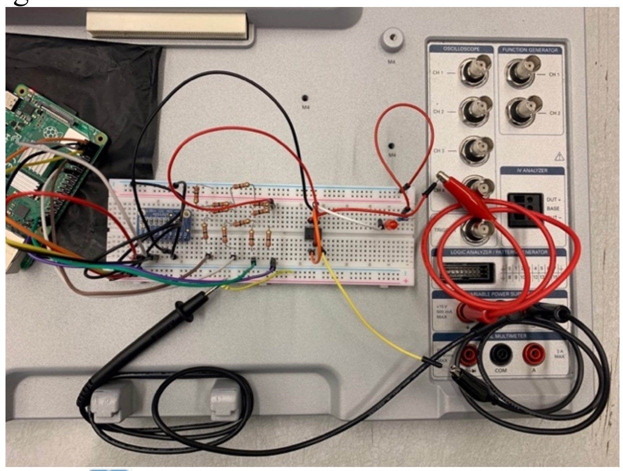
4. Comparing the two tables you obtained in Exercise 3 and 4, respectively, what is the difference? Why is there such a difference?.

Submission

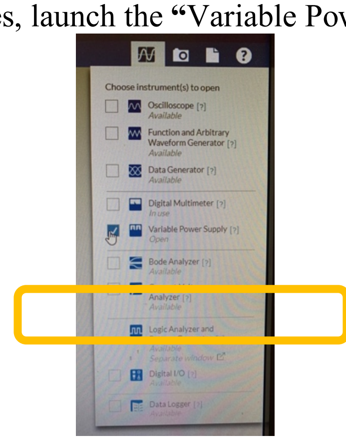
Submit your lab report through Canvas. Your lab report should include code, supplemental questions, the table and the screenshots in Exercise 3 and 4. Put your supplemental questions, the table and the screenshots in a word file or PDF file. Your code should be in the .cpp file. Zip all files. Make sure your code is thoroughly commented.

Appendix

1. Connect the Variable Power Supplies' probes to the VCC+ and VCC- pins of LM358N and the ground line of the breadboard. As shown in the following figure.



2. Click the **Instruments** tab. A list of instruments such as **Oscilloscope, Function Generator, Digital Multimeter**, etc. are shown as in the following figure. To use the Variable Power Supplies, launch the **"**Variable Power Supplies**"** instrument.



3. Configure the Positive (+) and Negative (-) of Variable Power Supplies as follows. Click the "Run" button to get started.