

LAB Week 7: Data Acquisition

Wright State University: Mechanical Engineering

ME 3600L Section 01

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1. ABSTRACT

A software program called LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) was used to gain an understanding of how sample rates can affect data acquisition. An analog signal was sampled at frequencies below, equal to and above what the sampling theorem requires to study the effects it has in the practical world. The relationship between sine and square wave functions were analyzed as well. Alias frequencies created by the lowest frequency were shown. Analyzing the data collected it showed the importance of the sampling theorem. The uncertainty for the square wave was calculated for an example of how the sampling frequency effects the data.

2. NOMENCLATURE

B – Systematic Uncertainty

f – Frequency (Hz) (τ^{-1})

f_s – Sample Frequency (samples/second)

f_a – Alias Frequency

f_N – Nyquist Frequency

f_{max} – Maximum Frequency (Hz)

N – Total number of discrete data points; integer

δt – Sample Time Increments

S_x – Random Standard uncertainty

S_x' – Standard Deviation of Sample

T_v – Student-*t* value at *v*

U – Total Uncertainty

3. INTRODUCTION

The purpose of this lab was to learn and become familiar with the use of LabVIEW and to acquire data to understand the fundamentals of uncertainty and sampling theorem. The understanding of the Nyquist frequency when sampling signals was the underlining aspect of the lab. LabVIEW is software that allows users to collect and analyze data; it allows for various equipment inputs to collect the data, including a few for this lab: A waveform generator, short wires, voltmeter, data acquisition card and the computer itself. The wires are used to connect the waveform generator to the data acquisition card; which is connected to the computer with LabVIEW. By connecting the equipment in this order, the software is able to collect data about the signal produced by the waveform generator. Using LabVIEW to graph multiple waveforms of the known 120 Hz sine and square signal, the user is able to see the difference between the alias frequencies and the actual frequency. This will be shown by analyzing at three different sampling frequencies. Analyzing the signal at frequencies below, equal to and above the Nyquist frequency, the user can understand the importance of the sampling theorem. The uncertainty of the analyzed data is also found to show the accuracy of the data.

4. THEORY

An analog signal continuous in time and amplitude is transformed into a digital signal which is not continuous in either, so the data can be analyzed. The sampling frequency is the rate at which data points from the analog signal are acquired

$$f_s = 1 / (\delta t) \quad (1)$$

The sampling theorem is used when analog signals are processed and transformed into digital signals. The sampling theorem requires that the sampling frequency must be a minimum of twice as much as the maximum frequency of the signal to avoid having an alias frequency (f_a).

$$f_s > 2 * f_{max} \quad (2)$$

This equation assures that the frequency of the digital signal will accurately represent the frequency of the analog signal. An alias frequency is a false frequency that is created when an analog signal is converted into a digital signal using a sampling rate lower than the twice the maximum frequency. There is a folding point for this aliasing phenomenon called the Nyquist frequency which is half of the sampling frequency. This equation can be used with the folding diagram to predict the alias frequency that would be created in the process.

$$fN = (1/2) * fs \quad (3)$$

The uncertainty of the 120 Hz square wave signal analyzed at a sampling rate of 12000 samples per second, was calculated to determine the accuracy of the experiment. The specifications of the instrument provided in the manuals were used to solve for the systematic uncertainty, B . The information can be found on the fourth page of the DAQ card spec sheet PDF found on Pilot. The equations to find the accuracy, offset error, and gain error are shown below.

$$AbsoluteAccuracy = Reading(GainError) + Range(OffsetError) + NoiseUncert \quad (4)$$

$$GainError = ResidualGainError + GainTempco(TempChangeInt) + ReferenceTempco(TempChangeExt) \quad (5)$$

$$OffsetError = ResidualOffsetError + OffsetTempco(TempChangeInt) + INL_{Error} \quad (6)$$

The Standard deviation, average and sample standard deviation were needed to calculate the random standard uncertainty. Which is equal to the standard deviation of the sample divided by the square root of the number of sample points. The use of a calculator in this case Excel was used to perform the task.

$$Sx = Sx' / \sqrt{N} \quad (7)$$

A 95% confidence interval was assumed using the student-t distribution tables, meaning the results of the experiment are within the average plus or minus the uncertainty. This means that the total uncertainty can be found using the following equation.

$$U = Tv, 95\% \sqrt{B^2 + (Sx)^2} \quad (8)$$

5. EXPERIMENTAL APPARATUS AND PROCEDURE

In this data acquisition lab, the use of several pieces of equipment are used to collect and analyze analog signals converted to digital signals. All equipment is provided in the laboratory. A waveform generator, voltmeter, data acquisition card (DAQ, figure 1), wires, connector box, computer, LabVIEW and Excel, are all that are needed for the lab. The waveform generator used in the lab was a BK PRECISION 4003A; this generates electrical signals that can be controlled by the student to acquire the data with the data acquisition card using the connector box. The connector box is a National Instruments model SCC-68 with a tolerance of $\pm 5\%$. The data acquisition card is a National Instrument 6221 model, as seen in figure 1, with 8 differential channels and 16 single ended channel. Once the card has captured the signal, it sends the data to the LabVIEW on the computer. The computer which was used in the lab is a HP with a 3.40GHZ processor. It has 8 GB of RAM and a hard drive for data storage, scene in figure 2.



Figure 1: Picture of the Data Acquisition Card (DAQ).

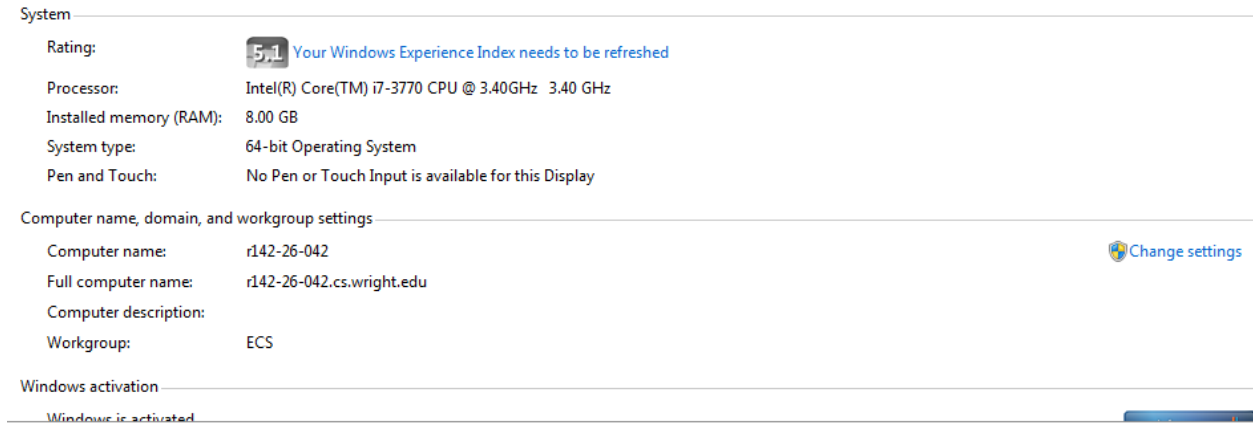


Figure 2: Computer specs.

To begin this lab, the student must first connect the equipment in a particular arrangement. The waveform generator must be connected to the box connector using the cables of the waveform generator and the wires already attached to the channels to be used. The connector box is already connected to the computer and data acquisition card, which then sends the data to LabVIEW. The student needs to create a block diagram in LabVIEW to analyze the data, scene in figure 5. Figure 2 below shows the overall procedure of how the data is produced to the collection for the lab.

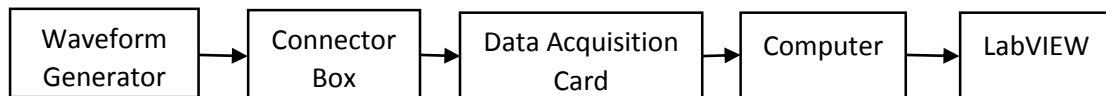


Figure 3: Setup Diagram.

In case the connection setup is not preset by the lab TA, the student must know where to make the connections. When you open up the connector box with a flathead screw driver to remove the top it reveal the terminals. This lab uses input 57 and 23 (See Figure 4), loosen these screws to allow a wire to be inserted into each terminal. Once a wire has been placed in the AI 7 terminal (57 screw) and another wire has been placed in the AI 15 terminal (23 screw), the screws must be tightened back down to hold the wires in place. After insuring the wires are connected the student can connect the cables from the waveform generator. The red cable is the input source and is connected, using the alligator clamp, to the wire in terminal AI 7. The black cable is the ground and is therefore connected in the same manner to the other wire coming out of terminal AI 15. Once these connections have been made the waveform generator can be turned. The waveform generator must be set to single wave for the first 3 data acquisitions and a square for the fourth set. The student must also try and get the frequency as close as they can to 120 Hz with a 0mA offset.

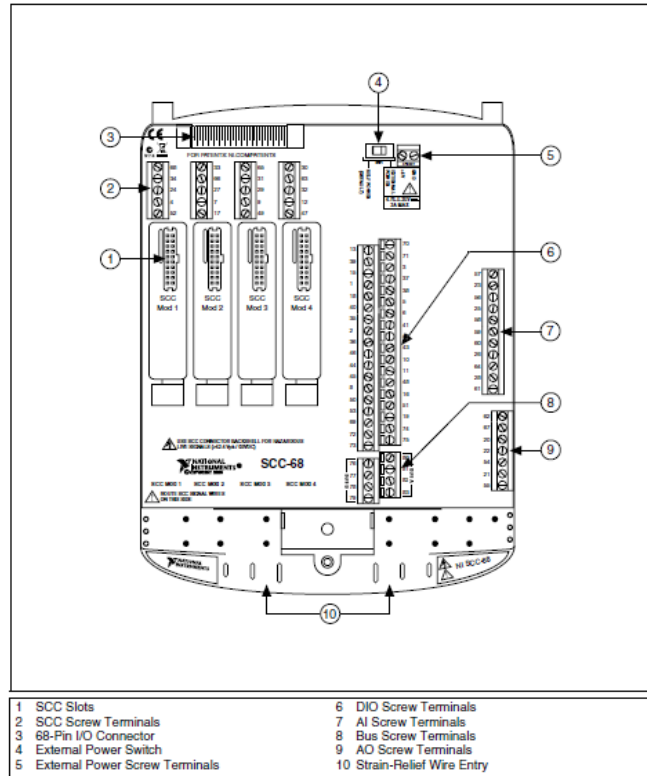


Figure 6. SCC-68 Features

Figure 4: Connector Box.

When the setup is done, the program to be used must be created to analyze the data. First open up the LabVIEW program and to select the Blank Sheet option. This will then open up a new front panel as well as a block diagram window. Right click on the block diagram window and select the express section on the function toolbox. Select the DAQ Assistant input in this section and drag it onto the block diagram. It is also required to graph the data on the front panel, right click on “data” on the block diagram window for the DAQ and go to create and select graphic indicator. Then right click on the “number of sample”, “rate” and “timeout” button go to create and select control. This lab also asks the student to find the amplitude of the last two functions as well as to save the data of each. To do this student must add an “amplitude” indicator to the graph. It is also

required to insert a “Write to Measurements File” function and connect it to the graphic indicator. Figure 5 shows what one possible block diagram of the program, which is the one used to collect the data in this report.

After the program has been created, it can be used in the lab to run at multiple sampling frequencies and collect the data the waveform generator is producing. Running the program from the front panel with the frequency control set to 96 Hz, 240 Hz and then 12000 Hz in the sine wave output. Then one more time at 12000 Hz after this the waveform generator is switched to a square wave output. The uncertainty of the data of the square wave will later be calculated, with the following process: first find the average, standard deviation, and the standard deviation of the mean.

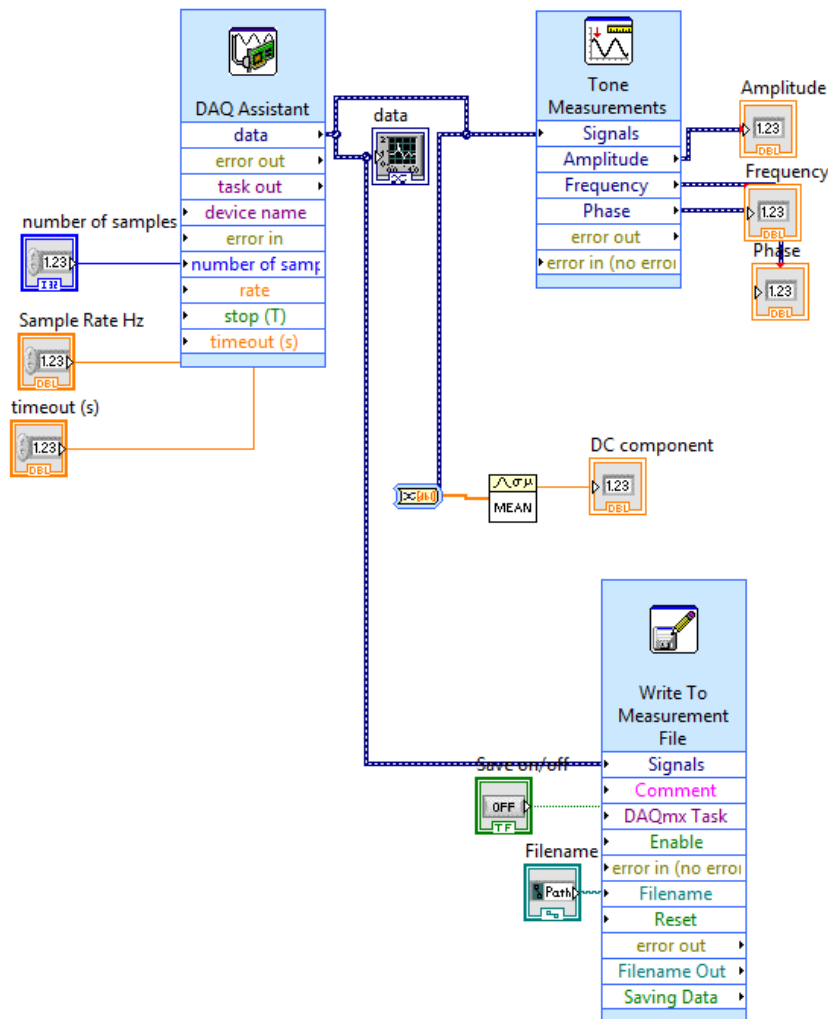


Figure 5: Block Diagram of the LabVIEW program used to analyze data.

6. RESULTS AND DISCUSSION

The lab has four different sets of data to be collected, which is shown in figures 6, 7, 8 and 9. It is collected and analyzed in the process shown in figure 3. The first set is a 120 Hz sine wave with a sample frequency of 96 samples per second; seen in figure 6. This is a representation of when the sine wave has a sampling frequency lower than the sampling theorem requirements. This results in not having the right shape of the true sine wave, as well as having an alias frequency in the data. The second set is a 120 Hz sine wave with a sample frequency of 240 samples per second; seen in figure 7. This is a representation of the minimum acceptable sampling frequency. The graph is correct for the frequency, but does not have the shape of the actual signal, and does not have an alias frequency. The third set is a 120 Hz sine wave sampled at 12000 samples per second; as seen in figure 8. This allows for a good representation of the analog signal to finally be seen in the graph. The sample rate is much higher than the minimum sampling frequency required by the theory, allowing for a very accurate digital signal of the analog signal to be graphed. The fourth set is a 120 Hz square wave sampled at 12000 samples per second, seen in figure 9. This is like the sine wave a very accurate analog signal, but in the square form vs sine.

The results of the square wave were imported to Excel to calculate the total uncertainty. Using equations 7 and 8 with 301 sample points from the data the total uncertainty was found. The average, standard deviation, $T_{v,95\%}$ value, and the random standard uncertainty must be found Excel has these functions built in. The systematic error must be found using equations 5 and 6. Using the 5 nominal range, with a change in temp of 5 degrees, the gain error was found to be 235 (micro-volts) and the offset error was 396 (micro-volts). By using equation 8 the systematic uncertainty was found to be 0.003411 (volts). To find the total systematic error, these values must be combined using the Root-Sum-Squares method. Combining the errors in this manner resulted in a total systematic uncertainty of 0.006884888 (volts). This uncertainty would be much lower if a larger number of samples would have been used. The complete uncertainty equation for the amplitude of the square wave can be expressed as $3.785702437 \pm 0.006884888$ (volts). The rise time for the square wave will only be as accurate as the sample size allows. The delta time between low and high samples for the data was 8.33E-05 seconds.

	f_s	N	f_m	Amplitude	Mean	Phase
120Hz Sine	96Hz	25	23.8118	3.79174	-0.03	194.215
120Hz Sine	240Hz	15	127.973	3.792917	-0.28	-179.694
120Hz Sine	1200Hz	300	119.827	3.81737	-0.02	-241.993
120Hz Square	1200Hz	300	120.048	4.8213	0.01	-5.44

Table 1: The first measurement of the analog signals at of the following graphs.

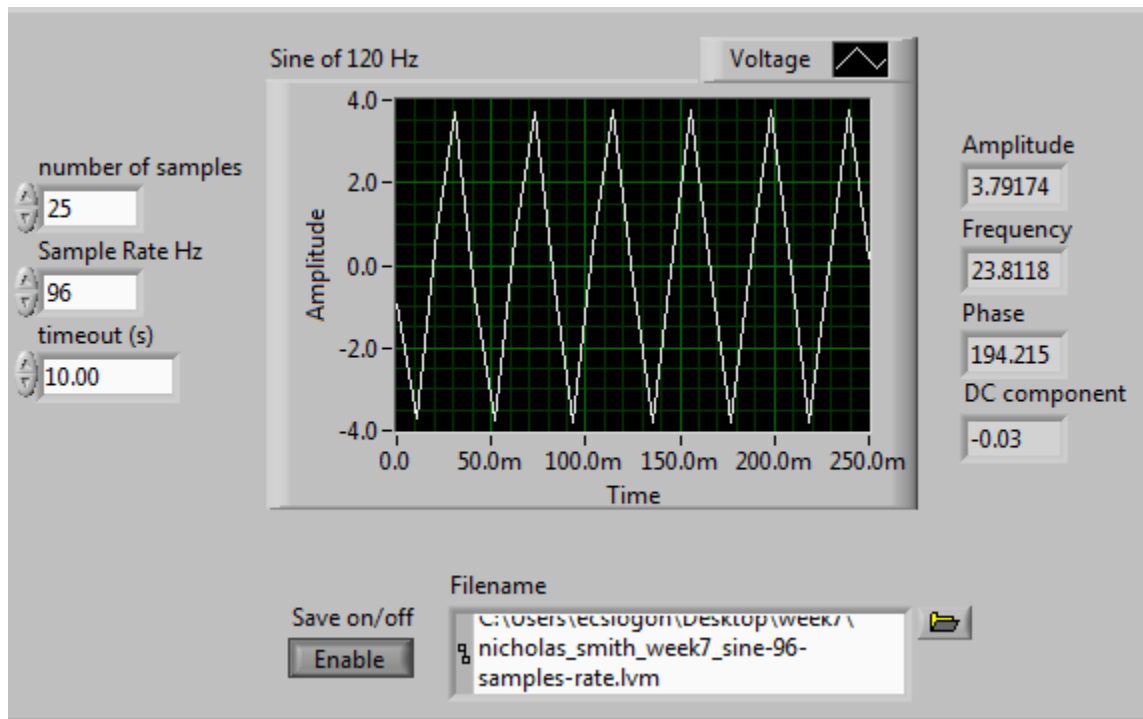


Figure 6: 120Hz sine wave at a sampling rate of $f_s = 96$ samples per second.

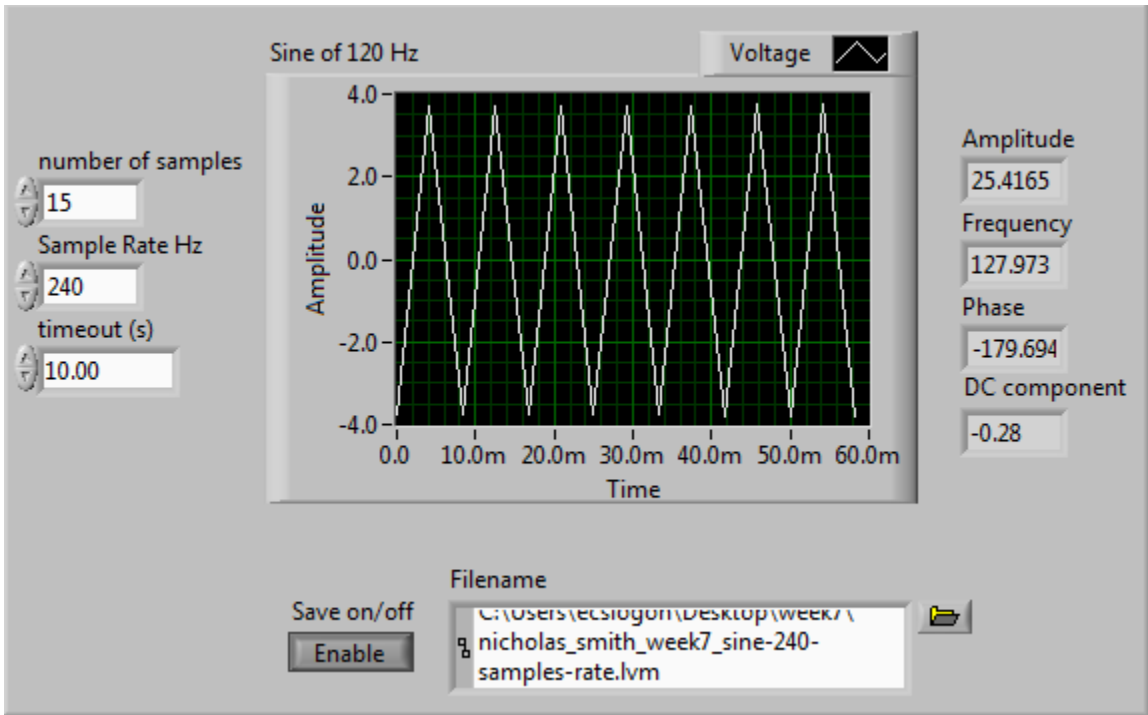


Figure 7: 120Hz sine wave at a sampling rate of $f_s = 240$ samples per second.

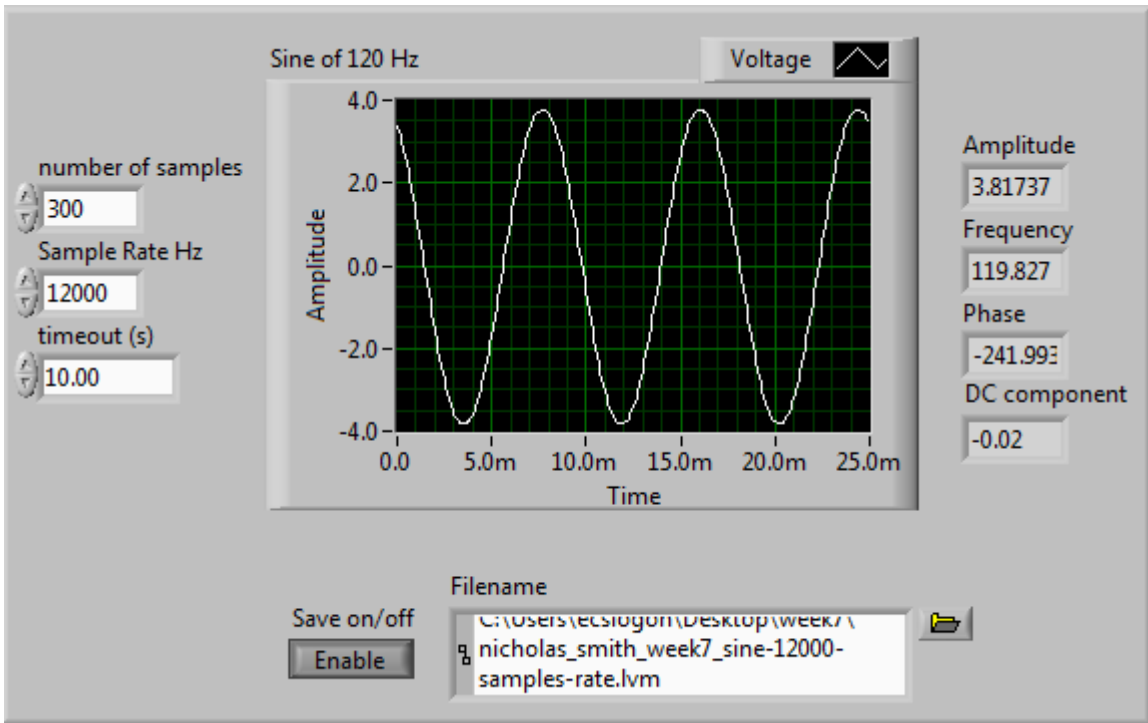


Figure 8: 120Hz sine wave at a sampling rate of $f_s = 12000$ samples per second.

Max: 3.756782 Min: -3.82018; acquired form data output.

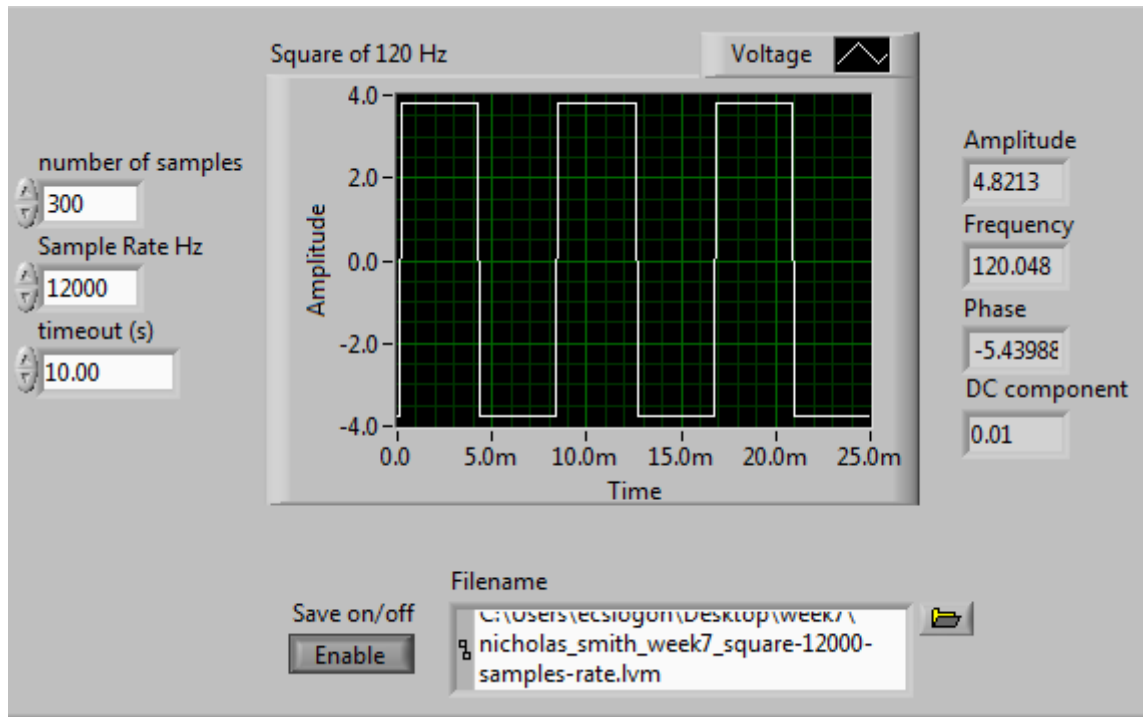


Figure 9: 120Hz square wave at a sampling rate of $f_s = 12000$ samples per second.

Max: 3.801241 Min: -3.77994; acquired form data output.

8. CONCLUSIONS

The objective of this experiment in the lab was to learn the effects of sample rates and data acquisition by using LabVIEW. Data acquisition of an analog signal by collecting points and combining them to approximate the waveform, frequency and amplitude. The lab also demonstrated the importance of the Nyquist frequency to avoid having alias frequencies in the data, some data is lost in the process. A waveform generator, data acquisition card and the computer were used to acquire the data that is analyzed by LabVIEW. Aliasing occurred in the waveforms with low sample frequencies, which can be seen in figures 6 and 7, because the sampling rate was too slow. However, using a sampling rate much higher than the Nyquist frequency gave very accurate data results. The uncertainty of results in experiments were calculated with the uncertainty of the measurements from the devices.

REFERENCES

1. Laboratory Manual, Week 6 Lab: Data acquisition, Dr. Yang, Wright State University 2015
2. Sections 1 and 2 of Chapter 7 of Figliola, R. S. and Beasley, D. E, *Theory and Design for Mechanical Measurements*, 5th Edition, Wiley, 2011
3. LabVIEW Help
4. Equipment Manuals, Dr. Yang, Pilot, Wright State University 2015

APPENDIX

Measured data available upon request.

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