

# Frequency Analysis

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## Instructor's Portion

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### Summary

One of the more difficult concepts of mathematics is the conversion from one independent variable or domain to another. While the natural inclination of most humans is to think in the *time domain*, many everyday applications require looking at the response of a system in the *frequency domain*. Examples that require this type of conversion are everywhere; this lab uses the most common example of sound waves.

In the first part of the lab, students collect data using LabVIEW and learn how to calculate the power spectrum of a signal using a spreadsheet program (Microsoft Excel). The later part of the lab is a chance for students to experiment with different sound sources and see what the power spectra of complex non-periodic signals look like. The overall educational goal is to get students to the point where they can analyze the frequency spectra for a given signal.

An element missing from this lab is phase analysis. Because the lab uses the power spectrum, the phase information is lost and not analyzed.

### Uses

This lab has applications in mechanical engineering, electrical engineering, and physics.

### Equipment List

- Computer running Windows, Macintosh, Linux, Sun, or HP-UX (visit [http://www.ni.com/labview/lv\\_sysreq.htm](http://www.ni.com/labview/lv_sysreq.htm) for requirements specific to your operating system). Make sure your computer has either a CD drive or a sound card for playing sound files.

- Breadboard Connector Starter Kit from National Instruments (part number 777448-40)
  - LabVIEW Full Development System
  - PCI-6024E Data Acquisition Board
  - SC-2075 Breadboard Connector
  - SH68-68-EP Shielded Cable
- Function generator (i.e. BK Precision 3011B).
- BNC-to-BNC cable for connecting the function generator to the SC-2075 Breadboard Connector.
- Speakers with individual wires (i.e. stereo speakers) for easy connection to the data acquisition system. Most computer speakers have a connection jack that is difficult to connect to the data acquisition system so if your speakers have a connection jack you will need to strip the wires.
- Websites
  - BK Precision — [www.bkprecision.com](http://www.bkprecision.com)
  - National Instruments — [www.ni.com](http://www.ni.com)

## Setup

In this lab, the students need to sample either a \*.wav file or a song from a CD. A possible variation on this is to have the students sample their voice instead. To implement this variation, you will need to provide a microphone instead of the speakers listed in the equipment list, and consequently you should alter the setup, pre-lab preparation, workstation details and lab procedure to reflect this change.

Follow the steps listed to prepare the workstations for this experiment. The instructions assume you are using the equipment list shown previously.

**Note:** Most of the manuals that are referred to ship with National Instruments hardware and software. If you can't find your hardcopy of the manuals, you can get them online at <http://www.ni.com/manuals>. If you encounter problems during setup, contact technical support at <http://www.ni.com/support>.

### Before the Day of the Lab

1. Install LabVIEW (see the *LabVIEW Release Notes* for your version of LabVIEW).
2. Install your PCI-6024E board (see the *6023E/6024E/6025E User Manual*).
3. Configure the SC-2075 Breadboard Connector (see the *SC-2075 User Guide*).
4. Cable the PCI-6024E to the SC-2075 with the SH68-68-EP.
5. Configure the PCI-6024E board (See the *NI-DAQ Release Notes* for your version of NI-DAQ).
6. Create the following directory in your LabVIEW folder:  
\\LabVIEW\Experiments\Frequency Analysis
7. Copy **Frequency Analysis.llb** into the Frequency Analysis folder you just created.
8. Connect the stripped speaker wires from LINE OUT of the computer to CH0+ and CH0- (binding posts labeled floating differential analog inputs) on the SC-2075 Breadboard Connector.
9. Connect the speakers to SPEAKER OUT on the sound card for listening to the sound source.
10. Conduct a run-through of the lab procedure the students will perform.

### On the Day of the Lab

1. Power up the computers.

## References

- Wheeler, Anthony J. and Ganji, Ahmad R. (1996), *Introduction to Engineering Experimentation*, Prentice-Hall Inc. Englewood Cliffs, NJ.

## Student's Portion

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### Introduction

Your overall goal for this lab is to gather power spectrum data for several signals using two different techniques. One technique uses a LabVIEW VI to output the sample data from a given waveform to a file that can be read

by Excel. You will then use Excel to calculate the Fast Fourier Transform and power spectrum for the data. The other technique uses a LabVIEW VI that will do most of the work for you and output a file containing the power spectrum for several sampled waveforms.

## Objective

- To demonstrate the ability to measure frequency using Fourier transforms and the power spectrum.
- To analyze complex waveforms in the frequency domain.

## Theory

The first frequency measurement method you may think of is to measure the period (or time between peaks) of the waveform of interest. This method works, but there are two problems. First, you have measured the period of only one waveform cycle. Second, you must have a very fast timer to measure the waveform period accurately. This means that the fastest frequency you can measure is much slower than the speed of the internal timer.

Another method of measuring frequency is to count cycles of the signal of interest for a fixed period of time. This gives you an average frequency. Your timer need not be as fast as the signal you are measuring. In fact, it can be orders of magnitude slower. However, you will need a counter that can operate at the highest frequency you can measure. This is how frequency counters operate. You also need a zero cross detector. The *zero cross detector* is a circuit that gives a digital pulse whenever the incoming signal changes from a positive voltage to a negative voltage (or vice versa). Some detectors give a pulse on both edges. This discussion won't get into the details of operation of this type of circuitry.

Instead, we will consider a third method that requires you only to sample (perform A/D conversion) at twice the frequency of interest at regular intervals. You can use this last method of frequency measurement for periodic and aperiodic complex signals. This method takes the Discrete Fourier Transform (DFT) of the signal to determine the frequency components present in the signal. The DFT transforms the signal from the time domain to the frequency domain. In the frequency domain, you can look at information such as relative amplitudes of different frequency components and the relative phase. Details on the DFT can be found in Chapter 5 and Appendix A of the Wheeler and Ganji text. The calculation method employed here is called the Fast Fourier Transform (FFT). The FFT is simply a quicker way to calculate the DFT. To use the FFT, you must have exactly  $2^N$  data points, where  $N$  is a positive integer. One of the

LabVIEW VIs for this experiment, **Sound Power Spectrum.vi**, uses the FFT to determine the *power spectrum*. A graph of the power spectrum indicates the amplitude of the signal as a function of frequency without any information regarding the phase relationships. In this lab, you will find the power spectrum of several different signals using a LabVIEW program. You will also sample a single waveform of each of those signals and calculate the FFT and power spectrum using Excel.

## Pre-Lab Preparation

- Read through the theory section from this experiment.
- Read Sections 5.2 through 5.4 of *Introduction to Engineering Experimentation* by Wheeler and Ganji.
- Bring .wav file or CD to lab.
- Bring at least two virus-free blank floppy disks to lab.

## Workstation Details

- Computer with National Instruments LabVIEW software.
- National Instruments DAQ board (inside the computer).
- National Instruments SC-2075 Breadboard Connector (outside the computer).
- A function generator.
- BNC-to-BNC cable.
- A speaker.

## Lab Procedure

The following two sets of procedures use the FFT for frequency measurement. You must complete Part 1 before performing Part 2. The purpose of Part 1 is to help you learn about calculating Fourier transforms and the power spectrum. Part 2 allows you to capture several power spectra for different sound sources quickly.

### Part 1

This section of the lab helps you to learn how to collect data using LabVIEW and calculate the FFT using Excel.

### Setup

1. Launch LabVIEW.
2. Open **Capture Waveform.vi** located in **Frequency Analysis.llb** in the \\LabVIEW\Experiments\Frequency Analysis folder.
3. Set the parameters of the VI as shown in Table 1. Remember that the **Sample Size** must be set to a power of 2! You will need to determine values for the **Sample Rate** and **Voltage Range**. When setting the **Sample Rate**, think about the input frequency you are using and make sure your measurements follow the Nyquist theorem: sample rate > 2\*frequency.

Table 1. Parameters to set on the LabVIEW VI

Item	Value
Channel to Read	1
Sample Size	2048
Voltage Range	As small as possible, but still able to read the signal
Sample Rate	Adjust to follow the Nyquist criteria

4. Connect the function generator output to analog input channel 1 (BNC connector under Floating Differential Analog Inputs labeled CH1) on the SC-2075 Breadboard Connector.
5. Use a sine wave on the function generator for all measurements.
6. Run the **Capture Waveform VI**.

### Taking Measurements

The **Capture Waveform VI** will allow you to capture different waveforms and put them into individual files. The following leads you through the steps of gathering a waveform. Each individual student must gather at least one waveform for a single sine wave. Each student must choose a unique frequency and sample rate. The signal must be sustained for the full acquisition time of the VI.

1. Select and set a frequency on the function generator. Each group member should choose different frequencies. Record the frequency you choose in the appropriate table on your data sheet.
2. Press **Acquire Data Block** on the VI.
3. Inspect the waveform to make sure it was captured properly.

4. Save the waveform to a file using the **Save Waveform** button. DO NOT stop the program until you are completely done. Save each person's waveform to a different file. Does your sample look like a sine wave? Why or why not?

### Calculating the Fourier Transform and Power Spectrum

1. Import the data file (text formatted) into Excel.
2. Save the file as an Excel Workbook.
3. Add three columns labeled Frequency, FFT, and Power Spectrum to the right of the imported data.
4. In the Frequency column, enter numbers that start at 0 and increase by a number equal to the reciprocal of the **Acquisition Time** for the entire length of the column. Do this by actually calculating the acquisition time and its reciprocal in Excel. Put a zero in the first row in the Frequency column, then for each cell in the column add the calculated acquisition time to the value for the cell above. You need all the significant digits you can get, and just typing in 7 or 8 is not sufficient.
5. Use the **Data Analysis** tool (on the **Tools** menu) to calculate the FFT. Choose the **Fourier Analysis** tool from the Data Analysis window. The input range is the data samples and the output range is the column labeled FFT. **You must select a number of cells that is a power of 2 for both the input and the output.**
6. Finally, insert the following function in the Power Spectrum column where **cell** is the FFT value in the same row. The IMABS function in Excel takes the absolute value of a complex number. Then plot the power spectrum vs. frequency. Plot the entire data set.  
$$=IMABS(FFT\ cell)^2/(Sample\ Size)$$
7. Show your power spectrum vs. frequency plot to your instructor and have them initial your data sheet.

### Part 2

In this portion of the lab, you will take several samples of the same sound. You may bring a \*.wav file or a CD to the lab for this portion. It is best if you can sample the *exact* same sound several times for comparison.

### Setup

1. Open **Sound Power Spectrum.vi** located in **Frequency Analysis.llb** in the \\LabVIEW\Experiments\Frequency Analysis folder.

2. Set the parameters of the VI as shown in Table 2. Remember that you must have the number of samples set to a power of 2! When setting the **Sample Rate**, think about your input and the Nyquist theorem: sample rate  $> 2 \times$  frequency.

Table 2. Parameters for Taking Data in Part 2

Item	Value
Channel	0
Sample Size	4096
Voltage Range	As small as possible and still able to read the signal
Sample Rate	44,100 samples per second is a good value for audio (obey the Nyquist Theorem)

3. A speaker is connected to voltage input channels CH0+ and CH0- of the SC-2075 Breadboard Connector from LINE OUT of the computer, and to SPEAKER OUT on the sound card for listening to the sound source.
4. Run the **Sound Power Spectrum VI**.

### Taking Measurements

The **Sound Power Spectrum VI** will allow you to capture different waveforms and place them into a single file. The sound must be sustained for the full acquisition time of the VI.

1. Now you will sample your sound source. Try to sample the same point on the sound source each time.
  - a. Start the sound source (either the \*.wav file or CD you brought with you to lab).
  - b. Press **Take a Sample** on the **Sound Power Spectrum VI**.
  - c. When the VI finishes acquiring the waveform, stop the sound source.
  - d. If the waveform is acceptable, press the **Keep Data** button to save the power spectrum data to an internal array.
2. **Repeat step 1 at least three times for each sound source.**

3. Save the power spectrum data to a file using the **Save to File and Quit** button.
4. Record the information you will need to retrieve the data in the appropriate table on your data sheet.
5. Restart the **Sound Power Spectrum** VI for each person in the group. Each person in the group must gather three samples of his or her own individual sound source. Save each person's waveform to a different file. Note that the power spectrum is already calculated for you. The file will contain a frequency column and three power spectrum data columns.

## Lab Report

You must include the following in your lab report:

- Typed and formatted tables describing the data taken. Use the format from the data sheets. These should be very detailed.
- A table of representative data from the first part of the lab (one full page is sufficient; an entire data set is not necessary).
- A description of the power spectrum calculation process from Part 1 of the lab. Describe the process using Excel and how it relates to the theory of Fourier analysis.
- Power spectrum plots for data from Part 1 of the lab, one plot for each frequency. You should have one plot per person. The y-axis should be a log scale.
- A power spectrum plot of each waveform taken in Part 2 of the lab. Be careful with units and labeling axes. You should place different data series of the same sound source on one graph, so that each person will have one plot. Describe with some detail each sound source sampled. Comment on why the waveforms on one graph may look slightly different from each other even though they are from the same source.
- Discussion of any problems that occurred in taking data and the solutions used to solve the problems.
- Your data sheet stapled to the back of your report.

## Data Sheet

1. Does your sample from Part 1 look like a sine wave? Why or why not?
  
2. What is the minimum frequency you can sample at to accurately analyze a waveform with frequency components as high as 1000 Hz?
  
3. Is each sample of Part 2 unique in some way? Explain how and why.

### Table for Part I

For both parts of today's lab, you need to record the name of the waveform and file for each measurement. The following is a table for recording the frequency of the function generator for Part 1 of the lab. Each person should use a different frequency. Your instructor will initial this part when you have displayed a graph in Excel of the Power Spectrum column vs. the frequency column for at least one waveform. If you have only one function generator for each pair of stations, you will need to coordinate efforts with another group. Both groups can use the same set of frequencies.

Team Member Taking Measurement	Frequency of Input	Filename	Sample Size	Sample Rate

Instructor's initials \_\_\_\_\_

**Table for Part 2**

Record in the following table the information you will need to retrieve the data from Part 2. This time, you should record a description of the input instead of the frequency.

Team Member Taking Measurement	Description of Input	Filename	Sample Size	Sample Rate

Instructor's initials \_\_\_\_\_

Make sure all your data is readable and safely stored before you leave the lab. Lost data is not an excuse for not finishing your report.