

# Waveform Measurements

(Adapted from National Instruments' Lab exercises for LabVIEW; Danial J. Neebel, Joseph R. Blandino, and David J. Lawrence, College of Integrated Science and Technology, James Madison University). Use as a REFERENCE

## Instructor's Portion

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### Summary

This lab illustrates the importance of different laboratory instruments and the different ways of measuring the same type of signal. A strong point in this lab is to try and make some measurements that cannot be made with the equipment available. This is so that students can see the limitations of the equipment. The students will be testing the functionality of a digital multimeter, digital oscilloscope, function generator, and a LabVIEW VI, **Frequency Counter.vi**.

### Uses

This exercise has applications in 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)
- 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
- A function generator (i.e. BK Precision 3011B)
- A digital oscilloscope (i.e. Tektronics TDS-220)
- A digital multimeter (i.e. BK Precision 388A)
- Cables for connecting the previous equipment together, such as:

- Two banana-to-alligator clips
- A BNC-to-BNC cable
- A BNC-to-banana converter
- Websites
  - BK Precision – [www.bkprecision.com](http://www.bkprecision.com)
  - Tektronics — [www.tek.com](http://www.tek.com)
  - National Instruments — [www.ni.com](http://www.ni.com)

## Setup

You do not need one of everything at each station. For example, you could have DMMs at half the stations and digital scopes at the other half of the stations. Students can then “swap” stations halfway through. Follow the steps listed to prepare the workstations for this experiment. The instructions assume you are using the equipment list shown previously.

The chosen digital multimeter cannot measure the voltage of an AC signal below about 10 Hz. The LabVIEW **Frequency Counter** VI is limited to a range of about 0.1 Hz to roughly 20 kHz.

**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. Connect the BK Precision 388A OUT to CH0+ and CH0-, with respect to red for positive and black for negative, on the SC-2075 Breadboard Connector with a BNC-to-Banana cable.
7. Create the following directory in your LabVIEW folder:  
\\LabVIEW\Experiments\Waveform Measurements
8. Copy **Waveform Measurements.llb** into the Waveform Measurements folder you just created.
9. 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.
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## Student's Portion

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### Introduction

In this experiment, you will make multiple measurements of one signal using different types of instruments. Engineers and scientists use different types of instruments to measure different aspects of an input signal. You will measure the shape of the waveform, the frequency, the period, and the voltage level. Shape is a qualitative measurement, and the remaining measurements are quantitative. Recall that the period and frequency are reciprocals of one another. This means that you can measure one and calculate the other. Whenever possible, you will measure them directly.

On the surface, it appears that the simplest item to measure today is the voltage level. That is not quite true. Voltage level is not always a single fixed value. For time-varying signals, it matters just how and when you measure the voltage level. You can measure voltage at a single point in time, average several points, or perform a Root Mean Square (RMS) measurement. Root mean square means the instrument takes the *mean* of the *square* of the voltages and then takes the square *root* of that value. When the digital multimeter measures an AC voltage, it finds the RMS value of the voltage.

The instruments used in this lab exercise are a digital oscilloscope, a frequency counter, and a digital multimeter. You will measure the same signal using all of the instruments. The lab procedure outlines the steps necessary to read each value from the specified device. If you find the procedures a little vague, experiment with settings until you get the reading you are looking for.

### Objective

- To perform waveform measurements with a digital oscilloscope, a frequency counter, and a digital multimeter.
- To demonstrate measurement of waveform shape, period, frequency, and voltage level using different tools.
- To compare the measurements of the signal quantities made by different methods.

## Theory

### Oscilloscopes

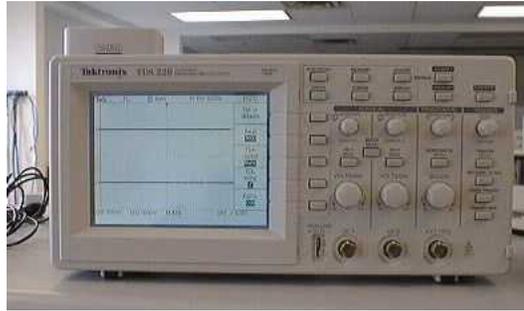


Figure 1. Tektronix TDS 220 Digital Oscilloscope

Oscilloscopes provide a graphical view of the voltage at the probe with respect to time. The graph is a grid of squares called “divisions” because the grid divides the screen into squares. You can change the vertical scale by changing the number of *volts per division* and change the horizontal scale by changing the *time per division*. Oscilloscopes typically come with two channels displayed with the same horizontal scale, but separate vertical scale adjustments. This only scratches the surface because oscilloscopes (especially digital scopes) have a host of other features, but the features presented are the most critical.

You can measure the period and peak-to-peak voltage of a waveform using the oscilloscope. From the period, you can calculate the frequency; from peak-to-peak voltage, you can calculate the RMS voltage by knowing the shape of the wave. You can find the RMS voltage of a sine wave by multiplying by the square root of two. You should try to determine how to find the RMS value for a triangle wave and a square wave before coming to lab.

### Digital Multimeters

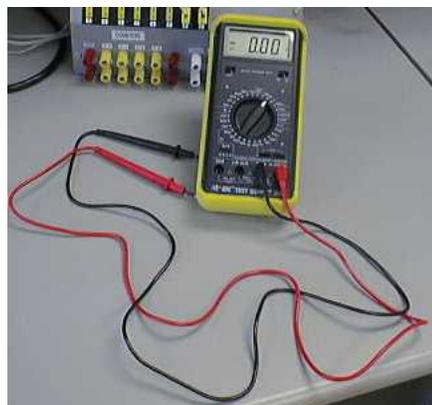


Figure 2. BK Precision 388A Digital Multimeter

Not that long ago, digital multimeters (DMMs) were high-priced and under-featured tools that did little more than their analog counterparts (measure voltage, current, and resistance). Today, DMMs range from inexpensive pocket models with the basic features to graphing versions that look and operate very much like a hand-held oscilloscope! The BK Precision 388A shown in Figure 2 has several features that you can explore in this lab. You will use your digital multimeter to measure AC voltage, DC voltage, and frequency. Most importantly, you will learn about the limitations of digital multimeters.

### Function Generators



Figure 3. BK Precision 3011B Function Generator

The function generator shown in Figure 3 outputs a single frequency waveform. The three types of waveforms available are a sine wave, a triangle or sawtooth wave, and a square wave. These waves are named for their shape. The range of frequencies is from 0.5 Hz to 19,000 Hz.

### Frequency Counters

The concept of a frequency counter is simple: Hook it up to your system and it tells you the frequency of the signal—nothing more, nothing less. The front panel for a simple LabVIEW **Frequency Counter** VI is shown in Figure 4. How it operates behind the front panel is also simple. The DAQ system converts a periodic waveform to a sequence of pulses, one pulse for every rising edge that crosses the zero voltage point. Then a counter counts these pulses for a specified period of time. Knowing the *pulses per time period*, the counter can easily calculate the *cycles per second* and display the frequency. The user usually must specify the *time period* for counting. This time period is called the *gate time*.

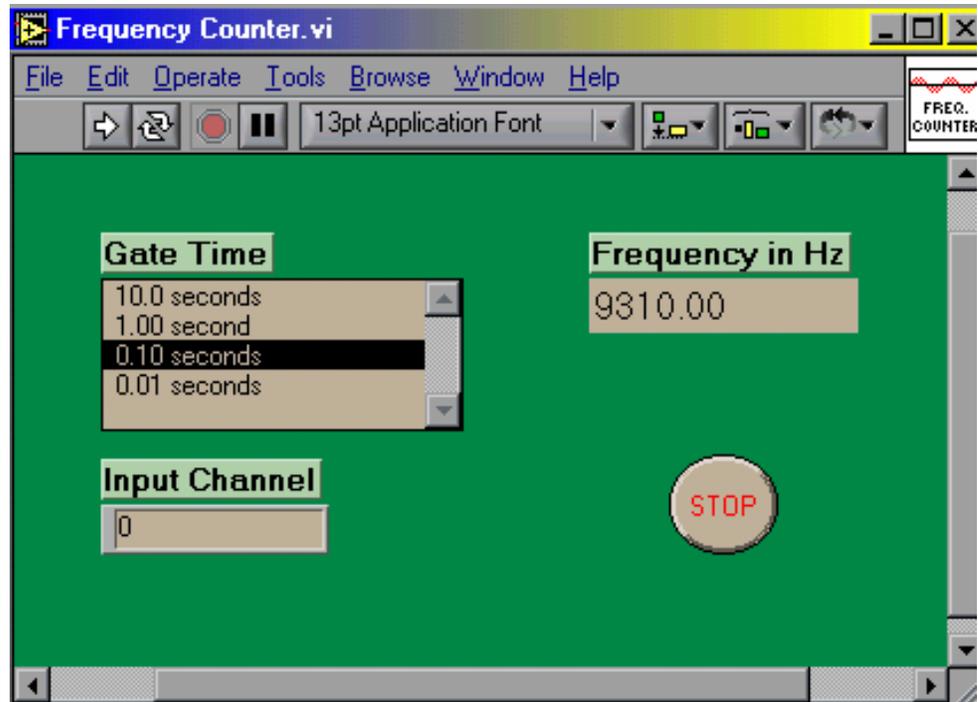


Figure 4. Front Panel for Frequency Counter VI

In the **Frequency Counter** VI, the frequency is always given in Hertz with two decimal places to the right of the decimal point. Because the display is constant, not all of the digits displayed are significant. That is, the resolution of the display does not always match the reading resolution.

## Pre-Lab Preparation

- Read through the theory and lab procedure for this experiment.
- Bring the following to lab with you:
  - This experiment.
  - Your lab notebook and pencil.
  - A virus-free formatted 3.5-inch floppy disk.

## Workstation Details

Your workstation should have the following items:

- A computer with National Instruments LabVIEW software
- National Instruments DAQ board (inside computer).
- National Instruments SC-2075 Breadboard Connector.

- A function generator (the BK Precision 3011B)
- A digital oscilloscope (the TDS-220)
- A digital multimeter (the BK Precision 388A) with a frequency readout and probes
- Cables for connecting the previous equipment together, such as:
  - Two banana-to-alligator clips
  - A BNC-to-BNC cable
  - A BNC-to-banana converter

## Lab Procedure

In this lab, you will measure waveform shape, frequency, period, and voltage levels (peak, AC, and DC) using multiple instruments. Whenever possible, measure the quantity directly. If direct measurement is not possible, calculate the value. If neither of those is possible, indicate that the parameter cannot be measured with the device.

The following sets of procedures are for each instrument. It is assumed you have some basic knowledge of waveforms and voltage measurements. You should measure the first parameter with each instrument before moving on to the second parameter. That is, measure waveform shape with each instrument, and then measure frequency with each instrument, then measure period, etc.

### Lab Equipment Inventory

1. Record the following information for all of the measurement devices at your station:
  - Name and device type (what is it?)
  - Manufacturer and model number
  - Input voltage range (if available)
  - Frequency input range (if applicable)
  - Period timing input range (if applicable)
2. Record the following information for the function generator you are using:
  - Name and device type

- Manufacturer and model number
- Range of frequencies for generated signals
- Types of signals available

### Overall Process

Because the major goal of this lab is to give you some background in using various pieces of equipment for measuring electrical signals, the lab procedure is not laid out step-by-step. Instead, the procedures give you some information about how the equipment works and what measurements to take. Read through the entire process and do your best at learning the equipment on your own. If you still need assistance, ask your instructor.

Next is a description of the overall process of taking data for this lab exercise. Following this general process description are descriptions for operating individual pieces of equipment, such as the frequency counter.

1. Set the function generator to output one of the following waveforms. By the end of the experiment you will have taken measurements with each waveform:
  - 1,000 Hz sine wave
  - 20,000 Hz square wave
  - 0.1 Hz triangle wave
  - 100 Hz triangle wave
  - 2 MHz sine wave
2. Take and record measurements using each of the following devices.
  - LabVIEW **Frequency Counter VI**
  - Oscilloscope
  - Digital multimeter

The data sheet contains a column for each device. Record the values for each parameter listed on the sheet. Indicate in the “M” column whether you measured the value directly or indirectly or if the parameter cannot be measured at all. Use “D” for a direct measurement, a “C” for calculated values, and an “X” if the parameter can’t be measured.

3. Check to make sure the measurements for all devices agree with one another. Note whether any measurements seem to disagree and make a

decision whether to redo the readings later. (Do NOT redo the readings at this point.)

4. **Demonstrate taking a reading for your instructor.** Have your instructor check your data, and initial your data sheet.
5. Repeat steps 1, 2, and 3 for each of the five waveforms listed in step 1.

## Procedures for Specific Devices

### Frequency Counter VI

The frequency counter lets you measure only frequency. No other parameters are available. Below are the steps required for taking a frequency measurement. Read through them carefully and do not be afraid to try things on the device. If you have a question after trying things on your own, ask your instructor.

1. Launch LabVIEW.
2. Open **Waveform Measurements.llb**. The file is under \\LabVIEW\Experiments\Waveform Measurements on your computer.
3. Make sure the value of the **Input Channel** parameter (default value = 0) for the **Frequency Counter VI** matches the channel on the SC-2075 Breadboard Connector that the function generator is connected to.
4. Start the **Frequency Counter VI** by clicking on the Run button.
5. Turn on the function generator.
6. The **Frequency Counter VI** allows you to measure the frequency of the input signal directly. The hardest part is to find a range that allows you to record the highest number of significant digits (highest resolution). Frequency counters and function generators often have a series of push buttons or a selection knob for selecting a gate time. This selection tells the counter how long to count pulses. If the device counts the number of pulses that occurred within a specific time period, it can calculate the frequency in Hertz (pulses per second).
  - a. Select the shortest gate time and check (do not record) the reading.
  - b. Select the next highest gate time and see what readings you get. Try all of the possible gate times. Record the value with the highest resolution. Remember that the display resolution does not necessarily match the actual resolution.

## Oscilloscope

1. Find the power switch for the oscilloscope. Turn on the oscilloscope.
2. Connect the OUT of the function generator to the IN of the oscilloscope with a BNC-to-BNC cable.
3. Check the period and peak voltage of the signal from the function generator using the oscilloscope.
  - a. Switch to AC mode.
  - b. Adjust the Volts/Division setting so that the waveform is clearly displayed on the screen. The waveform should be as large as possible and still be completely displayed on the screen.
  - c. Adjust the Time/Division setting so that you can see at least one complete period of the waveform clearly. Use the largest Time/Division setting so that one complete period is as large as possible.
  - d. Switch to GND mode.
  - e. Adjust the position of the line on the screen. There should be two knobs for positioning the waveform, one labeled with up and down arrows and the other labeled with left and right arrows. The line should lie directly on top of the X-axis in the center of the screen and run the entire width of the screen.
  - f. Switch to AC mode.
  - g. Count the number of horizontal divisions (boxes) for one complete period. Using the time/division setting on the scope, calculate and record the time for one complete period on your data sheet. (**Note:** If more than one complete period is displayed, you can find the time for multiple periods and then determine the average time for one period.)
  - h. Count the number of vertical divisions (boxes) from the lower peak (trough) to the upper peak of the waveform. Using the Volts/Division setting on the scope, calculate and record the peak-to-peak voltage.
4. Calculate and record the RMS value for the voltage from the above measurements.
5. Calculate and record the frequency from the above measurements.
6. Observe the voltage in DC mode. (This method does NOT actually measure the DC voltage!)

- a. Switch to DC mode.
- b. **Question:** Does the displayed waveform look like a DC voltage?
- c. Measure the peak voltage in this mode. Count the divisions between the horizontal x-axis and the upper peak. Multiply this value by two to get the “peak-to-peak” value.
- d. **Question:** Does this value differ from the value found using AC mode? Why or why not?

### Digital Multimeter

The digital multimeter (DMM) lets you measure AC and DC voltage and frequency.

1. **AC and DC voltage measurement:** Digital multimeters typically have several ranges for displaying voltage, current, and resistance data. Some meters automatically select the range to provide the highest resolution. However, the BK Precision 388A does not have this *autoranging* capability. Perform the following steps to provide the highest resolution reading:
  - a. Select the largest range for the quantity you want to measure (AC or DC voltage, current, or resistance).
  - b. Connect the leads from the multimeter to the function generator.
  - c. Decrease the range selection to the next smaller value.
  - d. Repeat step c until the display shows an “OL” (meaning overload) instead of numbers.
  - e. Increase the range selection by one step.
  - f. Read and record on your data sheet the value on the display.
2. **Frequency Measurement:** The BK Precision 388A allows you to read the frequency of the given signal. There is only one range for the frequency display. The following steps are for reading frequency.
  - a. Turn the knob on the front of the multimeter to the kHz selector.
  - b. Connect the leads from the multimeter to the signal source.
  - c. Read and record on your data sheet the value on the display.

## Lab Report

This lab report should be an informal report. The lab report will consist of the normal contents of an informal report: title, introduction, results, and discussion. The report must be typed. You should include the following in your lab report:

- Staple your data sheet to the back of your report
- Measurement data typed and formatted into tables. Use the form of the tables in the data sheet and label each table clearly in your report.
- Further discussion of any problems that occurred in taking data and the solutions used to solve the problems. In particular, discuss readings that do not agree between instruments and readings that are not correct due to limitations of the equipment.
- A comprehensive analysis of the usefulness of each instrument in reading the frequencies and analyzing the waveforms generated in lab today. Briefly state the advantages and disadvantages of each instrument when measuring waveforms. You may find a table useful for showing the differences.

## Data Sheet

Signal	Frequency Counter		Oscilloscope		DMM	
	Value, Units	M	Value, Units	M	Value, Units	M
Frequency						
Period						
Peak-to-Peak Voltage						
AC Voltage						
DC Voltage						

Signal	Frequency Counter		Oscilloscope		DMM	
	Value, Units	M	Value, Units	M	Value, Units	M
Frequency						
Period						
Peak-to-Peak Voltage						
AC Voltage						
DC Voltage						

Signal	Frequency Counter		Oscilloscope		DMM	
	Value, Units	M	Value, Units	M	Value, Units	M
Frequency						
Period						
Peak-to-Peak Voltage						
AC Voltage						
DC Voltage						

Signal	Frequency Counter		Oscilloscope		DMM	
	Value, Units	M	Value, Units	M	Value, Units	M
Frequency						
Period						
Peak-to-Peak Voltage						
AC Voltage						
DC Voltage						

Signal	Frequency Counter		Oscilloscope		DMM	
	Value, Units	M	Value, Units	M	Value, Units	M
Frequency						
Period						
Peak-to-Peak Voltage						
AC Voltage						
DC Voltage						

