ELEX 4340 : Data Communications
2013 Fall Session

Lab 5 - Signal Analysis

Introduction

This lab introduces some useful tools for signal analysis. These include: a waveform editor, numerical analysis software and a spreadsheet. These tools allow you to perform sophisticated measurements.

In this lab you will use these tools to sample three waveforms, compute their probability distributions and calculate the RMS voltages of the waveforms from their probability distributions.

Each of these tools is very flexible and their functionality overlaps. However, each program is best suited for different tasks and it's useful to be able to transfer data between them. Each program typically reads and writes a limited set of file formats. To exchange data between programs you must understand the differences between file formats and how to convert between them. You will use a program called a hex editor to examine the file contents and this will help you understand the differences between the file formats.

To become familiar with these tools you will measure the statistics of the three waveforms that can be generated by the lab's function generator: square, triangle and sine waves. You will capture these waveforms and use Matlab or FreeMat to compute histograms that estimate the probability density functions of the waveforms. You will also measure the signal powers using an RMS voltmeter. You will import the histogram data into a spreadsheet and use the spreadsheet to plot the probability distributions, compute the RMS powers from the distributions and compare them to the powers measured using the voltmeter.

Waveform Capture

The purpose of waveform capture is to sample a signal at the desired sampling rate and resolution and save the samples to a file. For low-frequency signals a computer's sound input hardware can be used. In this lab we will use the Audacity sound editor for waveform capture.

However, in most cases a digital oscilloscope would be a better option because the input levels are calibrated and it has well-defined input impedance and frequency response.

Numerical Analysis

Numerical analysis software can be used to analyze digitized signals more flexibly than is possible with normal test equipment. For example, the software can compute simple statistics (mean value, power, etc), estimate probability distributions, compute power spectra (power versus frequency), modify the signal by filtering it, compare signals (such as the transmitted and received versions), search for and count events of interest (such as errors) and many other tasks.

Numerical analysis software has extensive signal-processing and statistics libraries and support for high-level data structures such as complex vectors and matrices. This makes it possible to perform complex analyses with relatively little programming.

For this lab you can use Matlab or a free and largely compatible alternative called FreeMat.

Spreadsheets

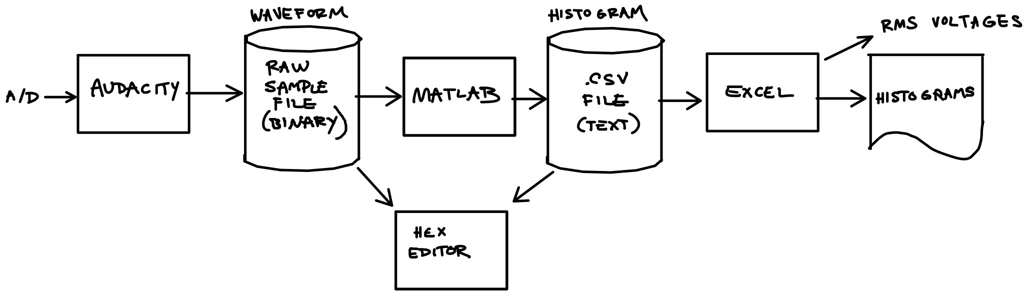
You should already be familiar with spreadsheets. They are useful for manipulating and presenting limited amounts of data and formatting numerical data for reports.

For this lab you can use Excel or OpenOffice Calc.

Hex Editor

Hex editors allow you to examine and modify the individual bytes stored in files. This provides a very flexible but low-level interface to files. You can use HxD or wxHexEditor, two free hex editors, to compare different file formats.

File Formats



Binary (Raw Data) Files

The simplest file format consists of the sample values written to a file. The user must keep track of the number of bytes per sample, the endian-ness of the data if there is more than one byte per sample, the sampling rate, duration, etc.

The term "binary" in this case simply means that the data is not in text format.

Text Files

Text files contain characters and can be read by people. For example, you can print a text file containing numbers and read the values directly.

A common text file format for exchanging data between spreadsheets uses comma-separated values (CSV). Each line of the file corresponds to one row and the values for each column are separated by columns.

Strings can also be included in CSV files by quoting them although in this lab we will restrict ourselves to CSV files with numerical values.

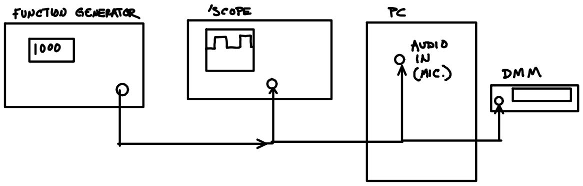
Files with Metadata

There are also many file formats that include metadata (data about the data) such as the number of samples, sampling rate, bits per sample, etc. Examples include the `.wav` file format typically used for uncompressed audio files. Although these types of files are very common we will not have time to examine them in this lab.

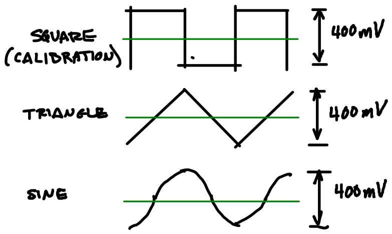
Procedure

Signal Capture

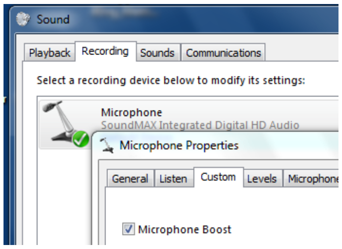
Connect the output of the function generator to both the 'scope and the voltmeter so you can view the waveform and measure it's voltage on the DMM simultaneously. Note that the Fluke multimeters in the lab are unusual in that they are RMS-responding. Most DMMs are average-responding and only measure the average value of a signal. These DMMs voltage reading only corresponds to the RMS voltage when the signal is a sine wave.



Adjust the signal generator output for a square-wave output at a 1 kHz frequency with a 200mV amplitude (400 mV peak-to-peak).



The sound input on the PC can be configured for either microphone or line-level inputs. To avoid over-driving the sound card, configure it for line-level inputs by using the Sound applet in the Control Panel (on the right column when you press the Start button the lower left of the screen). Select the Recording tab in the Sound applet, select the Microphone input and click on Properties. Under the Custom tab de-select the Microphone Boost checkbox. Click on OK to close the Properties window and OK to close the Sound window.



Select a recording device below to modify its settings:

Microphone
SoundMAX Integrated Digital HD Audio

Microphone Properties

☑ Microphone Boost

Plug in the patch cable used in previous labs to the microphone input on the front of the PC. Connect the yellow wire to ground and either of the other two wires to the signal generator output.

The additional load presented by the sound card input will reduce the signal level. Re-adjust the signal generator's output level and DC offset so that the DC voltage is zero and the (RMS) AC voltage is 200mV. For a square wave this corresponds to a 400mV peak-to-peak voltage.

Run Audacity. On the devices toolbar select "1 (Mono) Input" and then press the red record button. This will create a new mono audio track and begin recording waveform samples. Adjust the input volume control (beside the microphone icon) so that the waveform takes up about half of the total range. Leave the input volume control fixed at this level for subsequent steps.

Press Stop, delete the waveform and press Record again to create a new track. Record about 10 seconds of the waveform. At a sample rate of 44.1 kHz you will have about 400,000 samples.

Select File->Export. Choose an appropriate folder and file name (e.g. `lab5square` on your `H:` drive) and "Other uncompressed files" as the file type. Click on Options and select "RAW (headerless)" for the Header and "Signed 16 bit PCM" for the Encoding. Leave Metadata fields blank.

Change the signal generator to a triangle-wave output and check with the 'scope that the amplitude (peak-to-peak) voltage is still 400 mV. Check that the average (DC) voltage is zero. Record the meter's RMS voltage reading.

Delete the previous track, capture the triangle wave signal and save the waveform to a new file.

Switch to a sine wave signal and again check that the peak-to-peak voltage is 400 mV, measure the RMS meter reading and capture about 10 s of waveform.

You should now have three RMS voltage readings and three waveform files all captured with the same input volume control level. Each file should be about 800kB (two bytes for each of 400,000 samples).

The rest of the lab can be done without test equipment but you should try to do as much of it as possible during the lab session in case you need to repeat some of your measurements.

Waveform Analysis

Run Matlab or FreeMat. Open the waveform data file using the command:

```
fi = fopen('h:lab5square')
```

which should return a small positive value, typically 3. Read all the samples in the file:

```
s = fread(fi,inf,'int16') ;
```

print the first two sample values:

```
s(1:2)
```

and record the values. Plot the first 100 samples of the waveform to make sure you captured and have read the waveform correctly:

```
plot(s(1:100)) ;
```

Save this plot to an image file so that you can include it your report later:

```
print('h:lab5square.png')
```

Compute the scaling factor that will convert the sample values to volts by dividing the known RMS voltage by the RMS value of the sample values:

```
c=0.2/std(s)
```

Compute the histogram of the voltage waveform using the hist() function:

```
[n,v]=hist(c*s,100);
```

which will return a 100-element vector `n` with the number of samples values in each histogram 'bin' and a vector `v` with the voltages at the midpoints of each bin.

We can then export the histogram to a CSV file by opening a file for writing:

```
fo=fopen('h:lab5square.csv','w')
```

and writing the values to the file as strings separated by commas, two per line:

```
fprintf(fo,'%d, %f\n',[n,v])
```

and closing the file:

```
fclose(fo)
```

Repeat for the triangle and sine waves using the value of the scaling factor computed for the square wave (the variable c above).

File Formats

Run the HxD or wxHexEditor hex editor (you may need to install it from the course web site). Open and examine the first 16 bytes of the waveform file. Compare the hex values to the sample values printed by Matlab and answer the following questions:

- how many bytes are required to store each sample value?
- are the bytes in little-endian or big-endian order?

Use the hex editor to examine the first line of the CSV file. Answer the following questions:

- how many bytes, including control characters, are required to store each pair of values?
- are the values in little-endian or big-endian format? Explain. (*Hint: this is a trick question.*)
- what are some advantages and disadvantages of text and binary files?

RMS Calculation and Report

To compute the RMS (root mean square) voltage we must compute the mean (average) of the square of the voltage and then take the square root of the mean. In cases where different powers have different probabilities we must scale each power by the probability of that power and then compute the sum. For example, if 20% of the values had a power of 0.3W and 80% had a power of 0.2W then the average power would be $0.2 \times 0.3 + 0.8 \times 0.2 = 0.06 + 0.16 = 0.22$.

We can use a spreadsheet to do this calculation on the histogram values stored in the CSV file.

Run Excel or OpenOffice Calc. Open the CSV file (File->Open) which will result in a spreadsheet with two columns, the first with the bin counts and the second with the bin voltages.

Enter a formula at the bottom of the first column to compute the total number of samples. Add additional formulas to divide by this value to normalize the bin counts to probabilities. Then compute the square of each bin voltage and scale it by the probability of that voltage. Compute the sum of the scaled squared voltages. This is the mean square voltage. Finally, compute the square root of the sum. This is the RMS voltage of the waveform.

Repeat using the histograms for the triangle and sine waves (Data->Get External Data or Import->Sheet from File). Compare your results to the values read from the DMM.

Create a line graph (chart) with curves showing the normalized values of the sine and triangle wave histograms.

Lab Report

Create a zip file containing:

1. the three histogram files (`.csv` format)
2. the Excel (or OpenOffice Calc) file (`.xls` format)
3. your report (`.pdf` format)

and submit it to the course dropbox for this lab.

Your report should include:

- student and lab identification as described in the first lab,
- plots of the first 100 samples of the three sampled waveforms,
- answers to the questions given in the section on file formats above,
- the chart showing the three histograms as created by your spreadsheet,
- a table comparing the measured and computed RMS voltages for each of the three waveforms

Please don't show your data to other students or copy other's data. Plagiarism will result in a mark of zero for both students.