Laboratory 2 - Basics of A to D Conversion

Objective

To become more familiar with the process of data acquisition by analog to digital conversion and to explore the capabilities and limitations of A to D conversion. We will again use LabView's Virtual Bench in this experiment – selecting the virtual bench oscilloscope for capturing data. Through out the semester, you will find the VirtualScope to be a very basic tool for monitoring instrumentation signals.

Background

Data acquisition by analog to digital conversion has become the most common way (by far) to record and process laboratory measurements. In this experiment we will use a function generator to produce time varying voltage. The voltage produced by the function generator simulates the voltages produced by transducers taking measurements during experiments or by the transducers that are part of modern machines. This experiment is divided into three parts – the first part will familiarize you with the process of performing data acquisition with the Virtual Scope. The second will consider "aliasing" which refers to the time domain limitations of the sampling process inherent in A to D conversion. Finally, in the third part, we will carefully consider the issue of "quantization". This is related to precision limitations in the A to D conversion of voltage measurements.
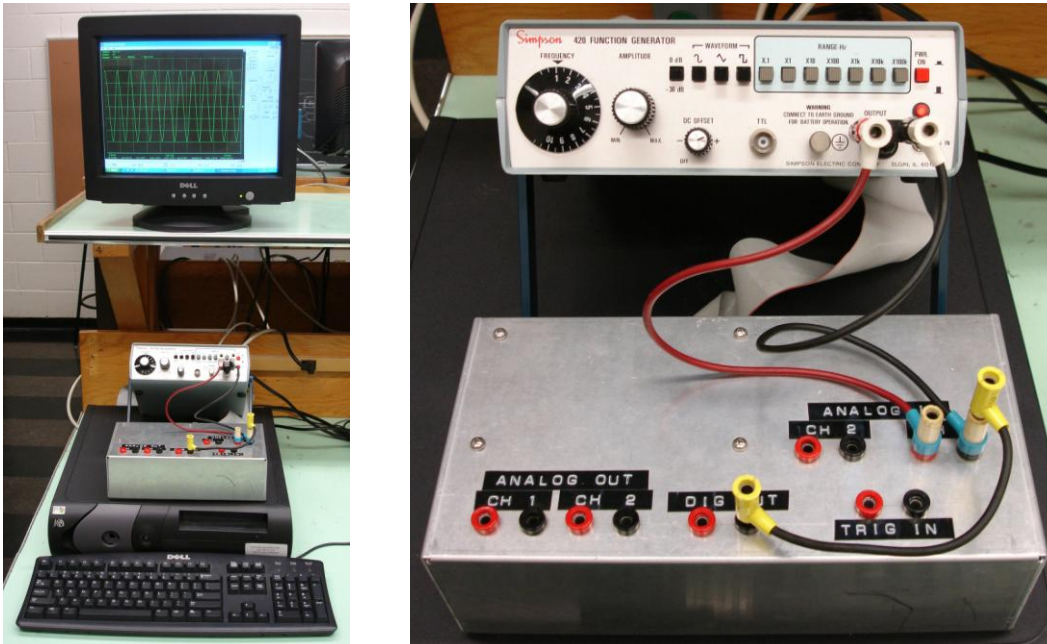

Figure 1. Setup Photo for Lab 2

Part 1 – Basic Operation of the A to D Process

1. From the desktop icon, click on the LabView Virtual Bench program.

2. When the Virtual Bench tool bar buttons appear, select the VirtualScope (the left most button).

3. When the VirtualScope window appears, resize the Scope window to properly position the graphic display and adjust the size or maximize as desired. Your display should look similar to Figure 2. Click on *Edit* and then *General Settings* to display the dialog window of Figure 3. Begin this experiment by setting the Virtual Bench Scope to have the lowest buffer size possible (500 pts, as shown). Doing this will cause any single run of the Virtual Bench Scope to plot and record 500 data points over the full scale time selected.

4. Set the oscilloscope time display and sampling speed by adjusting the time base (center knob to the right of the plot seen in Figure 2) to ten seconds full scale (one second per division). Look to the upper left just above the plot to verify your setting. It should show "1 Sec/div". Over the full scale time of 10 seconds, the 500 samples correspond to a
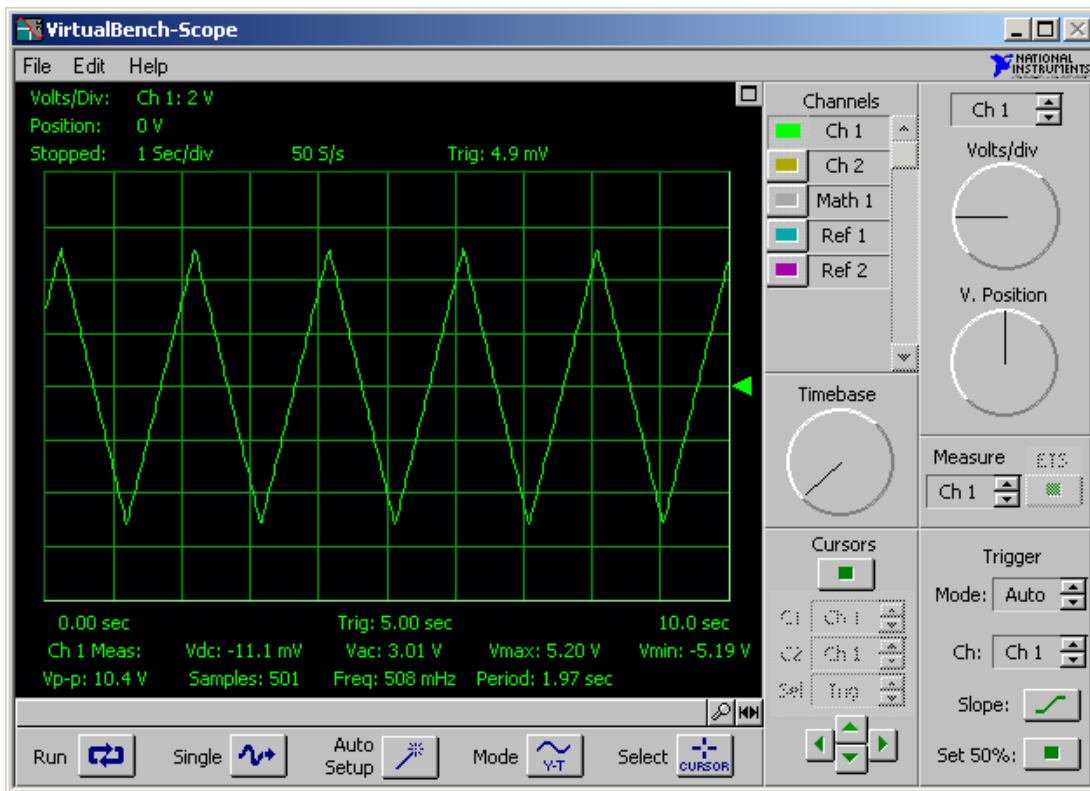

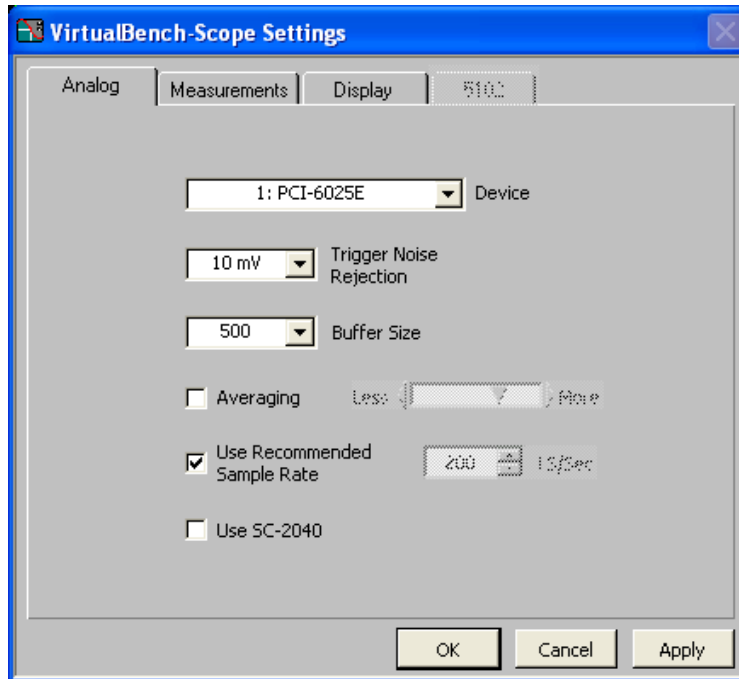**Figure 2. The Standard Display for the Virtual Bench Oscilloscope**

Figure 3. Virtual Bench *Edit - General Settings* dialog window. This is used to set the number of samples desired. The Device name may differ on some of the lab systems.

sampling rate of 50 S/s (Figure 2). This indicates that the scope is sampling at 50 samples per second (i.e., the "sampling frequency" is 50 Hz). Time, of course, is displayed on the horizontal axis.

5. Next, set the oscilloscope voltage sensitivity (the vertical axis) by adjusting the knob on the upper right to obtain 2 volts per division ("2V" as shown in Figure 2). Since the full scale range of the ADC (analog to digital converter) is +/- 10 V, setting the volts/division to 2 will nominally display the full range of the ADC.

6. Verify that the other Scope settings are as pictured above in Figure 2. Only **Ch 1** is enabled, the Measure is set to **Ch 1**, the Trigger Mode: **Auto, Ch 1**.

7. The function generator of Figure 4 can be used to produce waveforms of variable frequency and amplitude. Start, as in Figure 2, with a triangle wave, a signal frequency of 0.5 HZ and an amplitude of about +/-5 V (that is 10 volts or 5 vertical divisions from minimum peak to maximum peak). Check that the 0 dB/-30 dB push button is in, the FREQUENCY knob is at 5 and the RANGE Hz X.1 button is selected.
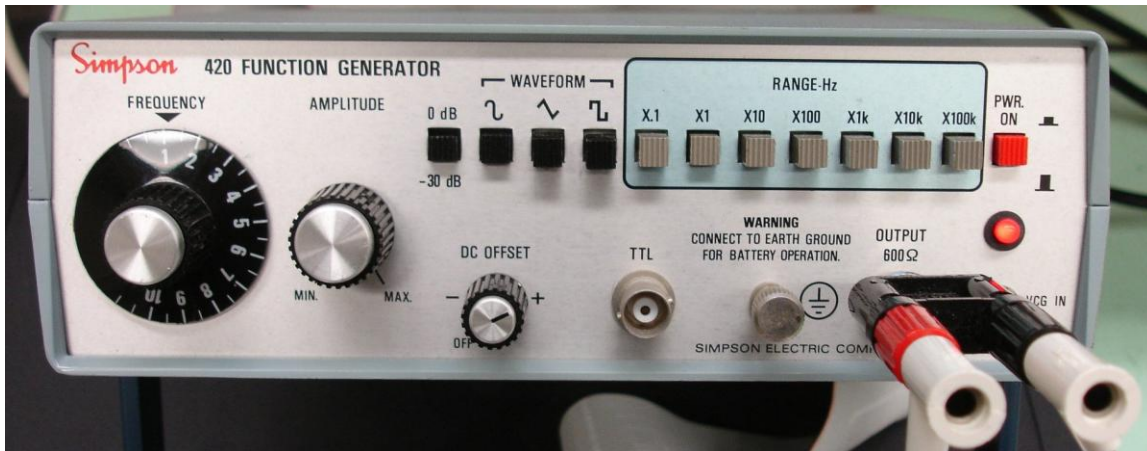
Figure 4. Simpson function generator

8. When you have a stable display, similar to Figure 2, become familiar with the overall arrangement. Change the triangle wave frequency. Adjust the voltage amplitude up and down. Try square waves and sine waves. Try a 5 volt/division scope setting. Adjust your amplitude to exceed +/- 10 volts. Activate the 0/-30 db push button. Use the scope's zoom in/zoom out buttons on the lower right of the plot to enhance the horizontal (time) resolution of the plot. Try the "Run" and "Single" buttons.

9. Return to the nominal condition described by items 5, 6 and 7 above and indicated in Figure 2. We now want to save a single data record. While the scope is running, click the "Single" button, to store a single data record of the triangular waveform of 500 points. To save this exact data record to a file, click on *File* and then *Save Waveforms* on the drop down menu. You will obtain the dialog window shown in Figure 5. The User Name and Comments fields will appear at the beginning of the saved data file. The file created by the Virtual Scope is a text file readily compatible with Excel. After you click the OK button in the dialog window, you will be prompted for a data file name and storage location. You can store it in My Documents or c:\temp or on your USB flash disk.

10. Explore your saved file with Excel. You should see each of the 500 data points, the time at which each sample occurs and the voltage measured for each sample. Use Excel "x/y" scatter plotting to display a graph equivalent to your original Virtual Scope display. Obtain a "print screen" image of your Virtual Scope display to print in your report (this will be ReportFigure 1). Your report should also include a copy of your nicely scaled Excel plot (ReportFigure 2).
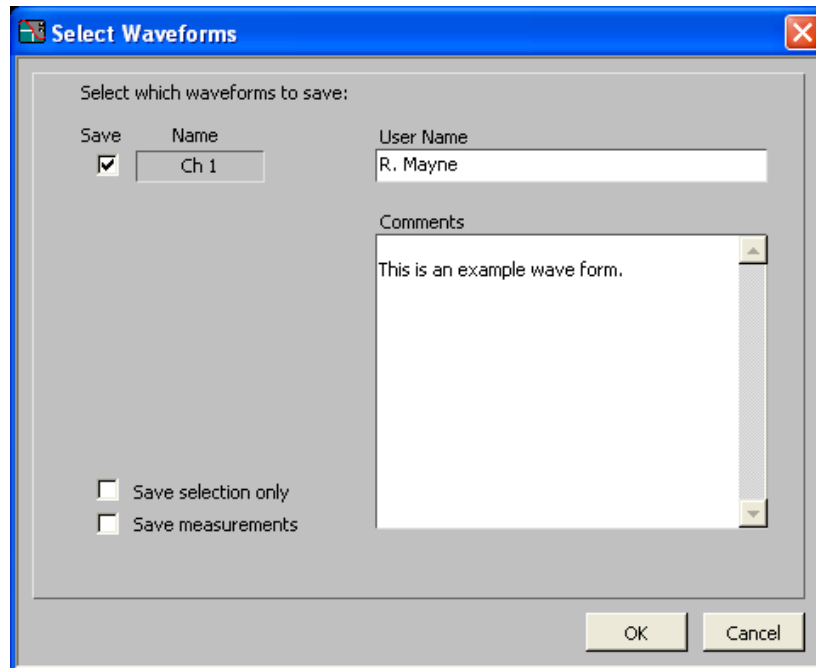
Figure 5. Select Waveforms window found under the *File - Save Waveforms...* pull down menu

Part 2 – Aliasing

In a complex periodic or a random signal, the "sampling theorem" states that a minimum of two points per cycle of the highest frequency component must be obtained in order to accurately reconstruct the signal's frequency content. Of course, for a deterministic sinusoidal signal, more than two points per cycle are necessary to graphically display the voltage. BUT – if there are fewer than two points per cycle, a mathematical analysis of the waveform may indicate a frequency lower than the true frequency. That is, it will display an "alias" of the true frequency. The "Nyquist Frequency" is half the sampling frequency and represents the maximum signal frequency for which aliasing will not occur.

1. Set the function generator to produce a sine wave with a magnitude of a few volts with a nominal frequency of 50 Hz.

2. Switch to a buffer size of about 5000 so that you can increase the sampling frequency to, say, 2500 S/s. Also adjust the function generator so that its frequency is very close to 50 Hz by observing the "Freq:" data measure just below the plot. Now, keep the function generator frequency constant and gradually reduce the sampling rate (by changing full scale time or buffer size). Consider sampling frequencies from over 1000 samples per second down through 50 S/s. Notice that sampling frequency changes with both buffer size and with full scale display time. A buffer of 5000 at a display time of 10 sec produces 500 samples/sec. Save a data file for the first reduced sampling frequency that you feel graphically shows a somewhat distorted version of the sine wave (ReportFigure 3). How many samples **per cycle** are you showing?

3. Recall that you are keeping the input sine wave frequency constant and that the function generator continually produces a smooth 50 Hz sine wave. As you lower the sampling frequency, the Virtual Scope analyzer is eventually unable to recognize the frequency of the 50 Hz signal. Signal frequency aliasing implies that an input frequency appears to be at some other lower frequency than it is in reality. Obtain a "print screen" image of the Virtual Scope's display of the wave form where the frequency analysis results shown on the display significantly misrepresent the actual frequency (ReportFigure 4). Of course, the input signal from the function generator should still be at 50 Hz.

Part 3 – Quantization

The number of values that can be represented by a 12 bit binary number is 2^{12}. The A/D converters in the lab are twelve bit converters. In normal unity gain mode, they have a 20 volt range (+/- 10 volts). This means that nominally each of the 4096 values is separated by 20/4096 (0.0049) volts. The concept of representing a continuous range with a discrete number of values is referred to as "quantization" and the precision of an A/D converter is limited by the input range and the number of bits used in the conversion process. The exercise below illustrates the limits imposed by quantizing.

1. Set the Virtual Bench Scope vertical voltage sensitivity to 5 Volts/Div.

2. Set the sampling frequency to about 500 Hz (use a buffer size of 5000).
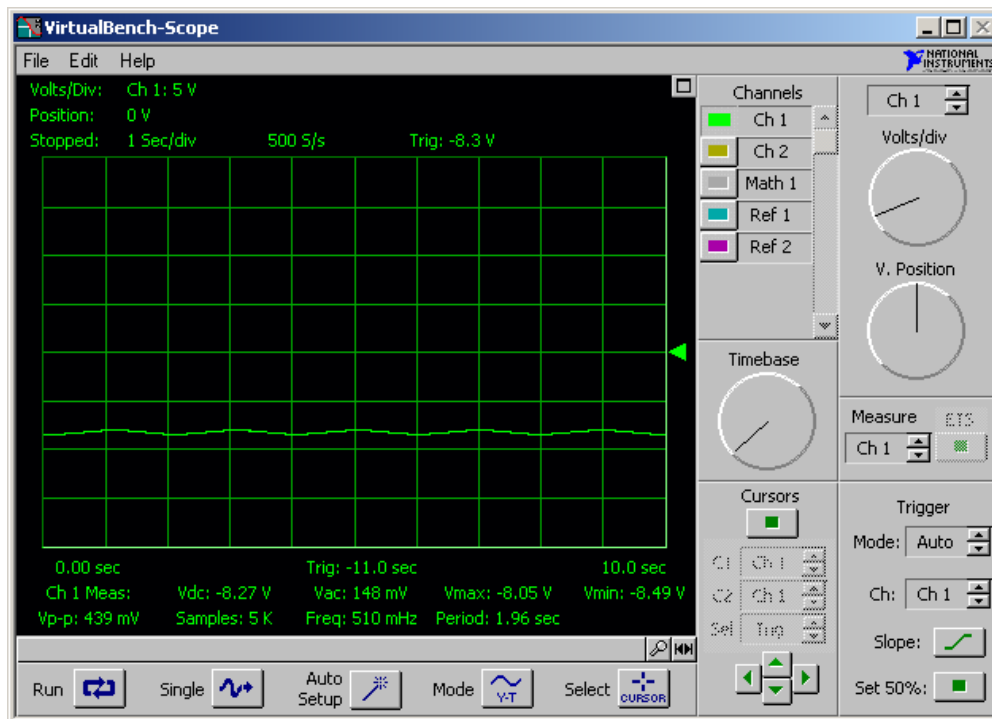

Figure 6. Small Oscillations with a Negative Average Value

3. Set the function generator to produce a low frequency sine wave (about 0.5 Hz) with an average value in the range of about -8 volts and a small oscillation less than 500 millivolts peak to peak (the numeric values for Vdc and Vp-p shown below your scope plot may be helpful to you). Use the AMPLITUDE and the DC - OFFSET (bias) controls on the function generator to obtain the waveform. Figure 6 shows a reasonable representation of the desired signal.

4. Using the scope in single run mode, capture the waveform and save it in a file to be read by Excel. Use the convenient plotting capability of Excel to adjust the scales and the range of an "x/y" plot to clearly show the quantization level of the signal. What is it? Include this Excel plot in your report (ReportFigure 5).

5. We now want to study a signal with very small square wave oscillations about zero volts. Readjust the function generator to remove the bias voltage from the signal. Also reduce the signal amplitude so that its oscillations are less than 20 millivolts peak to peak. You will find the -30 db button to be helpful here. Adjust the sensitivity of the Virtual Scope to 10 millivolts per division. With this series of changes, your Virtual Scope display should now look very much like Figure 7.

6. Using the scope in single run mode, capture this new waveform and save it in a file to be read by Excel. Use the convenient plotting capability of Excel to adjust the scales and the range of an "x/y" plot so that the quantization level of the signal is apparent. What is it? Include this graph in your report (it should be ReportFigure 6).
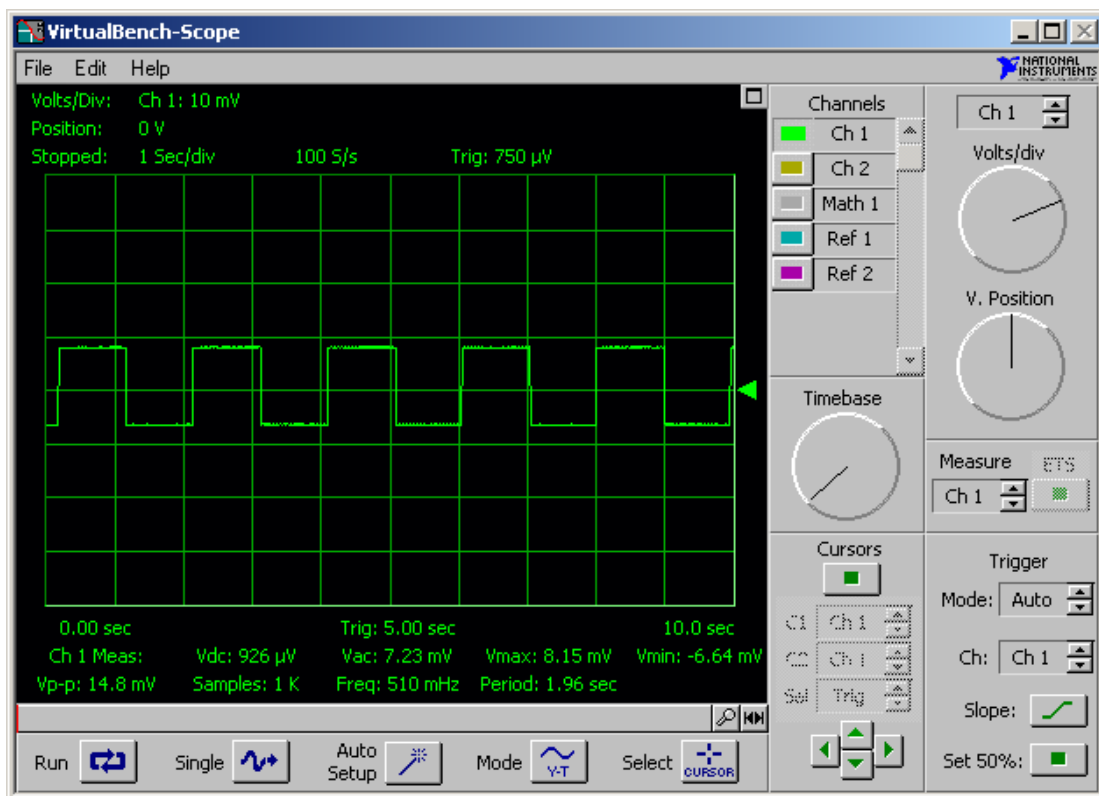

Figure 7. Very Small Oscillations about Zero

Simulations

Using Excel, simulate the digital sampling process by calculating an "ADC Value" and then converting that to its equivalent voltage. The

$$ADC\ Value = INT(V/Q + 0.5)$$

where V is the input signal voltage and Q is the ADC resolution in volts. With unity gain for the input to the ADC:

$$Q = ADC_{FSR}/2^M$$

where ADC_{FSR} is the ADC Full Scale Range in volts (maximum limit $-$ minimum limit $= 20$ Volts for the lab ADC). M is the number of bits of resolution of the ADC. For the ADCs used in the lab $M = 12$. Of course, if the gain is not unity, an adjustment of these equations would be required.

Use this representation in Excel to simulate the aliasing phenomenon by considering the oscillating voltage described by:

$$V = A \sin(2 * \pi * f * t(i) + phase) + offset$$

where:

A = half of the peak to peak amplitude, f = sine wave frequency in Hertz, t(i) = the time calculated by dt*i where i = 1,2,3,...500, dt = 1/sr is the time change between each sample where sr = sampling rate in Hertz (S/s).

Use this Excel simulation to graphically study the sampling behavior. Note that each point in your graphs represents the equivalent of one digital sample. By varying the sampling rate while the input sine wave remains the same (constant frequency, amplitude, phase and offset) obtain a plot which corresponds to your Excel plot from the laboratory. Obtain a plot (ReportFigure 7) which mimics the figure you obtained in the lab for Part 2 item 2. You'll want to avoid setting the signal frequency and the sampling frequency exactly at integral multiples of each other.

Also consider the quantization issue with your Excel simulation. For the quantization simulation, a simple sine wave may be taken as the input. Set the magnitude and frequency to match the specifications of Part 3 items 2 and 3. Plot your simulation results so that you can compare them directly to Figure 6 of this write-up (this is your ReportFigure 8) and to your detailed Excel plot from the laboratory data for Part 3 item 4 (call this ReportFigure 9).

Before You Leave the Lab…

have your teaching assistant check off your Excel spreadsheets showing your first draft of the plots for ReportFigure 3 (distortion of a sine wave) and ReportFigure 6 (second illustration of quantization).

For Your Week 2 Interview

Have all of your report figures prepared and printed (each partner working independently). You can expect your teaching assistant to ask you and/or your partner to discuss specific results – either the lab data or simulation or both. You should be able to demonstrate understanding of the material and the calculations used to obtain your results. Bring your Excel spreadsheets on USB flash disks and be prepared to load one or more of the spreadsheet calculations into Excel as requested to discuss your spreadsheet program.

Report

The <u>Results</u> section should include all of the specified plots/graphs (9 are requested). Each graph or plot should be in a carefully numbered and titled figure. Figure titles should clearly indicate the contents of the figure. Be sure that all of your graphs are fully labeled and that the units for the axes are shown. You may add material here if you would like to discuss something not specifically requested.

Your <u>Discussion of Results</u> should describe your ability to simulate the behavior of the A to D conversion process with Excel for sampling and quantization. Do your simulations agree with the actual behavior of the analog/digital converter that you have experienced? Be sure to discuss the quantization level indicated in ReportFigure 6. How do you explain the apparently very small quantization level compared to the basic ADC resolution?

Specific Questions

1. Given that the A/D converters in the lab have a fixed range of input voltage, what will be the expected behavior if that range is exceeded? Consider a case where a square wave of +/- 12 volts is applied to the input of our laboratory A/D converters. Describe the display that would appear on the VirtualScope. Explain.

2. Assume that you are sampling a sine wave of 500 Hz and you would like to see a reasonably accurate description of its behavior on a digital display. What minimum sampling frequency would you recommend and why? How many samples per cycle does this correspond to?

3. Pretend that you have a "-10 db" button on the function generator (instead of a -30 db button). If this button were released it would reduce a signal by 10 db. Consider a signal that is originally a 1 volt square wave (peak-to-peak) at "full" output. With the -10 db button released, what would be the resulting size of the new wave form?

4. Make a visit to the library or use the web to find an application of data acquisition in an automotive engineering application that interests you. This should be a data acquisition process used in the control of the vehicle (perhaps the vehicle stability assist) or engine. Briefly discuss the application. What kinds of sensors are used in the data acquisition? What are the names of the companies who provide sensors, hardware or software? As a bonus – can you identify the sampling rate for data acquisition and the number of bits (i.e. accuracy) in the A/D conversion?