EE 4440 – Comm Theory – Lab #4

Sampling Theory

Purpose:

The purpose of this lab is to investigate sampling including the concepts of aliasing and quantization noise.

Note: For this lab, no formal report is due. Just turn in the answers to the questions including any sketches taken during the lab. The questions are in **Bold Type**. A typed report (but not formal) is required for this lab. Be sure to label all sketches and keep the sketches relatively neat and clean.

Equipment:

This lab will utilize the Agilent 54622D mixed signal oscilloscope, Agilent 33120A arbitrary waveform generator, and the computers equipped with LabVIEW and Data Acquisition Cards (DAQs). Further information about these items was covered in Labs 1 – 3.

Background:

The Agilent 54622D mixed signal oscilloscope provides an ideal setting for studying sampling. Both the sampling theorem and quantization effects can be studied using the oscilloscope. They are perfect for studying sampling for two main reasons. First, they have a built in Analog to Digital (A/D) converter and all the supporting electronics. Second, they have built in display capabilities for viewing the effects of sampling (e.g. aliasing and quantization noise). The oscilloscopes are designed to have the feel and look of an analog oscilloscope, so they try to minimize the impact of the sampling and quantization process. Yet, with a little effort we can investigate the impact of the sampling and quantization processes.

The A/D converter inside the oscilloscopes has a maximum sampling rate of 200 Msamples/second. The actual value of the sampling rate depends partly on the time base selection. The oscilloscope uses a maximum buffer size of 2 million samples. The sampling rate reaches a maximum of 200 Msamples/second (at 1 ms/division) and is then adjusted for the longer time bases to provide the 2 million sample buffer. Using the formula $Sampling\_rate = \frac{(buffer\_size)}{(\frac{time}{div})x(10div)}$, the sampling rate for longer time divisions can easily be calculated (with exception to 5 ms/div which uses a slightly different method). Stopping the oscilloscope and adjusting the time base allows the student to zoom in and thus get fewer samples per division.

The A/D converter inside the oscilloscope has 8 bits of resolution resulting in 256 levels. The quantization step size, Δv, is not fixed but depends on the vertical scale amplifier setting (volts/division). Regardless of the amplifier setting, the 256 levels are equally spaced over the visible vertical scale.

Procedure and Questions:

Notes:

- Connect the function generator's "sync" output to Channel 2 of the oscilloscope and edge trigger from this channel. Check labs 2 and 3 for assistance.
- Set the function generator's anticipated output impedance to "High-Z"
- LabVIEW should be stopped with the STOP button or ESC key.
- The FFT sampling rate is not the same as the analog channel sampling rate. The FFT sampling rate can be obtained from the oscilloscope itself under the FFT menus (listed right above the softkeys) or the FFT folding frequency can be calculated using the formula $\frac{f_{s(FFT)}}{2} = \frac{102.4}{\frac{time}{div}}$.

Part 1: Horizontal Sampling

■ ■Generate a 10 Vpp, 1000 Hz sine wave signal using the Agilent function generator and display this output on Channel 1 of the oscilloscope.
■ Set the time base to 1 ms/div on the oscilloscope.
■ Change the display mode into the individual samples by pushing the Display button (under the Waveform section) and then pressing the "Vectors" soft-key so that the option is unchecked. This displays the individual samples of the oscilloscope's A/D rather than connecting lines between them.

i) ■ Once the signal is visible on the oscilloscope screen and you are satisfied with the vertical scaling (it is not crucial to this portion of the lab), press the Run/Stop button on the oscilloscope.
■ With the oscilloscope stopped, adjust the horizontal time base setting until you can clearly see the individual samples.
■ Use the cursors to measure the time between the samples and estimate the sampling rate. How does that number compare with the calculated sampling rate using the equation given in the Background section?

ii) ■ Unmagnify the time base (back to 1 ms/div) and press the Run/Stop key again to resume the oscilloscope output.
■ Turn the "vectors" option of the display back on. Display the FFT of the signal. Leave the FFT span and center settings to the default.
■ You may adjust the scaling and offset of the FFT to provide a better display (they are not crucial for this portion of the lab either).
■ Use the cursor on the FFT and find the frequency of the far right of the display. What frequency does this correspond to? Why is that the upper limit of the displayed frequency?

Part 2: Aliasing

i) ■ Leave the time base setting at 1 ms/div. Ensure the FFT function of the oscilloscope is still active.
■ Gradually increase the function generator's frequency (in steps of 5 kHz) from 5 kHz to 200 kHz. **Explain what you observed in both the time and frequency domain giving special attention to frequencies near 50 kHz, 100 kHz, 150 kHz, and 200 kHz.**

ii) ■ Change the function generator to generate a 14 kHz square wave.
■ **Sketch the signal in the frequency domain and identify the spectral components that are due to aliasing (label first folded set of frequencies with their true values).**

Part 3: Quantization

i) ■ Turn off the FFT math function of the oscilloscope.
■ Set the output of the function generator to a 1 Vpp 1000 Hz sine wave.
■ Change the vertical scale to 5 V/div and the time base to 1 ms/div.
■ Turn the "vectors" mode of the display off again.
■ Press the Run/Stop button on the oscilloscope to stop the display.
■ Adjust the vertical scale so the individual quantization levels are visible. You can adjust the horizontal time base if desired to make the individual samples more apparent. Notice how multiple samples are quantized to the same level.
■ **Use the cursors to measure the quantization step size, Δv. How does this compare with the expected quantization step size?**

ii) ■ Run the display again and set the oscilloscope to a vertical scaling of 1 V/div and a horizontal scaling of 1 ms/div. Stop the oscilloscope once again.
■ Adjust the vertical and horizontal scales to obtain clear results for the quantization levels.
■ **Use the cursors to measure the quantization step size, Δv. How does this compare with the expected quantization step size? Does this value make sense in relation to the 5 V/div case? Explain.**

Part 4: Quantization Noise

i) ■ Run the oscilloscope once more. Adjust the display to 1 ms/div and 5 V/div.
■ Turn the FFT function back on and turn the "vectors" mode of the display back on.
■ **Measure the approximate value of the noise floor in dB.** Be sure to measure this value absolutely, not relative to any point in the FFT. The offset of the FFT may need to be adjusted so the noise floor is easier to measure. Note that in the frequency domain the quantization noise is uniformly distributed between 0 Hz and the folding frequency.

ii) Change the vertical scale to 1 V/div. **Measure the approximate value of the noise floor in dB. Justify the change in the noise floor based on your observation of the quantization levels from part 3.**

Part 5: Sampling of a sine wave

i) ■ Connect the oscilloscope to the DAC 0 channel (yellow wire) of the DAQ board.
■ Run the LabVIEW module named Lab 4.vi on the desktop.
■ Adjust the oscilloscope to 5 ms/div and 5 V/div. Change the trigger on the oscilloscope back to Channel 1 edge triggering. The signal generated is a 100 Hz 3.0 Volt sine wave sampled at 1 kSamples/s.
■ **Sketch and label the amplitudes of 2 complete cycles of the sampled waveform.**

ii) ■ Ensure the FFT function of the oscilloscope is still enabled. Adjust the FFT span and center frequencies to 10 kHz and 5 kHz respectively.
■ **Sketch the frequency spectrum of the "sampled" signal. Explain the frequency content of the signal.**

EE 4440 – Comm Theory – Prelab for Lab 4

The following two questions should be answered before coming lab. The prelab will be due at the beginning of the lab period.

1) Suppose the oscilloscope is using a sampling frequency of 750 kHz. With this sampling rate, what is the highest frequency the oscilloscope can accurately display on the oscilloscope (specifically for the FFT)? Given this sampling rate, what would the expected time/div setting be for the oscilloscope?

2) Suppose the oscilloscope is set to 5 V/div on the vertical scaling. What is the expected quantization step for this value (remember the oscilloscope only has 8 divisions of vertical display)? What is the expected quantization noise power (relative to 1W) for this vertical scale setting?