PROCEDURE
Digital Data Acquisition, Fourier Transforms, First Order Systems

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PLEASE READ THESE INSTRUCTIONS CAREFULLY AND SLOWLY SO THAT YOU DO NOT MISS ANYTHING.

REMEMBER TO RECORD ALL MEASUREMENTS AND OBSERVATIONS IN YOUR LAB BOOK.

A. Digital Data Acquisition

Equipment
- Computer with GPIB Suite
- 1 short BNC-BNC cable
- 1 long BNC-BNC cable
- 1 GPIB to USB converter
- 1 T-connector

Voltage Resolution of the A/D Converter in Computer

1. Connect the T-connector to the FG's output. Then using the BNC-BNC cables, connect the function generator (FG) to both the oscilloscope (O-scope) and to the Multifunction I/O Module (MIO-16) ACH 1 connector (that is on the Labstation DAQ panel above the desk). Make sure there is a blue GPIB to USB converter connected to the Labstation DAQ. Plug in to the USB port on the computer

2. Open the "ITLL documentation" folder, there is a shortcut on the desktop. Open "ITLL Modules," then the "Digital data aquisition" folder. Open "Digital Representation.vi". The window that subsequently opens has an empty area for a plot of Volts vs. Time, and areas for DAQ and Function Generator control.

3. Make sure the O-scope and the FG are turned on. To be able to control the instruments, it is first required to use "measurement and Automation Explorer" on the computer desktop to find the instruments. Expand "devices and Interfaces" in the left pane. Clicking "GPIB0 (GPIB-USB-B)" in the left pane and pressing "Scan for Instruments" should display both the function generator and the oscilloscope as being found by LabView.

4. Run the VI by clicking the arrow in the top left corner. According to the settings displayed in the boxes, LabVIEW has now changed the FG to a 100 Hz, 1 V_{pp} sine wave, changed the settings on the scope, instructed the DAQ system to acquire 250 samples at 10,000 samples/sec, and displayed the trace on the screen. The sample points are clearly displayed in the graph connected by lines. You can change any of the FG or DAQ settings shown by clicking on the boxes and either selecting a new value or keying in a new setting, depending on which box you click on. However, you should always press the *Enter* key on the numeric keypad after keying in any changes by hand to the settings. Change the Waveform Type to a triangle wave and run the VI. Change the sample rate to 5000 samples/sec and run the VI again. Notice that the time scale on the graph is controlled by the sample rate and the number of samples selected.

5. Determine the voltage resolution of the DAQ with an input range of 2 volts. To view the resolution, you'll need a voltage that varies slowly compared to the sample rate, so decrease the function generator frequency and increase the sample rate. Zoom in on the graph on a peak or a trough and look for discrete data points (The tab key can be used to scroll through the various available cursors on the LabView graph until you get the zoom cursor.). Vary the sample rate and/or signal frequency until you can see that several samples appear to be at the same voltage level, with a jump to several samples at the next level. You may need to run the VI several times before getting a good display. What is the vertical spacing between points? Since the Y-axis displays volts, this number is the voltage resolution of the DAQ when the full-scale range is 2 V.

   Keep in mind that the DAQ system has 12-bit resolution, so all samples are represented by a binary number between 0 and 2^{12}=4096. Thus the resolution of the DAQ is limited to one part in 4096. Compare your observed resolution with the expected resolution attainable with a 2 V full-scale range and a 12-bit converter. Note that the maximum resolution of the DAQ system depends on the full-scale voltage range, which depends on analog amplifiers which are in-line between the front panel connections and the ADC. We will not explore those capabilities today.

Time Resolution of the A/D Converter in Computer

1. Run the VI for a 100 Hz, 1 V_{pp} sine wave, acquiring 250 samples at 10,000 samples/sec. Zoom in until discrete data points are seen. Count the number of samples on the screen and, using the time scale, calculate the sample rate. Does your estimate agree with the VI setting?

Nyquist and Aliasing

1. When the sampled waveform has a frequency greater than half the sampling device's sample rate, aliasing of the wave's frequency occurs. For example, if the scope's current sample rate is 20 Msamples/sec, then the corresponding **Nyquist frequency**

is 10 MHz. Change the FG output to a 10 MHz signal and press Autoscale on the O-scope. Change O-scope to Single mode. The oscilloscope now captures 2 points per cycle of the input waveform. You should see 4 points on the screen for a single trace. If the points are not clearly visible, press the Run button several times until 4 distinct points are shown. Notice that the apparent frequency of the signal is 10 MHz. Increase the frequency of the FG output to 15 MHz, press Run several times, and observe the resulting trace. Since 15 MHz is higher than the Nyquist frequency, the frequency of this wave appears to be less than 10 MHz. Change the Time/Div setting to 100 ns/Div (to make sure you can discern a complete cycle) and determine the apparent frequency of this digital wave using the cursors.

Questions that should be addressed in your Oral Presentation:

1. What was your measured voltage resolution of the DAQ when the full-scale range is 2V? What is the expected voltage resolution of an 12-bit A/D converter with a 2V range?

2. What is meant by "aliasing"? How may it be alleviated? What sorts of problems can aliasing cause? Why do you want to avoid?

3. Say you want to digitize five cycles of a 4 V_{pp}, 15-kHz sine wave. What is the slowest sample rate that will capture the frequency of the signal? How many points will be captured?

4. If a 3 Hz sine wave is digitized with a 0.25 s Δt, what is the apparent frequency of the digital signal?

5. How much memory (MB) is necessary to store 8 minutes of acoustic data that is digitized at 10 ksamples/s with an 8-bit A/D converter? In stereo at 44 ksamples/s with a 16 bit A/D converter?

B. Fourier Transforms

Equipment
- 2 BNC cables
- Computer with GPIB suite
- 1 T-connector

Fourier Transforms of Sine, Square, and Triangle Waves

1. Connect the output of the function generator to the oscilloscope and to "ACH 1" BNC connector on the "MULTIFUNCTION I/O MODULE (MIO-16)" on the "LABSTATION INPUT/OUTPUT PANEL". Set the FG to 2 V_{pp}, 1 kHz **sine** wave. Set the scope to 500 mV/Div and 1 ms/Div and check to see that the FG is producing the correct signal.

2. Using LabVIEW, open the VI entitled "Spectrum Analyzer.llb", located in the "ITLL Documentation/ITLL Modules/Musical Signal Analysis Labs" folder. The Spectrum Analyzer.vi is programmed to read the settings from the function generator.

3. In the VI, choose the rectangular (not the Hanning) window option. Select analog input channel MIO Channel 1. Run in Single Shot Mode. Make sure that the limiates are +/- 5 V, and number of points should be 4096. It is best to turn off autoscale for the x axis and change x axis to the appropriate scale to see the signal.

4. Start the VI by selecting the arrow button (in the upper left-hand corner of the screen), and then pressing the "Run" button on the VI (middle screen of the VI window). **To stop the VI, press the "quit" button – not the "stop" button at the top of the screen!** You may have to select the "Run" button twice to run the VI. There are two plots displayed on the VI: voltage vs. time and the FFT amplitude vs. frequency. Save all of your data to a file as you work using the "Save Data to Disk" button. Make sure that you label what each column contains! (From left to right, the columns are time, voltage, frequency, FFT amplitude). Also make sure to write down the file names in your lab notebook. Look at the plot using excel and measure the frequency of the main peak. How does this compare with the frequency of the sine wave produced by the FG?

5. Now, set the FG to 2 V_{pp}, 1 kHz **square** wave, no DC offset. Observe the FFT. Look at the graph and measure the amplitudes and frequencies of the first four peaks. Zoom into the graph using the "magnifying glass/zoom" button under the graph. How do they compare with theoretical predictions?

6. Set the FG to 2 V_{pp}, 1kHz **triangle** wave. Observe the FFT. Measure the amplitudes and frequencies of the first 4 peaks. How do they compare with theoretical predictions?

7. Examine the experimental setup. Determine the sources of uncertainty in the FFT. Quantify these sources of uncertainty. (i.e. what is the resolution of your FFT?)
8. Create a noisy sine wave by turning on the noise button in the LabView VI and set the noise level to 0.2 V. With the FG to 2 V_{pp},1 kHz **sine** wave, run the VI (set Sample Rate = 20000; N Samples = 2048; Rectangular Window) and save your data to excel. Repeat this procedure with a clean sine wave and save your data. How do the two FFTs compare?

Questions that should be addressed in your Oral Presentation:

1. If a digitized signal has *N* points and a sample rate of 1/d*t*, what are the frequency resolution and the total frequency range of the FFT?

2. How closely did the measured peak in the FFT spectrum agree with the input frequency (document for step 3 in lab procedure)? Is the difference within the frequency resolution of the FFT? What uncertainty would you estimate from this resolution? What was the measured error (% difference between known input frequency, and measured peak frequency in the FFT)?

3. What were the observed relative magnitudes of the first three peaks in the magnitude spectrum of the triangle wave? How does this compare with theory?

4. A common technique for extracting frequency information from noisy spectra is to perform a type of averaging. Take the first $1/4^{th}$ of the voltage data from the noisy sine wave and perform an FFT on it in Excel (see below for instructions). Repeat this for each of the subsequent $1/4^{th}$ data sections. Average the FFT results together, i.e. average the first frequency bin from the 4 FFT's together, then do this for each of the other frequency bins. Plot the FFT from the first $1/4^{th}$ of the data on the same graph as the averaged FFT. What does this tell you about the signal and the noise?

5. On the same graph, plot (1) FFT of $1/4^{th}$ of the clean sine wave data, (2) FFT of $1/4^{th}$ of the noisy sine wave data, and (3) FFT of all 2048 data points from the noisy sine wave. Note the differences between the three traces and explain them.

Fourier Transforms in Excel:

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1. Under *Tools, Add-ins,* select Analysis Toolpack.
2. Under *Tools* now select *Data Analysis, Fourier Analysis.* If this choice does not appear, click on a random cell, then try again
3. Input the range of data you want transformed. **Do not** include a time series (that is, time data). Make sure that you have selected a number of cells equal to a power of 2 (i.e. 526 cells).

4. Input the range of cells in which you want the transformed data to appear.
5. The results will appear as complex numbers. You need to find the magnitude of the complex number, so use the IMABS function. This will be your FFT.
6. Disregard the second (lower) half of the returned data. It is a mirror of the first (upper) half. This is an artifact of the FFT algorithm.
7. **This is your last step – You need to create the frequency data that the FFT represents.** You will plot these frequencies on the x axis and the FFT found in step 5 above on the y axis. To do this, remember that $\delta f = S_{rate}/N_{samples}$.

C. 1st-Order Systems

Equipment
- Type K Thermocouple with reference junction and banana plug connector
- Thermos filled with ice water
- Computer with GPIB suite
- Thermometer

Calibration of the Thermocouple

1. Fill the thermos with crushed ice and add sufficient water to make slush (ice will be provided by the TA).

2. Make sure the SCXI mainframe power is “on.” The On/Off switch is just above the computer tower.

3. Connect the thermocouple plug to the channel marked “CH 0” in the “ISOLATION AMPLIFIER (SCXI-1121-#1)” connection panel below the computer monitor. Put the positive end in the “+” jack and the negative end in the “-” jack. The side with the “ear” is negative.

4. Open the VI entitled “Thermocouple Transient Response”, located in the folder “ITLL Documentation\ITLL Modules\Transient Response of a Thermocouple”. You should see a screen with a voltage vs. time graph and several controls. Set the switch at the top of the VI to A or B, depending on whether you are working on an A or B side lab station.

5. Place one of the thermocouples in the ice bath and run the VI. Make sure the “in air” TC is not touching anything, but is exposed just to room air. If the “instantaneous voltage” is positive, the TC that is in the ice is the **reference junction**. If the voltage is negative, switch the thermocouples to get a positive voltage. Record the “Instantaneous Voltage”. Also record the room temperature as measured with the thermometer. Refer to the type K thermocouple reference table (http://www.omega.com/temperature/Z/pdf/z204-206.pdf in degrees C, http://www.omega.com/temperature/Z/pdf/z218-220.pdf in degrees F) and compare the thermocouple voltage to the expected voltage for room temperature.

6. Repeat this procedure with both ends of the thermocouple in the ice water. Record the instantaneous voltage and the ice bath temperature.

7. Using the temperature and instantaneous voltage data that you recorded, determine the linear calibration function for the thermocouples, T(v), in °C. This

function will be used later to convert your measured voltage data to temperature history data. Note: For 0 < T(v) < 40 °C, the T(v) data given by www.omega.com is linear ($R^2 = 1$).

Recording Transient Response of Thermocouple to Temperature Change

1. To start your experiment, leave the TC reference junction in the ice bath and take the other TC, the sensor, out of the ice bath, warm it up to room temperature. Run the VI. Hit the "Start Acquisition" button and place the sensor end of the thermocouple into the ice water. Observe the downward sloping curve on the VI graph. You may need to repeat this procedure several times to "fine-tune" your settings on the VI (i.e. the number of pre-trigger samples, trigger level, etc.) until you get the full curve. Record the total scan time from the graph and the number of samples. Divide the total scan time by the number of samples to calculate the sample rate (sec/sample). If you received a clean trace, save your data by hitting the "Save data to disk" button.

2. Repeat the trial a few more times. When you have stored three good traces, close Labview.

Data Analysis for Thermocouple Response

- Import your ASCII (text) data file into an Excel spreadsheet. You should see two columns of numeric data. The left column is "Time (sec)" and the right column is "TC Voltage (V)". Repeat for each of your three data sets, making a total of three spreadsheets.

- For each trial, plot TC voltage vs. time.

- On each plot, locate the x-axis value equal to 63.2% of the total voltage change. Use the spreadsheet data, not the graph. Determine the corresponding elapsed time since the time when the temperature began to change. This is your estimated time constant, τ.

- Make a semi-logarithmic plot (natural log on y-axis, linear on x-axis) of the right hand side of Eq. 6 vs. $t - t_0$ (where t_0 is the time when the temperature began to change) for each trial. Your plot should form a straight line passing through the origin. If your line seems to have an intercept, you probably made an error in choosing t_0. If the plot is not straight, check your V_∞ and V_0 values.

- Determine the value of the time constant τ using a regression line. First, find the slope of the line plotted above by right-clicking on the line and selecting "Add Trendline." Under the "Type" menu, select a linear regression. Under the "Options" menu, turn on the options: set Intercept, Display Equation, and Display R-Squared value.

Calculate $\tau = -1/slope$. Compare this result with the average τ obtained graphically in step 3 above. What is the difference? Which method do you think is better?

- For one good trial, convert the TC voltage data to temperature using the calibration function T(v) and then make a plot of the TC temperature versus time. What is your uncertainty in converting the voltage to temperature?

Questions that should be addressed in your Oral Presentation:

1. Plot the transient voltage response of the TC for your three experimental trials in Excel. Mark the time constant on each plot, using the 63% method based on your data. What is the value of the time constant?

2. Plot the linearized voltage response of the TC together with the least squares linear regression line (steps 5 and 6 of the TC data analysis). This is only necessary for one good trial. What is the time constant τ for the TC based on the least squares fit? What is the uncertainty in the time constant based on the linear regression?

3. What is the uncertainty in your temperature measurement using the TC with the calibration function (T(v)) you developed? For what temperature range is this valid?

4. Show a circuit for a thermocouple with a reference junction. What is the purpose of the reference junction?

5. How long does it take to reach the equilibrium temperature measurement? How many time constants does it take to reach equilibrium?

6. How would the time constant for a thermocouple change with the diameter of the thermocouple wire?