Name: _____

EE354 Spring 2009 Lab 1: Refresher

In this lab, you will be refreshed on how MATLAB and the lab hardware can be used to view the frequency content of signals, and how to use it with complex numbers. Parts of the lab marked with a ® indicate portions of the lab that must be turned in.

A. Complex Numbers

Last semester in EE322, complex numbers were introduced when working with Fourier analysis. This semester again, we will use complex numbers, but now phase will play a more important role in the course. Work through the following complex number problems first by hand:

1. Each row of the following table contains a complex number in its rectangular format, along with its magnitude and phase (which are the polar format components).

   a. ®Complete the table. Use your calculator if needed.

Rectangular Format	Magnitude	Phase (convert answers to degrees)
7 – 3j		
	15	**45°**
–1 + 2j		
1 – 2j		
– 1 – 2j		
–12		
	4	**115°**

   b. Now use the MATLAB *abs( )* and *angle( )* functions to check your answers. Note that the *angle( )* function gives angle in radians, not degrees.

2. Three complex functions are given in the following table.

   a. ®Find their magnitude and phase and fill in the following table.

Function	Magnitude Function	Phase Function
$Z(f) = 5f + j12f$		
$Z(f) = 2e^{-f} + j\cos(2\pi f)$		
$Z(f) = 5e^{-j2\pi f}$		

b. ®Use MATLAB to plot the magnitude and phase of these functions. Plot these for $-2 \le f \le 2$, with small step sizes (such as Δf=0.001). Use the subplot(2,1,1) and subplot(2,1,2) commands to plot the magnitude and phase in the same figure window. Your phase plots should have the y-axis in degrees, but the MATLAB *angle( )* function gives phase in radians…convert to degrees by multiplying radians by 180°/π .

B. FFT of a Single Sinusoid

1. Create a 15 kHz sinusoid using the following MATLAB commands.

» fs=50000; N=4096;	% "fs" is sampling frequency. "N" is the number of samples of the sinusoid
» T=1/fs;	% "T" is time between samples.
» t=(0:N-1)*T;	% "t" is the time vector
» f0=15000;	% "f0" is the frequency (in Hz) of the sinusoid, 15 kHz
» x=cos(2*pi* f0*t);	% "x" is our signal vector (a 15 kHz sinusoid)

Frequency content of sampled signals on a computer are calculated using the Fast Fourier Transform (FFT). The FFT is computed in MATLAB using the *fft*( ) function. MATLAB defines the coefficients $X[k]$ and the signal $x[n]$ the same as in our text:

$$X[k] = \sum_{n=0}^{N-1} x[n] \cdot e^{-jk\Omega_0 n} \qquad \Leftrightarrow \qquad x[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k] \cdot e^{jk\Omega_0 n}$$

To compute the FFT of the 4096 samples of the sine wave, the command

>> y = fft(x);

will return a vector *y* of length 4096 comprised of the FFT coefficients of the sinusoid. The division by N is needed to normalize the output, as was the case in EE322. The elements of *y* are complex numbers. In order to present usable plots of the magnitude/phase, we will only need to consider the first portion (approximately the first half) of the FFT values, since the second part is a mirror image and the FFT is periodic:

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>>N1 = ceil(N/2)+1;        % N1 is the number of points we will use from the FFT function
>> y=y(1:N1);              % the first (left) half of the FFT coefficients (2049 elements long)
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Now to accurately plot the magnitude/phase of the FFT, we need to specify the frequency values that correspond to these FFT coefficients. The frequency resolution (how far apart the frequency samples are separated on the x-axis) is:

$$\Delta f = \frac{f_s}{N}$$

so the frequencies corresponding to these coefficients are:

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>> deltaf = fs/N;           % "delta" is the frequency resolution for the plot
>> f=linspace(0,fs/2,N1);   % The frequency vector will be N1 elements long, starting at 0 Hz,
                            %    ending at fs/2 Hz, evenly spaced.
                            % The linspace function creates a vector of linearly spaced values.
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Now we can plot the magnitude result:

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>>figure(1)                % creates two plots in a 2x1 format on the same figure.
>> plot(f,abs(y)/N, 'linewidth', 2)
                            % the desired frequency plot of the magnitude of the FFT. Note: to view
                            % magnitude values such as we expect from a Fourier table, divide the FFT by
                            % the number of original samples of the time signal (N).
                            % The width of the plotted line is 2, vice the normal 1
>> title('Frequency Content of a 15kHz Sinusoid');
>> xlabel('Frequency (Hz)');
>> ylabel('Magnitude');
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C. FFT of an Unknown Number of Sinusoids

Download or copy the dat1.dat file to your working MATLAB directory. If downloading, **USE INTERNET EXPLORER, NOT NETSCAPE!!** It is available on the course website.

This file can be loaded into MATLAB from the work directory using the command **load dat1.dat –ascii**. This will create a variable called "dat1" that represents the time signal contained in dat1.dat. This file represents 1024 samples of a signal that contains an unknown number of sinusoids. Assume that the sinusoids have been sampled at 8000 samples/sec (**fs=8000**) and **N=1024**.

®Use the MATLAB *fft* function to determine how many sinusoids and what their frequency is. Use subplots to plot the time domain signal in the upper window and the magnitude of the FFT in the lower window. Include your name(s) in the figure title. If the largest sinusoid had amplitude in the ***time*** domain of 16V, using the frequency plot, estimate the amplitudes of the other sinusoids in the time domain using the following table (note: there may or may not be as many sinusoids as indicated in the table.

Frequency	**Estimate of Amplitude of the Cosine**

D. Hardware Introduction: Spectrum of a Single Sinusoid

1. Using the Agilent 33220A Function Generator, generate a 15 kHz sinusoid with peak-to-peak voltage of V_{P-P} = 2.0V. Ensure that the "Output" button is lighted. Connect this output to the input of a 1 giga sample/sec (1 GaS/sec) Infiniuum Oscilloscope (NOT a 4 GaS/sec Oscope). Connect to either Channel 1 or Channel 2 of the Oscope. When connected, push the "Autoscale" button on the Infiniuum; this will choose some optimal time and voltage scaling for the best display. Set the input impedance of the Oscope to match the output impedance of the function generator (that is, since the function generator output is 50 Ω, set the Oscope input to have 50 Ω impedance vice 1 MΩ).

2. ®Using Marker A and Marker B on the Infiniuum, measure the period, frequency and peak-to-peak voltage of the sinusoid. Compute the rms voltage of this sinusoid. Record them for your lab report.

   Period= _____ Frequency= _____

   V_{P-P}= _____ V_{rms} = _____

3. Now set up the Oscope to view the FFT of the sinusoid.

   a. On the Oscope, using the mouse select *Analyze→Math/FFT*. Set the *f1* operator to FFT Magnitude, and check "Display On". Stop viewing the time display of the sinusoid by unselecting the "1" or "2" on the Oscope front panel where the coax cable is connected.

b. As we have seen before, the FFT computes frequency content from 0 Hz to $f_s/2$ Hz, where f_s is the sample frequency. This means that the left end of the display is set for 0 Hz, and the right end is set for $f_s/2$ Hz. The current sample frequency is shown on the left side, right above the display, in units of Sa/s (which means samples/sec). Adjust the horizontal time scale (large knob) to adjust the sample frequency.

c. Ⓡ How low can the sample frequency be adjusted before the display stops making sense? Why?

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4. Disconnect the Oscope, and connect the function generator to the input of the HP8591E Spectrum Analyzer.

a. The spectrum analyzer will display a 1.8 GHz range of frequencies, which is too large to view the 15 kHz sinusoid. Using the "FREQUENCY" button, adjust the *Start Frequency* to 10 kHz. This can be done by depressing the following sequence of buttons:

"FREQUENCY", "Start Frequency", "1", "0", "kHz".
Similarly, adjust the *Stop Frequency* to 20 kHz.

b. Change the spectrum analyzer from a log (decibel) scale to a linear scale using the following sequence of buttons:

"AMPLITUDE", "Scale Log/Lin" (until the word "**LIN**" is underlined).

c. Now change the output units to be Volts (vice decibels) by using the following sequence of buttons:

"**AMPLITUDE**", "**More 1of 2**", "**Amptd Units**", "**Volts**"

d. If the peak is too high to fit in the display, adjust the reference level until you can see the peak contained within the display:

"**AMPLITUDE**", "**Ref Lvl**". Now adjust the large round knob until the peak can be seen.

e. ⓇWhy is it that when you select a linear scale that the sinusoid's peak stands out very well (that is, it is a narrow peak and is very high relative to other frequencies), but when a dB scale is selected, the peak is wider and the display looks noisy?

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f. ⓇUsing the marker (press "MKR", then turn the round white knob, measure the frequency and amplitude of the peak…the frequency and amplitude will be displayed when using the marker. Record these for your lab report.

Frequency: _____ Amplitude: _____ (V_{rms})

The frequency should be approximately the same as in part (b). However, the amplitude in the frequency domain should be less than the amplitude in the time domain. This is due to the fact that the spectrum analyzer is displaying the **rms** voltage vice the peak voltage. Note also that the spectrum analyzer only displays positive frequencies. Does the spectrum analyzer agree with what you expect to see?

Note: For the lab report, answer the questions on these sheets (one per group) and include the required plots.

Note: A figure should have x- and y-labels and some type of meaningful title.