Name:_____

EE322: Lab 12—Fast Fourier Transform

<u>Important: Work at a station that has a 1 GaSample/sec Oscope!!!</u>

In this lab you will experiment with some of the parameters associated with frequency analysis of signals using the Fast Fourier Transform (FFT). You will use MATLAB to evaluate these parameters, then use an oscilloscope (use an HP Infinium Oscilloscope—as a spectrum analyzer) to analyze the frequency spectrum in hardware.

I. Theory

Remember the key points from the DFT/FFT lecture:

-When sampling an analog signal, the sample rate (f_s) should be at least twice the highest frequency content of the analog signal (called f_{max}). If sample rate is not high enough, there will be aliasing present in the sampled signal. The value $2\times f_{max}$ is called the *Nyquist* rate.

-Similarly, the highest frequency that will be present in a digital signal is no more than ½ of the sample frequency (f_s). This means that the DFT/FFT will only display frequency information from $-f_s/2$ Hz to $f_s/2$ Hz. We are typically only concerned with positive frequencies, so it is usual to display 0 Hz to $f_s/2$ Hz.

-If there are N samples of the time signal passed to the FFT function, the FFT will produce N samples of the frequency spectrum. Only the first $N/2+1$ of these values correspond to frequencies from 0 Hz to $f_s/2$ Hz. The remainder corresponds to negative frequency information from $-f_s/2$ Hz to 0 Hz, and these values are the conjugate symmetric mirror image of the other values, so are not usually displayed.

-On the FFT display, the x-axis is frequency in Hz. The FFT values are spaced along the x-axis by $\Delta f = f_s/N$. This is called the frequency resolution. Again, these samples cover the frequency range from 0 Hz to $f_s/2$ Hz. A more accurate frequency plot is obtained if frequency resolution is small, which means either f_s is small (but still must meet the Nyquist criteria) or N is larger (more samples of the time signal).

-To scale the FFT amplitude so that its result matches the Fourier transform, after taking the FFT, multiply each value by $1/N$ if the time signal is periodic (such as a sinusoid), or multiply by Δt (time between samples) if the signal is not periodic (such as a rectangle).

II. Submarines—Passive Sonar

1. Assume you are the off-going OOD on a Cold War mission, and it is your job to analyze some recorded sonar data from your watch. Download the three files called "SonarSignalA.wav", "SonarSignalB.wav" and "SonarSignalC.wav". One of the files you downloaded gives evidence of a Soviet Victor-class submarine, one of these files is indicative of the presence of a U.S. Submarine (Los Angeles Class), and the third contains background noise (no apparent target). Since most European nations use electrical power systems based on 50 Hz, the Victor-class submarine's electrical system should be based on 50 Hz, and you should expect a 50 Hz tonal (or close to 50 Hz) and its harmonics to be present in the frequency spectrum. On the other hand, U.S. electrical power is based on 60 Hz. Both subs were running quiet and no propulsion information can be discerned.

2. Use the *wavread* function to read the files into MATLAB, <u>AND</u> to let you know what the sample frequency was. For example:
   ```
   >>[A,fs]=wavread('SonarSignalA.wav');
   ```
   Listen to each file using the *wavplay* function:
   ```
   >>wavplay(A,fs,'asynch');
   ```
   (IMPORTANT NOTE: you must pass the correct sample frequency to the *wavplay* function to hear the signal correctly!!). Can you tell the difference between the files? Listen closely, as if you were a sonar operator. For most of us, it is probably impossible to tell them apart by listening to them. But we should be able to with frequency analysis.

Figure 1: Soviet Victor Class Submarine

3. Use MATLAB FFT analyses to determine which file includes tonals from the Victor submarine and which is from the U.S. submarine. For each, record as <u>accurately</u> as you can which prominent

tonals are present for each sub. The amplitudes are not as important here as the presence of distinct tonals. Plot the magnitude of the FFT, label your axes, and indicate on your plot the distinct tonals. Turn in your plots of both of the submarine-related files FFT results.

Tonal (Hz) Lowest to highest freq)	**USSR Sub**	**US Sub**
1		
2		
3		
4		
5		
6		

4. Label the files with the type of contact determined:

   Signal A:

   Signal B:

   Signal C:

5. What is the frequency resolution of your FFT plot?

6. On the US sub, the frequency of the AC electrical power is controlled by the electrical operator, who sits in the control room called "Maneuvering". The ships electrical system has some components that cannot take a frequency of more than 61 Hz for more than a short time period. Based on your measurements above, should the CO of the US sub be concerned? Why or why not?

7. Choose one of the files with the submarine present and rerun your FFT code using ONLY the 1st 100 samples of the wav file. View the magnitude of the FFT. What is the resolution now? Can you still detect the correct tonals?

8. Run an audio cable from the computer's audio output (headphones) to the Infiniuum Oscope's channel 1. Set up Windows Media player to run in a continuous cycle (so the same file plays over and over). In Windows, double click on one of the wav files representing a submarine. Set up function 1 on the Oscope to analyze the magnitude of the FFT of channel 1, and ensure that "Display On" is checked so that channel 1 of the Oscope will display the FFT magnitude.

9. For Channel 1, select *Manual* scaling, and set the vertical scale to *5 dB/div* (this will ensure the relatively weak audio file will show up pretty easily).

10. Adjust the sample frequency that the Oscope uses as needed (using the large round horizontal time scale knob) so that these low frequency tonals will be discernable in the display. Recall that for the display, 0 Hz is the left edge, and $f_s/2$ Hz is the right edge, so if the sample frequency is too high, the tonals will be bunched up on the left end of the display and you may not be able to pick them out. Also, note that it doesn't matter what the wav file sample frequency is—the signal coming out of the headphone jack of the computer is analog, and the Oscope is digitizing it so it adjusts the sample frequency as needed.

11. Using a marker, annotate the distinct tonals that you are able to pick out of the average of the magnitude of the FFT and record them in the table below. The fundamental frequency and some of the harmonics should be visible, if there is a submarine present. Also note that the tonals may appear to be small in magnitude, but they should be distinct.

Tonal (Hz) Lowest to highest freq)	USSR Sub	US Sub
1		
2		
3		
4		
5		
6		

12. For ONE of the submarine files, once you have the Oscope display adjusted so the specific tonals are apparent, save the screen as a bmp file and put it on a 3.5" floppy provided by the professor. Use your name(s) in the filename. Print out your display's bmp image and turn it in with the rest of your lab. If the computer you're using doesn't read 3.5" floppy disks, give the floppy to the professor and he/she will email you the bmp file so you can print it out and add it to what you turn in. Be sure to annotate (by hand) the distinct tonals you've found and which submarine it is. Be sure to return the floppy disk to the professor.

13. Why can't you use the 10 kHz-1.8 GHz spectrum analyzer to analyze these sonar signals' spectrums?

For this lab, turn in your MATLAB code and the two MATLAB figures, as well as a figure from the Oscope, indicating the tonals present and which submarine it represents.