Written by: Sonia Gu ’22, Clare Cook ’20 and Joe Zhang ‘20
Please post to Piazza if you have any questions about the lab or the errata sheet.

ELE201, Spring 2020
Laboratory No. 1
Matlab and Signal Analysis
Info and Errata Sheet

General Information

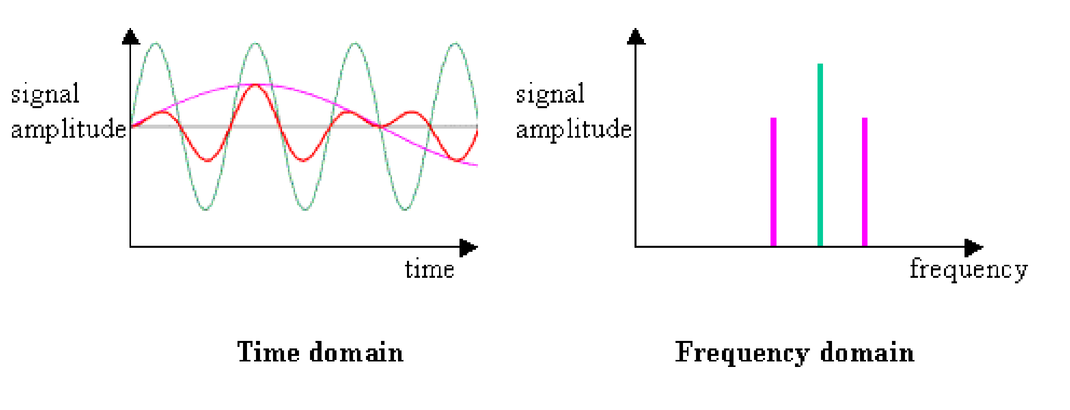
- In **Section 1 General Pointers**, the lab says boxes labeled ‘M’ indicate MATLAB signals or code that require demonstration to the TA. These demonstrations are NOT necessary (i.e., you do not have to come into lab to show your work to the TAs). Instead, please include the code/signals/plots as well as a paragraph of explanation (if necessary) in your lab write-up.
- You are free to complete the lab write-up in any software you wish (e.g., Microsoft Word, LaTeX). *Overleaf/Google Docs* is recommended if you and your partner would like to work on the lab write-up at the same time.
- Please structure your lab write-up in order of the Q, D, and M requirements in the lab manual (i.e., Q1 should be followed by M1, then M2, etc.).

Lab Manual Errata

1. In **Section 2.2 Matlab programming**, in the section **Listening to sound signals**, try using the functions *audioread* and *audiowrite* instead of *wavread* and *wavwrite* since *wavread* and *wavwrite* have been deprecated in recent versions of MATLAB.
2. In **Section 3.2 Simple 1-D signals**, M1 is referring to *rampprod*. Please plot this signal and include a copy of the plot in your final write-up.
3. In **Section 3.5 Signals as sounds**, for Windows computers, the interface for *splay* might open at the very top of the screen and out-of-view, simply drag the window down and expand it to see all the tools and buttons associated with the interface.

Written by: Sonia Gu ’22, Clare Cook ’20 and Joe Zhang ‘20
Please post to Piazza if you have any questions about the lab or the errata sheet.

4. In **Section 3.7 Simple 2-D signals**, the plots for M8, M9, and M10 that must be included in your final write-up can be made with either *imagesc* or *surf*. *surf* is recommended if you would like a 3-D visualization of your plot.
5. In **Section 5.1.2 Removing Unwanted Tones**, load the signals with *audioread* instead of *wavread* if you are using a more recent version of MATLAB. Also, for M13, instead of playing the sound for a TA please describe what the sound is in your final write-up.
6. In Part 2 of the lab you will use the MATLAB function for the Discrete Fourier Transform (DFT). We will cover the Fourier Transform thoroughly later on in this course, but in the meantime it may be helpful to have some understanding of how the function works. If you’ve studied Fourier Series in previous math courses, you know that most functions can be decomposed into sines and cosines of varying frequencies and magnitudes. Thus, you can represent a function either in the “time domain”, which is the representation you’ve mostly encountered in the past, or in the “frequency domain”, which is a representation of the frequencies of the various sines and cosines making up the function. For example, here is a function which is composed of 3 different sine waves, represented in both the frequency and time domain.



Written by: Sonia Gu ’22, Clare Cook ’20 and Joe Zhang ‘20
Please post to Piazza if you have any questions about the lab or the errata sheet.

The DFT you’ll use in this lab is a function for switching between the time domain representation and frequency domain representation of a function. That is all you need to know to complete the lab, but if you’d like a more in depth explanation, take a look at the image below.

In order to analyze the frequency content of a finite duration discrete time signal x with N samples, we use the Discrete Fourier Transform (DFT):

$$\hat{x}(k) = \sum_{n=0}^{N-1} x(n) e^{-i\frac{2\pi k}{N}n}, \quad k = 0, \dots, N-1.$$

This can be interpreted as the Fourier Transform of the finite duration signal evaluated at the frequencies $f = k/N$. Another interpretation is that the DFT is the Fourier Series of the periodic extension of x but is missing the $1/N$ scaling factor. This second interpretation gives rise to the Inverse DFT formula.

In order to go from $\hat{x}$ back to x, we use the Inverse DFT:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} \hat{x}(k) e^{-i\frac{2\pi k}{N}n}, \quad n = 0, \dots, N-1$$

These equations can be written in matrix form as

$$\begin{aligned} x &= \frac{1}{N} F\hat{x}, \\ \hat{x} &= \bar{F}x, \end{aligned}$$

where $\bar{F}$ is the complex conjugate of F, and F is the $n \times n$ Fourier matrix:

$$F = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{i\frac{2\pi}{N}} & e^{i\frac{4\pi}{N}} & \cdots & e^{i2\pi\frac{N-1}{N}} \\ 1 & e^{i\frac{4\pi}{N}} & e^{i\frac{8\pi}{N}} & \cdots & e^{i2\pi\frac{2(N-1)}{N}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & e^{i2\pi\frac{N-1}{N}} & e^{i2\pi\frac{2(N-1)}{N}} & \cdots & e^{i2\pi\frac{(N-1)^2}{N}} \end{bmatrix}.$$

We will often want to graphically depict the frequency content found in the DFT $\hat{x}$. Remember that $\hat{x}$ is in general a complex valued vector even if x is real valued, so it is usual to plot both the magnitude $|\hat{x}(k)|$ and phase $\arg(\hat{x}(k))$ on separate graphs.

The elements in the $\hat{x}$ vector are coefficients for the frequencies $f = 0, 1/N, 2/N, \dots, (N-1)/N$. However, notice that the high frequencies are equivalent to low negative frequencies due to aliasing. For example, $f = (N-1)/N$ is equivalent to $f = -1/N$. It is common to rearrange the vector $\hat{x}$ to represent the frequency components in the range $[-1/2, 1/2]$ rather than $[0, 1]$. Please read about the Matlab function `fftshift` which is used for this purpose.