Lab I

Signals & Spectrum Fundamentals

This multi-week lab will explore signals in the time and frequency domains. There are 3 parts to this lab, with required deliverables listed for each section.

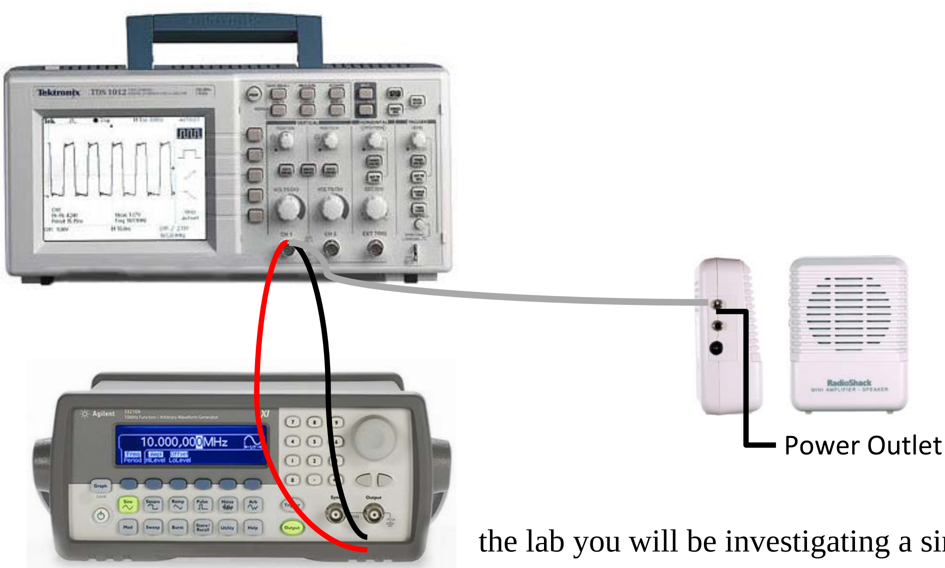
- Format for submission should follow the IEEE format (Found at: https://www.ieee.org/conferences/publishing/templates.html).
- **All code should be submitted in Appendix**.

- PART 1 -
Intro to Lab Bench; Signals in time & frequency

<u>Set-up</u>.
This lab will introduce you to the standard lab bench setup and explore the basic characteristics of a signal. We will use the following equipment:

- Agilent 33210A 10 MHz Function / Arbitrary Waveform Generator
- Tektronix TDS 1002B Two Channel Digital Storage Oscilloscope
- RadioShack Mini Amplifier/Speaker
- Microphone

☐ Connect your equipment as follows:



<u>Generate a Sine Wave.</u>
For the first portion of the lab you will be investigating a sinusoidal signal

from the function generator at your lab bench and displaying it on the oscilloscope.

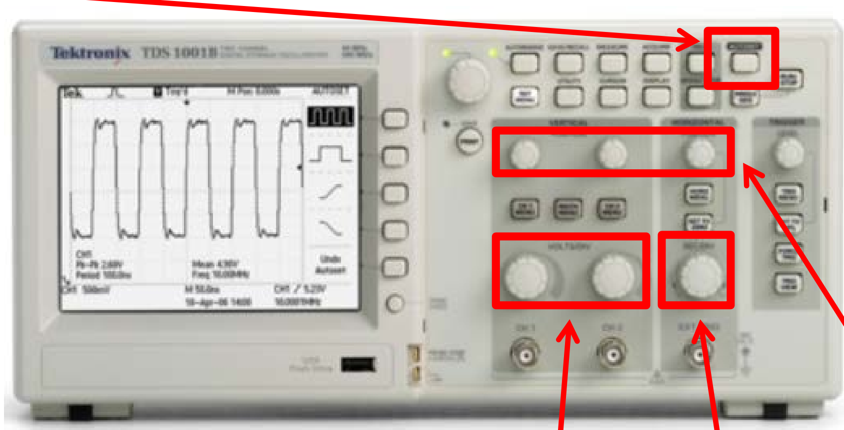
Step One: Function generator setup. [Turn bench power *on*: 120V switch on upper right]

- ☐ Ensure the lab bench power is on (120V switch on upper right panel).
- ☐ Power on your function generator (Bottom left hand side of the front panel).
- ☐ Select the sinusoidal function by pressing the button with the *Sine* wave on it. The function generator display should indicate a small sine wave.

- ☐ Select the *Frequency* (Freq) function (using the soft key directly above *Sine*) and set the frequency to **440 Hz** using the key pad.
    - o Enter the desired frequency (440) using the key pad on the right hand side.
    - o Enter the desired units (Hz) by pressing the button under **Hz** on the screen.
- ☐ Set the *Amplitude* (Ampl) to **2.00** $\mathbf{V_{PP}}$ using the same method.
- ☐ Select *Utility* -> *Output* -> and confirm *Load* is set to **High Z**. Push *Done*.

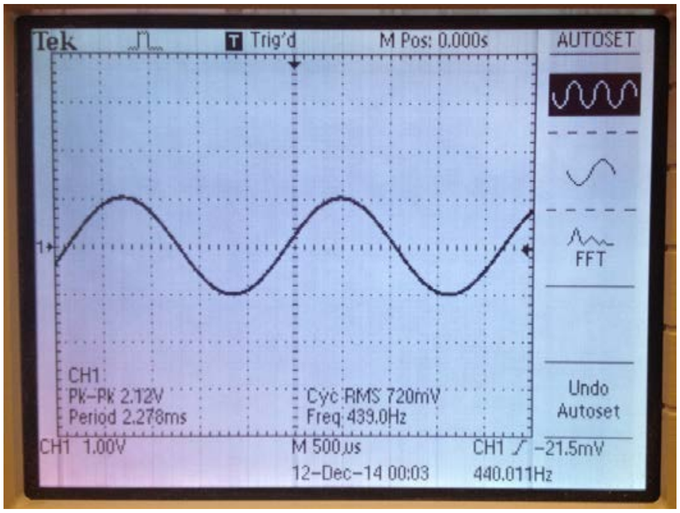
Step Two: Oscilloscope setup.

- ☐ Power on your oscilloscope (Left hand side of the top panel).
- ☐ Press *Autoset* to have the scope automatically calibrate to your signal.



- ☐ Both the horizontal and vertical position of the sine wave can be adjusted using the *Position* dials. The horizontal and vertical axis scales are controlled by the *Volts/Div* and *Sec/Div* dials. Experiment with all dials to see the effects on the sine wave.
- ☐ Adjust the vertical axis to *1 Volt/Division*. Bottom left hand corner of the screen will display **CH1 1.00V** when adjusted correctly.
- ☐ Adjust the horizontal axis to *500 µs/Division*. Bottom center of the screen will display **M 500µs** when adjusted correctly.

☐ Scope screen should be very similar to the image below when your scope is set up properly.



Exploring Signal Parameters in Time and Frequency domains.

To explore how changes in amplitude and frequency affect a sine wave, both the oscilloscope and the RadioShack speaker will be used.

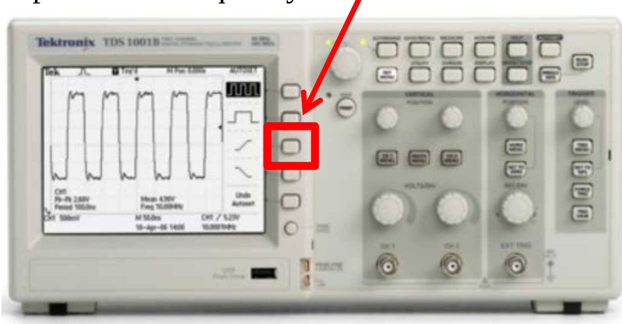
☐ Power on the RadioShack speaker by adjusting the volume dial on the right hand side.

☐ Using the dial on the Agilent Function Generator, adjust the amplitude and frequency of the sine wave and record your observations. Include how the changes impacted both the o-scope display and the speaker audio output. What is the lowest frequency you could hear? The highest?

☐ Reset your original sine wave by setting *Voltage* to **2.0 V_{PP}** and *Frequency* to **440 Hz**.

Our scope can also provide the frequency spectrum of a signal. For this particular sinusoidal signal, we know it is periodic and has a single frequency, *f*. Now let us explore how this signal is displayed in the frequency domain.

☐ Change your o-scope display from ***time domain*** to ***frequency domain*** as follows:
- Select the soft key next to *FFT* on the o-scope display to see your sine wave displayed as a function of amplitude vs. frequency.



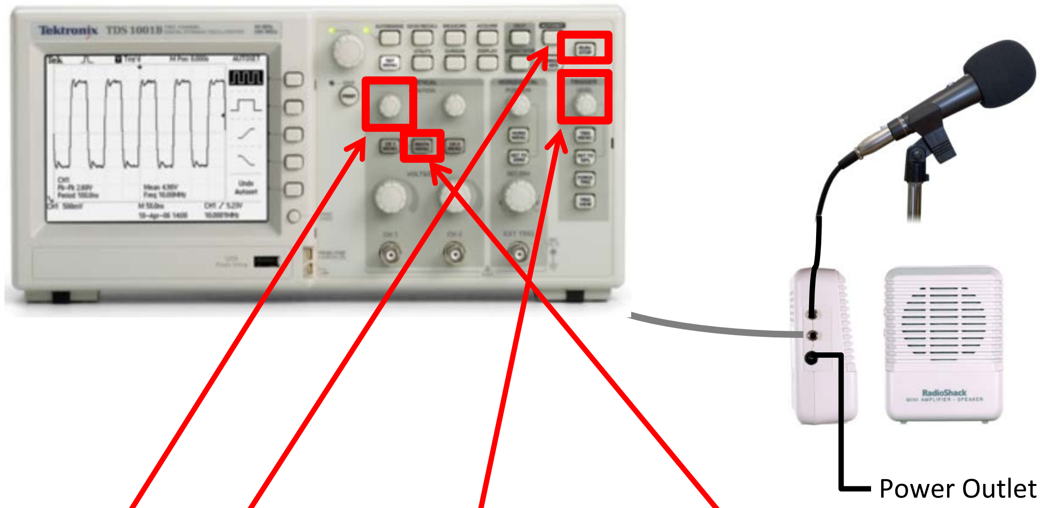
☐ Adjust the horizontal scale. How does this affect the o-scope display? Why?

☐ Using the dial on the Agilent Function Generator, repeat your previous step of adjusting the amplitude and frequency of the sine wave and record your observations.

Exploring a voice signal in time and frequency.

Since a sine wave is as simple as it gets, we'll modify the setup to display a more complicated signal: Voice.

☐ This section of the lab will continue using the o-scope and speaker, remove the function generator, and add a microphone. Set your equipment up as indicated below:



☐ Use *Autoset* to calibrate the o-scope if desired. You will likely need to adjust the horizontal and vertical axis by hand. 1.00 V/div and 2.50 ms are good starting points for this section.

☐ Speak into the microphone to observe the real-time signal your voice makes. You may need to adjust the *vertical position* of the signal and the *trigger* to observe a better waveform. Experiment with using lower and higher pitches and multiple speakers. Record your results.

☐ Press the *Run/Stop* button at various times to examine a "snapshot" of your voice signal. Record your results *(images of o-scope display are encouraged!*).

☐ To observe the near-real-time frequency content of your voice signal, select the *Math Menu* button. Continue speaking in the microphone to observe changes in the spectrum. Record your results *(images of o-scope display are encouraged!*).

Deliverables for Part I

1. Discussion of your procedure and findings regarding your exploration of a simple sinusoidal signal in the time domain. Include:
    a. A mathematical representation of your initial sine wave.
    b. How amplitude and frequency changes impacted both the o-scope display and the speaker audio output. Answer any questions posed in the lab procedure.
2. Discussion of your procedure and findings regarding your exploration of a simple sinusoidal signal in the frequency domain.
3. Discussion of your procedure and findings regarding your exploration of real-time voice in time and frequency.
4. Compare and contrast your simple sinusoidal signal and voice signal experiments. Point out any similarities and differences. (Images of your o-scope screen are recommended!)

- PART 2 -
Signal Analysis in MATLAB

Set-up.
Part 2 of this lab will be completed in MATLAB. If you do not have MATLAB installed on your laptop, go to:
http://intranet.usna.edu/ITSC/software-hardware/index.php
Scroll down to MATLAB and carefully follow the installation instructions. Please note that it will take about 30 minutes to complete the MATLAB installation, so you may want to do it ahead of time.

A Simple Sinusoid in MATLAB
First, we'll get used to MATLAB by generating a 440 Hz sine wave. Then we'll determine the frequency content using the provided `getSpectrum.m` function. **Note:** *When unsure how to use a command in MATLAB, use* `help`*!*

Additional tutorials:

https://www.tutorialspoint.com/matlab/matlab_plotting
https://www.mathworks.com/help/matlab/ref/plot.html

☐ Create a 440 Hz sinusoid. The following MATLAB commands may be useful:

```
fs = 10e5;                % "fs" is sampling frequency
f0 = 440                  % "f0" is the frequency (in Hz) of the sinusoid
A = 1;                    % "A" is the amplitude of the sinusoid, 1.0 Volts
Ts = 1/fs;                % "Ts" is the time between samples
dur = 1/f0 * 1e3;         % "dur"ation for 1000 periods of f0
N = fs*dur;               % "N" is the number of samples of the sinusoid for duration
t = 0:Ts:(N-1)*Ts;        % "t" is the time vector (StartTime:StepSize:StopTime)
s1 = A.*sin(2*pi*f0*t);   % "s1" is our signal vector (a 440 Hz sinusoid)
```

☐ To display your 440 Hz sinusoid, plot the signal as a function of time. When plotting the signal, the following plot options/commands may help:

```
plot(x,y,'m-','linewidth',2)    % These plot options produce lines of different
                                % colors/styles, as well as a thicker line that's
                                % easier to see.

axis([xmin xmax ymin ymax])     % Sets the amount of the waveform that's visible
                                % in the figure window so that you don't get a
                                % big blue (or pink, in this case) blob.  Suggest
                                % setting xmax to 10 µs or less.

xlabel('label (units)')         % All figures should have meaningful titles
ylabel('label (units)')         % and axes labels.
title('Title')
grid on;
```

☐ Next, we need to display the spectrum of our signal. Frequency content of sampled signals on a computer are calculated using the Fast Fourier Transform (FFT). Exactly how the FFT works is beyond the scope of this class, so we're going to use a MATLAB function, `getSpectrum.m`, to find the frequency spectrum of the signal. We can call the function with the statement:

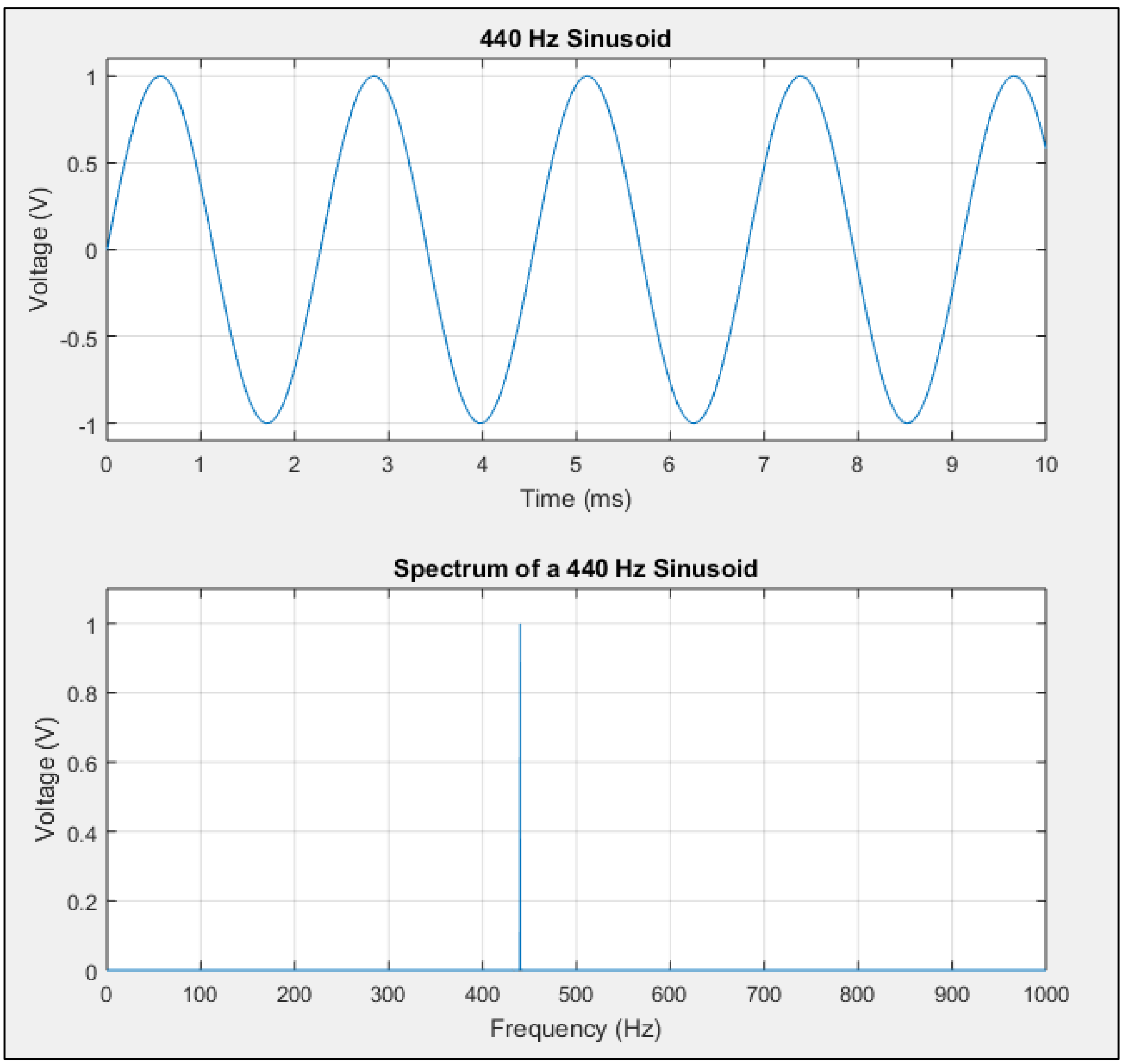
```
[freq, amp] = getSpectrum(amplitude, f_sampling)
```

getSpectrum.m:

```
function [freq, amp] = getSpectrum(amplitude, f_sampling)
%
% Generates the frequency spectrum of a time-domain signal
% Input to the function are the waveform samples and sampling frequency.
% Outputs are amplitude (in Volts) and Frequency (in Hz).
%

a = length(amplitude);
amp = fftshift(fft(amplitude,a))/a;
amp = abs(amp) * 2; %to show magnitude only and scale for half of signal power in negative frequencies
freq = (-(a/2 - 1):((a/2))) * ((f_sampling)/a);
end
```

☐ Your plot should look similar to this:



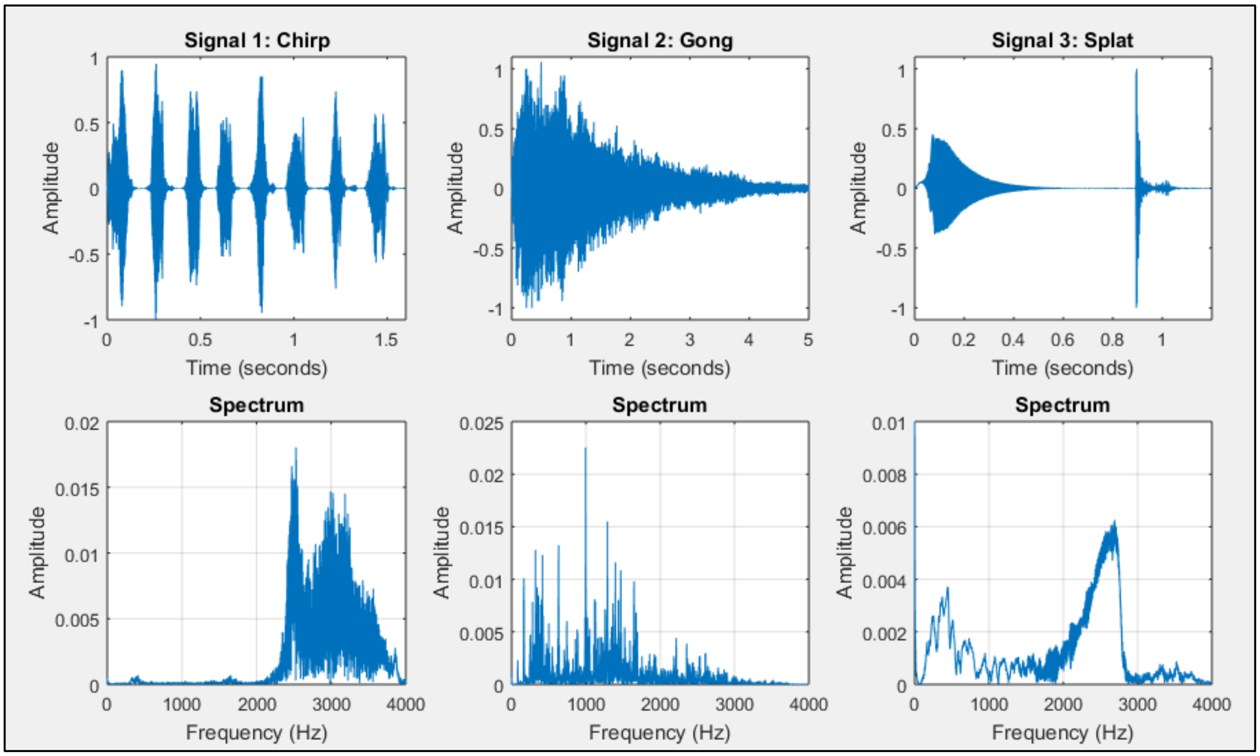
Spectrum of Signals with Multiple Frequencies

Similar to the real-time voice signal analysis you performed in Part 1, MATLAB includes sounds clips (`chirp`, `gong`, and `splat`) that can be played and displayed.

- ☐ The following code is provided to assist you in accessing these clips:

```
load chirp;
Fs = 8192;
s1 = y;
soundsc(s1,Fs);
```

- ☐ Plot these signals as a function of time.
- ☐ Obtain the frequency content of these signals using the `getSpectrum.m` function.
- ☐ Plot frequency content of these signals under their time domain representations. Something along these lines works:

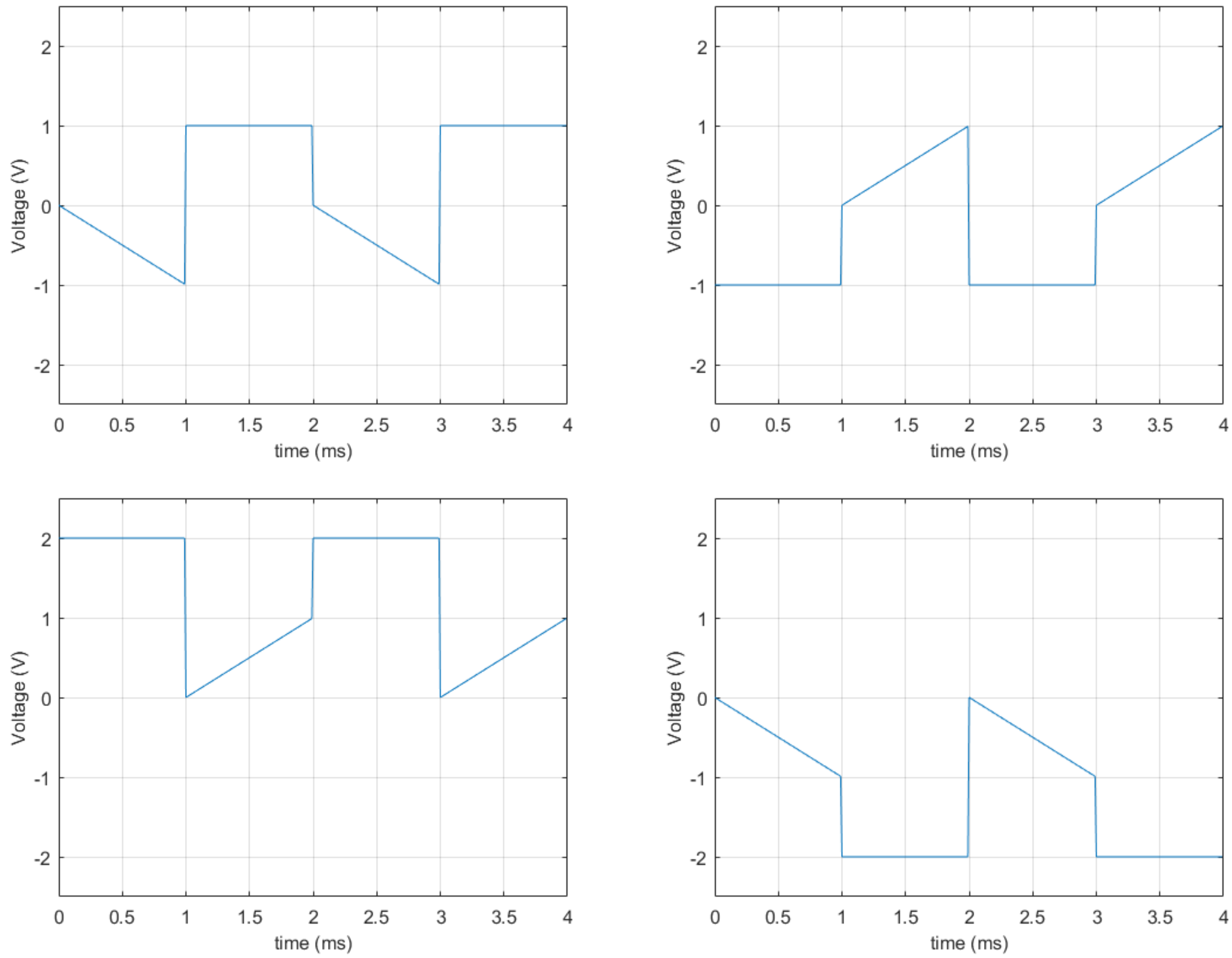


Deliverables for Part 2

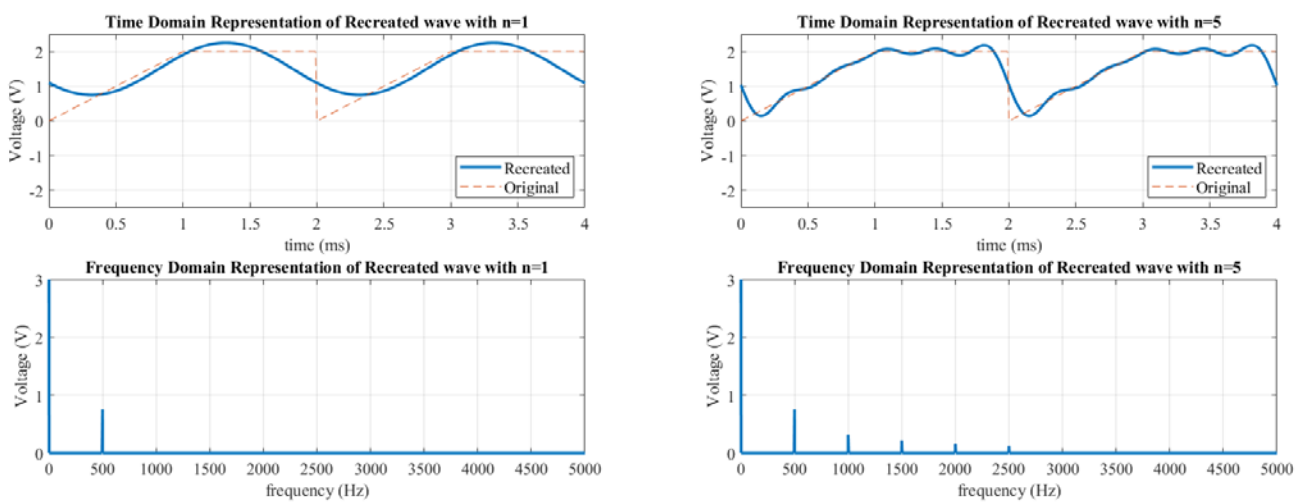
1. Plot of 440 Hz sinusoid in time and frequency. A single figure with two subplots is preferred! (Remember, all figures should have meaningful titles and axes labels!)
2. Plots of time and frequency domain representations of the MATLAB chirp, gong, and splat. A single figure with 6 subplots is preferred!
3. Discussion of findings for time and frequency domain of all four signals, to include signal bandwidth.
4. Printed, formatted MATLAB code for all plots (in Appendix).

- PART 3 -
Fourier Analysis

☐ Using Fourier series, graph the sinusoid and spectrum for the 1, 5, 10, and 100 elements (e.g. for 10 elements, the summation will from 1 to 10) of one of the give waveforms:



You should use 4 separate figures, each building on the previous, similar to the figures below. <u>Note</u>: Your sampling frequency should be *at least* 10 times the highest frequency component of your signal.



Deliverables for Part 3

1. Your factors of A_0, A_n, and B_n. (Calculations for each should be in an Appendix)
2. Plots (4) of the recreated wave and the corresponding spectrum with 1, 5, 10, and 100 elements. (Remember, all figures should have meaningful titles and axes labels!)
3. Printed, formatted MATLAB code for all plots (in Appendix).
4. Discussion of findings, to include how closely your signal approximates the original wave and bandwidth required.