Lab 4

Signal Analysis Using The Discrete Fourier Transform

ELECENG 3TP3

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Part 1.2

Listen to the contents in the file `tones2022.wav` using a media player on the PC or laptop that you are using. Describe what you hear.

The tones2022 file is a 10-second long, constant high-pitch noise.

Part 1.3

```
[signal, Fs] = audioread("tones2022.wav"); % Read in the signal
from the audio file
L = length(signal);  %Number of samples in the signal
T = 1/Fs; % Sampling period in seconds
t = [0:L-1]*T; % Time vector in seconds

% Plot the signal for t_plot msec
t_plot = 5;
msec_per_sec = 1000;
numSamples = t_plot*Fs/msec_per_sec;
plot(msec_per_sec*t(1:numSamples), signal(1:numSamples))
title('Gurleen Dhillon 400301955, Muneeb Shah 400307005')
xlabel('time (milliseconds)')
grid('minor');

%export graph
exportgraphics(gcf, 'lab4_part1a.jpg');
```

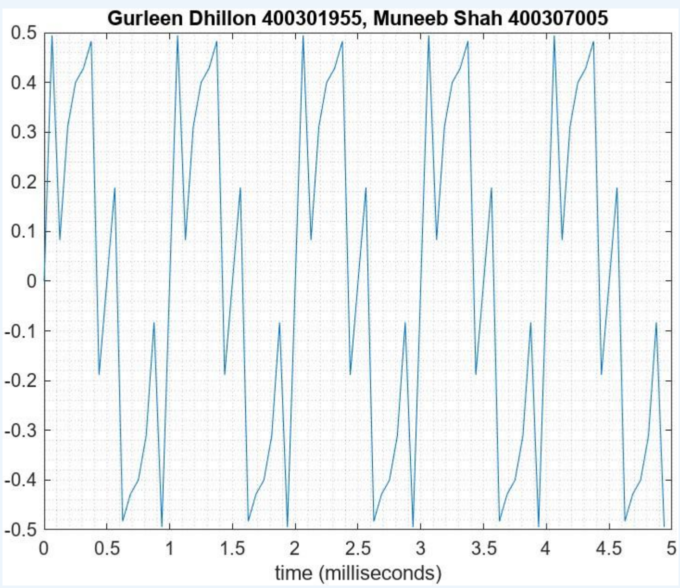


Figure 1: 5ms of waveform file containing the input signal

Part 1.4

Based on what you see in Part 3, estimate how many sinusoids make up the signal, and estimate their frequencies. Describe in detail how you made these estimations.

Based on the graph from part 3, we can conclude that there are 3 sinusoids in the signal due to the 3 peaks. There is a large amount of noise in the signal, and this is due to the combination of several sinusoids.

Part 1.5

```
% Take the DFT
Y = fft(signal)/L;
Ys = fftshift(signal)/L;
f = Fs/2*linspace(0,1,L/2+1);

% Plot the single-sided magnitude spectrum.
stem(f,2*abs(Y(1:L/2+1)))
hold on
stem(f,2*abs(Ys(1:L/2+1)))
title ('Gurleen Dhillon 400301955, Muneeb Shah 400307005')
xlabel('Frequency (Hz)')
ylabel('|Y(f)|')
axis([0 Fs/2 0 .5]);
grid('minor');
hold off

%export graph
exportgraphics(gcf, 'lab4_part1b.jpg');
```

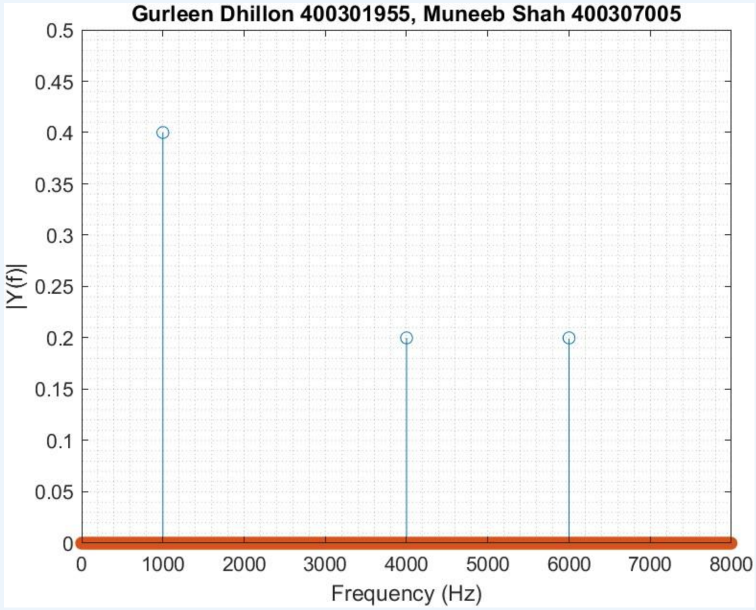


Figure 2: stem plots of the DFT using the fft and fftshift functions on matlab on the same plot

The stem plot seen in Figure 2 can be related to the audio signal. As seen in Figure 1, the stem plots here represent each sinusoid shown in that output with their respective frequencies.

Part 1.6

```
% Plot the single-sided magnitude spectrum.
plot(f,2*abs(Y(1:L/2+1)))
title('Gurleen Dhillon 400301955, Muneeb Shah 400307005')
xlabel('Frequency (Hz)')
ylabel('|Y(f)|')
axis([0 Fs/2 0 .5]);
grid('minor');

%export graph
exportgraphics(gcf, 'lab4_part1c.jpg');
```

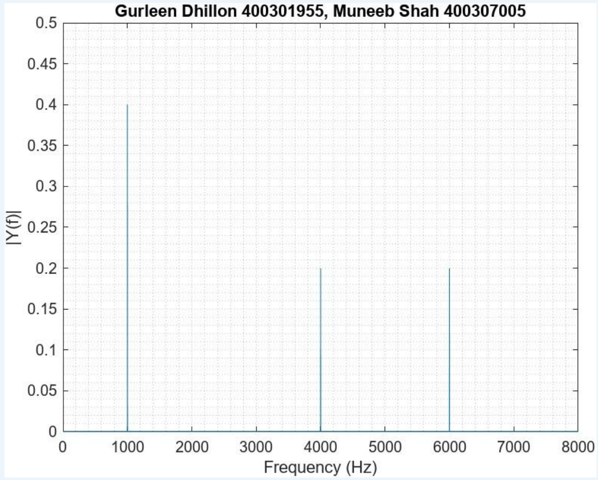


Figure 3: A single-sided magnitude spectrum that displays the frequencies and their corresponding magnitudes of the sinusoid from the audio signal.

Part 1.7

Using your results from Part 6, determine the frequencies and magnitudes of the sinusoids that make up the audio signal.

As seen in the graph from part 1.6, the frequencies of the sinusoids are 1000Hz, 4000Hz, and 6000Hz, and their respective magnitudes are 0.4, 0.2, and 0.2.

Part 1.8

```
clear
Fs = 16000;
T = 1/Fs; % Sampling period in seconds
t = [0:T*1000:5]; % Time vector in seconds

%create sinusoids with amplitudes and frequencies
sin1 = 0.4*sin(1*2*pi*t);
sin2 = 0.2*sin(4*2*pi*t);
sin3 = 0.2*sin(6*2*pi*t);
sin_total = sin1 + sin2 + sin3;

% Plot the signal for t_plot msec
plot(t, sin_total)
title('Gurleen Dhillon 400301955, Muneeb Shah 400307005')
xlabel('time (milliseconds)')
grid('minor');
```

```
%export graph
exportgraphics(gcf, 'lab4_part1d.jpg');
```

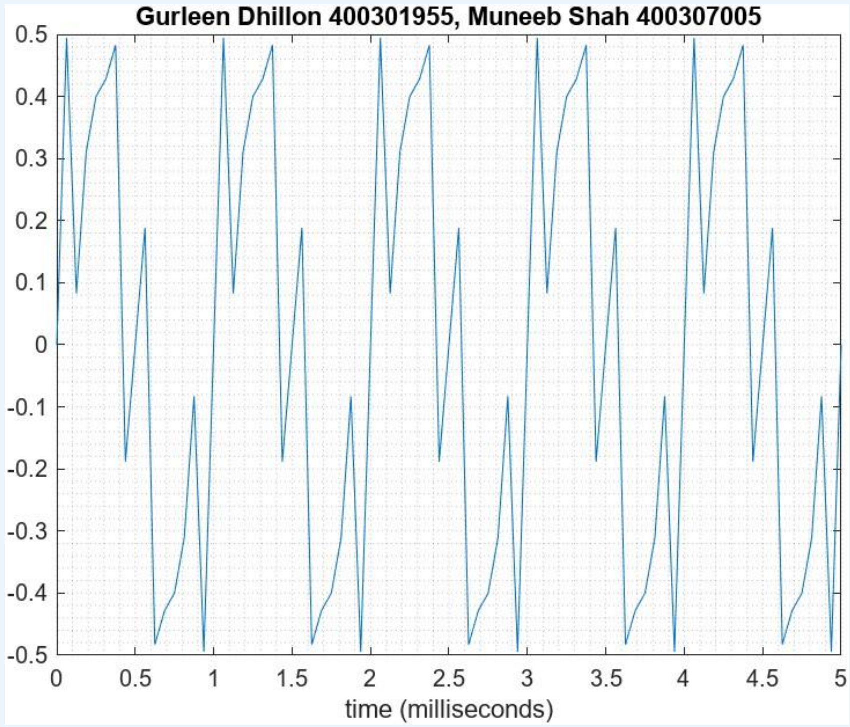


Figure 4: The reconstructed input audio signal using the frequencies and magnitudes over a 5ms range

When comparing the original input audio signal in part 1.3, it can be seen that the reconstructed input audio signal in figure 4 is identical. This means that the reconstruction was successful.

Part 2.2

As before, listen to the received signal and see if you can hear the tones that were sent. Describe what you hear.

The SecretMessage2022 file is a 76-second-long audio file comprised of 2 sounds: a static noise and a high-pitch noise that changes in volume.

Part 2.3

Using procedures such as that discussed in Part I, determine all of the frequencies that are used in this signal.

```
clear
[signal, Fs] = audioread("SecretMessage2022.wav"); % Read in
the signal from the audio file
L = length(signal);  %Number of samples in the signal
T = 1/Fs; % Sampling period in seconds

% Take the DFT
Y = fft(signal)/L;
f = Fs/2*linspace(0,1,L/2+1);

% Plot the single-sided magnitude spectrum.
plot(f,2*abs(Y(1:L/2+1)))
title('Gurleen Dhillon 400301955, Muneeb Shah 400307005')
xlabel('Frequency (Hz)')
ylabel('|Y(f)|')
axis([0 Fs/2 0 .1]);
grid('minor');

%export graph
exportgraphics(gcf, 'lab4_part2a.jpg');
```

As seen from the graph, all frequencies used in the signal are 1000, 2000, 3000, 4000, 5000, 6000, and 7000 Hz.

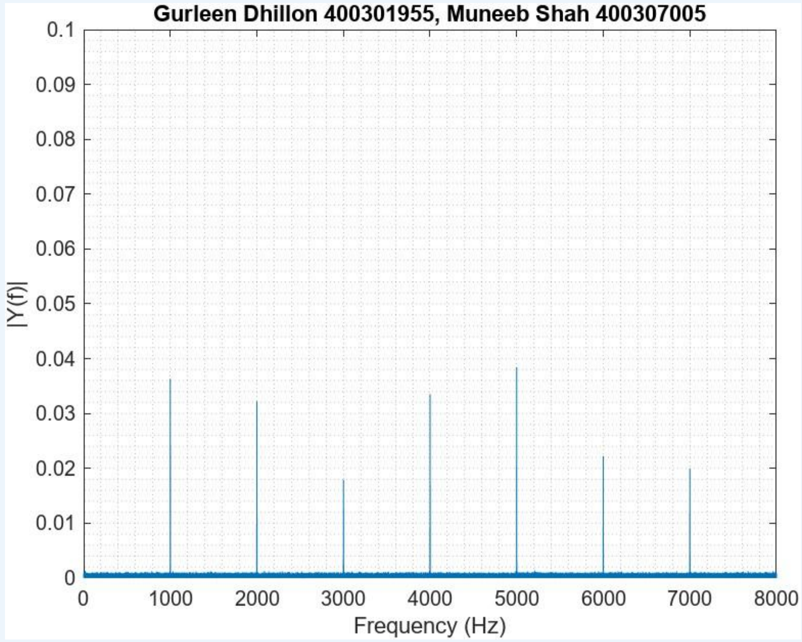


Figure 5: A single-sided magnitude spectrum that displays the frequencies and their corresponding magnitudes of the sinusoid from the audio signal

Part 2.4

The secret message in this file is encoded in multiple 1-second duration "symbol periods", where each period contains a single message character, encoded by sinusoidal tones. To decode the message you need to determine which frequencies are contained in each symbol period. Download the file CodeBook.pdf that will help you to decode the message. Include plots of the spectrum of each signal period in your report.

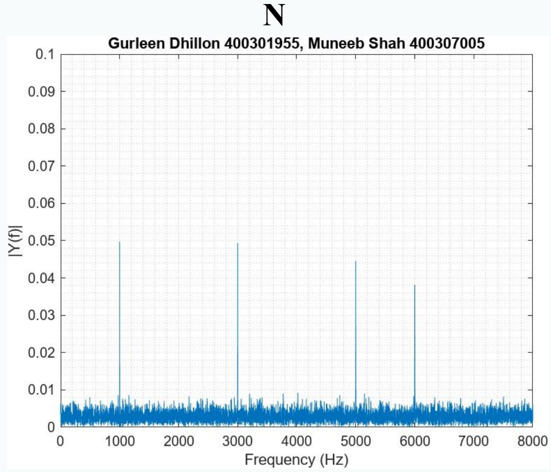
```
samples = [1*Fs, 2*Fs];
[signal, Fs] = audioread("SecretMessage2022.wav", samples); %
Read in the signal from the audio file
L = length(signal);  %Number of samples in the signal
T = 1/Fs; % Sampling period in seconds

% Take the DFT
Y = fft(signal)/L;
f = Fs/2*linspace(0,1,L/2+1);

% Plot the single-sided magnitude spectrum.
plot(f,2*abs(Y(1:L/2+1)))
title('Gurleen Dhillon 400301955, Muneeb Shah 400307005')
xlabel('Frequency (Hz)')
ylabel('|Y(f)|')
axis([0 Fs/2 0 .1]);
grid('minor');

%export graph
exportgraphics(gcf, 'lab4_part2a.jpg');
```

When changing the range of Fs, the message can be decoded. As seen in the bolded and highlighted blue text of the code, when shifting it every time for example for the next set, [2*Fs, 3*Fs] and so on, the entire message can be deciphered.

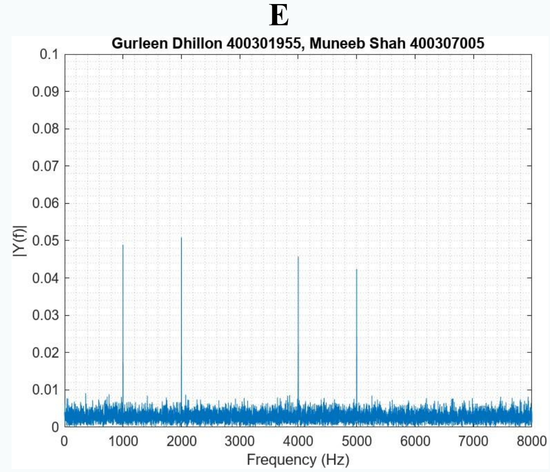
For the sake of marking, I will be including the plots of the first word, as 76 images may be a bit much (SEE NEXT PAGE). Instead, we have included all the frequencies of the words and characters we found.

The final decoded message is **"NEVER LET THE FEAR OF STRIKING OUT KEEP YOU FROM PLAYING THE GAME.BABE RUTH."**

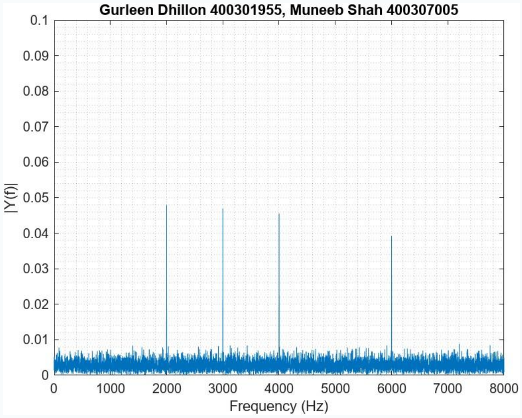
N



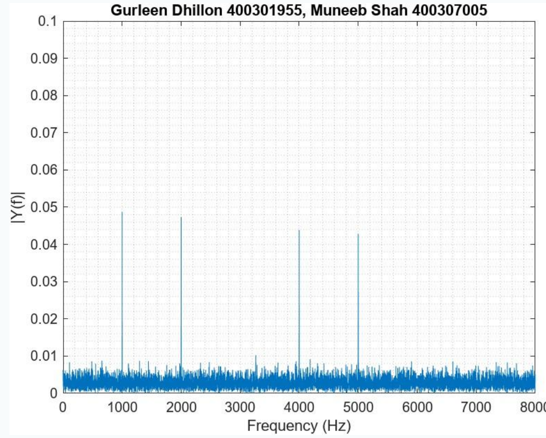
E



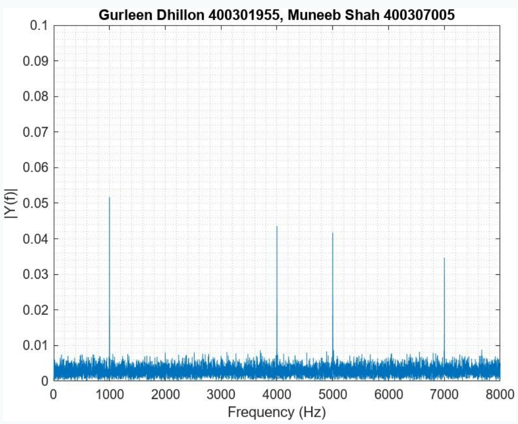
V



E



R



N [1000, 3000, 5000, 6000]
E [1000, 2000, 4000, 5000]
V [2000, 3000, 4000, 6000]
E [1000, 2000, 4000, 5000]
R [1000, 4000, 5000, 7000]

Frequencies	Coded Letters
[1000, 3000, 5000, 6000] [1000, 2000, 4000, 5000] [2000, 3000, 4000, 6000] [1000, 2000, 4000, 5000] [1000, 4000, 5000, 7000]	N E V E R
[2000, 4000, 5000, 6000]	space
[1000, 3000, 4000, 7000] [1000, 2000, 4000, 5000]	L E

[1000, 5000, 6000, 7000]	T
[2000, 4000, 5000, 6000]	space
[1000, 5000, 6000, 7000] [1000, 2000, 5000, 6000] [1000, 2000, 4000, 5000]	T H E
[2000, 4000, 5000, 6000]	space
[1000,2000, 4000, 6000] [1000, 2000, 4000, 5000] [1000, 2000, 3000, 4000] [1000, 4000, 5000, 6000]	F E A R
[2000, 4000, 5000, 6000]	space
[1000, 3000, 5000, 7000] [1000,2000, 4000, 6000]	O F
[2000, 4000, 5000, 6000]	space
[1000, 4000, 6000, 7000] [1000, 5000, 6000, 7000] [1000, 4000, 5000, 6000] [1000, 2000, 5000, 7000] [1000, 3000, 4000, 5000] [1000, 2000, 5000, 7000] [1000, 3000, 5000, 6000] [1000, 2000, 4000, 7000]	S T R I K I N G
[2000, 4000, 5000, 6000]	space
[1000, 3000, 5000, 7000] [2000, 3000, 4000, 5000] [1000, 5000, 6000, 7000]	O U T
[2000, 4000, 5000, 6000]	space
[1000, 3000, 4000, 5000] [1000, 2000, 4000, 5000] [1000, 2000, 4000, 5000] [1000, 3000, 6000, 7000]	K E E P
[2000, 4000, 5000, 6000]	space

[2000, 3000, 5000, 7000] [1000, 3000, 5000, 7000] [2000, 3000, 4000, 5000]	Y O U
[2000, 4000, 5000, 6000]	space
[1000,2000, 4000, 6000] [1000, 4000, 5000, 6000] [1000, 3000, 5000, 7000] [1000, 3000, 4000, 7000]	F R O M
[2000, 4000, 5000, 6000]	space
[1000, 3000, 6000, 7000] [1000, 3000, 4000, 6000] [1000, 2000, 3000, 4000] [2000, 3000, 5000, 7000] [1000, 2000, 5000, 7000] [1000, 3000, 5000, 6000] [1000, 2000, 4000, 7000]	P L A Y I N G
[2000, 4000, 5000, 6000]	space
[1000, 5000, 6000, 7000] [1000, 2000, 5000, 6000] [1000, 2000, 4000, 5000]	T H E
[2000, 4000, 5000, 6000]	space
[1000, 2000, 4000, 7000] [1000, 2000, 3000, 4000] [1000, 3000, 4000, 7000] [1000, 2000, 4000, 5000]	G A M E
[2000, 4000, 5000, 6000]	space
[2000, 4000, 5000, 7000]	.
[1000, 2000, 3000, 5000] [1000, 2000, 3000, 4000] [1000, 2000, 3000, 5000] [1000, 2000, 4000, 5000]	B A B E
[2000, 4000, 5000, 6000]	space

[1000, 4000, 5000, 6000] [2000, 3000, 4000, 5000] [1000, 5000, 6000, 7000] [1000, 2000, 5000, 6000]	R U T H
[2000, 4000, 5000, 7000]	.