Department of Electrical
& Computer Engineering
Faculty of Engineering & Architectural Science

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Instructor:	Instructor: Professor Javad Alirezaie, TA: Brendan Wood

Assignment/Lab Number:	Lab 4
Assignment/Lab Title:	The Fourier Transform: Properties and Applications

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Lab 4 - The Fourier Transform: Properties and Applications

By: Syed Maisam Abbas

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Introduction

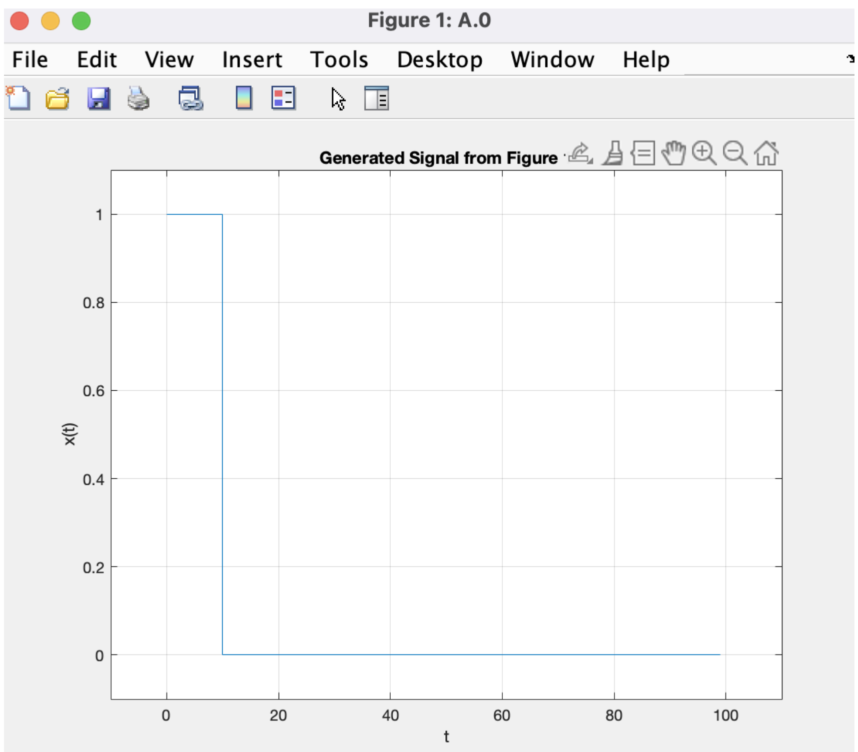
In this lab, the objective is to use the Fourier series to analyze, observe, and study frequency-domain characteristics of time waveforms while using MATLAB, the online programming software. Furthermore, this lab explores the properties of the Fourier series and utilizes the Fourier transform as a diagnostic tool to identify the characteristics of a bandpass transmission channel. Additionally, a simple communications system is designed and implemented that allows the user to transmit a voice signal over the bandpass transmission system and decode the received signal. These labs may prove to be beneficial in the future to analyze signals and different kinds of systems in the engineering field.

Lab Analysis

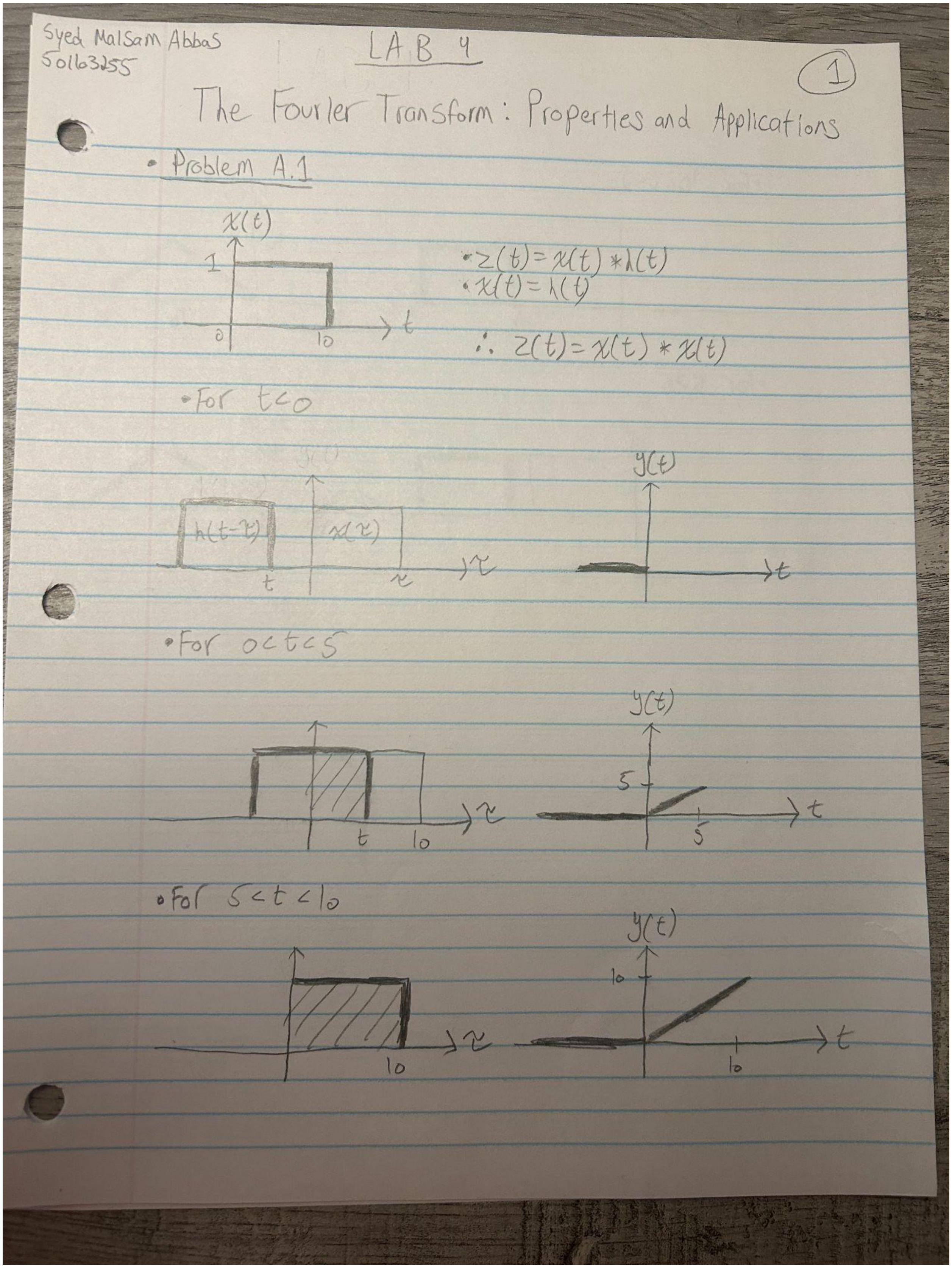
A. The Fourier Transform and its Properties

- **A.0**

Figure 1: This figure displays the plot of x(t) from Figure 1 of the lab manual



- **A.1**



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LAB 4

1

The Fourier Transform: Properties and Applications

- Problem A.1

- $z(t) = x(t) * h(t)$
- $x(t) = h(t)$

$\therefore\ z(t) = x(t) * x(t)$

- For $t<0$

- For $0<t<5$

- For $5<t<10$

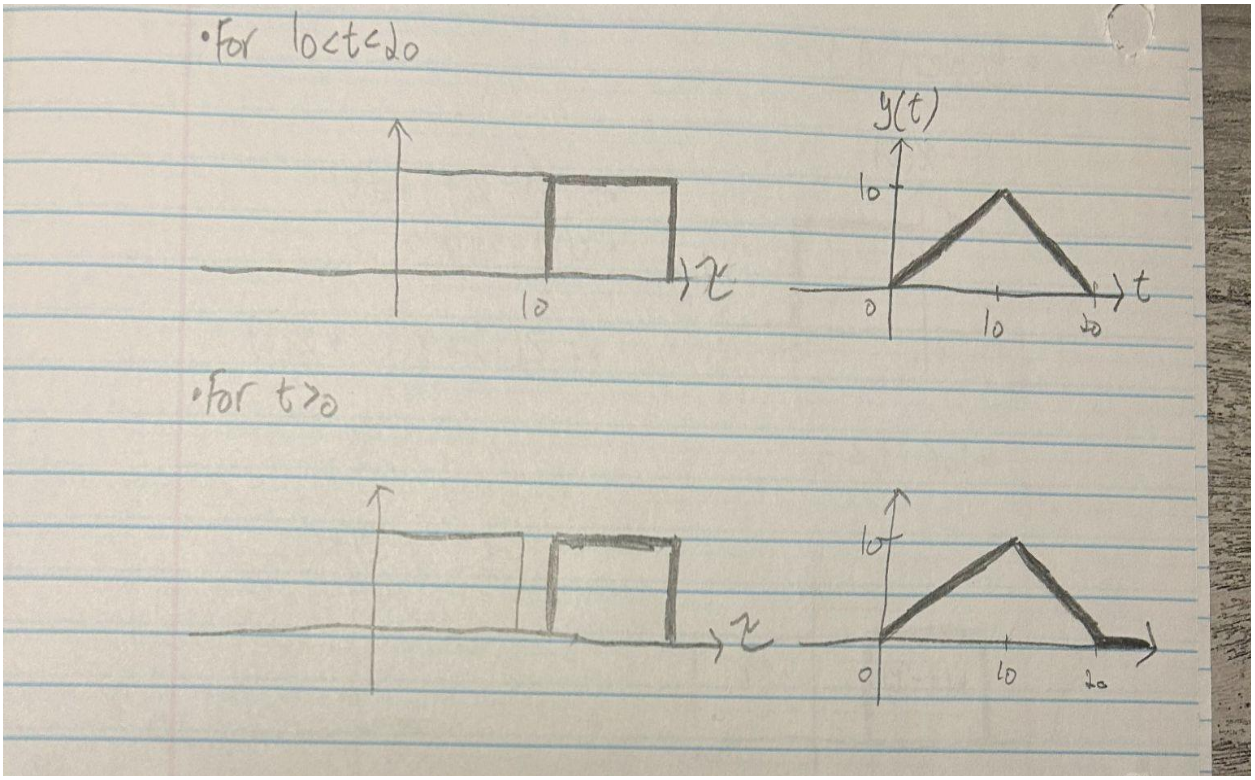
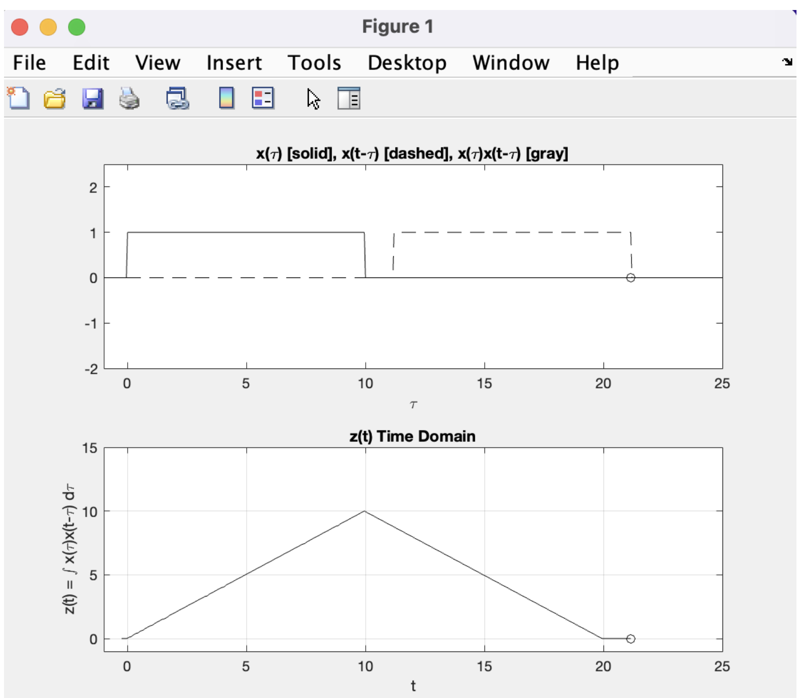


Figure 2: This figure displays the plot of z(t) calculated by x(t) * x(t)



- **A.2**

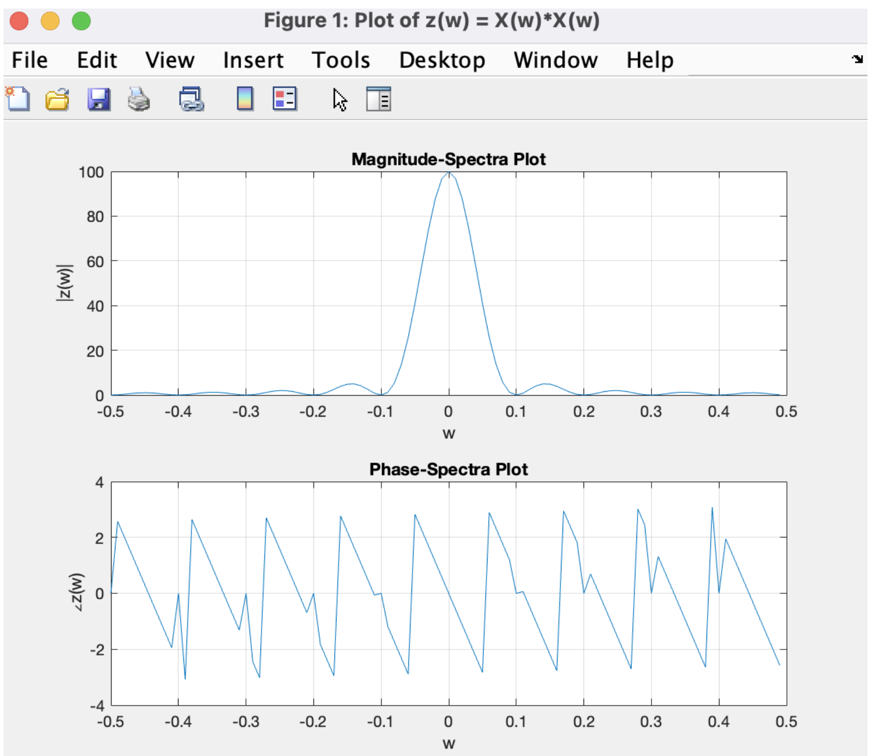
Figure 3: This figure displays the calculation of Z(w) = X(w) □ X(w) using MATLAB

```
% Compute X(w)
Xf = fft(x);

% Calculate Z(w) by multiplying in the frequency domain
zf = Xf.*Xf;
```

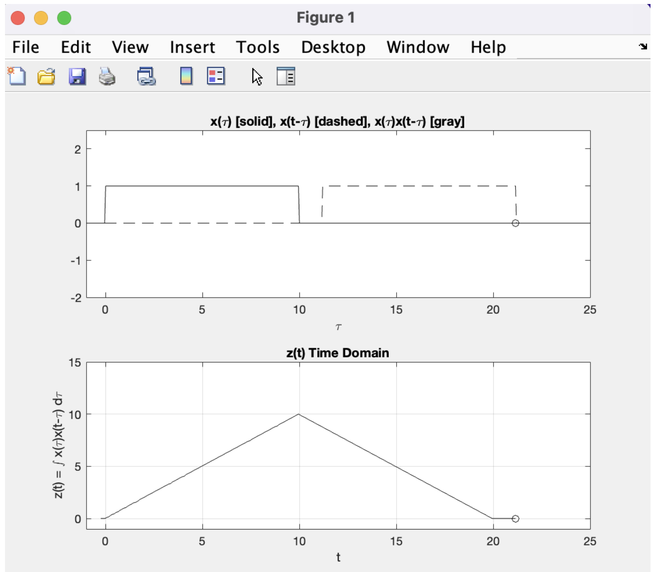
- **A.3**

Figure 4: This figure displays the magnitude- and phase-spectra plots of Z(w)



- **A.4**

Figure 5: This figure displays the plot of z(t) using MATLAB Fourier operations [x(t) * x(t)]



The outputs determined analytically in section A.1 are closely resembled by the results produced using both time and frequency domain operations. We found that when we generated z(t) by using convolution in the time domain and multiplication in the frequency domain, the outcomes were the same for both approaches. Therefore, it can be stated that the Fourier property used in this section is that the convolution of x(t) and y(t) is equal to the product of their respective Fourier transforms, written as X(w) and Y(w).

- **A.5**

Figure 6: Fourier Transform of x(t) with pulse width = 5, N = 1000

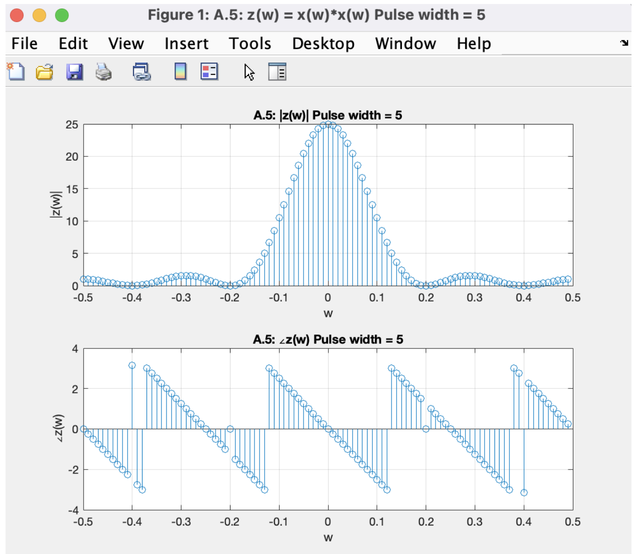
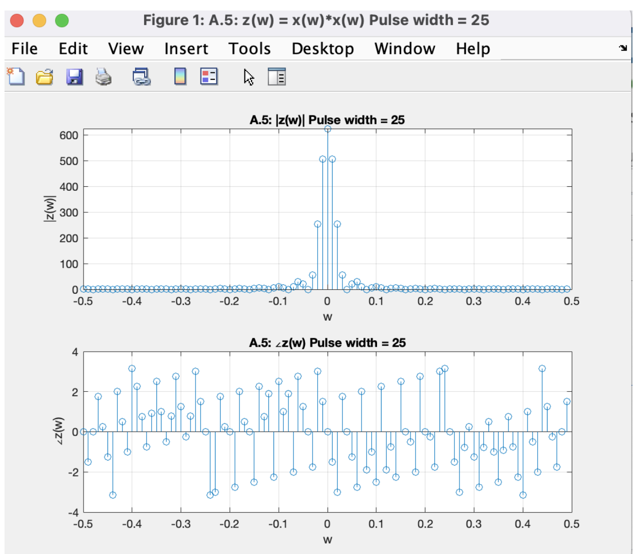


Figure 7: Fourier Transform of x(t) with pulse width = 25, N = 100



When the original function's pulse width is increased, the Fourier Transform shows a rise in both frequency and amplitude. On the other hand, the Fourier Transform's amplitude and frequency decrease when the pulse width is reduced. This feature of the Fourier Transform is frequently referred to as its time-scaling property.

- **A.6**

Figure 8: Magnitude- and Phase- Spectra for w+(t)

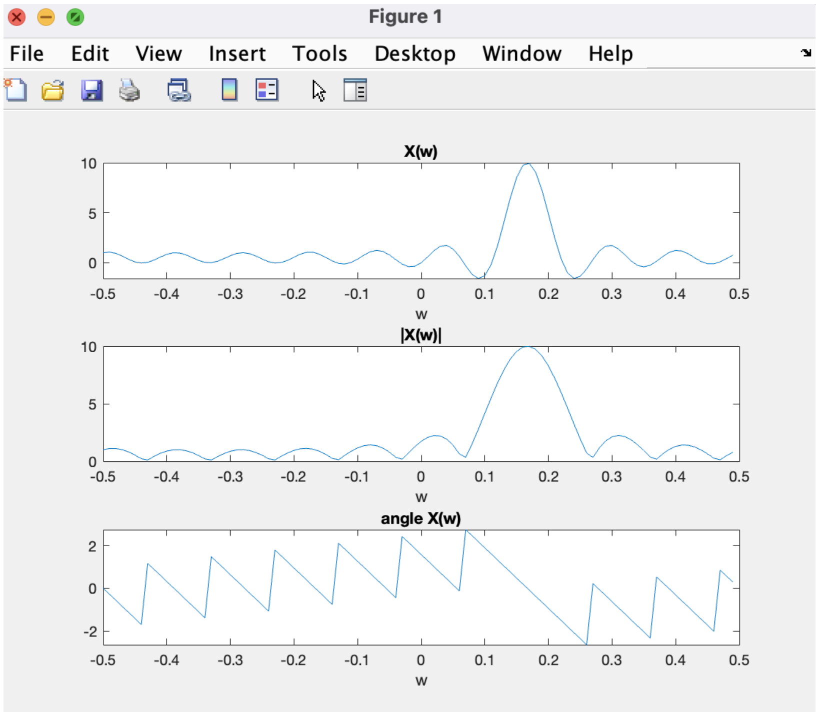


Figure 9: Magnitude- and Phase- Spectra for w-(t)

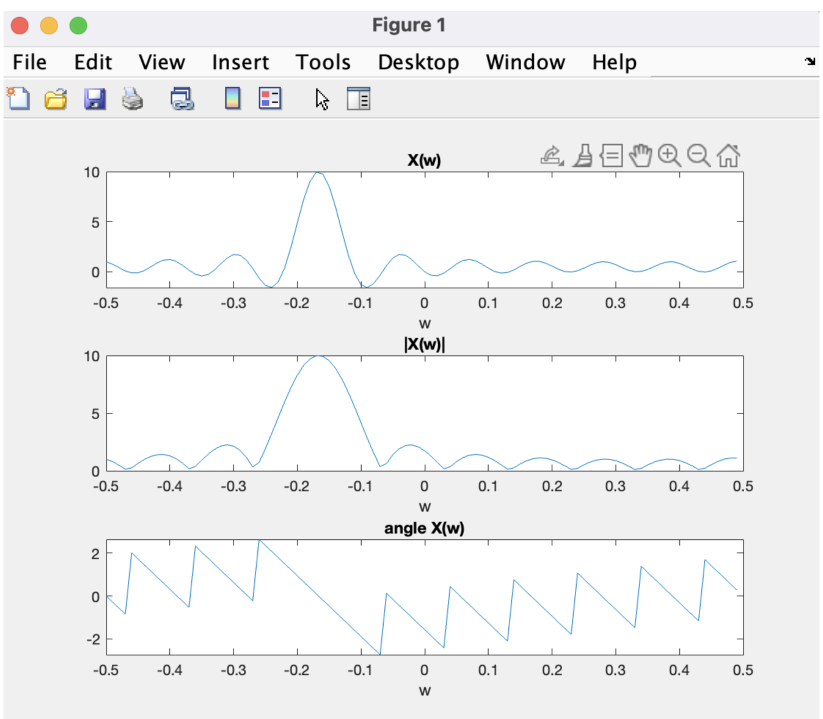
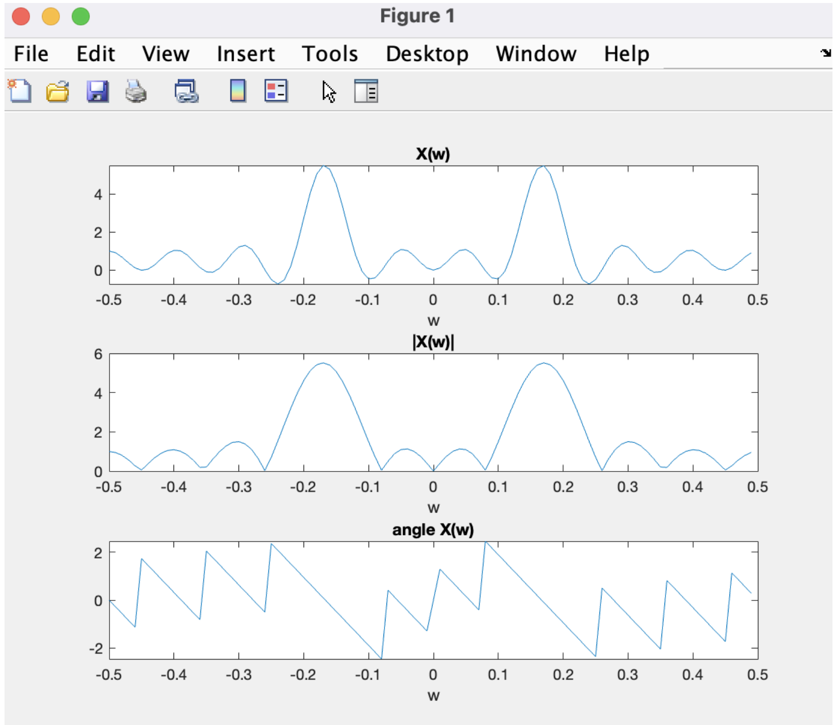


Figure 10: Magnitude- and Phase- Spectra for wc(t)



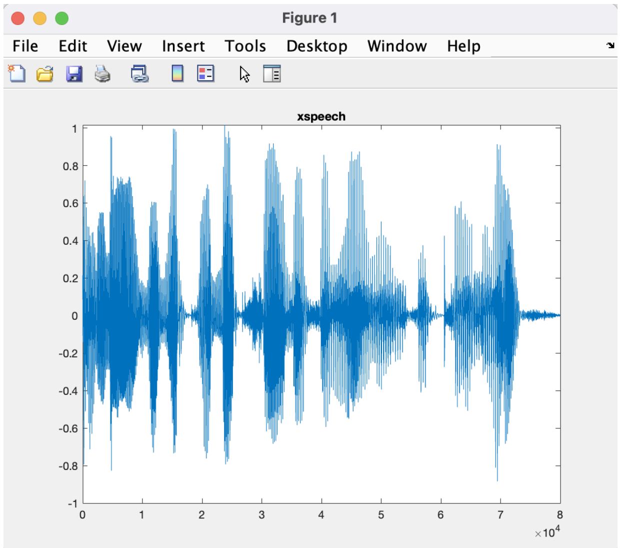
When we multiplied the original function by a complex exponential, it caused a shift in frequency. This interesting effect is known as the frequency shift property of the Fourier Transform. Essentially, if $x_1(t)$ has a Fourier Transform $x_1(jw)$, and we multiply $x_1(t)$ by e^{jw_0t}, the resulting function $x_2(t)$ will have a Fourier Transform $x_2(jw)$ equal to $x_1(j(w - w_0))$. This means that the entire frequency content of the signal $x_1(t)$ is shifted by w_0 in the frequency domain.

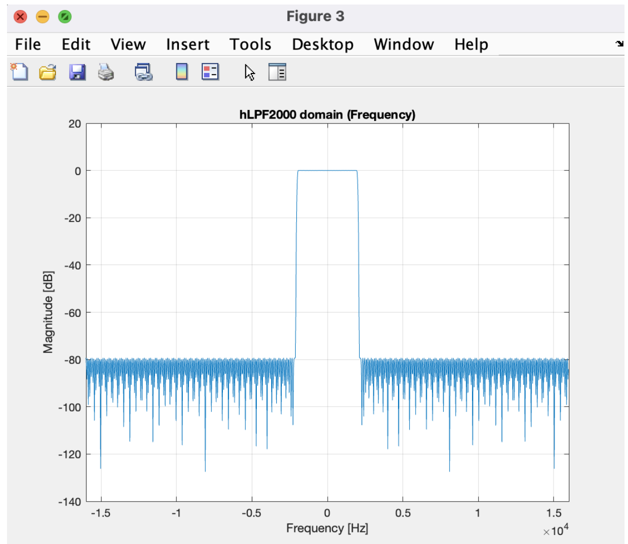
The equation, which demonstrates this Fourier Property is represented as:

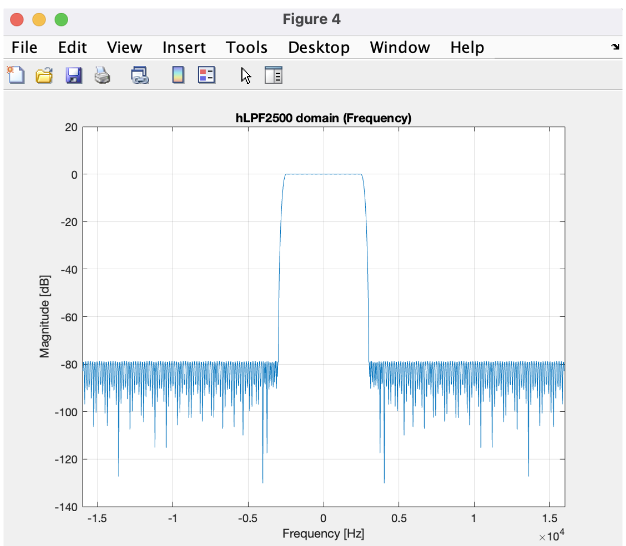
$$x_2(t) = e^{jw_0t} \bullet x_1(t) \quad \succ \quad X_2(jw) = X_1(j(w - w_0))$$

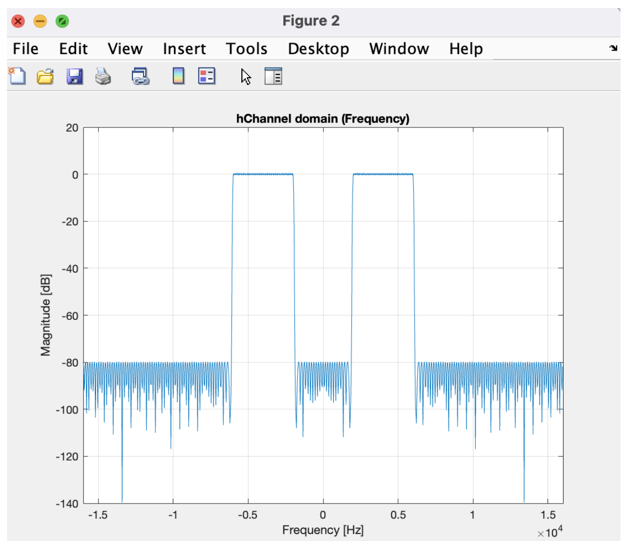
B. Application of the Fourier Transform

- Plotted data from the Lab4_Data.mat file to visualize the audio file and to generate a starting point for the Encoder and Decoder

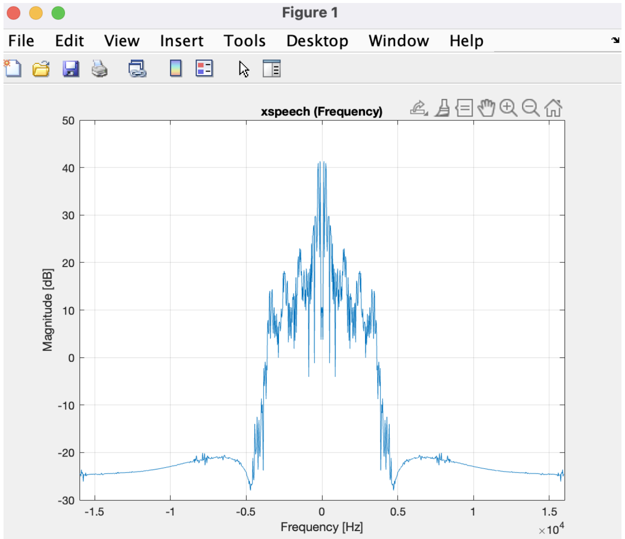


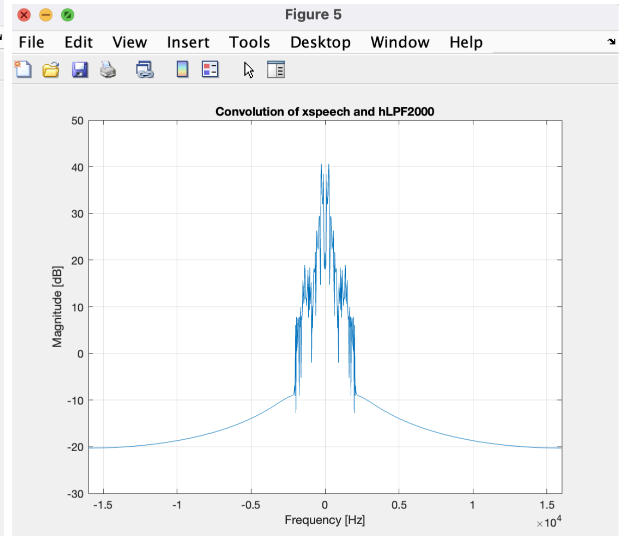


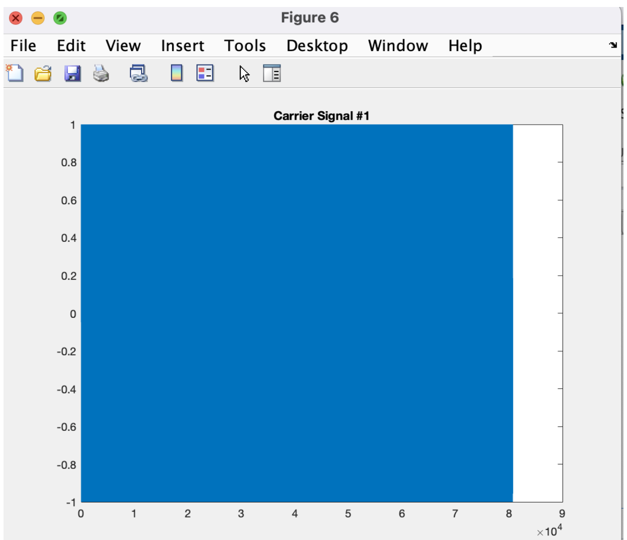


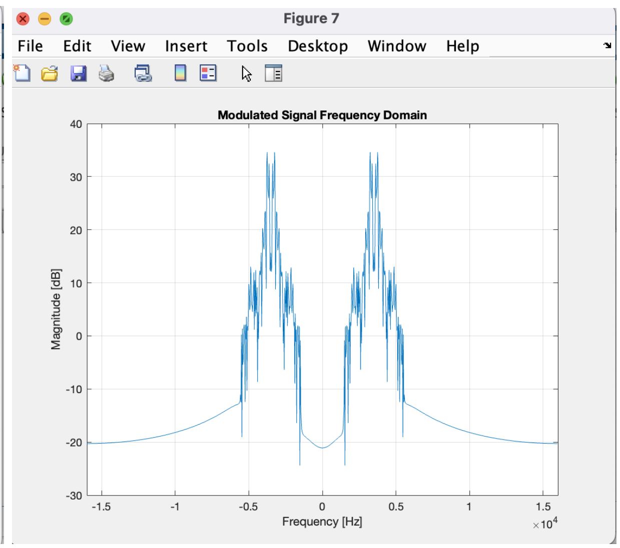


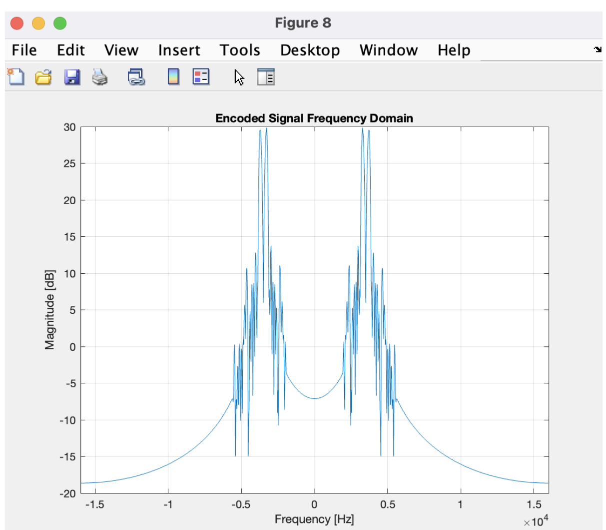
- Simulated Waveforms from the Encoder



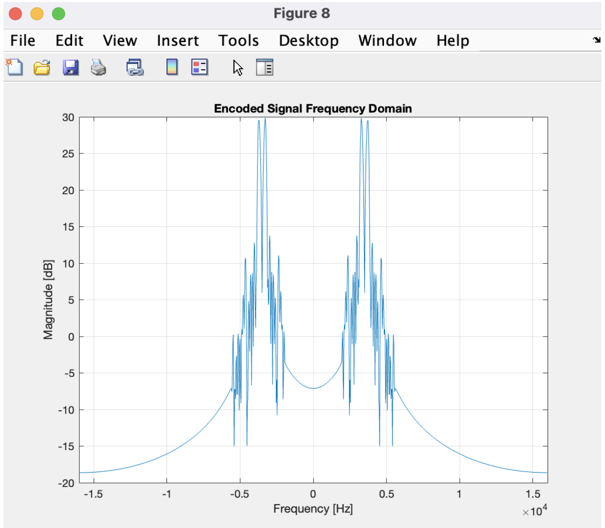


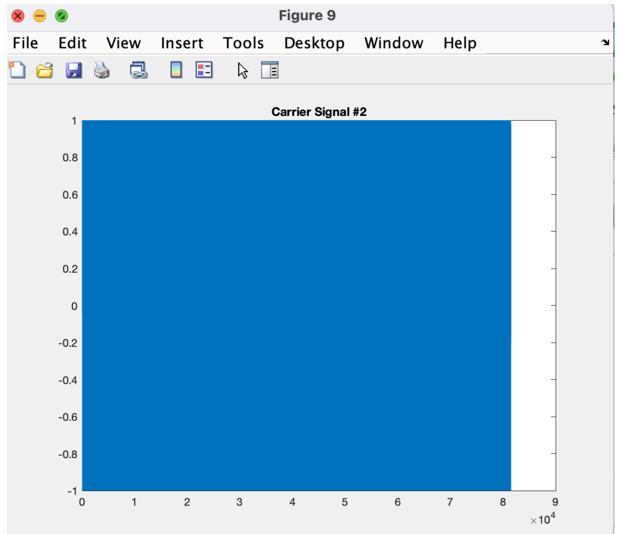


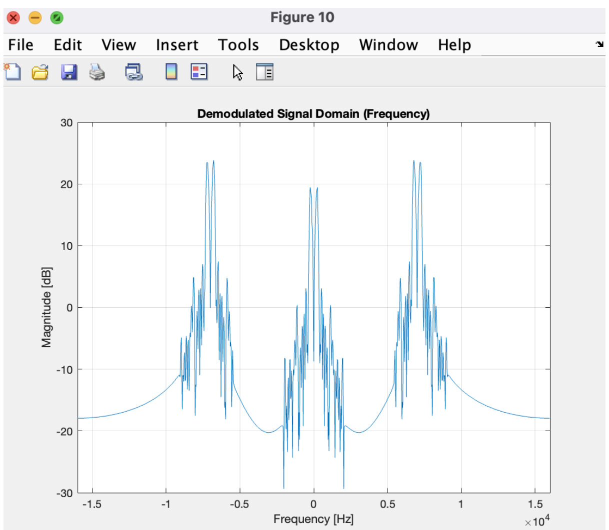


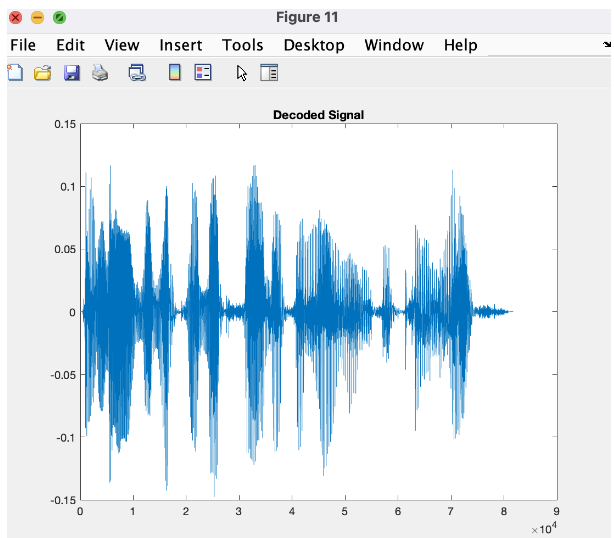


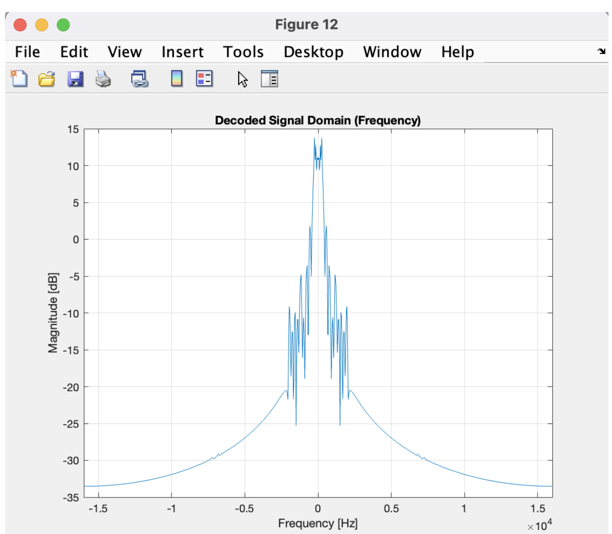
- Simulated Waveforms from the Decoder











- **B.1**

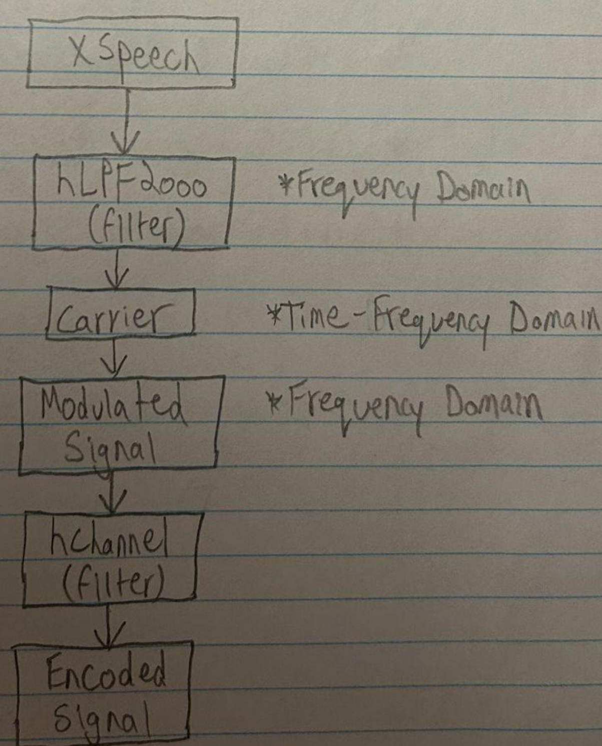
1

• Problem B.1

① Purpose

• Implement an audio transmission using an encoder and decoder. Compute the convolution of the xspeech file with the low pass filter, hLPF2000, modulating the result with a carrier signal, then convoluting again with the 'hchannel' filter. For the decoder, demodulating the signal, filter with the low-pass filter, hLPF2500.

• Conceptual Block Diagram representation:



② Domain-Analysis

- Analysis is proceeded in both time and frequency domain. Frequency is used to visualize the signal and filters in terms of their frequency components. The time domain is used to show the change of a signal over time.

③ Provided Data

- Magnitude Spectra is plotted using the 'Magspec' function

↳ xspeech: Input audio file

↳ hLPF2000: First Low-pass filter

↳ hLPF2500: Second Low-Pass filter

↳ Carrier: First carry signal

↳ Carrier_2: Second carry signal

↳ hChannel: Channel Filter

Step Analysis

3

4 Encoder

XSpeech (Frequency Domain)

↓ Convolution

hLPF2000 (Time Domain)

↓ Modulation

Carrier (Frequency Domain)

↓

hChannel (Frequency Domain)

↓

Encoded Signal (Frequency Domain)

- Magnitude Spectra is plotted after each Step for a visual representation of the frequency domain

5 Decoder

Encoded Signal (Frequency Domain)

↓ Demodulation

Carrier_2 (Frequency Domain)

↓ Convolution

hLPF2500 (Frequency Domain)

↓

Decoded Signal (Frequency Domain)

- Magnitude Spectra is plotted after each Step for a Visual representation of the frequency domain

- Once each of the Step listed above are completed, an audio Sound will play.

Conclusion

In conclusion, this lab proved to be very beneficial as it provided greater insight into MATLAB commands, graphing tools, data analysis, system properties, and Fourier series analysis (including the characteristics, coefficients, and signal reconstruction) These commands and operations will come of use in future applications of MATLAB and signal analysis.

Appendix

Lab4_data.mat

osc.m

MagSpect.m

- These files were provided prior to the execution of this lab and attached to the lab manual