

Introduction to Communication Systems and Networks

Laboratory L1 – Report

STUDENT 1

STUDENT 2 (Optional)

Name : _____Mike Wang_____

Name: ____Haowei Qiu_____

ID: _____260779031_____

ID: ____260762269_____

INSTRUCTIONS:

- Student(s) need to upload their report on *myCourses* before the due date.
- Upload a single, clearly readable pdf file, including this cover page plus answers.
 - DUE DATE: Tuesday Sept. 22

Part	Question	Mark
1	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
2	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	

McGill University

Montreal, Canada

Part 1: Presentation of Signals and Noise

1.1 Sine Wave

Question: Observe the outputs on Scope and Spectrum. Plot the Sine wave over Three periods. Indicate the amplitude, the period, and the frequency of the sine wave. What are the fundamental and harmonic components?

Answer: The amplitude of the sine wave is 1, the period of the sine wave is $0.38715\text{s} - 0.38705\text{s} = 0.0001\text{s}$, and the frequency of the sine wave is 10000 Hz. The fundamental frequency should in theory equal to the frequency of the sine wave, however as we observed in the frequency spectral which peaks at 9.776KHz, the fundamental frequency is 9.776KHz. The Harmonic frequency should be the integer multiple of the fundamental frequency, in this case they should be 19.552KHz, 29.328KHz, 39.104KHz, etc. However, in theory a sine wave should not contain any other harmonic frequency aside from its fundamental frequency.

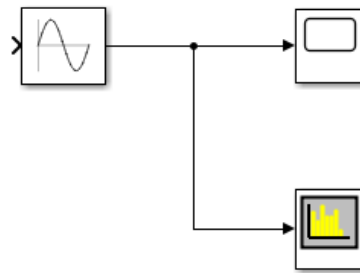


Figure 1: Simulink Diagram

Parameters	
Sine type:	Sample based
Time (t):	Use simulation time
Amplitude:	1
Bias:	0
Samples per period:	100
Number of offset samples:	0
Sample time:	1e-6

Figure 2: Sine signal generator configuration

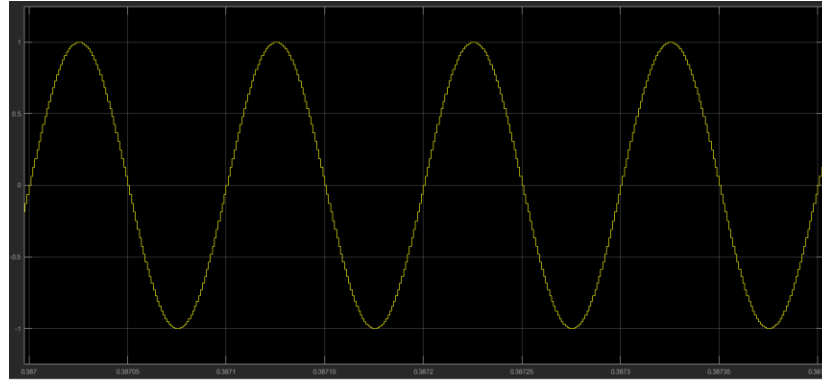


Figure 3: Scope plot with Sine signal

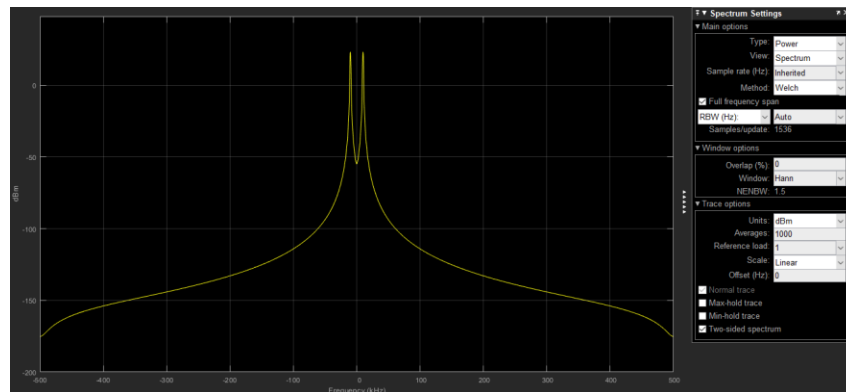


Figure 4: Spectrum plot with Sine signal

1.2 Triangle Wave

Question: Observe the outputs on Scope and Spectrum. Plot the Triangle wave over Three periods. Indicate the amplitude, the period, and the frequency of the sine wave. What are the fundamental and harmonic components?

Answer: The amplitude of the sine wave is 1, the period of the triangle wave is $0.38715\text{s} - 0.38705\text{s} = 0.0001\text{s}$, and the frequency of the sine wave is 10000 Hz. The fundamental frequency should in theory equal to 10kHz. The Harmonic frequency should be the odd integer multiple (From Fourier Series) of the fundamental frequency, in this case they should be 30KHz, 50KHz, 70KHz, etc.

Parameters

Frequency (Hz):

Phase (degrees):

Sample time:

Figure 5: Triangle wave parameters

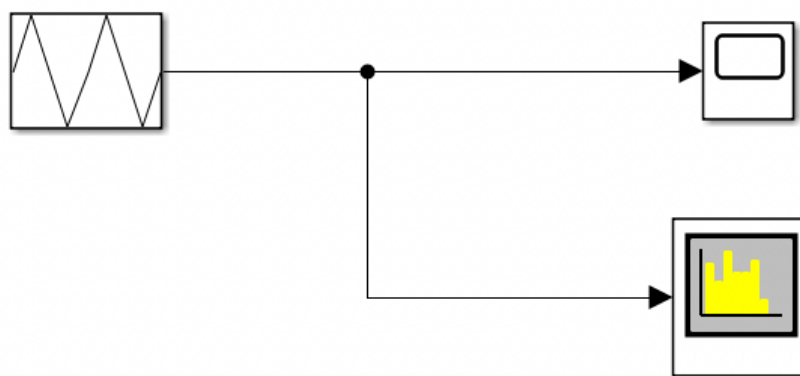


Figure 6: Simulink setup

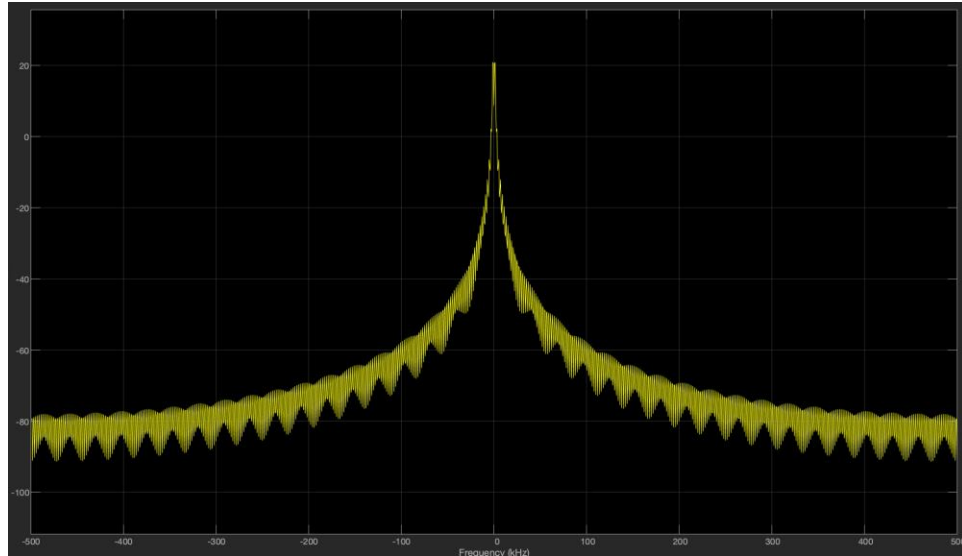


Figure 7: Spectrum Graph

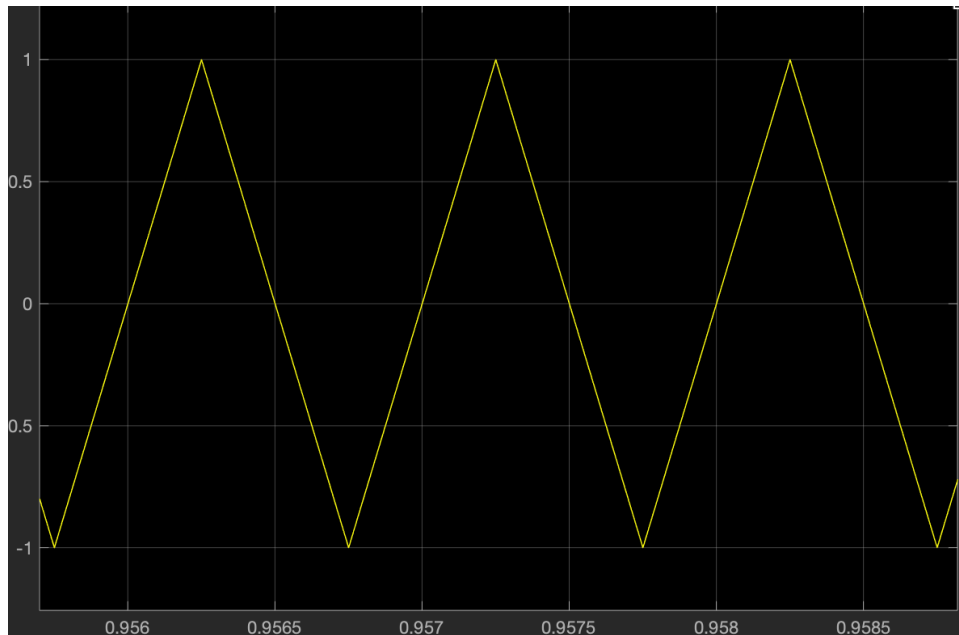


Figure 8: Scope Graph

1.3 Pulse Wave

Question: Observe the outputs on Scope and Spectrum. Plot the 50% duty cycle square wave over Three periods. Indicate the amplitude, the period, and the frequency of the 50% duty cycle square wave. What are the fundamental and harmonic components?

Answer: The amplitude of the 50% duty cycle square wave is 1. The period of the 50% duty cycle square wave is $0.4039\text{s} - 0.4038\text{s} = 0.0001\text{ s}$. The frequency of the 50% duty cycle (where the 1 occupies 50% of the period of the signal) square wave is 10 kHz.

The fundamental component is 10kHz, the harmonic component is in this case they should be odd multiple of the fundamental frequency 30KHz, 50KHz, 70KHz, etc.

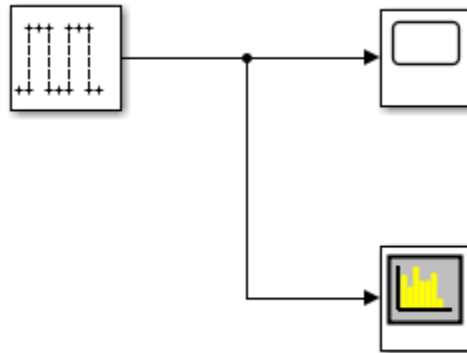


Figure 9: Simulink Diagram

Parameters	
Pulse type:	Sample based
Time (t):	Use simulation time
Amplitude:	1
Period (number of samples):	100
Pulse width (number of samples):	50
Phase delay (number of samples):	0
Sample time:	1e-6
<input checked="" type="checkbox"/> Interpret vector parameters as 1-D	

Figure 10: Pulse signal generator configuration

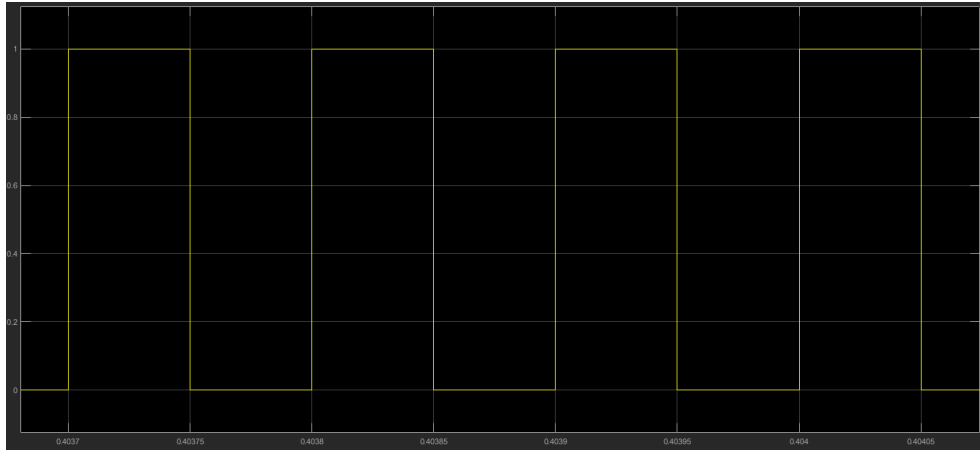


Figure 11: Scope plot with pulse signal

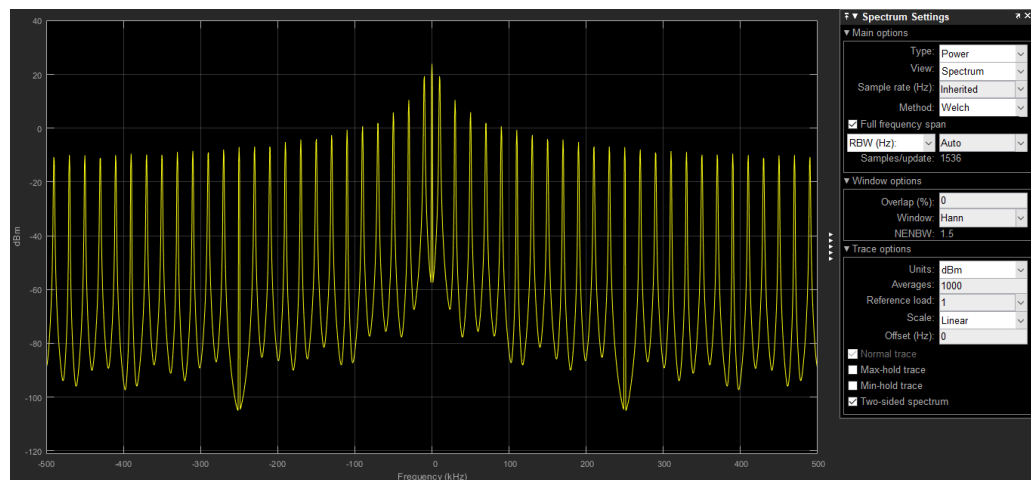



Figure 12: Spectrum plot with Pulse signal


1.4 Sine + Triangle + Pulse waves

Question: Observe the scope and spectrum analyzer for the following setup and comment on fundamental and harmonic components of the three signals.

Answer: As we can observe from the scopes, the fundamental frequency for the pulse and sine wave are $1/(0.28065\text{s}-0.28075\text{s}) = 10000\text{Hz}$, the fundamental frequency for the triangle wave is 1000Hz . The Harmonic frequency should be the odd integer multiple of the fundamental frequency for the square pulse wave and the triangle wave. However, as stated in the previous question, the sine wave should not contain any harmonics. Thus, the harmonic frequency for the pulse wave are 30kHz , 50kHz , 70kHz , etc. And the harmonic frequency for the triangle frequency are 3kHz , 5kHz , 7kHz , etc.

Parameters

Frequency (Hz):
 

Phase (degrees):
 





Sample time:
 


Figure 13: Triangle Wave Parameter


Parameters


Pulse type: 

Time (t): 

Amplitude:
 

Period (number of samples):
 

Pulse width (number of samples):
 

Phase delay (number of samples):
 


Sample time:
 

Figure 14: Sine Wave and Pulse Wave Parameter

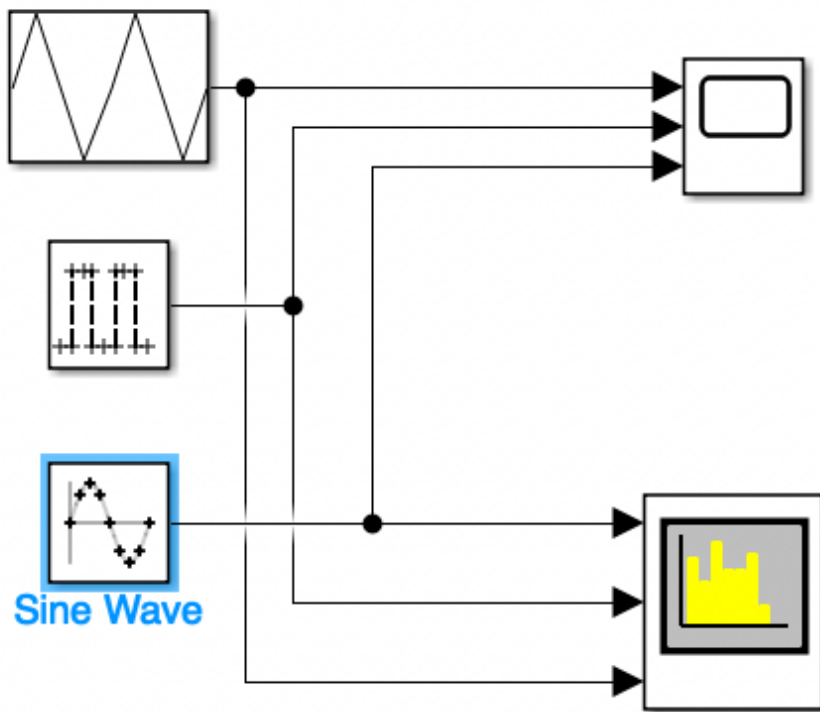


Figure 15: Triangle + Sine + Pulse setup

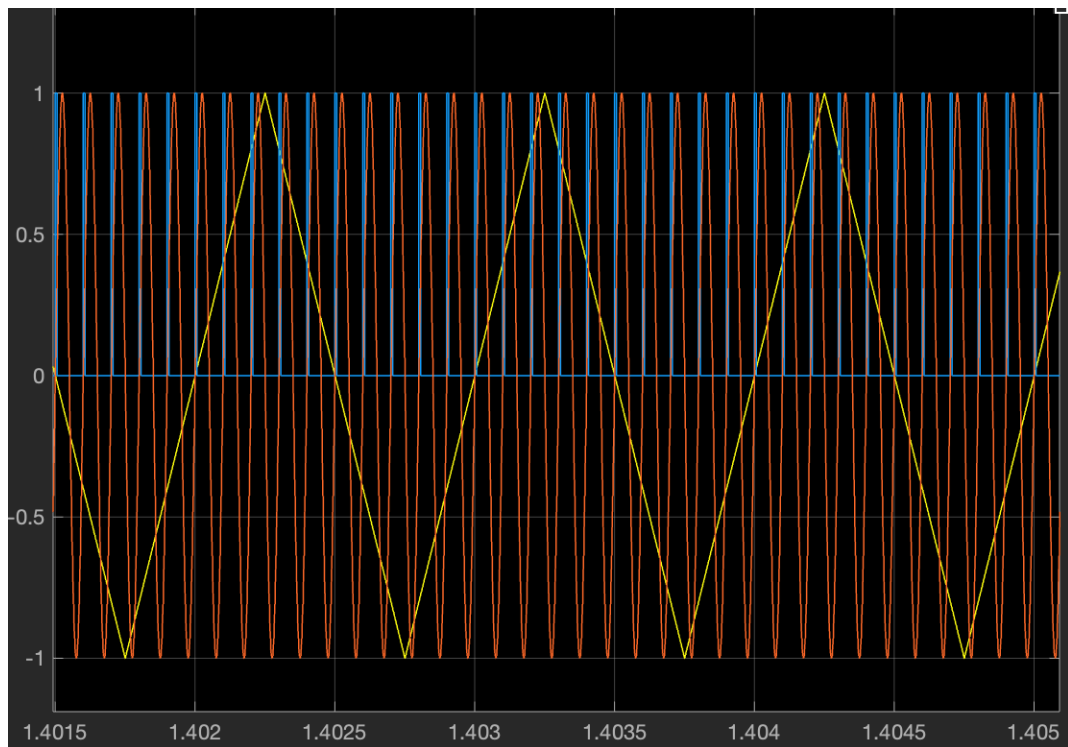


Figure 16: Scope Graph

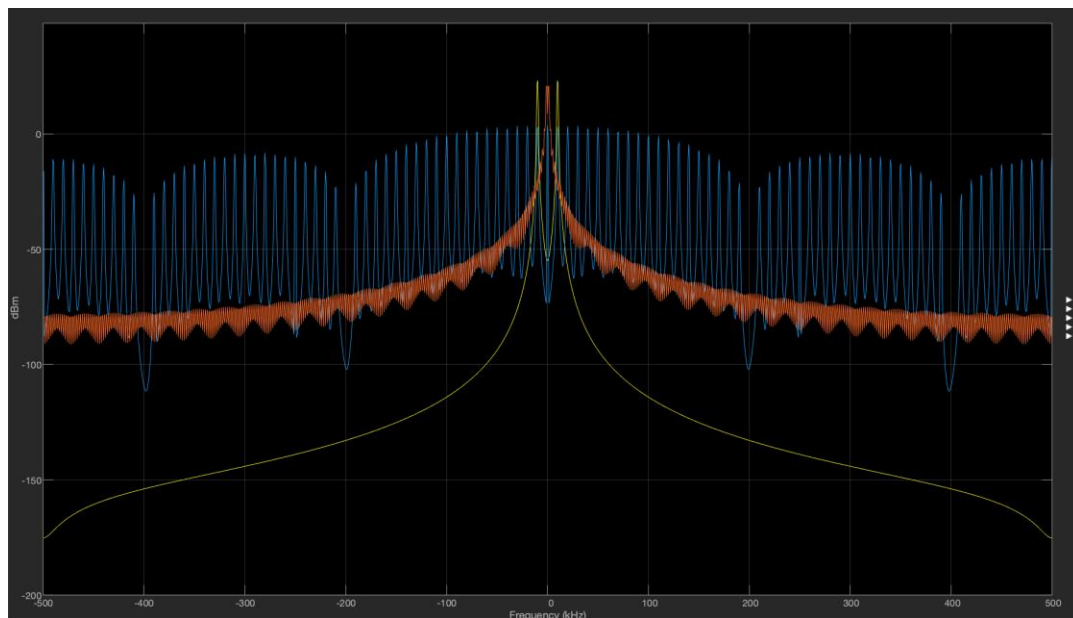


Figure 17: Spectrum Graph

1.5 Three Sine waves

Question: Observe the outputs on Scope and Spectrum. Plot the 3 Sine waves together. Indicate the amplitude, the period, and the frequency of the sine wave. What are the fundamental and harmonic components?

Answer: the amplitude of the combined sine wave is 2.25 which is not the sum of the three-sine wave amplitude, this is because for different frequency sine waves, there will be interference, thus the peak value will be smaller than 3. the period of the resulting sine wave is 0.0002s (0.3942s-0.394s), which is the longest component sine wave, thus the frequency is 5000Hz. The fundamental frequency is also 5000Hz and the corresponding harmonic frequencies are 10000Hz (100 samples per period) and 20000Hz (50 samples per period)

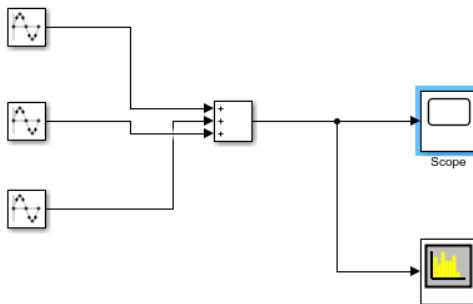


Figure 18: Simulink plot for addition of three sine waves

Parameters	
Sine type:	Sample based
Time (t):	Use simulation time
Amplitude:	1
Bias:	0
Samples per period:	50
Number of offset samples:	0
Sample time:	1e-6

Figure 19: Sine wave function 1 configuration

Parameters

Sine type:

Time (t):

Amplitude:

Bias:

Samples per period:

Number of offset samples:

Sample time:

Figure 20: Sine wave function 2 configuration

Parameters

Sine type:

Time (t):

Amplitude:

Bias:

Samples per period:

Number of offset samples:

Sample time:

Figure 21: Sine wave function 3 configuration

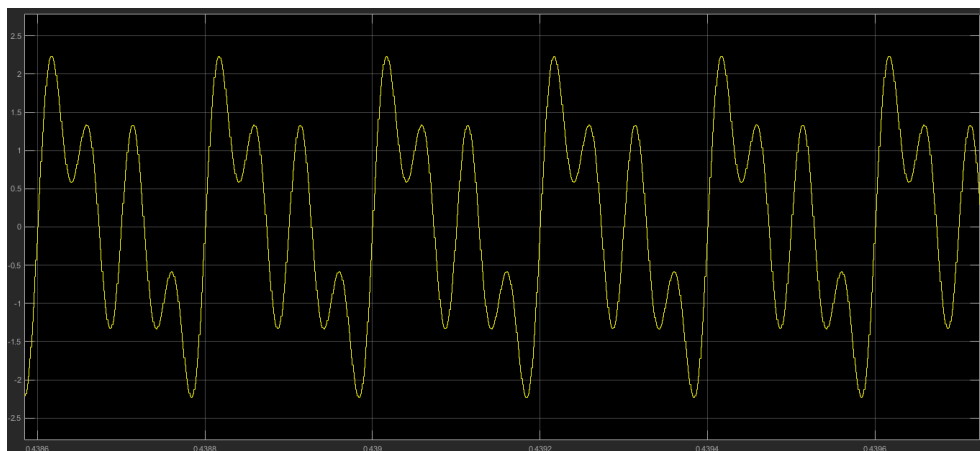


Figure 22: Scope plot with addition of three sine waves

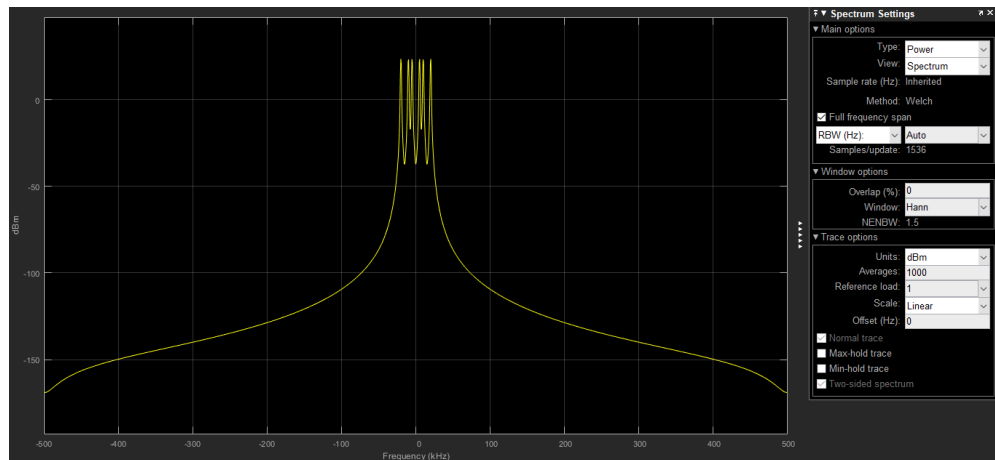


Figure 23: Spectrum plot with addition of three sine waves (A)

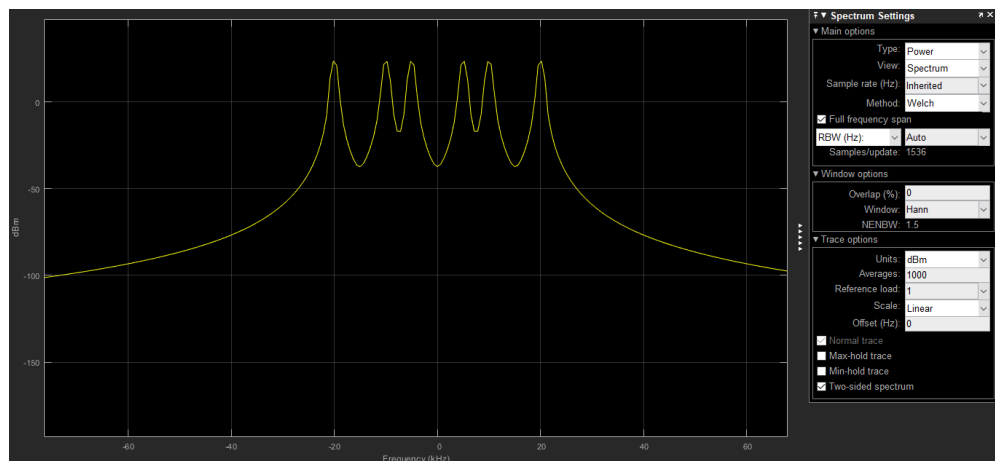



Figure 24: Spectrum plot with addition of three sine waves (B)


1.6 Step + Sine Waves


Question: Observe the output on Scope. Comment on periodicity of the sine wave.


Answer: According to the scope plot, the period of the sine wave is 1.


Parameters


Sine type: 

Time (t): 

Amplitude: 

Bias: 

Samples per period: 

Number of offset samples: 





Sample time: 

Figure 25: Sine wave 1 and Sine wave 2 Parameters

Parameters

Step time: 

Initial value: 

Final value: 

Sample time: 

Figure 26: Step 1 Parameters

Parameters

Step time:

4

Initial value:

0

Final value:

1

Sample time:

0

Figure 27: Step 2 Parameters

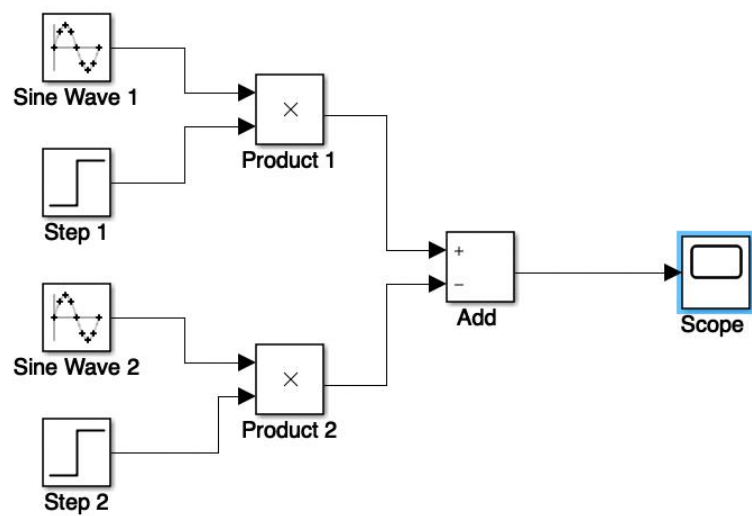


Figure 28: Step+Sine setups

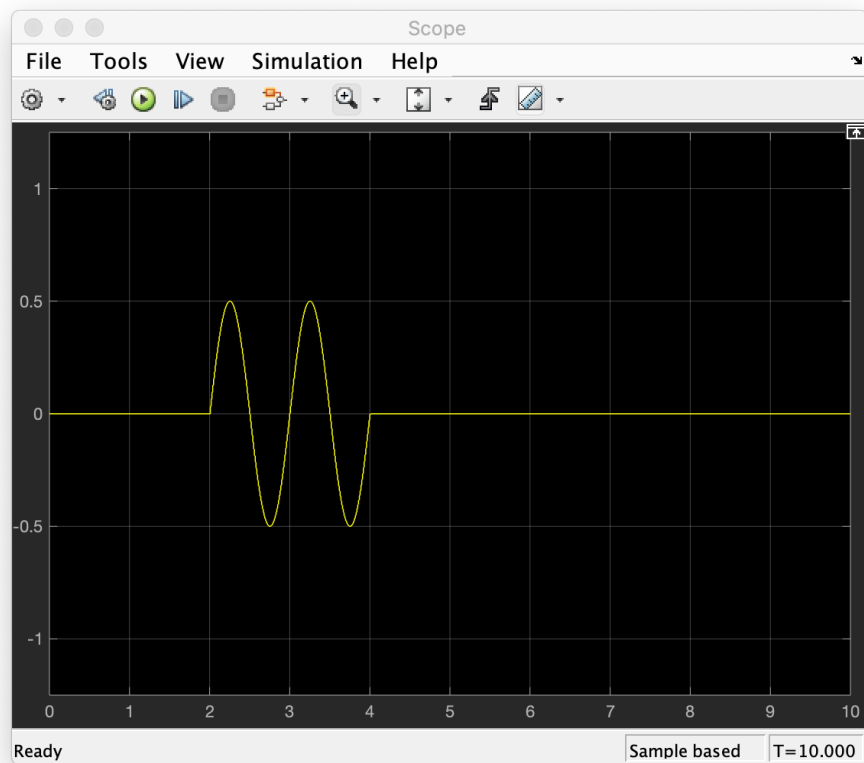


Figure 29: Scope Graph

1.7 Thermal noise

Questions: What is the bandwidth and the power spectral density of thermal noise? To obtain a more accurate spectrum, open the view/spectrum setting, in the Trace option window, input 1000 in front of averages.

HINT from lab TA:

Power = $KT B$

K: Boltzman's constant

T: Temp

B: the bandwidth

Answer: The bandwidth of this thermal noise is 179.76kHz (90% energy occupied). The noise power spectral density (N_0) can be calculated from the product of Boltzmann constant ($1.3806 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}$) with the temperature (kelvin). In this case for the thermal noise in 290K we have $1.3806 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1} * 290\text{K} = 4.00 \times 10^{-21} \text{ W/Hz}$

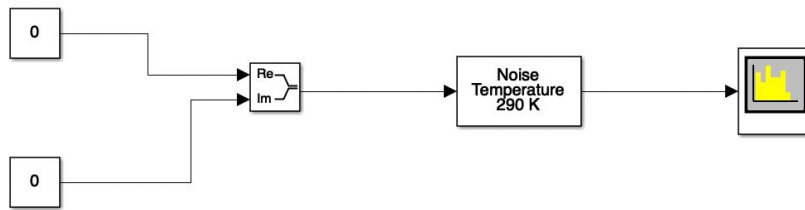


Figure 30: Thermal noise setting

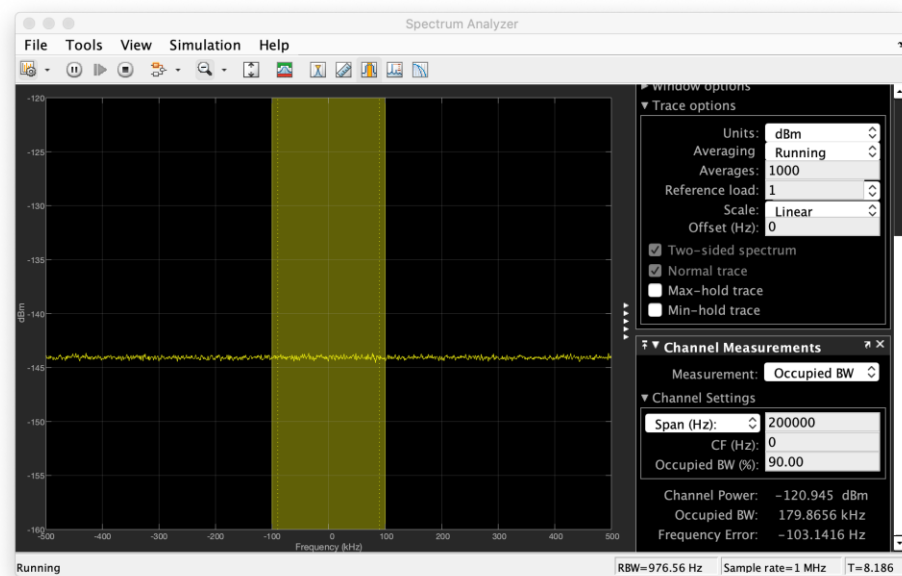


Figure 31: Spectrum plot with 90% occupied bandwidth

1.8 Random source with Auto Correlator

Question: Vary the variance of the source. Explain how the peak value of the output on Auto Correlator is related to the variance, and thus the noise power.

Answer: According to observation, the peak value of the output on the Auto Correlator would increase when the variance increases. The noise power would also increase when the variance increases. The peak value of the output has the same value as the variance and has the same value as the noise power. As shown in Figure 34, the variance is set to 1, the auto correlation peak is 1 and the noise power is 1W.

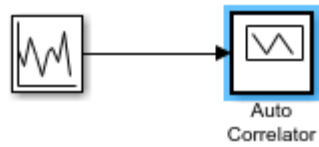


Figure 32: Simulink Diagram

Parameters

Source type: Gaussian

Method: Ziggurat

Mean: 0

Variance: 1

Repeatability: Not repeatable

☐ Inherit output port attributes

Sample mode: Discrete

Sample time: 0.001

Samples per frame: 1

Output data type: Double

Complexity: Real

Figure 33: Random Source Configuration

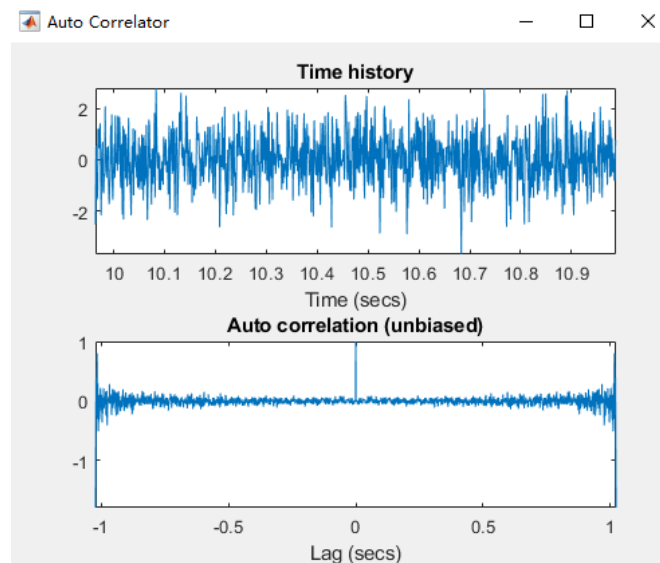


Figure 34: Output on Auto correlator at variance of 1

1.9 Theoretical Questions

Question: Explain the difference between random signals and deterministic signals such as sine waves, triangular waves, etc. In terms of mathematical characterization.

Answer: The random signal generator generates data base on the normal distribution with certain variance and uncertainties, the data cannot be summarized in to one mathematical equation. In contrary, deterministic signals are distributed with determined mathematical equations with no variance or uncertainty.

Part 2 Power, Bandwidth & SNR

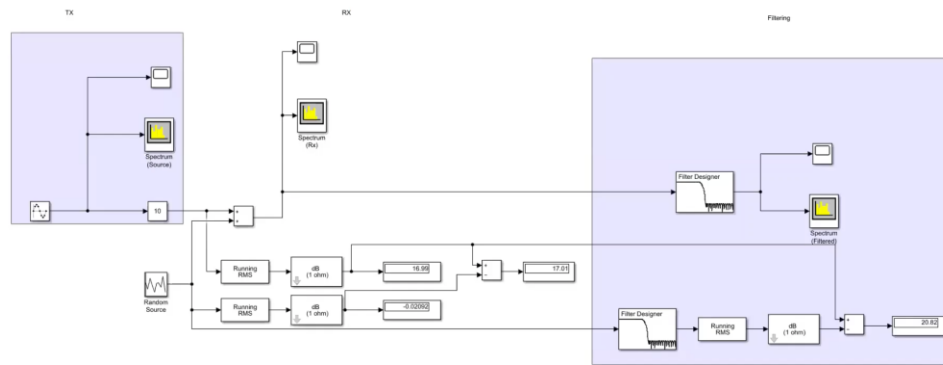


Figure 35: Simulink plot

HINT: $SNR = \text{Signal power} / \text{Noise Power}$ ($10 \log \text{signal power} - 10 \log \text{noise power in dB}$)

2.1 Observe the output on Spectrum (Source). What are the power and the bandwidth of the sine wave?

Answer: The power of the sine wave is 16.99 dB with 10 dB added gain, and the measured bandwidth is 21.173kHz.

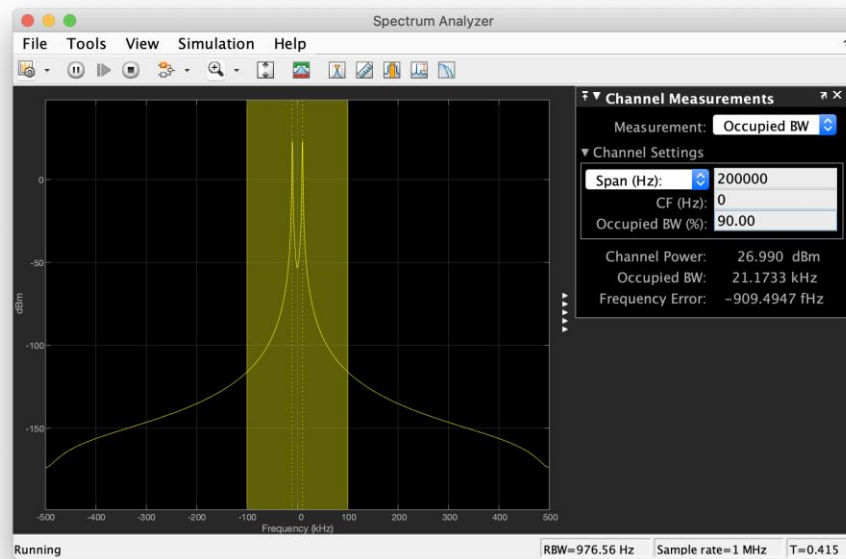


Figure 36: The spectrum analyzer window with (90% occupied BW)

2.2 Observe the output on Spectrum (Source). What are the power and the bandwidth of the triangular wave?

Answer: The power of the triangle wave is 15.23dB with 10dB added gain, and the bandwidth is 21.2175kHz.

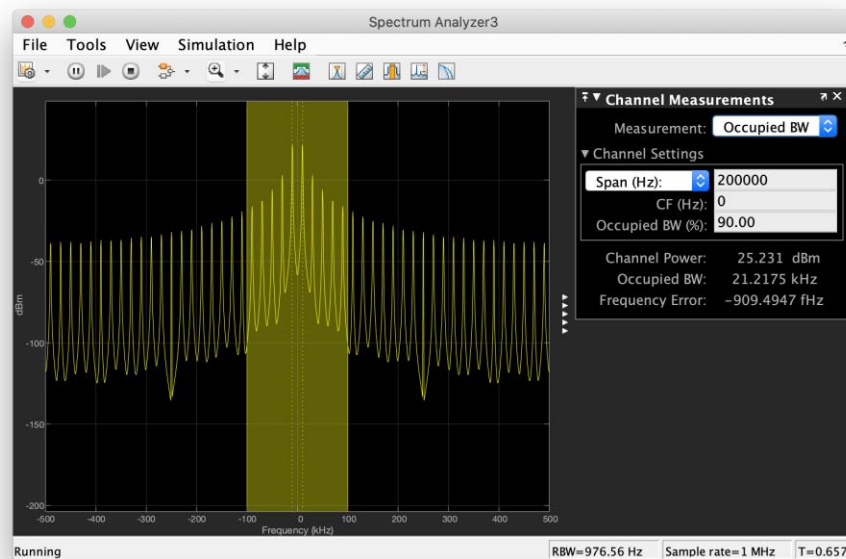


Figure 37: The spectrum analyzer window with (90% occupied BW)

2.3 Observe the output on Spectrum (Source). What are the power and the bandwidth of the 50% duty cycle square wave?

Answer: The power of the square wave is 16.99dB with 10dB added gain, and the bandwidth is 38.5041kHz.

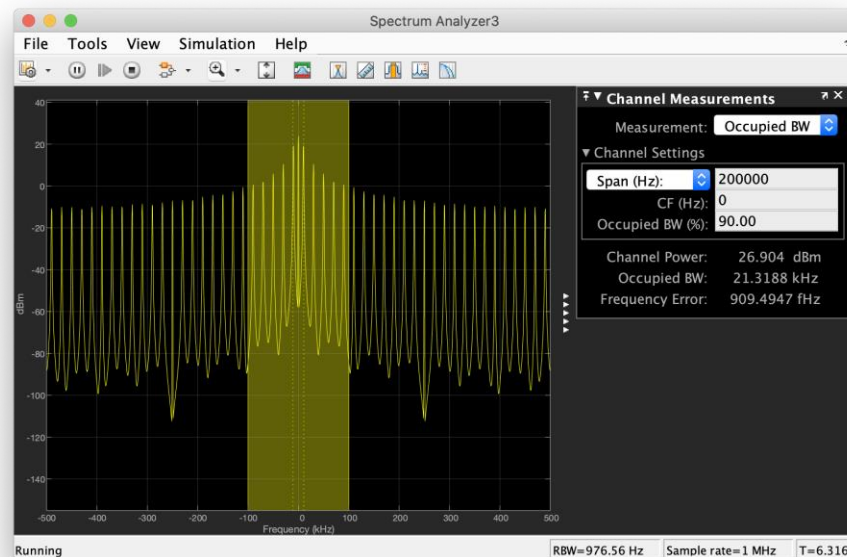


Figure 38: The spectrum analyzer window with (90% occupied BW)

2.4 Observe the output on Spectrum (Source). What are the power and the bandwidth of the 80% duty cycle square wave?

Answer: The power of the sine wave is 19.03dB with 10dB added gain, and the bandwidth is 38.5041kHz.

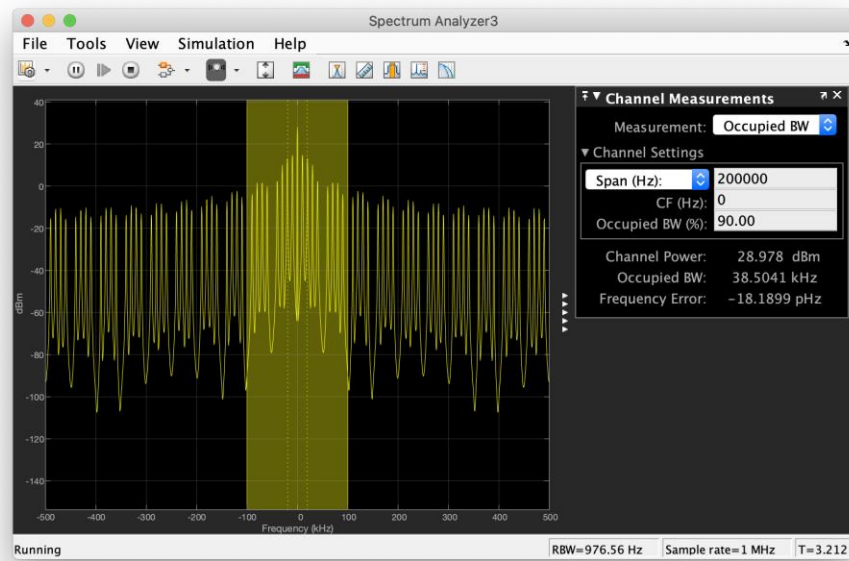


Figure 39: The spectrum analyzer window with (90% occupied BW)

2.5 Observe the output on Spectrum (Source). What are the power and the bandwidth of the added wave?

Answer: The power of the sine waves is 21.76dB with 10dB added gain, and the bandwidth is 40.4979kHz.

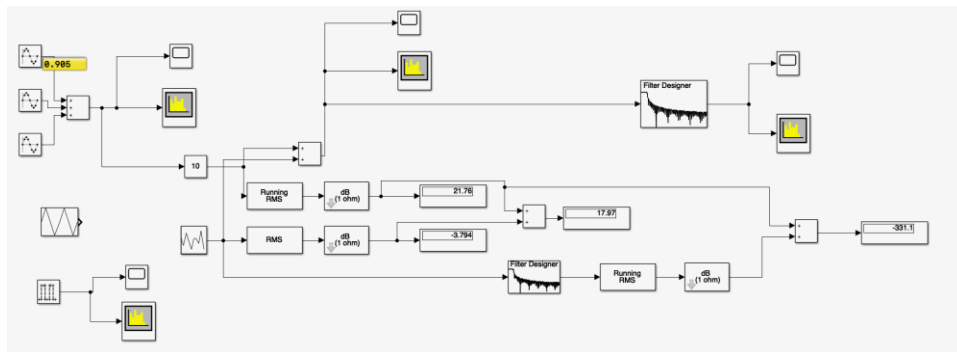


Figure 40: Setups of this questions (adding three sine waves to produce the signal)

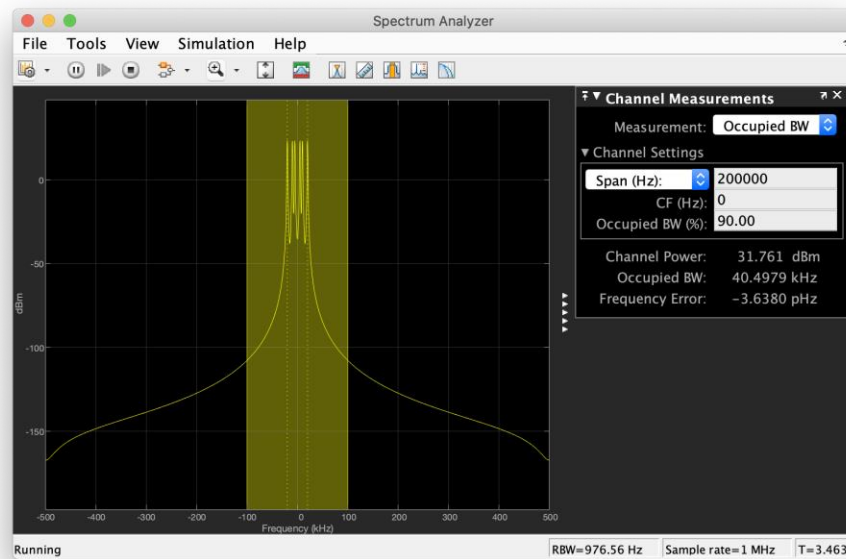


Figure 41: The spectrum analyzer window with (90% occupied BW)

2.6 Observe the outputs on Scope (Rx) and Spectrum (Rx) (as shown in the figures below). Comment on the effect of noise on the signal in the time domain and the frequency domain.

Answer: By comparing the graph on Scope (Source) and Scope (RX) we can see that with noise the time domain signal contains more throttle and sharp edges. Also, we noticed that the amplitude of the time domain signal measured on the RX side is larger than the Source side.

By inspecting the frequency spectrum on the source side and the RX side (as shown in the figures below), we conclude that, signal with noise in its frequency domain would be distorted significantly outside of 90% occupied frequency channel.

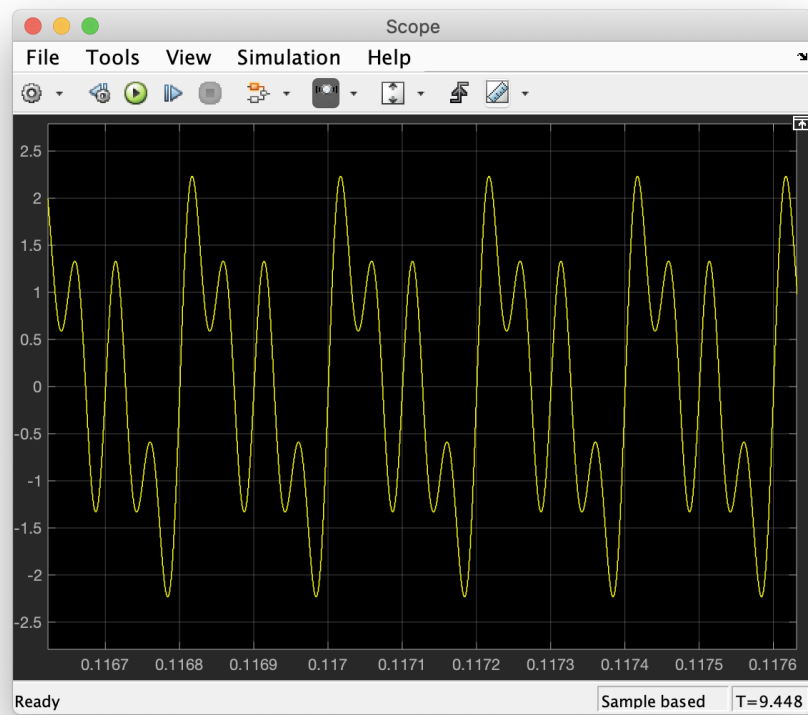


Figure 42: Scope (Source)

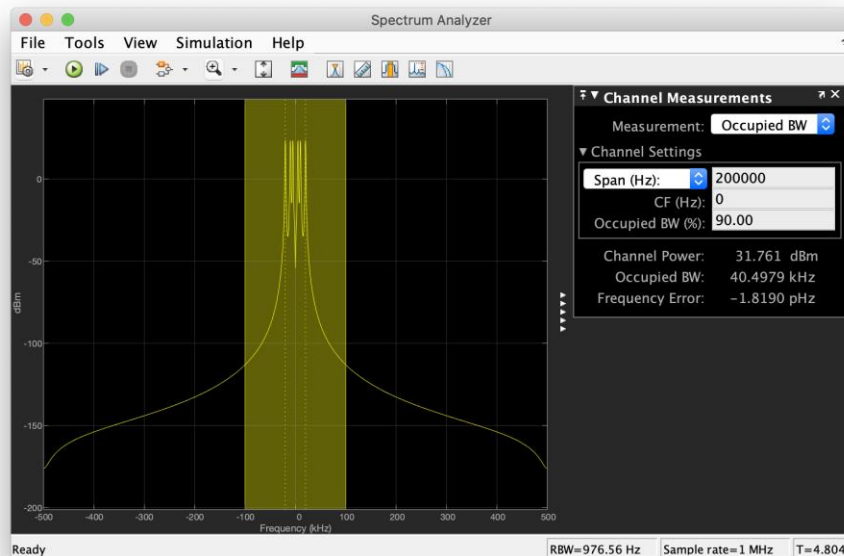


Figure 43: Spectrum (Source)

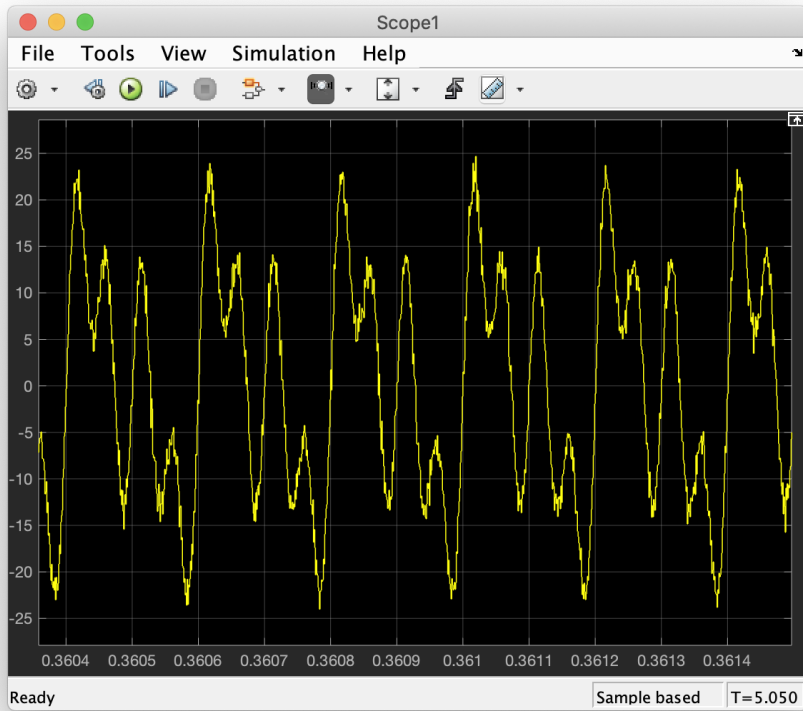


Figure 44: Scope (RX)

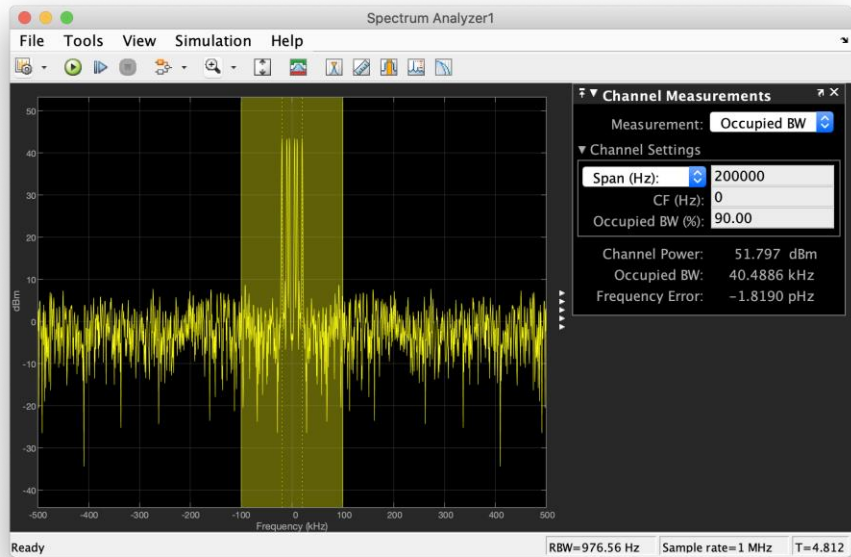


Figure 45: Spectrum (RX)

2.7 Compare the outputs on Scope (Filtered) and Spectrum (Filtered) with those on Scope (Rx) and Spectrum (Rx), respectively. Comment on the effect of filtering.

Answer: As shown in the figures below, the filtered scope plot has smoother curve compared to that of the unfiltered scope plot. Meanwhile, the filtered spectrum plot has more similar curve to the source spectrum plot compared with the unfiltered spectrum plot. Based on observation, the filter will help to filter the noise and make the signal smoother.

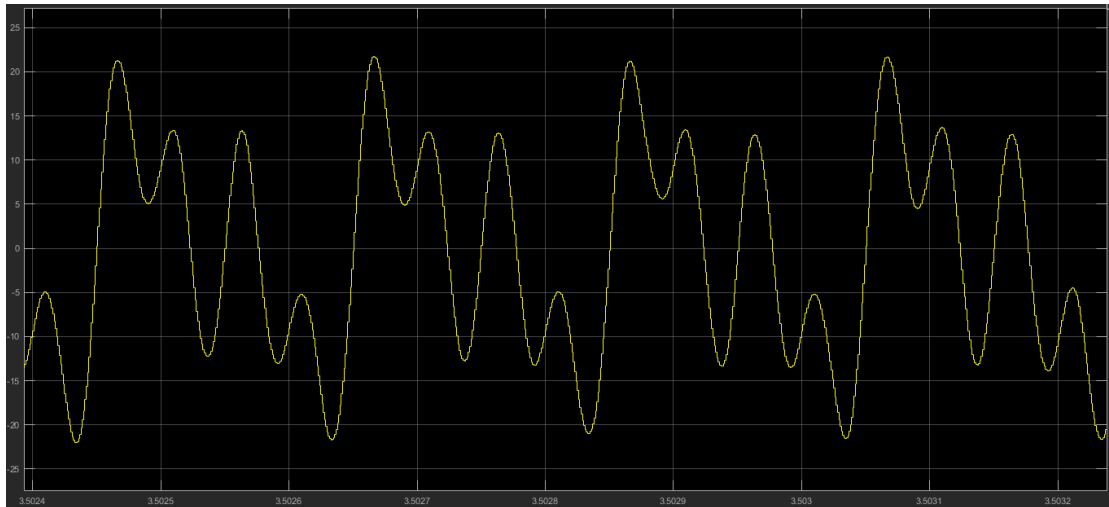


Figure 46: Scope (Filtered) plot

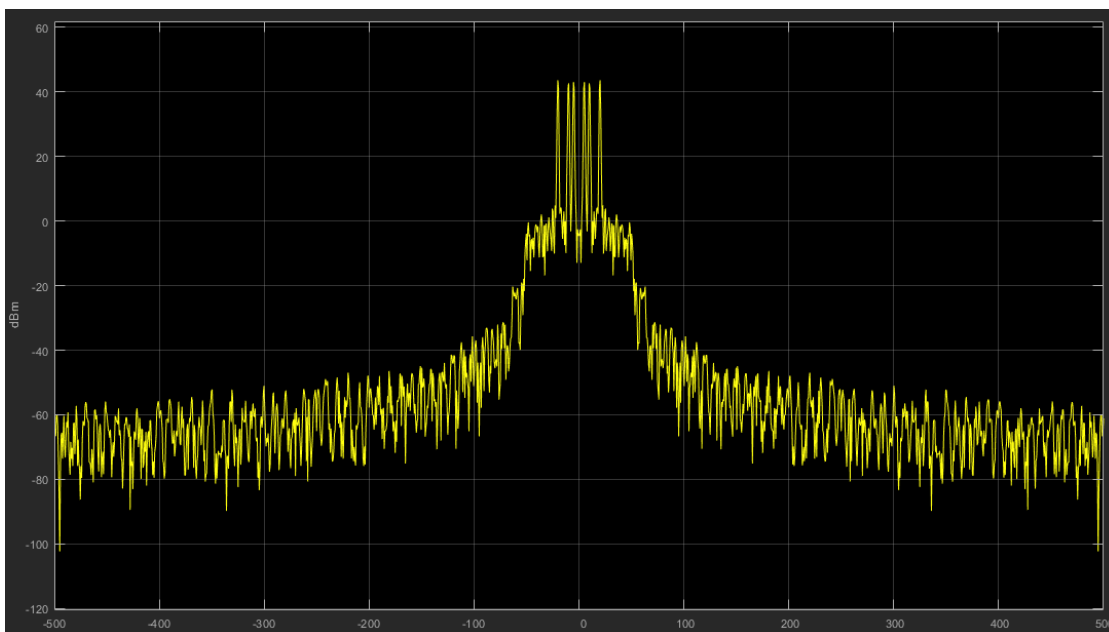


Figure 47 (a): Spectrum (Filtered) plot

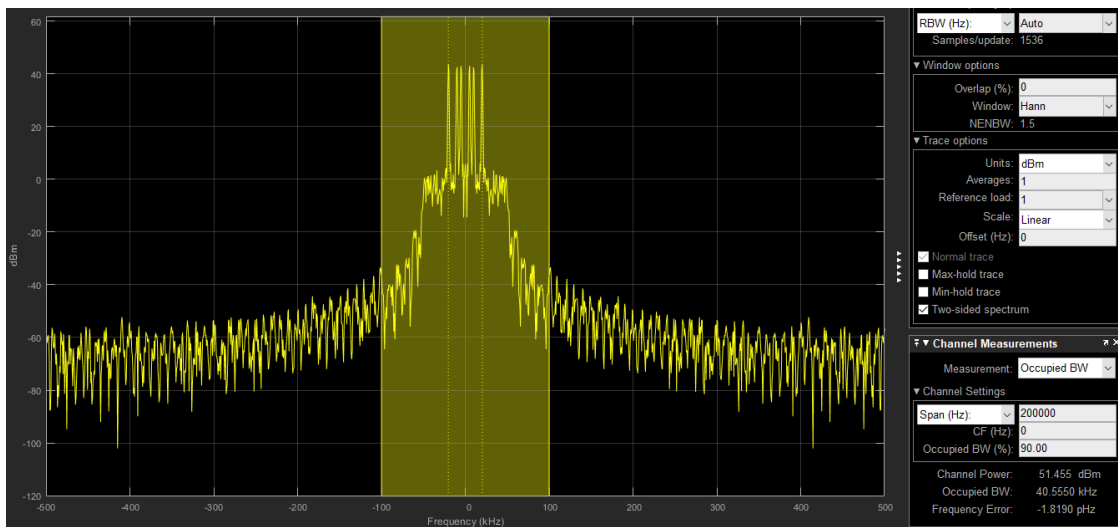


Figure 47 (b): Spectrum (Filtered) plot

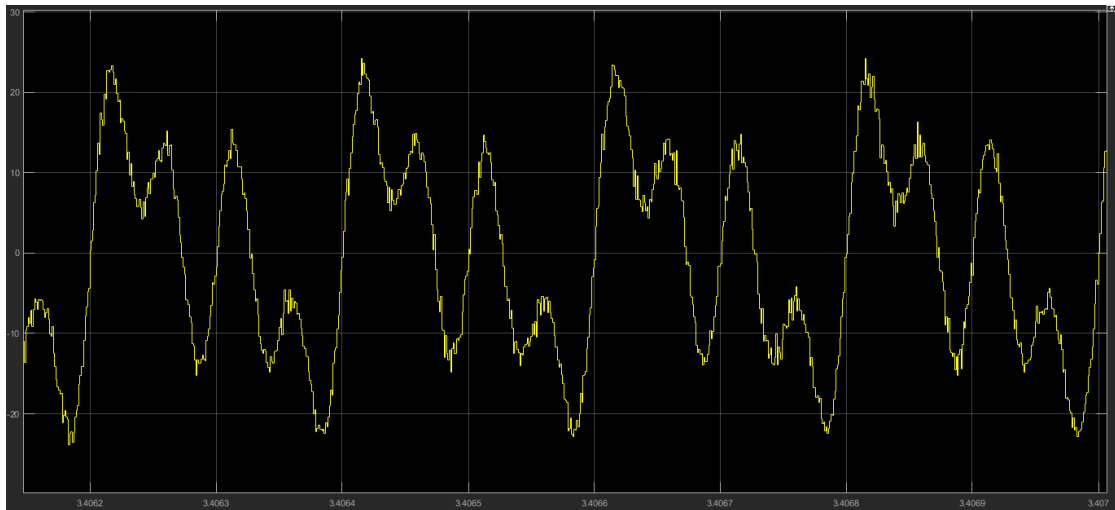


Figure 48: Scope (Rx) plot

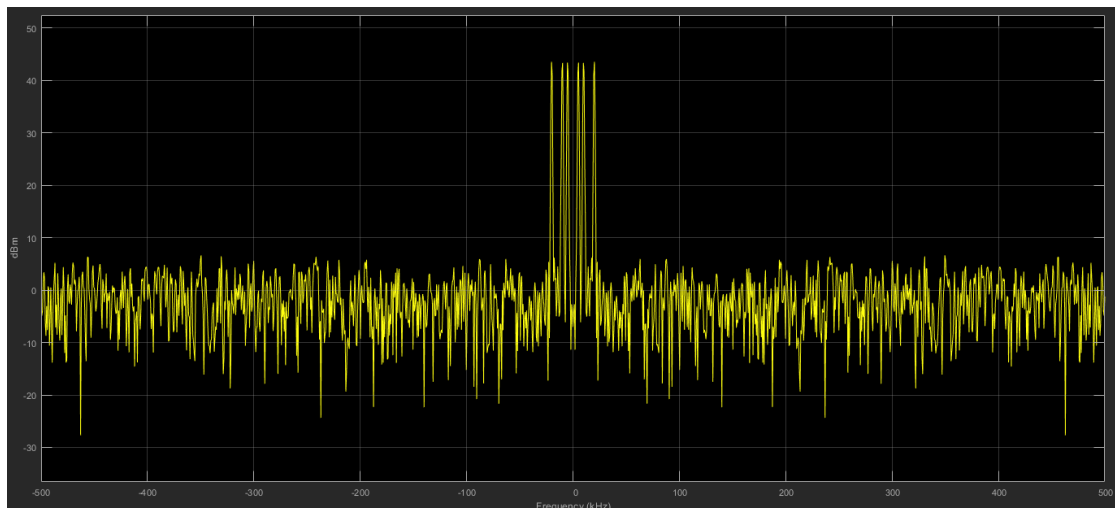


Figure 49: Spectrum (Rx) plot

2.8 Vary Slider Gain from small to large. Observe the outputs on Scope (Filtered) and Spectrum (Filtered). Comment on how the effect of noise varies in accordance with the SNR at the filter output. Repeat for a varied cut-off frequency F_c in Digital Filter Design.

Answer: Based on observation from Figures 50 to 53 and Figures 46 to 47, it was found that the peak value of curve in the scope plot would increase when the slider gain is increased. Meanwhile, it was also found that the peak value of the spectrum plot would increase when the slider gain is increased. As observed in the lab when the system has a 5dB gain, the SNR between the raw signal and noise is peaked at around 5.34 dB; As we change the gain to 10 dB, we have a SNR peaked at around 11.29 dB; When we have 15 dB of Gain SNR peaked at around 14.85 dB. Therefore, we can conclude that, as the Gain increases the SNR at the filter output will also be increased.

Based on observation from Figures 54 to 67 and Figures 46 to 47, it was found that the peak value of curve in the scope plot would increase when the cut-off frequency F_c is increased. The curve of the filtered scope would also change when the cut-off frequency F_c is changed. Meanwhile, it was found that the peak value of the spectrum plot generally does not change when the cut-off frequency F_c is changed. From Figure 47 (b) Figure 55 (b), and Figure 57 (b), it was found that when the cut-off frequency when the cut-off frequency F_c increases, the bandwidth would increase.

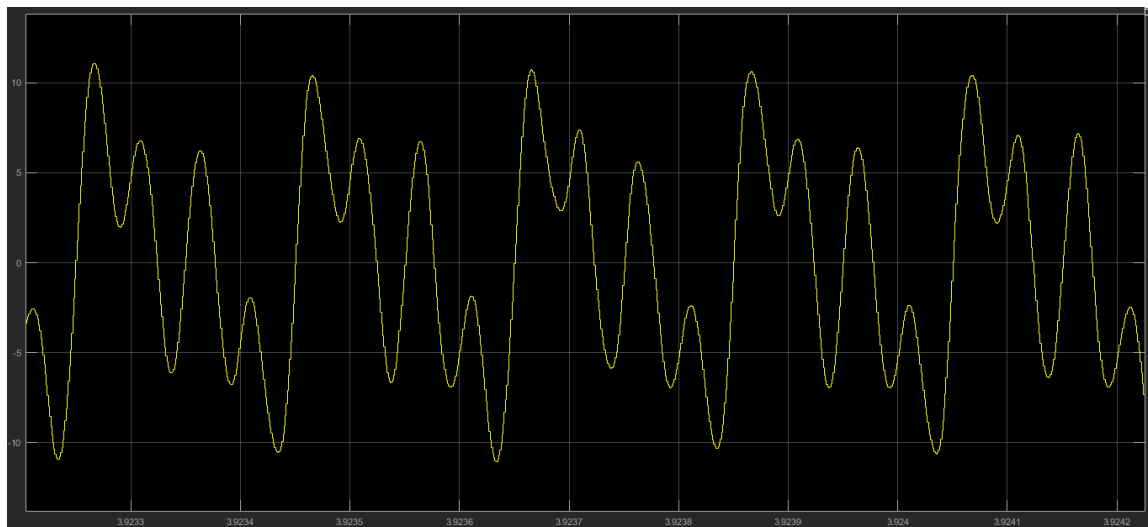


Figure 50: Scope (Filtered) plot (gain of 5db)

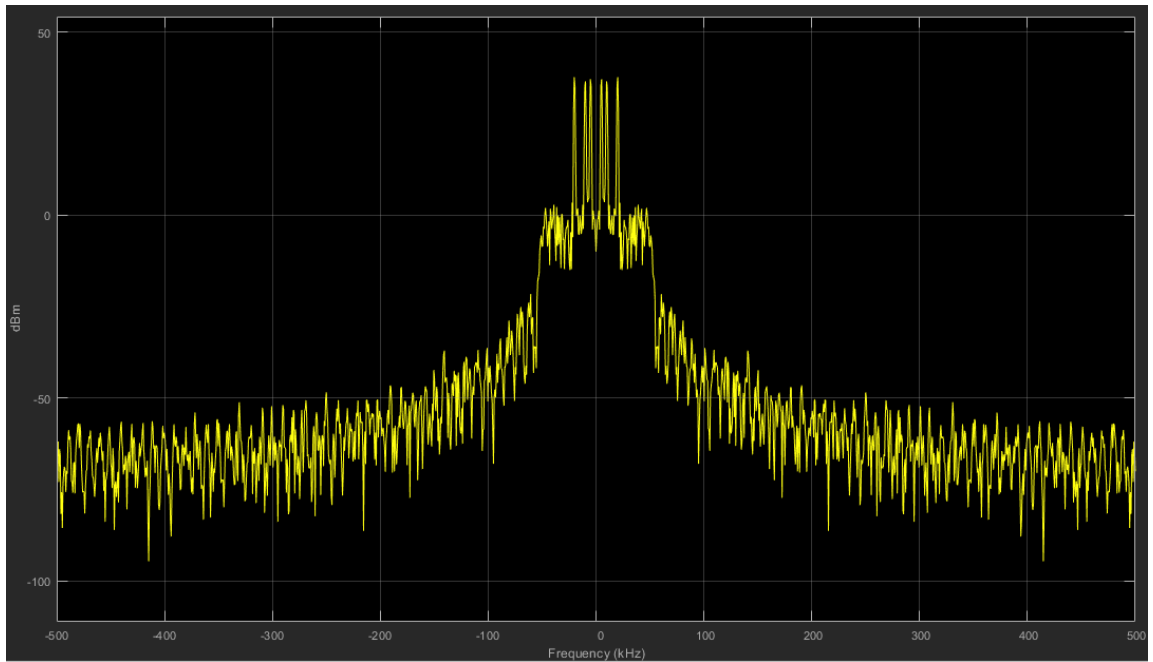


Figure 51: Spectrum (Filtered) plot (gain of 5db)

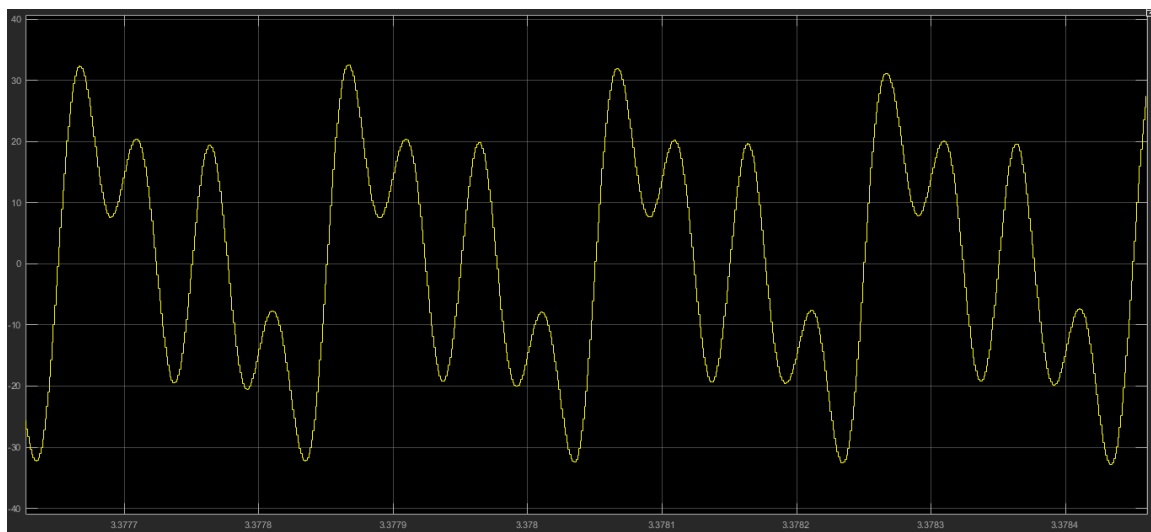


Figure 52: Scope (Filtered) plot (gain of 15db)

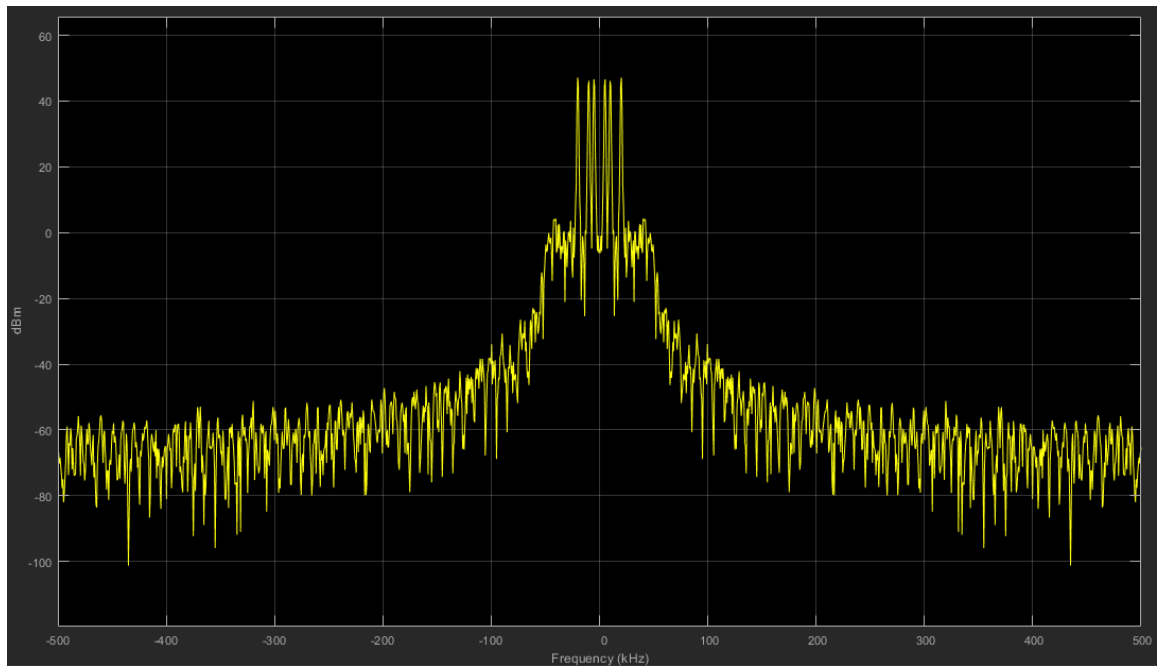


Figure 53: Spectrum (Filtered) plot (gain of 15db)

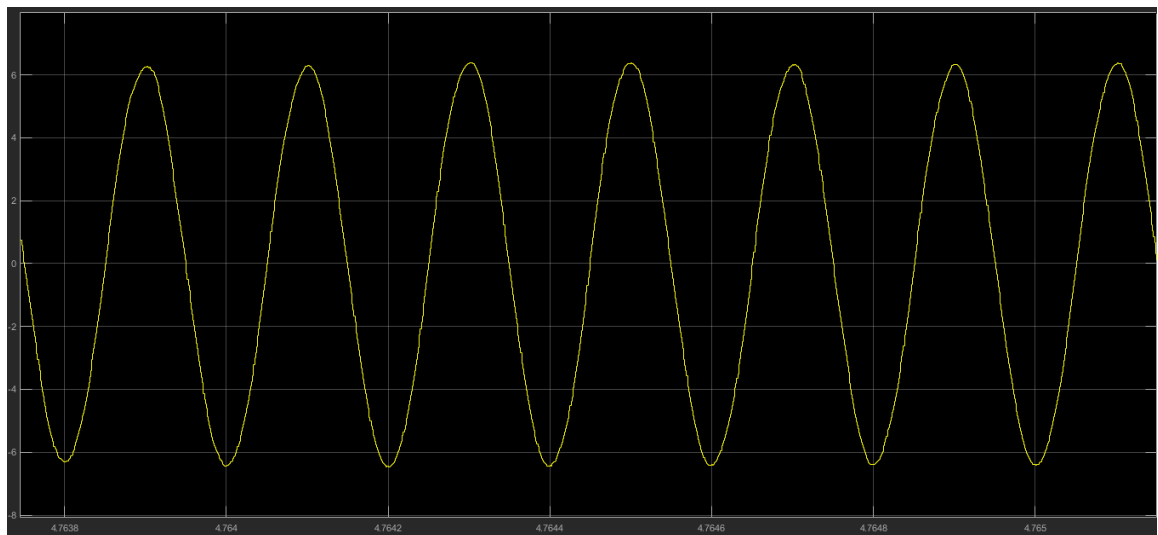


Figure 54: Scope (Filtered) plot (cut-off frequency of 5e2 Hz)

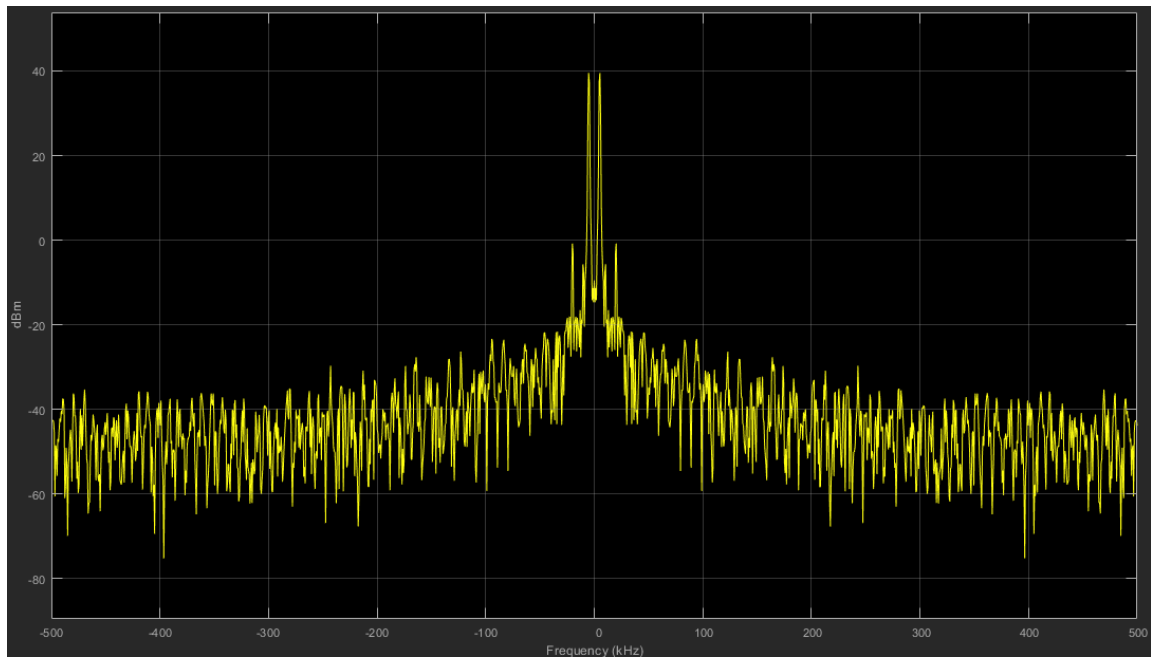


Figure 55 (a): Spectrum (Filtered) plot (cut-off frequency of 5e2 Hz)

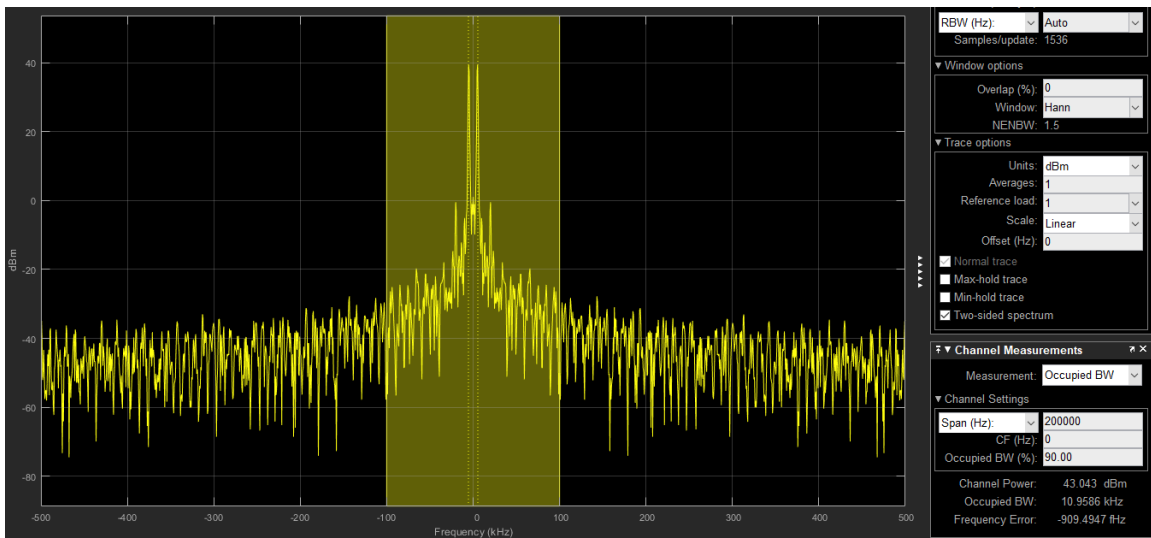


Figure 55 (b): Spectrum (Filtered) plot (cut-off frequency of 5e2 Hz)

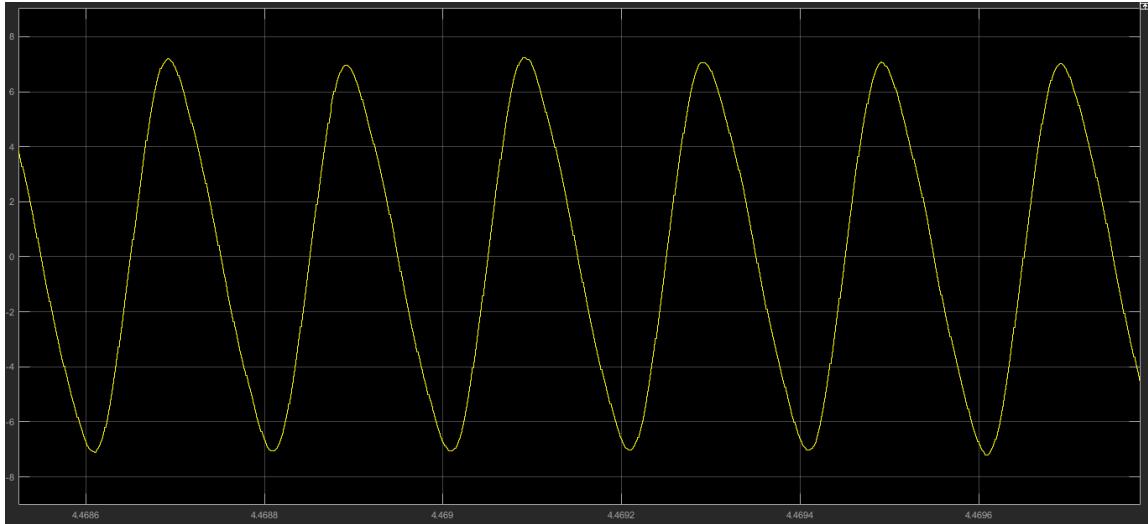


Figure 56: Scope (Filtered) plot (cut-off frequency of 5e3 Hz)

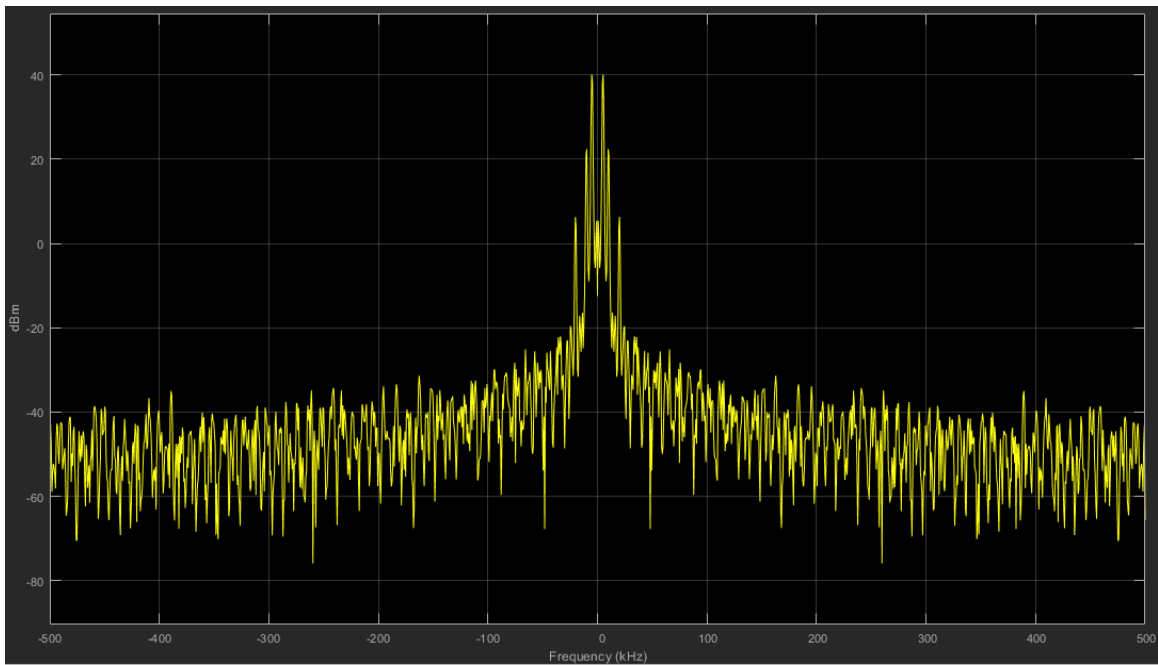


Figure 57 (a): Spectrum (Filtered) plot (cut-off frequency of 5e3 Hz)

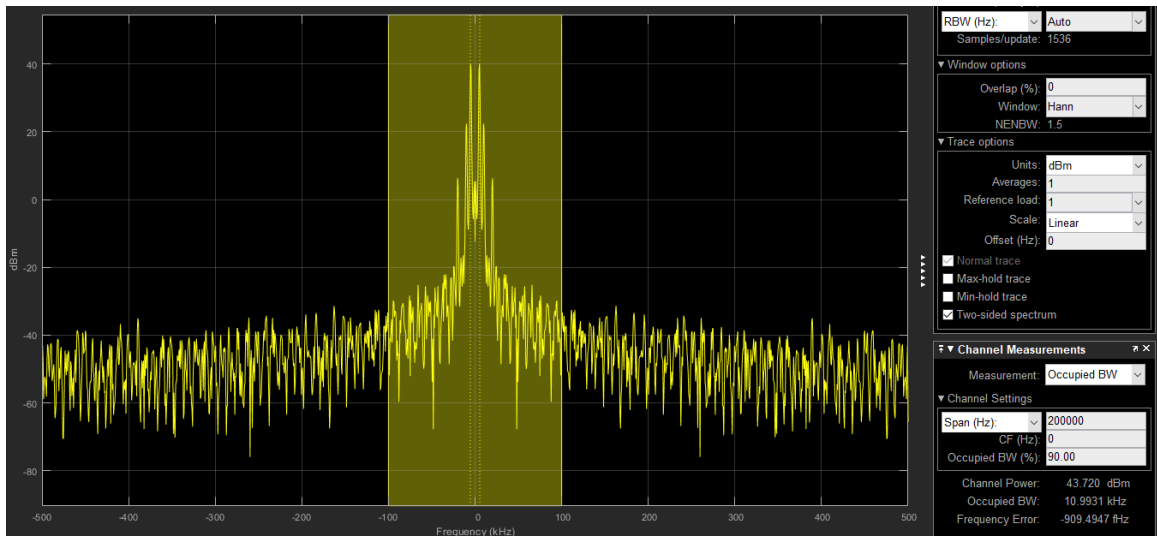


Figure 57 (b): Spectrum (Filtered) plot (cut-off frequency of 5e3 Hz)