ECSE 308, Fall 2020

Introduction to Communication Systems and Networks

Laboratory L1 – Report

STUDENT 1

Name : _____Mike Wang_____

ID: ________260779031_______

STUDENT 2 (Optional)

Name: ___Haowei Qiu______

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 0.38715s - 0.38705s = 0.0001s, 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.

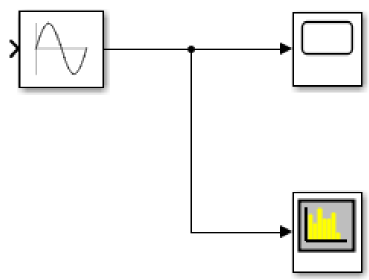

Figure 1: Simulink Diagram

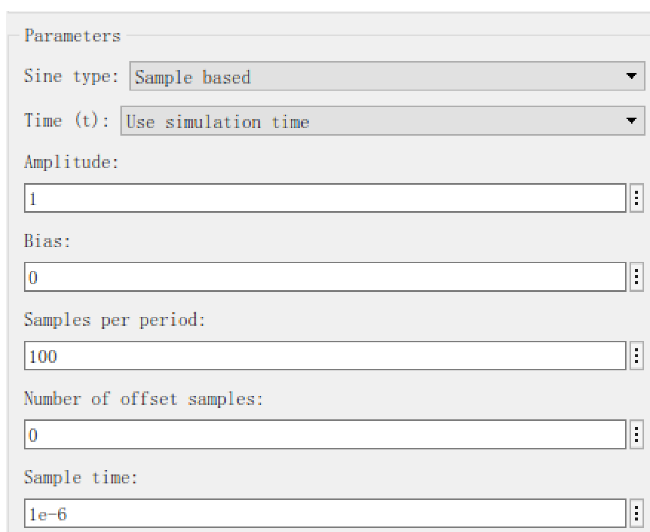

Figure 2: Sine signal generator configuration

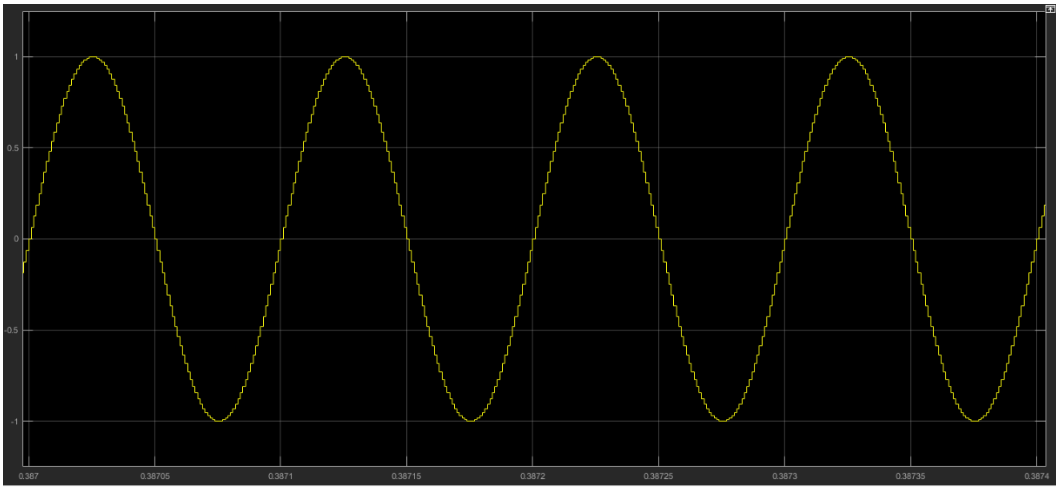

Figure 3: Scope plot with Sine signal

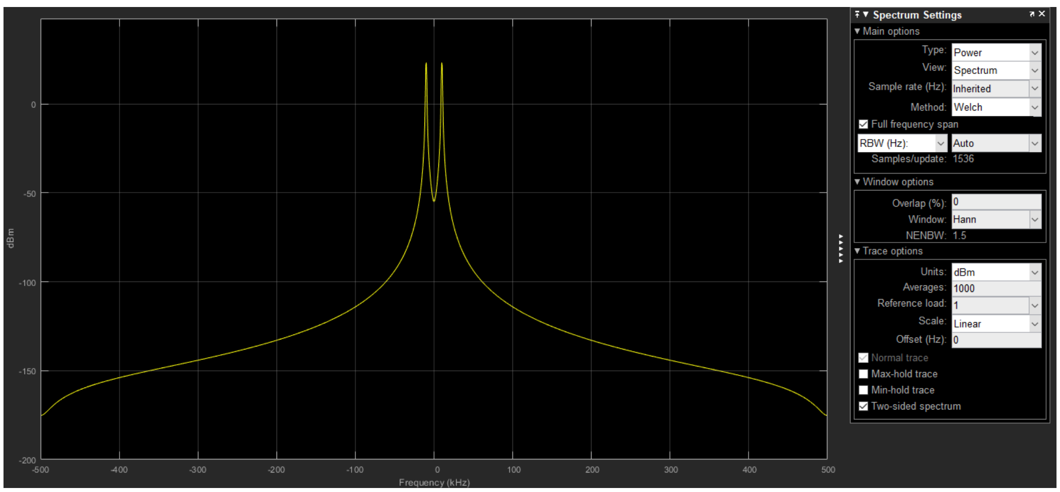

Figure 4: Spectrum plot with Sine signal

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 triangular wave is 1, the period of the triangle wave is 0.38715s-0.38705s = 0.0001s, and the frequency of the triangular 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.

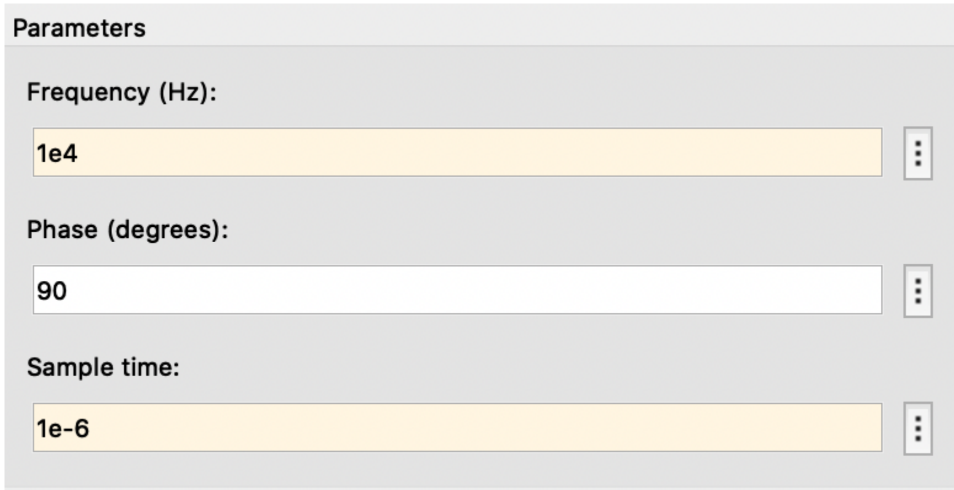

Figure 5: Triangle wave parameters

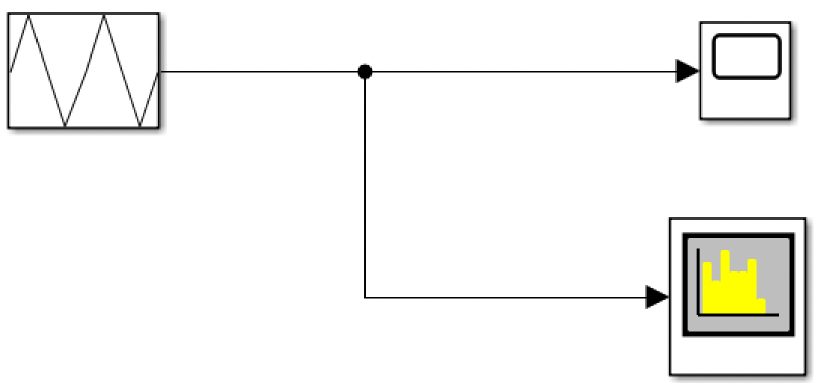

Figure 6: Simulink setup

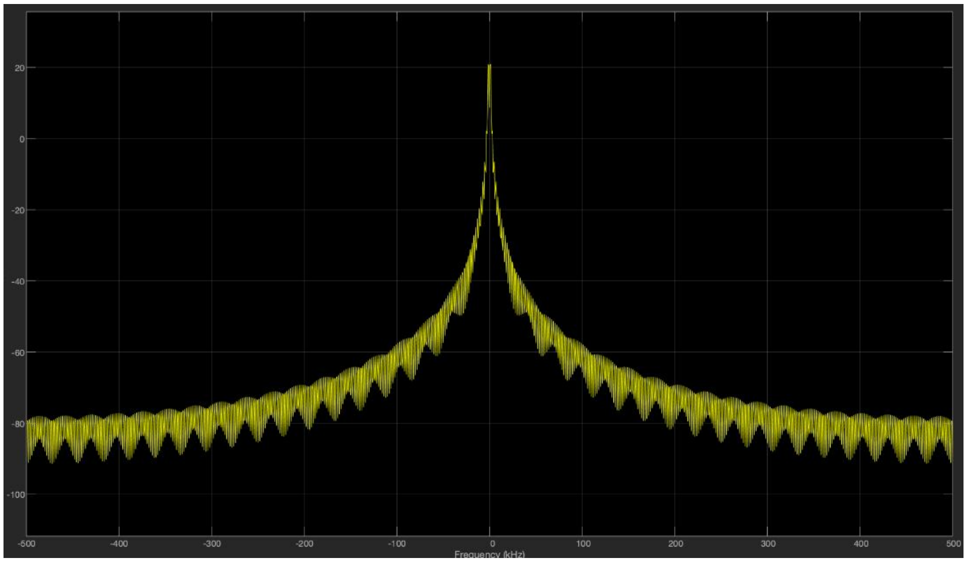

Figure 7: Spectrum Graph

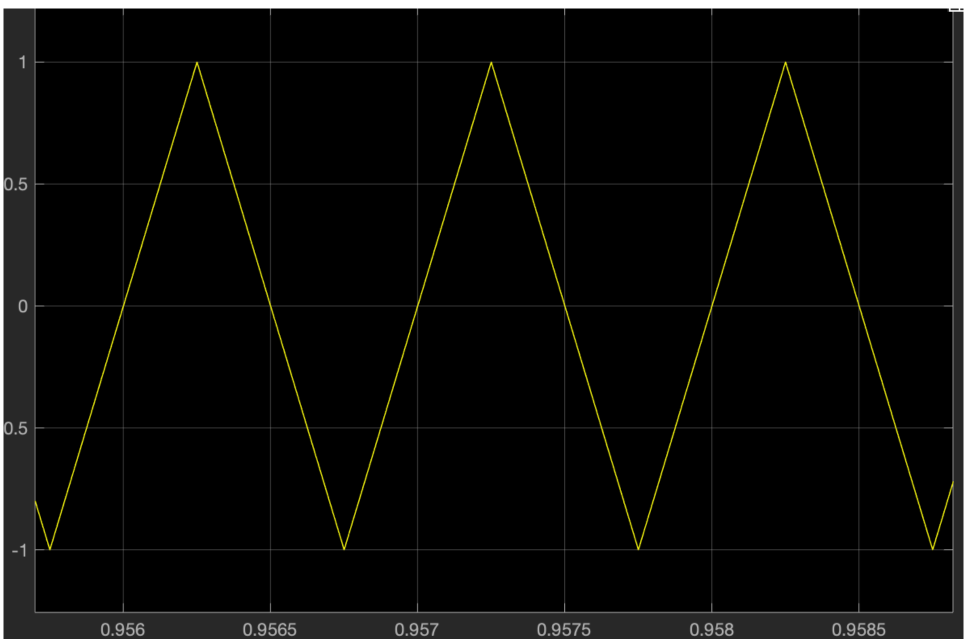

Figure 8: Scope Graph

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 0.4039s - 0.4038s = 0.0001 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.

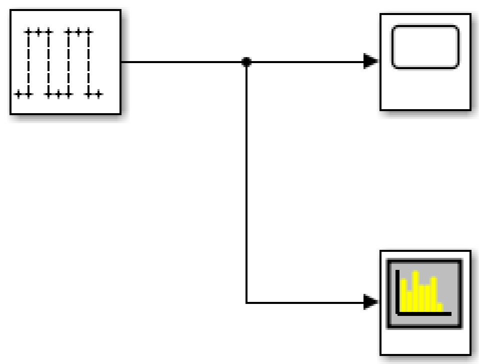

Figure 9: Simulink Diagram

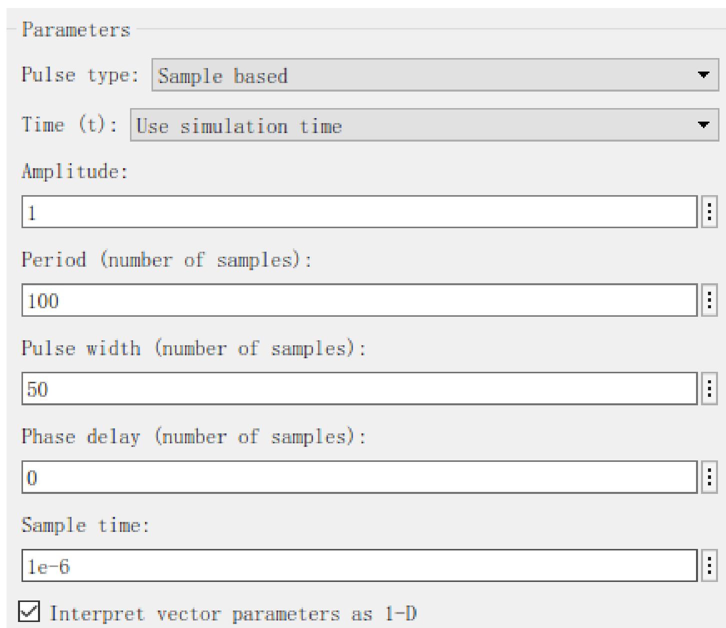

Figure 10: Pulse signal generator configuration

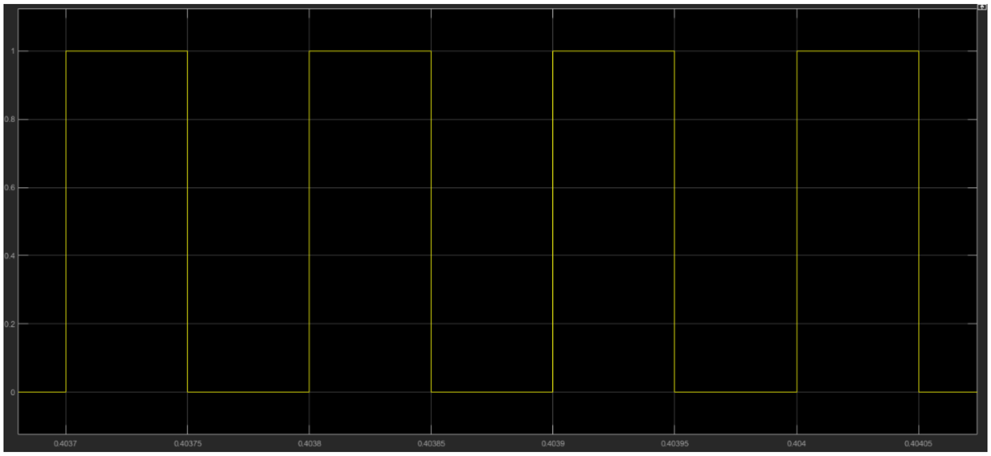

Figure 11: Scope plot with pulse signal

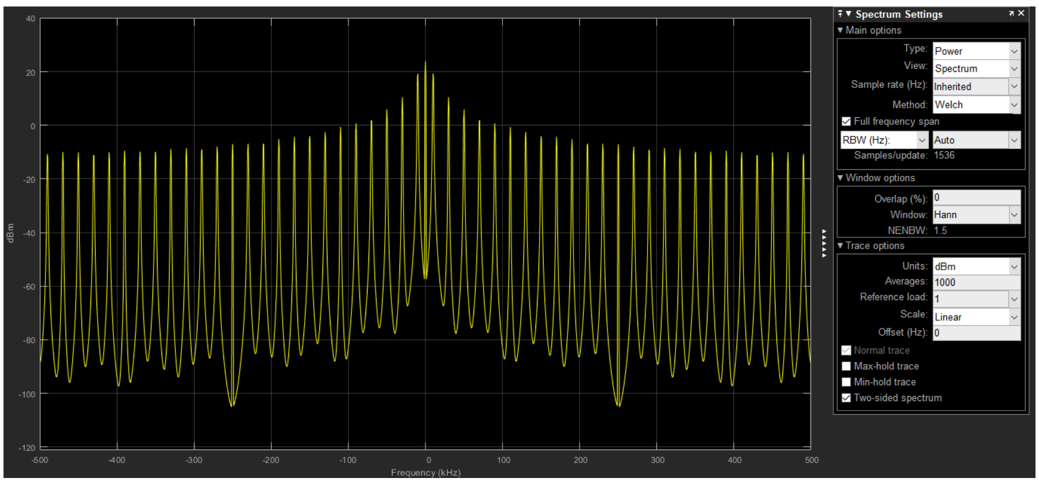

Figure 12: Spectrum plot with Pulse signal

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/(0.28065s-0.28075s) = 10000Hz, 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.

Figure 13: Triangle Wave Parameter

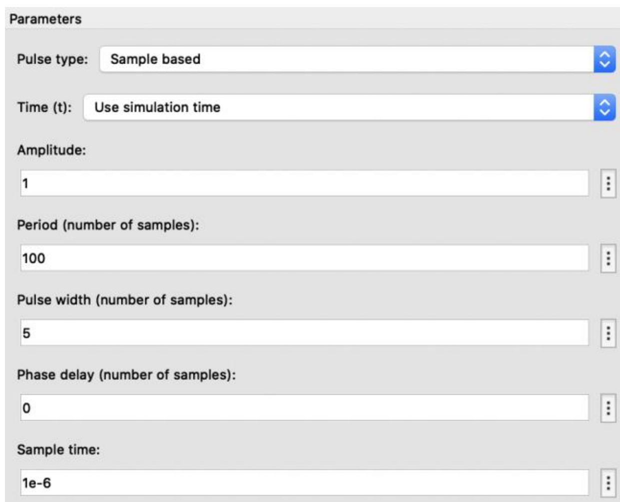

Figure 14: Sine Wave and Pulse Wave Parameter

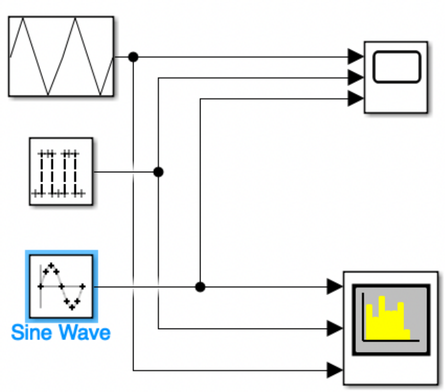

Figure 15: Triangle + Sine + Pulse setup

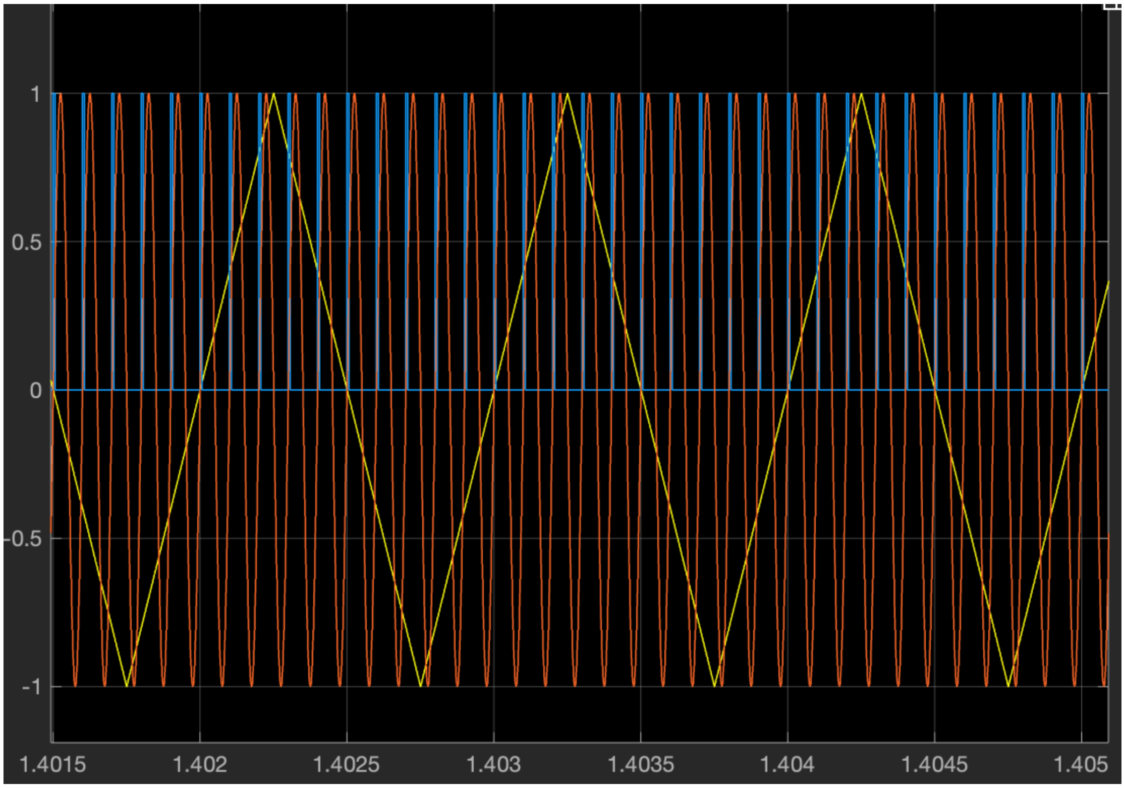

Figure 16: Scope Graph

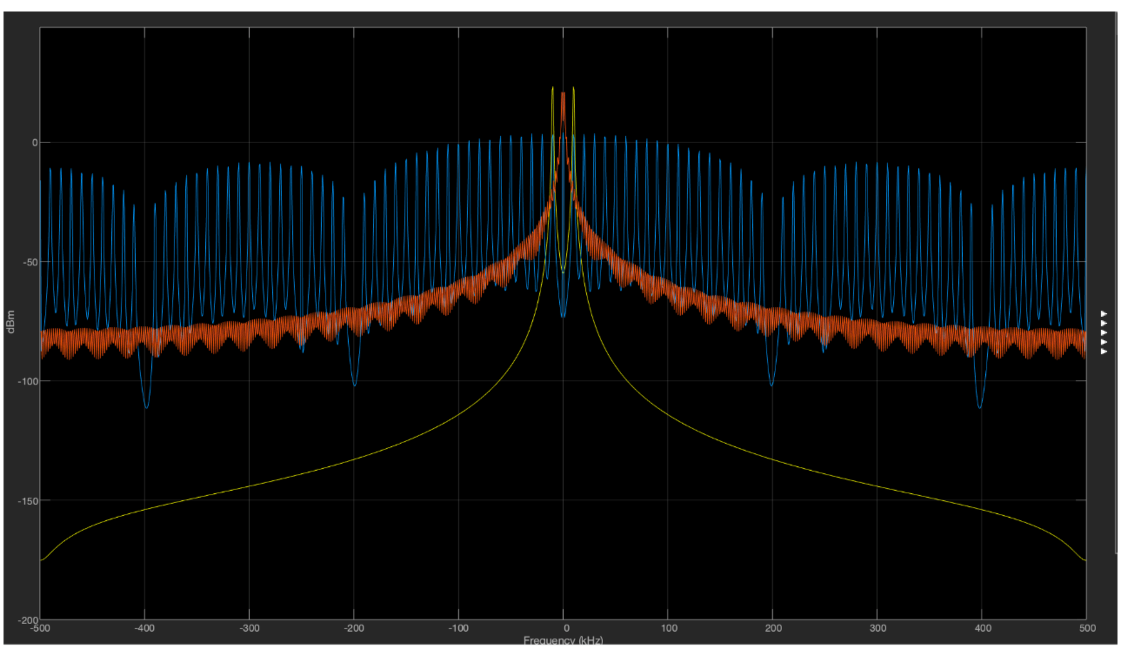

Figure 17: Spectrum Graph

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 0.3942s-0.394s = 0.0002s, 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)

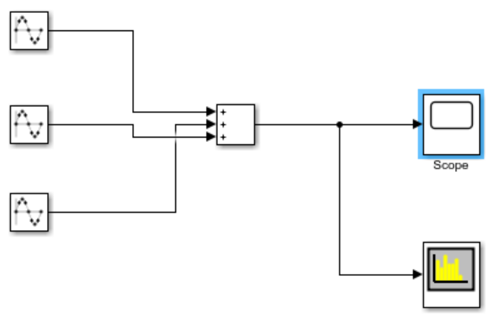

Figure 18: Simulink plot for addition of three sine waves

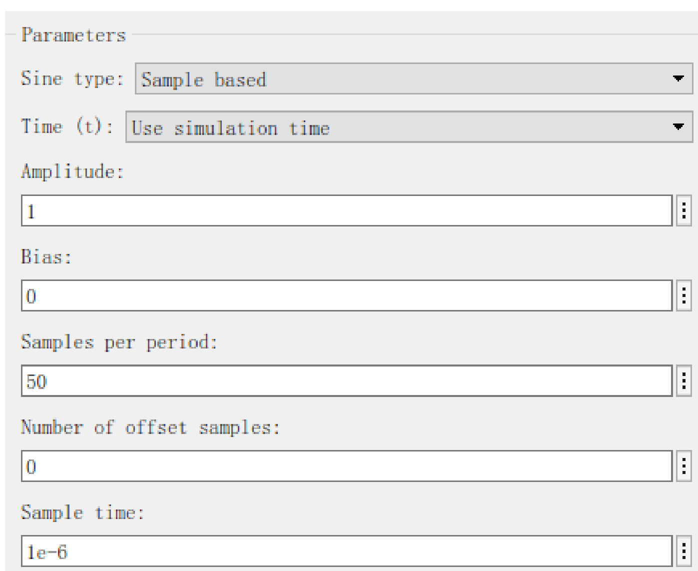

Figure 19: Sine wave function 1 configuration

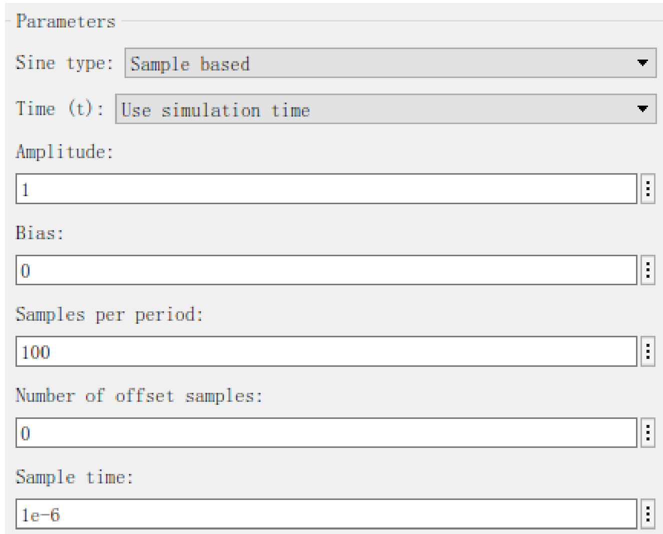

Figure 20: Sine wave function 2 configuration

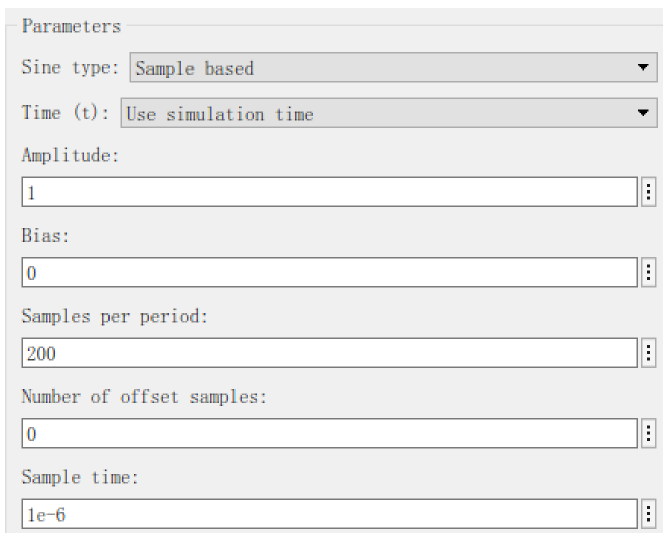

Figure 21: Sine wave function 3 configuration

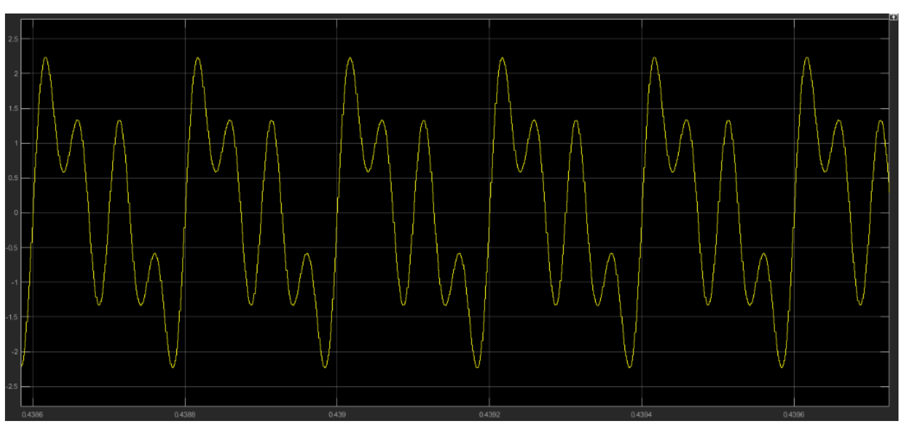

Figure 22: Scope plot with addition of three sine waves

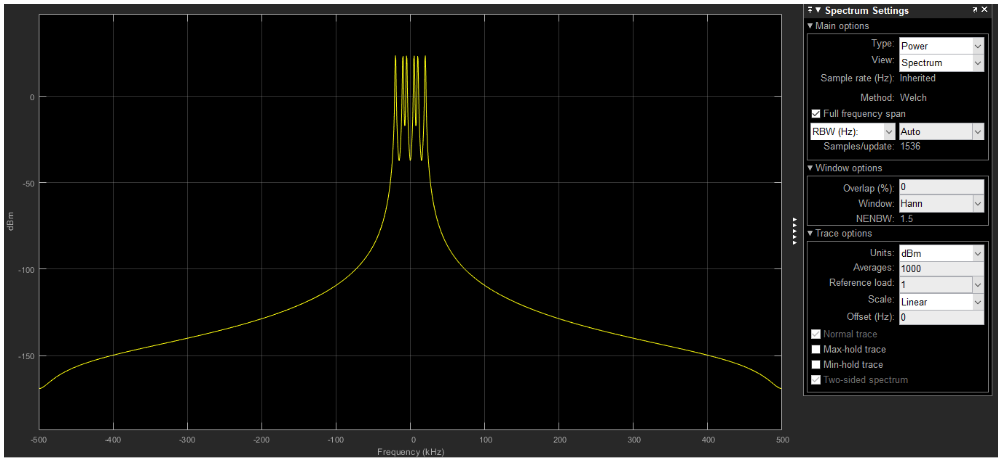

Figure 23: Spectrum plot with addition of three sine waves (A)

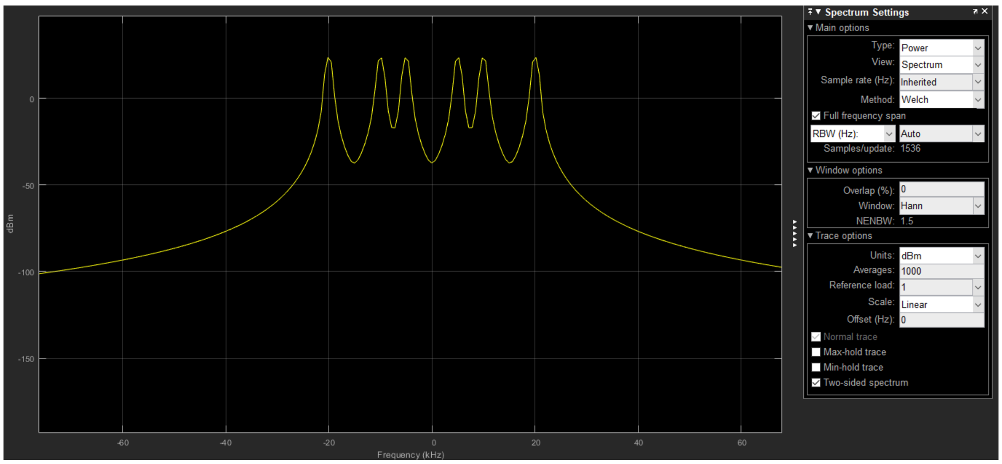

Figure 24: Spectrum plot with addition of three sine waves (B)

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 combined wave is 1.

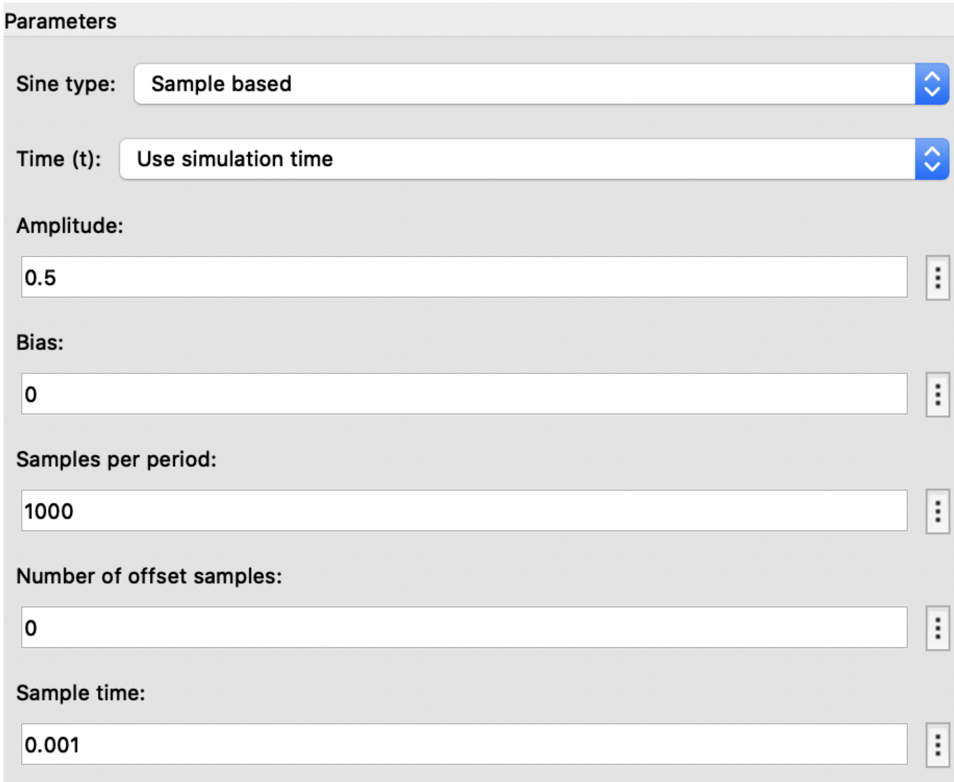

Figure 25: Sine wave 1 and Sine wave 2 Parameters

Figure 26: Step 1 Parameters

Figure 27: Step 2 Parameters

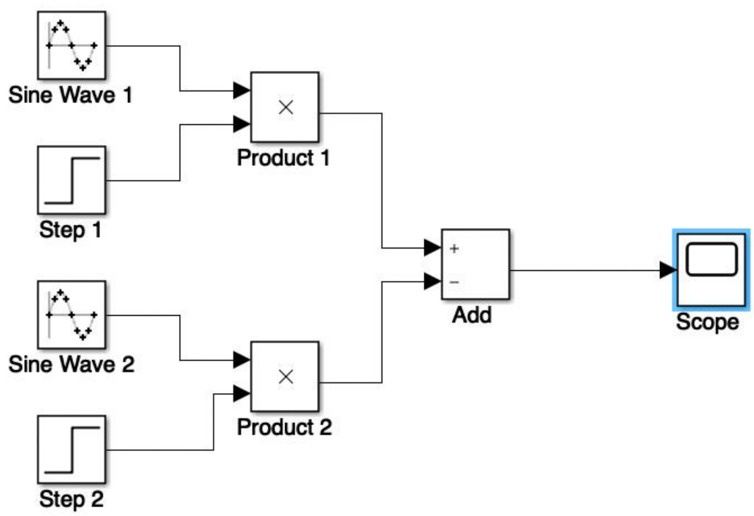

Figure 28: Step+Sine setups

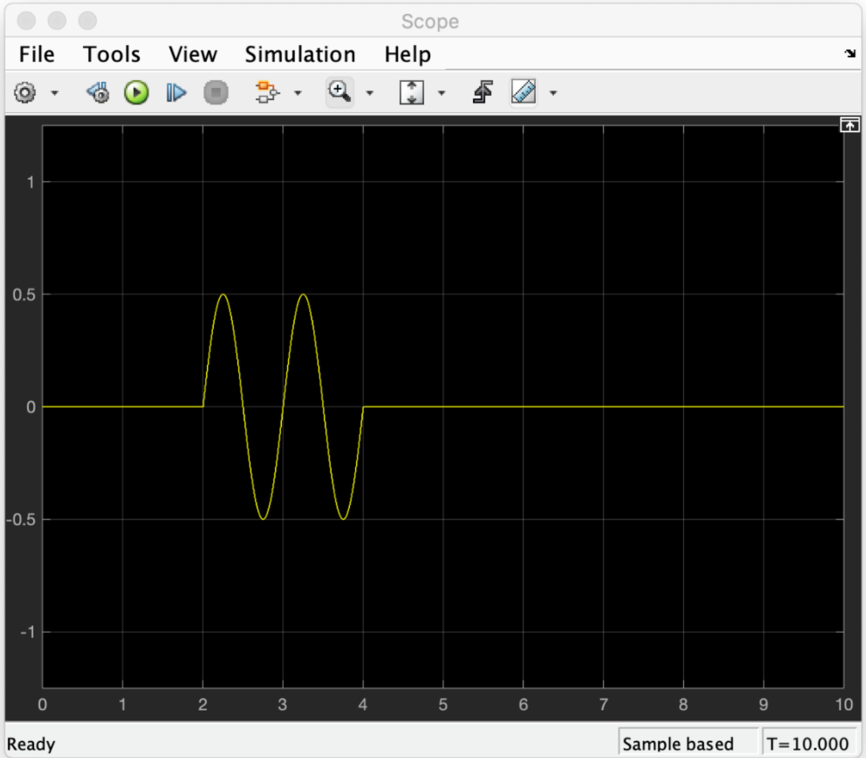

Figure 29: Scope Graph

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.

Answer: The bandwidth of this thermal noise is 179.76kHz (90% energy occupied). The noise power spectral density (N0) can be calculated from the product of Boltzmann constant (1.3806e-23 m^2 kg s^-2 K^-1) with the temperature (kelvin). In this case for the thermal noise in 290K we have 1.3806e-23 m^2 kg s^-2 K^-1 * 290K = 4.00e-21 W/Hz

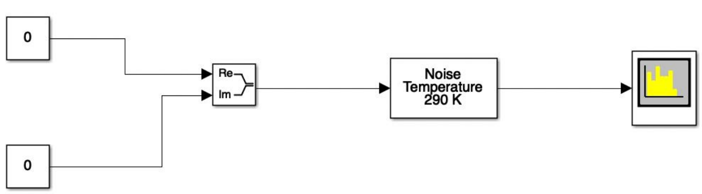

Figure 30: Thermal noise setting

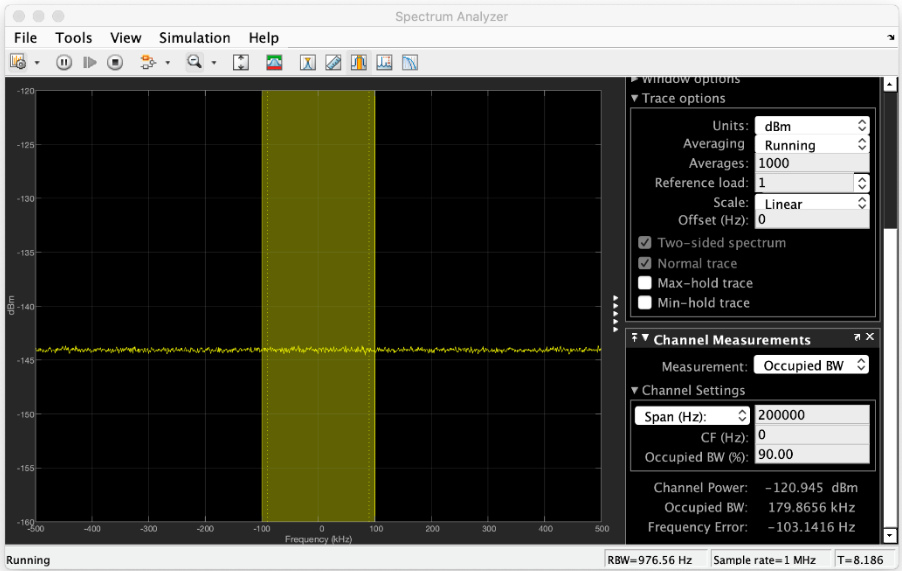

Figure 31: Spectrum plot with 90% occupied bandwidth

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.

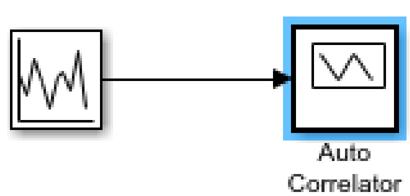

Figure 32: Simulink Diagram

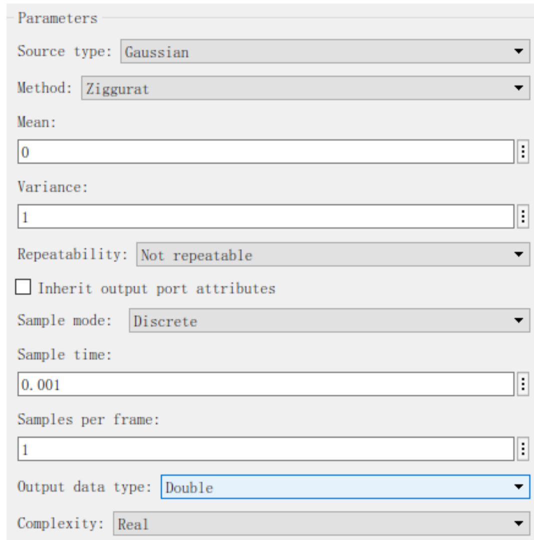

Figure 33: Random Source Configuration

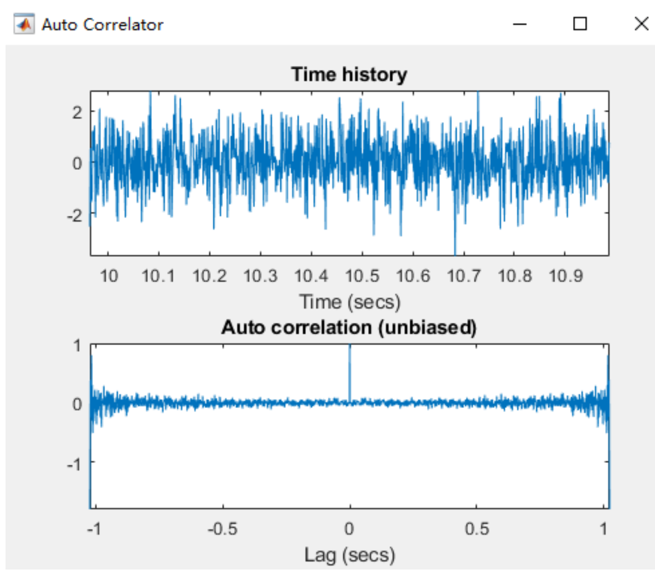

Figure 34: Output on Auto correlator at variance of 1

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 into one mathematical equation. In contrary, deterministic signals are distributed with determined mathematical equations with no variance or uncertainty.

Part 2 Power, Bandwidth & SNR

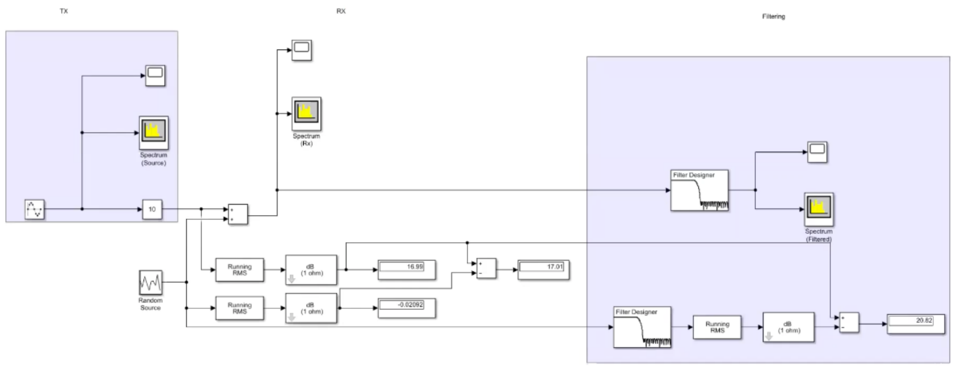

Figure 35: Simulink plot

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.

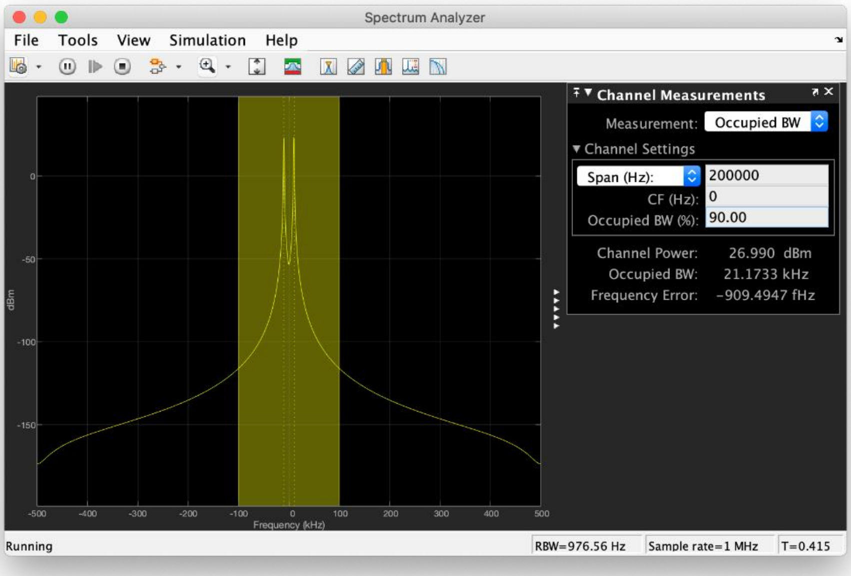

Figure 36: The spectrum analyzer window with (90% occupied BW)

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

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

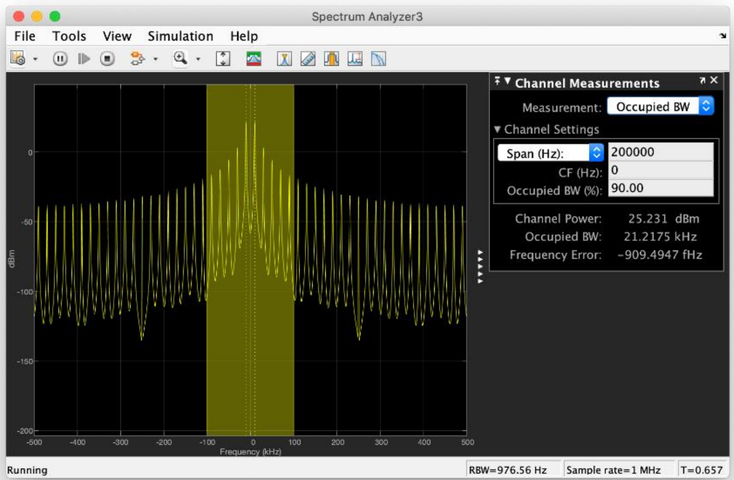

Figure 37: The spectrum analyzer window with (90% occupied BW)

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 50% duty cycle square wave is 16.99dB with 10dB added gain, and the bandwidth is 21.3188kHz.

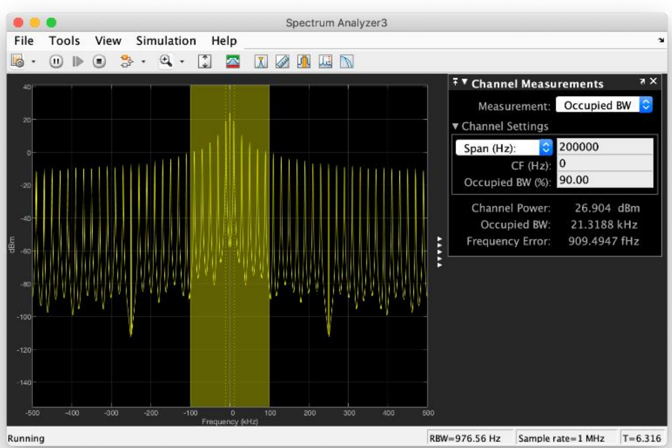

Figure 38: The spectrum analyzer window with (90% occupied BW)

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 80% duty cycle square wave is 19.03dB with 10dB added gain, and the bandwidth is 38.5041kHz.

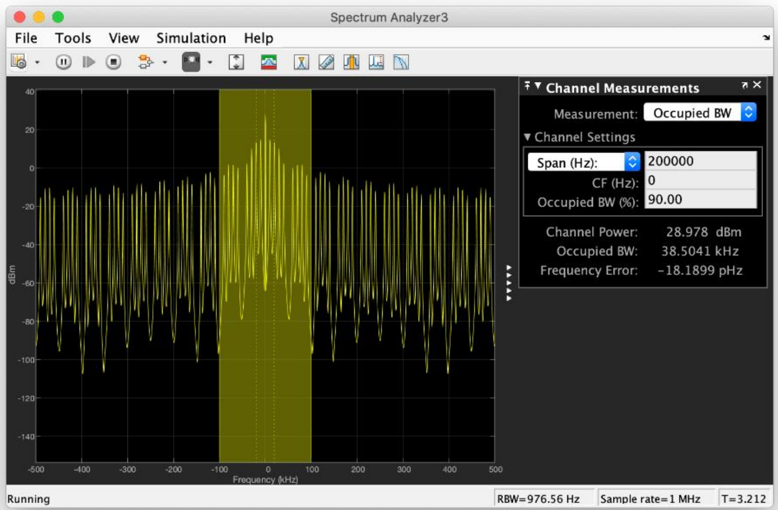

Figure 39: The spectrum analyzer window with (90% occupied BW)

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

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

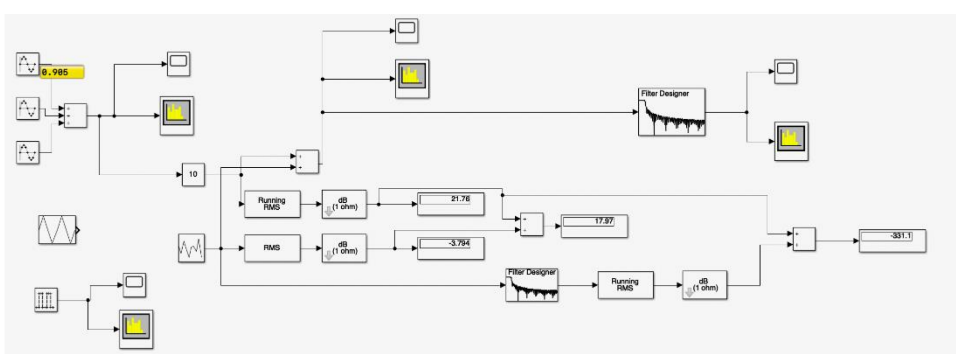

Figure 40: Setups of this questions (adding three sine waves to produce the signal)

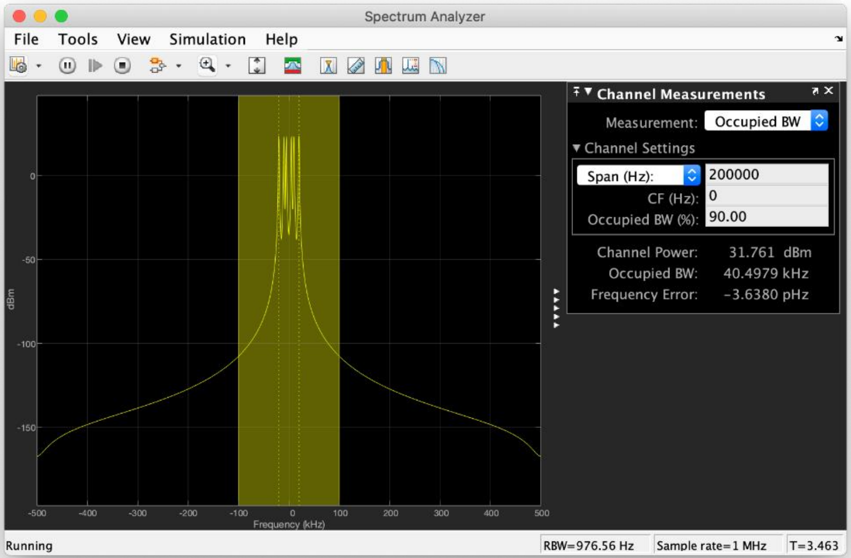

Figure 41: The spectrum analyzer window with (90% occupied BW)

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 fluctuations 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.

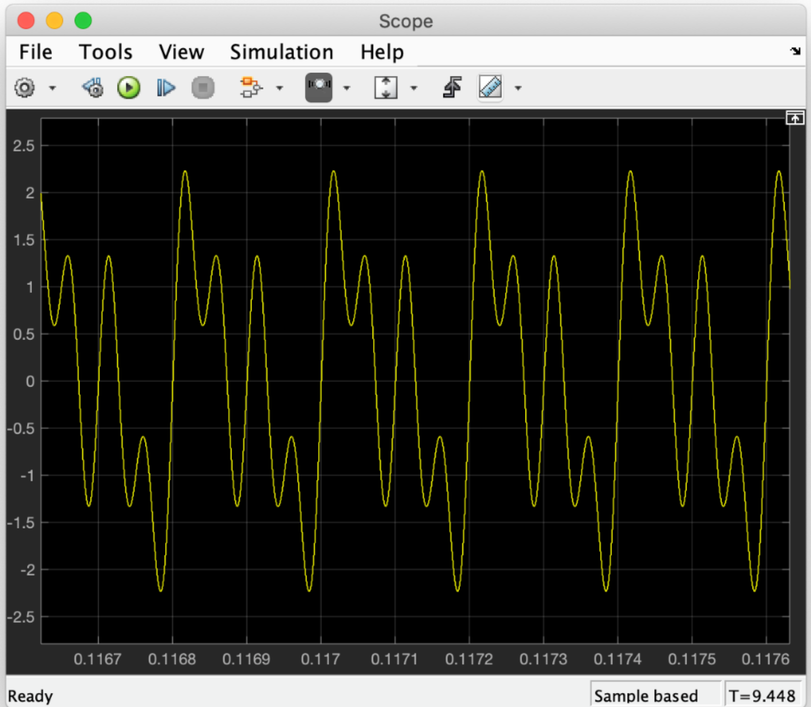

Figure 42: Scope (Source)

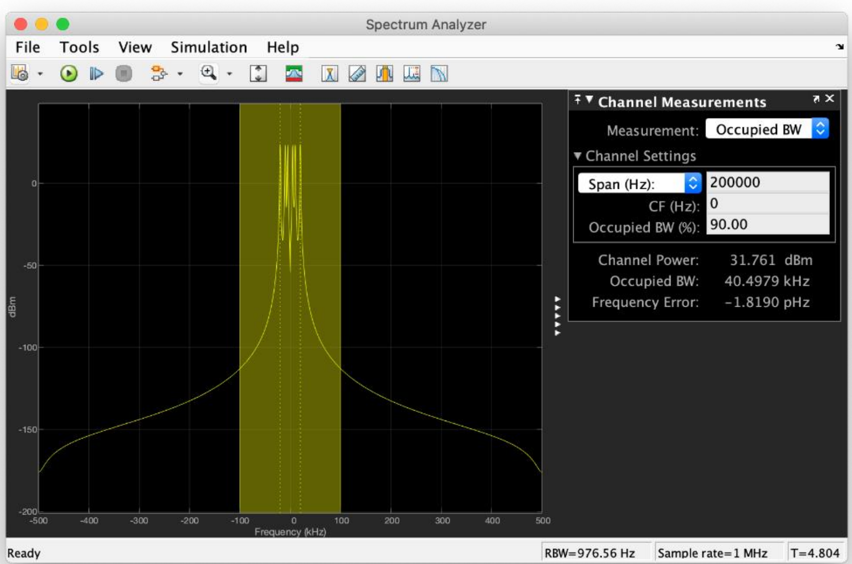

Figure 43: Spectrum (Source)

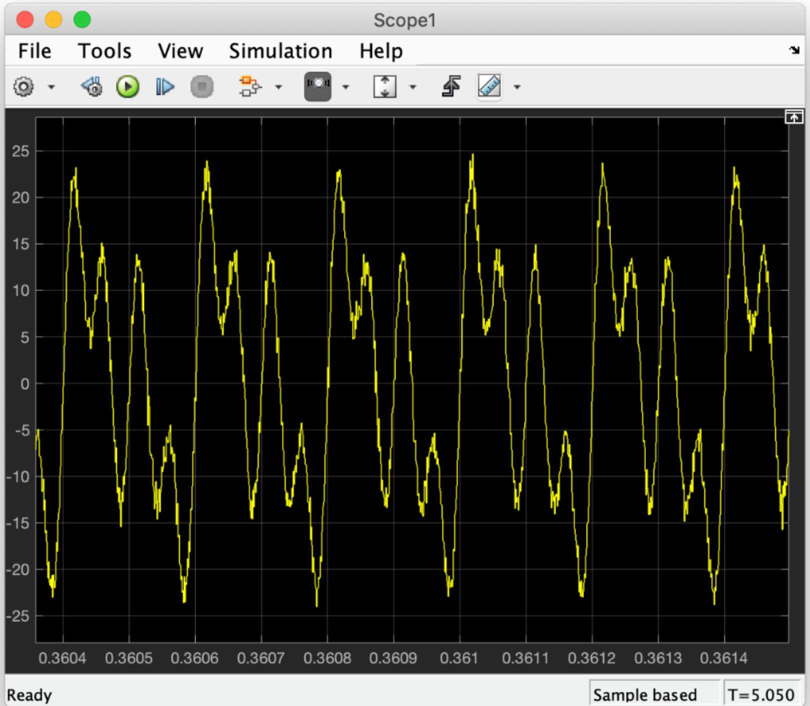

Figure 44: Scope (RX)

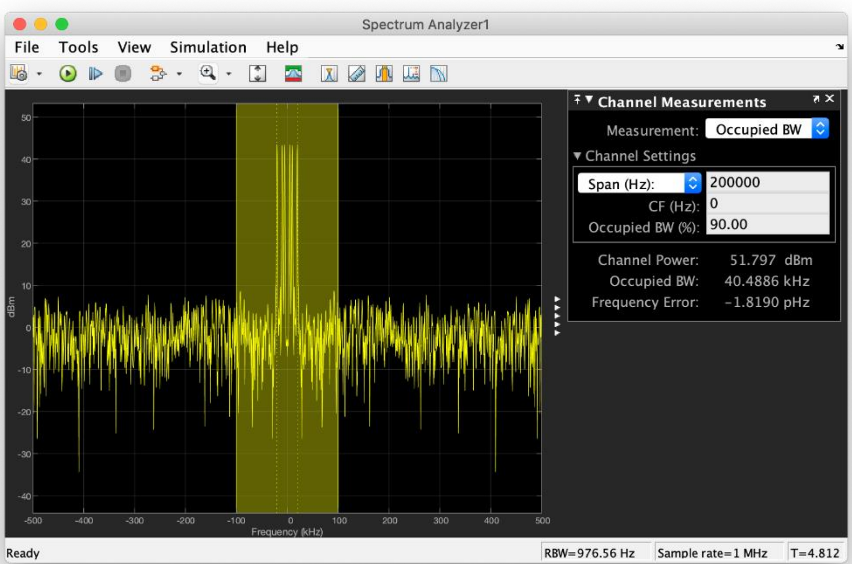

Figure 45: Spectrum (RX)

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 Figures 46 and 47 below, the filtered scope plot has clearer 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 curve clearer.

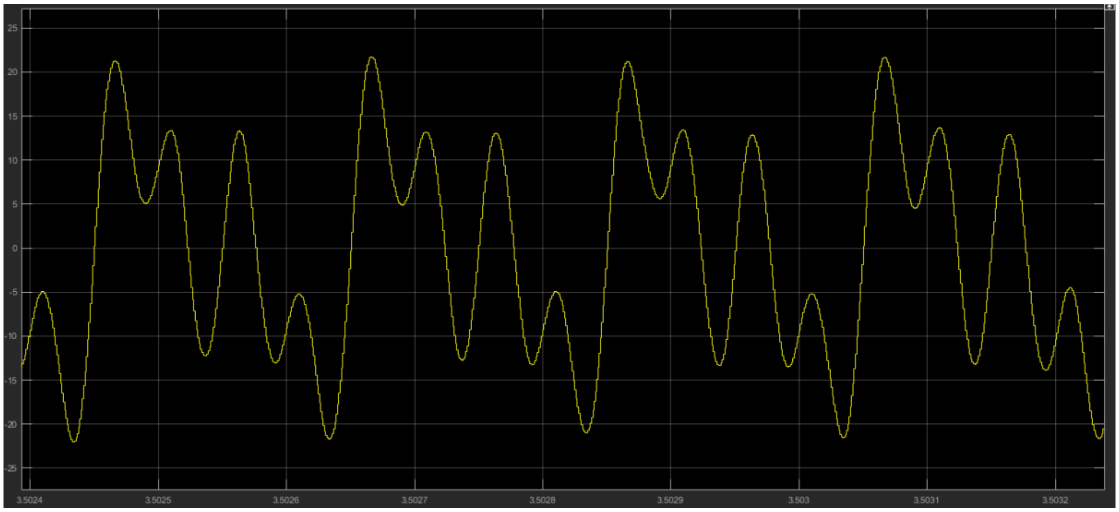

Figure 46: Scope (Filtered) plot

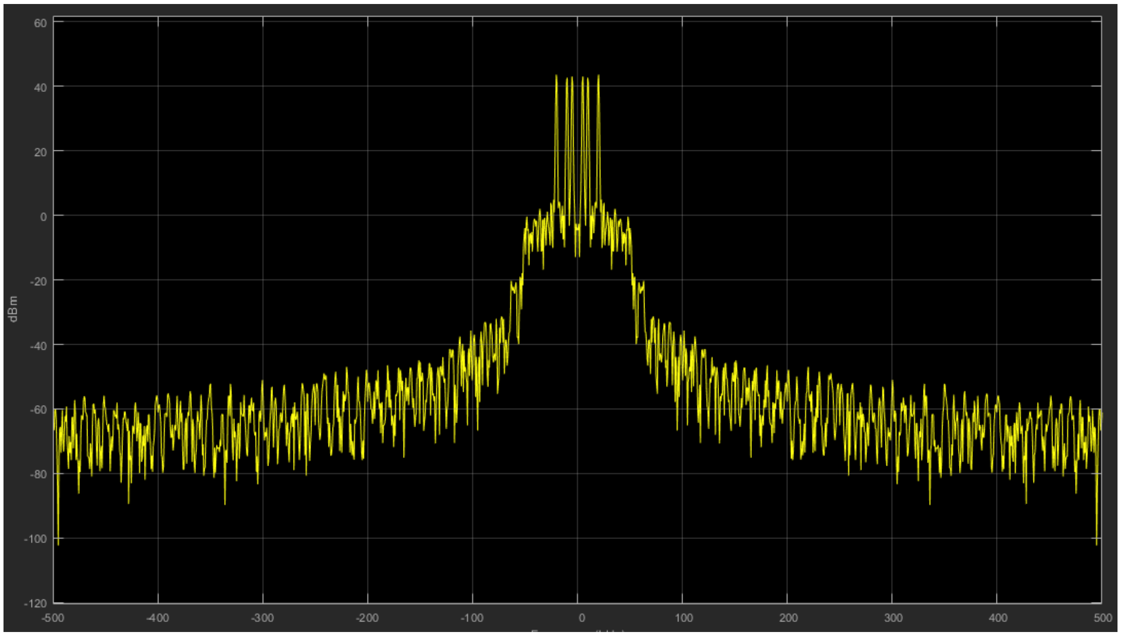

Figure 47 (a): Spectrum (Filtered) plot

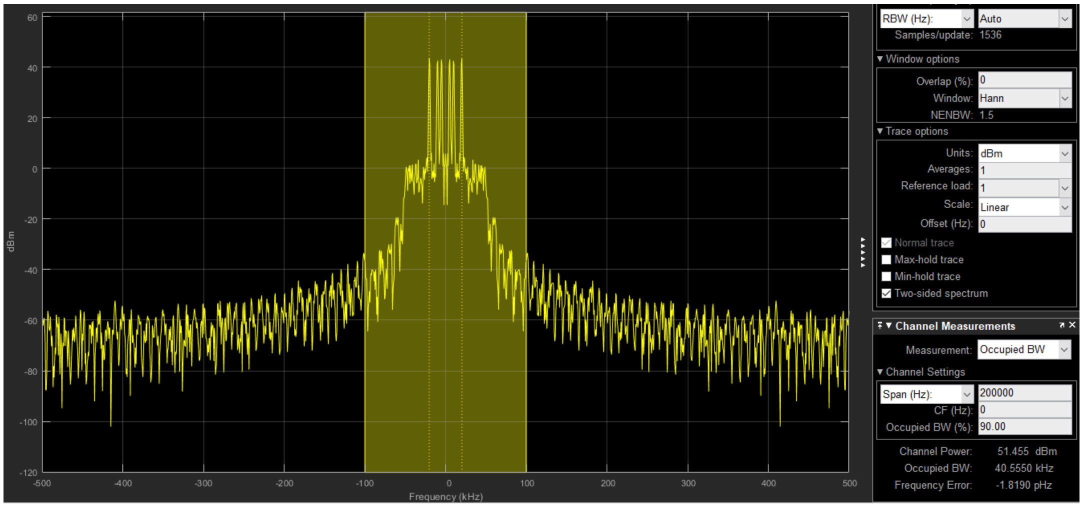

Figure 47 (b): Spectrum (Filtered) plot

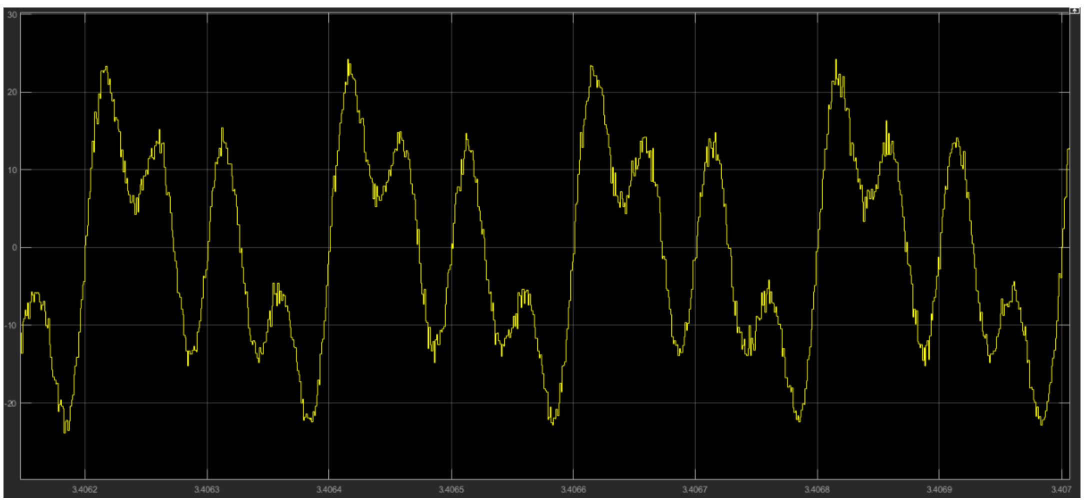

Figure 48: Scope (Rx) plot

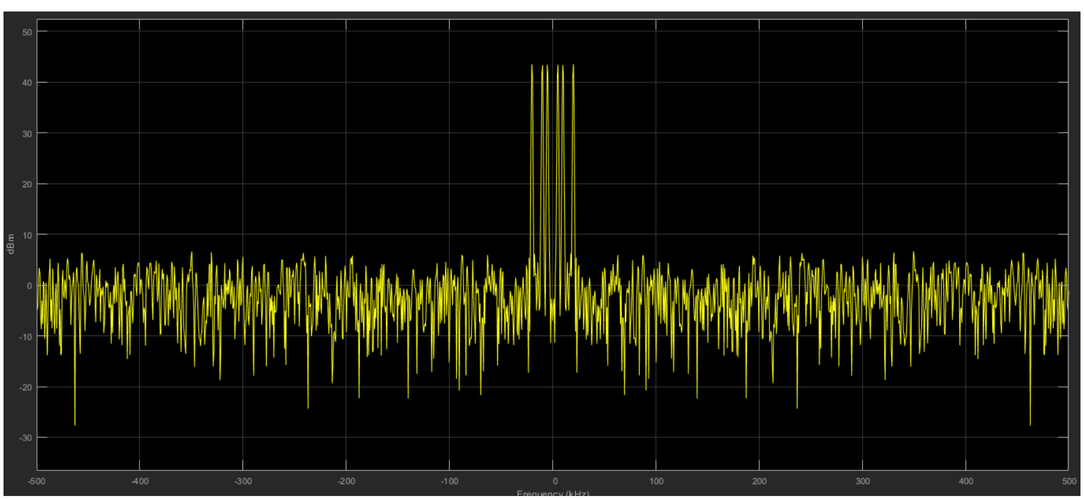

Figure 49: Spectrum (Rx) plot

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 Fc 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 57 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 Fc is increased. The curve of the filtered scope would also change when the cut-off frequency Fc is changed. Meanwhile, it was found that the peak value of the spectrum plot generally does not change when the cut-off frequency Fc is changed. From Figure 47 (b), Figure 55 (b), and Figure 57 (b), it was found that when the cut-off frequency Fc increases, the bandwidth would increase.

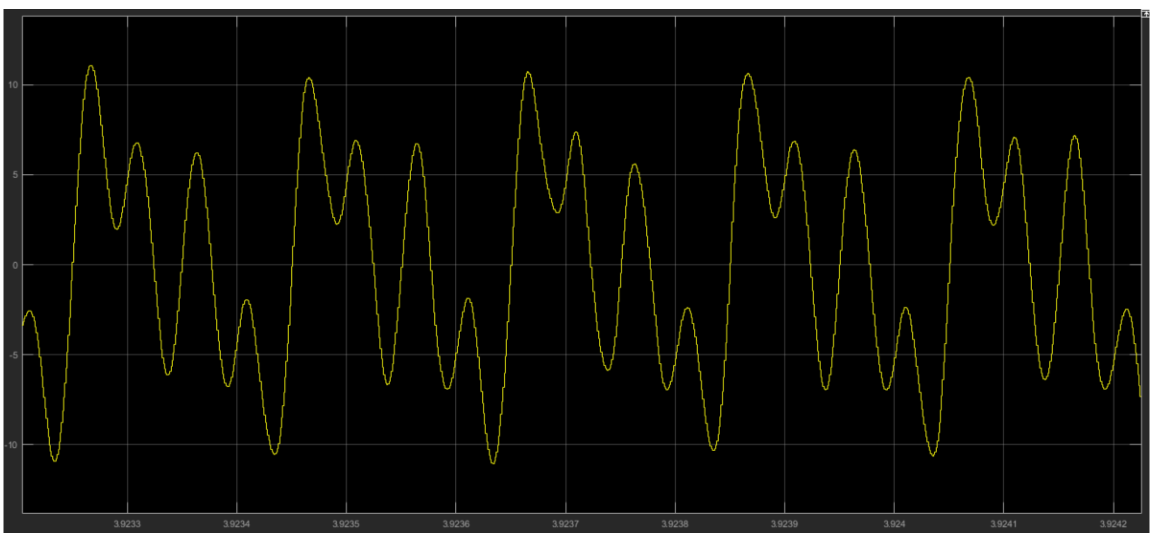

Figure 50: Scope (Filtered) plot (gain of 5db)

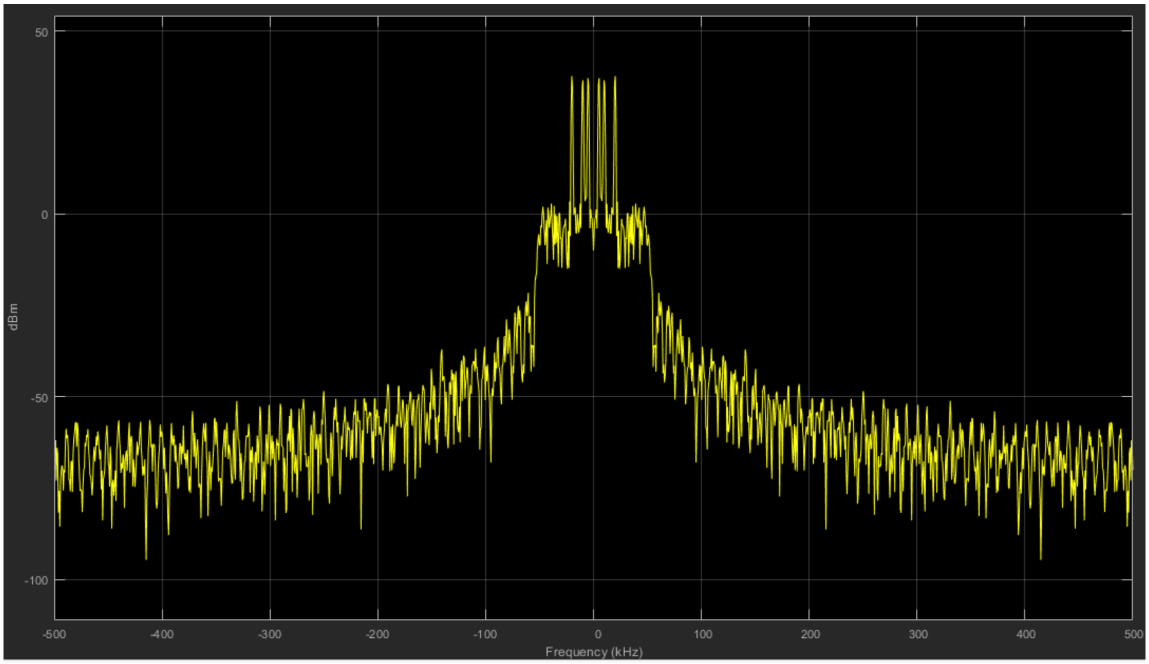

Figure 51: Spectrum (Filtered) plot (gain of 5db)

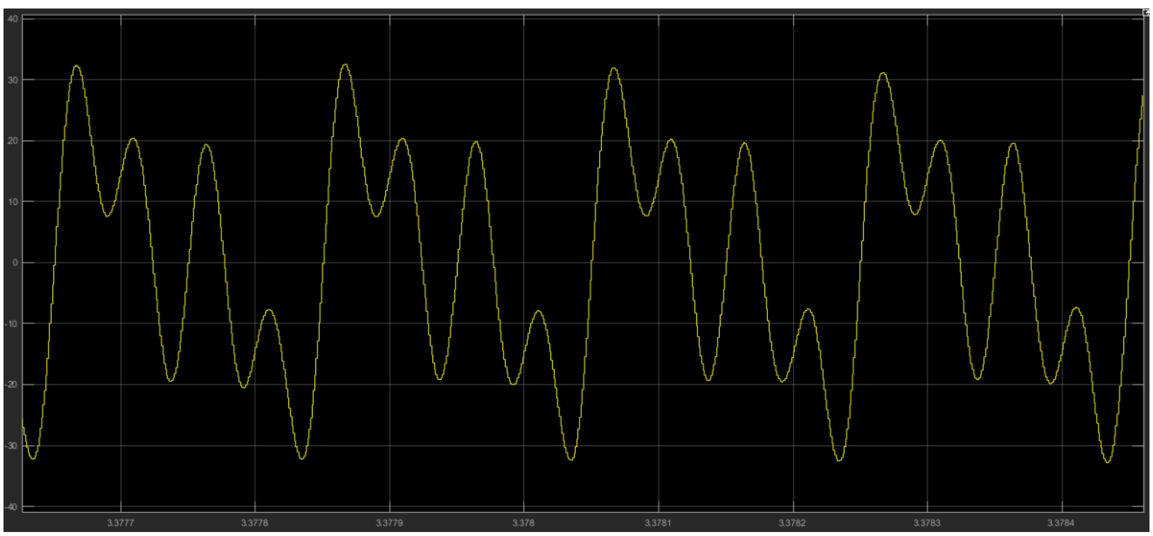

Figure 52: Scope (Filtered) plot (gain of 15db)

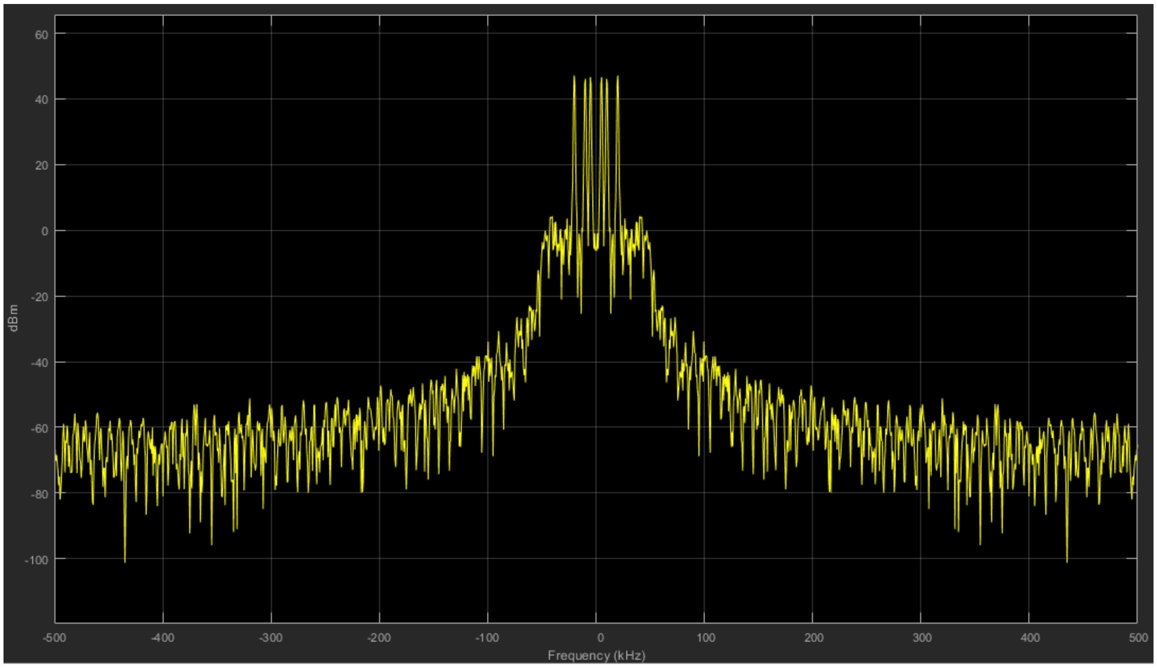

Figure 53: Spectrum (Filtered) plot (gain of 15db)

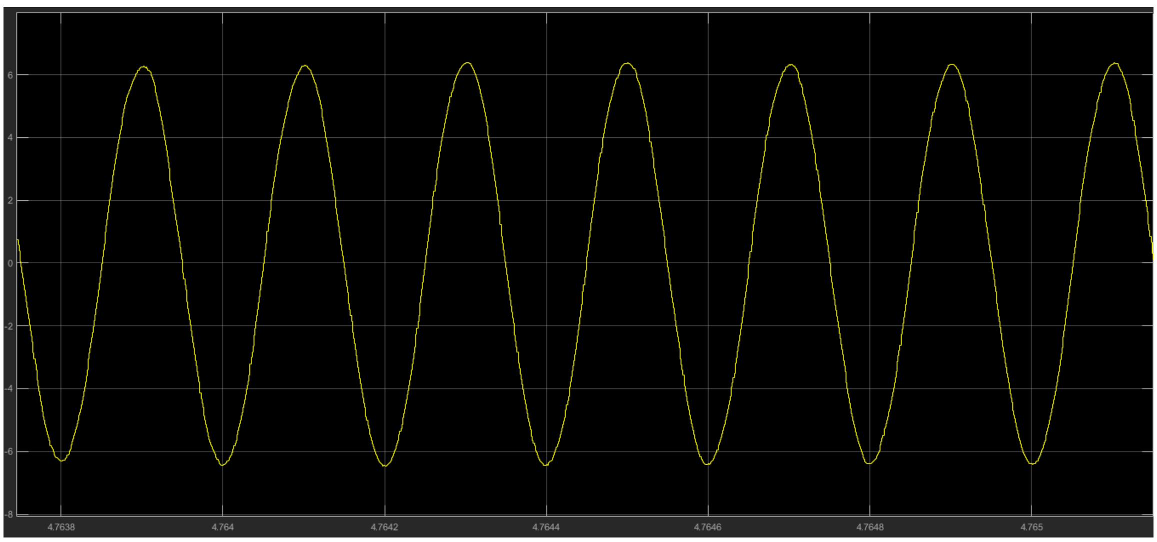

Figure 54: Scope (Filtered) plot (cut-off frequency of 5e2 Hz)

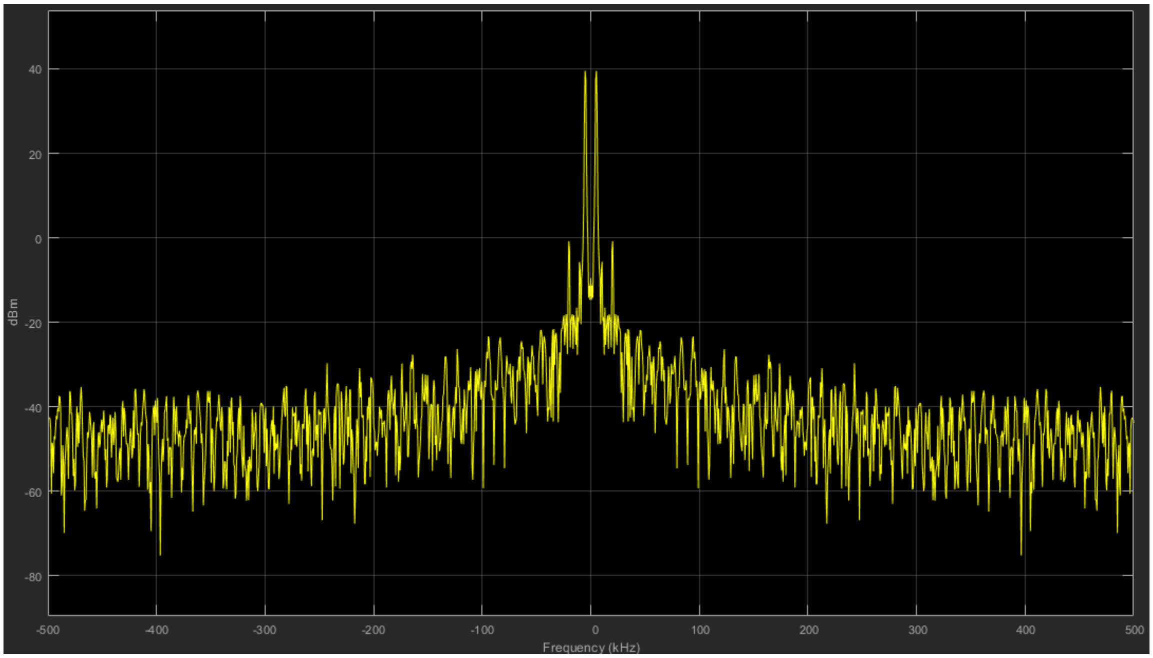

Figure 55 (a): Spectrum (Filtered) plot (cut-off frequency of 5e2 Hz)

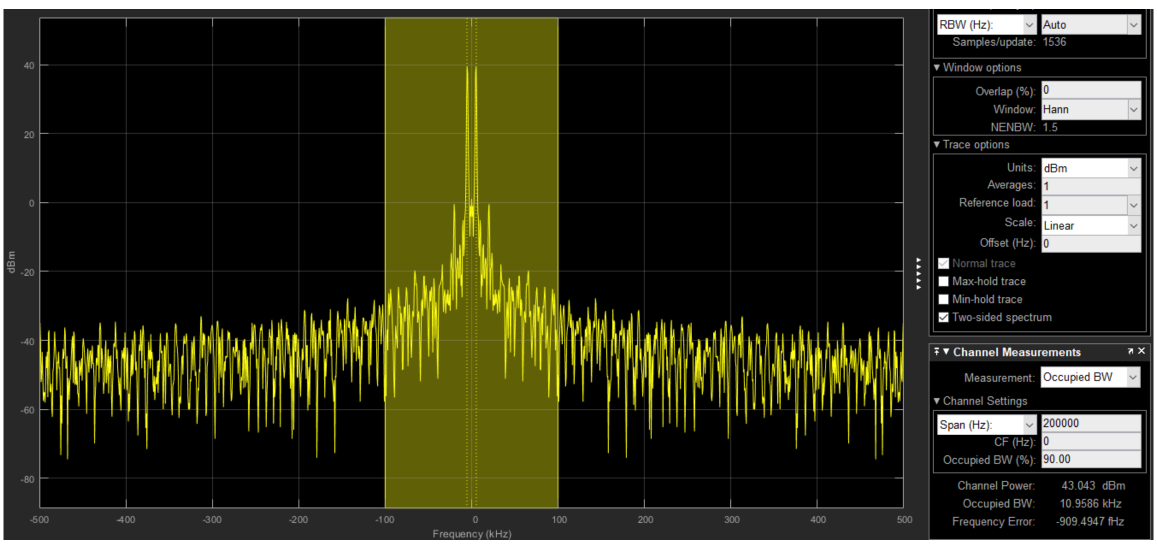

Figure 55 (b): Spectrum (Filtered) plot (cut-off frequency of 5e2 Hz)

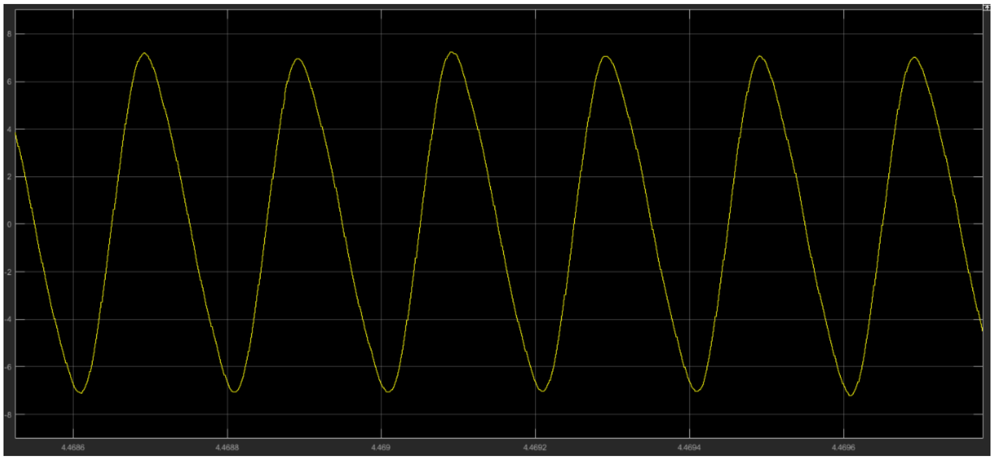

Figure 56: Scope (Filtered) plot (cut-off frequency of 5e3 Hz)

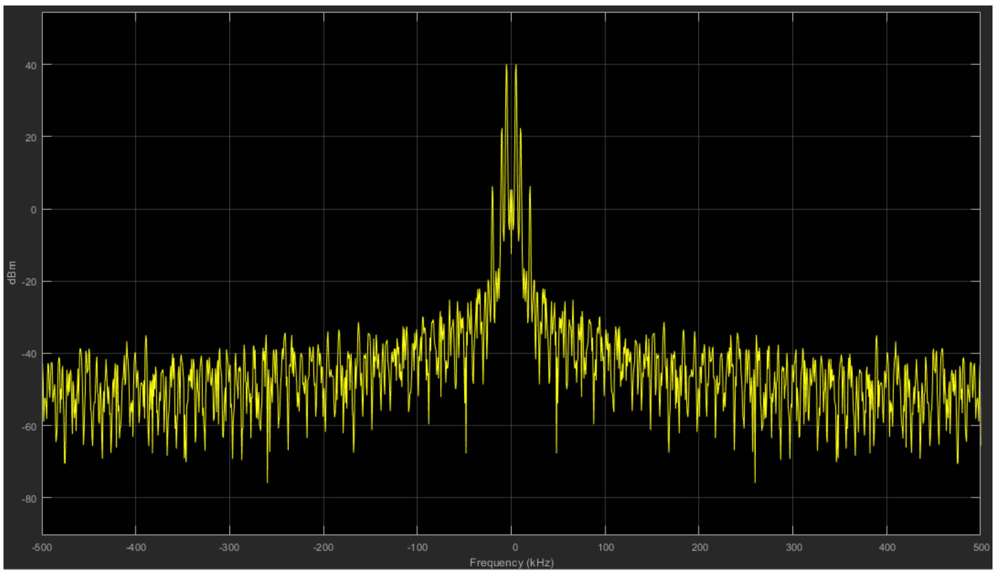

Figure 57 (a): Spectrum (Filtered) plot (cut-off frequency of 5e3 Hz)

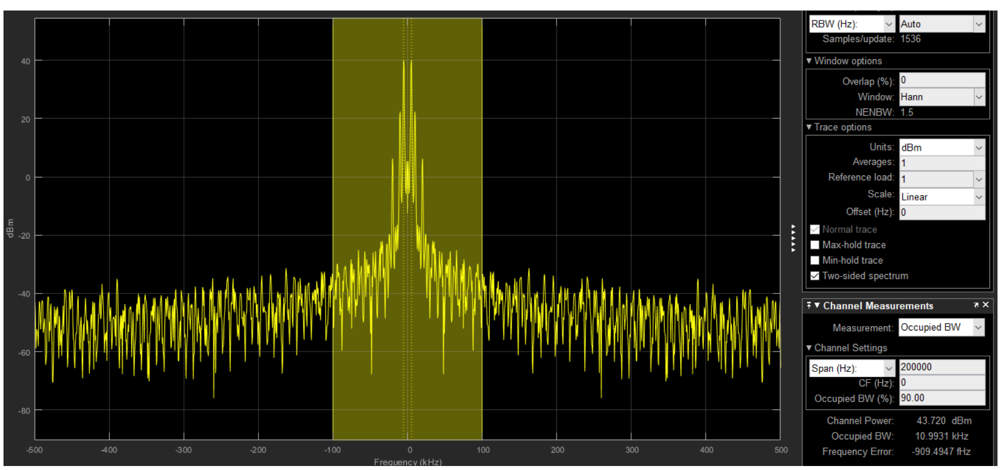

Figure 57 (b): Spectrum (Filtered) plot (cut-off frequency of 5e3 Hz)