ECSE308 Lab 1

Signals and Noise

ECSE308

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Lab 1: Signals and Noise

Part 1: Presentation of Signals and Noise

Introduction:

The objective of the first part of the lab is to understand the basic signal and noise concepts including periodic/non-periodic signals, deterministic/random signals, and Gaussian/thermal noise. Furthermore, the techniques to analyze both time-domain signals and frequency-domain signals are also introduced.

Experiments:

1) In this experiment, the first task is using a sample based sine wave with setting amplitude to 0.5, samples per period to 1000, and sample time to 1e-4. This sine wave is then connected to a scope and a spectrum, and the outputs on them are shown below (Fig. 1 and Fig. 2).

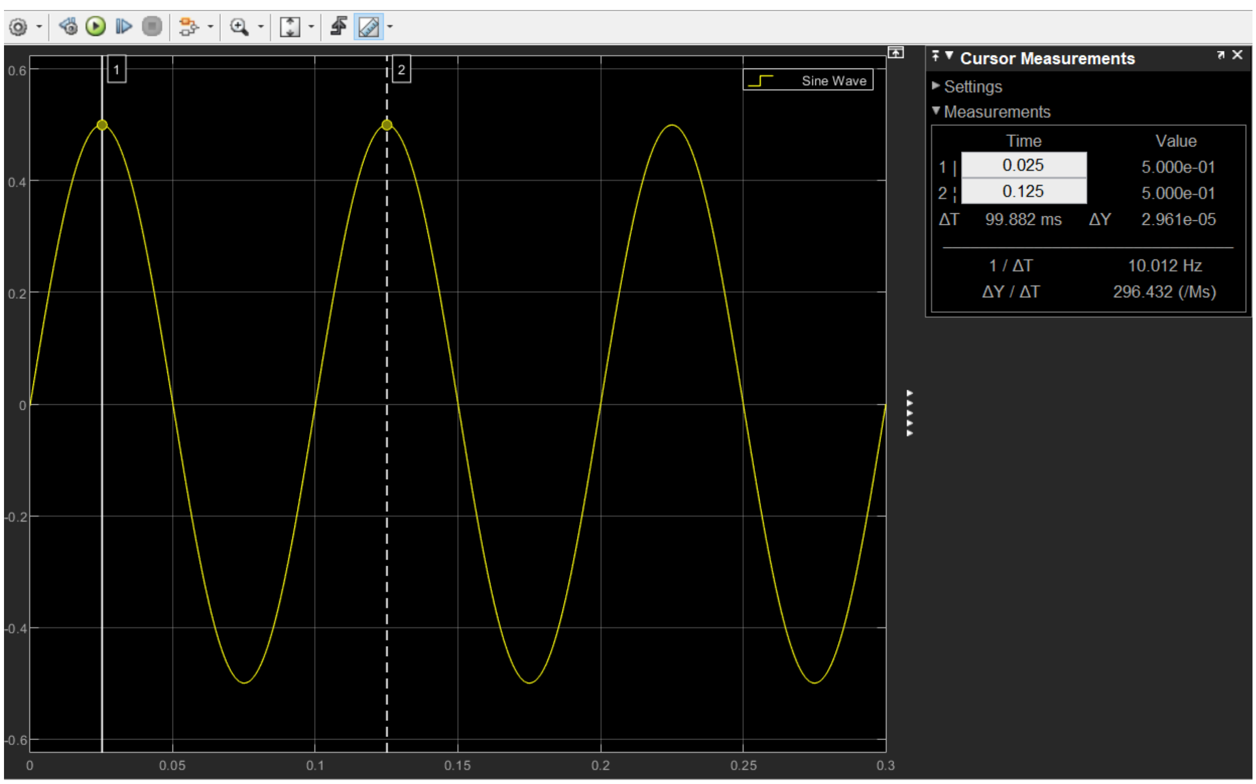

Fig. 1: Output of the sine-wave on the Scope

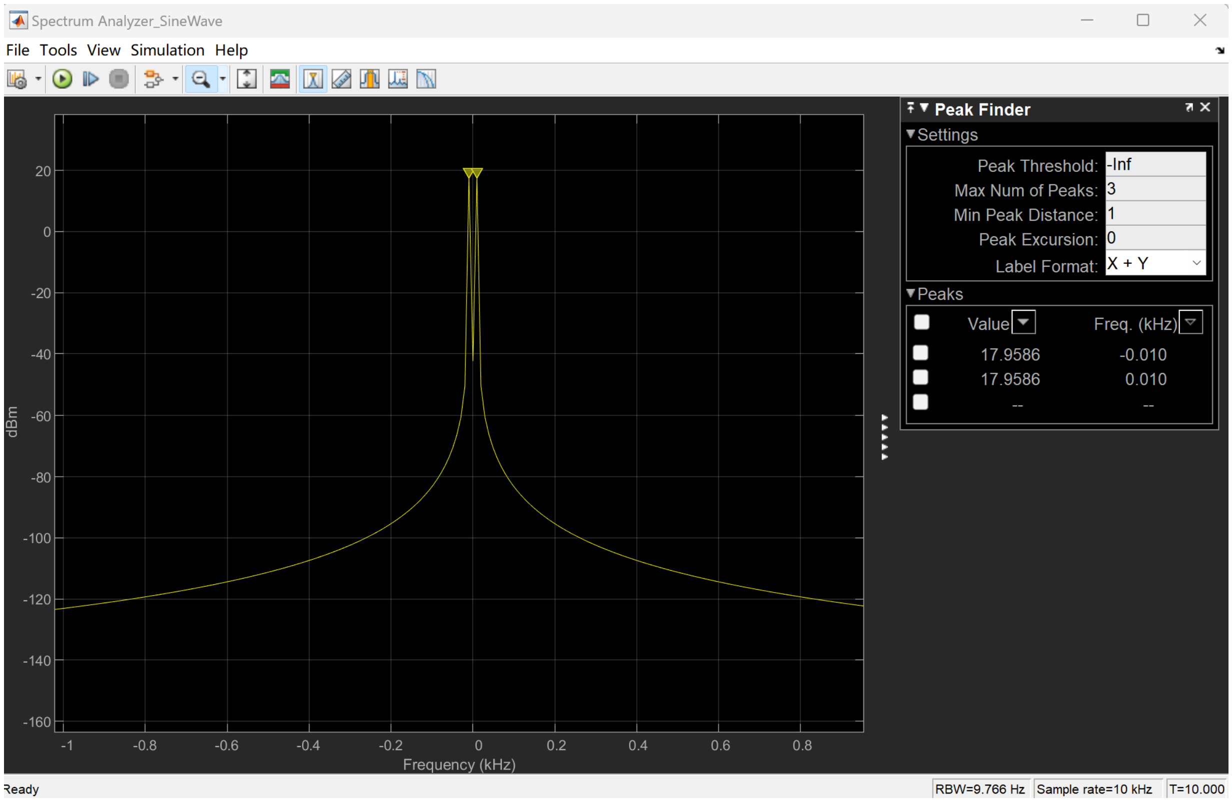

Fig. 2: Output of the sine-wave on the Spectrum

2) Replacing the sine wave with a triangular wave generated by a triangle generator, which was set up to sample based with a period (number of samples) of 5000 and a sample time of 1e-4, we observed the outputs on the Scope and the Spectrum (Fig. 3 and Fig. 4)

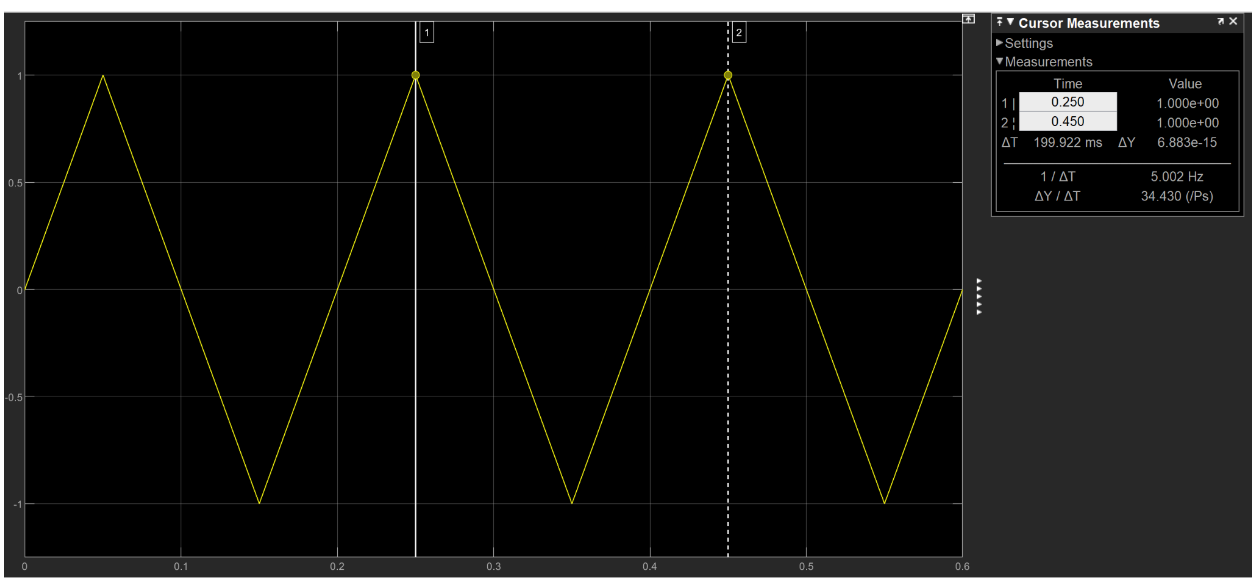

Fig. 3: Output of the triangular-wave on the Scope

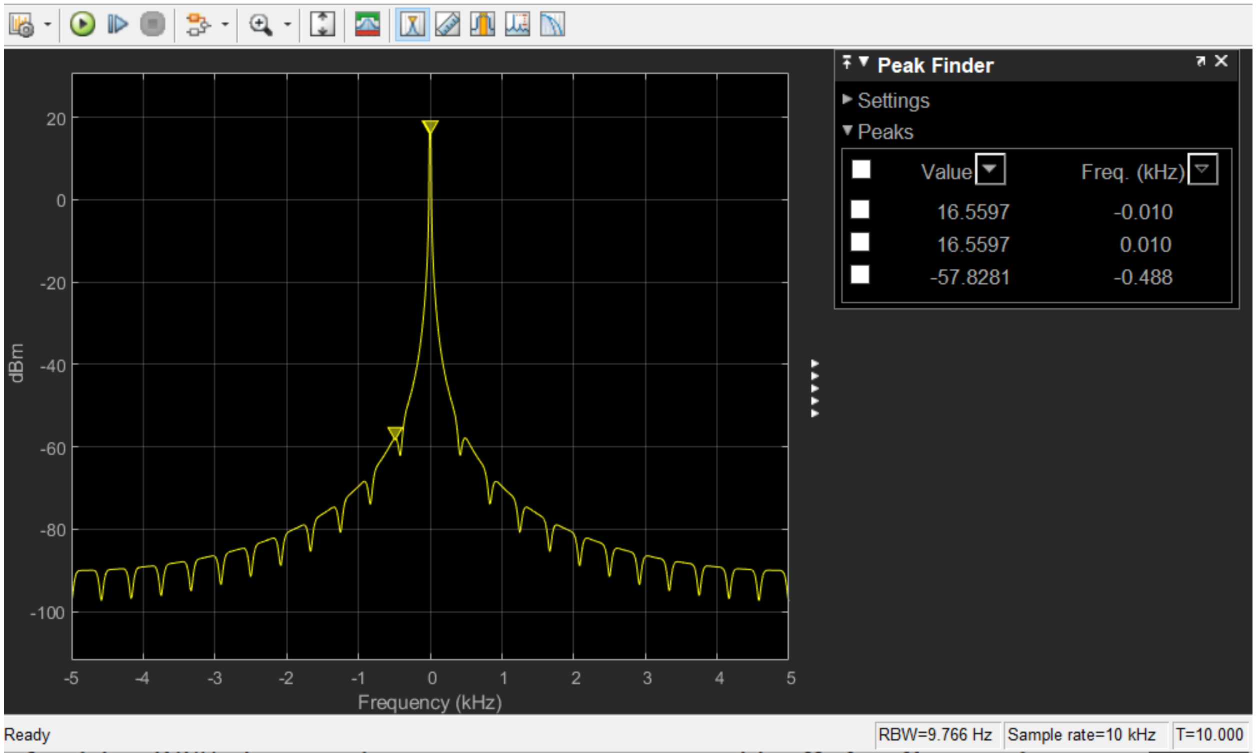

Fig. 4: Output of the triangular-wave on the Spectrum

3) We repeated step one with a square wave, with a 50% duty cycle, generated by the pulse generator. We set its pulse type to sample based and sample time to 1e-4. The outputs on the Scope and the Spectrum are shown in Fig. 5 and Fig. 6.

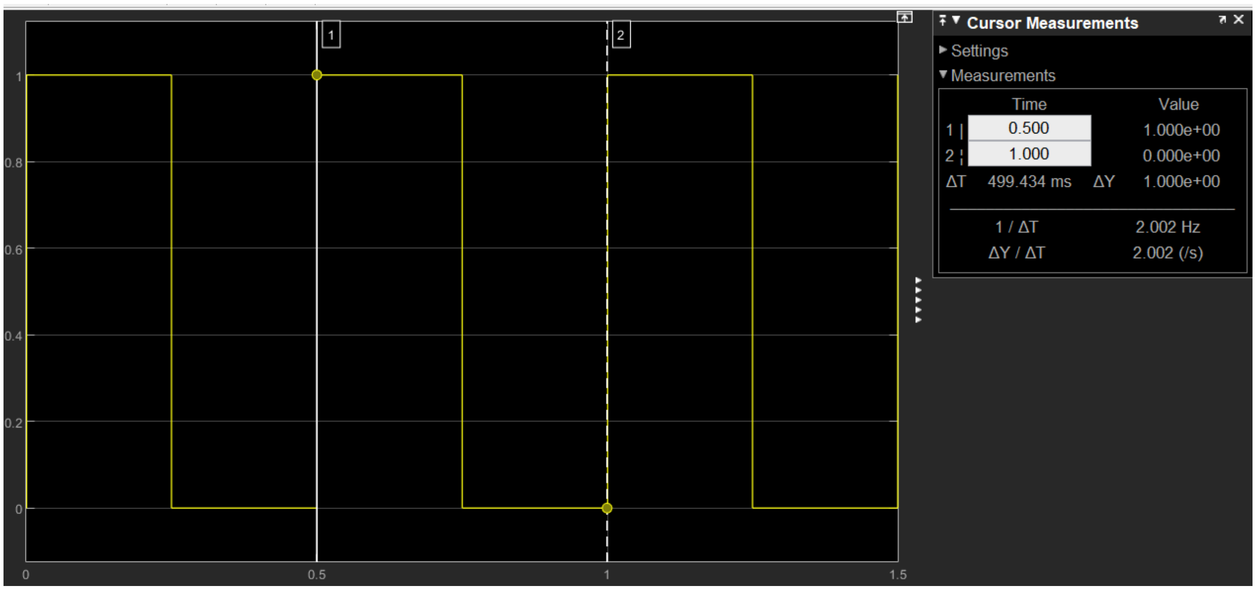

Fig. 5: Output of the square-wave (50% duty cycle) on the Scope

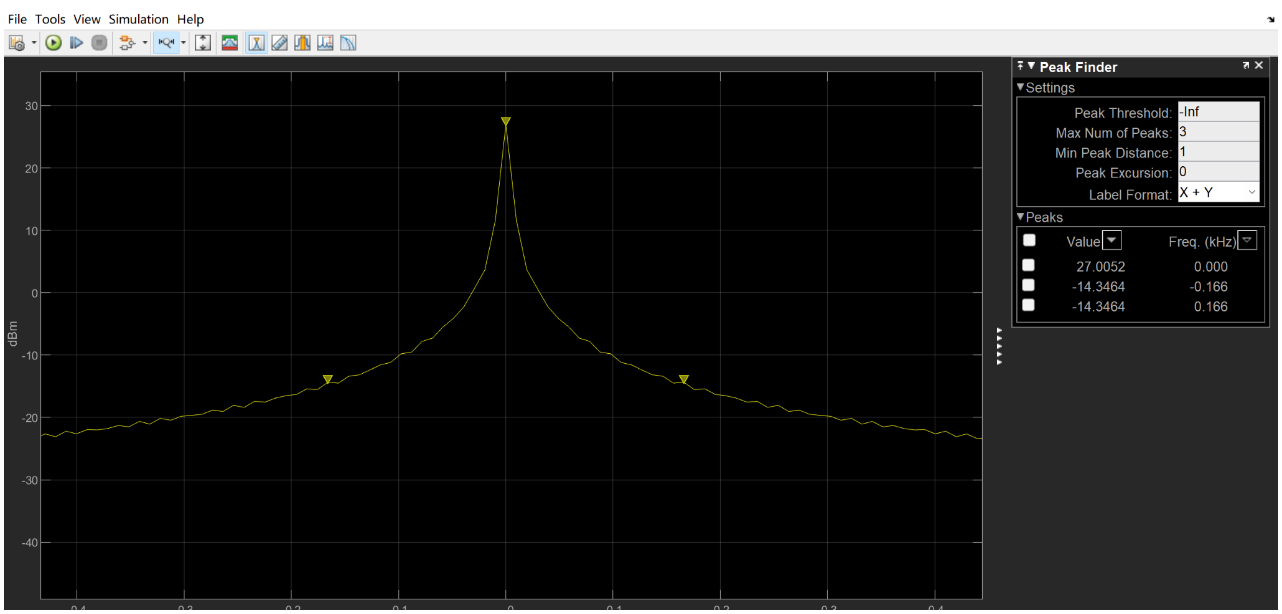

Fig. 6: Output of the square-wave (50% duty cycle) on the Spectrum

4) We then changed the duty cycle of the square wave to 20%, and observed the outputs on the Scope and the Spectrum (Fig. 7 and Fig. 8).

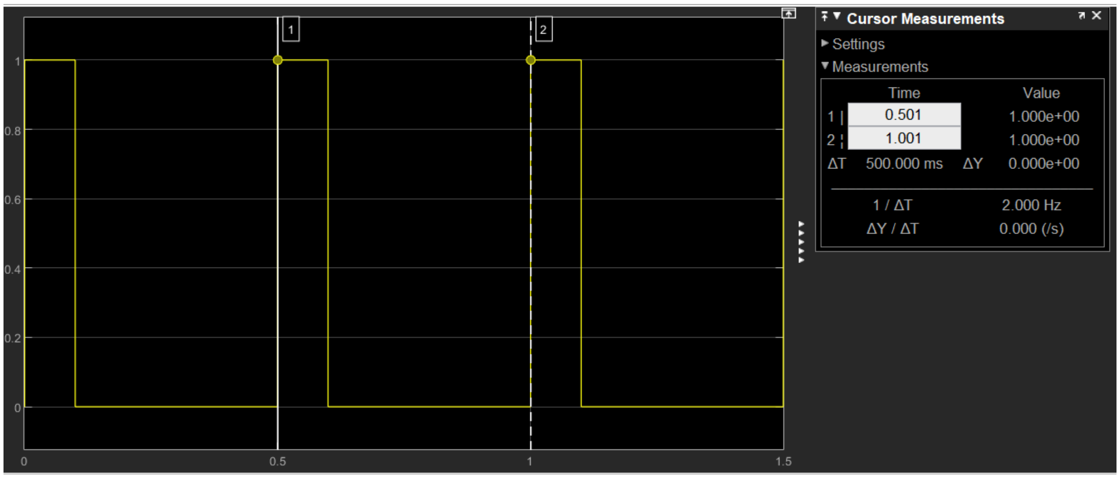

Fig. 7: Output of the square-wave (20% duty cycle) on the Scope

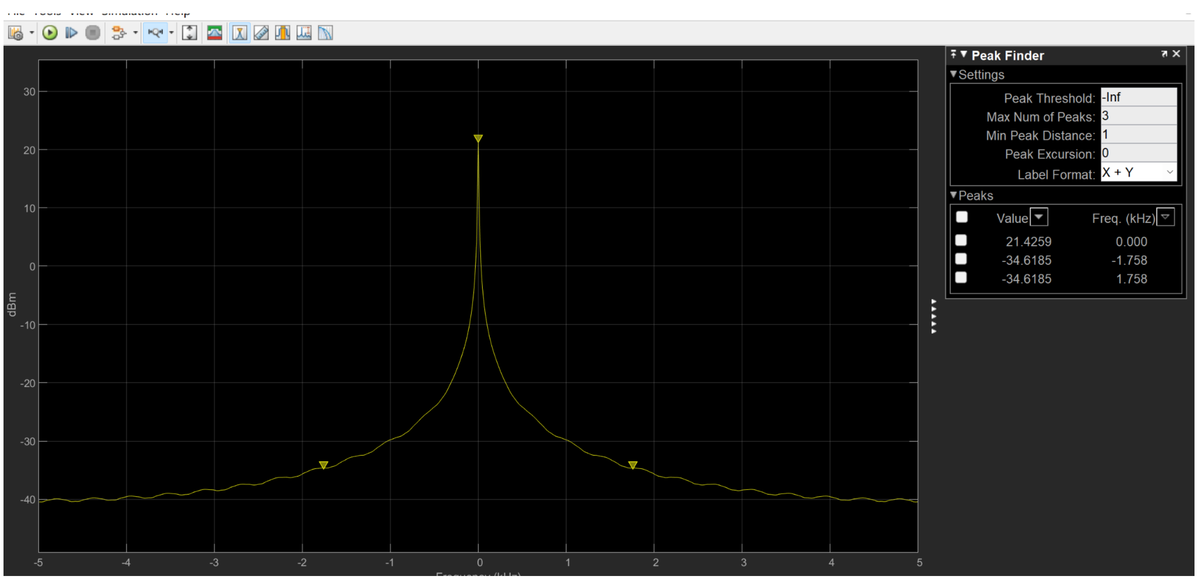

Fig. 8: Output of the square-wave (20% duty cycle) on the Spectrum

5) We then repeated this step, but this time with a sum of three ample based sine waves, and each has the sample time set to 1e-4. The first sine wave is set up with an amplitude of 0.5 and samples per period of 500; the second one is set up with an amplitude of 2 and samples per period of 1000; the third one is set up with an amplitude of 1.5 and samples per period of 100. We observed the outputs on the Scope and the Spectrum (Fig. 9 and Fig. 10)

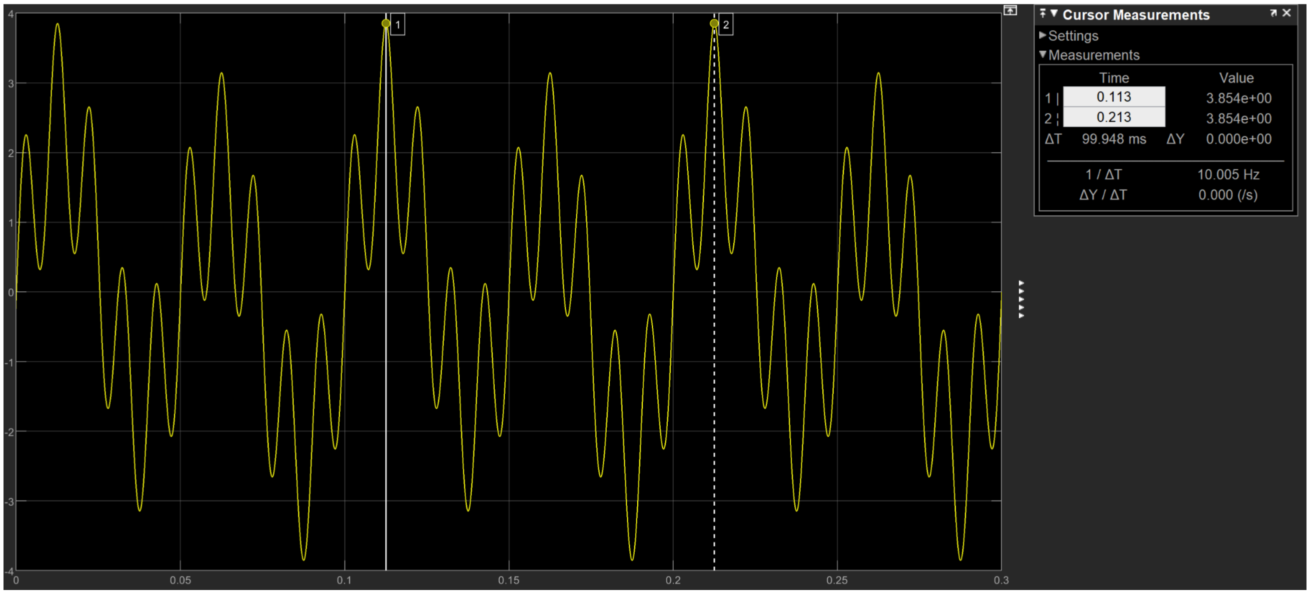

Fig. 9: Output of the sum of three sine-wave on the Scope

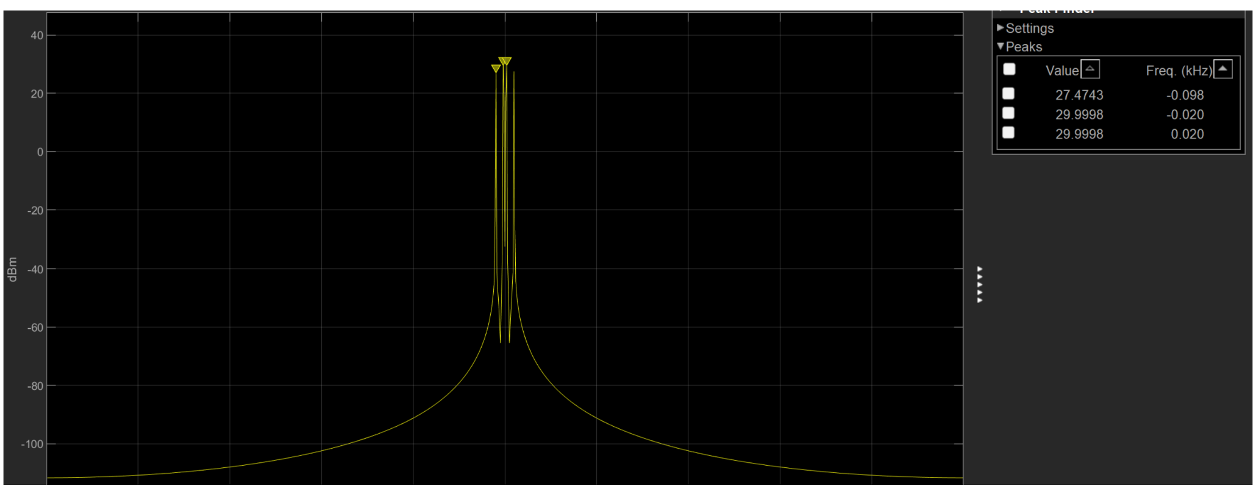

Fig. 10: Output of the sum of three sine-wave on the Spectrum

6) To observe the output on the Scope of sum of signals, we connected the blocks as shown in Fig. 11. We set up the parameters as listed in the following:
Sine Wave I and Sine Wave II: Amplitude: 0.5, samples per priod: 1000, and sample time: 1e-3
Step 1: Step time: 2
Step 2: Step time: 4
The output of this sum of signals on the Scope is shown in Fig. 12

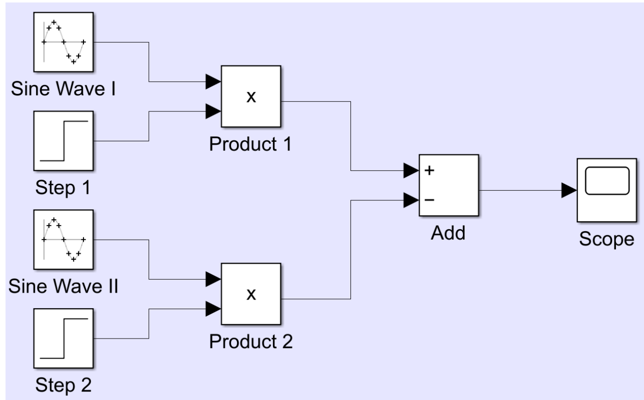

Fig. 11: Sum of signals

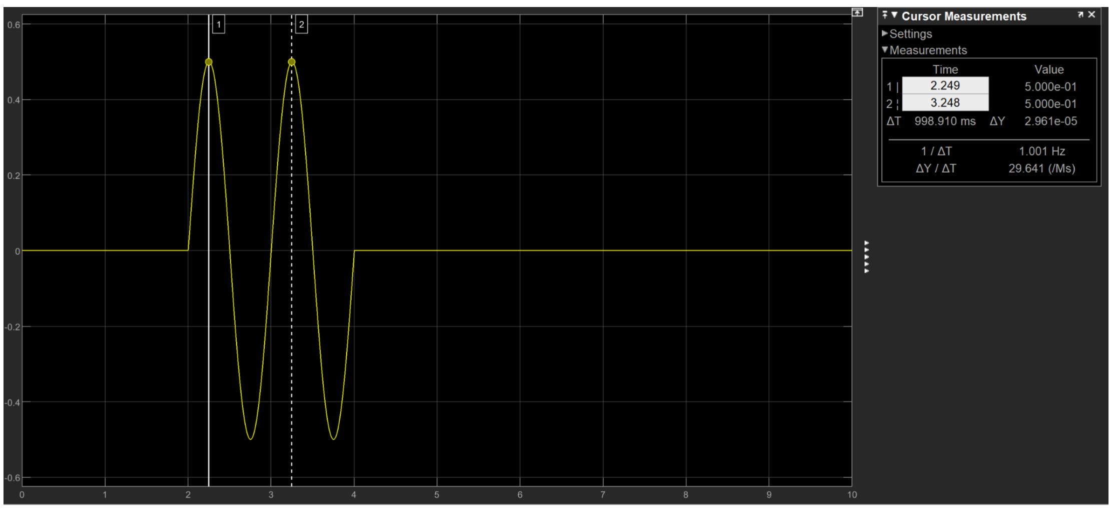

Fig. 12: Output of the sum of signals on the Scope

7) To better understand the thermal noise, we built connected these blocks as shown in Fig. 13. Our parameters were set up as listed below:
Constant 1 and Constant 2: Constant value: 0, Sample time: 1e-6
Receiver Thermal Noise: Specification method: noise temperature, Noise temperature: 290K

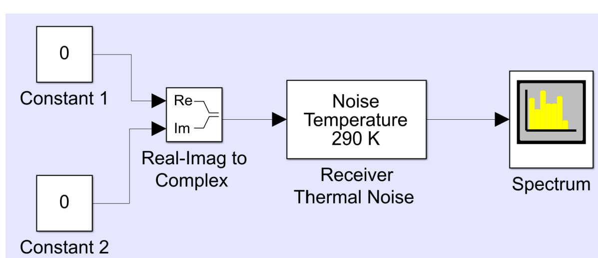

Fig. 13: Thermal noise

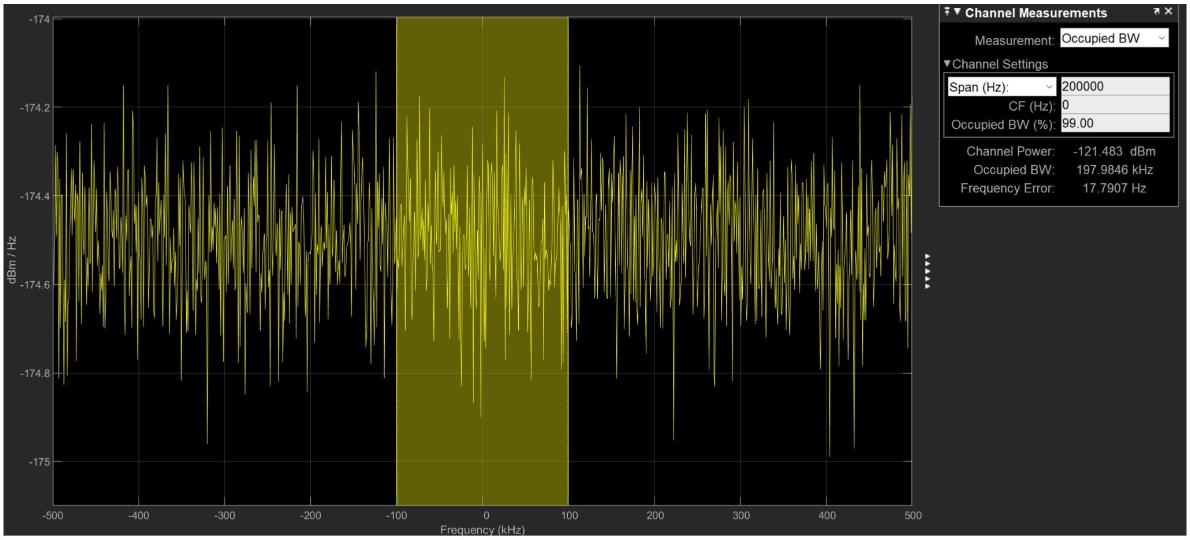

Fig. 14: Output of the thermal noise on the Spectrum

8) With a random source and an auto correaltor being connected and set up, we could gain further knowledge of noise power. We used Gaussian source type for the Random Source, and set its sample time to 1e-3. Then we set the length of buffer of the Auto Correlator to 1024, and set its sample time to 1e-3 as well.

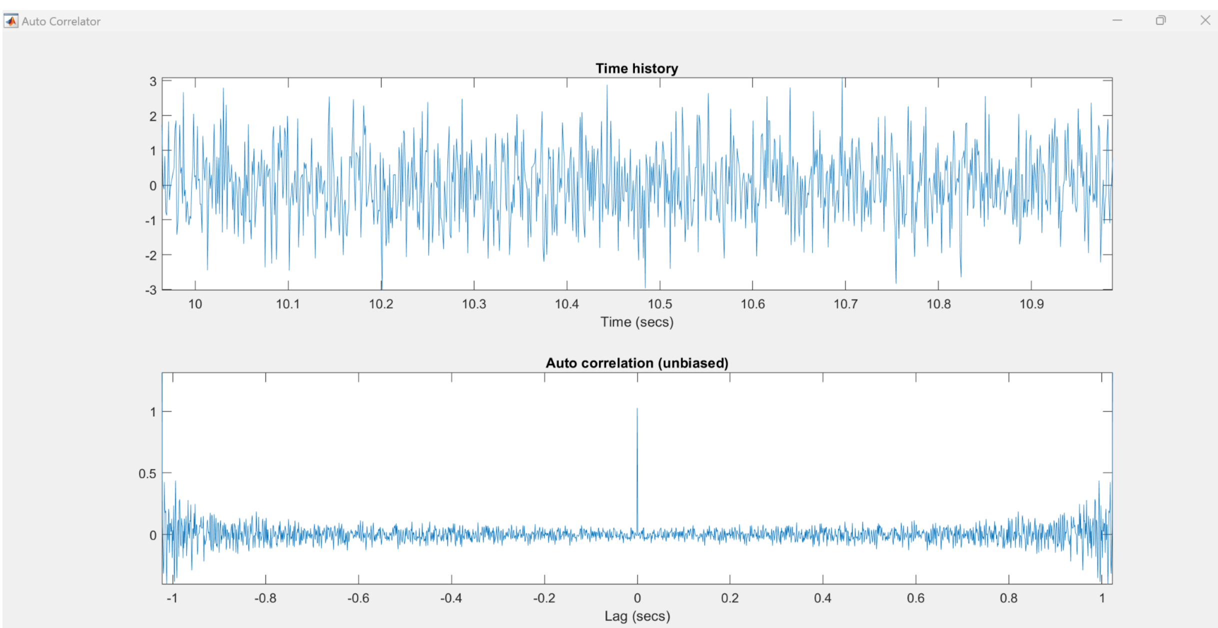

Fig. 15: Output on the Auto Correlator with source variance set to 1

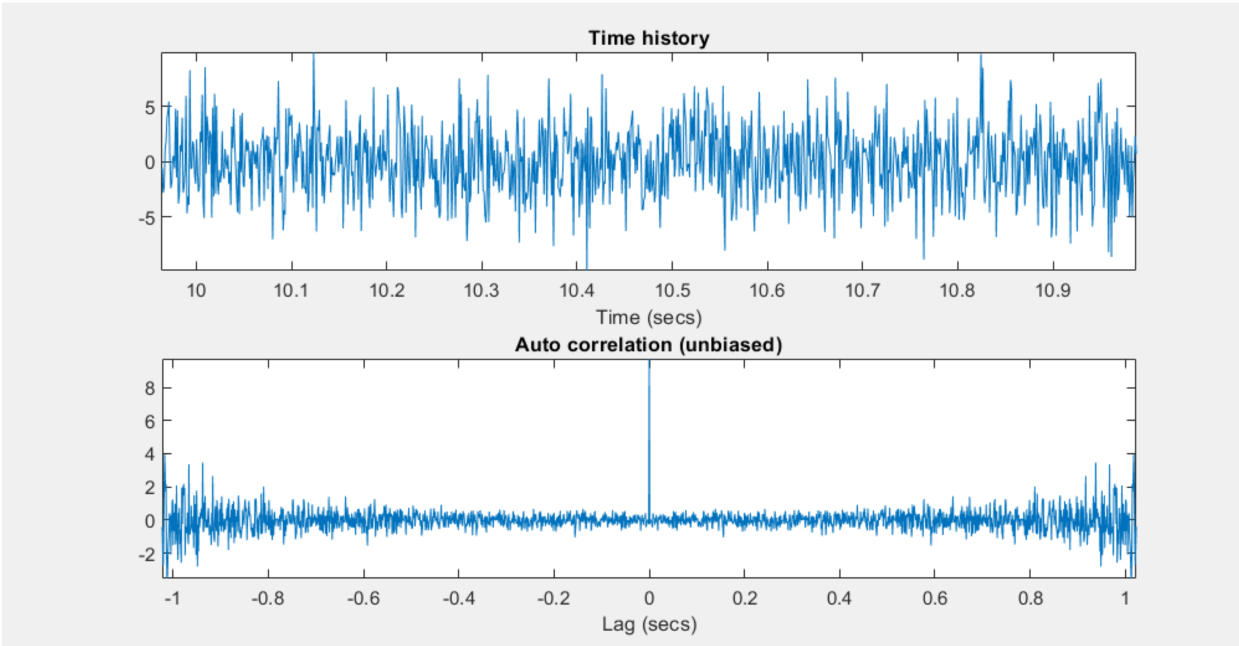

Fig. 16: Output on the Auto Correlator with source variance set to 10

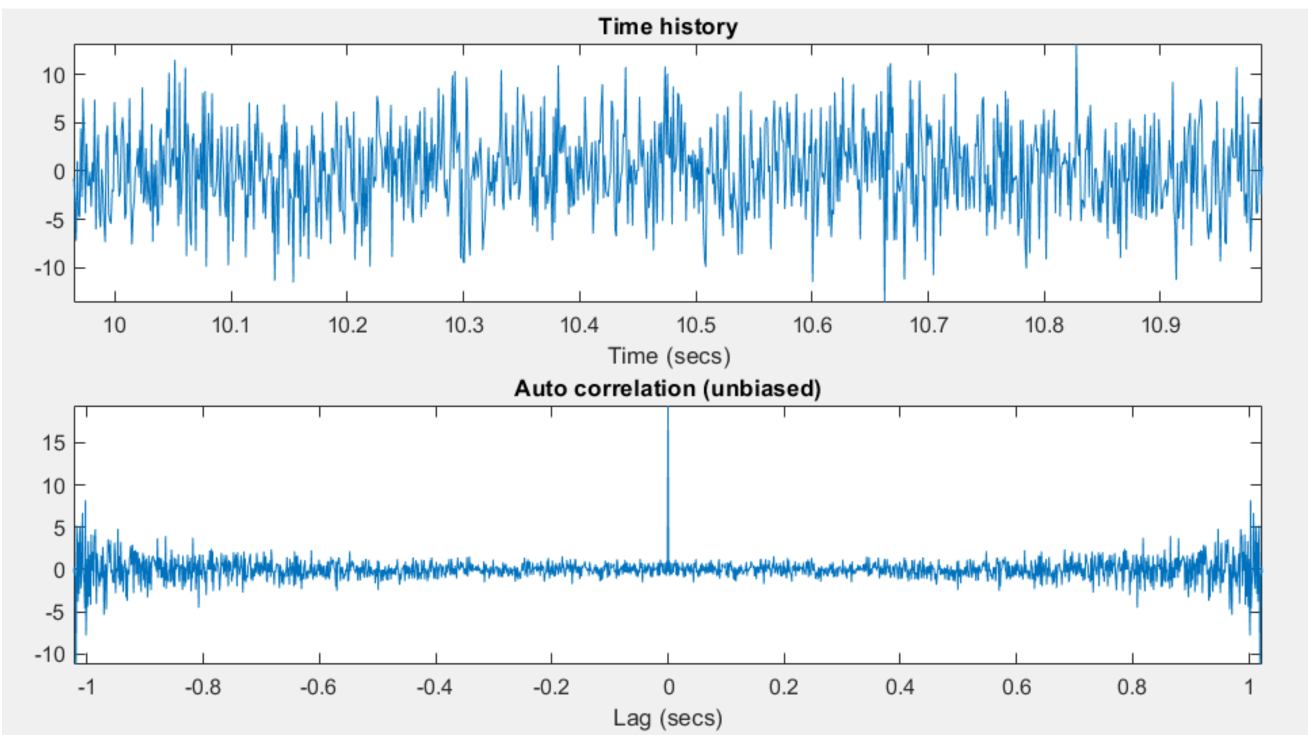

Fig. 17: Output on the Auto Correlator with source variance set to 20

Questions:

Q1: 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: Plot is shown in Fig. 1. From the outputs, we observed that:
Amplitude = 0.5
Period = 99.882ms
Frequency = 10.012Hz
Harmonic frequency = 0.01kHz = 10Hz(only one component since its a sine wave)
Hence harmonic component is $0.5sin(20\pi t)$ which is also the fundamental component since there's only one component.

Q2: Repeat Step 1 with a triangular wave generated by Triangle Generator.

Answer: Plot is shown in Fig. 3. The triangular-wave has:
Amplitude = 1
Period = 199.922ms
Frequency = 5.002Hz
Harmonic frequency = 0.01kHz = 10Hz, 0.488kHz = 488Hz where we found in the Peak finder. Thus the harmonic components are the 2nd and 98th harmonic shown in the plot, which are
$0.0453sin(2\pi \times 10t)$ and $1.649 \times 10^{-9}sin(2\pi \times 490t)$.
Fundamental component is $f_0 = \frac{1}{T} = 5Hz$

Q3: Repeat Step 1 with a 50% duty cycle square wave generated by Pulse Generator.

Answer: Plot is shown in Fig. 5. We observed that the square wave with 50% duty cycle has:
Amplitude = 1
Period = 499.434ms
Frequency = 2.002Hz
Harmonic components = 0.166kHz = 166Hz as shown in peak finder. Theoretically, harmonic component should be the combination of $f_t = nf_0 = 2n$, where n is an integer larger than 0.
The fundamental component of square wave with 50% duty cycle is 2Hz.

Q4: Repeat Step 1 with a 20% duty cycle square wave generated by Pulse Generator.

Answer: Plot is shown in Fig. 7. We observed that the square wave with 20% duty cycle has:
Amplitude = 1

Period = 500ms
Frequency = 2Hz
Harmonic components = 1.758kHz = 1758Hz as shown in peak finder. Theoretically, harmonic component should be the combination of $f_t = nf_0 = 2n$, where n is an integer bigger than 0.
The fundamental component of square wave with 20% duty cycle is 2Hz.

Q5: Repeat Step 1 with a sum of 3 sine waves as illustrated

Answer: Plot is shown in Fig. 9. We observed that the sum of three sine-waves has:
Amplitude = 3.854
Period = 99.948ms
Frequency = 10.005Hz
Harmonic components = 0.020kHz = 20Hz, 0.098kHz = 98Hz$\approx$ $100Hz$
The sum of three sine waves has a fundamental component of 10Hz

Q6: Observe the output on Scope. Comment on the periodicity of the sine wave.

Answer: We can notice from Fig. 12 that the period of sum of signals is 1Hz. However, the period is not continuous in time. A step function is called high when its value is 1 and is called low when its value is 0. Therefore, the wave cannot be seen until it is high when arriving at time 2. Due to the parameters we set (step time is two for Step 1, and is four for Step 2), this wave is displayed until time 4. After time 4, these inputs are cancelling each other. Hence, from time 2 to time 4, the sum of signals has a period of 1, and its period is not continuous.

Q7: What is the bandwidth and the power spectral density of the thermal noise? To obtain an accurate estimate of the power spectral density, you may increase the Average plotting number in the Trace options of Spectrum.

Answer: From Fig. 14, we observed that the the occupied bandwidth of the thermal noise is 197.98kHz. We increased the average plotting number to obtain an accurate estimation of the power density.

power spectral density=$BkT = 197.98 * 1.386 * 10^{-23} * 290 = 7.92 * 10^{-19} W/Hz$.
In this function, B is the bandwidth of this thermal noise, k is the Boltzmann constant, and T is the temperature in Kelvin (in our case, it is 290K).

Q8: Observe the output on Auto Correlator. 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: From Fig. 15, we noticed that when the variance is set to 1, the noise power is approximately equal to 1. Moreover, the peak of the Auto Correlator is 1 as well.
Increaing the variance of the source to 10, we noticed that the peak of the output increased and is of the same value as the variance. The noise power also increased (Fig. 16).
As increasing the variance to 20, we noticed that the peak of the output and the noise power increased as well (Fig. 17). By changing the variance several times and observing the output on the Auto Correlator and the noise power, we found that with variance getting larger, the noise power and the peak of the output will be increasing.

Q9: Explain the difference between random signals and deterministic signals such as sine waves, triangular waves, etc. in terms of mathematical characterization.

Answer: For the deterministic signals, there's no variance or uncertainty on a specific instant of time where the wave has a value. Hence, we can express deterministic signals with matahematicla equations. On the contrary, the random signals generates data with some degree of uncertainty. Thus, we cannot express random signals with mathematical equations.

Part 2: Power, Bandwidth & SNR

Introduction:

The objective of this part of the lab is to understand the power and the bandwidth of a deterministic/random signal. Also, the concept of signal-to-power ratio (SNR) and filtering are introduced. Our task is to connect the blocks based on the given diagram, then carry out a serious of tests and observe the output on the scopes and spectrums.

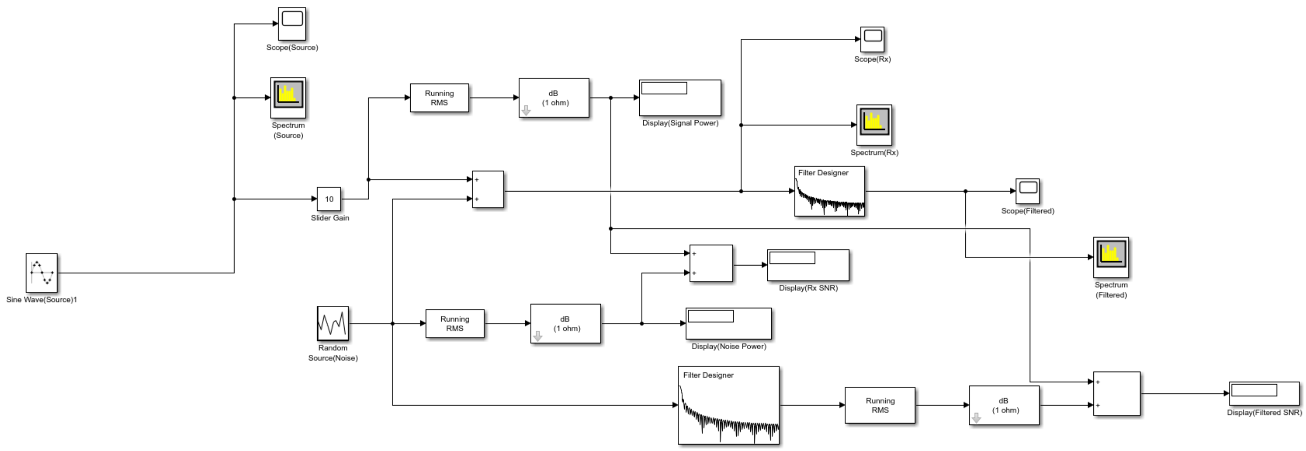

Figure 1. Our connected diagram with required blocks.

Experiments:

1) For the first part, we set the source as a sine wave with 100 samples per period, sample time of 1e-4 and an amplitude of 1. We then observed the source spectrum as shown in figure 2. With the help of Channel Measurements, we can clearly see that the power is $26.963\ dBm$ and bandwidth is $204.883\ Hz$.

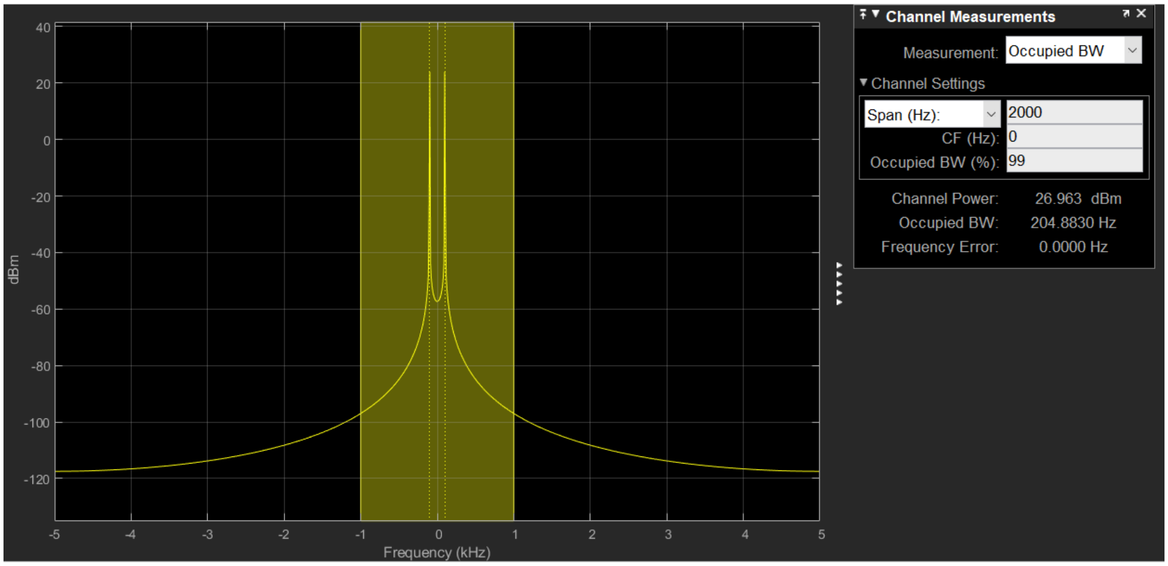

Figure 2. Source spectrum with a sine wave source.

2) For the second part, we change the source to a triangular generator with 5 Hz frequency and sample time of 1e-4. We observe that power is $20.94\ dBm$ and bandwidth is $27.1696\ Hz$.

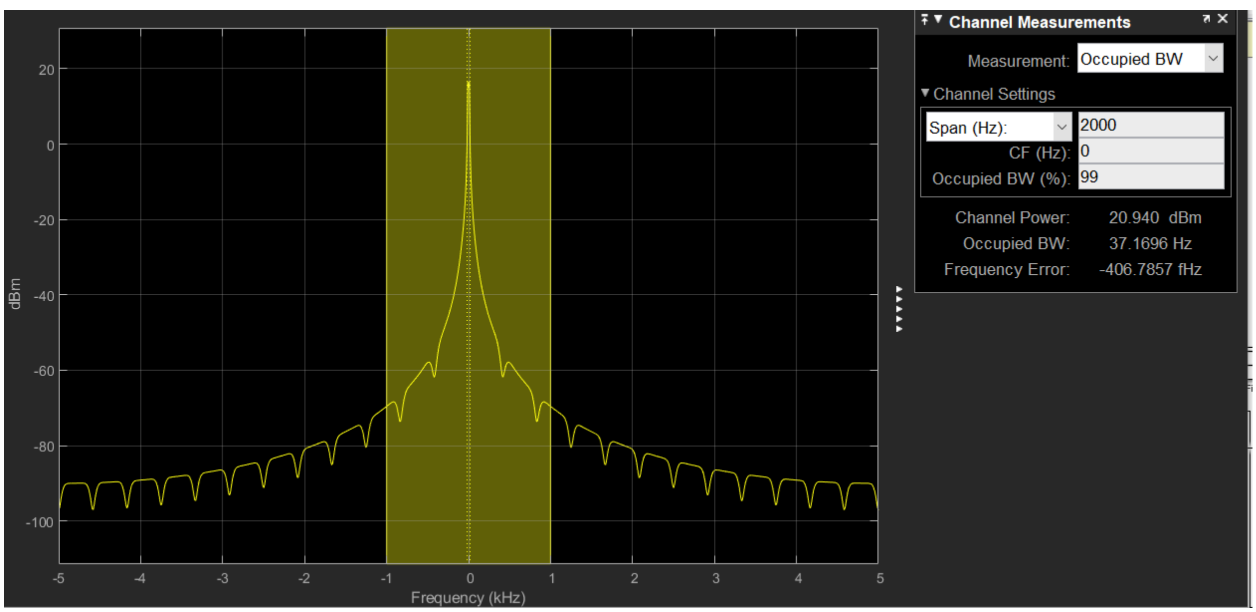

Figure 3. Source spectrum with a triangular wave source

3) For part 3, we repeated part 1 with a 50% duty circle square wave. We can clearly see that channel power is $28.395\ dBm$ and occupied bandwidth is $90.5188\ Hz$.

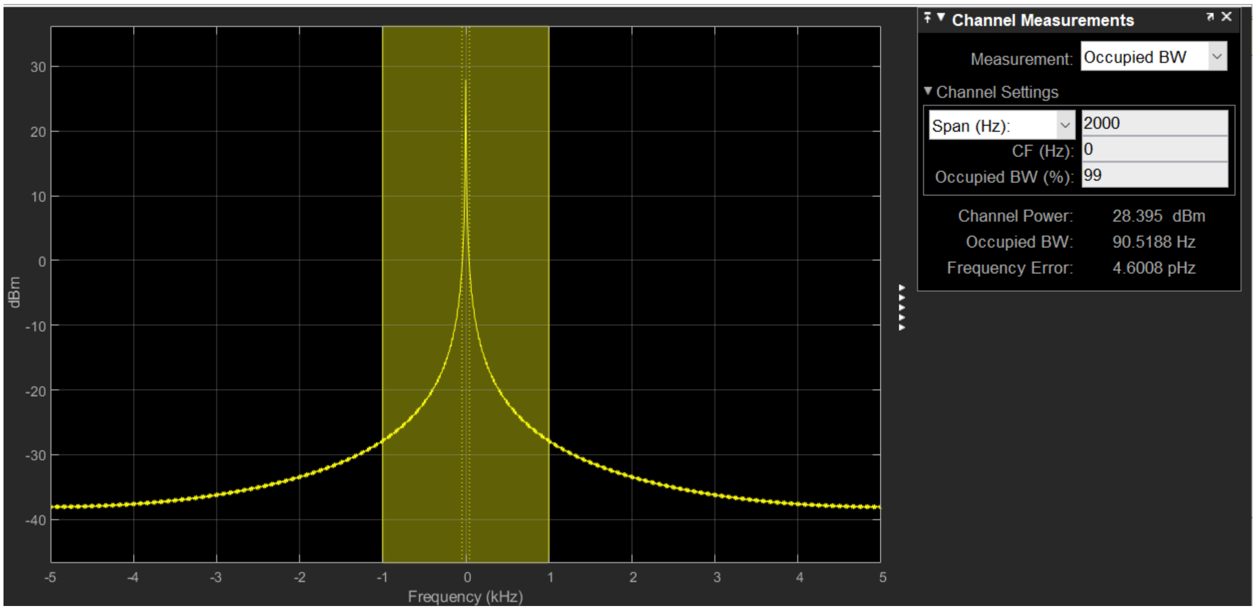

Figure 4. Source spectrum with a 50% duty cycle square wave.

4) We then repeated the step 1 with a 20% duty cycle square wave. It is shown that channel power is $10.251\ dBm$ and occupied bandwidth is $81.6761\ Hz$.

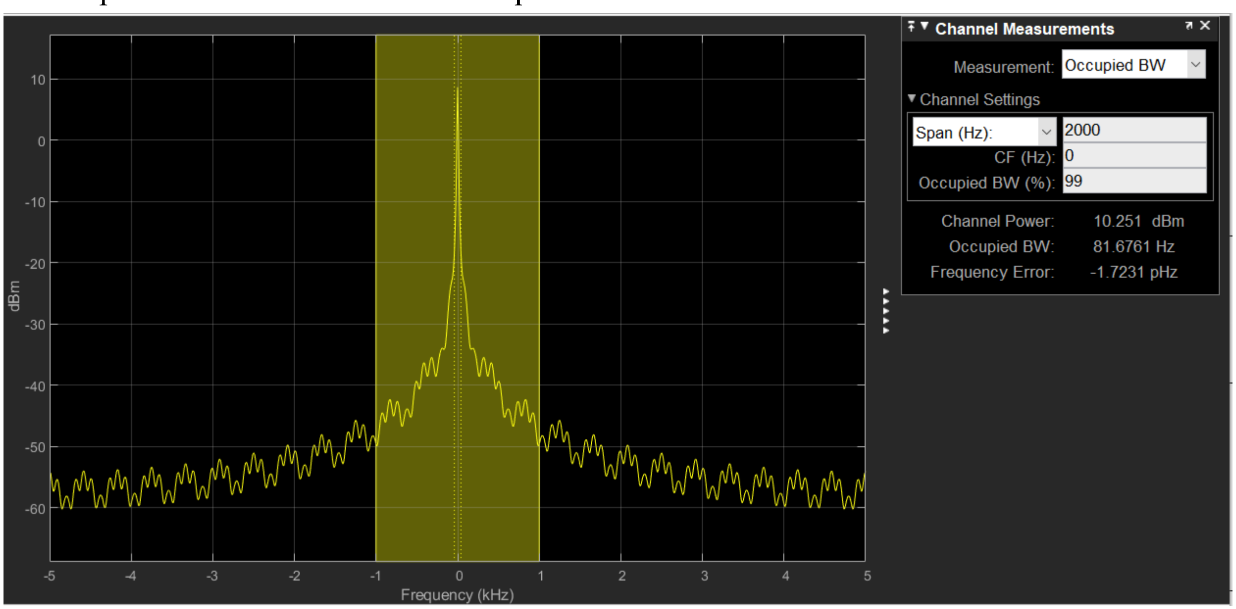

Figure 5. Source spectrum with a 20% duty cycle square wave.

5) We then changed the source to a sum of 3 sine waves with sine wave 1 having 0.5 amplitude and 1000 samples per period, sine wave having 2 amplitude and 500 samples per period, and 1.5 amplitude and 100 samples per period. We can find that channel power is $35.11\ dBm$ and occupied bandwidth is $204.5118\ Hz$.

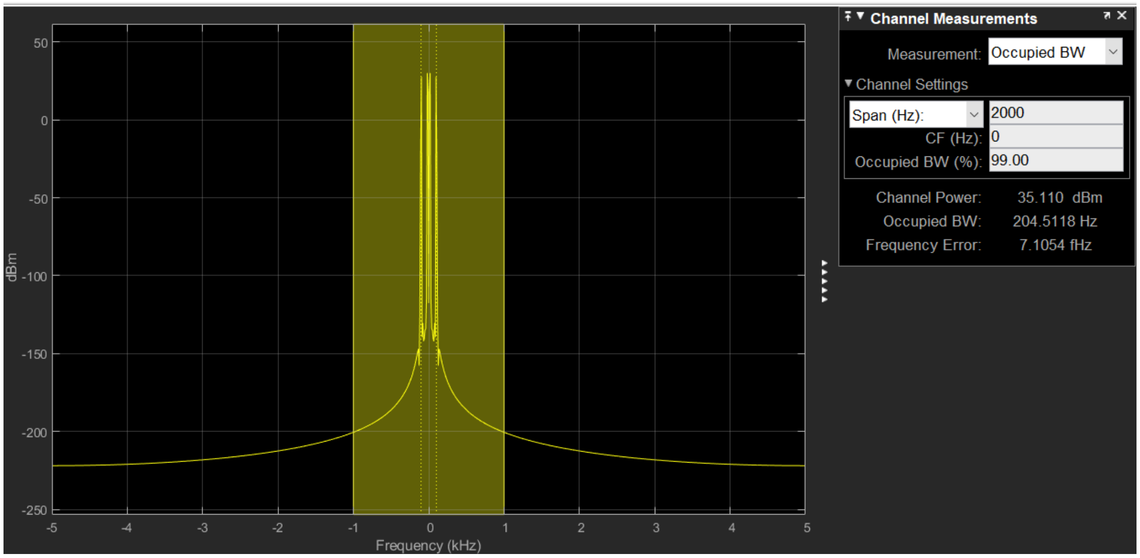

Figure 6. Source spectrum with a sum of three sine waves.

6) We then observe the outputs on Scope(Rx) and Spectrum(Rx) as shown in figure 7 and figure 8. We used the same parameter setup as part 5. Slider gain is set to 1. Comments on the noise will be provided at the Question section in the end.

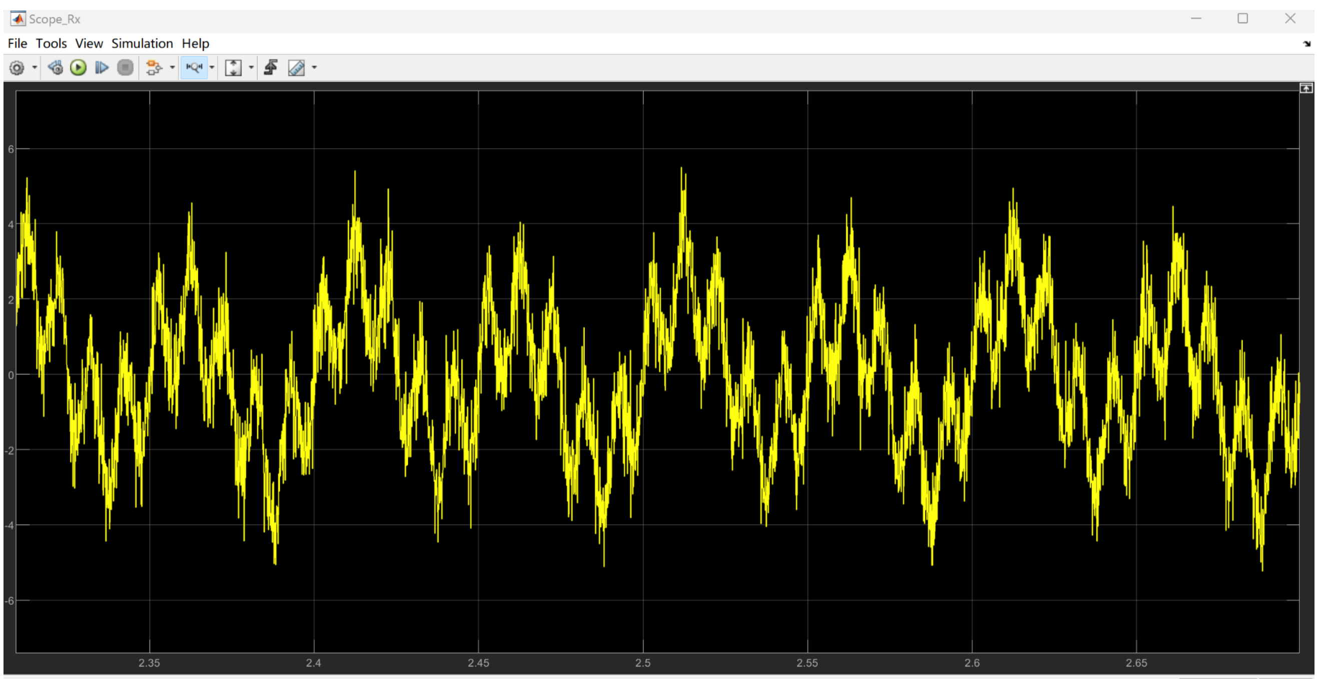

Figure 7. Rx scope plot with a sum of three sine waves.

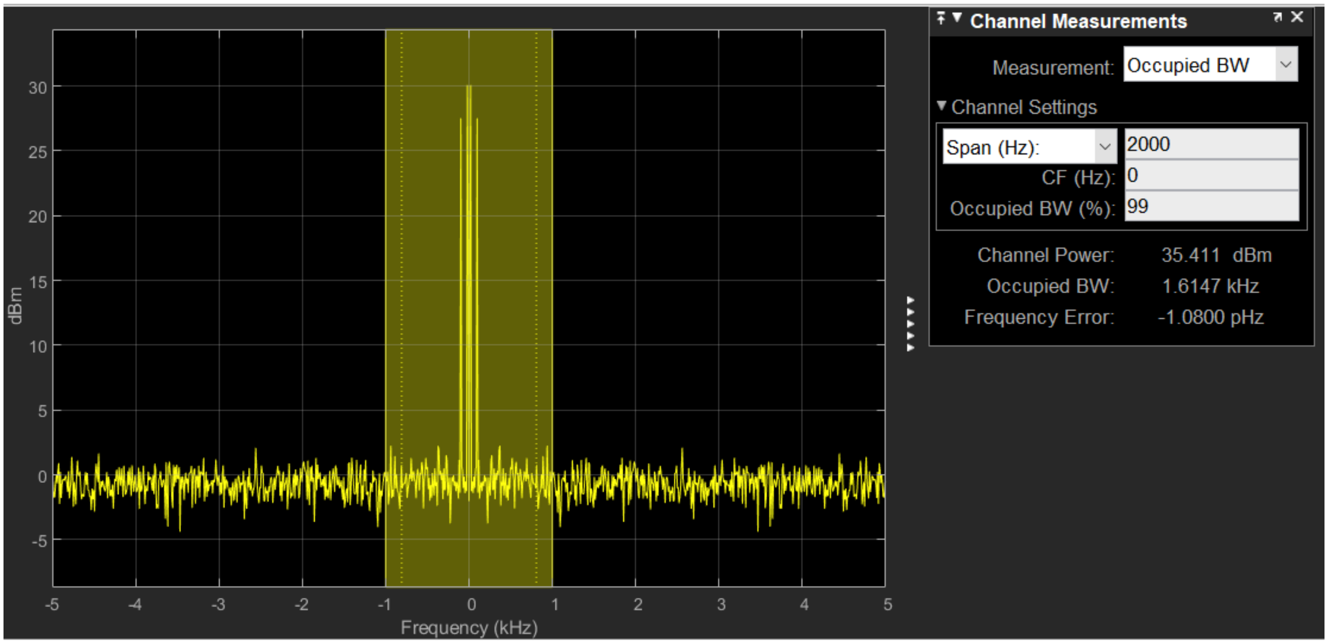

Figure 8. Rx spectrum plot with a sum of three sine waves.

7) In this part, we set up the model with same parameters as previous part. With a slider gain of 1, we gain the filtered scope plot and filtered spectrum as shown in figure 9 and 10, respectively. The comparison between them and the plots that we get from part 6 will be discussed in Question part.

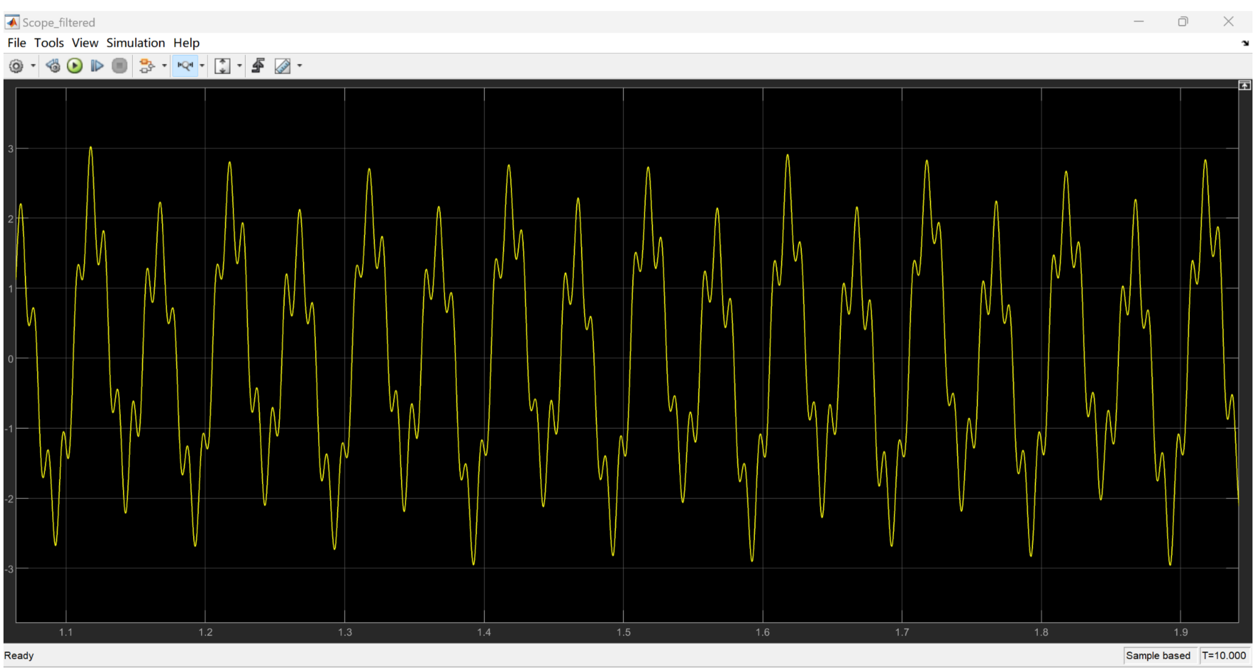

Figure 9. Filtered scope plot with a sum of three sine waves.

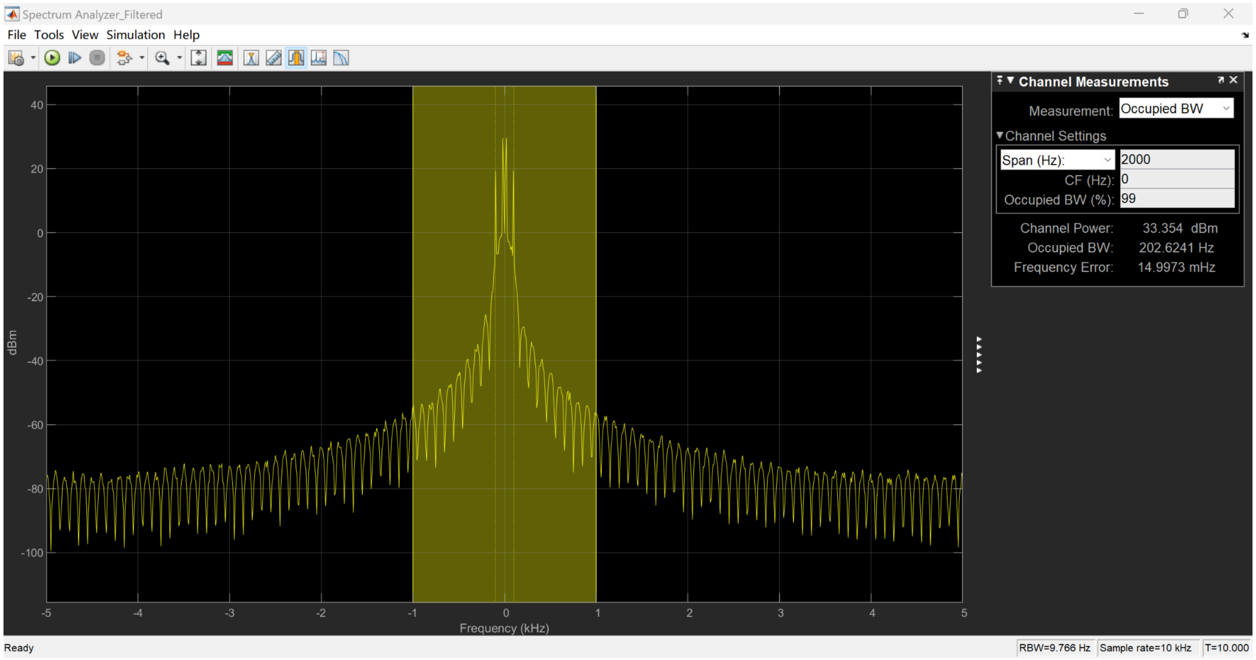

Figure 10. Filtered spectrum plot with a sum of three sine waves.

8) In this part, we investigate the effect of slider gain on filtered scope and spectrum plots when it's varied from low to high. Furthermore, we also varied the cutoff frequency F_C in digital filter design in order to visualize its effect on the output. We varied the slider gain to 10, 50, 100, and 1000. We varied the cut off frequency to 10,500,1000, and 4900. These plots are shown in the following figures. The comments on their effect will be provided in the Question section.

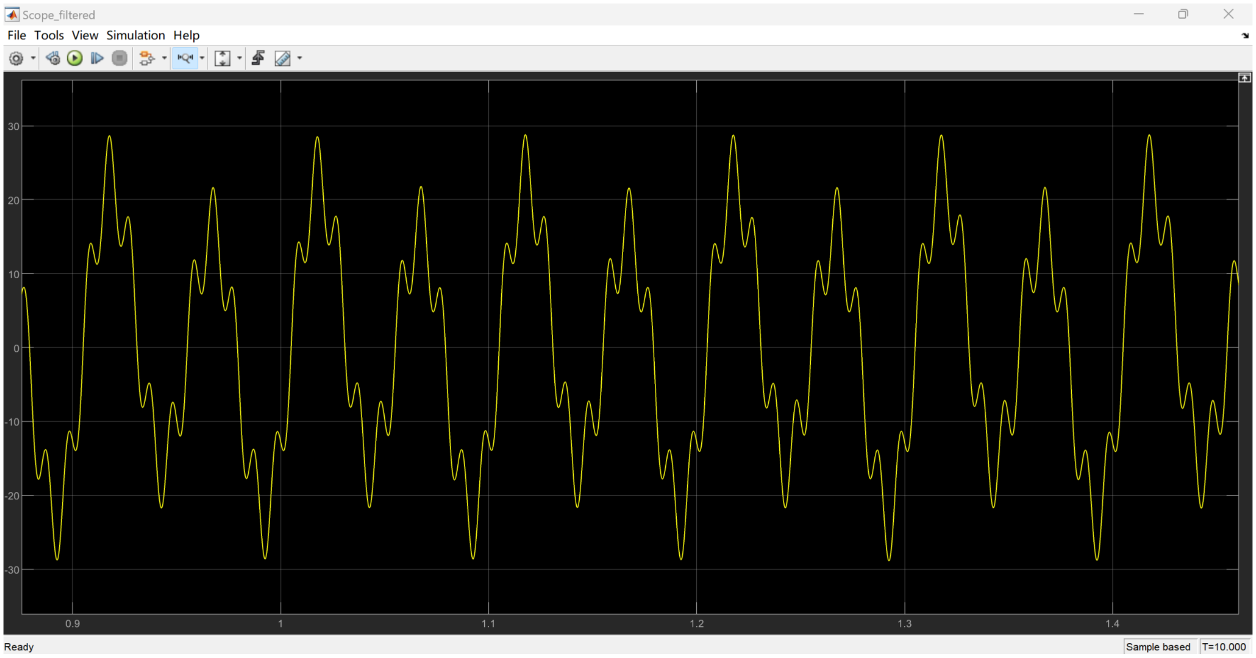

Figure 11. Filtered scope plot with a slider gain of 10.

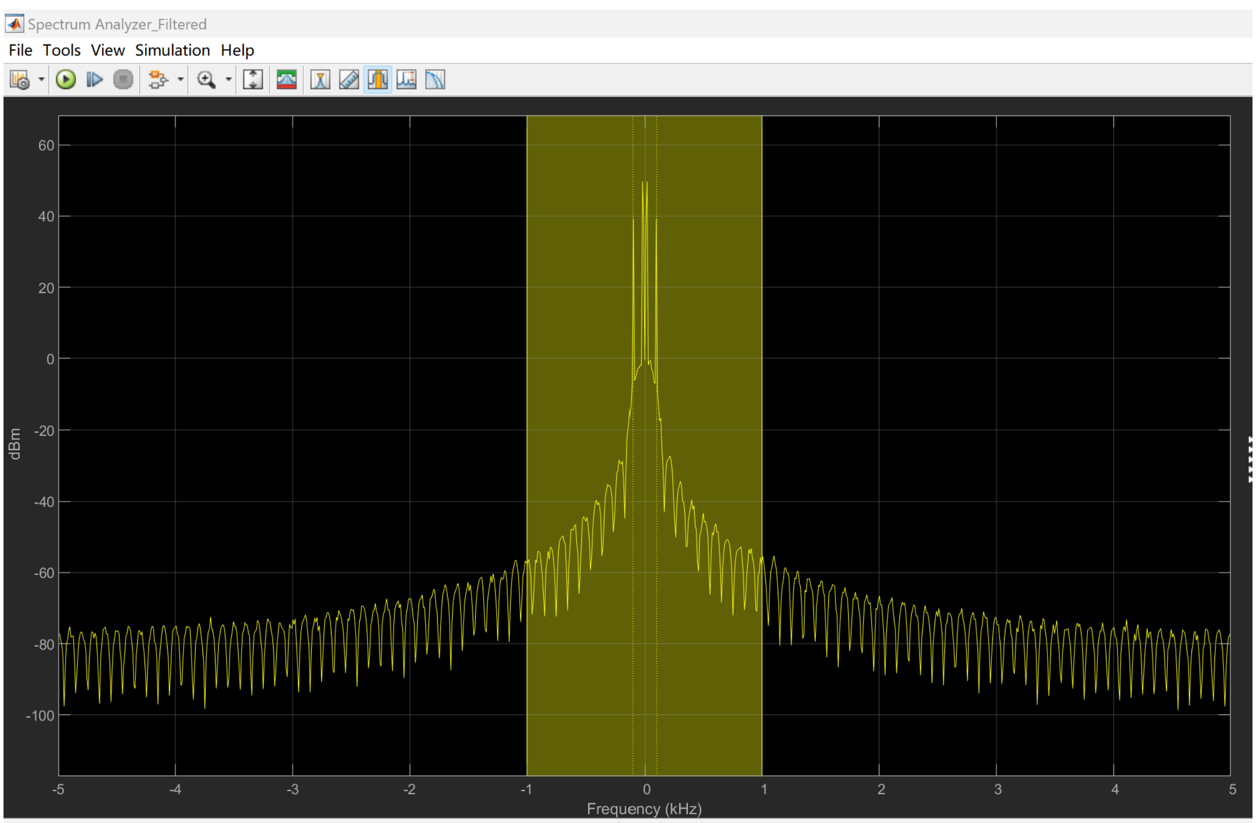

Figure 12. Filtered spectrum plot with a slider gain of 10.

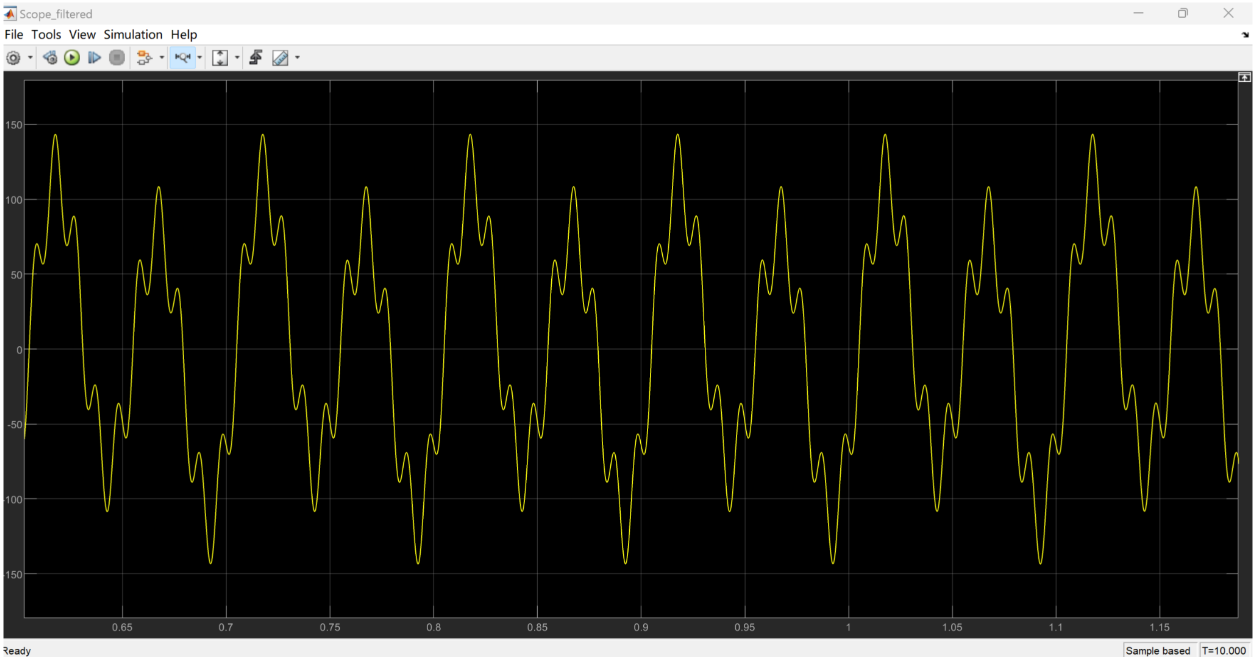

Figure 13. Filtered scope plot with a slider gain of 50.

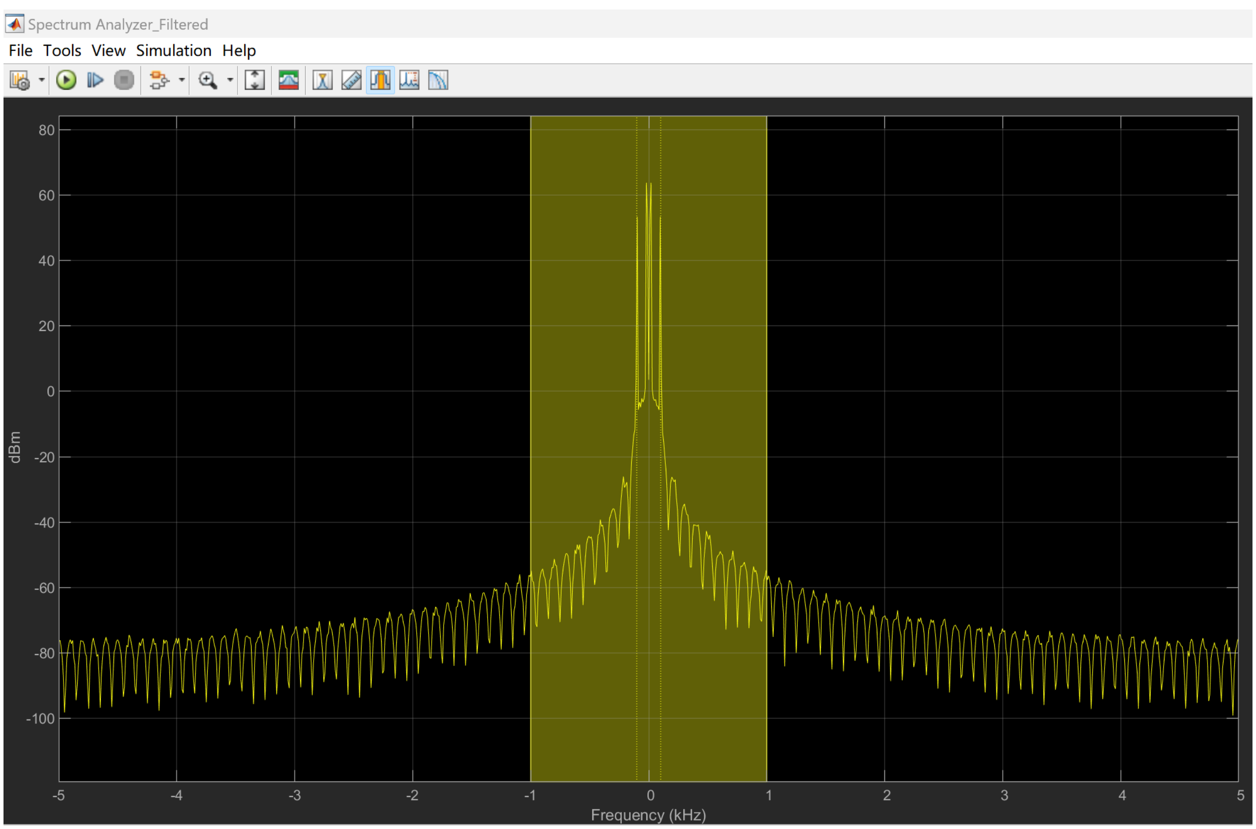

Figure 14. Filtered spectrum plot with a slider gain of 50.

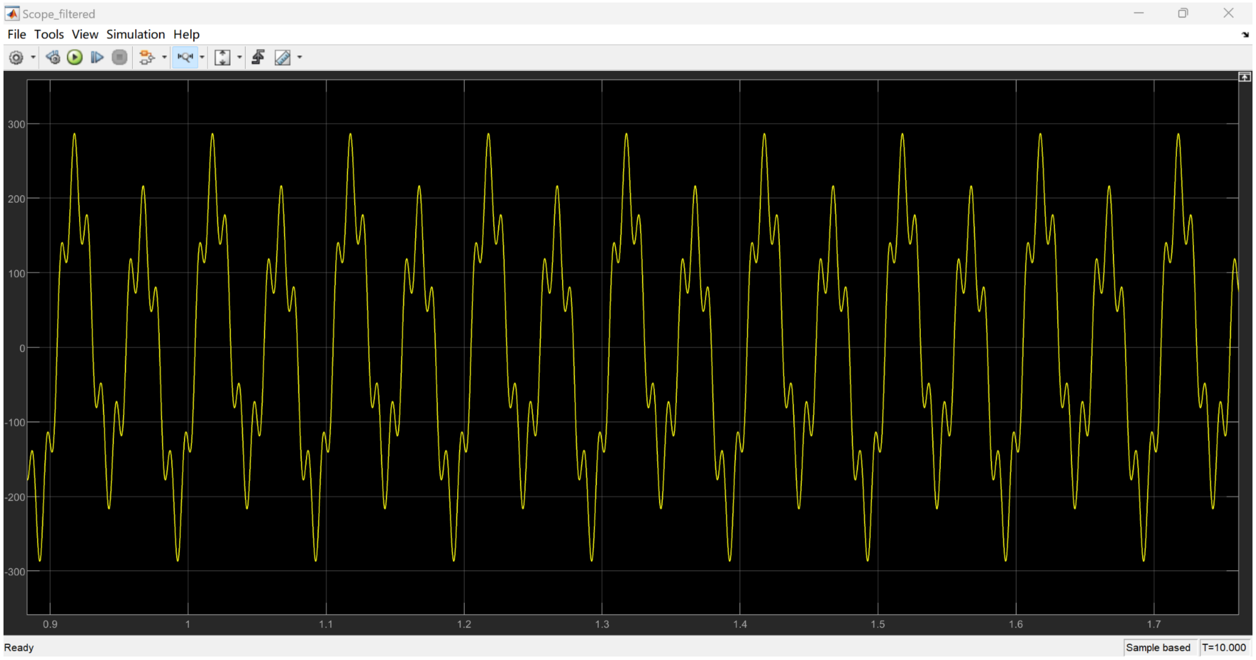

Figure 15. Filtered scope plot with a slider gain of 100.

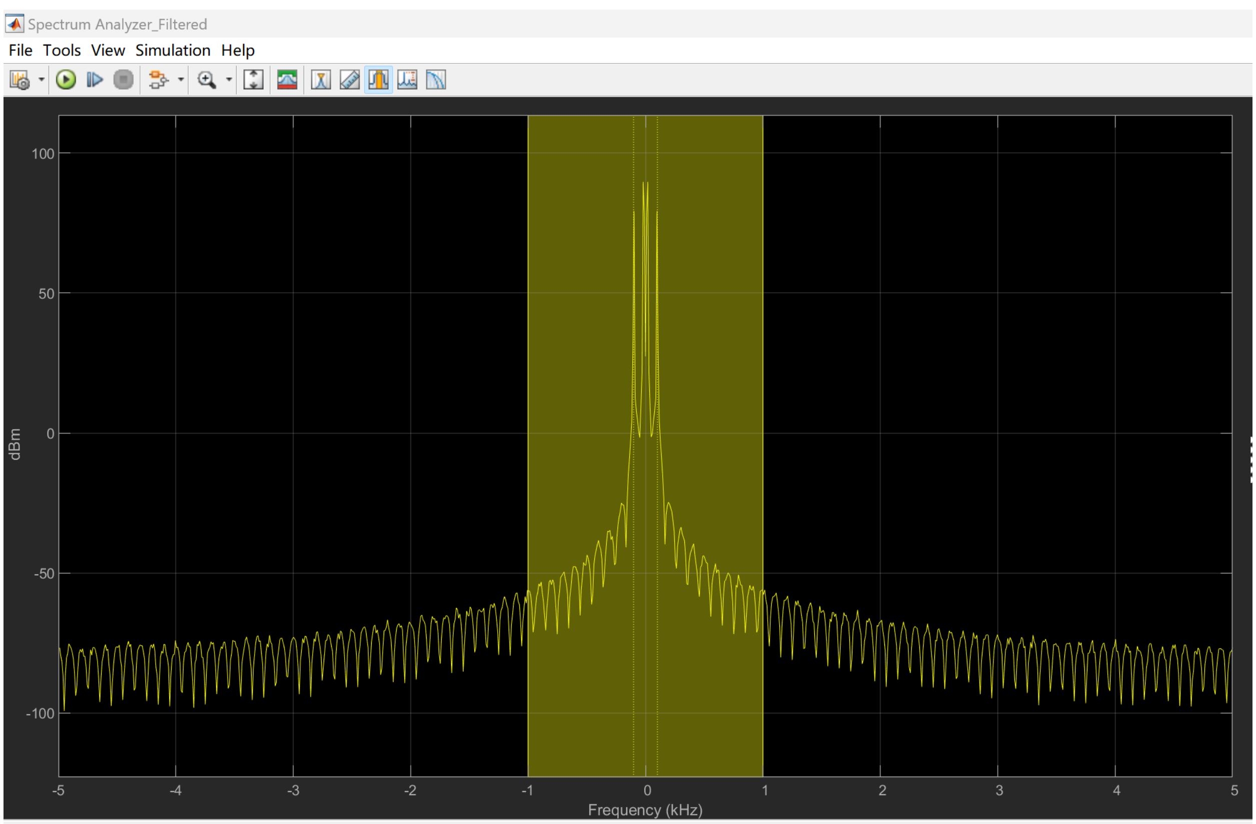

Figure 16. Filtered spectrum plot with a slider gain of 100.

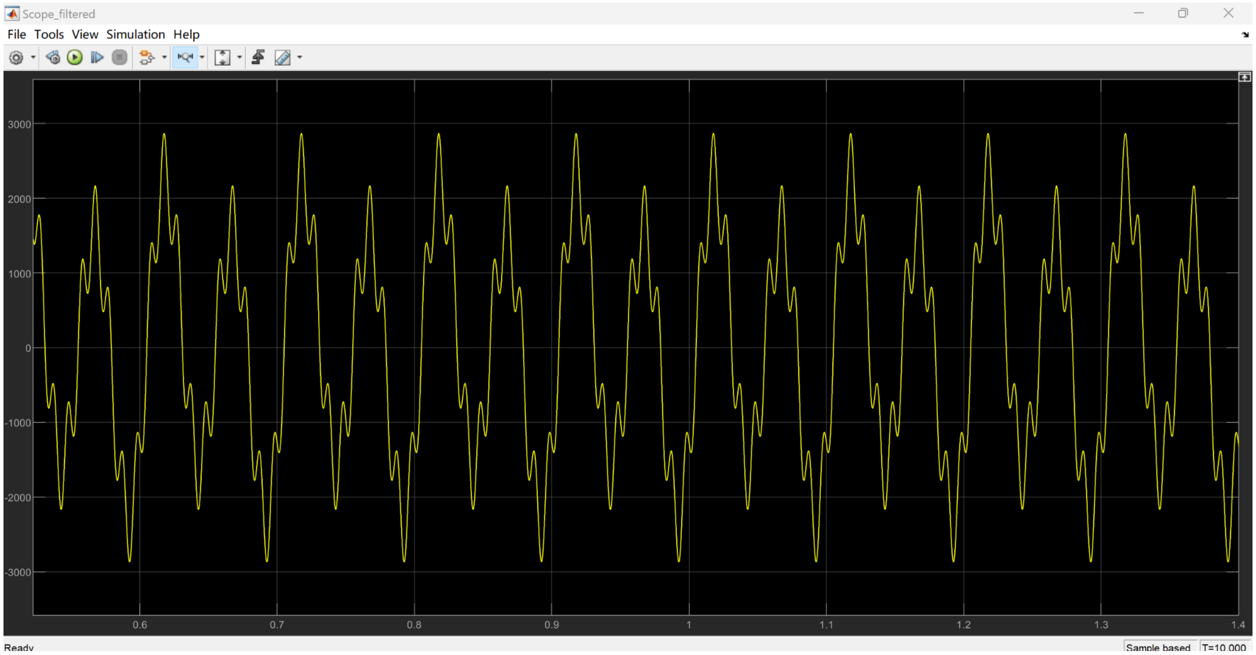

Figure 17. Filtered scope plot with a slider gain of 1000.

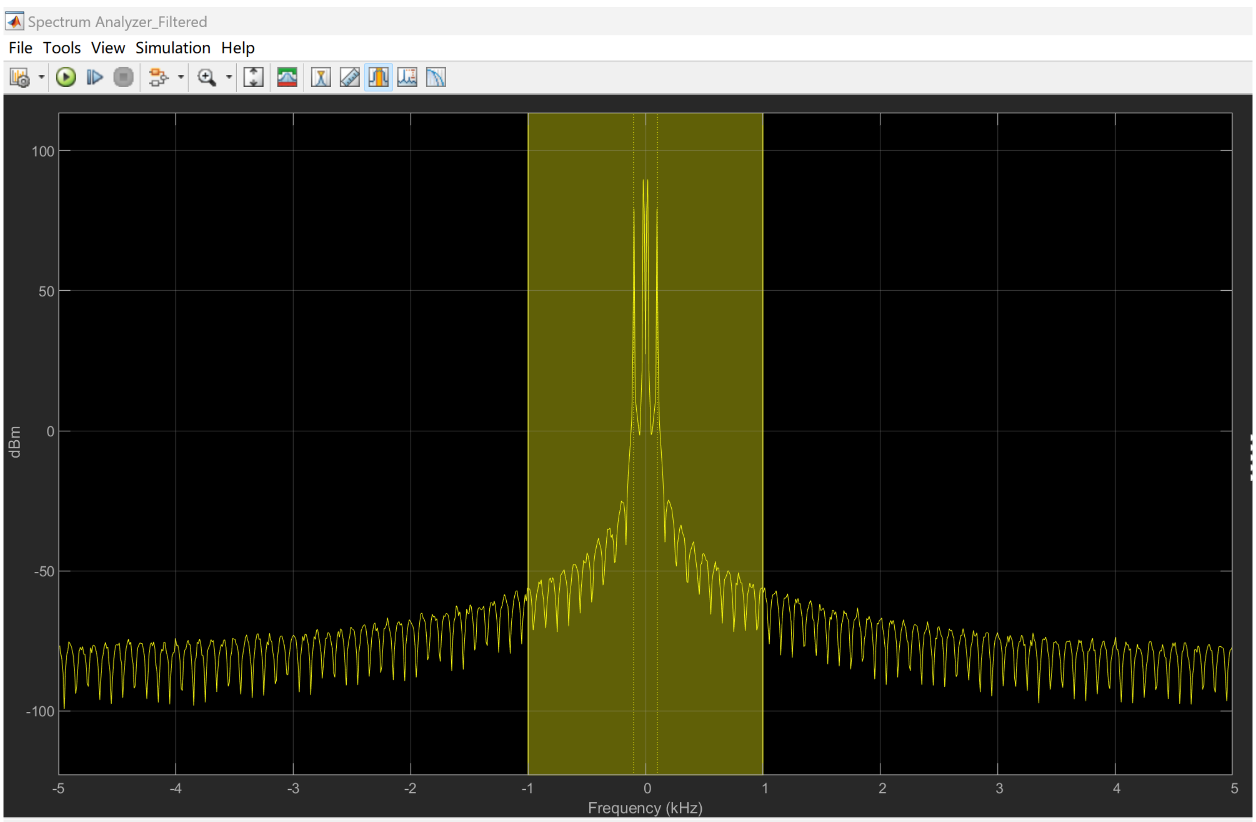

Figure 18. Filtered spectrum plot with a slider gain of 1000.

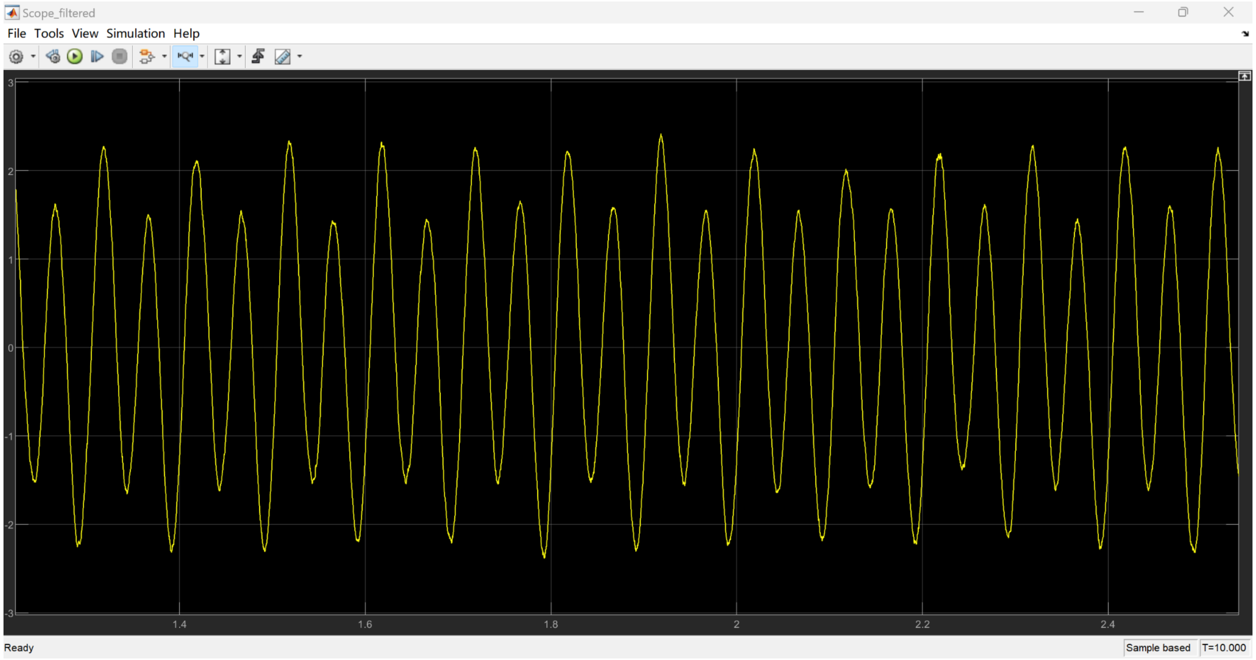

Figure 19. Filtered scope plot with a cut off frequency Fc of 10 Hz.

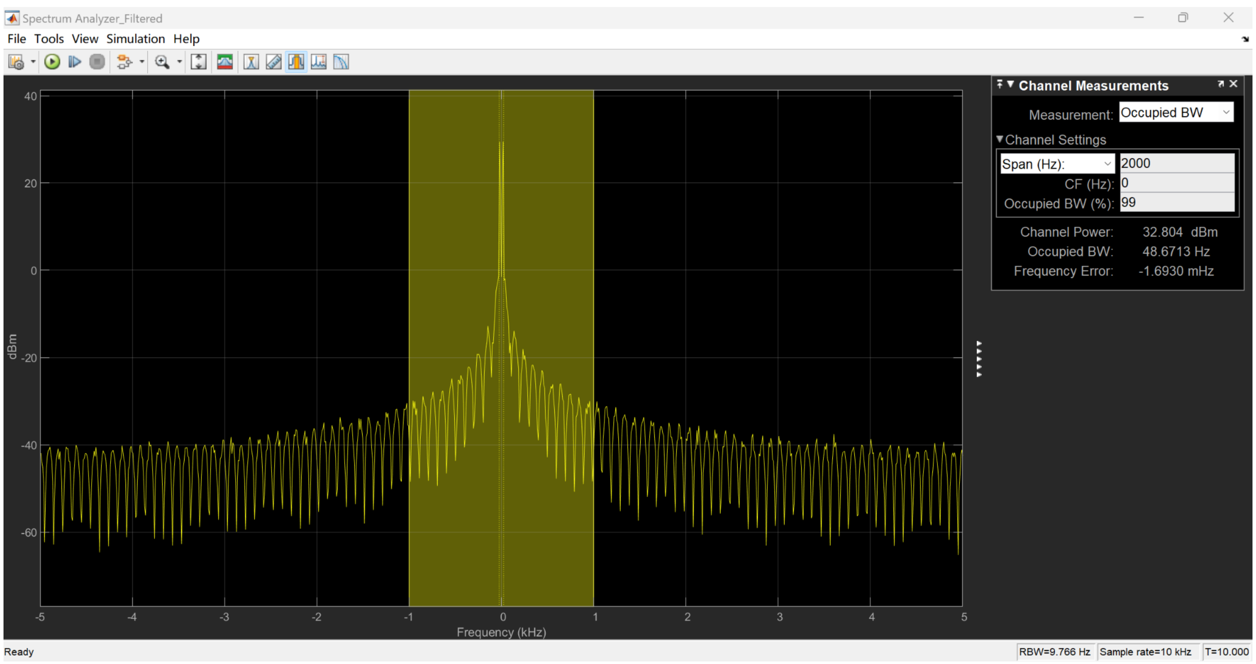

Figure 20. Filtered spectrum plot with a cut off frequency Fc of 10 Hz.

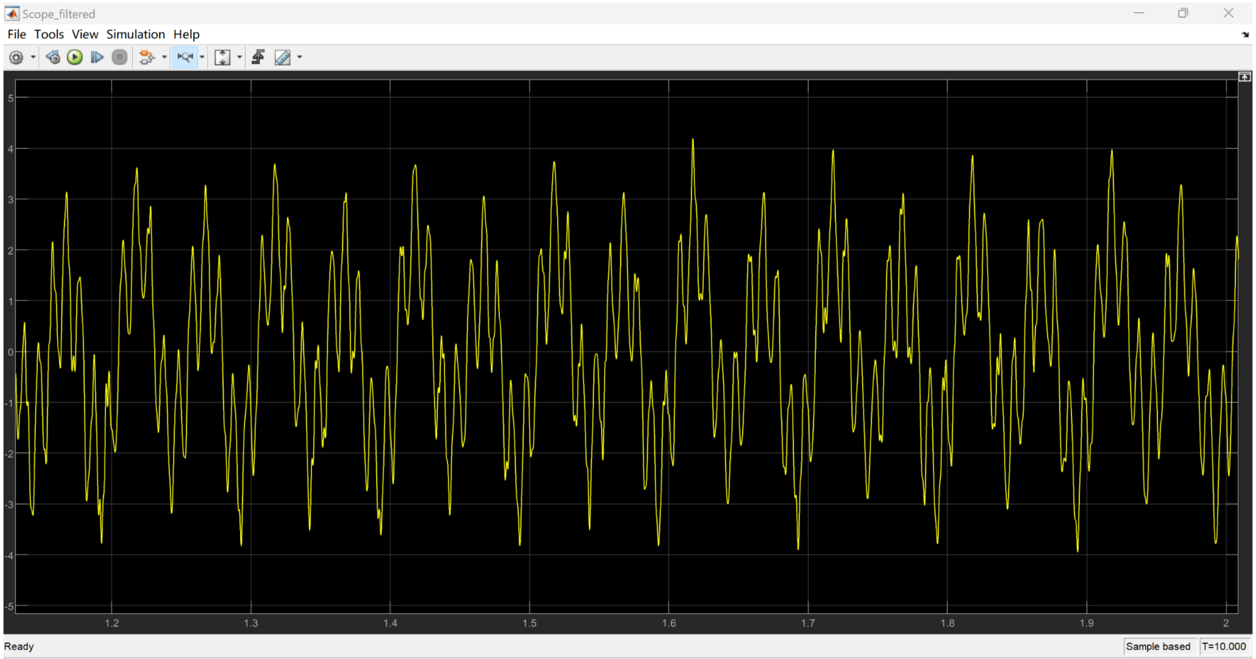

Figure 21. Filtered scope plot with a cut off frequency Fc of 500 Hz.

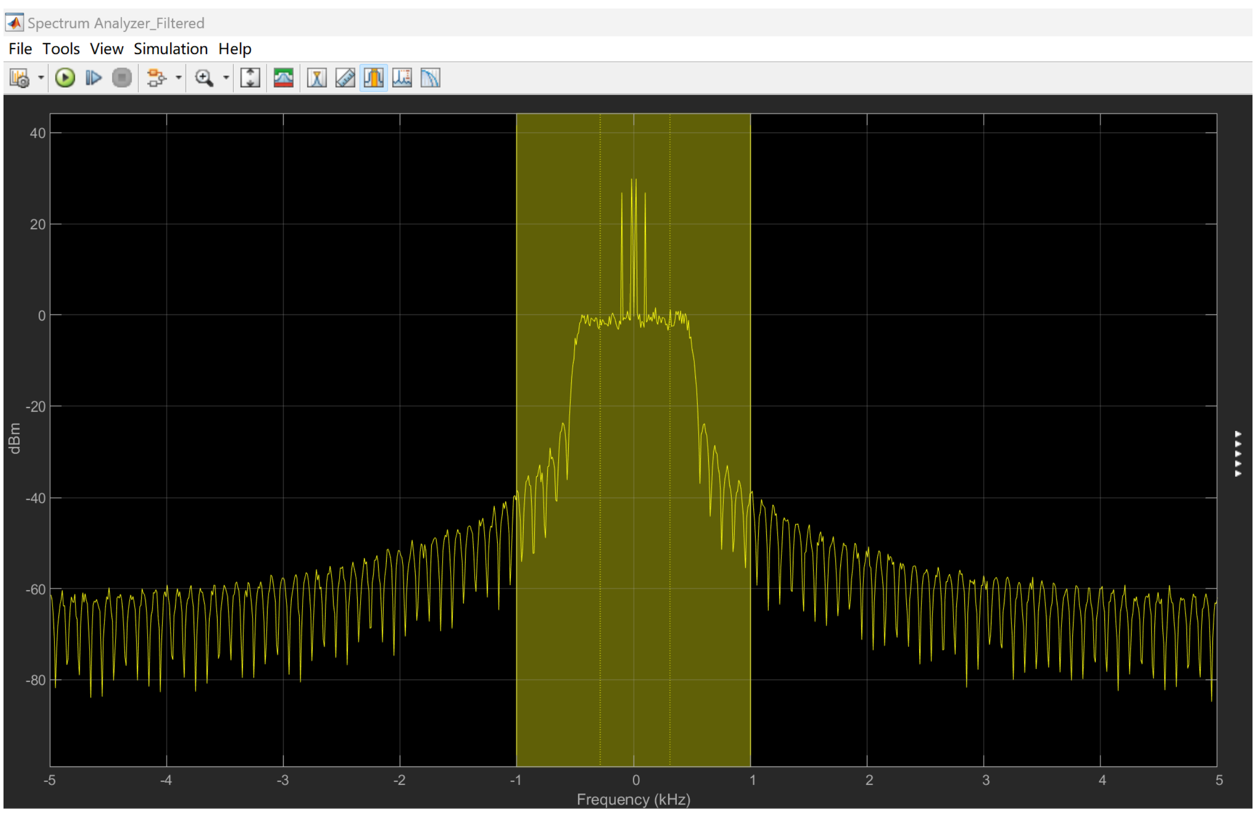

Figure 22. Filtered spectrum plot with a cut off frequency Fc of 500 Hz.

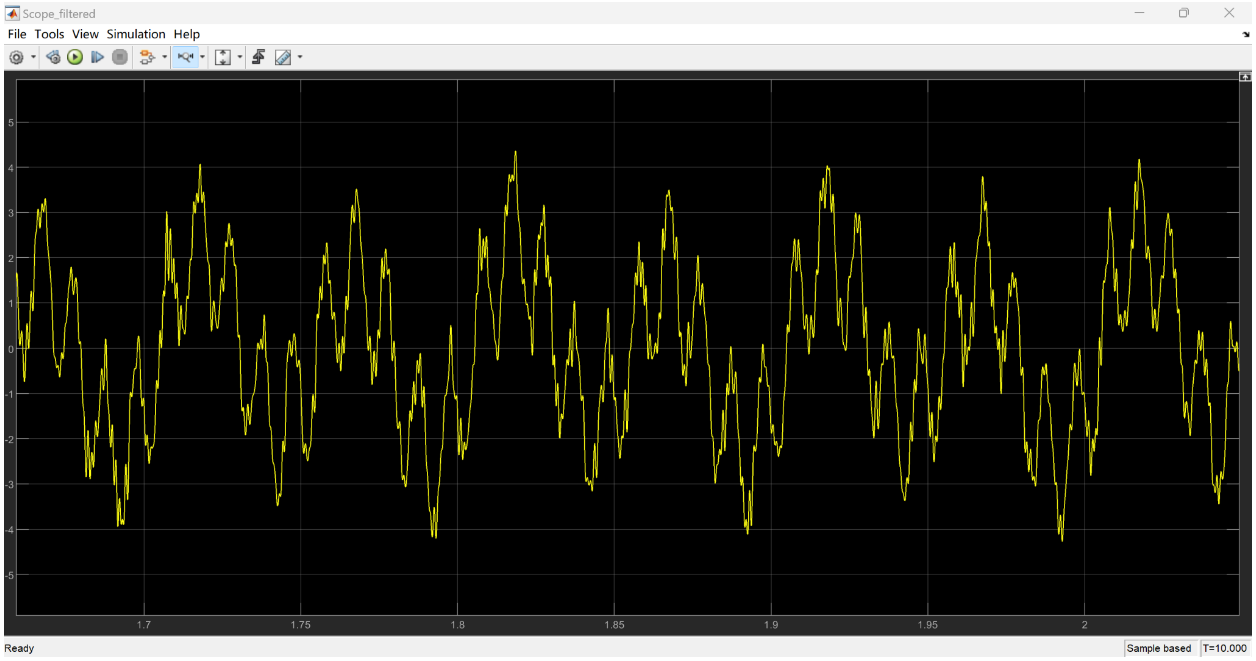

Figure 23. Filtered scope plot with a cut off frequency Fc of 1000 Hz.

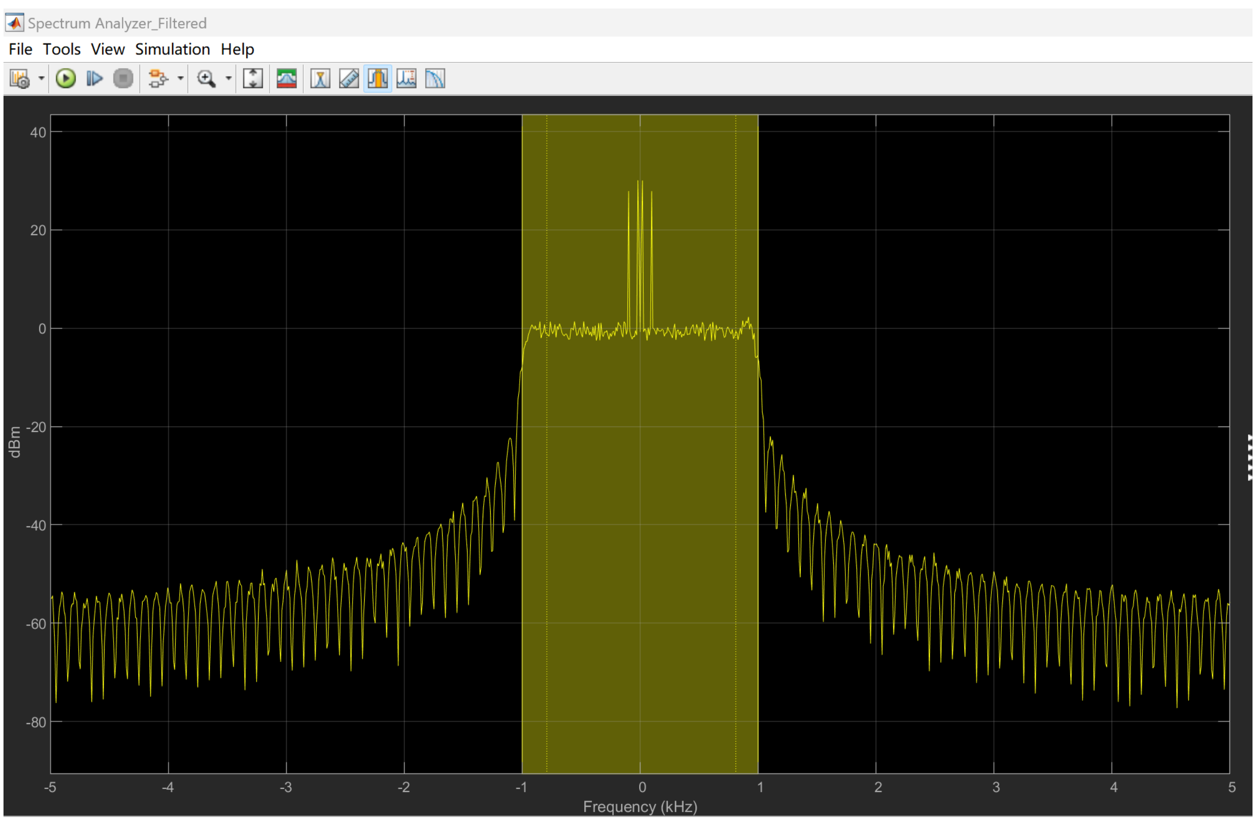

Figure 24. Filtered spectrum plot with a cut off frequency Fc of 1000 Hz.

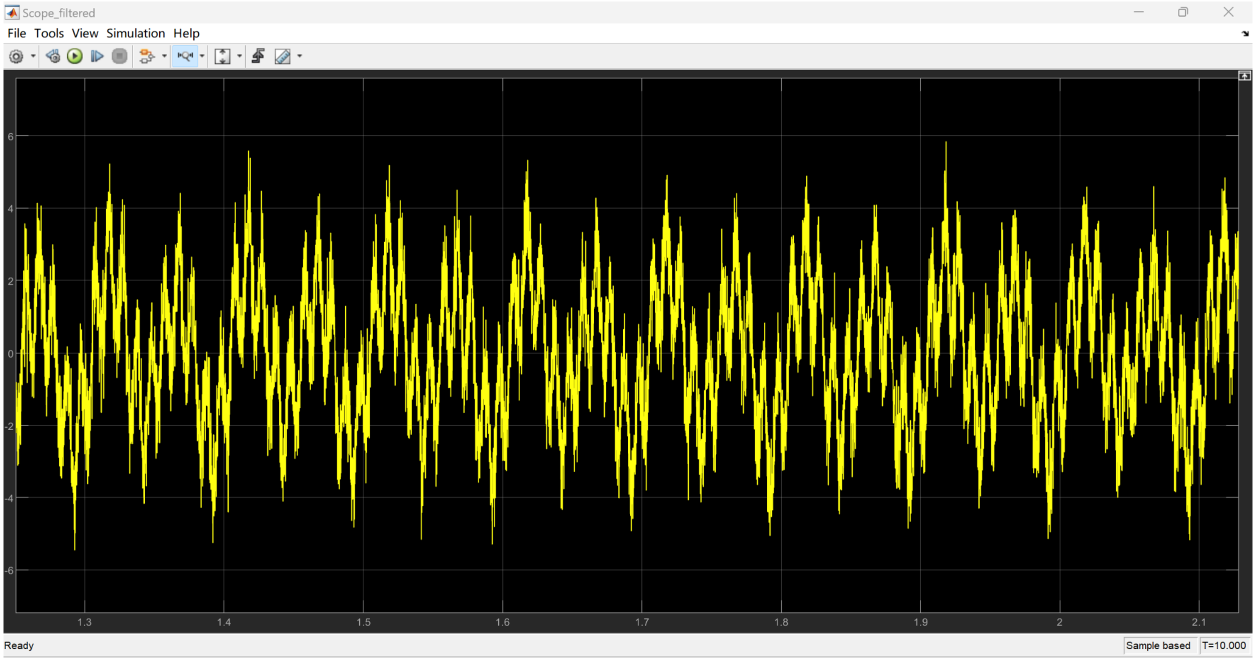

Figure 25. Filtered scope plot with a cut off frequency Fc of 4900 Hz.

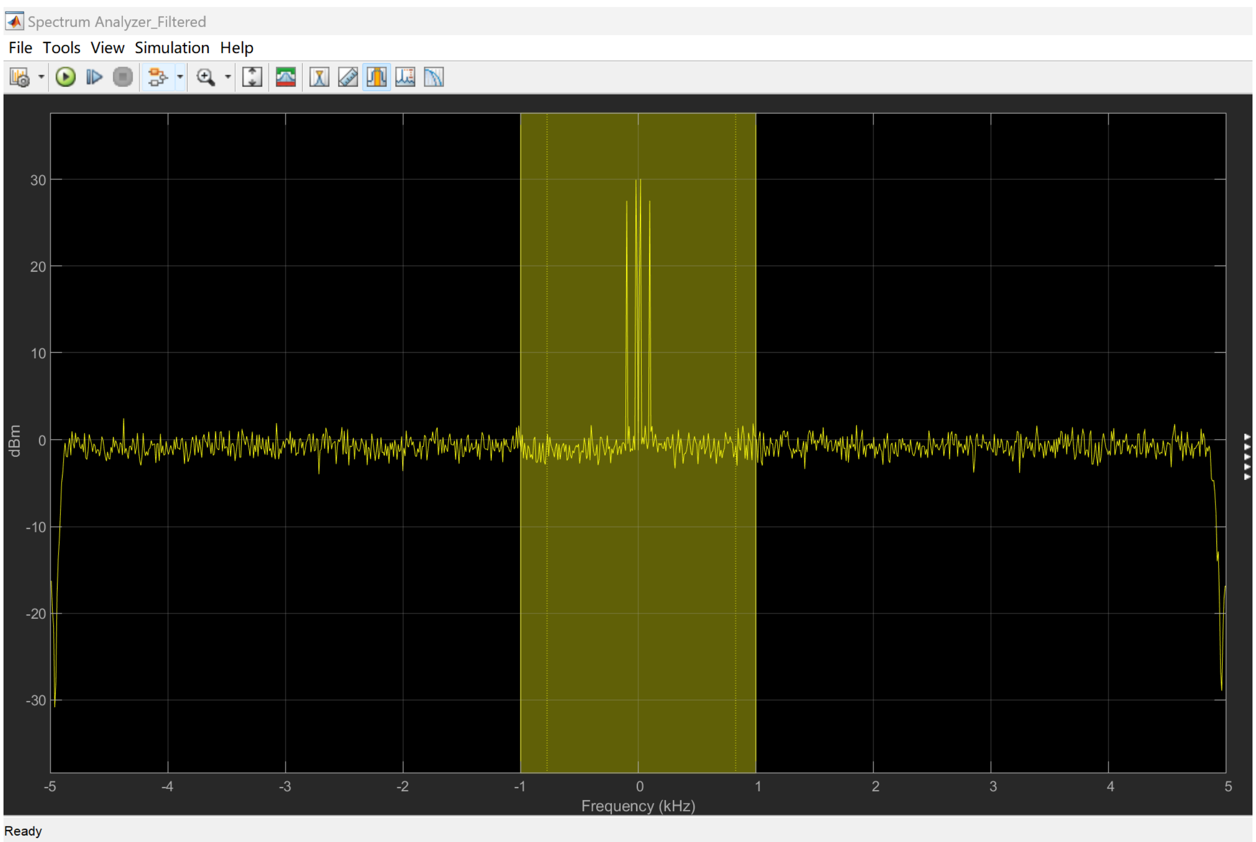

Figure 26. Filtered spectrum plot with a cut off frequency Fc of 4900 Hz.

Questions:

Q1. Comment on the effect of noise on the signal in the time domain and the frequency domain.

Answer: As shown in figure 7 and figure 8, we can clearly see in the time domain, noise distort the source signal and make it less clearer. In the frequency domain, occupied bandwidth has increased with the noise, peak value and power remain stable.

Q2. Compare the outputs on Scope (Filtered) and Spectrum (Filtered) with those on Scope (Rx) and Spectrum (Rx), respectively. Comment on the filtering.

Answer: Comparing Figure 9 and 10 with 7 and 8, we can see that filtered scope plot is much smoother than scope(Rx), and it is very close to the input source signal. As for the filtered spectrum, it removes most noise in the Rx spectrum and reflects the overall frequency behavior of the source signal. An appropriate filter can greatly help us remove the noise and recover the original signal.

Q3. 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 cutoff frequency Fc in Digital filter design.

Answer: We can clearly see that the output will increase in accordance with the increasing gain. We can see with a gain of 1000, the peak value of the filtered scope is around 2900, which is 1000 times larger than the value of around 2.9 when the gain is 1. The peak value of filtered is also increased with increasing gain. We can conclude that the Signal to Power Ratio has increased because the signal is much amplified relative to the noise. The effect of noise has relatively been lowered.

From the figures in the experiments section, when the cutoff frequency increases, the signal is amplified whereas there is much noise that is unfiltered. Therefore, the SNR will be lowered and thus the effect of the noise will be enhanced.