Lab 1: Signals and Noise

ECSE 308 Introduction to Communication Systems and Networks

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Abstract: This laboratory was designed to study the effect of different types of inputs on a system. In part one, the basic characteristics of signals and noise are observed and analyzed. The objective of part two is to examine the power and the bandwidth of both deterministic and random signals, access the signal to noise power ratio, and apply filtering technique

Keywords: SNR, Bandwidth, Filtering

Introduction

It is crucial to understand how different inputs affect system performance in signal processing. A signal can be either deterministic, where it's value can be modeled by mathematical equation at any time, or random, where values fluctuate unpredictably. Noise can be defined as the random, unwanted variation of fluctuation that degrades the quality of signals and data. Filtering techniques can be applied to mitigate its impact. The first part of the experiment focused on understating basic concepts of signals and noise. Bandwidth is defined as the difference between the upper and lower frequencies of the signal generated. Signal to noise ration measures the strength of a desired signal relative to noise, and its unit of expression is typically decibels. With the blocks connected as required, part two of the experiment analyzed the power and the bandwidth of different signals, the effect of noise on the signal, the effect of filtering, and how noise varies in accordance with SNR and cutoff frequency respectively.

Analysis

Part I: Presentation of Signals and Noise

A). Periodic Signals

In this part of the laboratory, sine wave generator, triangular generator, and pulse generator were connected to a spectrum and scope respectively as shown in Figure

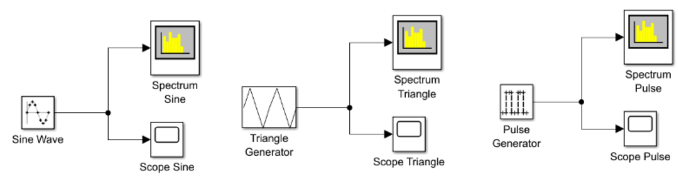

Figure 1 Periodic Signal Setup

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?

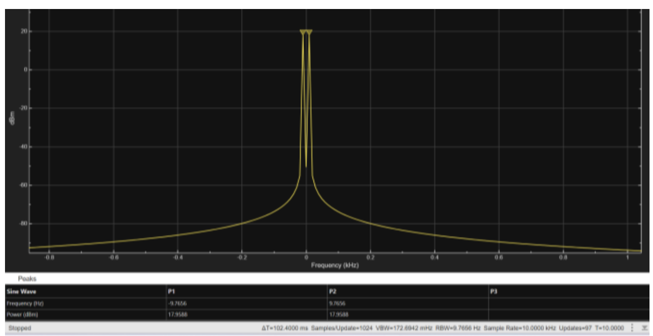

Figure 2 Sine wave Spectrum

Figure 3 Sine Wave Scope

The amplitude is 0.5 V. The period is 0.1 s. Frequency is the inverse of period which equals $\frac{1}{0.1\ s}$ =10 Hz. Therefore, the fundamental frequency is 10 Hz. There is no harmonic component since it contains only one frequency.

Q2: Repeat with a triangular wave

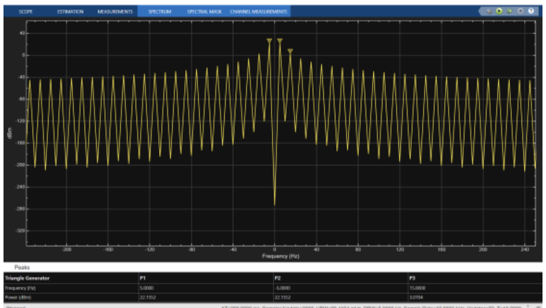

Figure 4 Triangular Wave Spectrum

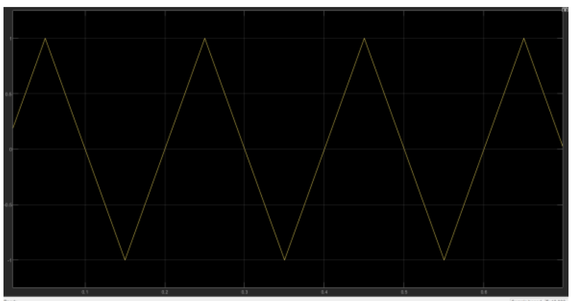

Figure 5 Triangular Wave Scope

The amplitude is 1.0 V. The period is 0.2 s. Frequency is the inverse of period which equals $\frac{1}{0.2\ s}$ = 5 Hz. The fundamental frequency is 5 Hz. The harmonics of a triangle wave are all odd multiples of the fundamental frequency which are 15 Hz, 25 Hz, 35 Hz, and etc.

Q3: Repeat with 50% duty cycle square wave

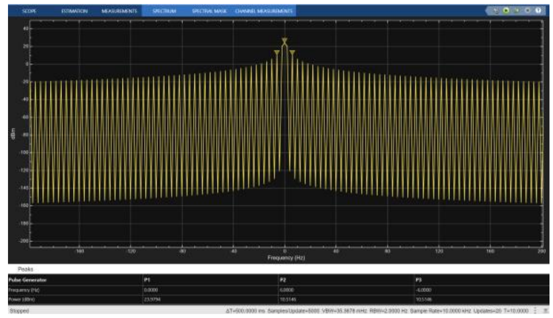

Figure 6 50% duty cycle square wave spectrum

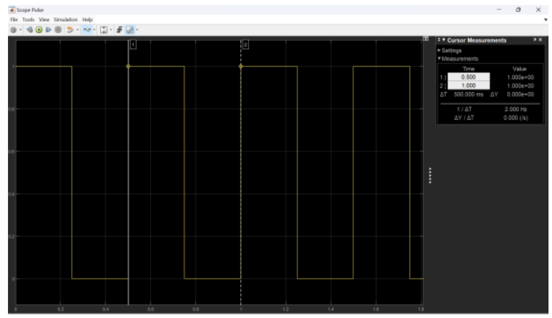

Figure 7 50% duty cycle square wave scope

The amplitude is 1.0 V. The period is 0.5 s. Frequency is the inverse of period which equals $\frac{1}{0.5\ s}$ =2 Hz. The fundamental frequency is 2 Hz. The harmonics are as before all odd multiples of the fundamental frequency which are 6 Hz, 10 Hz, 14 Hz, and etc.

Q4: Repeat with 20% duty cycle square wave

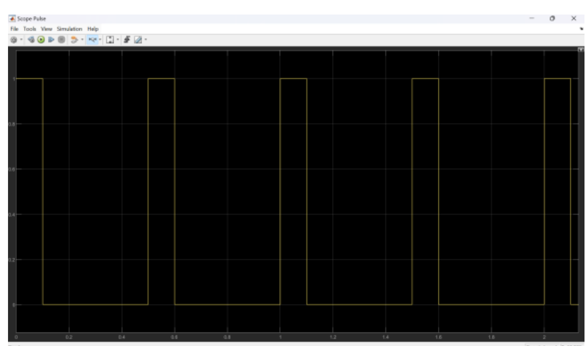

Figure 8 20% Duty Cycle square wave scope

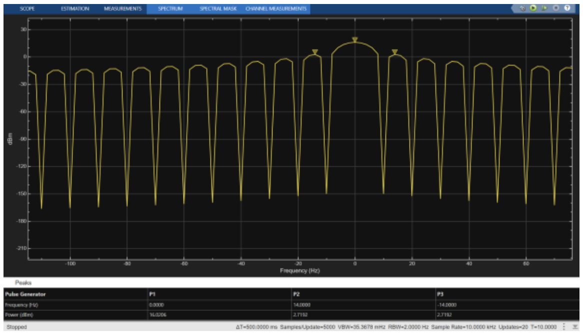

Figure 9 20% Duty Cycle Spectrum

The amplitude is 1V. The period is 0.5 s. Frequency is the inverse of period which equals $\frac{1}{0.5\ s}$ = 2 Hz. The fundamental frequency is 2 Hz. For a 20% duty cycle, both odd and even harmonics will appear which are 4 Hz, 6 Hz, 8 Hz, and etc. Since the duty cycle is 20%, every 5th harmonic would be missing.

B). Sum of Periodic Signals

Q5: Repeat with sum of 3 sine waves

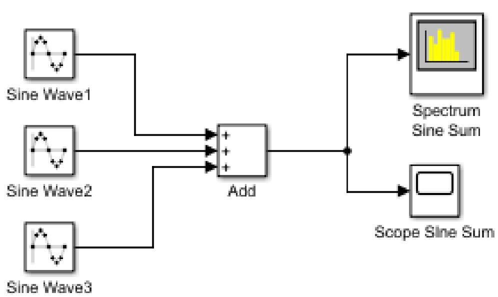

Figure 10 Sum of 3 Sine Waves Connection

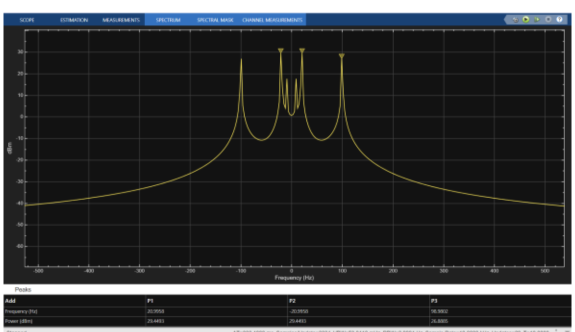

Figure 11 Sum of 3 Sine Waves Spectrum

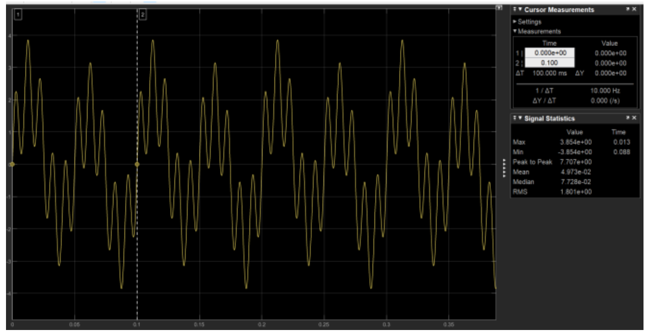

Figure 12 Sum of 3 Sine Wave Scope

The amplitude is 3.854 V. Period is 0.1s. Frequency is the inverse of the period which is 10 Hz. The fundamental frequency is 10 Hz resulting from the smallest frequency of the input signal. Since sine waves does not generate harmonics beyond their original frequencies, the harmonic components should be 10Hz from Sine Wave 1, 20 Hz from Sine Wave 2 and 100 Hz from Sine Wave 3.

C). Sum of Signals

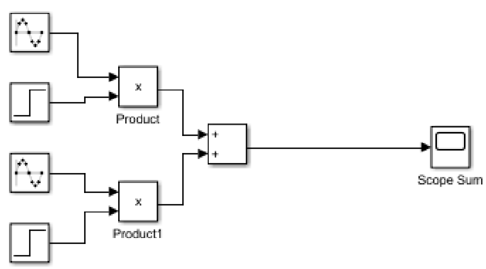

Figure 13 Sum of Signals Connection

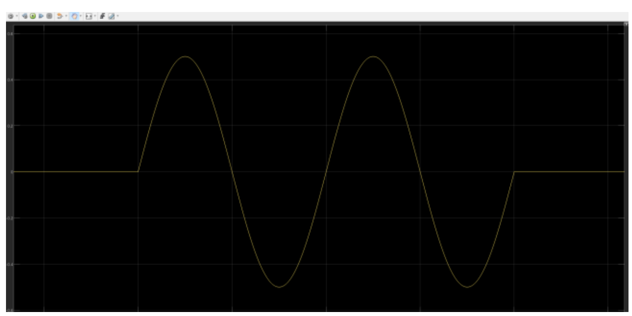

Figure 14 Sum of Signals Scope

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

The sine waves are multiplied by the step and then added together. The signal is initially flat with 0 amplitude since the step functions aren't activated. With the activation of step functions, values are multiplied with sine waves result in the oscillation of regular sine waves with an amplitude of 0.5 for the duration of step function which is 2 to 4 s in this case. Once the step function deactivates, the sine wave will be multiplied by zero again resulting in a flat 0 V signal.

D). Thermal Noise

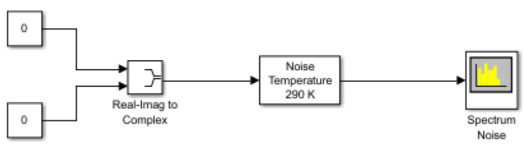

Figure 15 Thermal Noise Connection

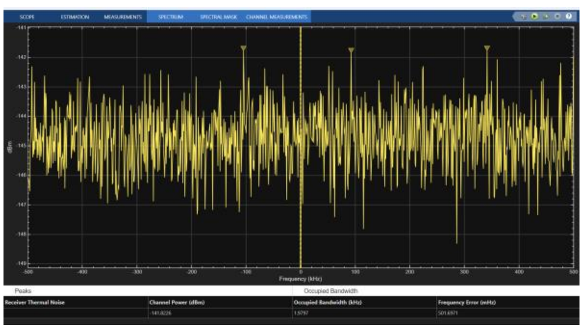

Figure 16 Thermal Noise Spectrum

Thermal noise also called Johnson-Nyquist noise is a result of thermal agitation of electrons. It is often referred to as white noise because of its uniform spectral density.

Q7: What is the bandwidth and the power spectral density of the thermal noise?

The noise temperature is 290 k. The bandwidth is the full range of frequencies over which the noise power is measured. The power spectral density is N=KT which $= 1.38 \times 10^{-23} \frac{J}{K} \times 290\, k = 4.002 \times 10^{-21} \frac{W}{Hz}$

E). Noise Power

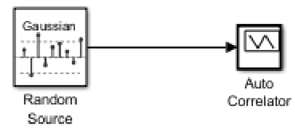

Figure 17 Noise Power Connection

Q8). Observe the output on Auto Correlator. Vary the variance of the source. Explain how the peak value of the output on Auto Correlator related to the variance, and thus the noise power.

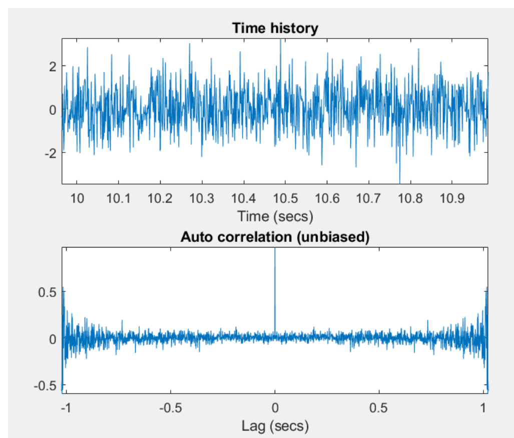

Figure 18 Variance of 1

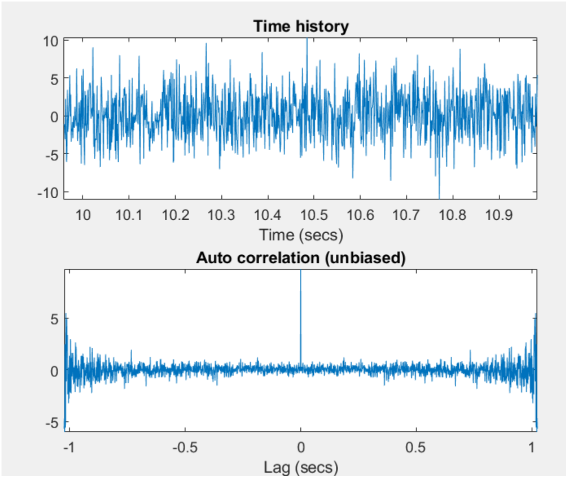

Figure 19 Variance of 10

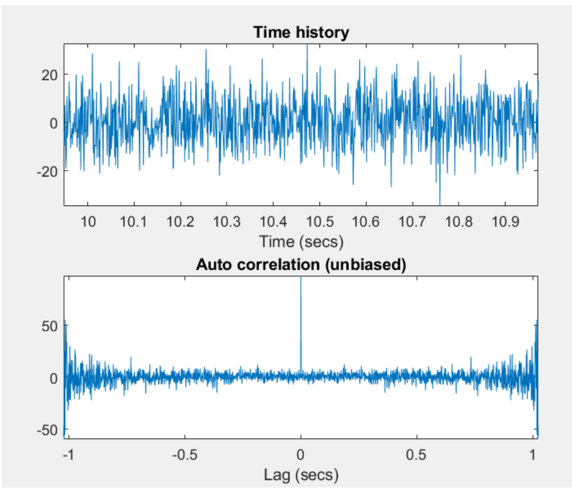

Figure 20 Variance of 100

A variance of 1, 10, and 100 are tested respectively. We can observe a correlation between the variance and the output on Auto correlator. As the variance increases, the peak of the auto correlator function increases accordingly. This shows the noise power is increasing.

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

Deterministic signals can be defined exactly by a mathematical formula. There is no uncertainty with respect to its value at any instant of time. Their frequency, amplitude, and phase can be precisely defined.
Random signals cannot be represented by mathematical equations. They are not precisely predictable and random in nature. They are modelled in probabilistic terms.

Part II: Power, Bandwidth & SNR

As instructed, the completed block connection diagram is shown below.

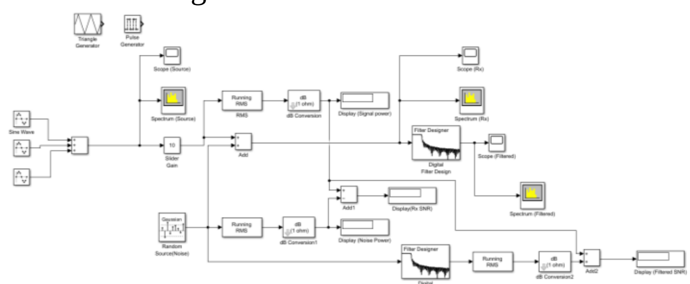

Figure 21 Block Connection Part II

Q1: Observe the output on Spectrum (Source). What are the power and the bandwidth of the sine wave.

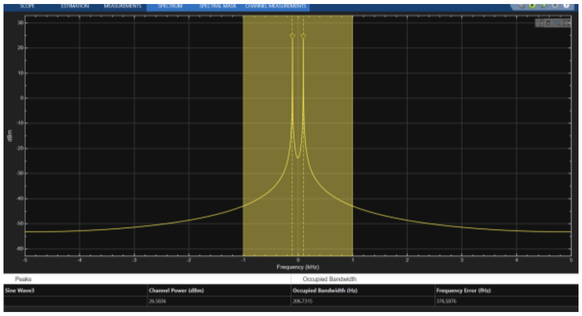

Figure 22 Spectrum Source Sine

As shown in the spectrum diagram above, using peak finder, the occupied bandwidth is 206.7315 Hz. Channel power is 26.58 dBm.

Q2: Repeat With triangular wave

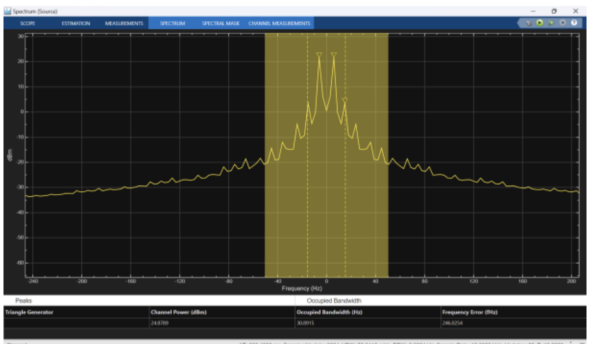

Figure 23 Triangular wave Spectrum

We have repeated the steps with a triangular wave as source. The channel power is 24.8789 dBm and the occupied bandwidth is 30.8915 Hz.

Q3: Repeat With 50% cycle square wave

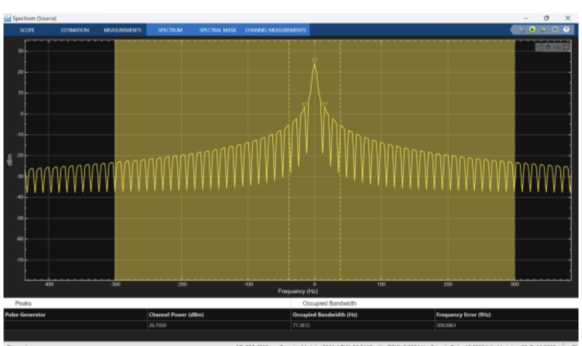

Figure 24: 50% Duty Cycle Square wave spectrum

With the same connection, but changing the source to 50% duty square wave, the channel power is 26.7930 dBm and the occupied bandwidth is 77.3812 Hz

Q4: Repeat With 20% cycle square wave

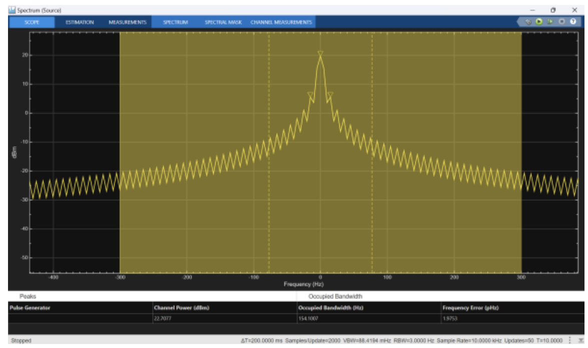

Figure 25: 20% Duty Cycle wave spectrum

Then the source is changed to a 20% duty cycle wave. The channel power is 22.7077 dBm and the bandwidth is 154.1007 Hz.

Q5: Repeat step 1 with a sum of 3 sine waves.

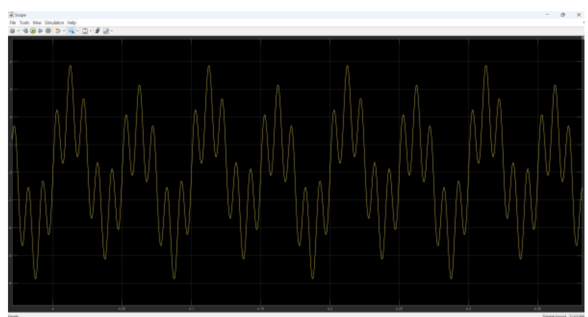

Figure 26: Original Signal with 3 Sine Waves in Time Domain

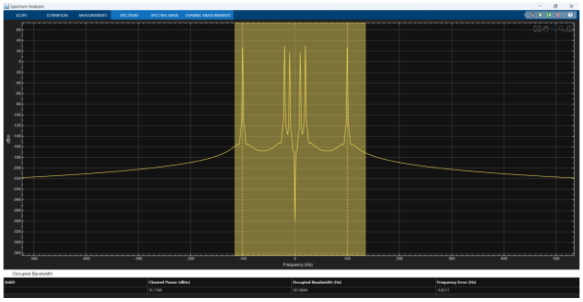

Figure 27: Original Signal with 3 Sine Waves in Frequency Domain

The power for the 3-sine wave is 204.7196 Hz and the power is 35.1222 dBm.

Q6: Observe the outputs on the Scope (Rx) and Spectrum (Rx). Comment on the effect of noise on the signal in the time domain and the frequency domain

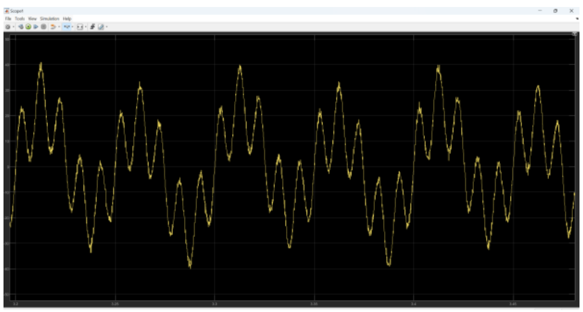

Figure 28: 3 Sine Wave output in Time Spectrum

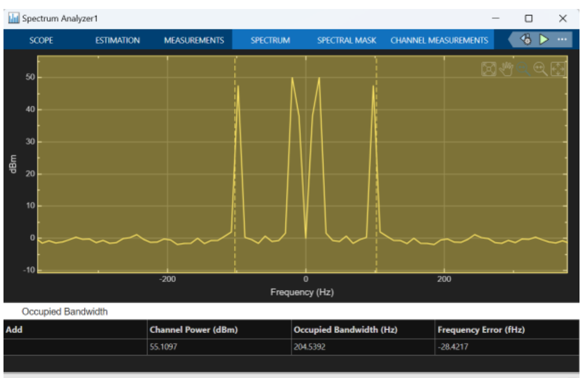

Figure 29: 3 Sine Wave output in Frequency Spectrum

In the time domain, the shape of the wave is still resembling to the original wave, but there are a lot of noises being added into it. The wave is not smooth and present sharp edges. In the frequency domain, four spikes can still be seen, however, it has lost two spikes, and the slowly declining level of power compared to the original signal, instead, its power drops rapidly. The shape of spectrum was distorted.

Q7: Compare the outputs on Scope (Filtered) and Spectrum (Filtered) with those on Scope (Rx) and Spectrum (Rx), respectively. Comment on the effect of filtering

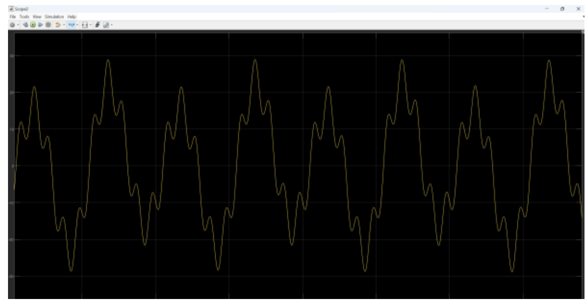

Figure 30: 3 Sine Wave filtered output in Time Spectrum

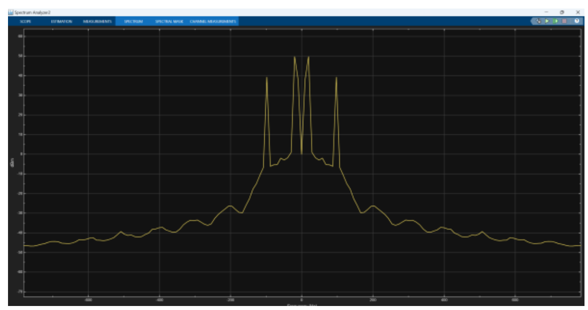

Figure 31: 3 Sine Wave filtered output in Frequency Spectrum

After the filtering, we observe that the peak value has decreased. The general shape remain to be the same and noise has been reduced. It is smother than before. On the other hand, after filtering, the frequency domain is reobtaining some characteristics of the original wave and having a less steep energy decline slope.

Q8: 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.

We chose to vary slider gain at a value of 4, 6, 8, and 15.

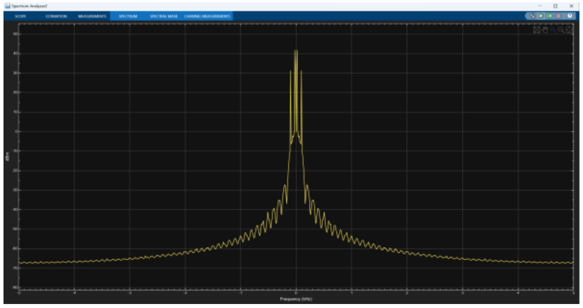

Figure 32: Frequency Spectrum Slider Gain at 4

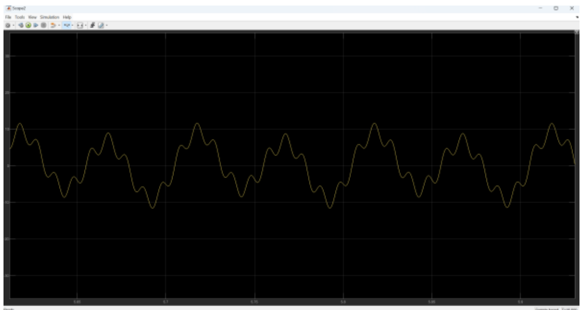

Figure 33: Time Spectrum Slider Gain at 4

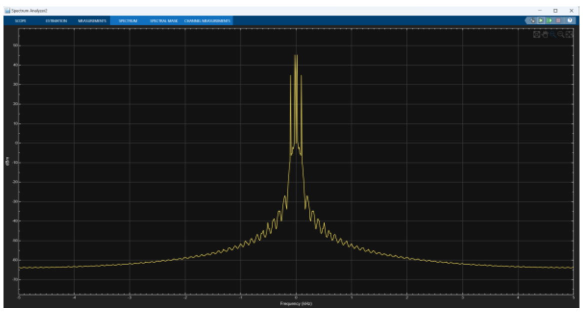

Figure 34: Frequency Spectrum Slider Gain at 6

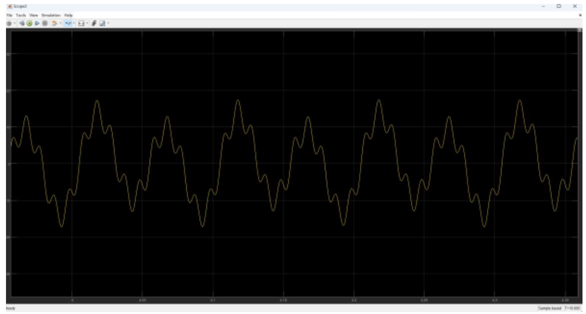

Figure 35 Time Spectrum Slider Gain at 6

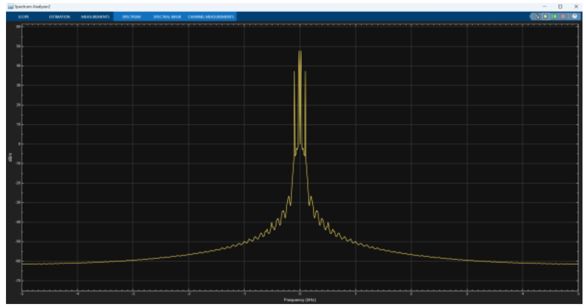

Figure 36: Frequency Spectrum Slider Gain at 8

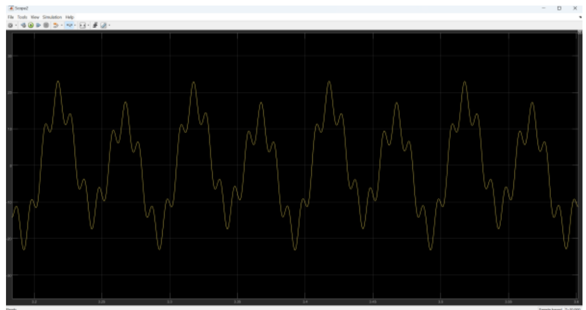

Figure 37: Time Spectrum Slider Gain at 8

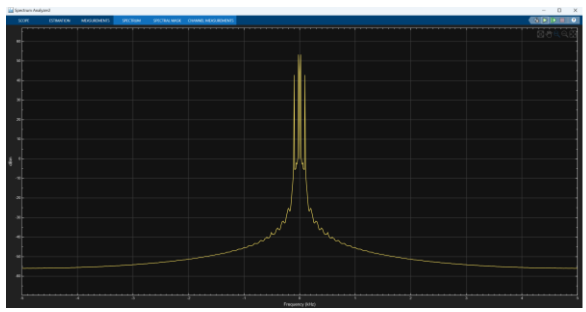

Figure 38: Frequency Spectrum Slider Gain at 15

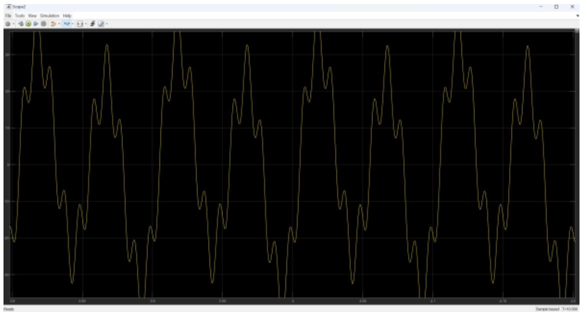

Figure 39: Time Spectrum Slider Gain at 15

According to *figure 32-39* and *figure 30-31*, the variations in the gain leads to an increase in amplitude of the signal peaks. Amplifications only increase the magnitude of the waveform. The shape and fundamental frequency remain unchanged. Additionally, increase slider gain, increase the channel power. There does not appear to be a change in the noise level. Therefore, in the range of slider gain variation of 4-15, increased gain enhanced the signal to noise ratio.

We examined the system with cut-off frequencies at 20 Hz, 40 Hz, 60 Hz, 80 Hz, 1000 Hz, and 4500 Hz.

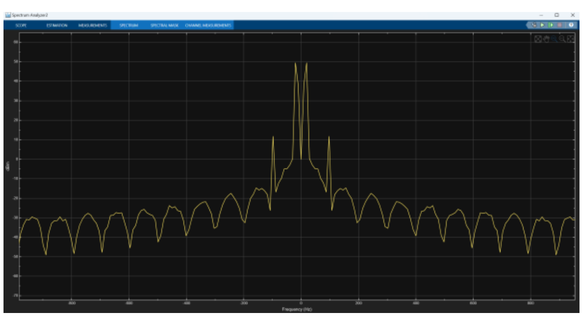

Figure 40: Frequency Domain Fc at 20

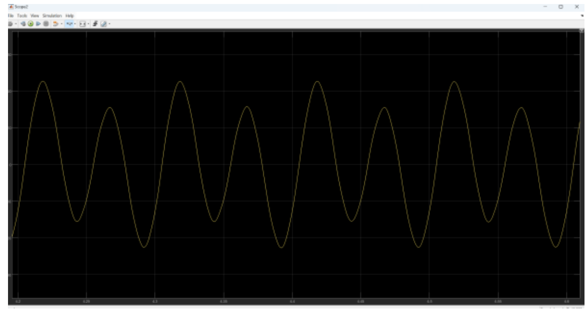

Figure 41: Time Domain Fc at 20

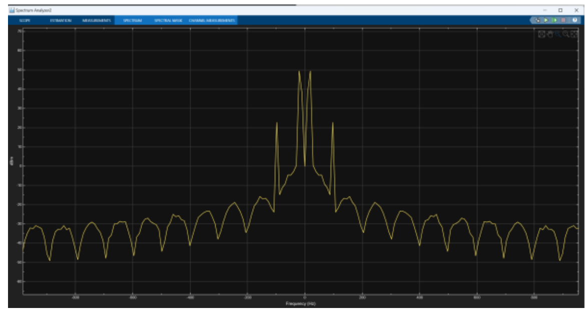

Figure 42: Frequency Domain Fc at 40

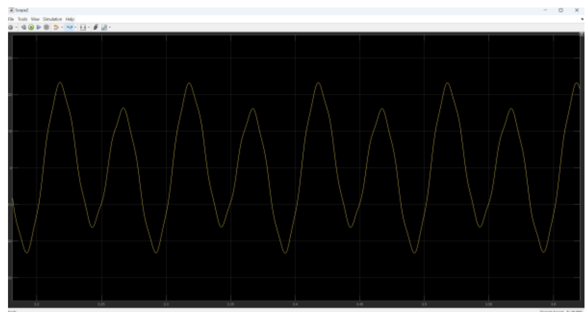

Figure 43: Time Domain Fc at 40

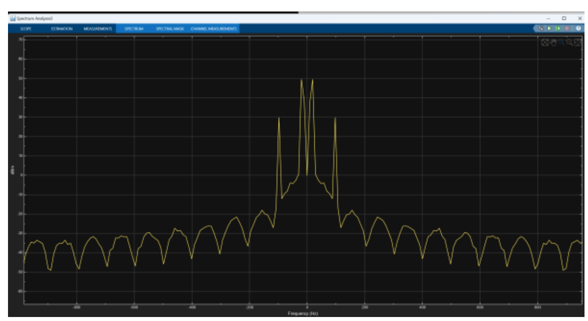

Figure 44: Frequency Domain Fc at 60

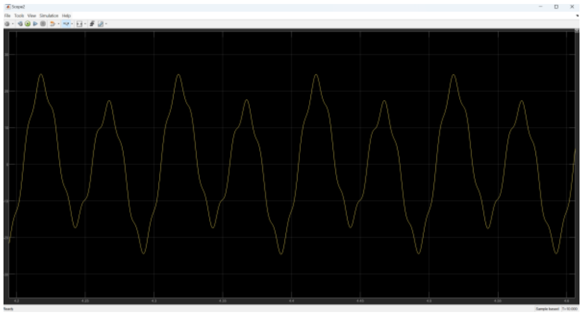

Figure 45: Time Domain Fc at 60

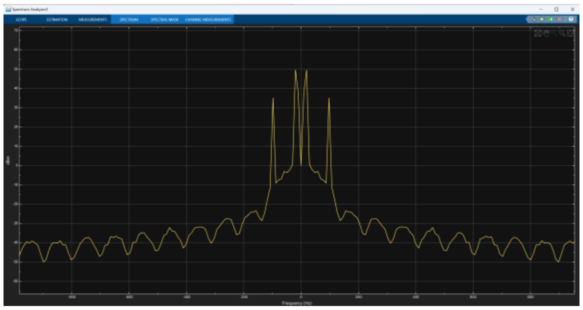

Figure 46: Frequency Domain Fc at 80

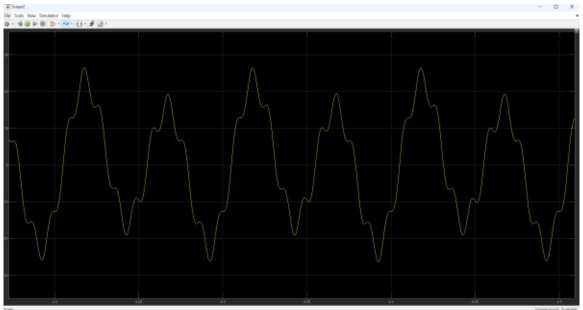

Figure 47: Time Domain Fc at 80

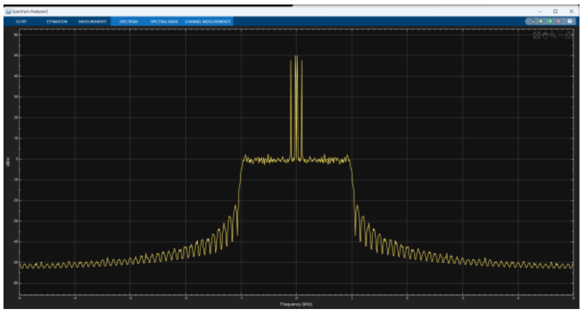

Figure 48: Frequency Domain Fc at 1000

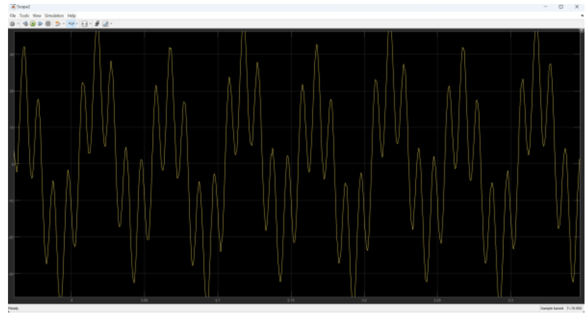

Figure 49: Time domain Fc at 1000

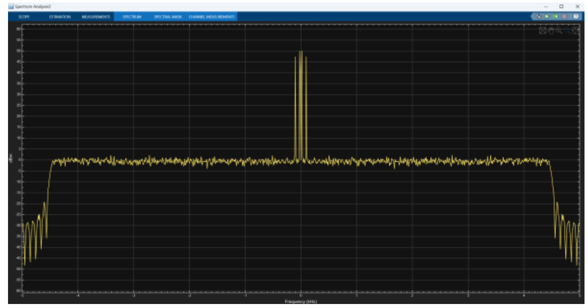

Figure 50: Frequency Domain Fc at 4500

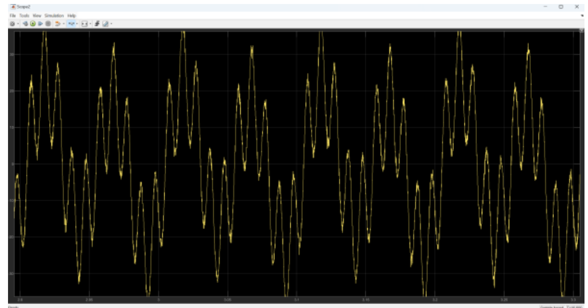

Figure 51: Time Domain Fc at 4500

In this part, according to *figure 40-51* the slider gain value is set to 10 and the cutoff frequency Fc varies from 4500 to 20 in Digital Filter Design, as the Fc values decreases, the time domain signal is getting smoother and smoother which signifies a reduction of noise but at the same time it loses all the characteristics of a 3-sine wave curve. The frequency domain has a plateaued energy level of high cut off frequency such as those of 1000Hz and 4500 Hz. This plateau signifies the noise being introduced into the signal. In the smaller cut off frequency, the plateau disappeared, and the energy level is very consistent throughout the whole graph. This indicates that the higher the cut-off frequency, the more noise is permitted into the signal that leads to a lower SNR. To obtain a high SNR, it is preferred to keep the cut-off frequency low so that less noise is presented in the signal.

Conclusion

This laboratory experiment provided valuable insights into signal processing, noise analysis, and filtering techniques in a simulated environment. Key concepts in signal theory were explored through exercises, starting with signal and noise fundamentals. Simulations of sine, triangular, square waves, and sum of different signals improved understanding of waveform parameters, while thermal noise analysis offered practical experience with non-ideal conditions.

The experiment advanced to signal bandwidth determination, power spectral density calculation, and time and frequency domain analysis, deepening understanding of noise effects on signals. Filtering techniques were then applied, showing how filtering enhances signal clarity. The impact of Signal-to-Noise Ratio (SNR) on filter performance was examined by adjusting Slider Gain, offering hands-on experience in optimizing filters.

Finally, filter design was explored by experimenting with cutoff frequencies in Digital Filter Design, demonstrating how design choices influence noise reduction. Overall, the experiment provided a strong foundation for advanced signal processing and filter design studies.