EXPERIMENT 3 PART 2
SIGNAL GENERATION, FILTERING, CROSS CORRELATION, A/D, D/A, DMA LabVIEW IMPLEMENTATION
Report Template

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Tasks

1. Place the block diagram and front panel.

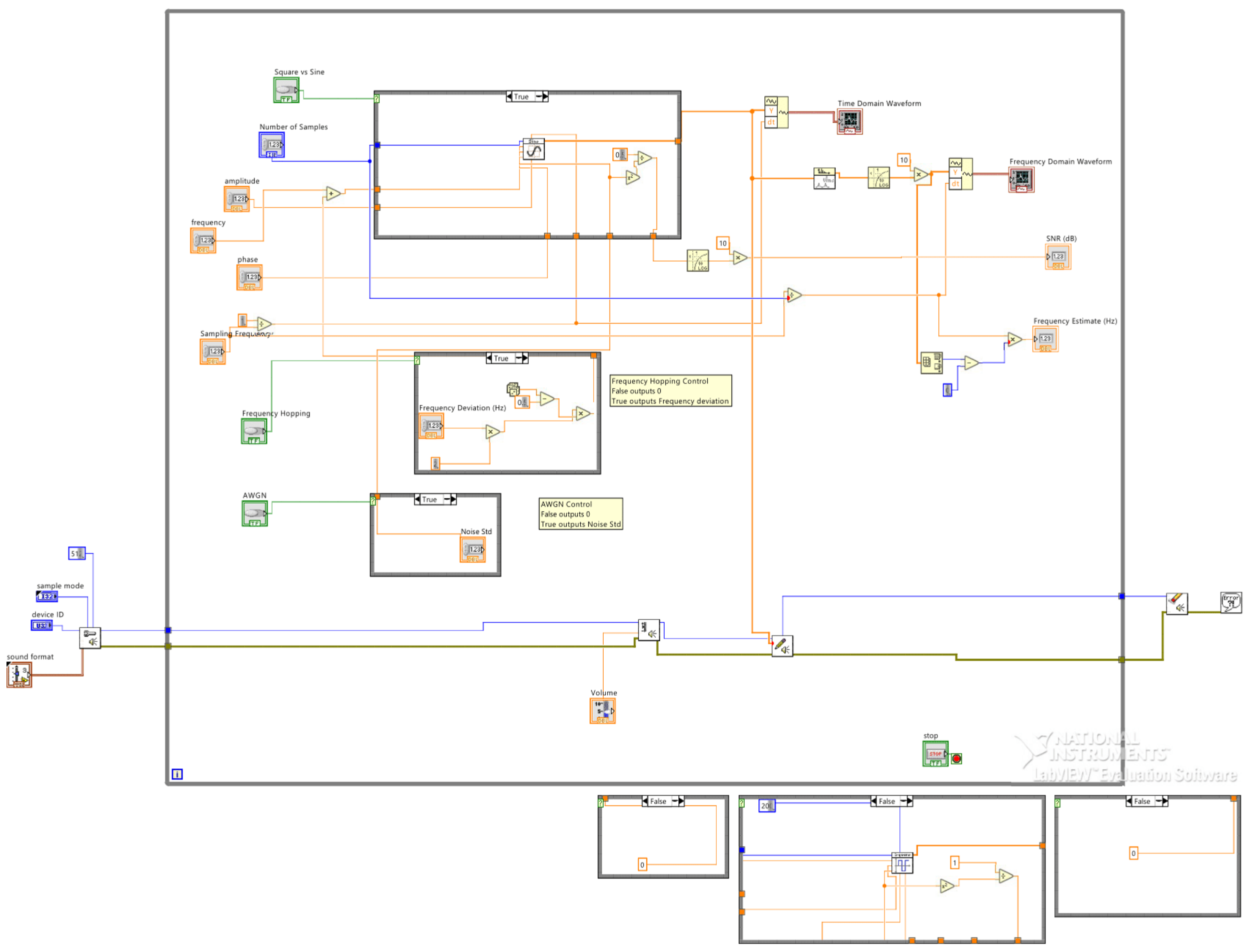

Figure 1: Block diagram of LabVIEW implementation of the experiment

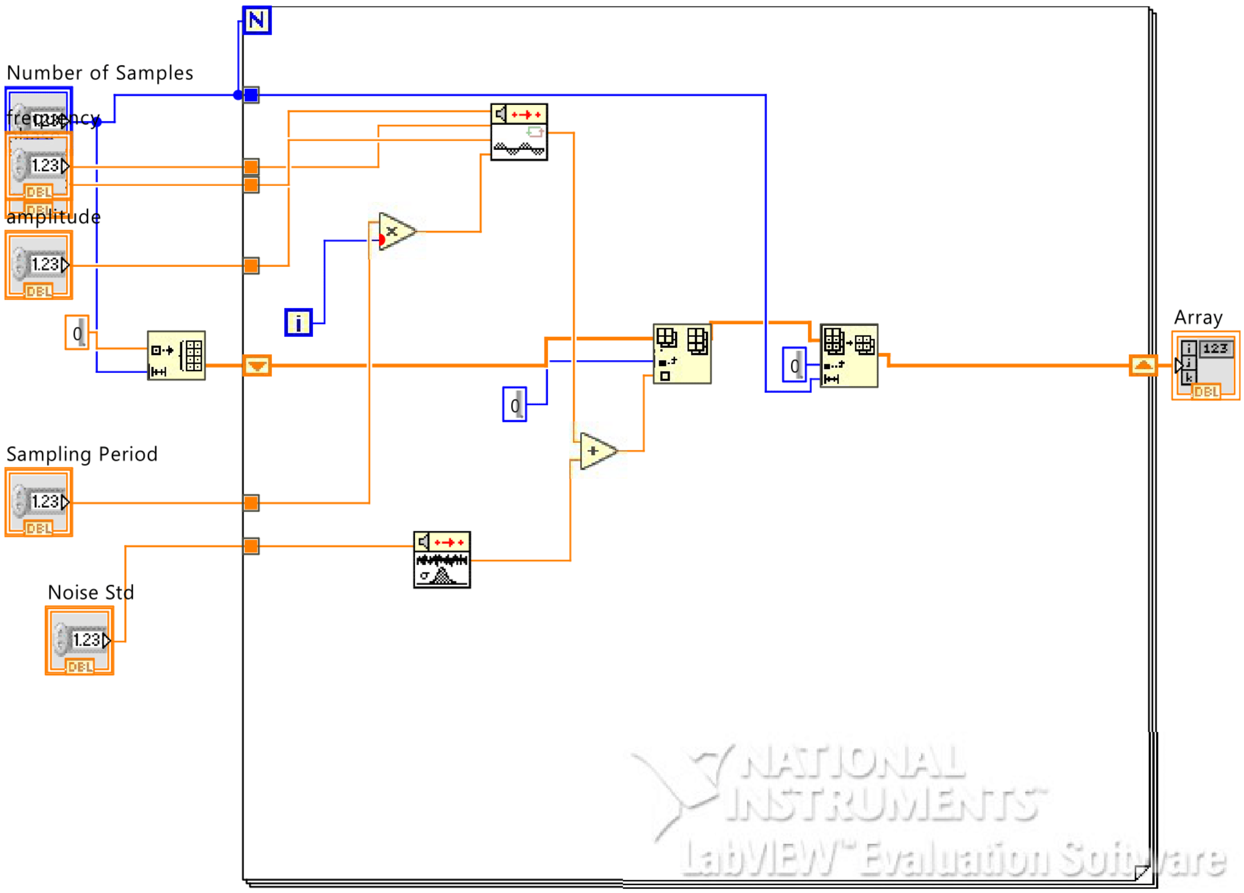

Figure 2: Block diagram of LabVIEW implementation of sinusoidal wave

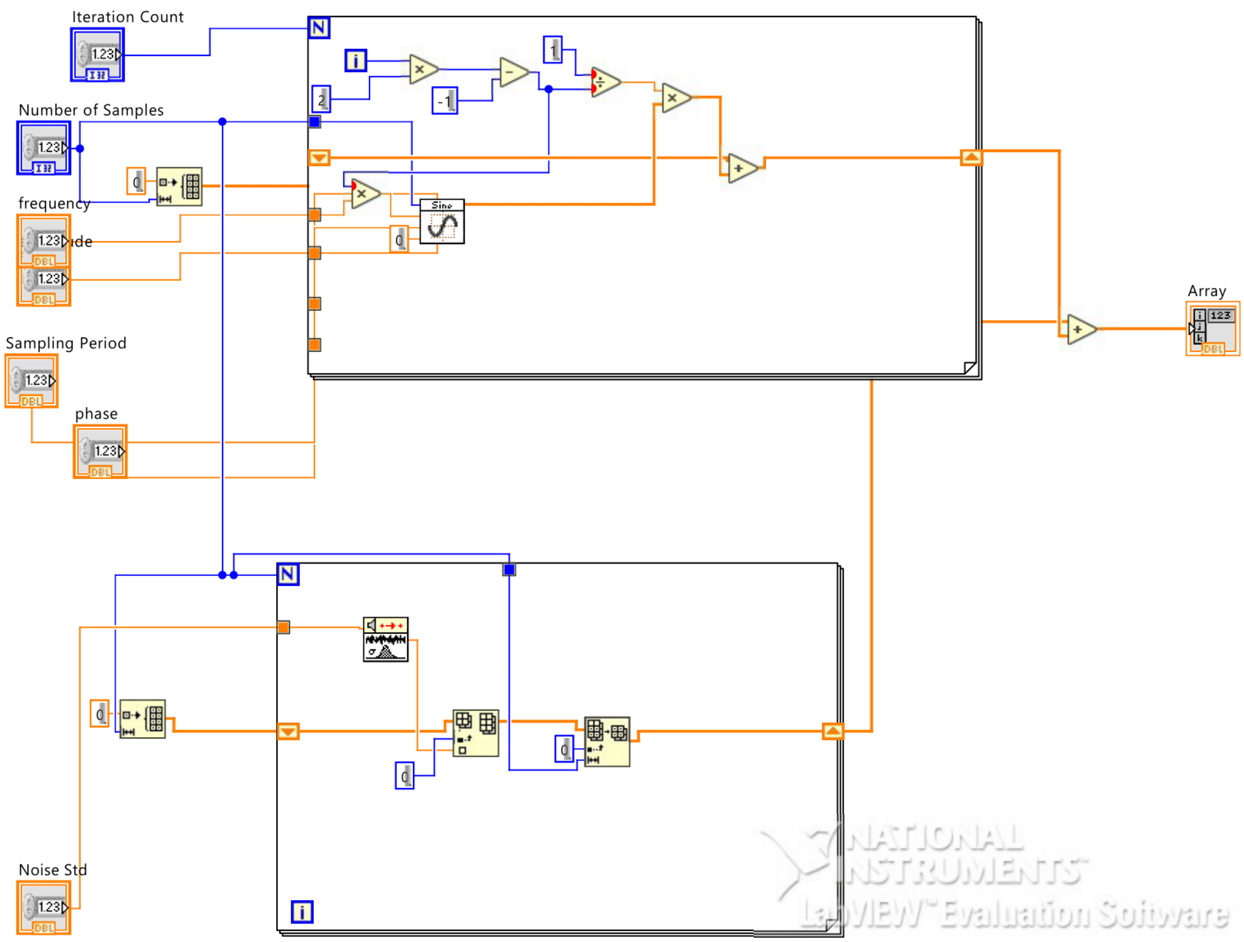

Figure 3: Block diagram of LabVIEW implementation of square wave

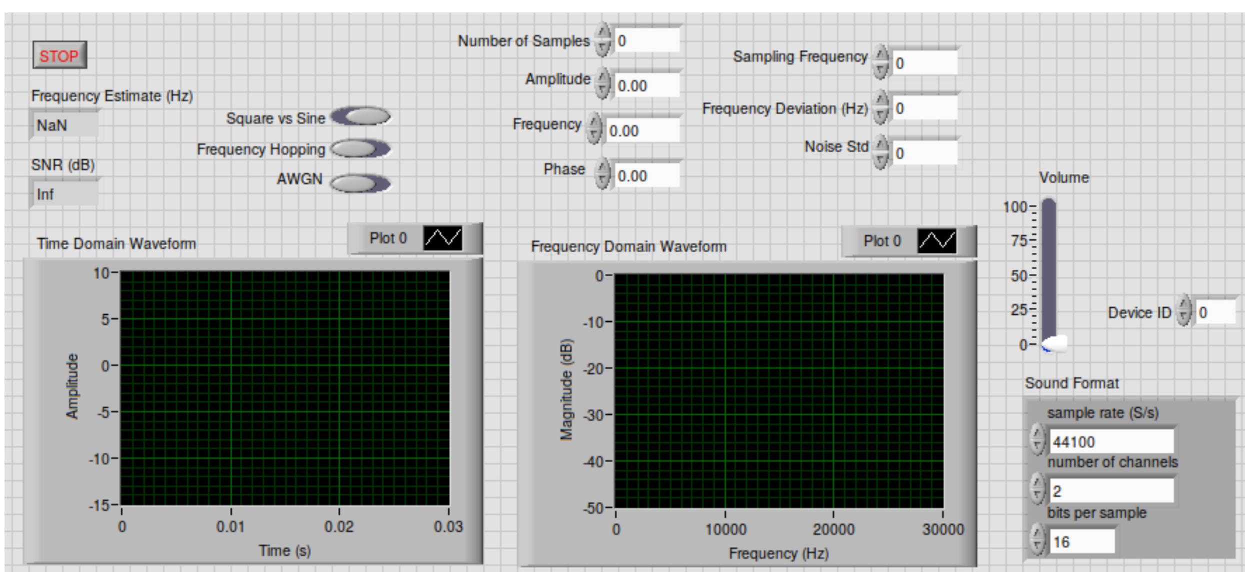

Figure 4: Front panel of LabVIEW implementation of the experiment

2. Set the amplitude to 1, number of samples to 512, phase to 0, and frequency to 500 Hz of the wave generator. Choose **Sine vs Square** true so that the sine wave will be generated. Choose the sampling frequency 25 kHz. Increase the sine wave frequency from 500 Hz to 2500 Hz by 500 Hz steps. **Comment on the change in the waveforms. Attach** the plot for the 2500 Hz case.

We observed the frequency value correctly in each case because the frequencies of the sinusoidals does not exceed Nyquist Frequency = 12500 Hz and the DFT calculation gives the correct result. Moreover, as we keep the number of samples and sampling frequency constant, we observe more pressed sinusoidals in the time domain when frequency is increased. When the frequency is 2500 Hz there are more than 50 periods of the signal in the plot.

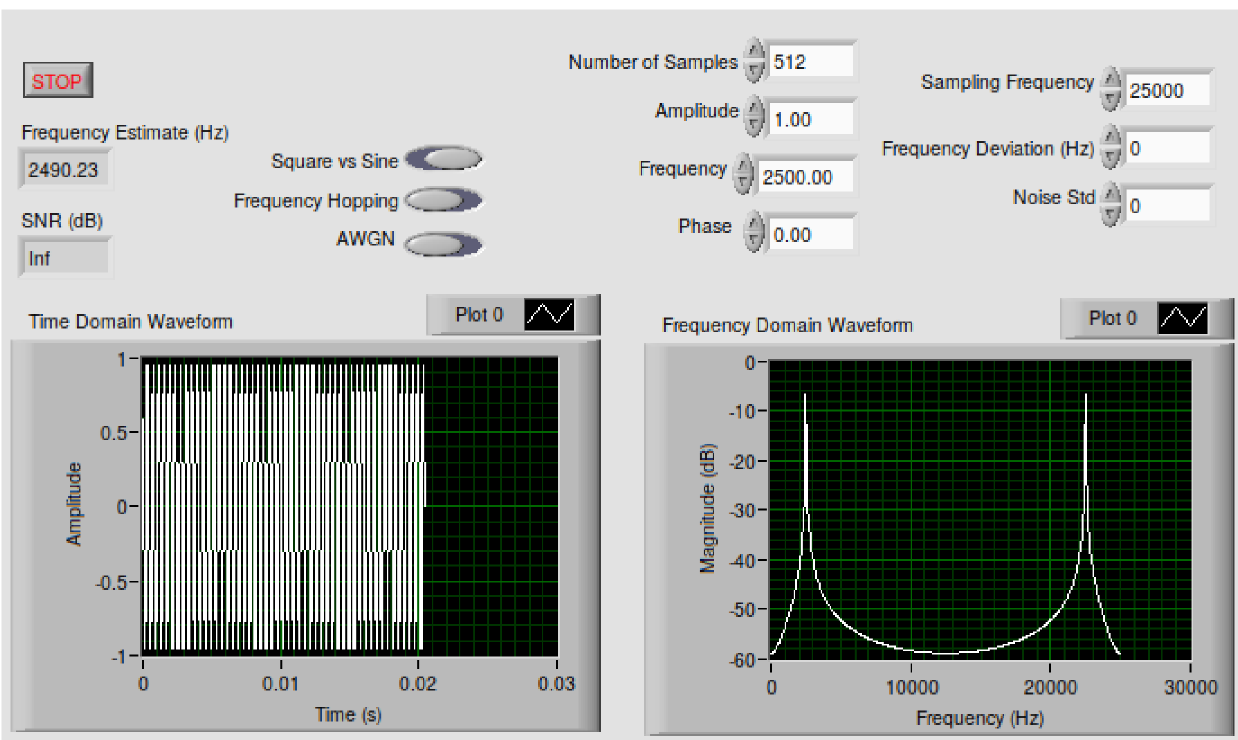

Figure 5: Time and frequency domain waveforms of sine wave for testing increase in frequency

3. Keep the frequency of the sine wave at 500 Hz. **Increase the sampling rate from 25 kHz to 175 kHz in 50 kHz steps**. **Comment** on the change in the waveforms. **Attach** the plot for the **175 kHz** case.

In the time domain, we observe that the time axis shrinks in time, while increasing the sampling rate. Even though there is an increase in sampling rate, sinusoidal can be inspected by looking at it for all sampling rates. Since we observe in smaller time intervals when the sampling rate is higher, it is easier to inspect the sinusoidal, which indicates a better time resolution in a way.

In frequency domain, we observe that the peaks of the frequency component of the sinusoidal approaches to the boundaries, since the sampling rate is increased, which means that it becomes harder and harder to inspect its frequency. So, there is a trade-off between frequency resolution and time resolution.

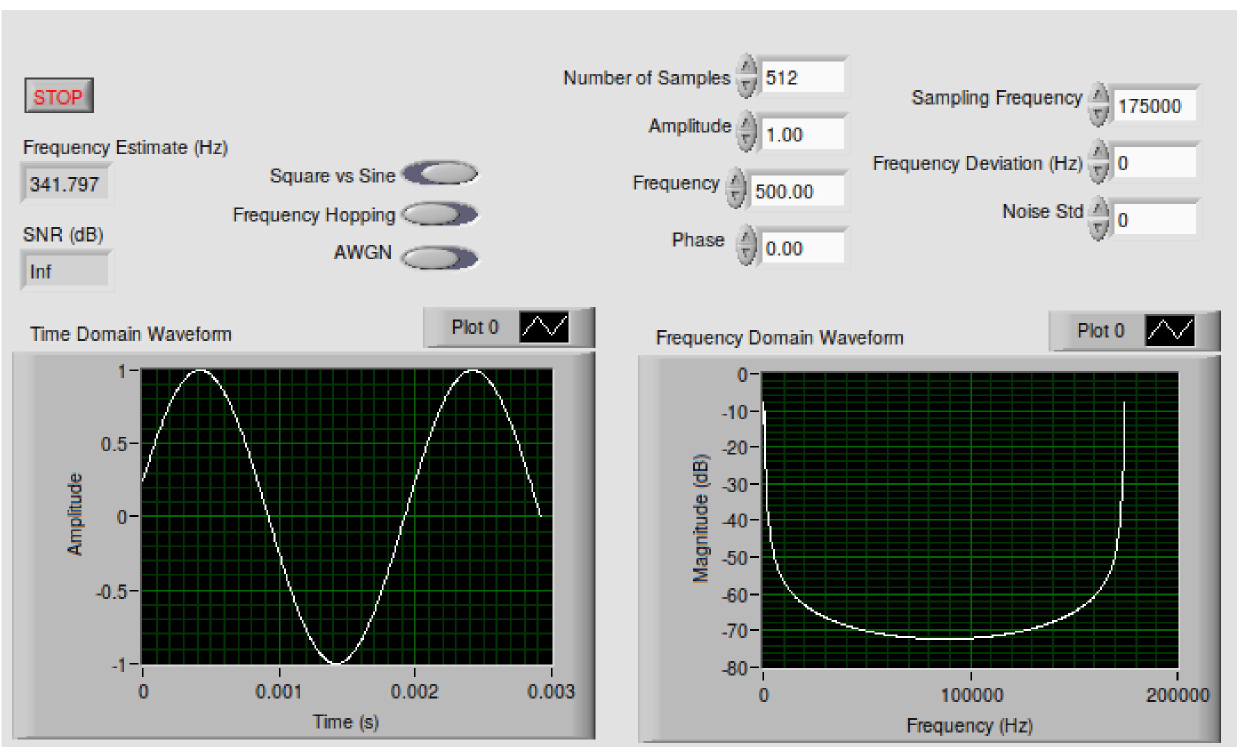

Figure 6: Time and frequency domain waveforms of sine wave for testing increase in sampling frequency

4. Keep the sine wave frequency at 500 Hz. **Decrease the sampling rate from 25 kHz to 5 kHz in 5 kHz steps**. Comment on the change in the waveforms. **Attach** the plot for the **5 kHz** case.

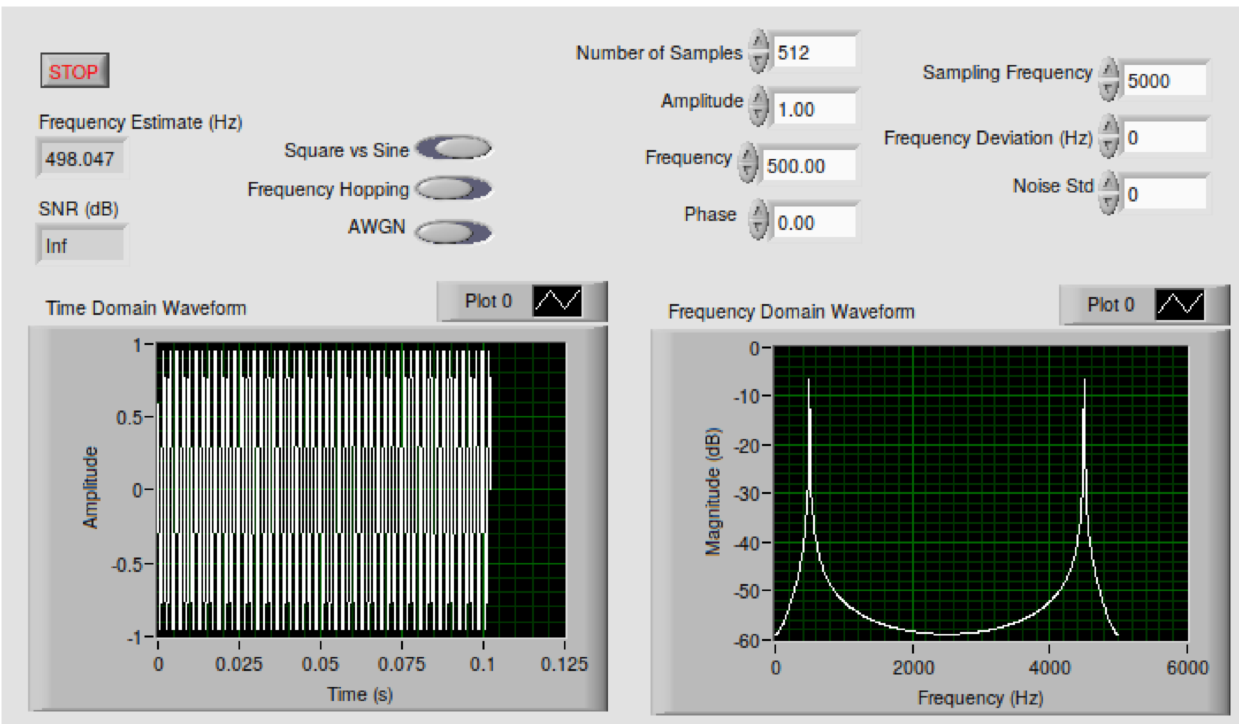

Figure 7: Time and frequency domain waveforms of sine wave for testing decrease in sampling frequency

Here, there is also a trade-off between frequency resolution and time resolution. As we decrease the sampling rate, it gets easier to understand the frequency content by looking at the 512 point DFT of the signal. On the other hand, time resolution decreases with decreasing sampling rate and it becomes much harder to understand that the signal is a sine wave at 500 Hz by looking at the time plot.

5. **Now**, set the **sine wave frequency** and **sampling frequency** to **500 Hz and 25 kHz**, respectively. **Activate the frequency hopping**. Set the **frequency deviation to 1 Hz**. Observe the waveforms. Increase the frequency deviation **from 1 Hz to 250 Hz in 50 Hz steps**. **Observe** the changes in the waveforms. **Comment** on the results.

What we expect in this task is that in the DFT of the signal, we will see a peak at its frequency. However, since there is a deviation in the frequency, the frequency of the signal will change in a neighborhood, thus we will observe several peaks instead of one at that neighborhood. We have observed that the frequency of the sinusoidal changed over time and in its frequency domain waveform, the position of the peak has changed with time in a neighborhood for corresponding frequency deviation.

6. **Repeat steps 2, 3, 4, and 5 for the square wave.**

A square wave can be expressed as a sum of sinusoids at odd harmonics of the wave frequency where each sinusoidal's amplitude is inversely proportional to its frequency. For example, in Figure 9 we can clearly observe the harmonics of the square wave until the end of the spectrum. On the other hand, higher order frequency terms are not visible in Figure 8 because sampling frequency is lower and the addition of harmonics to the spectrum from aliasing does not increase the values significantly. Other than this effect, the observations of time and frequency components are the same with the sinusoidal signals as this signal can be expressed as superposition of sinusoidal signals.

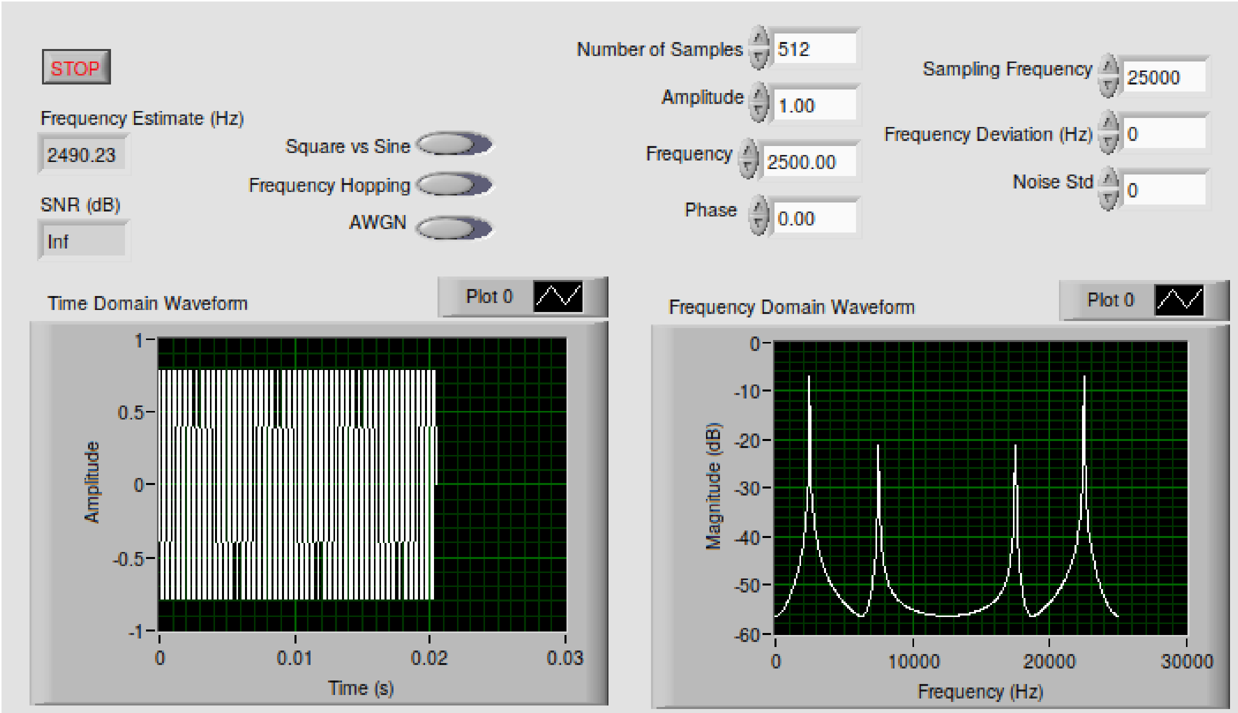

Figure 8: Time and frequency domain waveforms of square wave for testing increase in frequency

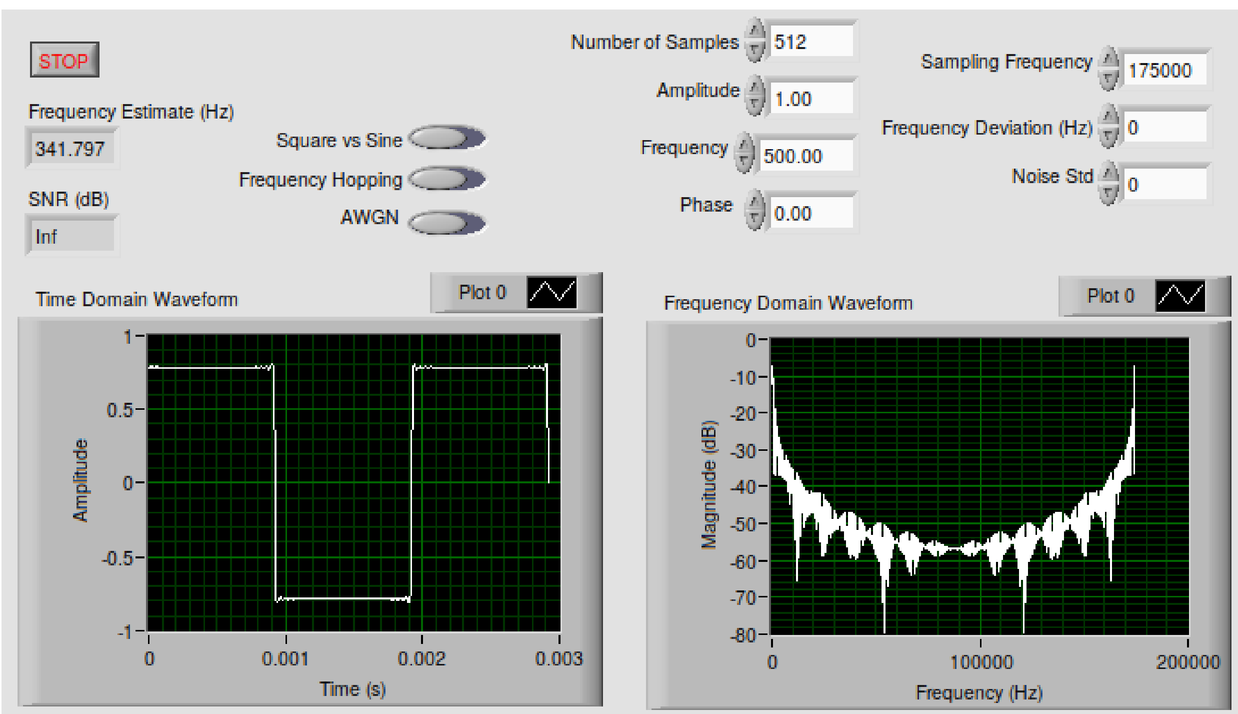

Figure 9: Time and frequency domain waveforms of square wave for testing increase in sampling frequency

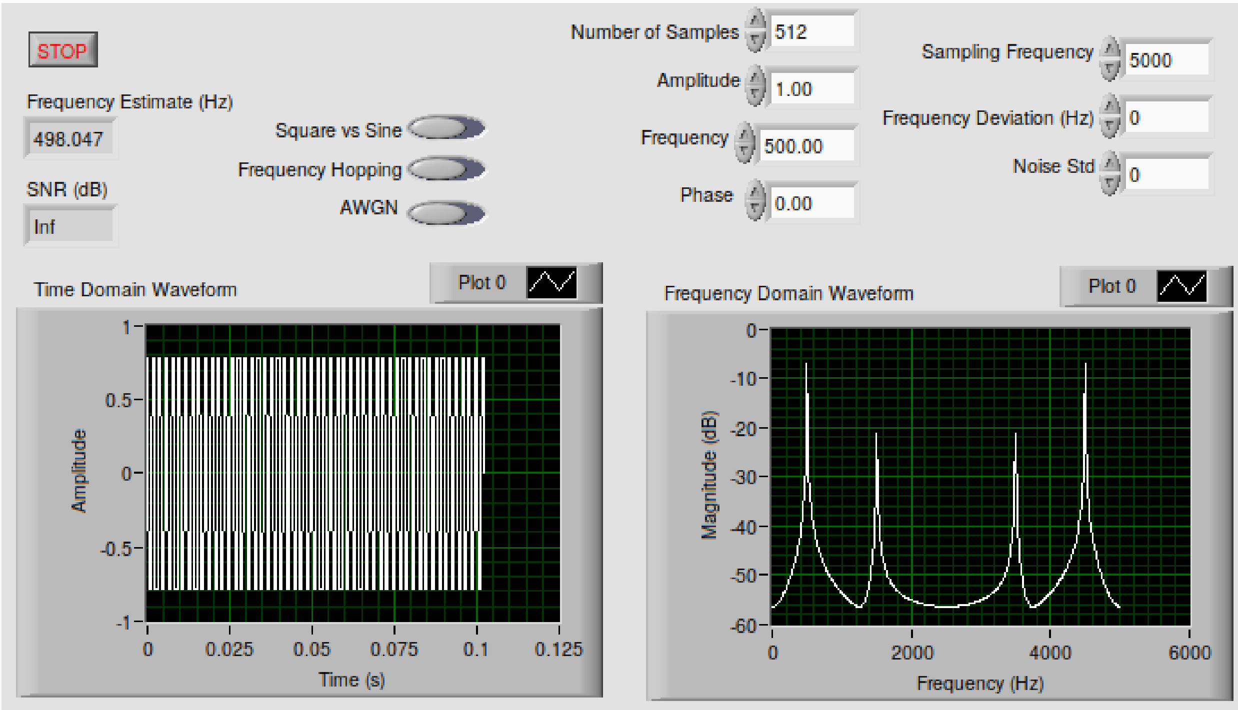

Figure 10: Time and frequency domain waveforms of square wave for testing decrease in sampling frequency

7. Generate a sine wave without frequency hopping with a **sampling frequency of 100 Hz**. Adjust the frequency of the sine wave to 101 Hz. What do you observe? What is the frequency of the observed signal? **Comment** on the results. Attach the front panel.

We observed a sinusoidal with a frequency of 1 Hz. The reason behind this phenomena can be explained by looking at the way sampling operation affects the signals frequency spectrum. By sampling, signal is multiplied with an impulse train with frequency equal to the sampling frequency. This operation means convolving the frequency spectrum with an impulse train with period equal to the sampling frequency. Hence the amplitude of 101 Hz frequency is carried to the 1 Hz by the effect of this shift operation and the spectrum becomes the same with the spectrum of a 1 Hz signal sampled with a sampling frequency of 100 Hz.

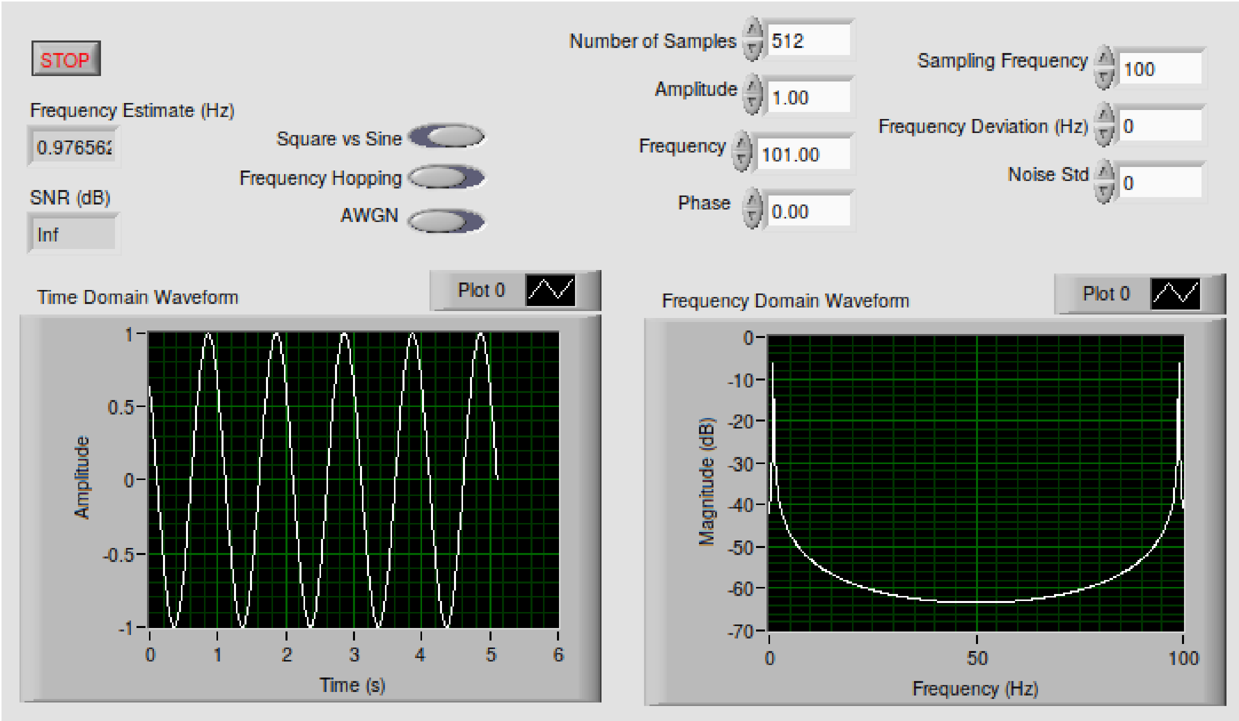

Figure 11: Sine wave at 101 Hz with a sampling rate 100Hz and its frequency spectrum

8. Now, increase the frequency to 105 Hz in 1 Hz steps. **Comment** on the frequencies of the waveforms.

As in Task 7, since the frequency is higher than the sampling frequency, observed frequencies of the signals are 1 Hz, 2 Hz, 3 Hz, 4 Hz, and 5 Hz, respectively.

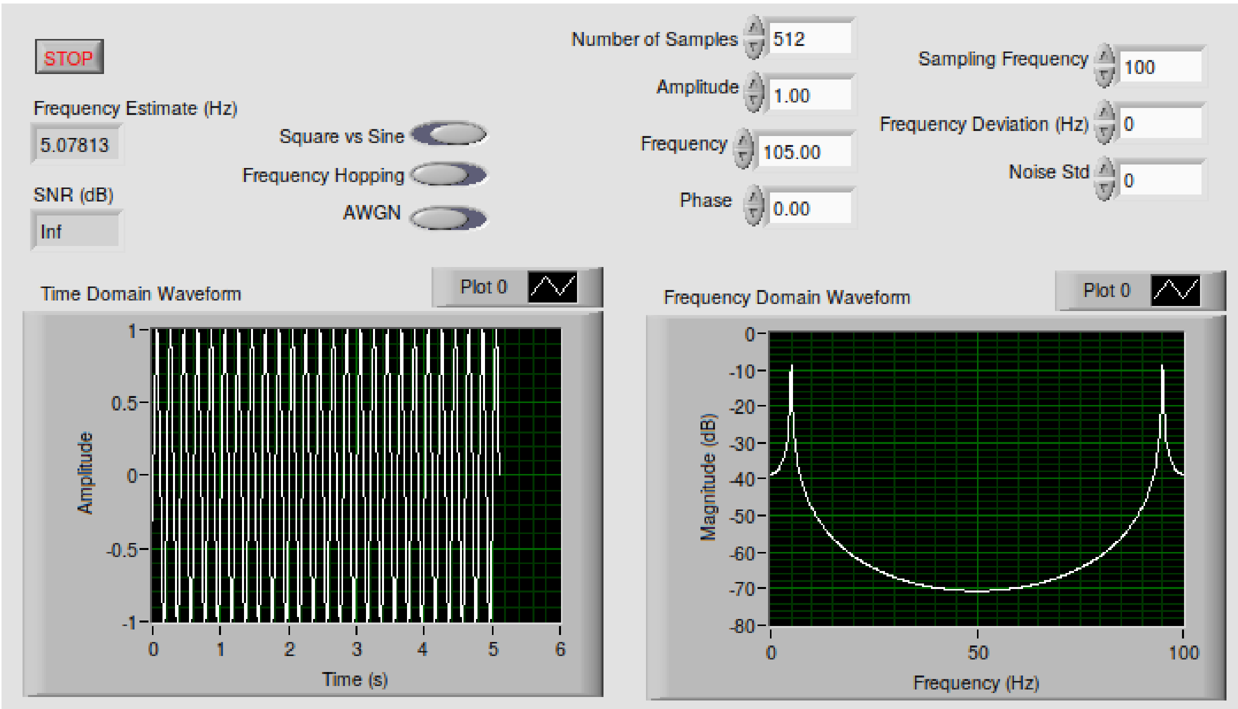

Figure 12: Sine wave at 105 Hz with a sampling rate 100Hz and its frequency spectrum

9. **Increase** the sine wave frequency from **1001 Hz to 1005 Hz in 1 Hz steps** while the **sampling frequency is still 100 Hz**. Are the results similar to 8? **Why**?

The result is the same with the 101 Hz sine wave. As the impulse train is infinite, from the impulse at the 1000 Hz in the spectrum, shifting carries the frequency component at the 1001 Hz to 1 Hz. For any signal with frequency k*100+1 Hz where k is a positive integer, we will observe the same spectrum.

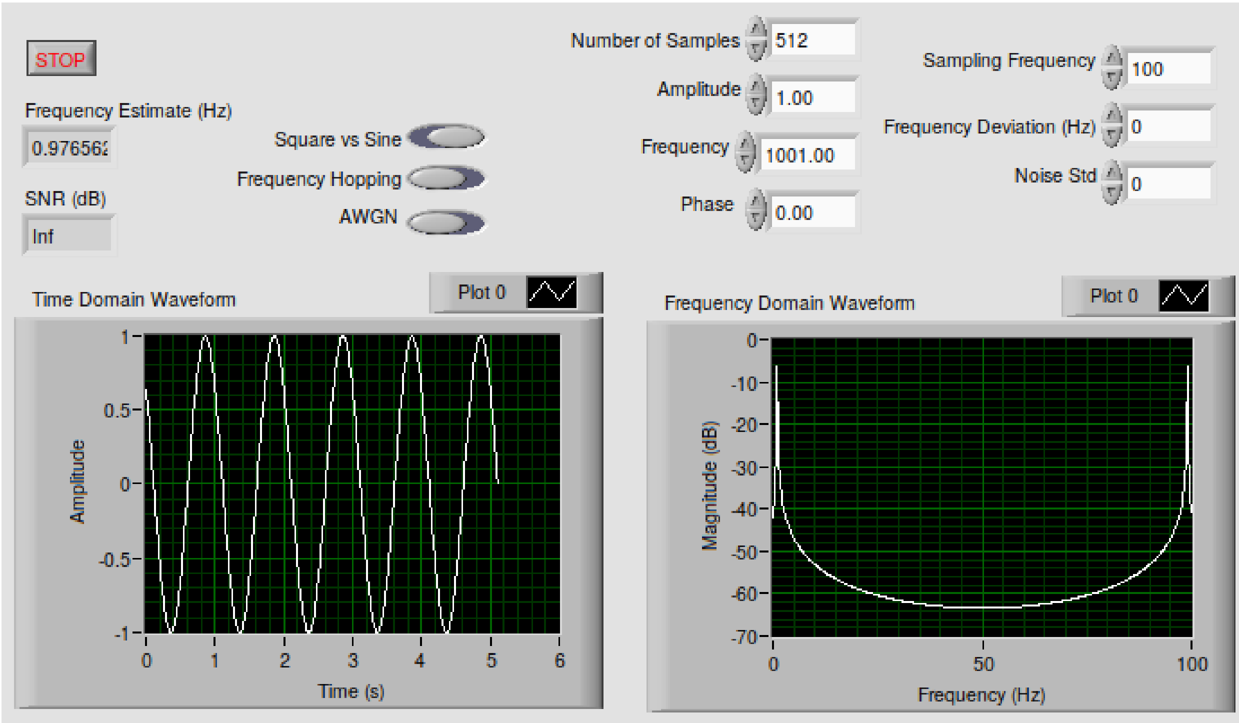

Figure 13: Sine wave at 1001 Hz with a sampling rate 100Hz and its frequency spectrum

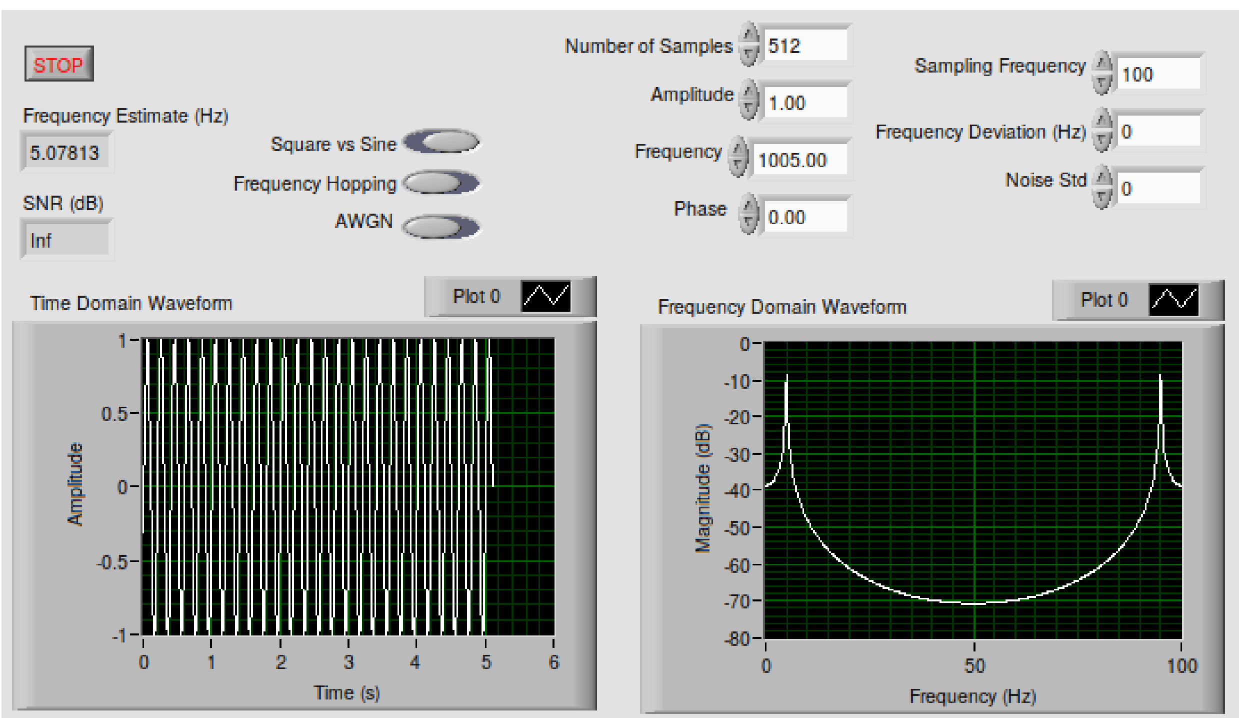

Figure 14: Sine wave at 1005 Hz with a sampling rate 100Hz and its frequency spectrum

10. Set the amplitude to 1, number of samples to 512, phase to 0, and frequency to 500 Hz of the wave generator. Choose the sampling frequency 25 kHz. **Note the estimated frequency**. Now increase the number of samples by powers of two, i.e., 1024, 2048, 4096. **Note the estimated frequencies**. **Comment** on the results.

Table 1: Estimated frequencies for increasing number of samples

Number of Samples	512	1024	2048	4096
Estimated Frequency (Hz)	488.281	488.281	500.488	500.488

For number of sample values 512, 1024, 2048, 4096 each frequency bin corresponds to 25000/512 = 48.8281 Hz , 25000/1024 = 24.4141 Hz, 25000/2048 = 12.2070 Hz, 25000/4096 = 6.1035 Hz jump respectively. We see that for the number of sample values 2048 and 4096, (488.281 + jump value) is closer to the 500 Hz.

11. Generate a sinusoid at 500 Hz. Choose the sampling frequency of 25 kHz. **Add noise** to the generated signal **by changing the noise standard deviation from 0 to 5 with an increase in 5 steps**. Note the **estimated frequency and SNR** in each case. Now increase the noise standard deviation to a value such that sinusoid frequency cannot be estimated any longer. **Note this value** and write it in your report. **Comment** on the results.

Table 2: Estimated frequencies and SNRs for increasing noise standard deviation

Noise Standard Deviation	0	1.25	2.5	3.75	5
Estimated Frequency (Hz)	488.281	488.281	488.281	488.281	8349.61
SNR	Inf	-4.9485	-10.9691	-14.4909	-16.9897

We observed that when the noise standard deviation value exceeds 3.8, the frequency estimation becomes false. We write the value in a random instance to Table 2 as the value oscillates randomly in the plot.

12. Set the amplitude to 1, number of samples to 512, phase to 0, frequency to 500 Hz, and sampling frequency to 44100 Hz. Choose sine or square as true. Hear the signal. **What** do you hear? Change the frequency to 3000 Hz by 500 Hz steps. **Comment** on the changes.

When we increase the frequency of the sine wave, the pitch of the sound gets higher and higher as expected.

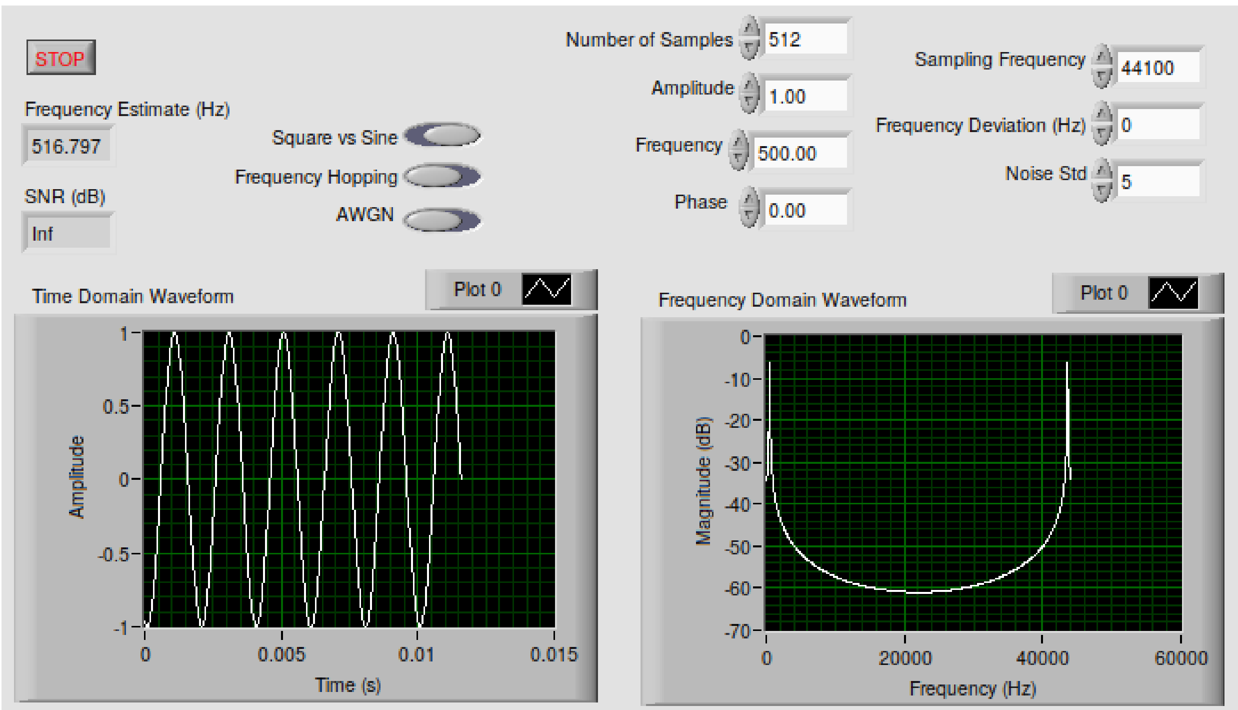

Figure 15: Time and frequency domain waveforms of sine wave for testing increase in frequency

13. Now, choose sine or square as false, such that a square wave is generated. Repeat the 12. **Compare** your findings with 12 as well. **What is the difference between sine and square wave sounds?**

The square wave has especially a more splendid and harsher tone contrasted with the sine wave which is extremely smooth. Where a sine wave just has one frequency component, its fundamental, the square wave has the fundamental and harmonics at all odd-number multiples of the fundamental. So as the frequency increases the harmonics of the square wave become inaudible leaving only the fundamental. So at a high enough frequency it sounds exactly the same as a sine wave.

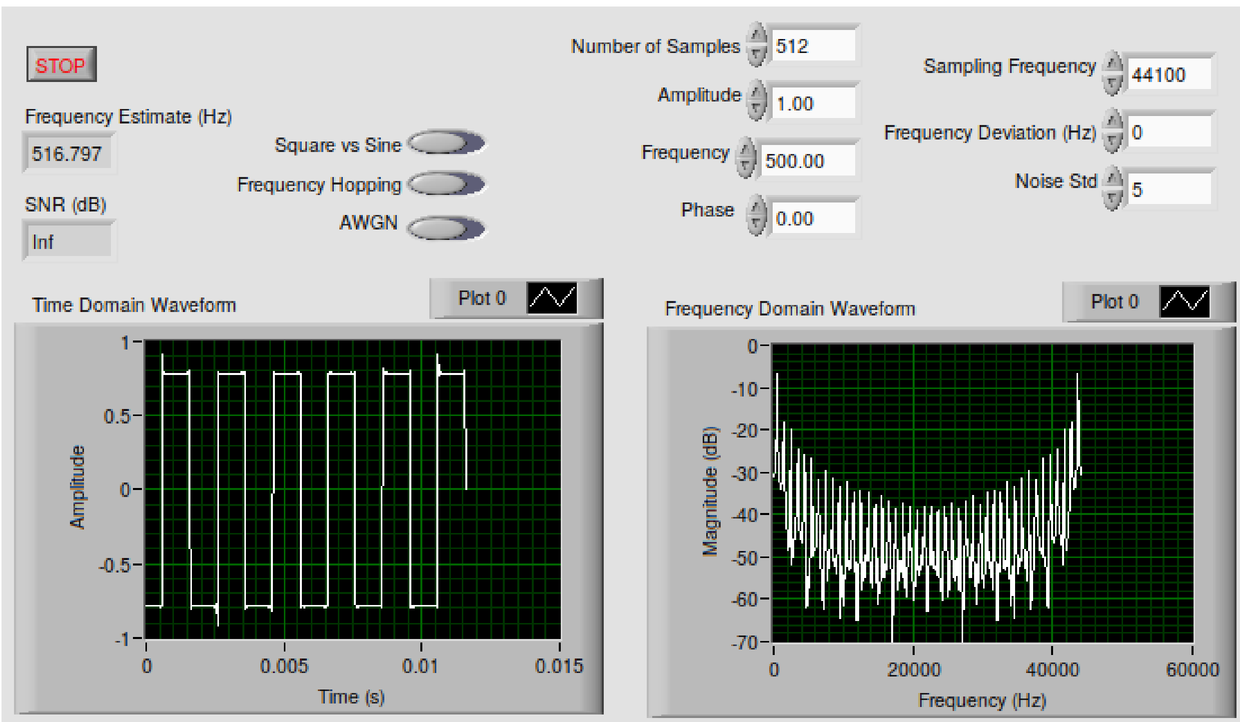

Figure 16: Time and frequency domain waveforms of square wave for testing increase in frequency

14. Set the amplitude to 1, number of samples to 512, sine or square to true, phase to 0, frequency to 500 Hz, and sampling frequency to 44100 Hz. Now **change the sampling frequency of the sound output configure to 22050 and 88200** Hz. **What** do you hear? **What** is the reason? **Comment** on the results.

When we hear the sounds for 22050 Hz, at frequency 500 Hz, we see that sound has a lower pitch, i.e. the frequency we hear decreases. Also, when the sampling frequency for the audio is 88200, pitch of the sound gets higher, i.e. the frequency we hear increases. The reason for this phenomenon is that we keep our sample count and sampling frequency constant, so, when the audio input gets 512 samples with difference frequency, the time window of 512 samples, changes according to the sampling rate of the generator, therefore, the frequency of the wave changes as we change the sampling rate, by keeping sample number constant. For example, for 22050 Hz, time window widens therefore, periods per second decreases and eventually frequency we hear decreases at the audio output.