MÜHENDİSLİK FAKÜLTESİ
FACULTY OF ENGINEERING
ELEKTRİK-ELEKTRONİK MÜHENDİSLİĞİ BÖLÜMÜ
DEPARTMENT OF ELECTRICAL AND
ELECTRONICS ENGINEERING

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

DUMLUPINAR BULVARI 06800
ÇANKAYA ANKARA/TURKEY
T: +90 312 210 23 02
F: +90 312 210 23 04
ee@metu.edu.tr
www.eee.metu.edu.tr

EXPERIMENT 3. SIGNAL GENERATION, FILTERING, CROSS CORRELATION, A/D, D/A, DMA

PART 2

LABORATORY REPORT

Student 1:Süleyman Emre CAN-2093524
Student 2:Yekta Demirci-2093607

Task 2

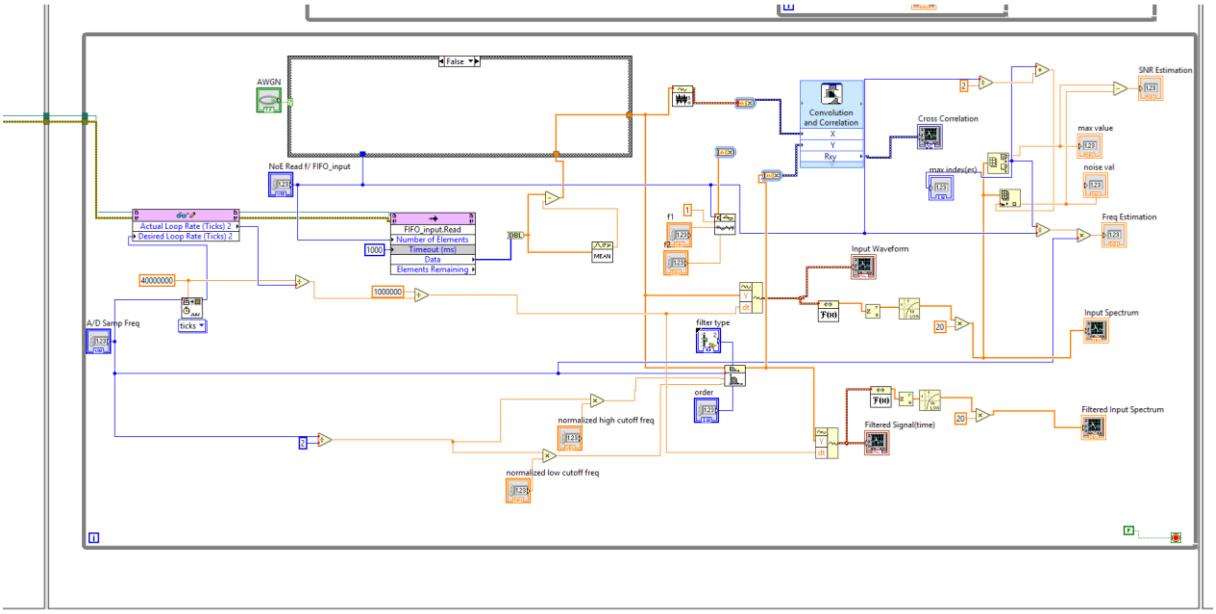

Fig 0.a: Screenshot of the constructed diagram on the CPU

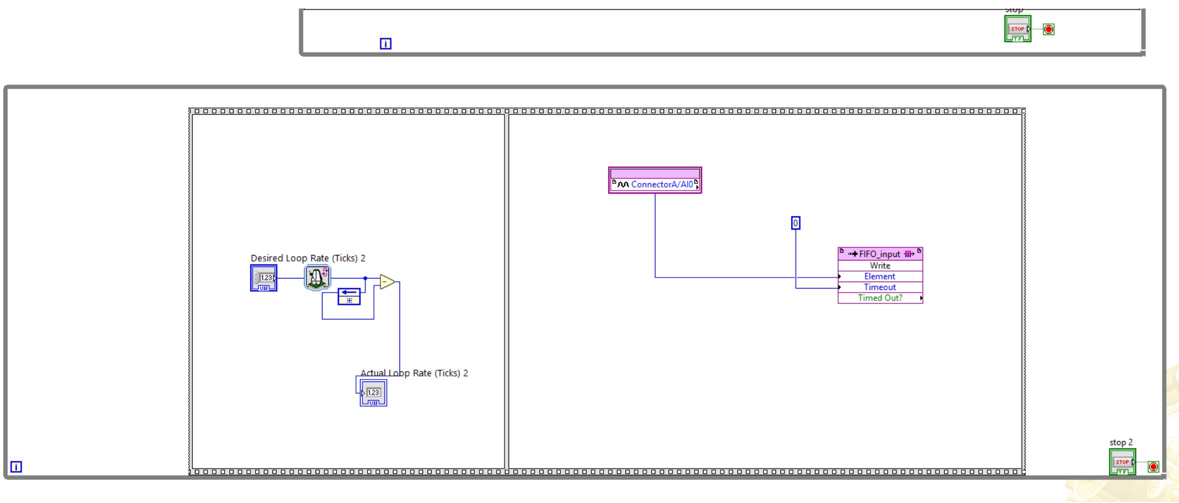

Fig 0.b: Screenshot of the constructed diagram on the FPGA

1. Generate a **sinusoid at 1000 Hz frequency** and **select the sampling rate as f_{s1}=16kHz for the D/A converter**. Note that **AWGN** button is **off**. **Estimate the frequency for the received signal after A/D converter while the sampling rate for A/D is selected as f_{s2}=16kHz.** Increase and decrease **fs1** to **32kHz and 8kHz** respectively and note the **estimated frequency** of the received signal. Now select **f_{s1}=16kHz** and change **f_{s2} to 32kHz and 8 kHz** respectively. **Write the estimated frequency each case.**

   Since the created sinusoidal is 1k Hertz. Either 8k or 32k Hertz are above the Nyquist rate. Therefore, changing either D/A or A/D sampling rates didn't change the estimated frequency. We have obtained 1k in all cases.

2. Select **f_{s1}= f_{s2}=16kHz**. Generate a **sinusoid at 1kHz**. **Add noise** to the generated signal by changing the **noise standard deviation from 0 to 1000 with an increase in 5 steps**. Note the **estimated frequency and SNR at 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 in your report.

Noise Std Dev	Frequency Estimation(Hz)	SNR Estimation(dB)
0	1000	61.3
200	1000	37
400	1000	28
600	1000	20
800	1000	16
1000	1000	10
2400	N/A	3

As Std Dev increases, noise power increases. As a result, SNR value decreases. After some noise, the max value is not stable therefore we cannot estimate a frequency.

3. Continue **from 2** but select **noise standard deviation as 5**. Observe the **cross correlation of the input with the chirp**. Select the chirp **f1 and f2 frequencies as 0.01 and 0.4. Increase the value of f1 in 0.1 steps until 0.4. Comment on the changes in cross correlation. Attach** all the cross correlation plots.

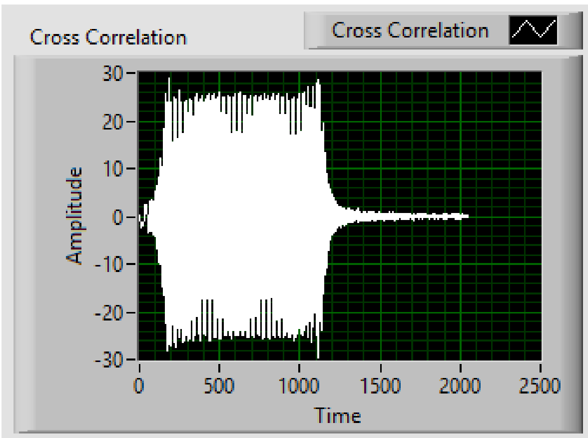

Fig 1: Cross correlation when f1 is 0.01

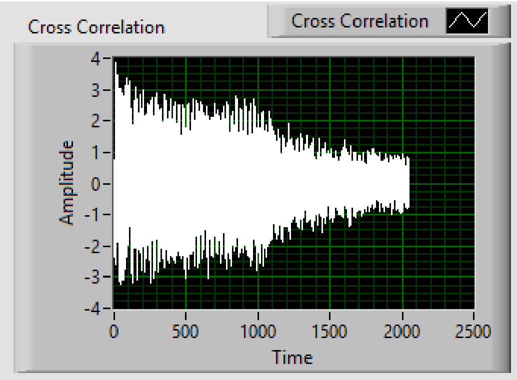

Fig 2: Cross correlation when f1 is 0.11

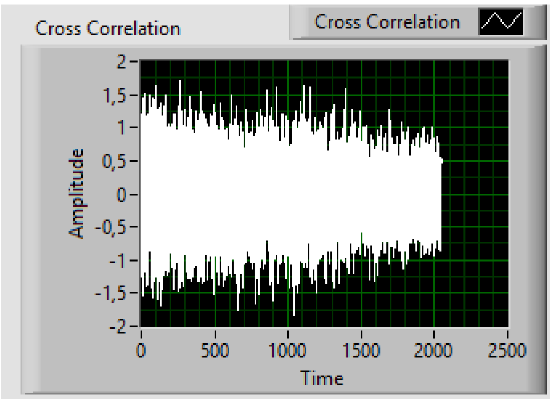

Fig 3: Cross correlation when f1 is 0.21

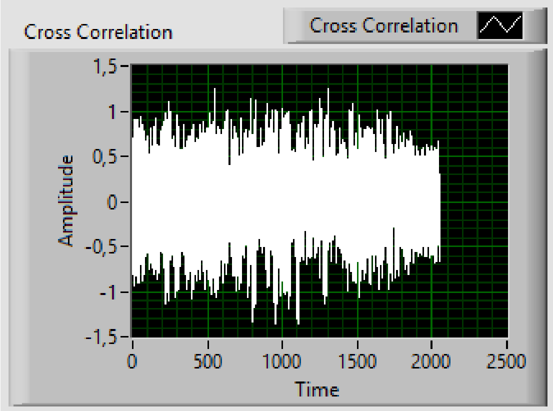

Fig 4: Cross correlation when f1 is 0.31

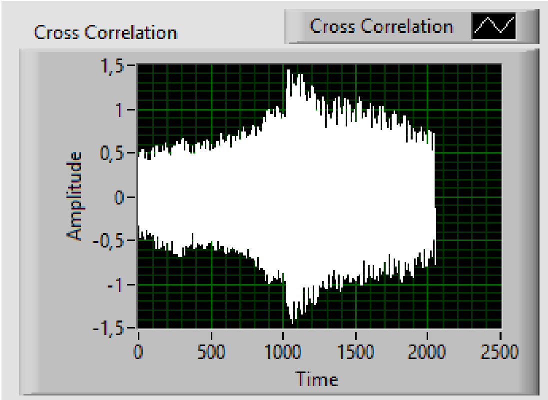

Fig 5: Cross correlation when f1 is 0.4

The sampling frequency is 16k. The input signal is 1k. When 1k is normalized with 16k, normalized value is 0.0625. When the chirp is between 0.01 and 0.4 this interval covers 0.0625 therefore we observe a high value at the cross correlation like 30. As we increase f1, the new interval does not cover 0.0625 value therefore the output of correlator goes down to low values like 2. Because there is no similar frequency between cross correlated signals.

4. **Repeat 2 using frequency hopping mode** where the **frequency deviation** is set as **50Hz**.

Noise Std Dev	Frequency Estimation(Hz)	SNR Estimation(dB)
0	1025	60
200	1026	35
400	1030	24
600	1021	18
800	1035	14
1000	1022	13
2000	N/A	4

The problem here is not directly related with noise. Even though the noise std deviation is low we cannot exactly estimate the true frequency. Because the sinusoidal has a hopping on its pure form. Therefore, the exact 1000 Hertz cannot be observed. As the Noise Std Dev increases SNR decreases as expected. Since the sine already hops itself, it gets unnoticeable faster than the pure sine. In the previous case we could see estimation frequency while Noise Std Dev. was around 2300, however in this case due to hopping it is lost around 2000 Std Dev.

5. Generate a **square wave** with a **period** of **T=0.5ms**. Set **noise standard deviation** to **0**. Choose the **sampling rate as 16 kHz for the A/D converter**. Choose the **normalized low and high cutoff frequencies of Butterworth filter** as **0.2 and 0.4** respectively. **Plot** the **input and filtered signal waveforms** both **in time and in frequency**. Determine **the main spectrum width** for the square wave and **its relation to the period, T**. You can change the period to see its effect on the frequency spectrum. **Decrease T by 2 and increase it by 2** to identify the **time-frequency relation**. **Plot** the **input and filtered signal waveforms** both **in time and in frequency** for both cases. **Comment on** the results.

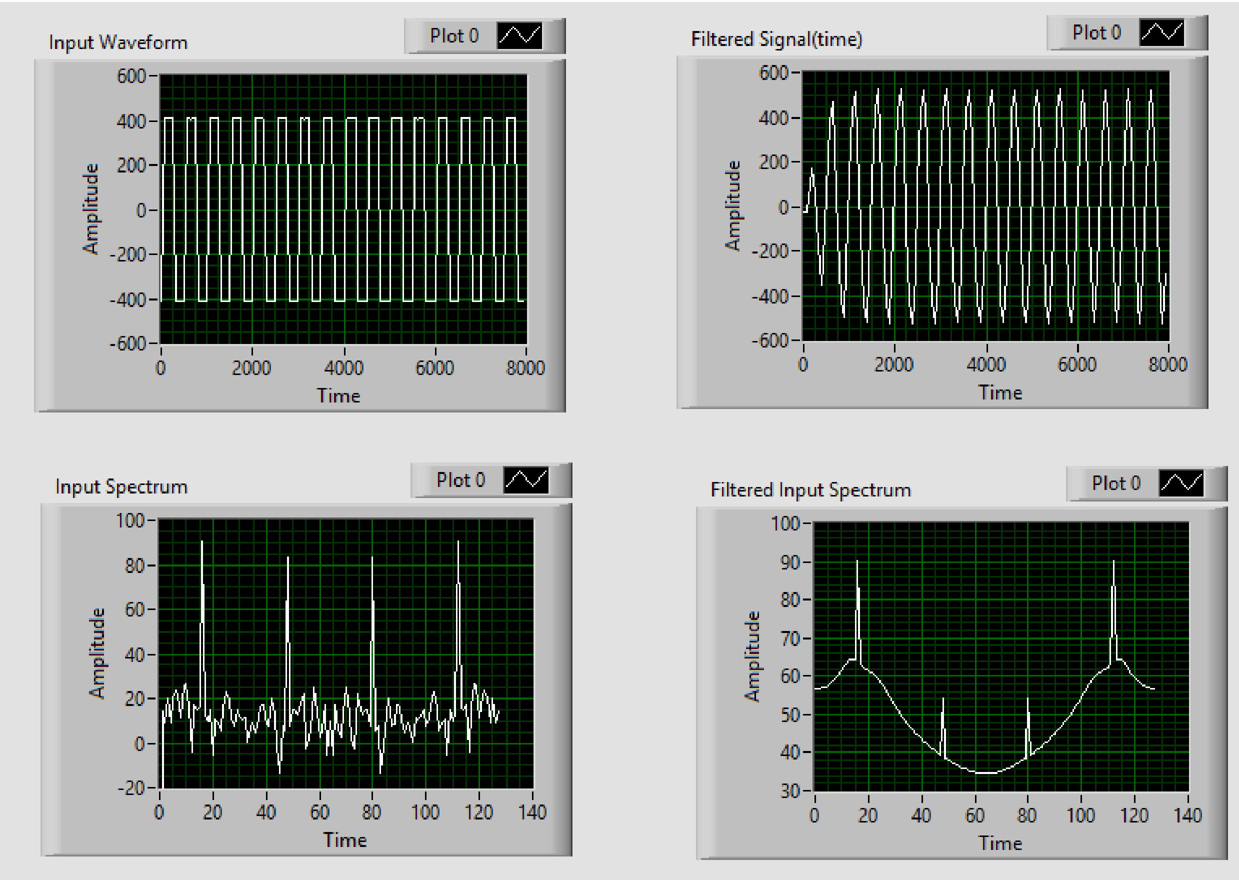

Fig 6: When the square wave is generated with 2k Hz.

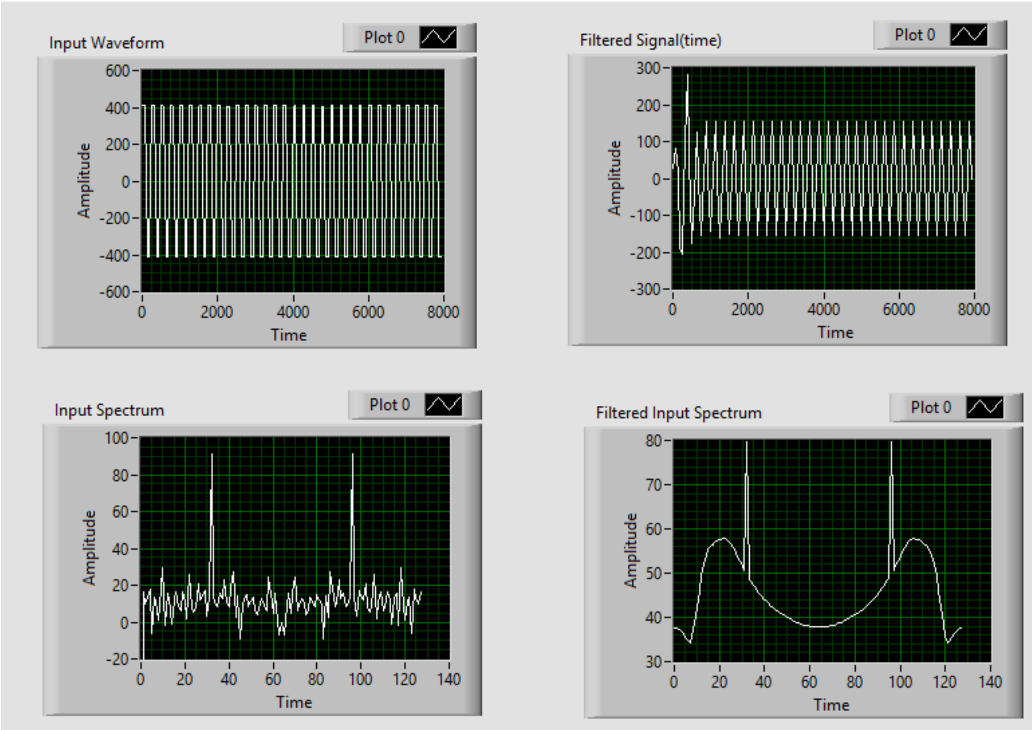

Fig 7: When the square wave is generated with 4k Hz.

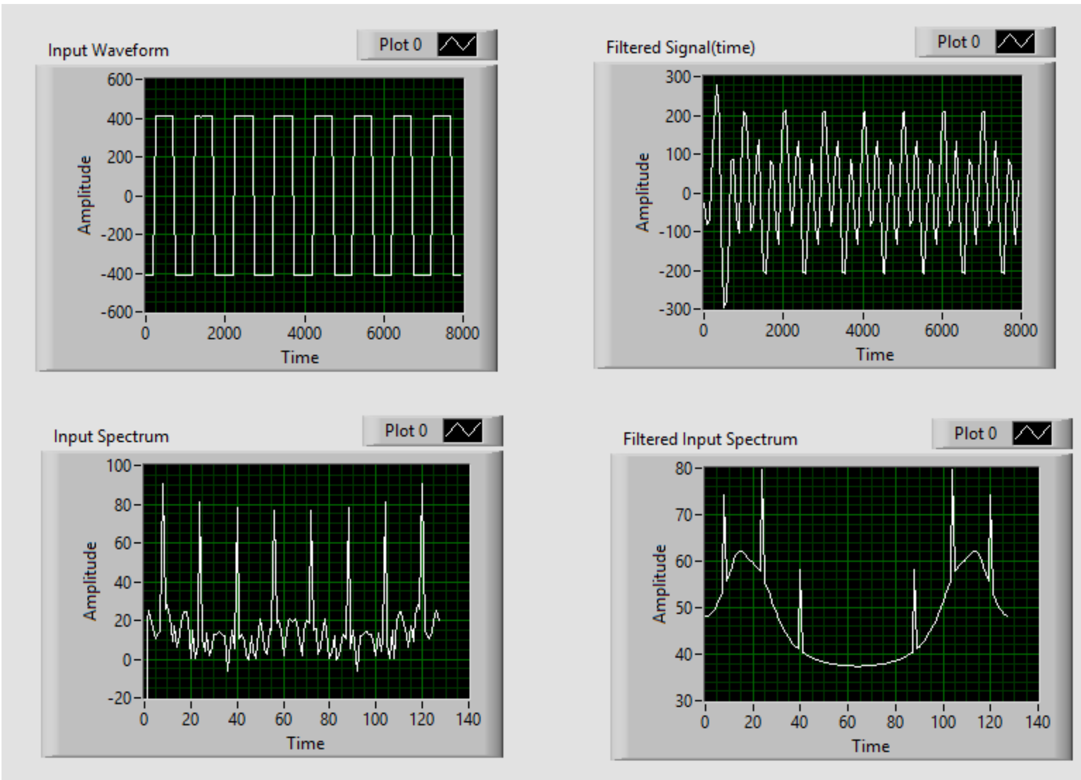

Fig 8: When the square wave is generated with 1k Hz.

The square wave has odd harmonics. When 2k is used 2 harmonics fall into the spectrum. When band pass is used it stops the second harmonic. When it is looked to fig 6 it seems like both harmonics have passed. However, the magnitude of the second harmonic is very low.

When 4k Hz square is used, there is already only 1 harmonic appears in the spectrum due to fs values. After filter only this harmonic can pass.

In the case of 1k Hz square, 4 harmonics fall into the spectrum. Only first two harmonics can pass. It seems like 4 harmonics have passed in figure 8 however the last two harmonics have very low value.

6. Set the frequency of the square wave to **3200 Hz**. **Plot the cross-correlation function** between **the input** and the **filtered output for the following cases**.

- **i.** **Normalized low and high cutoff frequencies of Butterworth filter** are **0.2 and 0.4** respectively.
- **ii.** **Normalized low and high cutoff frequencies of Butterworth filter** are **0.3 and 0.5** respectively.
- **iii.** **Normalized low and high cutoff frequencies of Butterworth filter** are **0.4 and 0.6** respectively.
- **iv.** **Normalized low and high cutoff frequencies of Butterworth filter** are **0.5 and 0.7** respectively.

Comment on the results.

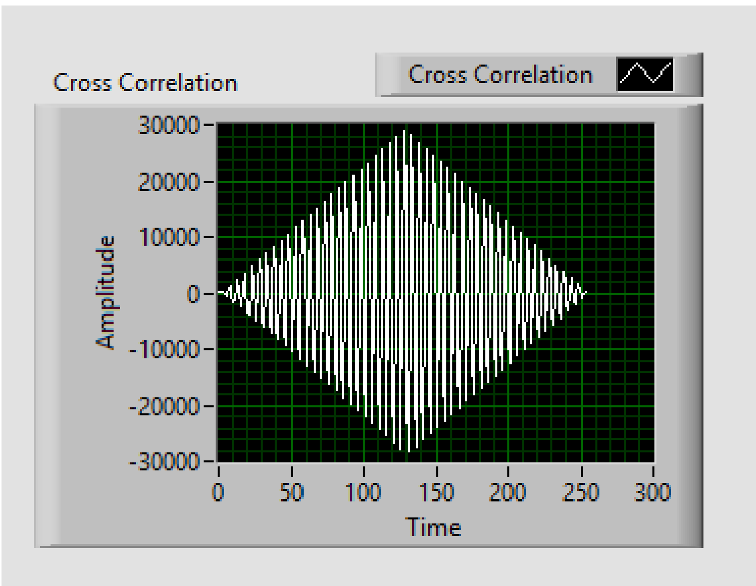

Fig 9: Cross-correlation output when filter values are 0.2-0.4

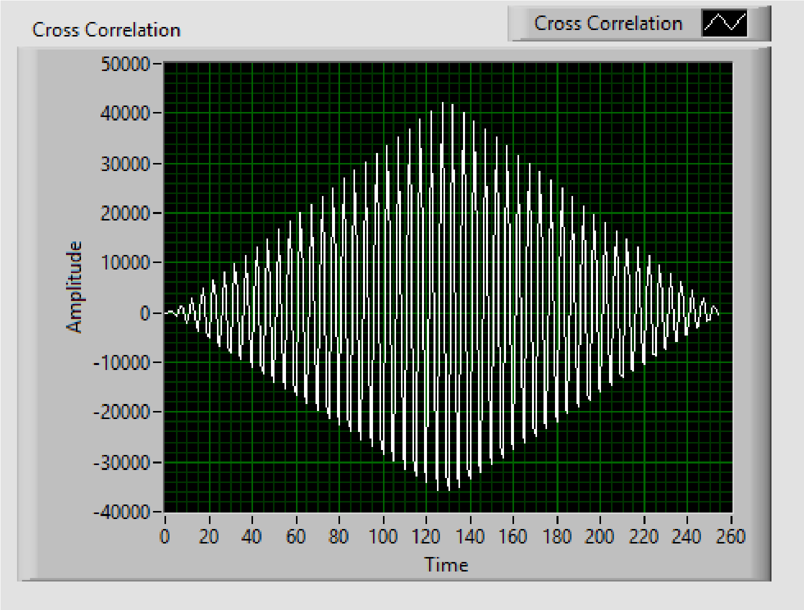

Fig 9: Cross-correlation output when filter values are 0.3-0.5

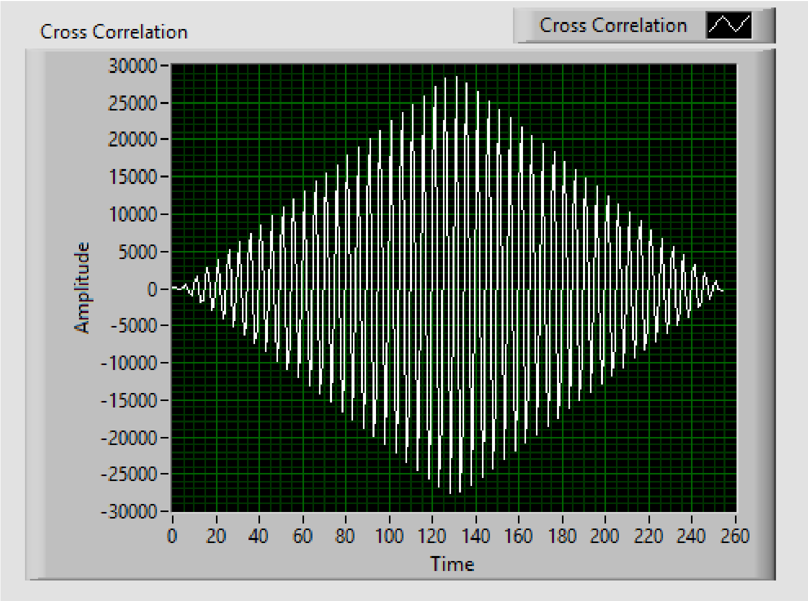

Fig 10: Cross-correlation output when filter values are 0.4-0.6

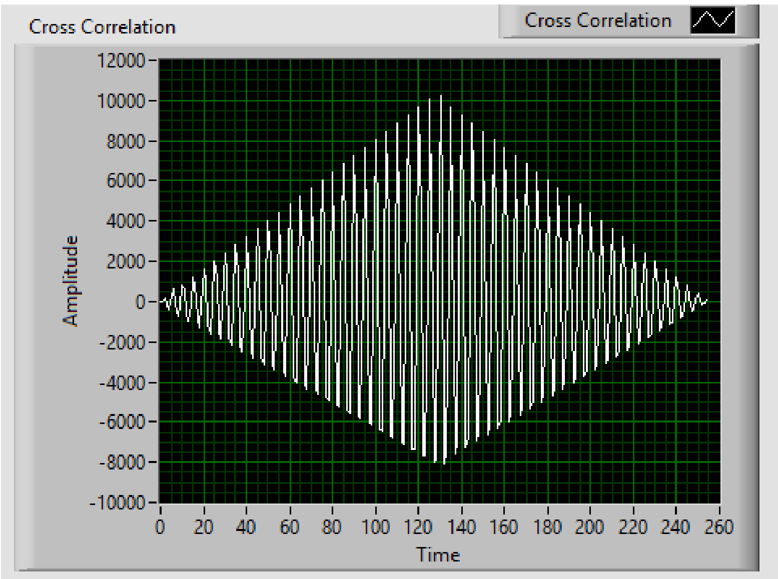

Fig 11: Cross-correlation output when filter values are 0.5-0.7

In all cases, normalized 1 value represents 8k for the Butterworth filter.

In the first case when the filter is adjusted to 0.2-0.4 it is the 1.6k-3.2k Hz band and there is only 1 harmonic inside the pass-band. However, the midpoint of the filter is at around 2.4kHz Therefore upper values are a little suppressed.

In the second case, 0.3-0.05 region shows 2.4k and 4k Hz band. There is also 1 harmonic. But unlike the previous case, midpoint of the filter is around 3.2; therefore, the main harmonic is not suppressed as much as the first case. Therefore, the cross correlator outputs higher values.

In the third case, it is similar to the first one. There is only 1 harmonic. However mid-point of the filter is around 3.5Hz therefore, lower parts of the square is suppressed. Therefore, the value is similar to the first one.

In the last case, there is also only 1 harmonic but it is in the suppressed region of the filter. Therefore, the result is way lower than the previous ones.

7. **(Bonus 20pts) Modulate the square wave generated in step 5 by a 6kHz sinusoid**. Select the **noise standard deviation as 1**. **Filter the resulting signal with a bandpass filter to remove noise as much as possible while keeping the signal characteristics**. **Determine the minimum bandwidth that you can use for this purpose**. **Demodulate** the signal down to baseband by **multiplying with another sinusoid** with the same frequency and **lowpass filtering** the resulting waveform. **Plot the input and demodulated signal time and frequency characteristics in the front panel.** Note that this structure is used to transmit and receive signals just like a standard communication system.