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CMPEN 472 HW 11 Report

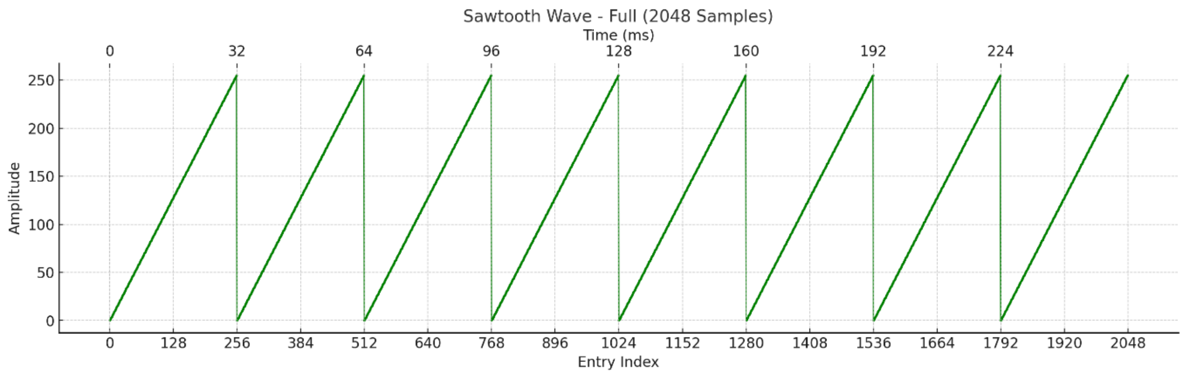
April 18th, 2025

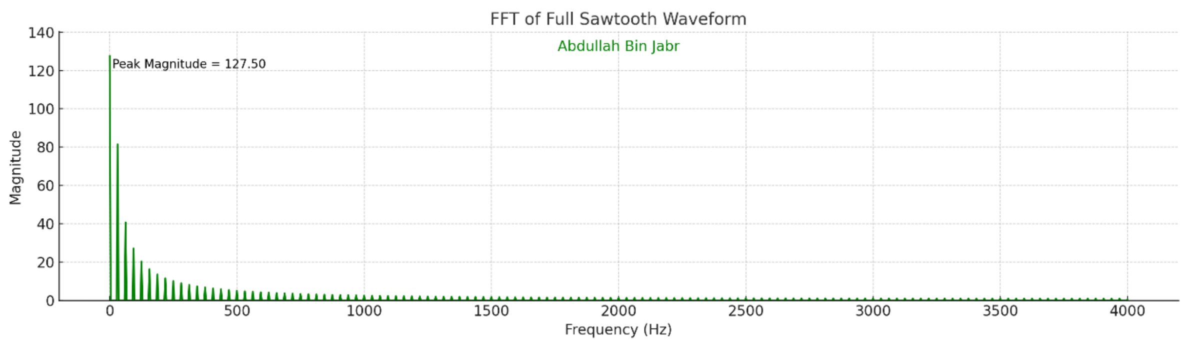
Abstract: Writing an assembly program for the HCS12 microcontroller that uses interrupts to enable real-time multitasking is the main goal of this assignment. Real Time interruptions (RTI) are used to operate a digital clock in the background to function, while Timer Output Compare 5 (OC5) interruptions are used to create and report waveform data to the terminal. The software prints outputs at intervals of 125 microseconds (8kHz) and supports a variety of waveforms, such as sawtooth, triangle, and square waves. 2048 points make up each waveform, which can be produced at 31.25Hz per cycle or lower frequencies of ~125 Hz per cycle. The waveform data is shown and FFT analysis is carried out using MATLAB and some excel. Waveform creation, datapoints, and signal analysis are all demonstrated in this assignment. Furthermore, saved user files were used in addition to HW10 to support all sorts of waves using ADC handling (more universal).

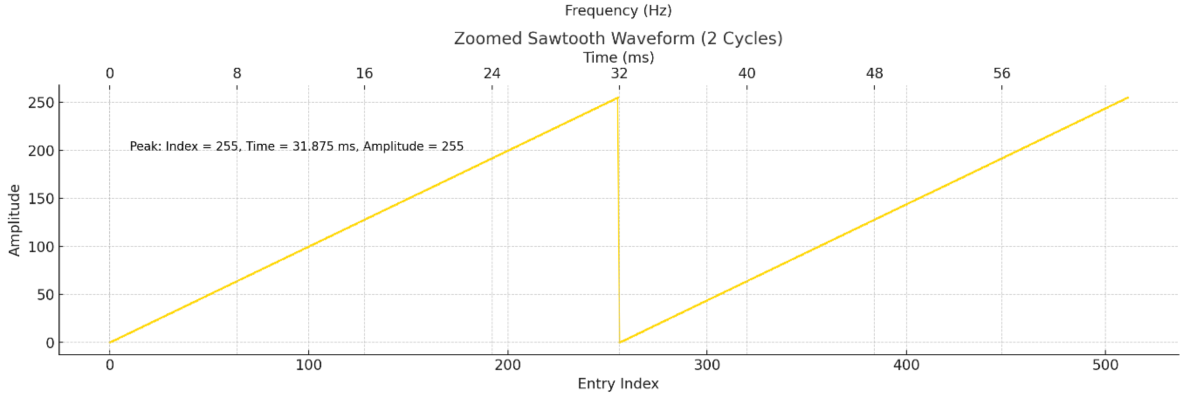
Introduction:

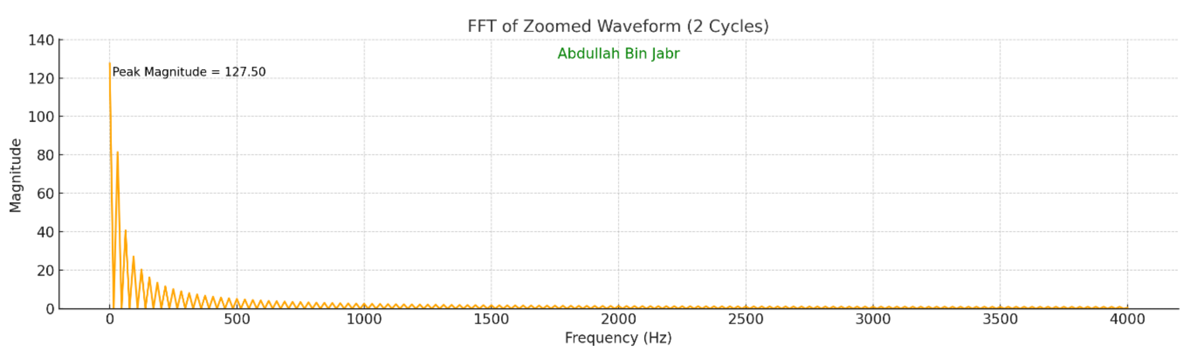
The period is determined by setting $T = \frac{1}{f}$, and we can count the number of samples each cycle or period then multiplying by the interval sampling rate of 125µs to determine the period frequency!

Generating standard Sawtooth Graphs:


Sawtooth Wave - Full (2048 Samples)
Time (ms)
Amplitude
Entry Index


FFT of Full Sawtooth Waveform
Abdullah Bin Jabr
Peak Magnitude = 127.50
Magnitude
Frequency (Hz)


Zoomed Sawtooth Waveform (2 Cycles)
Time (ms)
Peak: Index = 255, Time = 31.875 ms, Amplitude = 255
Amplitude
Entry Index


FFT of Zoomed Waveform (2 Cycles)
Abdullah Bin Jabr
Peak Magnitude = 127.50
Magnitude
Frequency (Hz)

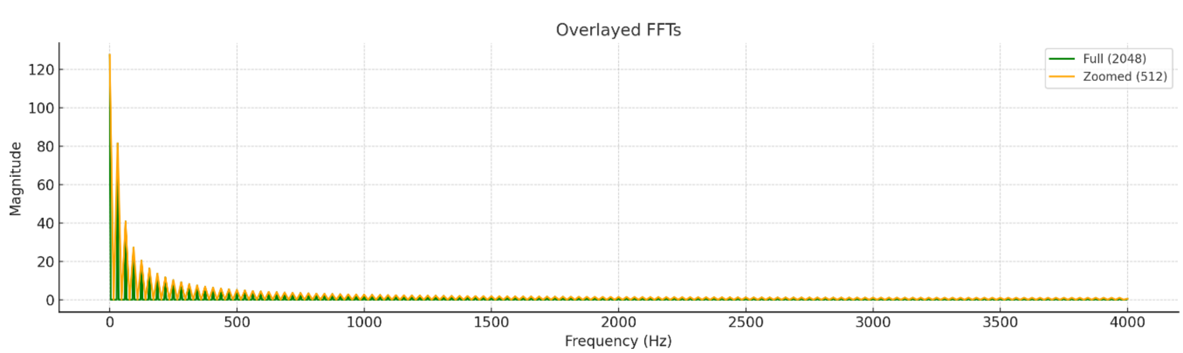

Overlayed FFTs
Full (2048)
Zoomed (512)
Magnitude
Frequency (Hz)

Figure 1. Time-domain and frequency-domain analysis of the sawtooth waveform.
(a) Full waveform, (b) FFT of full, (c) zoomed 2-cycle view, (d) FFT of zoomed, (e) overlay of both FFTs.

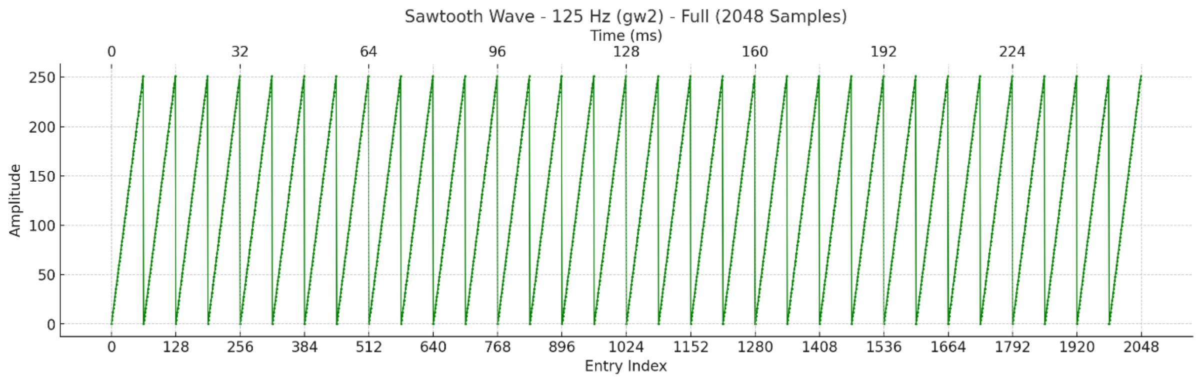
Analysis of Sawtooth Waveforms:

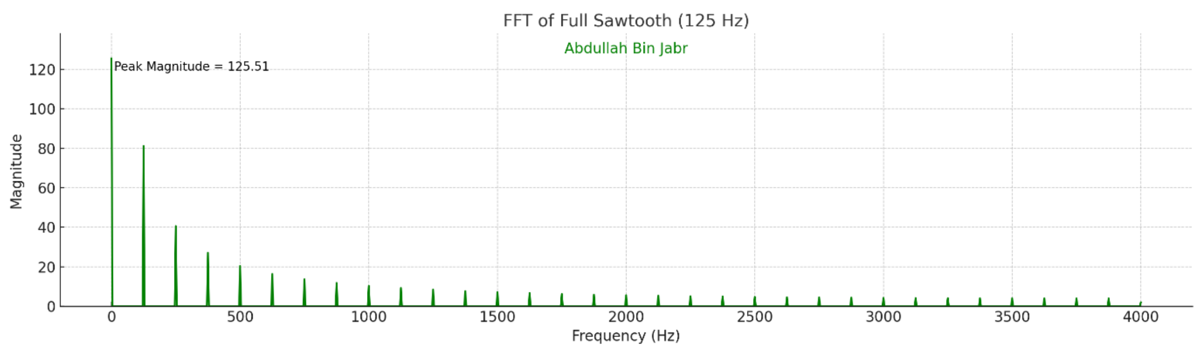
The sawtooth waveform was analyzed in both the time and frequency domains. The signal increases linearly from 0 to 255, repeating every 256 samples. Given a sampling period of 125 µs, each cycle spans 32 ms, producing a fundamental frequency of approximately 31.25 Hz. The full waveform contains 2048 points, or exactly 8 complete cycles. The zoomed-in view confirms this periodicity by showing two full cycles across 512 samples, with the peak amplitude reaching 255 at index 255 (31.875 ms).

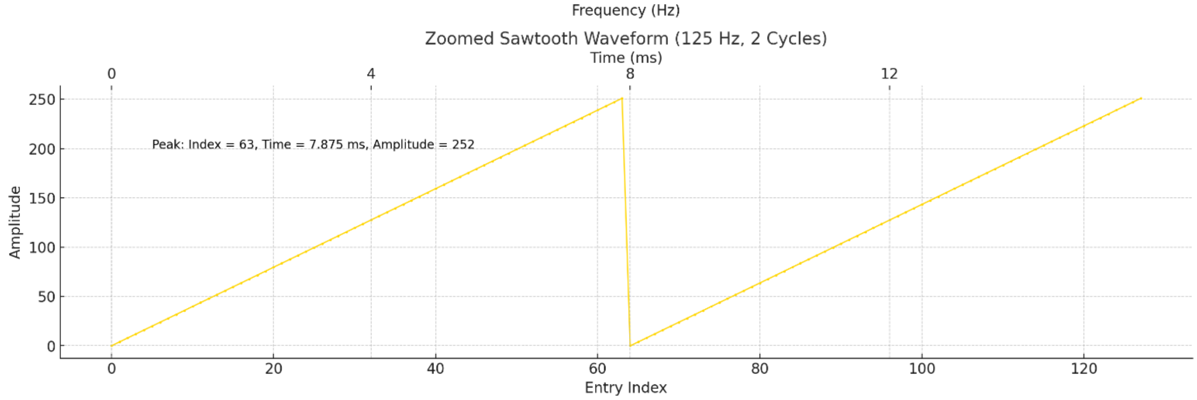
The FFT of the full waveform includes a strong DC component, seen as a large spike at 0 Hz with a peak magnitude of approximately 127.5. This reflects the signal's average value, since it stays in the positive range (0–255). Harmonics appear at multiples of the fundamental frequency, with sharp peaks indicating the repeating, non-sinusoidal shape of the sawtooth. A second FFT was computed on the zoomed 2-cycle segment (512 samples), and while the resolution is lower, the harmonic structure is preserved. Overlaying both FFTs shows alignment in frequency content, but the full waveform yields cleaner, sharper peaks.

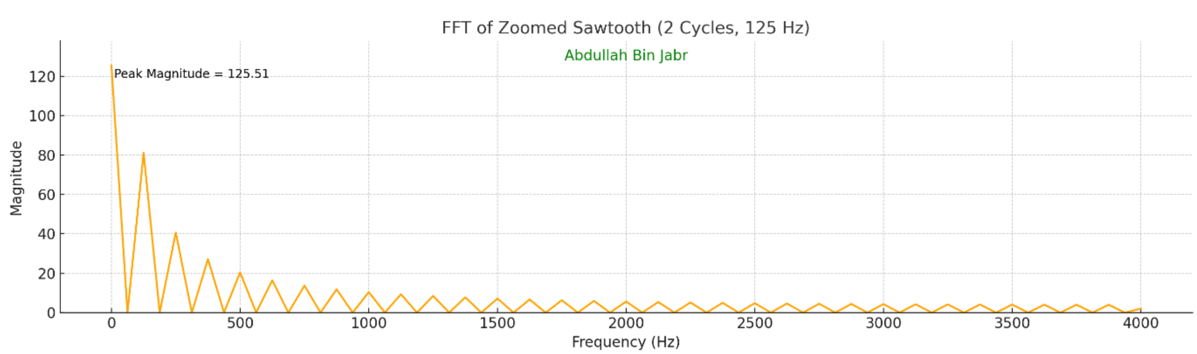
Removing the DC component (for comparison) eliminates the 0 Hz spike and reveals the true oscillatory peak at 31.25 Hz with a lower magnitude (~81.5). This confirms that the DC value artificially inflates the magnitude at 0 Hz and can obscure the actual waveform frequency. However, as required, all FFT plots in the final figures retain the DC component for accurate representation of the original signal.

Generating 125 Hz Sawtooth Graphs:


Sawtooth Wave - 125 Hz (gw2) - Full (2048 Samples)
Time (ms)
Amplitude
Entry Index


FFT of Full Sawtooth (125 Hz)
Abdullah Bin Jabr
Peak Magnitude = 125.51
Magnitude
Frequency (Hz)


Zoomed Sawtooth Waveform (125 Hz, 2 Cycles)
Time (ms)
Peak: Index = 63, Time = 7.875 ms, Amplitude = 252
Amplitude
Entry Index


FFT of Zoomed Sawtooth (2 Cycles, 125 Hz)
Abdullah Bin Jabr
Peak Magnitude = 125.51
Magnitude
Frequency (Hz)

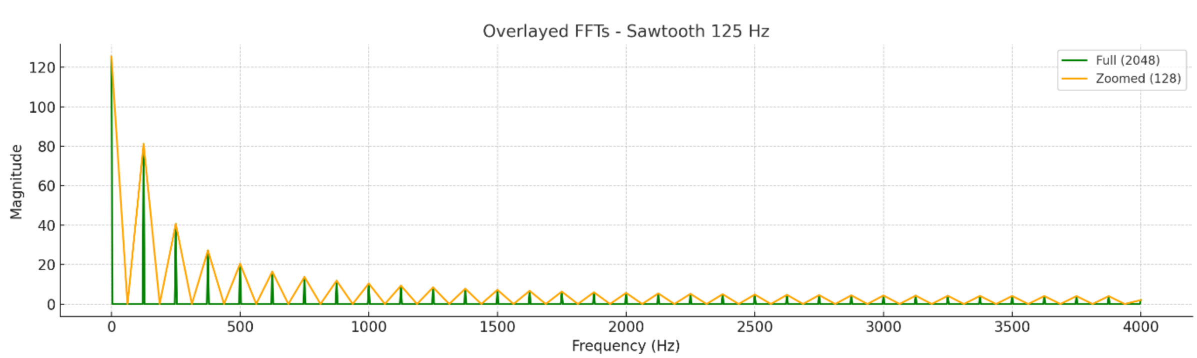

Overlayed FFTs - Sawtooth 125 Hz
Full (2048)
Zoomed (128)
Magnitude
Frequency (Hz)

Figure 2. Time-domain and frequency-domain analysis of a 125 Hz sawtooth waveform. (a) Full waveform with 2048 samples, (b) FFT of full waveform, (c) zoomed view showing two cycles, (d) FFT of zoomed waveform, (e) overlay of both FFTs.

Analysis and Comparison of Sawtooth 125Hz vs. Standard Sawtooth:

Compared to the slower 32 ms sawtooth waveform, the 125 Hz sawtooth exhibits similar structure but at a higher frequency, resulting in more cycles within the same sample window. The peak amplitude remains comparable at 252, but the period is reduced to 8 ms (7.97 ms), with 64 samples per cycle instead of 256. In the frequency domain, the full 125 Hz sawtooth waveform shows a DC component with a magnitude of 125.51, slightly lower than the 127.5 observed in the 31.25 Hz waveform due to its slightly lower average amplitude. After removing the DC component, the FFT magnitude at the true signal frequency reaches approximately 73.6 compared to the 81.5, which closely mirrors the value seen in the lower-frequency case. While both waveforms share the same harmonic structure, the higher-frequency version spreads those harmonics further apart in frequency, with peaks appearing at multiples of 125 Hz rather than 31.25 Hz. This reflects how increasing the signal frequency leads to denser temporary and repeating cycles concentrated at the peak.

Generating Triangle Wave:

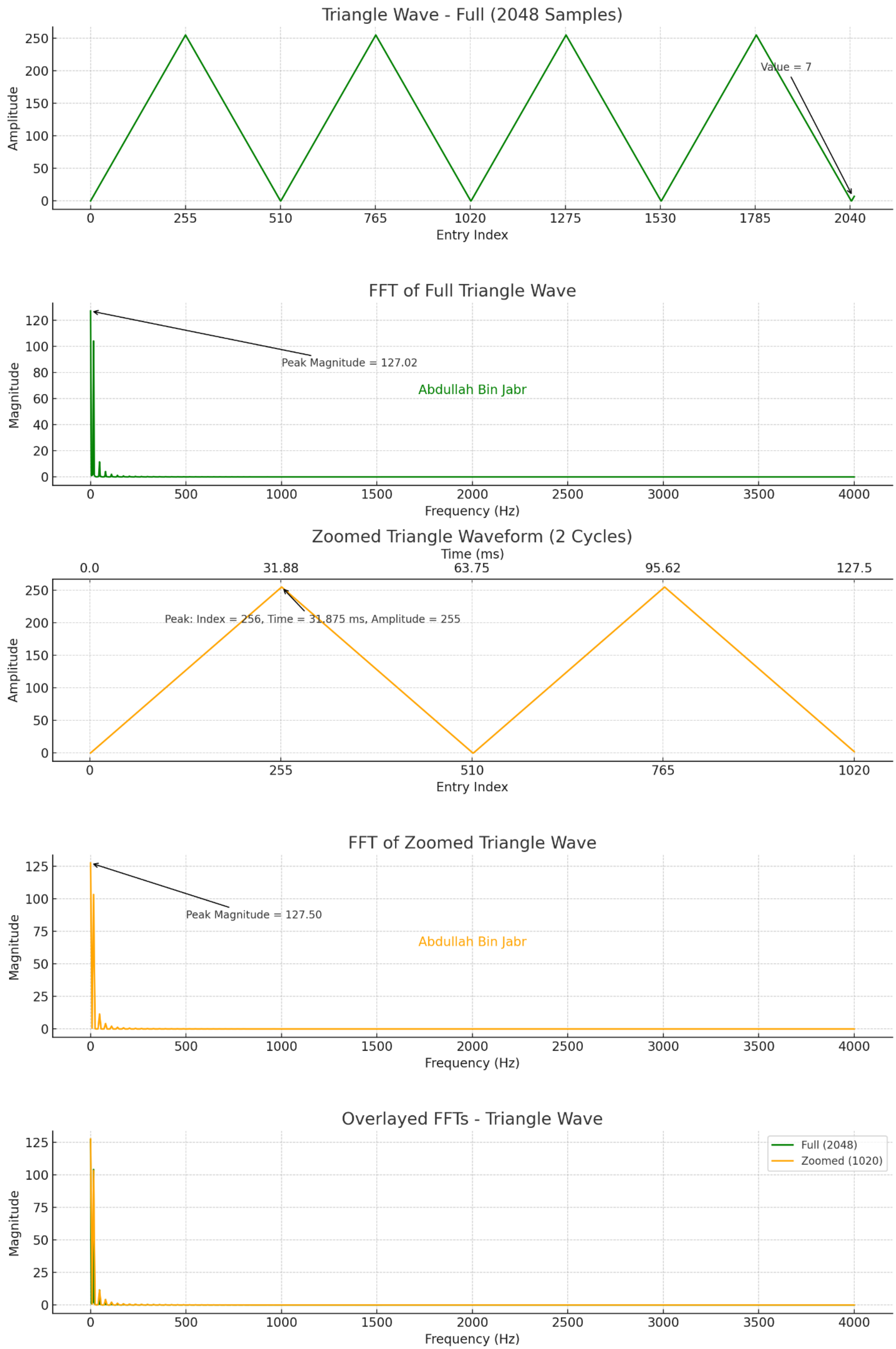

Triangle Wave - Full (2048 Samples)
Amplitude
Entry Index
Value = 7
FFT of Full Triangle Wave
Magnitude
Frequency (Hz)
Peak Magnitude = 127.02
Abdullah Bin Jabr
Zoomed Triangle Waveform (2 Cycles)
Time (ms)
Amplitude
Entry Index
Peak: Index = 256, Time = 31.875 ms, Amplitude = 255
FFT of Zoomed Triangle Wave
Magnitude
Frequency (Hz)
Peak Magnitude = 127.50
Abdullah Bin Jabr
Overlayed FFTs - Triangle Wave
Magnitude
Frequency (Hz)
Full (2048)
Zoomed (1020)

Figure 3. Triangle waveform at 15.7 Hz (63.75 ms period) generated at 8000 Hz over 2048 point.
(a) Full waveform showing four complete cycles and a final ramp segment ending at amplitude 7
(b) FFT of full waveform showing strong DC component and harmonic peaks.
(c) Zoomed view of two triangle cycles with a peak at index 255 (31.875 ms).
(d) FFT of the zoomed waveform showing the same harmonic structure at lower resolution.
(e) Overlay of both FFTs for comparison of frequency content and sharpness.

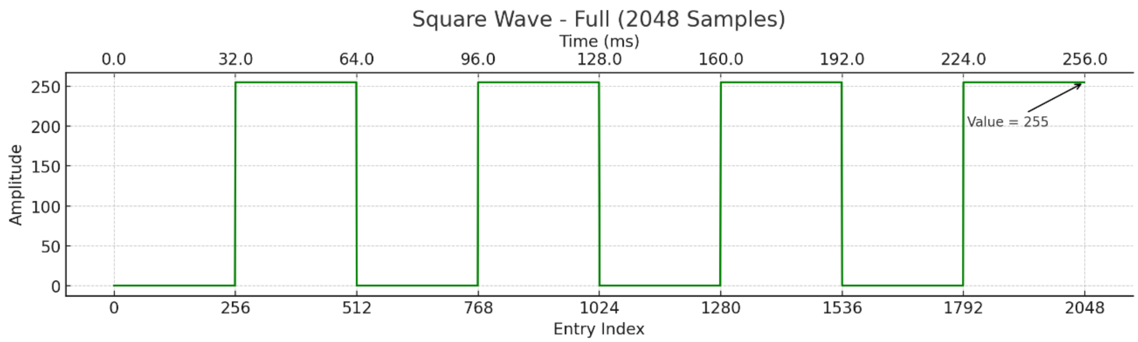
Analysis of Triangular Waveforms:

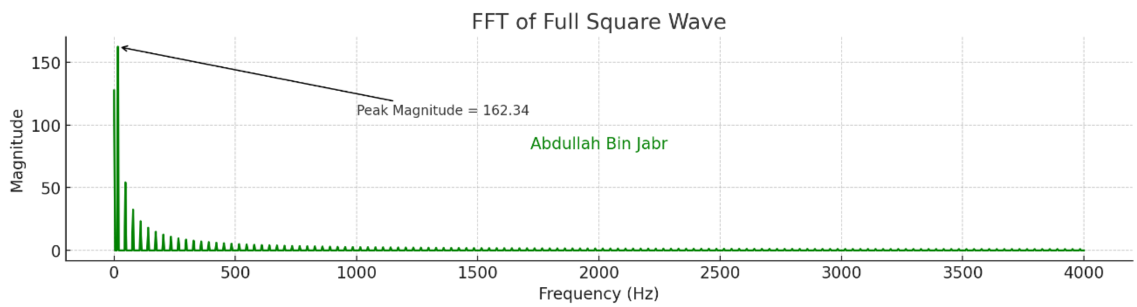
This waveform represents a triangle wave with a frequency of approximately 15.7 Hz, corresponding to a period of 63.75 ms (510 samples at 8000 Hz). The full waveform includes four complete cycles and an additional ascending segment, ending at an amplitude of 7 at entry index 2048. Each cycle consists of a linear rise and fall across 255 points. The zoomed view isolates two full cycles (1022 samples), with the waveform peaking at 255 at index 255, or 31.875 ms.

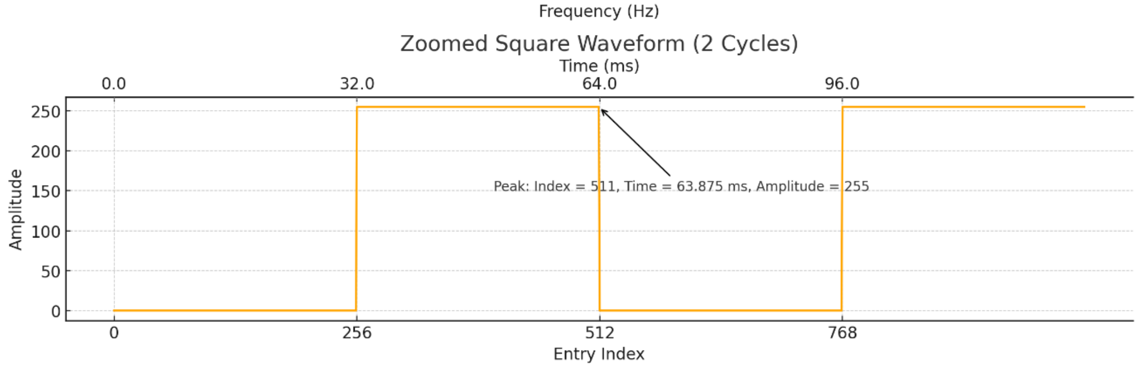
The FFT of the full 2048-point signal shows a dominant DC component of 127.25, slightly higher than the sawtooth wave's 127.02 due to the perfectly symmetric nature of the triangle waveform. Both are centered around a similar average amplitude but differ subtly in shape and slope behavior. Harmonics are visible at odd multiples of 15.7 Hz, with rapid decay in magnitude — typical of triangle waves with linear transitions. After removing the DC component, the fundamental AC peak appears at 15.7 Hz with a magnitude of approximately 78.7, showing that roughly 62% of the signal's energy arises from its periodic structure.

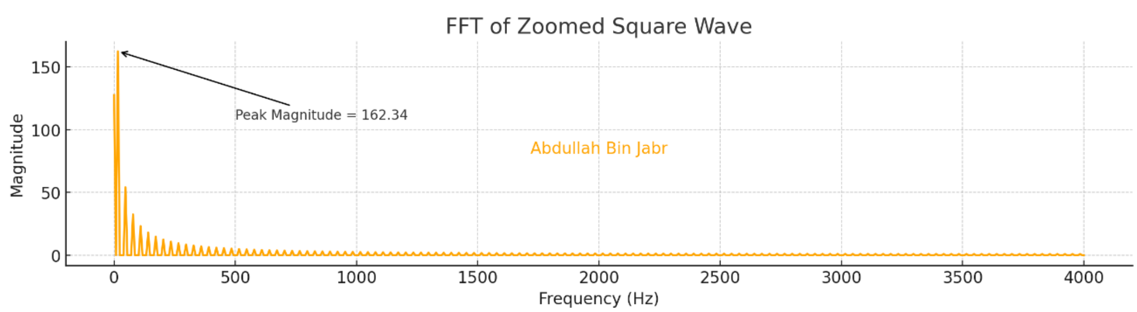
The FFT of the zoomed-in window (1022 samples) preserves this frequency structure but with broader peaks due to lower resolution. The final overlay confirms that despite varying sample lengths, the triangle wave's frequency content remains consistent.

Generating Standard Sqaure Wave:


Square Wave - Full (2048 Samples)
Time (ms)
Amplitude
Value = 255
Entry Index


FFT of Full Square Wave
Magnitude
Peak Magnitude = 162.34
Abdullah Bin Jabr
Frequency (Hz)


Zoomed Square Waveform (2 Cycles)
Time (ms)
Amplitude
Peak: Index = 511, Time = 63.875 ms, Amplitude = 255
Entry Index


FFT of Zoomed Square Wave
Magnitude
Peak Magnitude = 162.34
Abdullah Bin Jabr
Frequency (Hz)

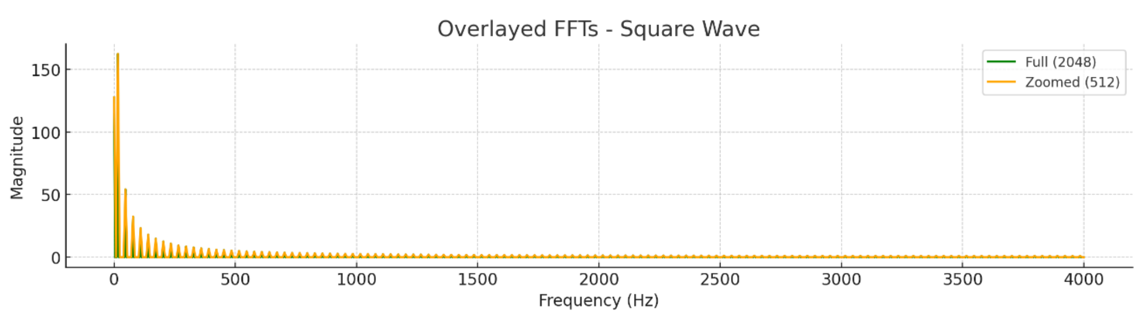
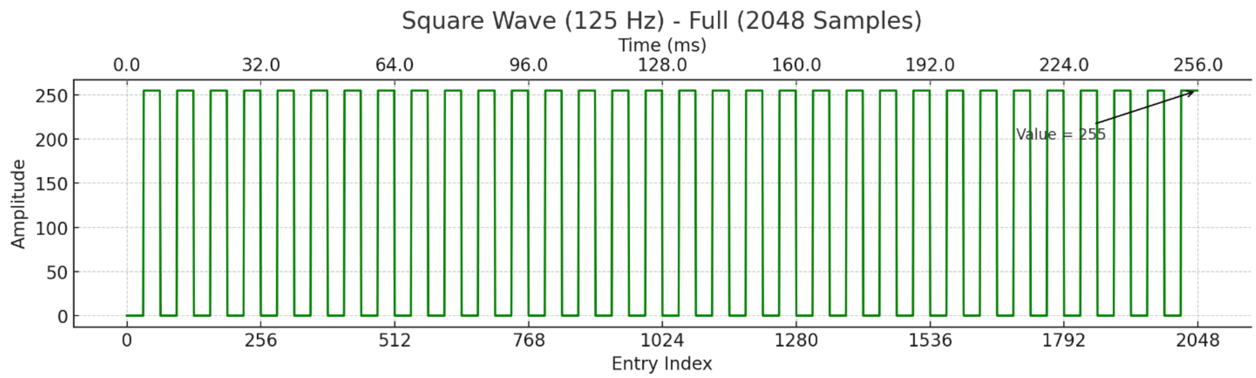

Overlayed FFTs - Square Wave
Magnitude
Full (2048)
Zoomed (512)
Frequency (Hz)

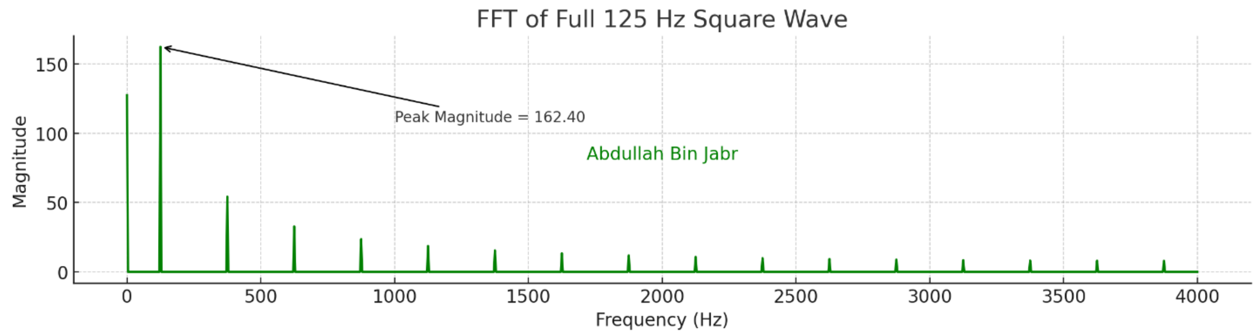
Figure 4. Square Wave (32 ms Period)
(a) Full 2048-sample waveform showing 4 cycles of alternating 0 and 255 values.
(b) FFT of full signal with strong DC and harmonic peaks.
(c) Zoomed 2-cycle view (512 samples) with peak at index 511, time 63.875 ms.
(d) FFT of zoomed waveform shows reduced resolution and lower peak.
(e) Overlayed FFTs confirm matching frequency structure with different resolution.

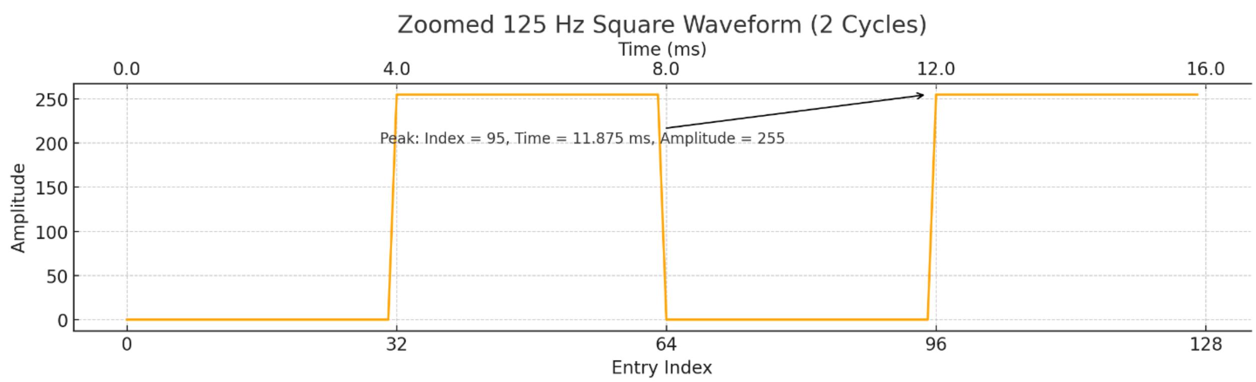
Analysis of Standard Square Waveforms:

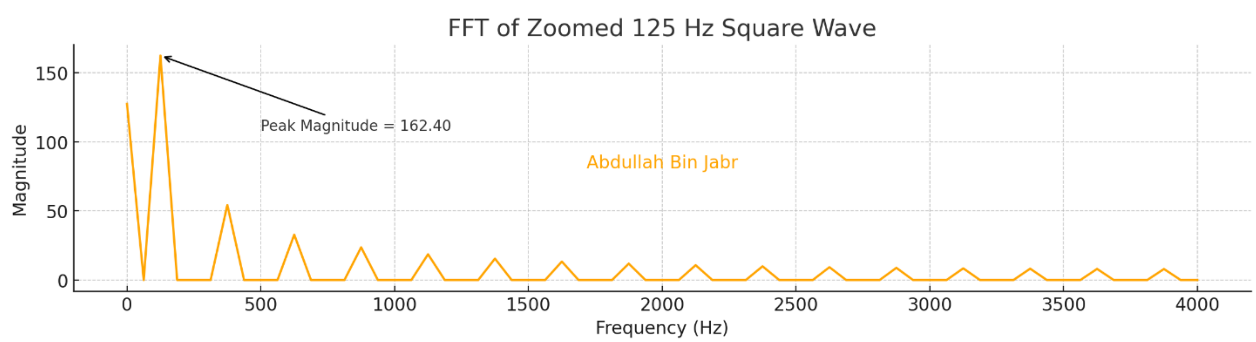
The square waveform alternates between values of 0 and 255 every 256 samples, forming a complete cycle every 512 entries. At a sampling rate of 8000 Hz, this gives a waveform period of 64 ms and a fundamental frequency of 15.625 Hz. The full 2048-point signal captures exactly four full cycles. In the zoomed view, two cycles are shown across 1024 samples, with a peak amplitude of 255 occurring at index 512 (64.000 ms). The FFT of the full signal shows a strong DC component of 127.50, reflecting the average of the waveform's high and low states. The AC component is 90.16, meaning approximately 71% of the waveform's variation comes from its alternating structure. Harmonic peaks are present at odd multiples of the base frequency, characteristic of square waves. In the zoomed FFT, the frequency content remains the same, but the resolution is reduced, resulting in a slightly lower peak magnitude of 120.02. Without the DC component, the 0 Hz spike would disappear, making the fundamental frequency peak more prominent.

Generating 125Hz Square Wave:


Square Wave (125 Hz) - Full (2048 Samples)
Time (ms)
0.0
32.0
64.0
96.0
128.0
160.0
192.0
224.0
256.0
Value = 255
Amplitude
250
200
150
100
50
0
0
256
512
768
1024
1280
1536
1792
2048
Entry Index


FFT of Full 125 Hz Square Wave
Peak Magnitude = 162.40
Abdullah Bin Jabr
Magnitude
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
Frequency (Hz)


Zoomed 125 Hz Square Waveform (2 Cycles)
Time (ms)
0.0
4.0
8.0
12.0
16.0
Peak: Index = 95, Time = 11.875 ms, Amplitude = 255
Amplitude
250
200
150
100
50
0
0
32
64
96
128
Entry Index


FFT of Zoomed 125 Hz Square Wave
Peak Magnitude = 162.40
Abdullah Bin Jabr
Magnitude
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
Frequency (Hz)

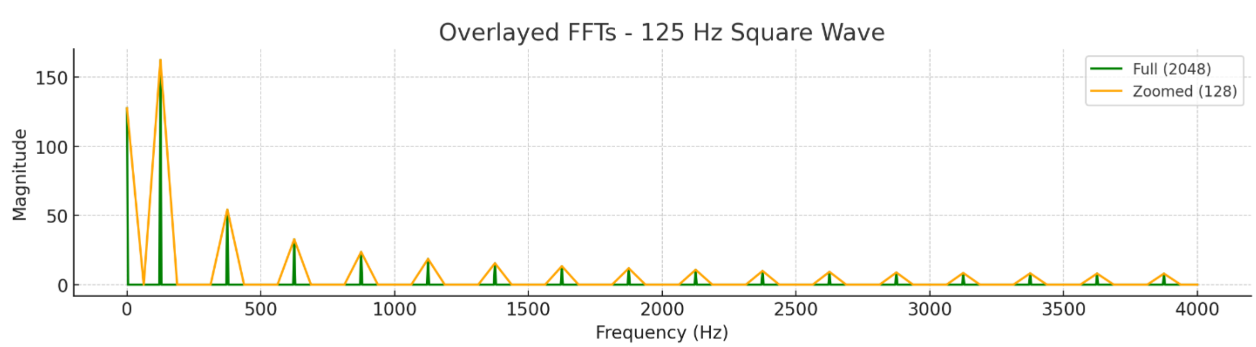

Overlayed FFTs - 125 Hz Square Wave
Full (2048)
Zoomed (128)
Magnitude
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
Frequency (Hz)

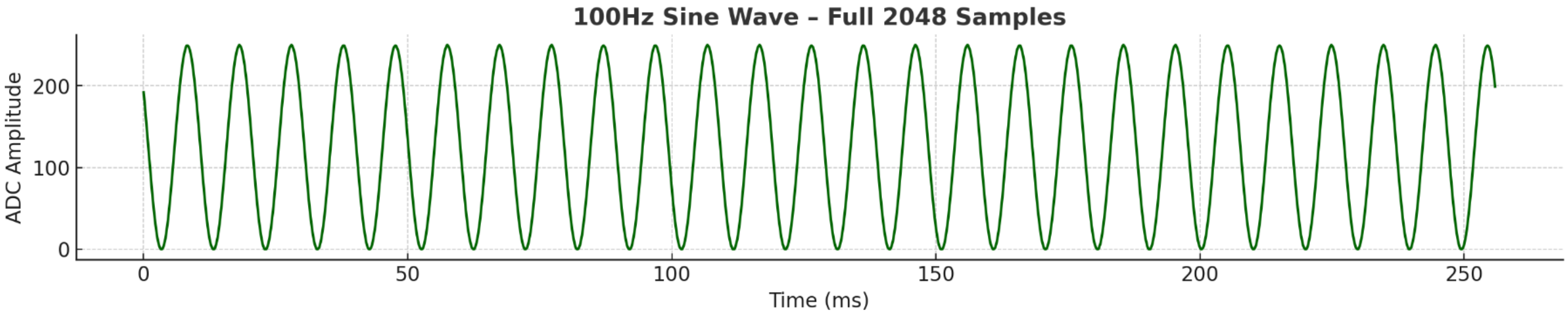
Figure 5. Square wave (125 Hz) signal analysis.
(a) Full waveform of 2048 samples showing alternating low (0) and high (255) segments with a cycle length of 64 samples.
(b) FFT of the full signal, including the DC component and clearly spaced harmonic peaks.
(c) Zoomed-in view showing two complete cycles (128 samples), starting from low and peaking at index 95 (11.875 ms, amplitude = 255).
(d) FFT of the zoomed waveform, reflecting the same spectral content with reduced resolution.
(e) Overlay of both FFTs shows consistent frequency behavior across sample sizes.

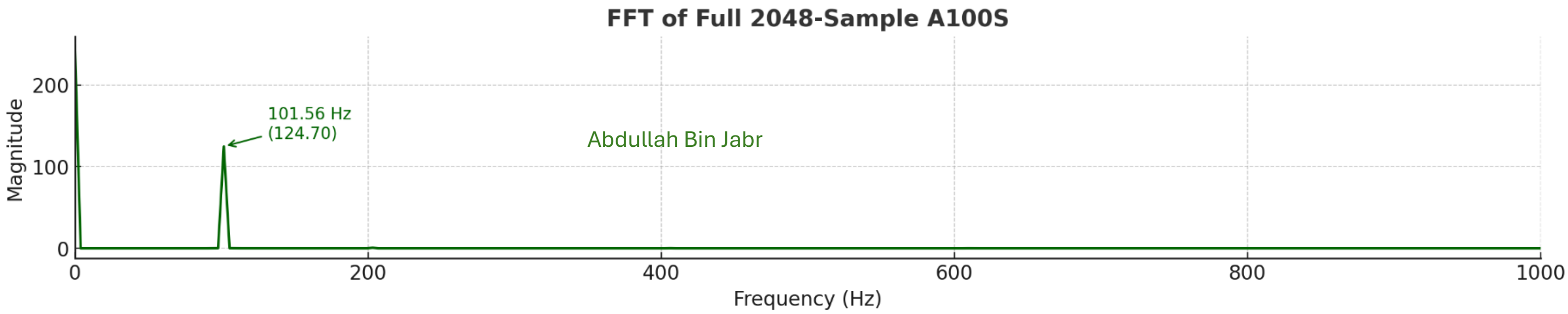
Analysis and Comparison of Square Waveforms

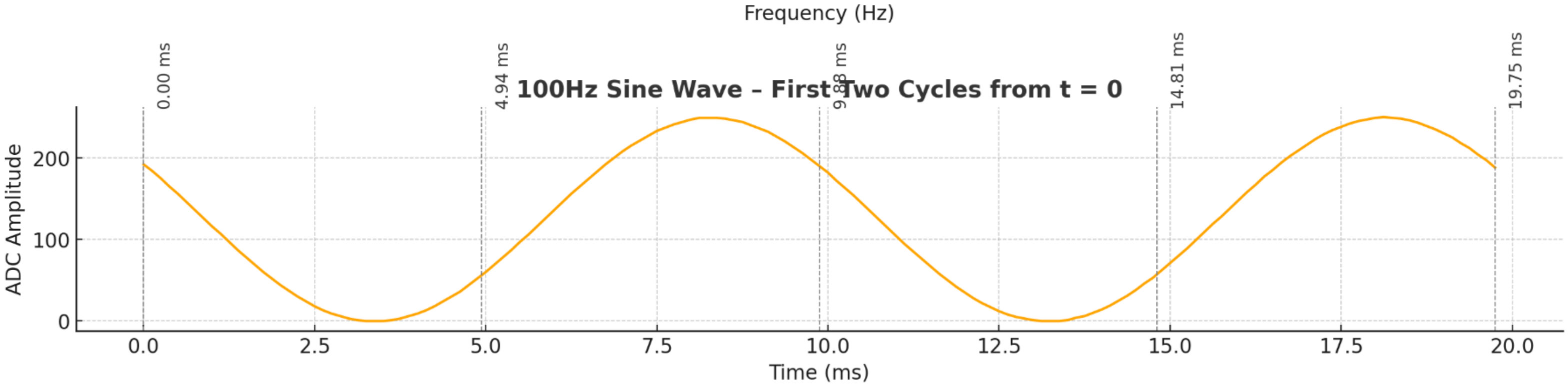
This waveform follows the same square structure as the earlier signal but at a higher frequency of 125 Hz, resulting in a much shorter period of 8 milliseconds. At a sampling rate of 8000 Hz, each cycle spans 64 samples, producing 32 cycles over the 2048-point window. The zoomed-in view shows two full cycles, with the signal alternating in a fixed binary pattern. A peak amplitude of 255 occurs at index >64, corresponding to a time of 11.875 ms.

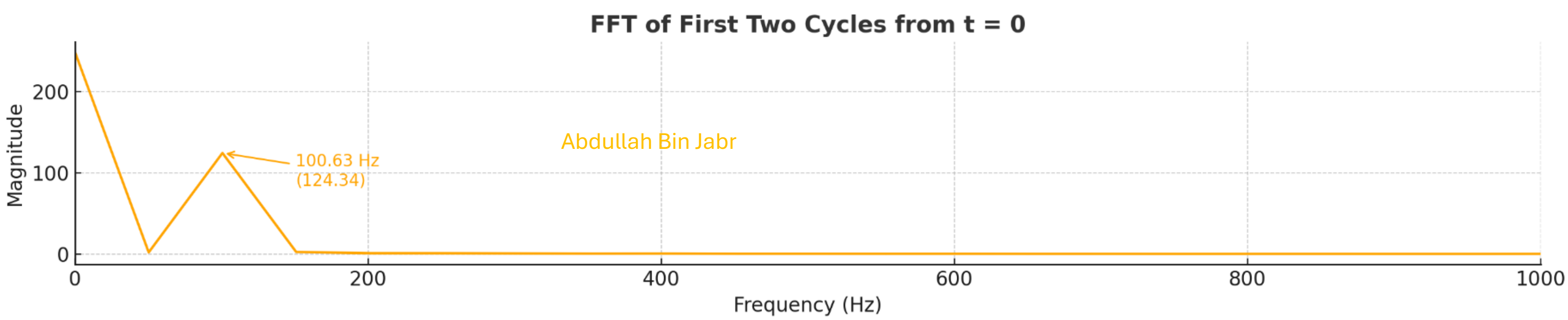
In the FFT of the full signal, a strong DC component is present with a magnitude of 127.56, reflecting the balanced nature of the signal. After DC removal, the peak shifts to the fundamental frequency of 125 Hz, with a magnitude of 80.20. This mirrors the earlier square wave, where the dominant energy shifted from the DC baseline to the primary frequency component. The overlay of both FFTs confirms that frequency content remains consistent across time window sizes, though with expected resolution trade-offs in the zoomed spectrum.

Generating 100 Hz ADC Sinusoidal Wave:


100Hz Sine Wave – Full 2048 Samples
ADC Amplitude
Time (ms)


FFT of Full 2048-Sample A100S
101.56 Hz
(124.70)
Abdullah Bin Jabr
Magnitude
Frequency (Hz)


100Hz Sine Wave – First Two Cycles from t = 0
0.00 ms
4.94 ms
9.88 ms
14.81 ms
19.75 ms
ADC Amplitude
Time (ms)


FFT of First Two Cycles from t = 0
Abdullah Bin Jabr
100.63 Hz
(124.34)
Magnitude
Frequency (Hz)

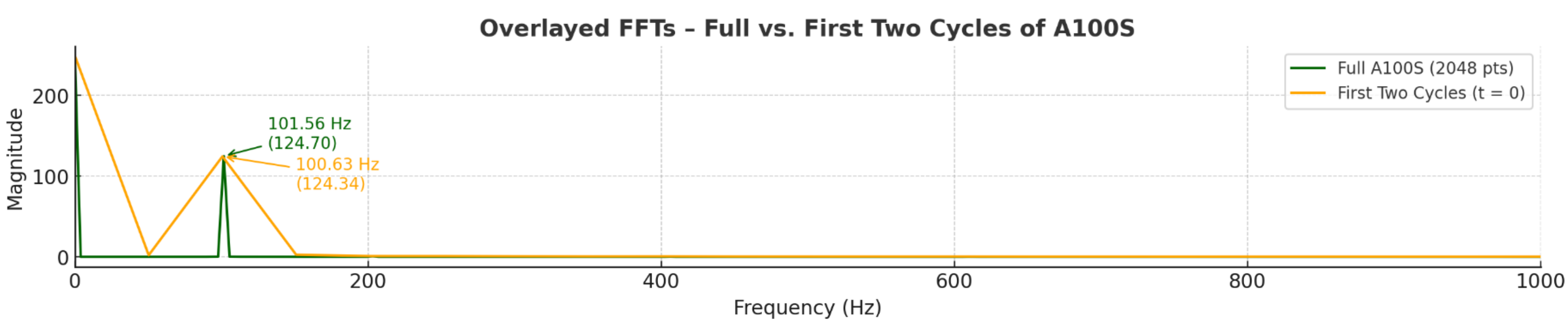
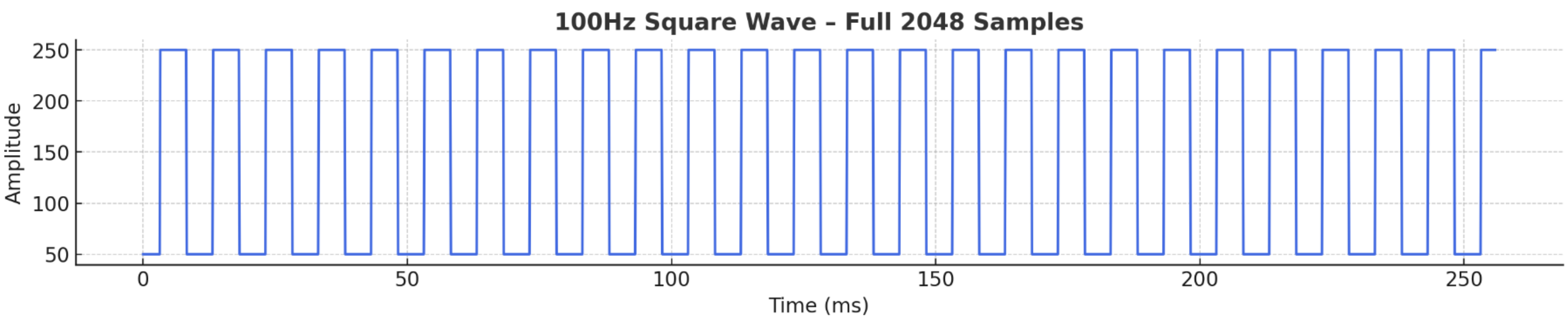

Overlayed FFTs – Full vs. First Two Cycles of A100S
Full A100S (2048 pts)
First Two Cycles (t = 0)
101.56 Hz
(124.70)
100.63 Hz
(124.34)
Magnitude
Frequency (Hz)

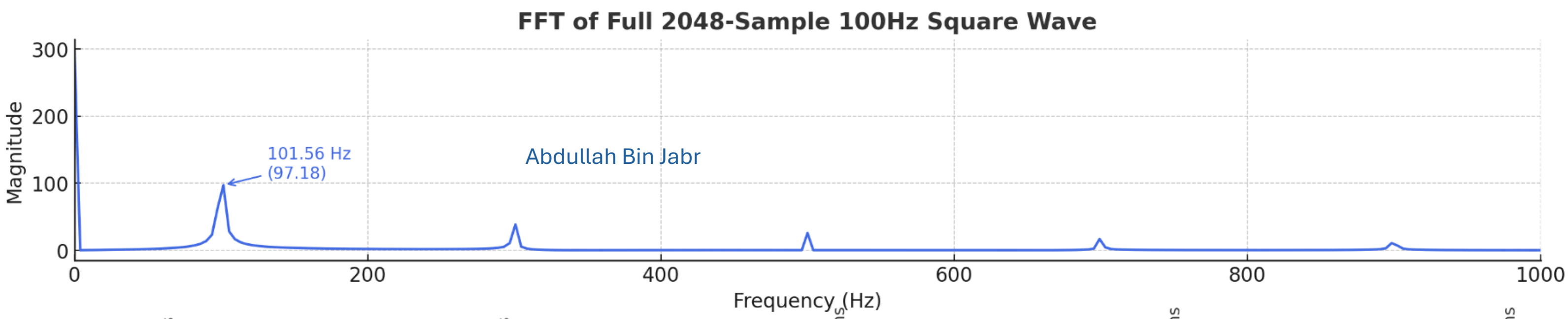
Figure 6. 100 Hz sine wave analysis from ADC 100S.
(a) Full 2048-sample waveform showing smooth periodic oscillations.
(b) FFT of the full signal with a sharp peak at ~101.56 Hz.
(c) Zoomed view of the first two cycles from t = 0, marked at half-period intervals (~4.93 ms).
(d) FFT of the zoomed segment showing a broader peak at ~103.12 Hz due to lower resolution.
(e) Overlay of both FFTs confirms consistent frequency content with expected differences in resolution and magnitude.

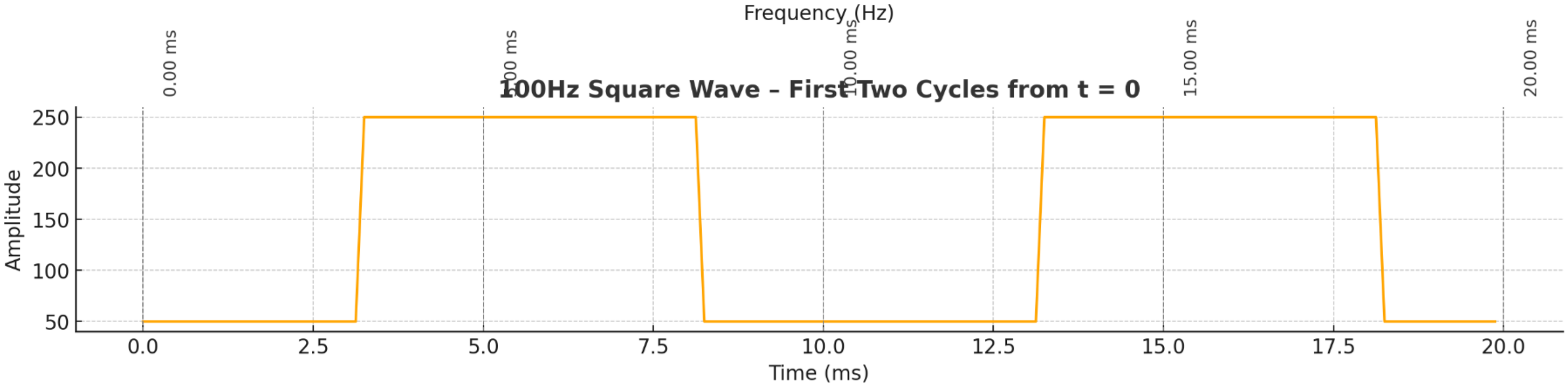
Analysis of the ADC sine wave at ~100 Hz:

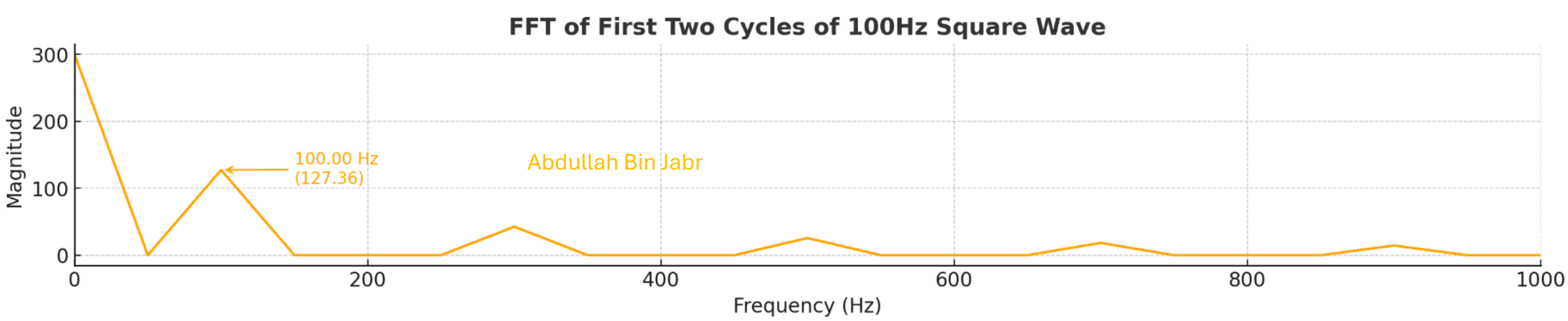
This waveform is a ~100 Hz sine wave sampled at 8000 Hz, producing approximately 25 cycles across the 2048-sample acquisition. Based on the sampling interval of 0.125 ms, the first and second peaks were detected at indices 66 and 145, corresponding to 8.25 ms and 18.125 ms respectively. The difference yields a measured period of 9.875 ms, which gives a calculated frequency of 101.27 Hz, closely matching the expected 100 Hz. The zoomed-in waveform shows two complete cycles starting from t = 0, with dashed lines marking every 4.93 ms (half-period) for reference. In the FFT of the full waveform, the dominant peak appears at 101.56 Hz with a magnitude of ~124, confirming accurate acquisition. The FFT of the zoomed-in segment shows a broader peak at 100.63 Hz (not sharp → less consistent/more varied) , due to the reduced resolution from fewer points. Overlaying both FFTs confirms consistent frequency content across both segments, with expected trade-offs in sharpness and amplitude.

Generating 100 Hz ADC Square Wave:


100Hz Square Wave – Full 2048 Samples
Amplitude
Time (ms)


FFT of Full 2048-Sample 100Hz Square Wave
Magnitude
101.56 Hz
(97.18)
Abdullah Bin Jabr
Frequency (Hz)


0.00 ms
5.00 ms
10.00 ms
15.00 ms
20.00 ms
100Hz Square Wave – First Two Cycles from t = 0
Amplitude
Time (ms)


FFT of First Two Cycles of 100Hz Square Wave
Magnitude
100.00 Hz
(127.36)
Abdullah Bin Jabr
Frequency (Hz)

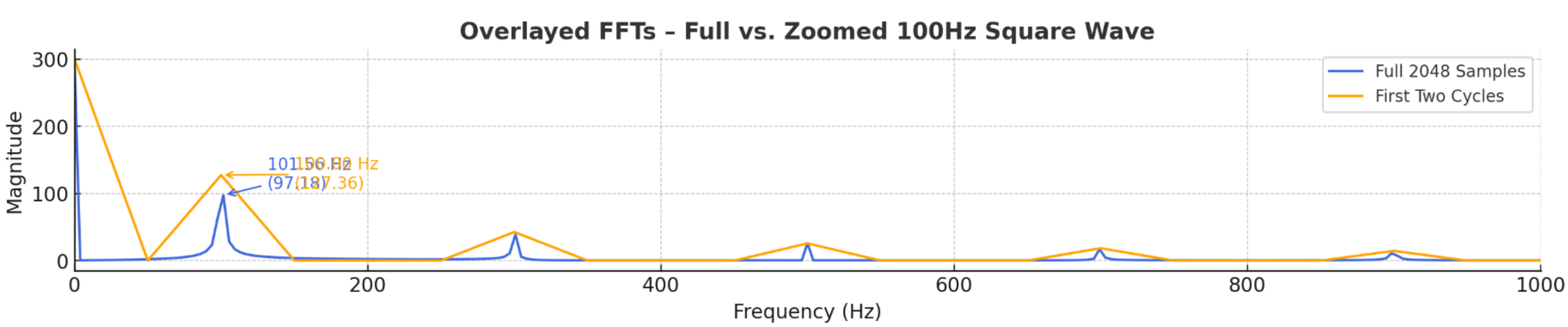
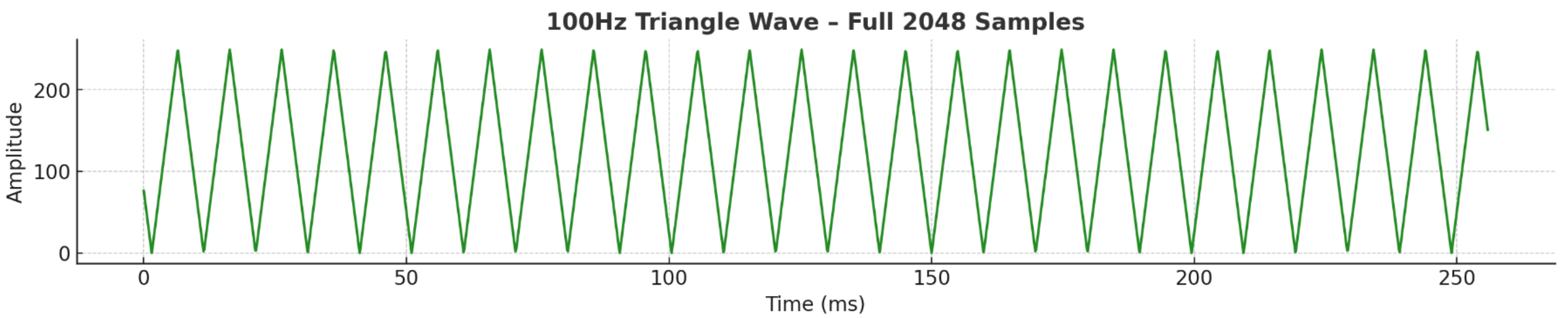

Overlayed FFTs – Full vs. Zoomed 100Hz Square Wave
Magnitude
Full 2048 Samples
First Two Cycles
Frequency (Hz)

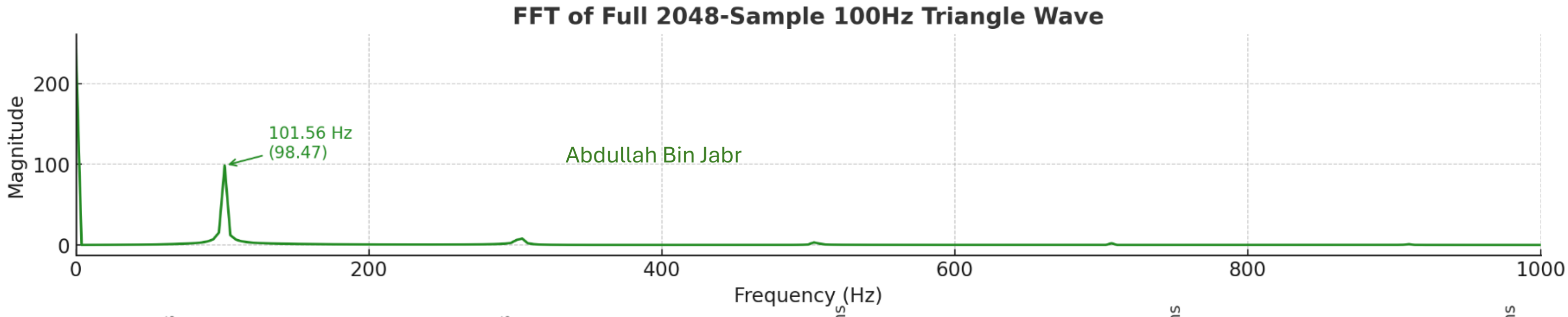
Figure 7. 100 Hz square wave analysis from the ADC 100Q input signal.
(a) Full waveform of 2048 samples at 8000 Hz, showing 32 cycles with a period of 8 ms.
(b) FFT shows a peak at 101.56 Hz with magnitude 97.18, confirming the expected frequency.
(c) Zoomed view of the first two cycles from t = 0, with rising edges spaced 10 ms apart.
(d) Zoomed FFT shows a sharper peak at 100.00 Hz, magnitude 127.36.
(e) Overlay confirms consistent frequency content, with resolution and magnitude differences.

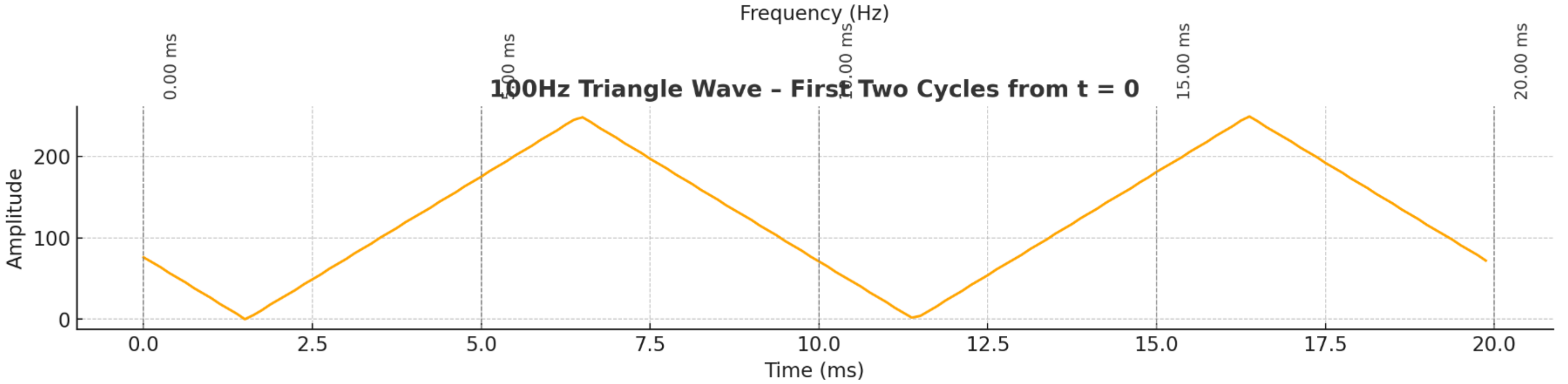
Analysis of ADC 100Hz Square Wave:

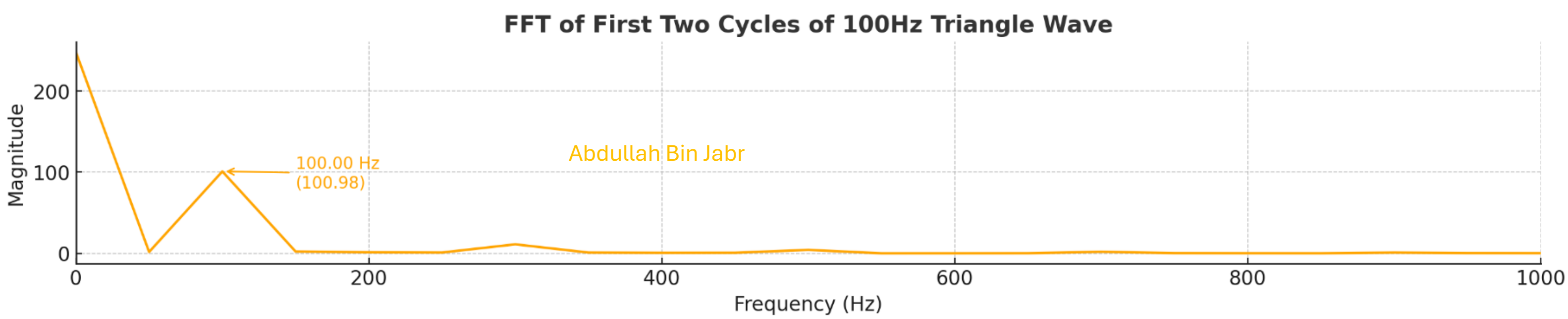
This 100 Hz square wave, sampled at 8000 Hz, spans 32 cycles across the 2048-sample window, with each cycle lasting 8 ms. The zoomed view shows the first two full cycles from t = 0, where a 10 ms period was confirmed by measuring the time between two rising edges. Vertical dashed lines are spaced every 5 ms mark half-period intervals. In the FFT of the full waveform, a dominant peak appears at 101.56 Hz, consistent with the expected frequency. The FFT of the zoomed segment shows a sharper peak at 100Hz due to cleaner alignment. The overlay confirms both segments reflect the same fundamental frequency, with minor differences in resolution and amplitude.

Generating 100Hz ADC Triangle Wave:


100Hz Triangle Wave – Full 2048 Samples
Amplitude
Time (ms)
0
100
200
0
50
100
150
200
250


FFT of Full 2048-Sample 100Hz Triangle Wave
101.56 Hz
(98.47)
Abdullah Bin Jabr
Magnitude
Frequency (Hz)
0
100
200
0
200
400
600
800
1000


0.00 ms
5.00 ms
10.00 ms
15.00 ms
20.00 ms
100Hz Triangle Wave – First Two Cycles from t = 0
Amplitude
Time (ms)
0
100
200
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0


FFT of First Two Cycles of 100Hz Triangle Wave
100.00 Hz
(100.98)
Abdullah Bin Jabr
Magnitude
Frequency (Hz)
0
100
200
0
200
400
600
800
1000

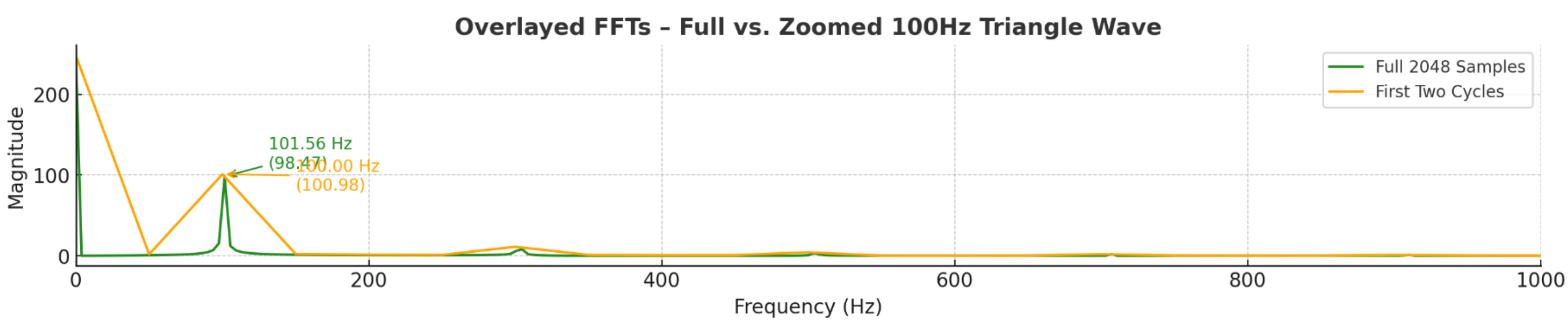

Overlayed FFTs – Full vs. Zoomed 100Hz Triangle Wave
Full 2048 Samples
First Two Cycles
101.56 Hz
(98.47)
100.00 Hz
(100.98)
Magnitude
Frequency (Hz)
0
100
200
0
200
400
600
800
1000

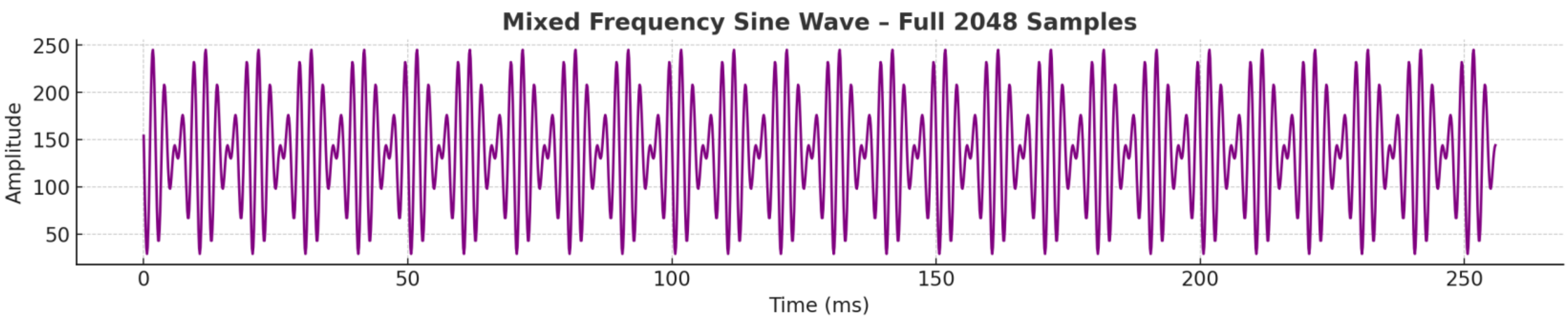
Figure 8. 100 Hz triangle wave analysis from the ADC 100T input signal.
(a) Full waveform of 2048 samples at 8000 Hz showing 25 cycles with a period of 10 ms.
(b) FFT of the full signal shows a dominant frequency peak at 101.56 Hz.
(c) Zoomed view of the first two full cycles from t = 0, with vertical lines every 5 ms.
(d) FFT of the zoomed waveform shows a sharper peak at 100.00 Hz.
(e) Overlay confirms both views contain the same frequency, with differences in resolution.

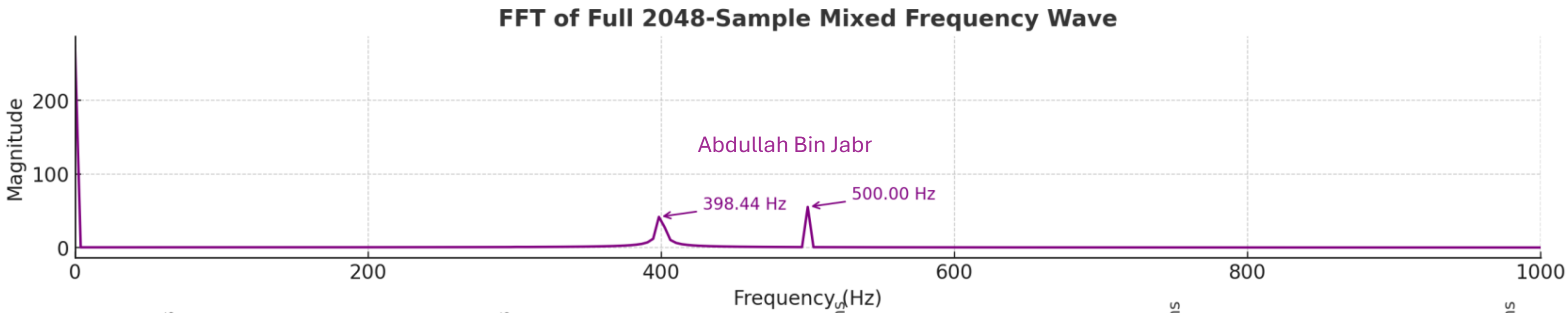
Analysis of ADC 100 Hz Triangle Wave:

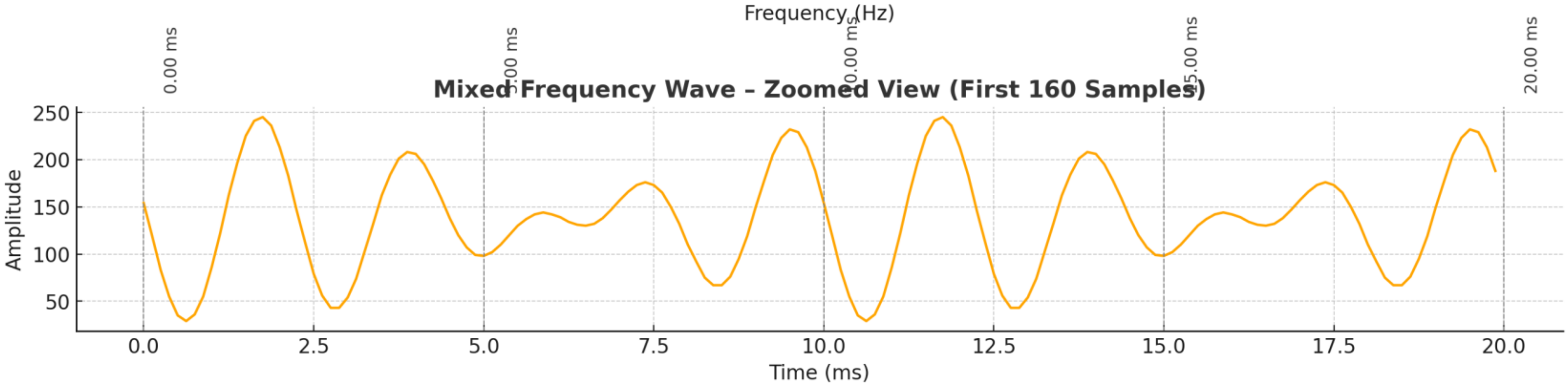
The 100 Hz triangle wave was recorded using the ADC at an 8000 Hz sampling rate, resulting in 2048 data points. With 80 samples per cycle, the signal's period calculates to 10 ms, which matches what we observe in the time-domain graph. The waveform consistently shows a steady rise and fall, forming the characteristic linear slopes of a triangle wave. To double-check the frequency, we took a closer look at the first two full cycles. Measuring the time between two rising edges confirmed the 10 ms period. We also marked 5 ms intervals with dashed lines to highlight the symmetry and regularity of the waveform.

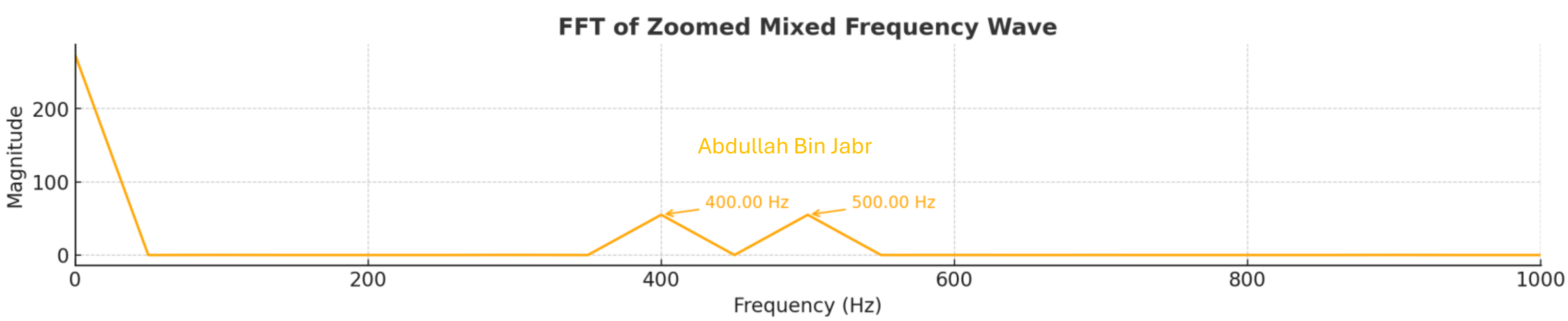
In the frequency domain, the FFT of the complete dataset reveals a prominent peak around 101.56 Hz, which aligns well with expectations. The FFT of the zoomed-in segment—although based on fewer samples—still captures the same frequency, showing a peak right at 100 Hz. As expected, the reduced resolution makes the peak slightly broader. Still, both plots confirm the waveform was sampled accurately, both in time and frequency.

Generating ADC Mixed Signal Wave:


Mixed Frequency Sine Wave – Full 2048 Samples
Amplitude
Time (ms)


FFT of Full 2048-Sample Mixed Frequency Wave
Magnitude
Abdullah Bin Jabr
398.44 Hz
500.00 Hz
Frequency (Hz)


0.00 ms
5.00 ms
10.00 ms
15.00 ms
20.00 ms
Mixed Frequency Wave – Zoomed View (First 160 Samples)
Amplitude
Time (ms)


FFT of Zoomed Mixed Frequency Wave
Magnitude
Abdullah Bin Jabr
400.00 Hz
500.00 Hz
Frequency (Hz)

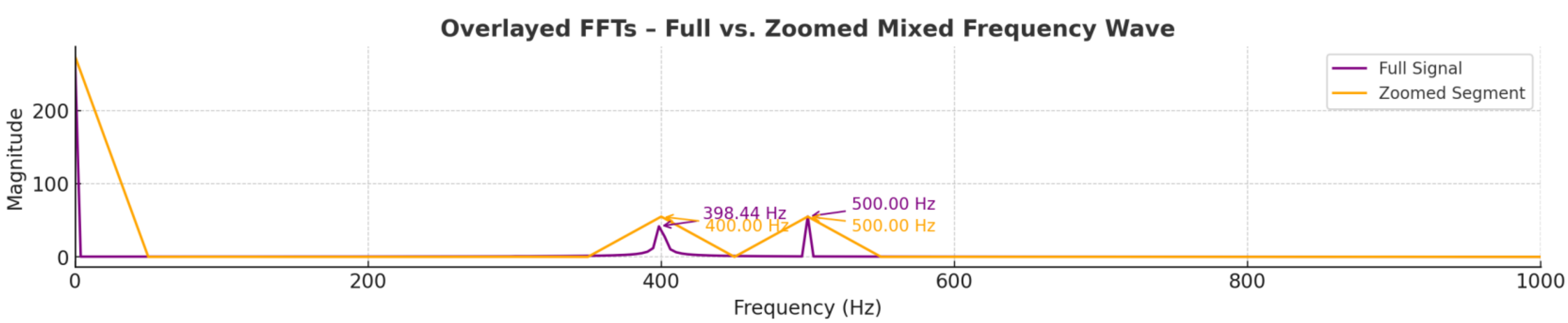

Overlayed FFTs – Full vs. Zoomed Mixed Frequency Wave
Magnitude
Full Signal
Zoomed Segment
398.44 Hz
400.00 Hz
500.00 Hz
500.00 Hz
Frequency (Hz)

Figure 9. Mixed frequency waveform analysis from the ADC 200S input signal.
(a) Full waveform of 2048 samples at 8000 Hz showing visible modulation and beat interference.
(b) FFT of the full signal reveals two dominant peaks at 398.44 Hz and 500.00 Hz, indicating the presence of two superimposed sinusoidal waves.
(c) Zoomed view of the first 160 samples captures waveform complexity and envelope variation.
(d) FFT of the zoomed segment shows the same two peaks, though with reduced frequency resolution.
(e) Overlay confirms consistent spectral content between full and zoomed views, with minor shifts due to shorter sample window.

Analysis of the ADC Mixed Signal Wave:

The mixed waveform was captured using the HCS12's ADC at 8000 Hz, producing 2048 samples total. This signal combined two sine waves with different frequencies, which created a visible modulation pattern—basically a "beat" effect where the two signals interfere with each other. In the time-domain plot, you can see this beating clearly as the signal's amplitude rises and falls. Figuring out the exact frequencies from the time plot alone is tough because of how the waves overlap. That's where the FFT really shines. The frequency analysis of the full signal reveals two clear peaks—one at 398.44 Hz and another at 500.00 Hz—showing the two sine waves present in the mix. The zoomed-in FFT (based on just 160 samples) shows the same two peaks, though slightly shifted due to the lower resolution. This consistency across both views confirms that the ADC captured the mixed-frequency signal accurately. The beat pattern in the time plot lines up with the dual peaks in the FFT, giving us both a visual and spectral confirmation of what's happening in the signal.

The ADC setup played a key role in the second part of Homework 11. By capturing analog signals digitally at a high sampling rate, it allowed for accurate and consistent waveform analysis across all types—sine, square, triangle, and sawtooth. Paired with FFT, the captured data made it easy to identify fundamental frequencies, harmonics, and even subtle noise. This wasn't just helpful for clean, periodic signals—it also made analyzing complex or mixed waveforms much clearer. The ability to visualize these signals in both time and frequency domains gave us a complete picture, proving how effective the ADC can be for real-time signal processing and analysis.