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CMPEN 472 HW 10 Report

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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.

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 125 μ s to determine the period frequency!

Generating standard Sawtooth Graphs:

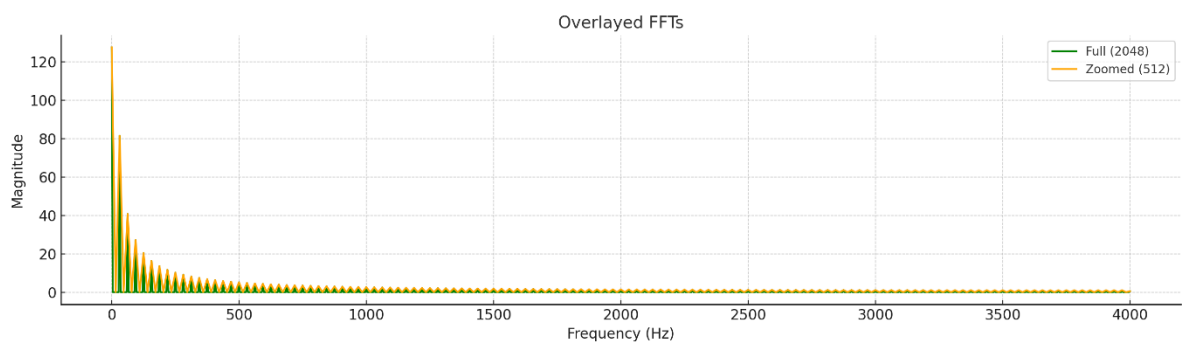
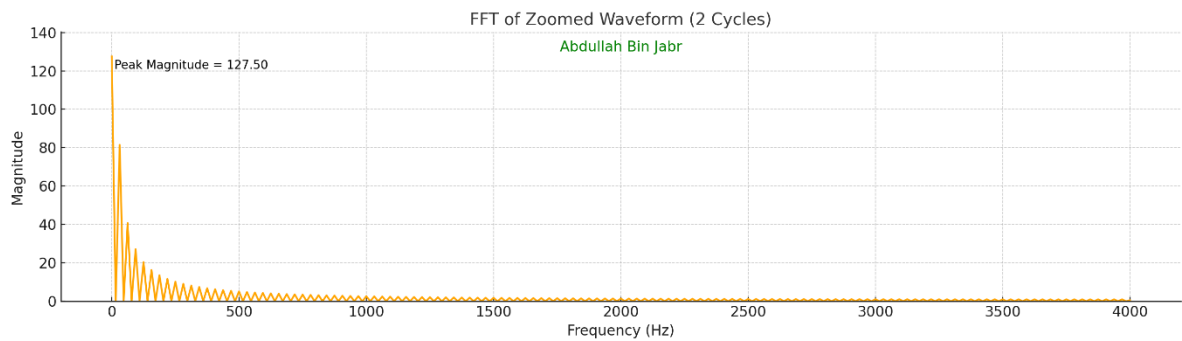
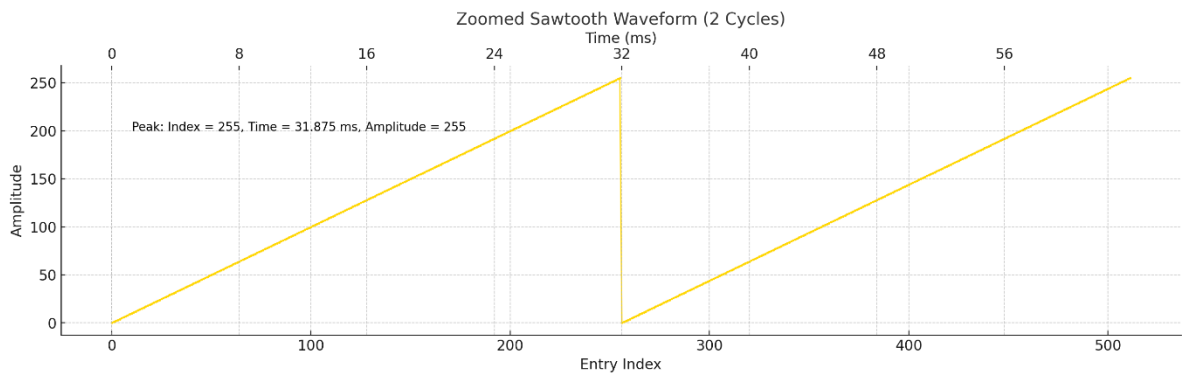
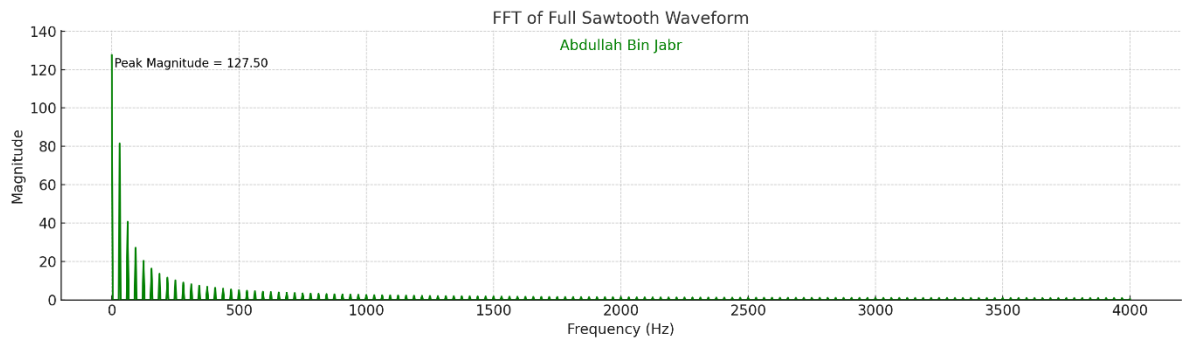
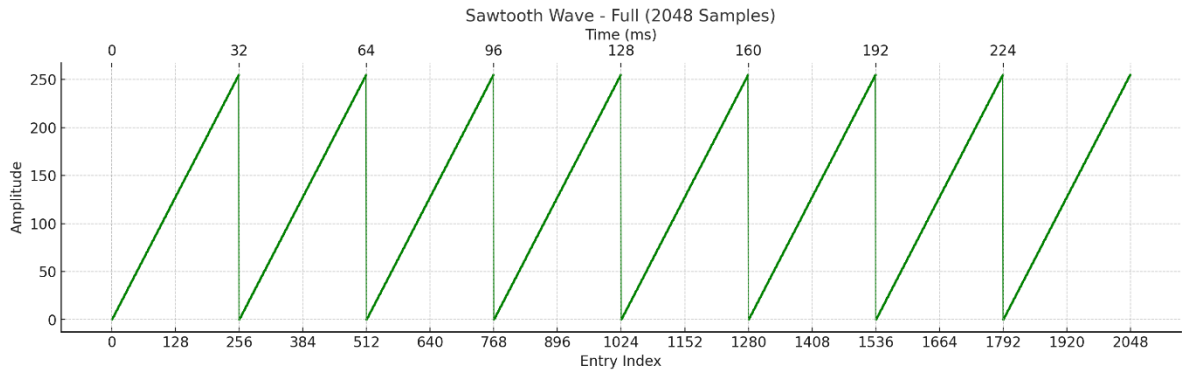


Figure 1. Time-domain and frequency-domain analysis of the sawtooth waveform.

(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 μ s, 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:

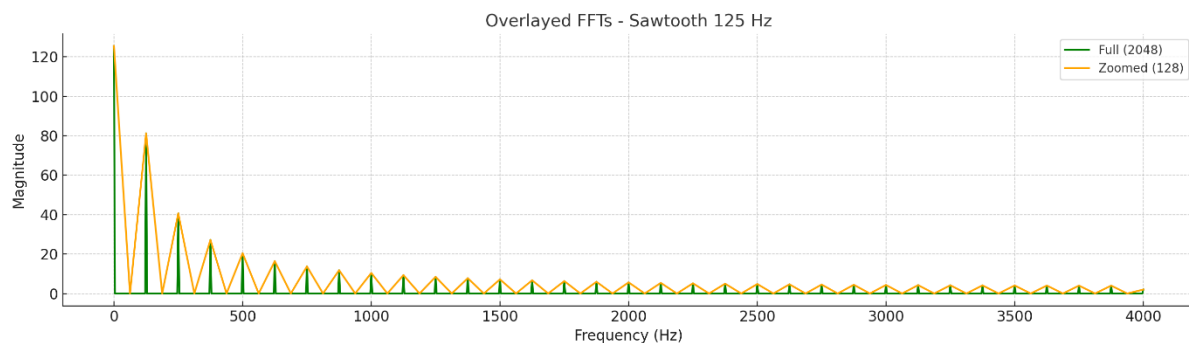
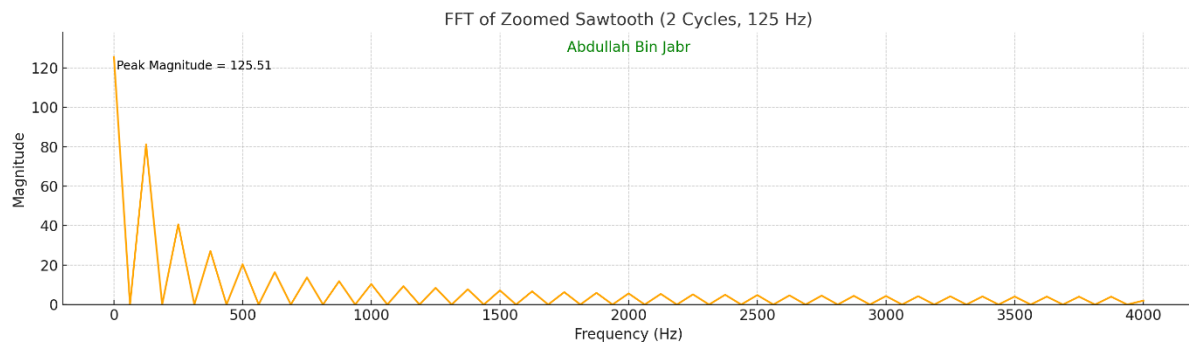
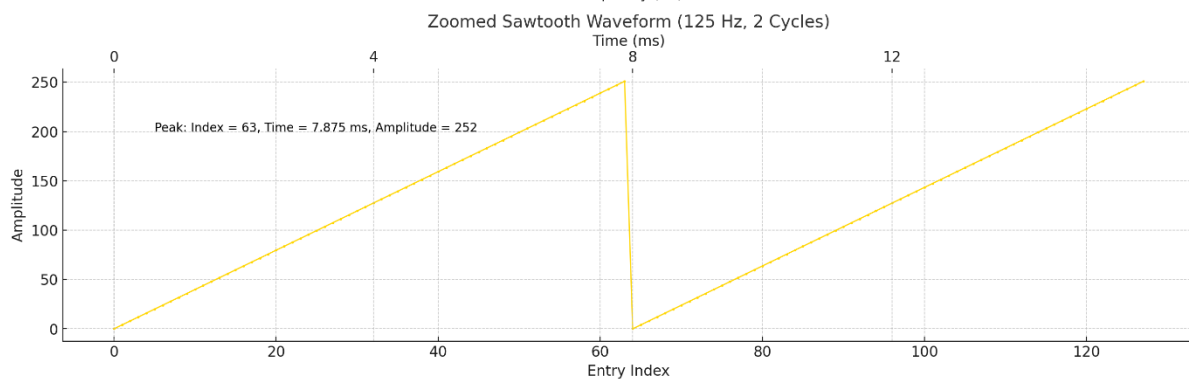
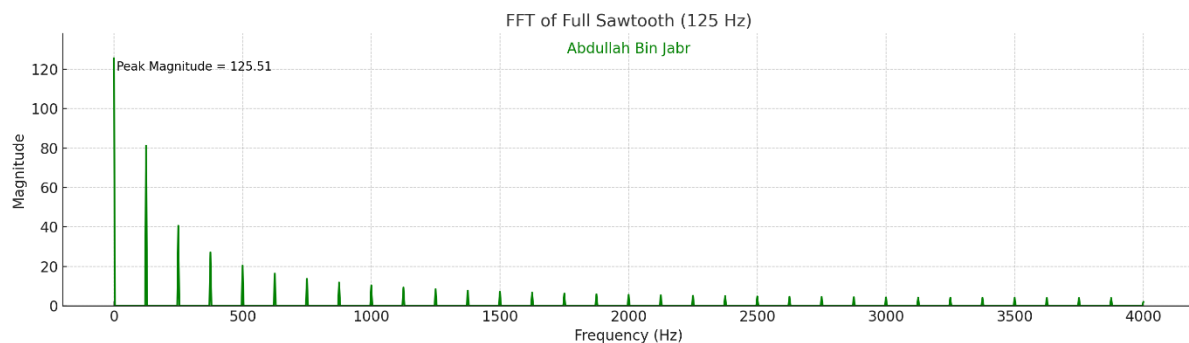
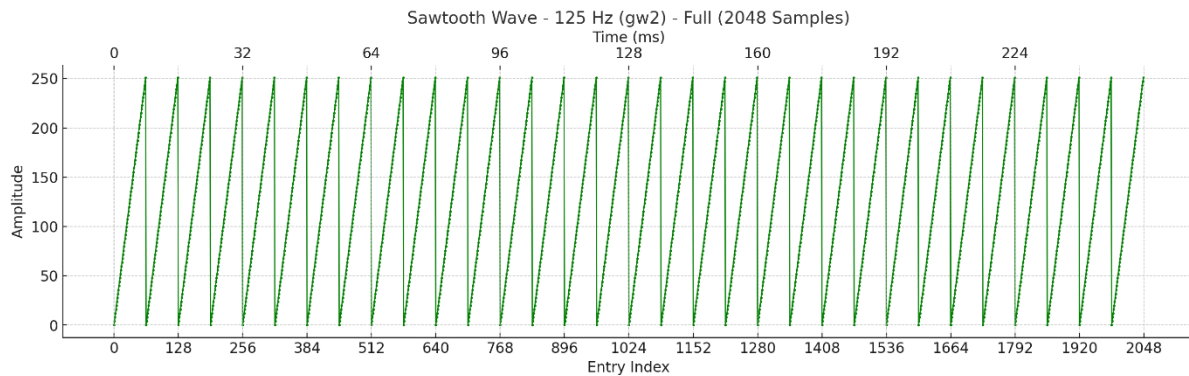


Figure 2. Time-domain and frequency-domain analysis of a 125 Hz sawtooth waveform. (a) Full waveform with 2048 samples, (b) FFT of full waveform, (c) zoomed view showing two cycles, (d) FFT of zoomed waveform, (e) overlay of both FFTs.

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:

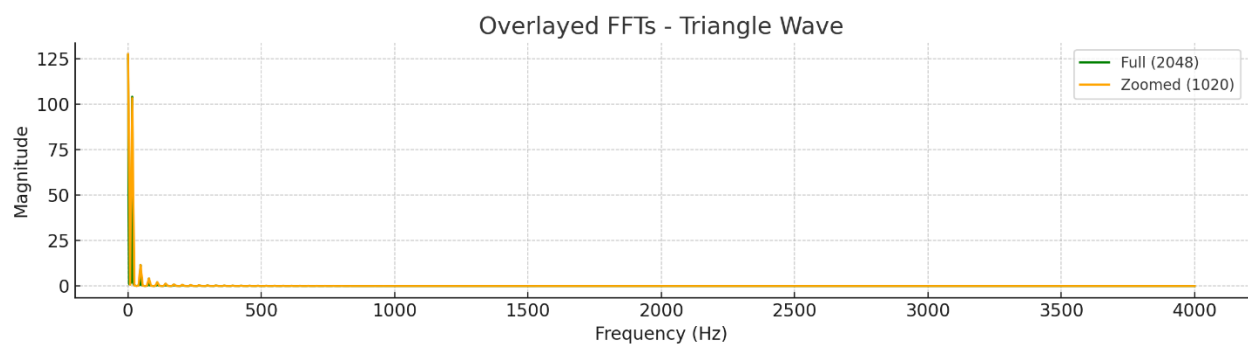
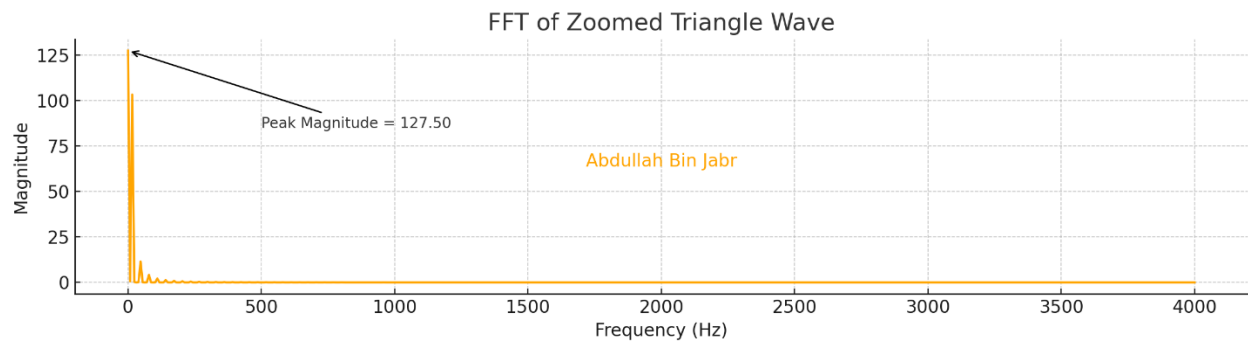
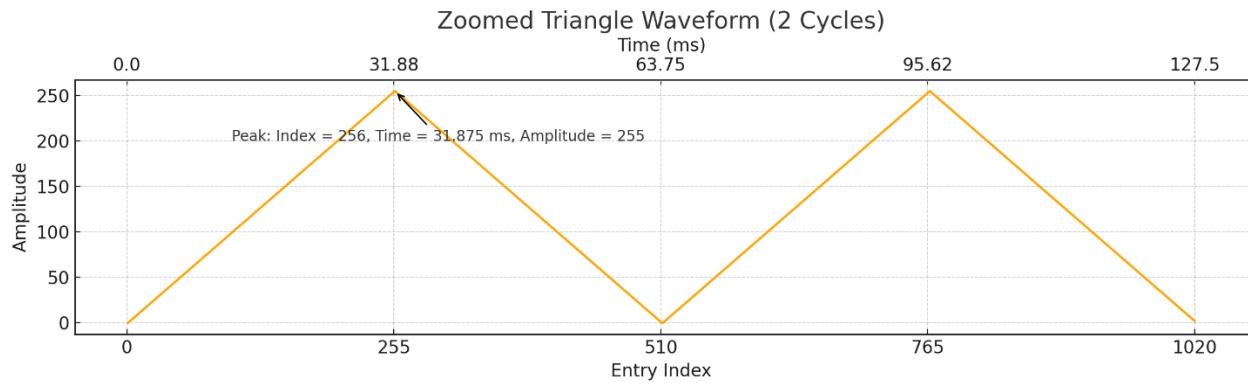
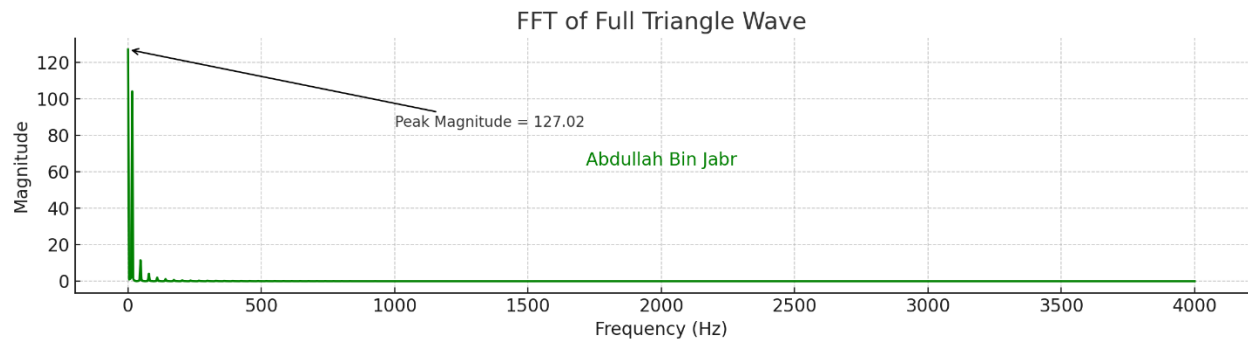
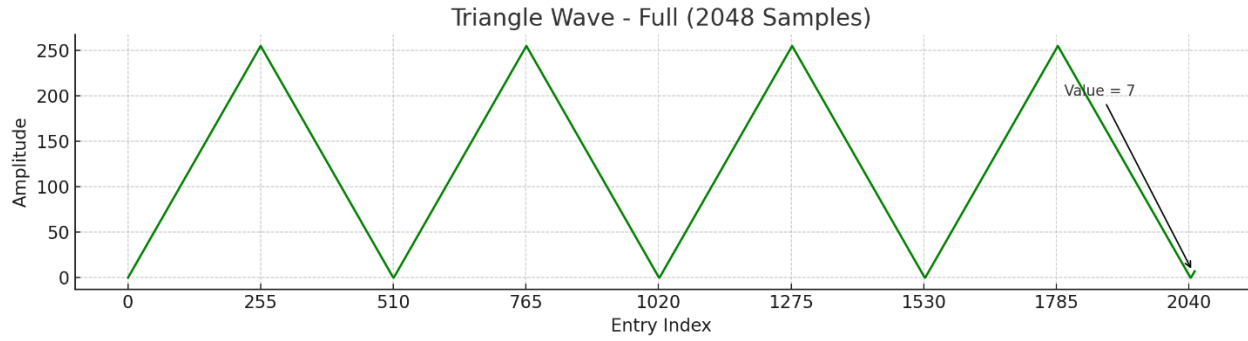


Figure 3. Triangle waveform at 15.7 Hz (63.75 ms period) generated at 8000 Hz over 2048 point.
(a) Full waveform showing four complete cycles and a final ramp segment ending at amplitude 7
(b) FFT of full waveform showing strong DC component and harmonic peaks.
(c) Zoomed view of two triangle cycles 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 Square Wave:

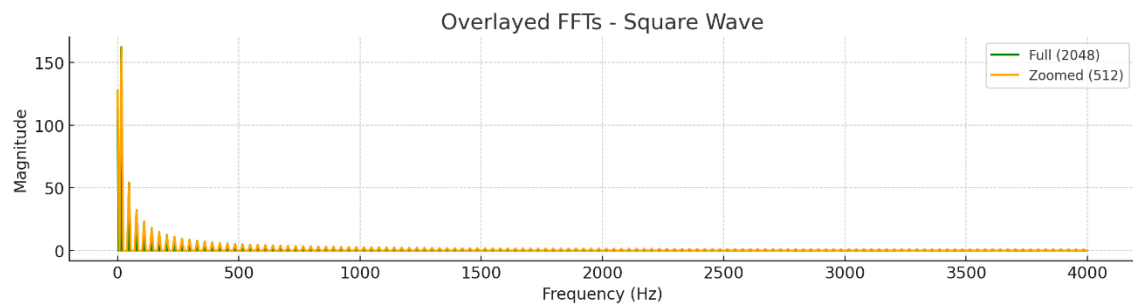
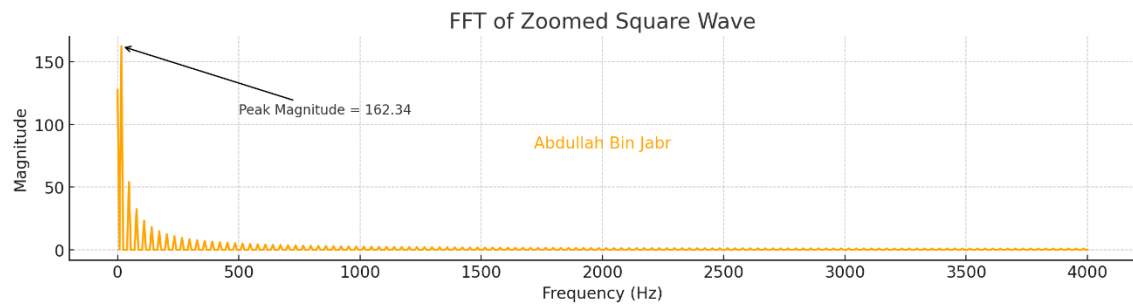
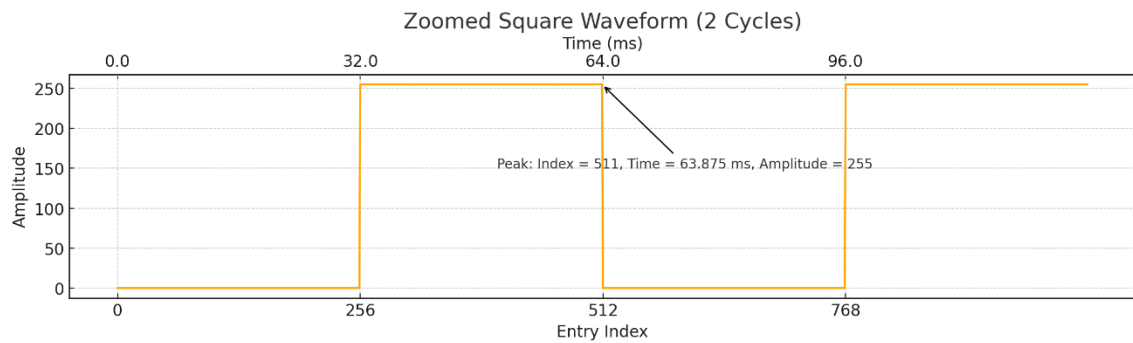
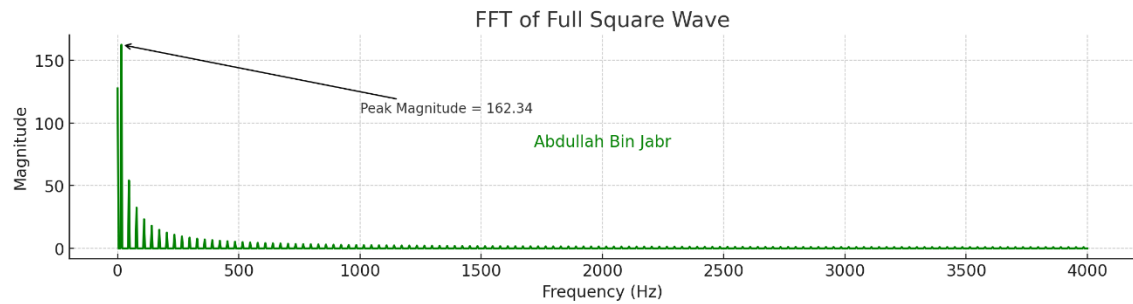
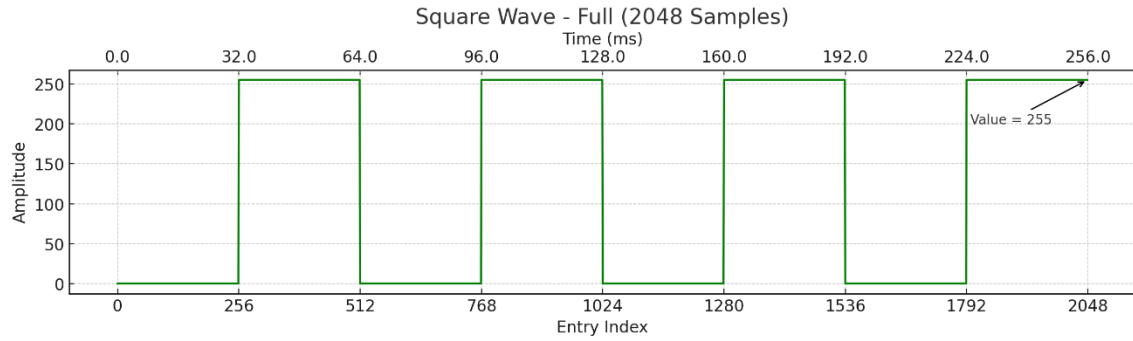


Figure 4. Square Wave (32 ms Period)

- (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) Overlaid 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:

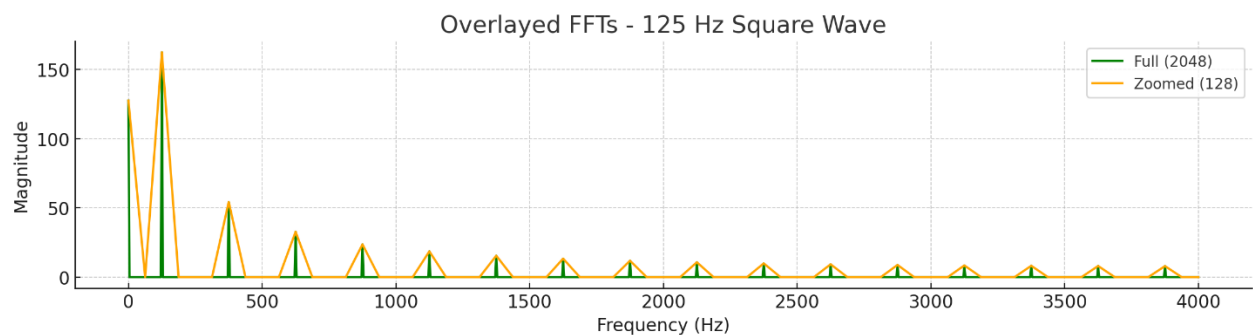
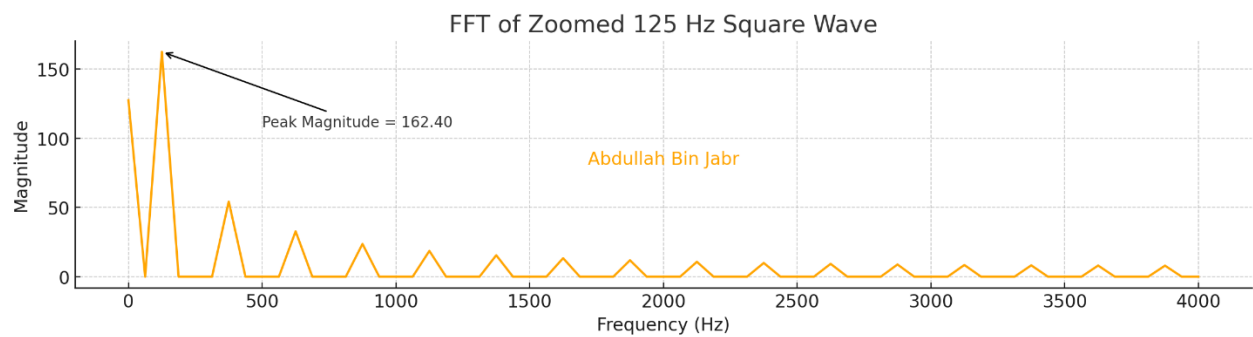
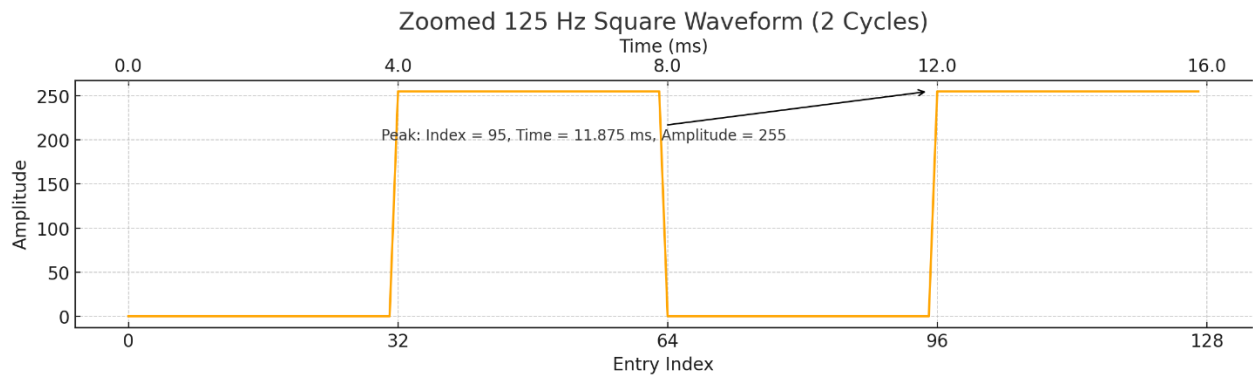
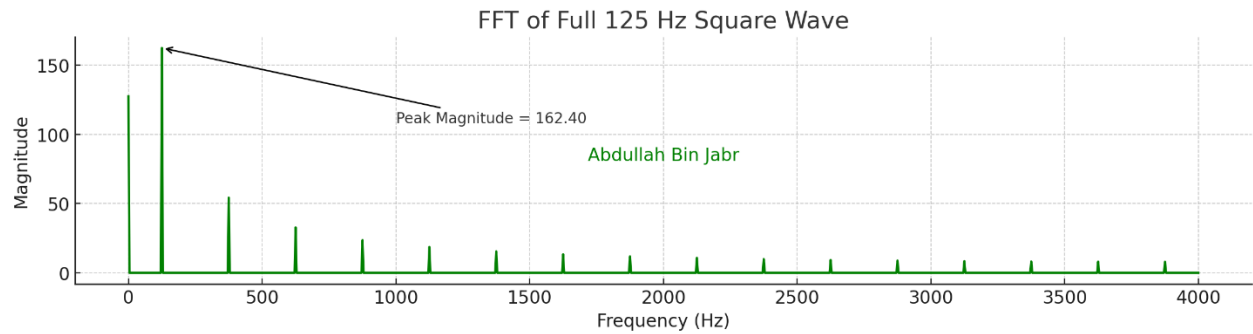
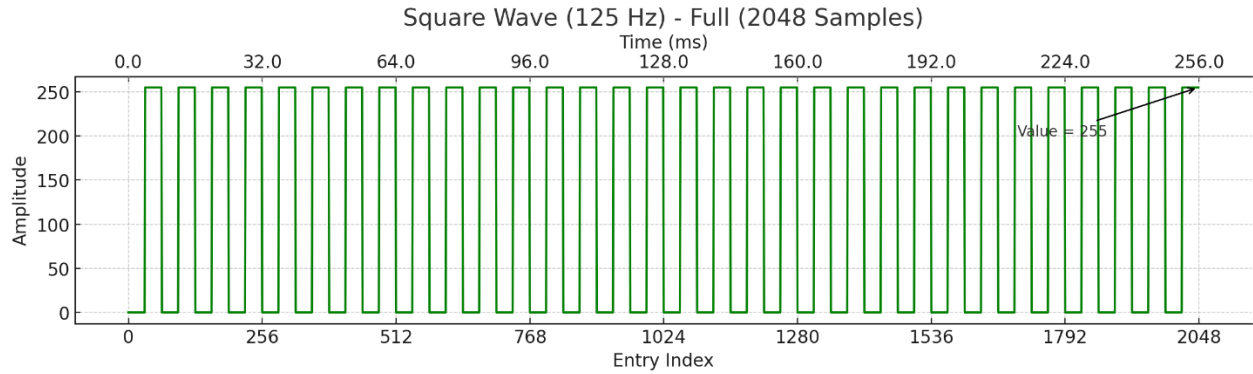


Figure 5. Square wave (125 Hz) signal analysis.

- (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.