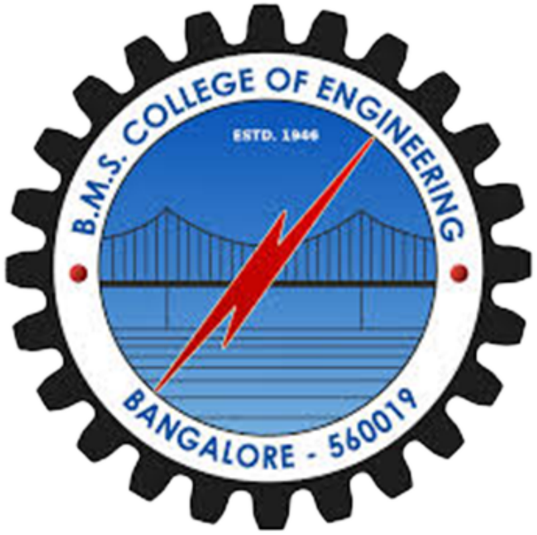
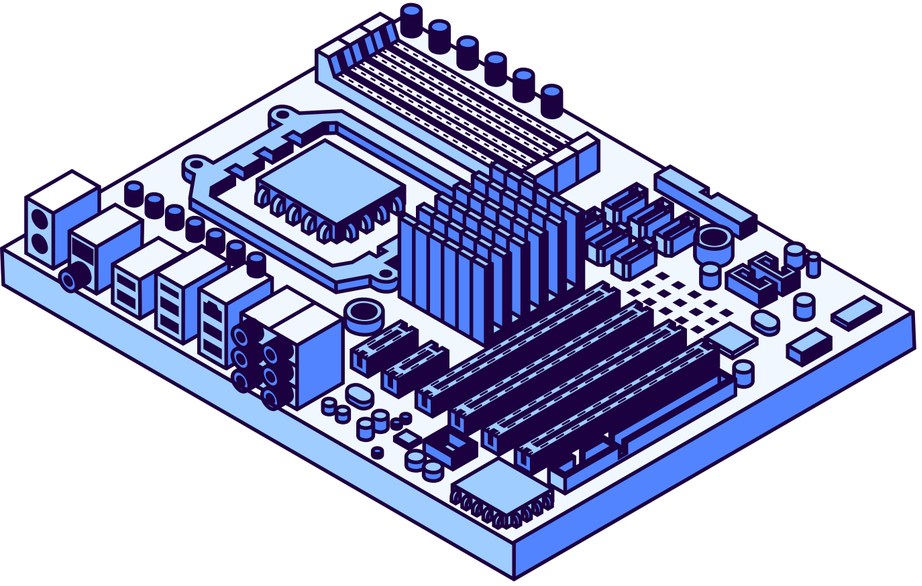
CSV Enhanced Signal Generator & Spectrum Analyzer



Dept. of Electronics and Telecommunication



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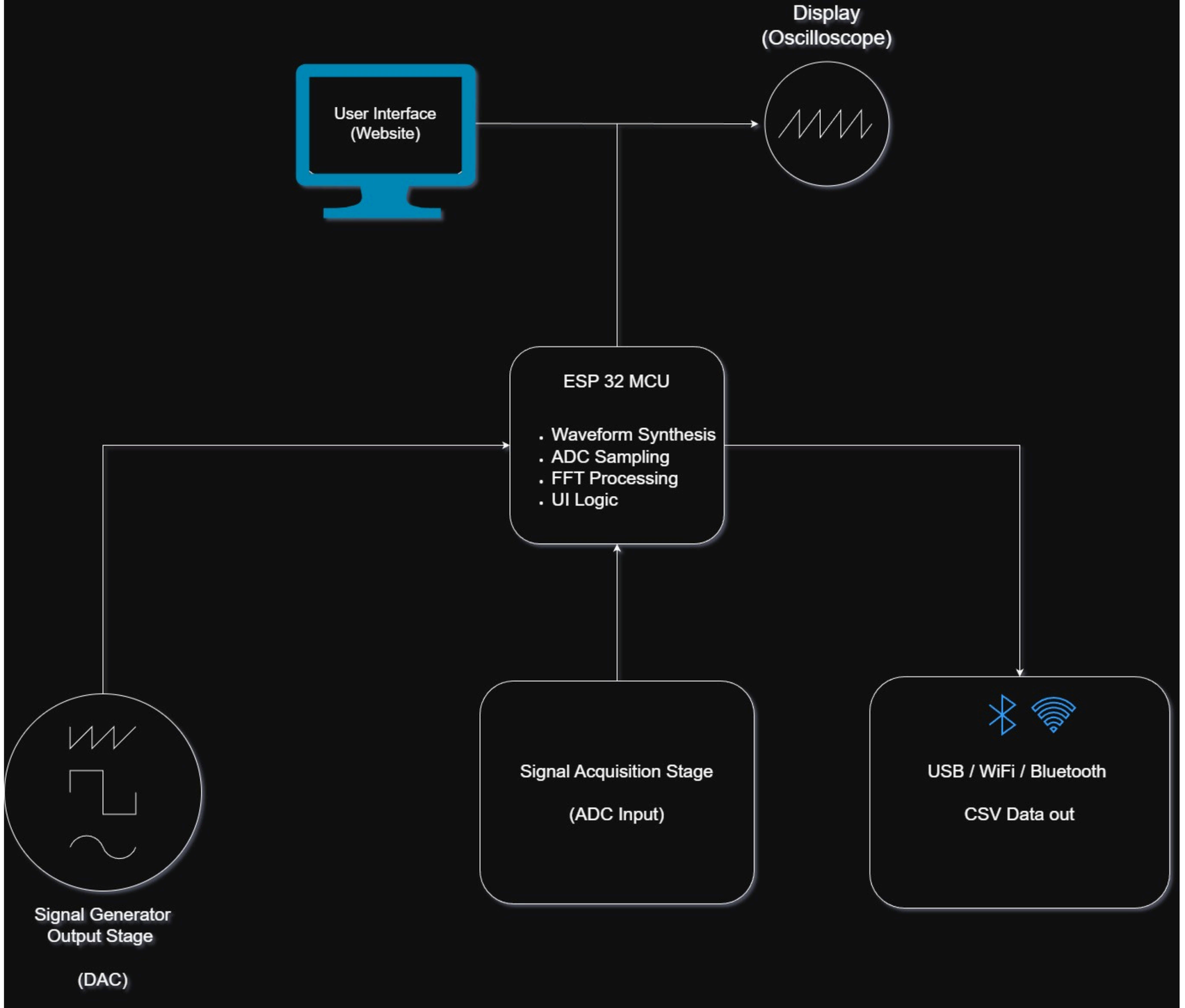
Problem and Objectives

- Accessible Generators: There is a significant lack of student-accessible signal generators in educational settings, limiting hands-on learning opportunities for engineering students.
- Multi-Waveform Generation: Providing multi-waveform generation capabilities enables students to experiment with various signal types, promoting a deeper understanding of their applications.
- Real-Time FFT: Implementing real-time FFT allows for instantaneous frequency analysis, facilitating immediate feedback during experiments and improving learning outcomes.
- Cost-Effective Design: A low-cost design approach ensures that resources are available to a larger number of students, fostering innovation and accessibility in engineering education.
- Spectral Analysis: The need for spectral analysis tools is crucial for understanding complex signals, enhancing students' learning experiences in signal processing.

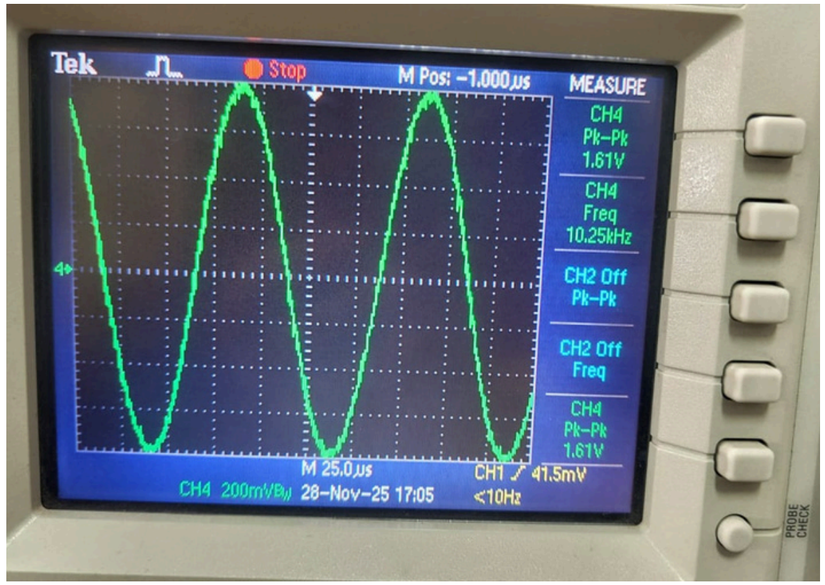
System Architecture

- ESP32 Core: The ESP32 serves as the central processing unit, enabling efficient management of all subsystems and facilitating communication between components.
- DAC for Sine: A digital-to-analog converter (DAC) generates precise sine waveforms, essential for accurate signal representation in various applications.
- PWM for Square: Pulse Width Modulation (PWM) is employed to create clean square waveforms, ensuring reliable performance in digital signal generation.
- LUT Timer: A Look-Up Table (LUT) timer facilitates triangle and sawtooth waveform generation, providing flexibility in signal output while maintaining precision.
- ADC + FFT: The Analog-to-Digital Converter (ADC) captures input signals and performs Fast Fourier Transform (FFT) analysis for real-time spectral evaluation.

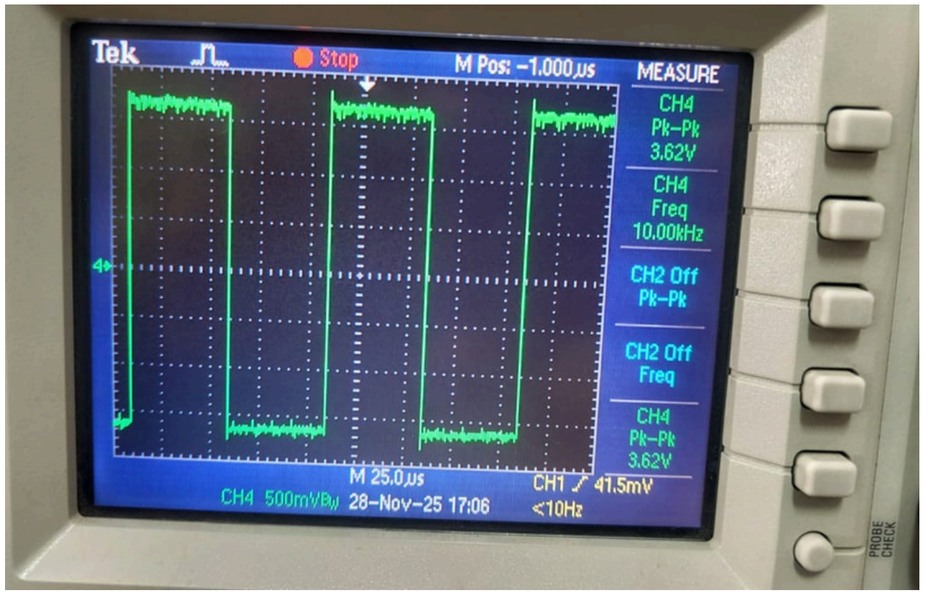

Display
(Oscilloscope)
User Interface
(Website)
ESP 32 MCU
. Waveform Synthesis
. ADC Sampling
. FFT Processing
. UI Logic
Signal Generator
Output Stage
(DAC)
Signal Acquisition Stage
(ADC Input)
USB / WiFi / Bluetooth
CSV Data out

Waveform Generation

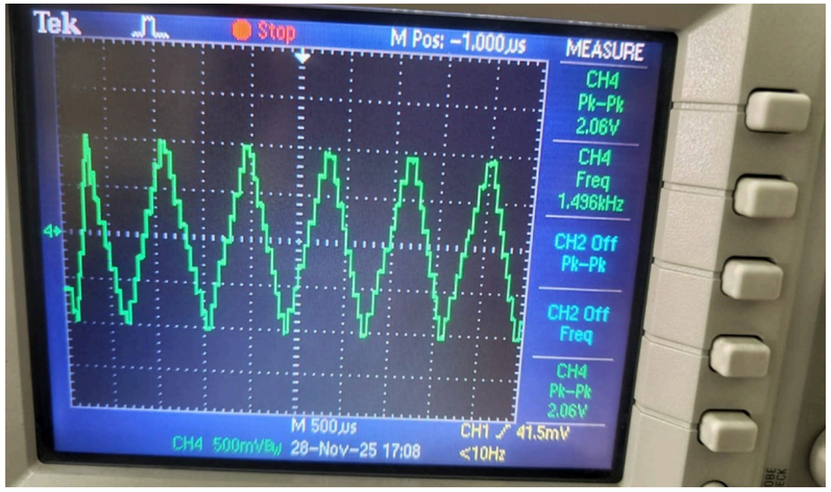
- DAC Cosine Generator: The DAC cosine generator produces precise sine waveforms by leveraging a mathematical approach to oscillation, ensuring high fidelity in output signals.
- Fixed amplitude PWM ensures consistent signal strength across varying frequencies, maintaining stability and reliability in waveform generation during different applications.
- 40 kHz Performance: The system demonstrates outstanding performance with sine and square waveforms, achieving stability and clarity up to 40 kHz without distortion.
- LUT Waveforms: Lookup tables (LUT) enhance efficiency in waveform generation by pre-storing values, allowing rapid retrieval and ensuring high-speed performance in real-time applications.
- LEDC PWM modulation allows for flexible control over duty cycles, enabling smooth transitions between signal states for more refined waveform outputs.



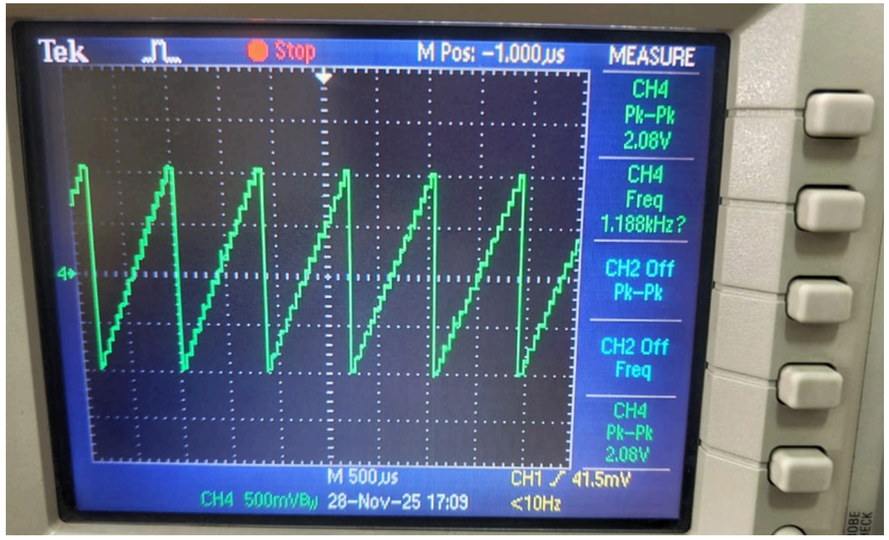
Sine wave - 10kHz



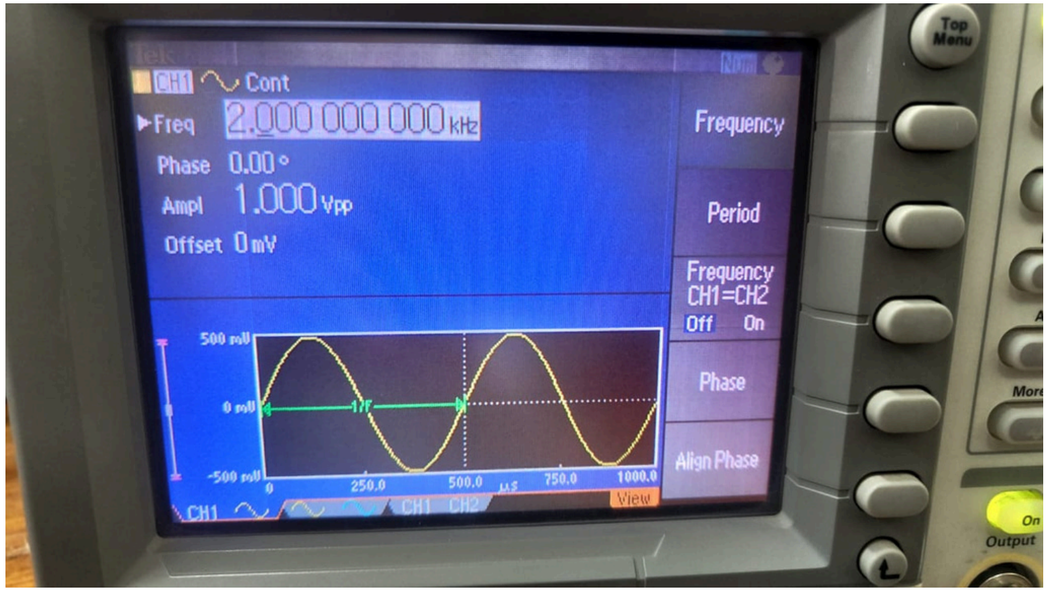
Square wave - 10kHz



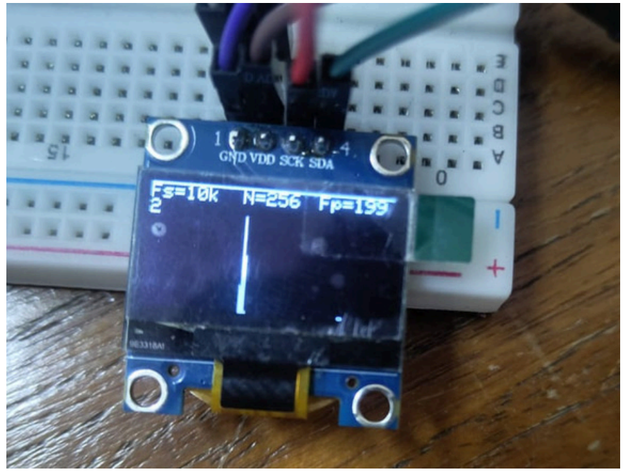
Triangular wave - 1.5kHz



Sawtooth wave - 1.1kHz

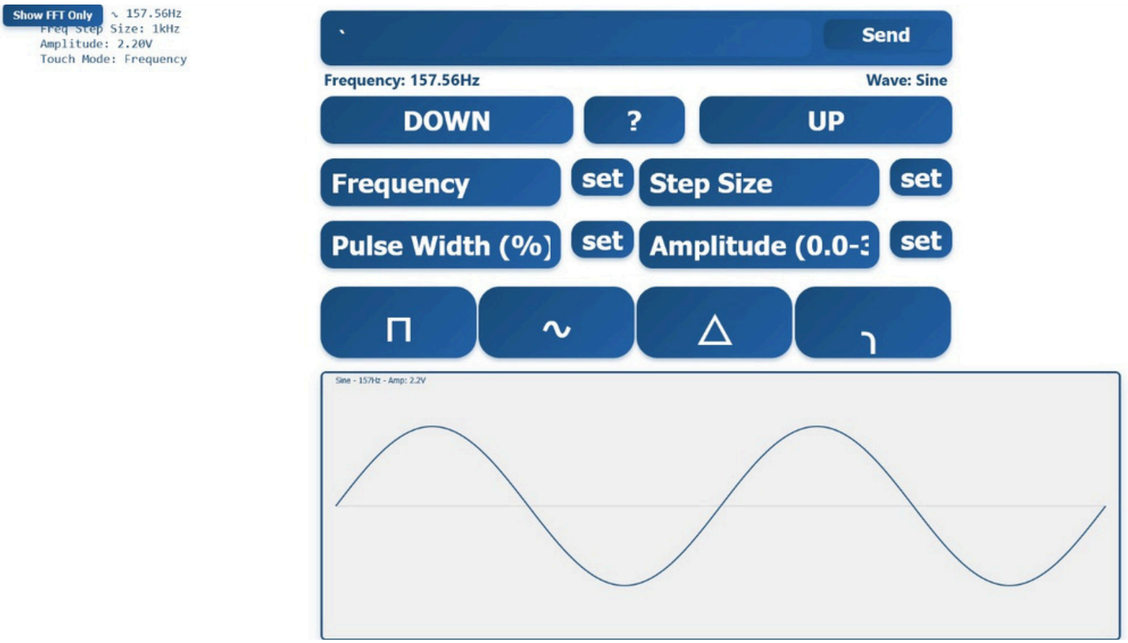


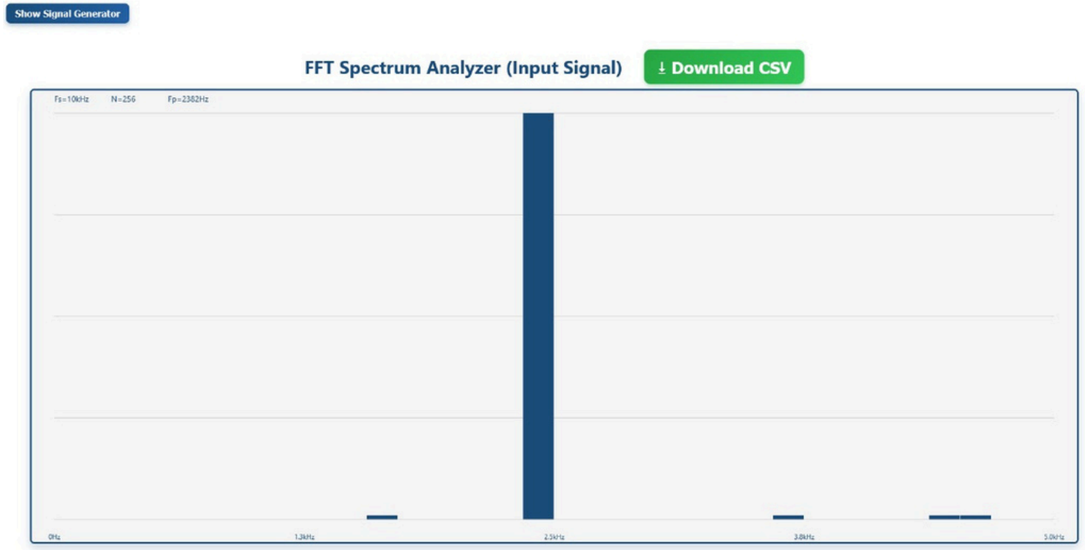
Input signal to GPIO 34



FFT output

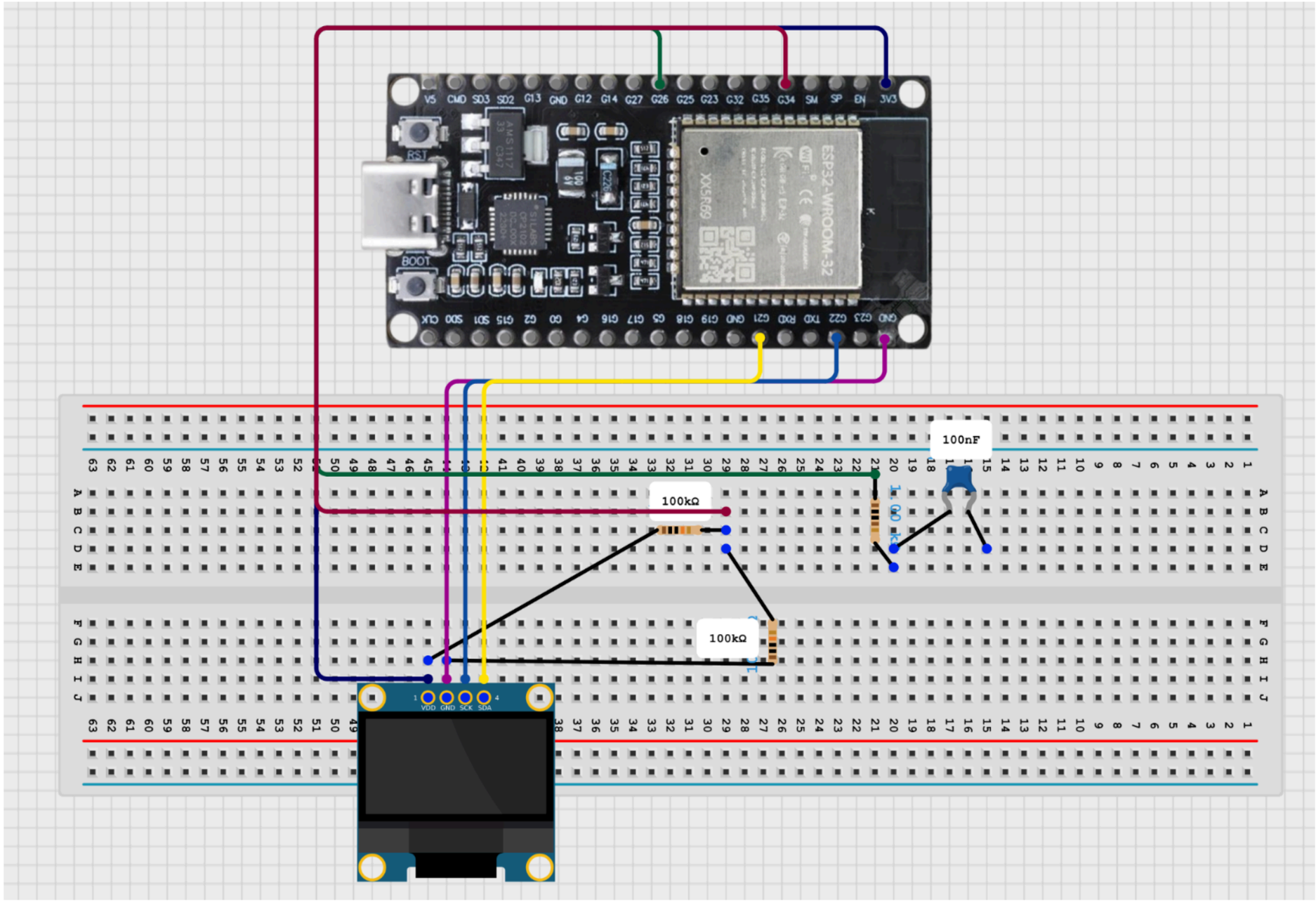
Web Interface





Experimental Setup

- Measurement Tool: The system was tested using the Tektronix TDS 2004B oscilloscope, providing precise readings during waveform evaluations and validations.
- Signal Quality: The square wave exhibited clean edges, confirming the efficiency of the pulse-width modulation technique employed in the design.
- Low Frequency Performance: The triangle and sawtooth waveforms displayed acceptable performance at low frequencies, showcasing versatility in the system's waveform generation capabilities.
- Waveform Stability: The sine wave remained stable up to 40 kHz, demonstrating the effectiveness of the ESP32's DAC in maintaining signal integrity.
- FFT Analysis: The frequency analysis revealed stability across the 1000–4500 Hz band, enabling effective spectrum visualization on the OLED interface.



Circuit Diagram

Results Overview

- The generated waveforms were consistently clean, demonstrating high fidelity across different frequencies, meeting engineering standards for waveform generation.
- Limitations in the DAC were identified, particularly in bandwidth, affecting maximum output frequencies during specific waveform generation scenarios.
- The FFT analysis showed exceptional stability, effectively capturing frequency components within the expected bandwidth, confirming reliable spectral performance.
- Wi-Fi Responsiveness: The system exhibited strong Wi-Fi responsiveness, allowing real-time control and monitoring through a user-friendly interface without noticeable latency.
- The fixed amplitude PWM method maintained consistent output levels, ensuring waveform integrity during various operational conditions, enhancing overall performance.

Cost and Limitations

- Cost Estimate: The total cost of the project is approximately ₹700, making it an affordable option for student projects.
- Timing Challenges: Challenges in triangle/saw waveform timing can lead to distortion, impacting the overall performance of signal generation.
- The FFT resolution is constrained by the sampling rate, which can limit the detail available in spectral analysis.
- Bandwidth Limits: The DAC/ADC bandwidth limits restrict the frequency range, affecting the accuracy of high-frequency waveform generation in practice.
- Future enhancements may include an external DAC for improved waveform quality and the potential for a dual-channel design implementation.

Component	Quantity	Approx. Unit Cost (INR)	Total Cost (INR)
ESP32-WROOM Development Board	1	350	350
SH1106 128×64 OLED Display (I^2C)	1	150	150
Breadboard (standard 830-point)	1	100	100
Resistors (100 kΩ, 1 kΩ, misc.)	Assorted	2 each (approx.)	~20
Capacitors (100 nF, 1 µF)	Assorted	2 each (approx.)	~20
Jumper Wires	1 set	30	30

Thank You