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Android-Based Oscilloscope for Signal Acquisition and Visualization

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Abstract: ***In this project, an ESP32–ADS1115 embedded hardware framework is used to design and implement a wired and wireless signal acquisition system with real-time visualisation on an Android-based oscilloscope. The ADS1115, a 16-bit precision analog-todigital converter, interfaces with the ESP32 via wired I²C communication to acquire low-frequency analogue signals with enhanced resolution and accuracy. The ESP32 microcontroller is integrated into the system for high-speed data processing and wireless communication. Signal data is either wirelessly transferred to an Android device via Wi-Fi or Bluetooth or recorded via wired inputs. The Termux-X11 environment is used to process and visualise the received data, allowing for oscilloscope-like functionality and timedomain waveform display on a portable platform. The suggested framework is appropriate for field measurement, laboratory, and educational settings since it provides a small, affordable, and power-efficient substitute for traditional oscilloscopes. The effectiveness of the suggested embedded system for portable signal analysis is validated by experimental results showing accurate waveform rendering, dependable signal acquisition, and stable wireless communication.***

Keywords: ESP32, ADS1115, Signal Acquisition, Android Oscilloscope, Termux-X11, Embedded System, Wireless Communication, Real-Time Visualization

I. INTRODUCTION

An electronic oscilloscope is an electronic test instrument that allows observation of constantly varying signal voltages in electronics, embedded systems and communication engineering laboratories in schools and universities. Oscilloscopes are widely used instruments for analysis of signals and debugging circuits by engineers and students. However, standard oscilloscopes are expensive, bulky and not portable which limits the fraction of students, field engineers and low-cost embedded systems and equipment that can use them. Advances in microcontrollers, handheld computers and smartphones are now making it practical to build low-cost, portable oscilloscopes controlled by smartphone applications and using embedded processors.

Recent advancements in embedded systems, especially microcontrollers like the ESP32, have made it possible to efficiently acquire, process, and communicate wirelessly using a single low-cost platform. The ESP32 is a potent microcontroller with integrated Bluetooth and Wi-Fi, which makes it ideal for Internet of Things (IoT) applications and real-time data transfer. Nevertheless, the ESP32's internal analog-to-digital converter (ADC) has poor resolution and accuracy, which might not be enough for accurate signal measurement. External high-resolution ADCs, like the ADS1115, can be incorporated into the system to get around this restriction. With its 16-bit resolution, programmable gain amplification, and I²C communication, the ADS1115 makes precise and dependable signal digitisation possible.

Modern Android smartphones offer powerful processing capabilities, high-resolution displays, and portable computing environments in addition to hardware advancements. Smartphones are the perfect tool for visualising and analysing signals because of these characteristics. With Termux, a Linux-based terminal emulator for Android, users can run Python and other programming languages and visualise waveforms in real time using open-source plotting libraries. Without the need for specialised oscilloscope hardware or the creation of unique Android applications, an Android device can be converted into a portable oscilloscope by utilising Termux software.

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Among the many benefits of the suggested system are its portability, affordability, high measurement resolution, adaptability in terms of communication modes, and simplicity of use. It makes it possible to monitor signals using widely accessible smartphones and does away with the need for large, cumbersome lab equipment. This system is especially helpful for lab experiments, embedded system development, education, and portable signal monitoring applications.

II. LITERATURE REVIEW

Oscilloscopes play a very important role in visualizing and analyzing electrical signals in laboratories, research and industry. Traditional oscilloscopes are however, costly and large-scale making them less accessible to students and low-cost systems. To beat these drawbacks, studies have been done to come up with small and low cost substitutes with microcontrollers, PCs and mobile devices. Initial work had shown PC based oscilloscopes using minimum data acquisition hardware to decrease the system price and complexity [1]. Subsequently, the microcontroller-based designs based on platforms like Arduino allowed portable and cheap signal measurement systems that could be used in education [2], [3].

The latest developments have taken advantage of smartphones as a visualisation platform by enhancing accessibility and portability [4]. Moreover, remote monitoring and real-time transmission of data in portable oscilloscopes have been made possible by the wireless communication and IoT technologies [7], [13], [15]. Software-defined and PC-based oscilloscopes have also been considered and further functions like spectrum analysis have been added to the oscilloscopes to increase signal processing [8]-[10].

Other contributions in the field of work are the Qscilloscope of Tew and Goi, PC-based real time system [11], and multifunctional virtual oscilloscopes that showcase the capability of sophisticated software [16]. On the whole, these changes are pointing to the direction of portable, low-cost and software-driven oscilloscopes. It is against this trend that the current work suggests a small scale signal acquisition system, real-time mobile display, which is affordable, portable, and can be used in education and experiments.

III. METHODOLOGY

A. *Block Diagram*

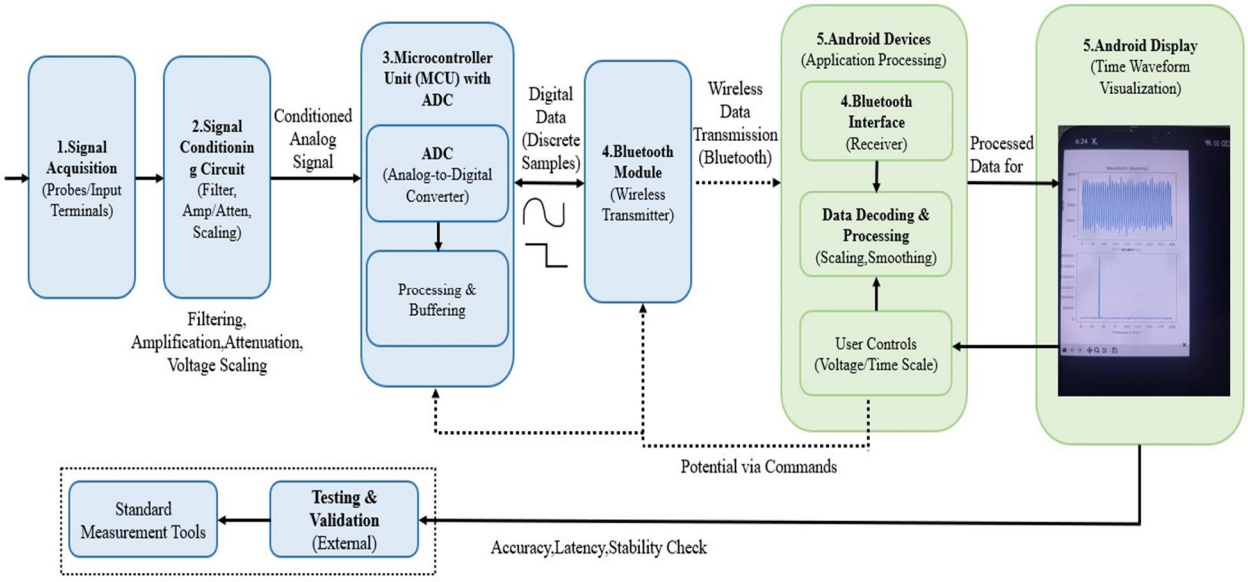


Fig. 1 Block Diagram of Portable Android Oscilloscope

The block diagram above shows compatibility with the ADC, the system first obtains an analog signal from the device being tested using input probes. This signal is then conditioned using filtering, amplification or attenuation, and voltage scaling. The ESP32 microcontroller interfaced with the ADS1115 ADC performs basic processing and buffering before converting the conditioned signal into high-resolution digital data. An Android device receives the digital data wirelessly through Bluetooth. The application on the Android device decodes and processes the data, applies user-specified voltage and time scaling, and shows the waveform in real time. Finally, standard measurement tools are used to assess system performance in order to confirm accuracy, latency, and overall stability.

B. Flowchart

As shown in the flowchart depicted in the figure, the proposed ESP32-ADS1115-based signal acquisition and Android oscilloscope system performs the signal acquisition, high-precision analysis and analog-to-digital conversion, and processing and wired and wireless transmission of the acquired signal. Using Termux and Termux X-11 to acquire and display data, the waveform data can be plotted on an Android phone in real time. This system can be implemented using a portable modular design and is inexpensive compared to commercial oscilloscopes.

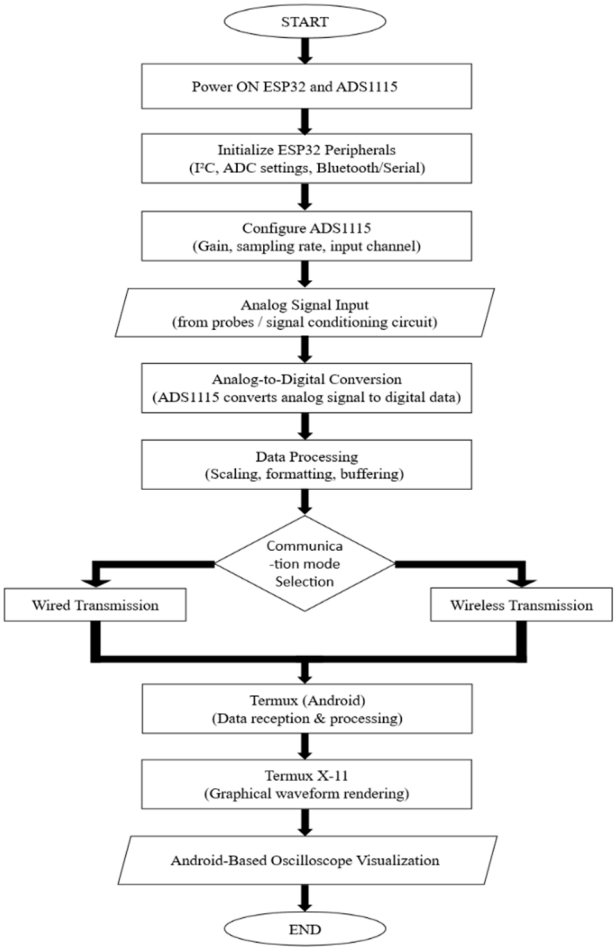


Fig. 2 Flow Diagram of Portable Android Oscilloscope

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C. System Architecture

An analog signal source, a signal conditioning circuit, an ADS1115 ADC, an ESP32 microcontroller, and an Android smartphone make up the suggested system. The ESP32, which is programmed using Arduino, manages data acquisition and transmission, while the ADS1115 carries out high-resolution analog-to-digital conversion. Using Termux, which offers a Linuxbased environment for data reception and processing on Android, and Termux X-11, which supports X11-based plotting and oscilloscope-like display, the Android device receives the digitized data and shows real-time waveforms.

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D. Hardware Implementation

1) ESP32 MicroController: The ESP32 is a low-cost, low-power microcontroller developed by Espressif Systems. It features built-in Wi-Fi and Bluetooth connectivity, making it suitable for Internet of Things (IoT), embedded systems, and wireless data acquisition applications.

- Operating Voltage: 3.0 V – 3.6 V (3.3 V nominal)
- Communication Interfaces: UART (wired), I²C (ADS1115), Bluetooth (wireless)
- Processor: Dual-core 32-bit Xtensa® LX6, up to 240 MHz
- Memory: 4 MB Flash, 520 KB SRAM
- Purpose: The ESP32-WROOM-32 is a powerful, low-cost Wi-Fi and Bluetooth-enabled microcontroller module. It features a dual-core 32-bit processor, operates at 3.3 V, and supports I²C, UART, SPI, and GPIO interfaces, making it well-suited for realtime data acquisition and wireless communication in the proposed oscilloscope project.

2) ADS115 Analog-to-Digital Converter: The ADS1115 is a high-precision, 16-bit analog-to-digital converter (ADC) developed by Texas Instruments. It is commonly used to convert analog signals into high-resolution digital data for microcontroller-based systems.

- Operating Voltage: 2.0 V – 5.5 V
- Resolution: 16-bit ADC
- Communication Interface: I²C
- Input Channels: 4 single-ended or 2 differential
- Sampling Rate: Up to 860 SPS

Purpose: The ADS1115 acts as a high-resolution external ADC, converting conditioned analog signals into 16-bit digital data for the ESP32 via I²C. Its higher accuracy and programmable gain enable precise signal acquisition and reliable real-time Android oscilloscope visualization.

3) Signal Conditioning Circuit: A signal conditioning circuit is used to scale, filter, and protect the input signal, ensuring compatibility with the ADS1115 input voltage range and improving measurement reliability.

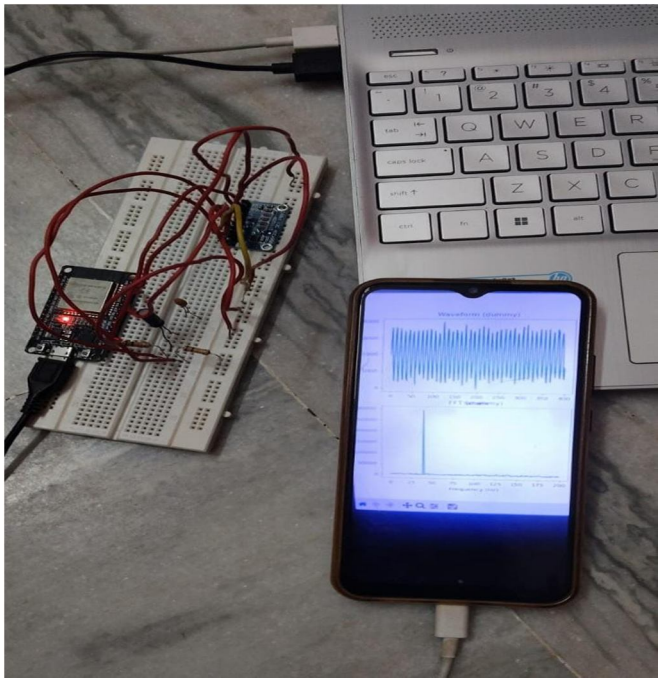


Fig. 3 Hardware Implementation

E. Software Implementation

The software implementation of the proposed ESP32–ADS1115 signal acquisition system enables real-time signal reception, processing, and visualization on an Android device using the Termux and Termux-X11 environment. The software architecture consists of two main parts: ESP32 firmware and Android-based visualization software.

1) ESP32 Firmware

The main processing unit of the proposed signal acquisition system is the ESP32 firmware. ESP32 microcontroller is programmed with Arduino IDE, and it is also set to communicate with ADS1115 analog-to-digital converter via the I²C communication protocol. The ESP32 will act as the I²C master device, with the ADS1115 acting as the slave device in this configuration. The firmware programmed in during the initializing stage establishes the I²C bus by assigning the SDA and SCL pins, communication frequency, and device address of the ADC. After communication is established, the ADS1115 is programmed with proper programmable gain amplifier (PGA) parameter settings and sampling rate parameter settings to be able to acquire low-frequency analog signals with high resolution. The ESP32 is configured to read 16-bit digital conversion values of the ADS1115 at a fixed rate after the start of the configuration. The raw ADC output values are calculated mathematically into the appropriate voltage levels based on calculations of reference voltage and resolution. This conversion is useful in the interpretation of the measured analog signals meaningfully. In order to sustain real-time performance, the firmware uses effective timing control and buffering methods in an attempt to prevent data loss and ensure uniform sampling. The ESP32 has both the wired and wireless modes of communication to transmit data. In wired mode, the sampled data is passed to the Android device through the USB serial communication where the data is transferred directly and stably. Using the Wi-Fi and Bluetooth integrated on its board, the ESP32 can use socket-based communication or Bluetooth Serial Profile (SPP) to send data in wireless mode. This enables the system to be used in the laboratory and even in the remote field. All in all, the ESP32 firmware guarantees synchronized signal intake, precise data transformation, and stable real-time transmission to the
Android-based visualization unit

2) Andriod Software Implementation Using Termux

Python is installed in Termux to manage the acquisition and visualisation of signals. In wired mode, USB serial (via PySerial) is used to establish communication with the ESP32, whereas Bluetooth or Wi-Fi sockets are used for wireless communication. ADC samples are continuously received by the Python script, which efficiently uses NumPy to process them after converting them into voltage values using appropriate scaling and reference calculations.

Matplotlib is used to implement real-time waveform visualisation, which shows voltage versus time in a manner akin to an oscilloscope. All things considered, Termux turns the Android gadget into a small, portable signal monitoring and analysis system.

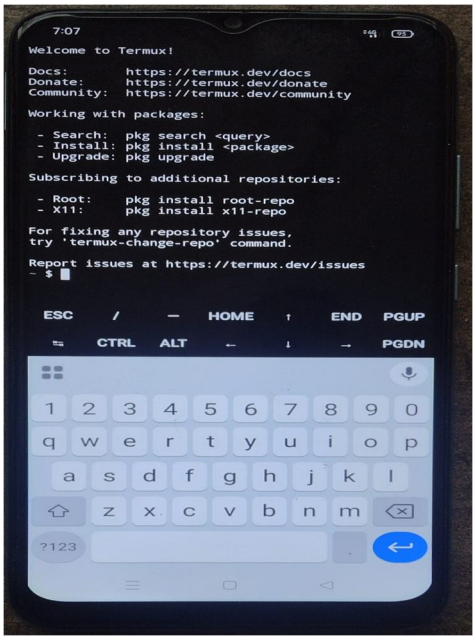


Fig. 4 Termux Software Interface

The figure Termux software is a terminal emulator for Android that offers a Linux-like environment without requiring root access. It serves as the primary software platform in the suggested system to receive, process, and display signal data sent from the ESP32. This makes the system portable and affordable while doing away with the requirement for a separate computer.

3) Graphical Visualization Using Termux-X11

Termux-X11 is a graphical addon that can make use of X11 display server in the Termux environment, so that GUI-based programs can also be executed on an Android platform. Termux being mainly a command-line operating system, Termux-X11 gives the required graphical interface to view real-time waveforms in the proposed system.

When the Python visualization script is run in Termux the graphical output (e.g. Matplotlib plots) is redirected into the Termux-X11 display server. Termux-X11 displays the waveforms of voltages verses time in a different display on the Android screen. The waveform is plotted dynamically as the new signal samples in the ESP32 are received, and it ensures smooth and real-time visualization.

This configuration enables a user to examine significant signal properties, including the shape of a signal, change in amplitude, frequency response, and signal permanence. Termux-X11 is also an effective display rendering and refresh management system that provides responsive and transparent graphical display.

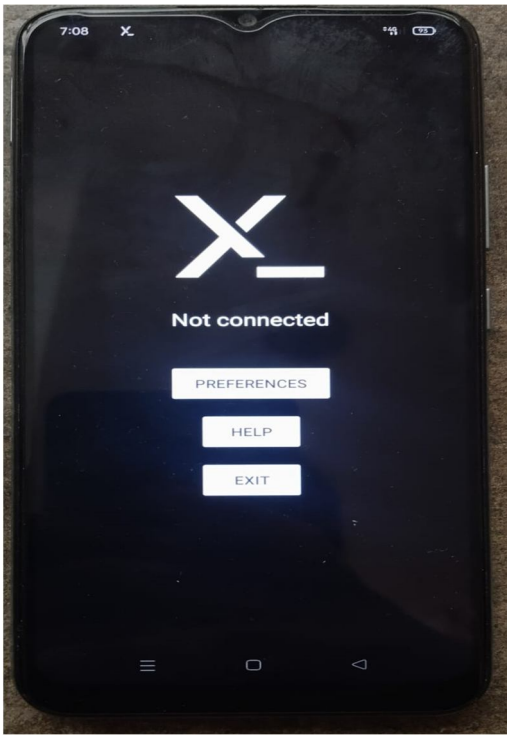


Fig.5 Termux-X11 Graphical Interface

The figure Termux-X11, in general, adds the feature of real-time graphical display to the already existing termux that allows the Android smartphone to become a portable and inexpensive and, in size, similar version of an oscilloscope that is able to monitor and analyze the signal in real-time without using additional computers or specific display devices.

IV. COMMUNICATION METHODS

A. Wired Communication Mode

In wired communication mode, the ESP32 transmits signal data directly to the Android device through a USB connection. This is typically achieved using a USB-to-Serial interface, where the ESP32 sends digitized data via UART serial communication, and the Android device receives it through a USB OTG (On-The-Go) connection.

The ESP32 reads analog signal samples from the ADS1115 analog-to-digital converter and converts them into digital values. These digital samples are transmitted continuously through the serial port at a defined baud rate (for example, 115200 bps). The Android device, running a Python script in the Termux environment, receives the serial data using the PySerial library.

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Advantages of Wired Communication:

- High data transfer reliability
- Low latency and minimal signal loss
- Stable and continuous data transmission
- No interference from external wireless sources

B. Wireless Communication Mode

In wireless communication mode, the ESP32 transmits signal data to the Android device using built-in wireless communication technologies such as Wi-Fi or Bluetooth. This eliminates the need for physical connections and allows remote monitoring of signals.

1) Wi-Fi Communication

The ESP32 uses its integrated Wi-Fi module to transmit data over a wireless network. The ESP32 can operate either as:

- Wi-Fi Access Point (AP), or
- Wi-Fi Station connected to an existing network

The ESP32 sends signal data to the Android device using socket communication over TCP or UDP protocols. The Android device, running a Python script in Termux, receives the incoming data through a network socket and processes it for visualization.

Advantages of Wi-Fi Communication

- Long communication range
- High data transfer speed
- Supports real-time signal transmission
- Suitable for remote monitoring

2) Bluetooth Communication

The ESP32 also supports Bluetooth communication for short-range wireless data transfer. The ESP32 transmits signal data using Bluetooth Serial communication, and the Android device receives the data using Bluetooth socket communication.

Bluetooth communication consumes less power compared to Wi-Fi and is suitable for portable and battery-powered applications.

Advantages of Bluetooth Communication

- Low power consumption
- Wireless and portable operation
- Easy device pairing

V. RESULT AND CONCLUSIONS

The experimental results demonstrate reliable performance of the proposed portable signal acquisition system. The timedomain waveform exhibits stable and periodic behavior with consistent amplitude levels, confirming accurate analog-to-digital conversion and proper signal conditioning. The absence of clipping or irregular fluctuations indicates stable sampling and effective noise reduction.

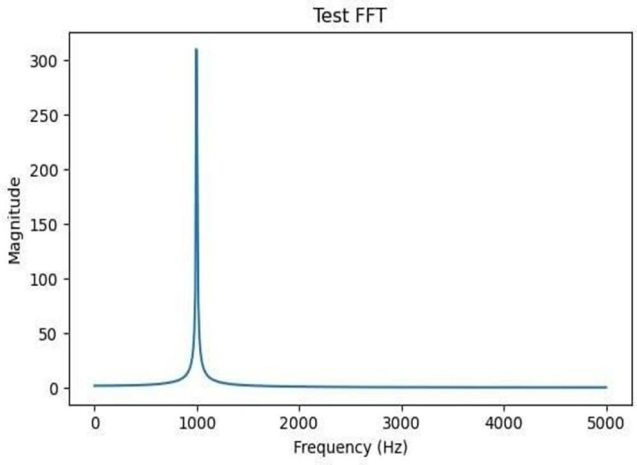


Fig. 6 FFT Spectrum of Test Signal

Figure 6 represents Fast Fourier Transform (FFT) of the test signal. The graph indicates the frequency spectrum obtained following application of FFT algorithm to the sampled data. The horizontal axis represents the frequency in Hertz (Hz) and the vertical axis is the magnitude of the spectral components. The figure shows how the frequency- domain analysis was successfully applied in the developed system.

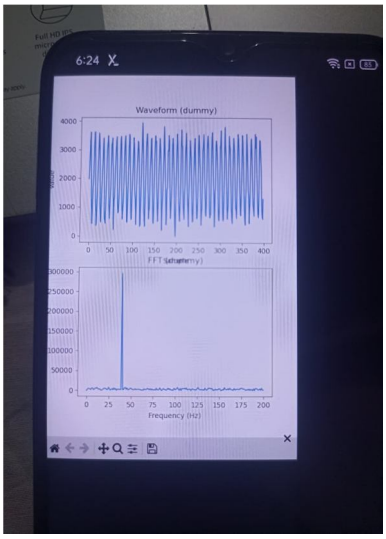


Fig. 7 Time and Frequency domain plots

Figure 7 shows the frequency-domain analysis using FFT shows a clear and dominant fundamental frequency component, validating correct spectral extraction. The low noise floor and minimal harmonic distortion further indicate that the system maintains signal integrity during acquisition and processing.

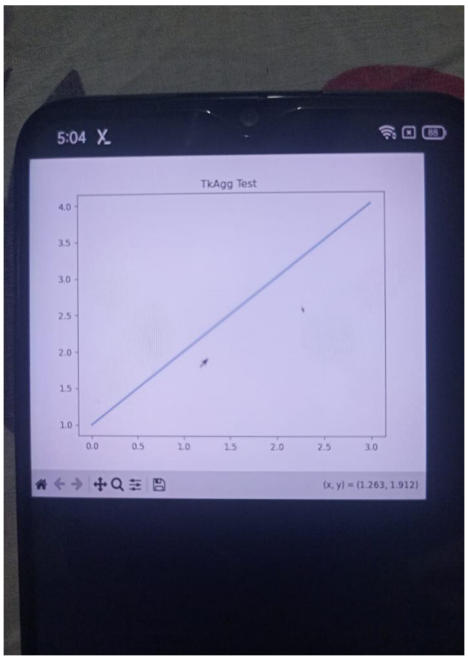


Fig.8 TKAgg plot rendering Test

Figure 8 is the successful graphical rendering through the Python TkAgg backend in the Termux-X11 environment confirms smooth real-time visualization on the Android platform. The combined results verify accurate data acquisition, efficient serial communication, reliable signal processing, and effective mobile-based waveform display, demonstrating the feasibility of the system as a compact and low-cost alternative for basic oscilloscope applications.

VI. ACKNOWLEDGMENT

Yeshwanth Botsa supervised the project. Ch. Likitha contributed to hardware design , implementation and managed documentation. B. Naidu developed the software interface.

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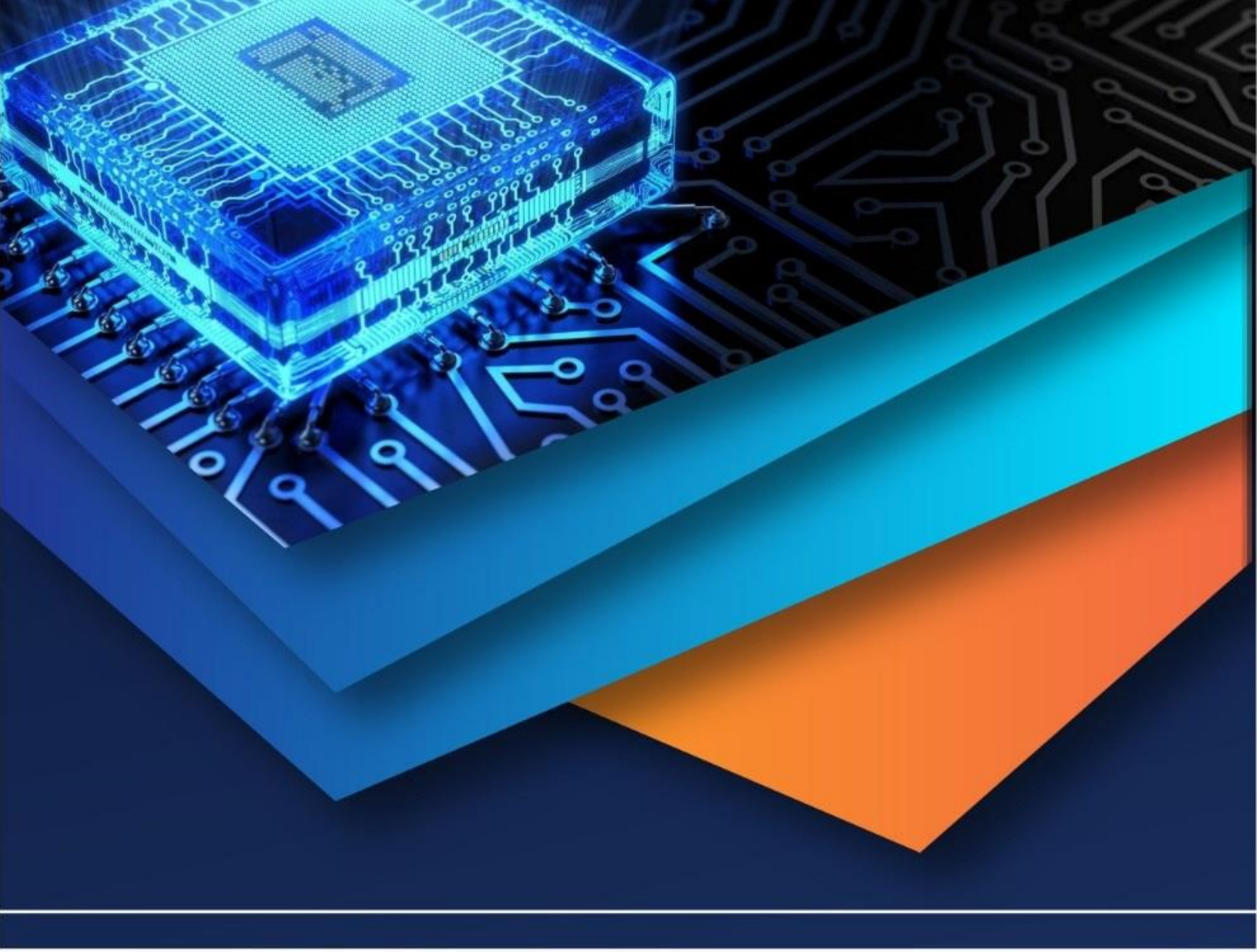
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