



An-Najah National University

Faculty of Engineering & information technology

Computer Engineering department

Presented in partial fulfillment of the requirements for
Bachelor degree in Computer Engineering

Graduation project 2

SynLab

IoT based electronics system

Students:

Ghassan Qasrawi (12111991)

Adel Qadi (12112188)

Supervisors:

Dr. Raed Qadi

Dr. Manar Qamhieh

Acknowledgment:

Praise be to Allah, lord of worlds, who taught us what we know, and enabled us to complete this research. We show our thanks and gratitude in it to our families for the continuous support and patience throughout the past years. We would like to sincerely show our honest gratitude to our supervisors Drs. Raed Qadi and Manar Qamhieh whose encouragement, expert guidance, and insightful suggestions were instrumental in the successful completion of the project. We also extend our appreciation to the Computer Engineering Department at An Najah National University along with its administrators and supervisors for providing the suitable productive academic environment and the required resources and skills to ensure successful completion of this project.

We can't forget to acknowledge and thank everyone who contributed their time, effort, insight, and assistance during the preparation of this project. And we hope this work shows the knowledge and effort invested throughout the development of this graduation project.

Disclaimer:

This report was written by students Ghassan Qasrawi and Adel Qadi at the Computer Engineering Department, Faculty of Engineering and Information Technology, An-Najah National University. It has not been altered or corrected, other than editorial corrections, as a result of assessment, it may contain language as well as content errors. The views expressed in it together with any outcomes and recommendations are solely those of the students. An-Najah National University accepts no responsibility or liability for the consequences of this report being used for a purpose other than the purpose for which it was commissioned.

Table of contents:

Chapter 1: Introduction	10
1.1 General background	10
1.2 Objectives	10
1.3 Organization of the report.....	10
Chapter 2: Theoretical background and literature review.....	11
2.1 Theoretical background	11
Microcontrollers and Embedded Systems	11
Digital and Analog Laboratory Instruments	11
Internet of Things (IoT) and Wireless Connectivity	11
Modular System Design and Data Management	11
Human-Machine Interfaces (HMI) and Software Platforms	12
2.2 Literature review	12
2.2.1 Microcontroller-Based Electronic Laboratory Measurement Devices	12
2.2.2 Improving Learning Outcomes in Microcontroller Courses Using an Integrated STM32 Laboratory	12
2.2.3 Integrating Instrument Networking & Programming into Electronics Curricula .	12
2.2.4 Impact of IoT on Learning and Smart Labs	13
2.2.5 IoT-Based Lab System for Teaching	13
Chapter 3: Constrains and Earlier Coursework	14
3.1. Constrains and limitations	14
3.2. Standards / Codes	14
3.3. Earlier course work.....	14
Chapter 4: Methodology	15
4.1. System structure and design	15
4.1.1. System’s overall design	15
4.1.2. System’s structure and modules	15
4.1.2.1. Function generator.....	15
4.1.2.2. IC Tester	16
4.1.2.3. PIC Programmer	17

4.1.2.4.	Oscilloscope	18
4.1.2.5.	DC Monitor	19
4.1.2.6.	AC Monitor	20
4.1.3.	Screen interface	21
4.2.	Hardware components	27
4.2.1.	Arduino Mega 2560	27
4.2.2.	Arduino Uno R3 microcontrollers	27
4.2.3.	NodeMCU ESP32 Dev Boards	28
4.2.4.	Nextion 3.5" Discovery Display	28
4.2.5.	Zero Insertion Force (ZIF) sockets	29
4.2.6.	PZEM-004T V3 Power measurement module	29
4.2.7.	INA219 Current and voltage sensor	30
4.2.8.	LM324 Operational Amplifiers IC	30
4.2.9.	20 K Ω Potentiometer	30
4.2.10.	Carbon resistors (Different Ω values)	31
4.2.11.	Solderless Boards (Breadboards)	31
4.2.12.	Jumper wires	32
4.2.13.	Female DC Power Jack Adapter Connector Plug Button Switch	32
4.2.14.	Power adapters from AC 220V to DC 12V and 5V	32
4.3.	Mobile application	33
4.3.1.	Main page	33
4.3.2.	IC tester page	34
4.3.3.	Test details page	35
4.3.4.	Function generator page	36
4.3.5.	Oscilloscope page	37
4.3.6.	AC / DC Monitor page	38
4.3.7.	AC Monitor Live feed page	39
4.3.8.	DC Monitor Live feed page	40
Chapter 5: Discussion and Results		41

Chapter 6: Conclusion	43
6.1. Conclusion	43
6.2. Future work	43
6.3. References	44

Table of figures:

Figure 1:SynLab Overall Design	15
Figure 2:Function generator module	16
Figure 3: IC Tester module	16
Figure 4:PIC Programmer module.....	17
Figure 5:PIC Programmer Interface	17
Figure 6:Oscilloscope module.....	18
Figure 7: DC Monitor module	19
Figure 8AC monitor module:	20
Figure 9:Main interface	21
Figure 10:Auto testing interface.....	21
Figure 11:Manual test interface	22
Figure 12:Auto testing interface 2	22
Figure 13: Manual test interface 2	23
Figure 14:Manual testing interface 3	23
Figure 15:Wifi networks interface	24
Figure 16: Function generator interface.....	24
Figure 17:AC Monitor interface	25
Figure 18:DC Monitor interface	25
Figure 19: Oscilloscope interface	26
Figure 20:Arduino Mega 2560	27
Figure 21:Arduino Uno R3	27
Figure 22: ESP32 Development board	28
Figure 23:Nextion display.....	28
Figure 24: IC ZIF Sockets.....	29
Figure 25: PZEM-004T V3 module	29
Figure 26: INA219 sensor	30
Figure 27: LM324.....	30
Figure 28:20K Ohms POT	31
Figure 29:10K ohms carbon resistor	31
Figure 30: Breadboards.....	31
Figure 31: Jumper wires	32
Figure 32: Female DC Power Jack Adapter Connector	32
Figure 33: 12V and 5V DC Power adapters.....	32
Figure 34:Mobile main page	33
Figure 35: IC Tester page.....	34
Figure 36: IC test details page	35

Figure 37: Function generator page.....	36
Figure 38: Oscilloscope page	37
Figure 39: AC / DC monitor page	38
Figure 40: AC monitor page	39
Figure 41: DC Monitor page.....	40

Project's Abstract:

SynLab project introduces a modular, IOT based electronic laboratory platform that merges several important digital and analog instruments into a single connected ecosystem. The system incorporates modules like a PIC programmer, IC tester, oscilloscope, waveform generator and many others, each is equipped with an ESP32 microcontroller for wireless connectivity and synchronization via a centralized software interface.

This project is significantly important because traditional electronics laboratories rely on bulky, expensive and standalone equipment, which restricts interconnectivity, accessibility and clearness, SynLab handles these challenges by implementing a networked and scalable smart lab which enables students and educators to execute experiments more efficiently and effectively. It bridges the gap between modern IOT technologies and physical hardware tools which makes laboratory experience more engaging and remotely accessible.

Main objectives of SynLab include designing and implementing an integrated digital laboratory system with several smart instruments, developing an IOT based communication framework that connects all modules in the system, building a software platform to allow users control, visualize and record data from all modules at real time, and providing a powerful extendable lab solution for developers and engineering students.

The project will be developed through an iterative modular approach where each device and module will contain a small microcontroller with an independent ESP32-based node connected which will communicate with each other via a central hub containing a main microcontroller to coordinate operations and data flow. For the software side, a Flutter based web interface, and mobile application will connect with the central hub module to manage devices and enable users to implement different operations on each module.

Although similar ideas exist - such as USB-based IC testers or PIC programmers - but few systems provide a complete integrated and functional laboratory environment with IOT modular connectivity. SynLab combines multiple devices and laboratory instruments to provide a flexible, effective and efficient educational environment.

Chapter 1: Introduction

1.1 General background

Modern electronics education increasingly requires flexible, interactive, and digitally connected laboratory environments, while the majority of academic laboratories are still equipped with isolated bulky, and rather expensive instruments that were not designed for operation within a unified integrated system. Moving the workflows of engineering toward automation, remote access, and data-driven experimentation, traditional lab setups—without synchronization among instruments, with manual data recording, and with restricted physical access—stand in the way of learning and innovation. At the same time, rapid development of IoT technologies and embedded systems brings new opportunities to transform physical labs into intelligent networked environments. By embedding connectivity, control, and data sharing directly into laboratory instruments, it becomes possible to create a unified digital ecosystem in which hardware tools will be able to communicate, coordinate, and be managed through software platforms. This evolution enables more efficient experimentation, remote operation, real-time visualization, and scalable expansion, forming the conceptual foundation upon which SynLab system is built.

1.2 Objectives

The key goal of SynLab is to design and implement a smart, modular electronic laboratory that integrates numerous devices covering digital and analog instruments into a single IoT-enabled system. The system should be capable of providing flexibility for the engineering students and developers with an open platform from which utilities can access, control, and monitor an IC tester, programmer, oscilloscope, signal generator, and other tools with the help of a software frontend. Another major objective is to establish a robust communication framework to enable every hardware module to share data with others and to synchronize their operations in real time. Furthermore, SynLab aims at enhancing the educational laboratory by means of logging data, remote access, and automated workflows for experiments. Overall, the system is designed to provide a versatile and efficient laboratory environment that enhances learning, experimentation, and real-time interaction with electronic systems

1.3 Organization of the report

The report's organization aims to give readers a thorough grasp of SynLab. Chapter 2 explores the theoretical Background and previous studies after this introduction, laying the foundation for this project. Chapter 3 dives into different constraints and earlier course work. The building process is described in Chapter 4. In Chapter 5, discussion and results are presented, providing an understanding of the project's results. In Chapter 6, recommendations and conclusions are combined to give a comprehensive summary of the project's journey.

Chapter 2: Theoretical background and literature review

2.1 Theoretical background

Microcontrollers and Embedded Systems

A microcontroller acts as an integrated small component used in the development of an embedded system. Each SynLab module features an ESP32-based microcontroller. A microcontroller offers both information processing and Wi-Fi services. It links an embedded instrument to both sensors and other electronic devices. It offers services in automation, integration, and measurements. Because of this, each SynLab device will operate independently while staying connected to the rest.

Digital and Analog Laboratory Instruments

The use of traditionally designed laboratory instruments, like oscilloscopes, waveform generators, and IC testers, is vital in electronic experimentation. SynLab combines these instruments with a modular digital environment. This allows users to accomplish electronic measurements, perform signal analysis tasks, and programming with maximum ease. The knowledge of operating principles of these instruments is completely vital to accomplish functional modules.

Internet of Things (IoT) and Wireless Connectivity

IoT implies a series of physical electronic devices that communicate through the use of the Internet of Things network. IoT plays an important role in SynLab by allowing wireless connections between all the modules in the system through the use of IoT. The significant concepts in IoT that SynLab relies on include client-server connection, message protocols that IoT applies, and the use of data synchronization that helps in the efficient running of the system.

Modular System Design and Data Management

The approach of a modular design allows a complex system composed of a series of elements that, while integrated as a cohesive system, at the same time function independently as detached units, hence providing a significant advantage in system complexity management. The system of syn-lab involves a series of modules communicating effectively through a focal hub, requiring understanding of network system architectures, system acquire, and structured data handling to function effectively as a system in this regard.

Human-Machine Interfaces (HMI) and Software Platforms

Intuitive interfaces allow users to interact effectively with the laboratory system. SynLab uses an application based on Nextion and Flutter for centralizing HMI, real-time visualization, device control, and data logging. The theoretical elements will involve GUI design principles, event-driven programming, and communication APIs interfacing with connected hardware for an easy and interactive user experience.

2.2 Literature review

This section will present some of the important research domains related to the development of the SynLab system, including IoT-based laboratory systems, remote electronic instrumentations, and embedded system integration. These research domains offer important research directions in utilizing advanced technologies for developing interactive, interconnected, and accessible environments for electronics experimentation or electronics education.

2.2.1 Microcontroller-Based Electronic Laboratory Measurement Devices

This paper presents an overview of the development of a portable and cost-effective oscilloscope and wave generator system based on a microcontroller device, specifically a PIC24FJ128GC006. This research is categorized according to hardware device, signal capture through ADC and DAC, and software development for a GUI interface, making this proposal suitable for SynLab's vision.[1]

2.2.2 Improving Learning Outcomes in Microcontroller Courses Using an Integrated STM32 Laboratory

This educational assessment represents a microcontroller interface that combines the basic peripherals like timers and PWM a student should have at hand to perform experiments, digging into the world of embedded systems in real-time signal validation, a subject germane to instrument development in a manner such as SynLab's.[2]

2.2.3 Integrating Instrument Networking & Programming into Electronics Curricula

This research proposes a networked laboratory design in which oscilloscopes, signal generators, and power supplies are interconnected in a LAN network using instrument command protocols (SCPI). It also stresses instrument networking as well as automation with its associated benefits for pedagogical programming transparency, as in the case of SynLab's distributed instrument network.[3]

2.2.4 Impact of IoT on Learning and Smart Labs

A systemic review of devices regarding IoT in the context of a learning environment reveals that “IoT enabled lab facilities enhance the technological and educational affordances of an environment and provide valuable opportunities for learners to become more engaged and to develop more hands-on experiences and integration of hardware and software skills, which are of significant value to engineering learners.”[4]

2.2.5 IoT-Based Lab System for Teaching

Researchers created a lab system based on IoT that supports remote education and access to experiments in times of crises, thus promoting distance education and interaction with real labs through internet technology. This exemplifies how IoT can be utilized in bridging the learning curve from theory to physical experimentation with electronics.[5]

Though microcontroller-based and IoT technology-related labs have demonstrated their potential in providing significant advantages in terms of improving ‘hands-on’ experience, accessibility, and device interconnection [1]-[5], many of the presently implemented solutions are restricted in their functionality to single or limited instruments in their focus on providing remotely accessible laboratories or supporting their use in educational settings. Thus, SynLab is designed as an overall system that integrates several types of instruments in electronic domains like oscilloscopes, waveform generators, IC testers, etc., to be operated together as part of an overall system with their respective control software, thereby not just improving the overall ‘hands-on’ experience but aiding in providing better educational facilities in the field.

Chapter 3: Constrains and Earlier Coursework

3.1. Constrains and limitations

- Modules depend mainly on microcontrollers (like Arduino and ESP32) which may have limited processing power or lack the advanced signal processing requirements.
- Heavy load on the ESP32 due to simultaneous connectivity between different modules and the mobile application.
- Use of breadboards due to complexity of building IoT system as PCBs and to not have any flaws.

3.2. Standards / Codes

- We used Arduino IDE along with many useful libraries to develop and upload the required software to control and manage Arduino and NodeMCU devices.
- We implemented the mobile application using Flutter with Hive database for easy data storing.
- We used MQTT for managing communication between modules to achieve IoT concept and to communicate with the mobile application.

3.3. Earlier course work

- Microprocessor and microcontroller courses, during which we gained knowledge of how to control hardware components and build different apps in our project.
- Electronics and Signal processing courses helped greatly in understanding vital topics for the project.
- Critical Thinking courses, which helped us research specific issues, as well as enhance our documentation and report writing skills.
- Self-learning.

Chapter 4: Methodology

The current chapter will discuss the methodology that was followed in designing, developing, and building SynLab, focusing specifically on how this system allows a modular IoT-based electronics laboratory for students, professors, and enthusiasts alike. Additionally, this chapter will discuss and describe specifically the parts and components that are integrated in order to form this system, as well as those tools and interfaces that allow for real-time control, monitoring, and visualization of every laboratory module along with the software interfaces.

4.1. System structure and design

4.1.1. System's overall design

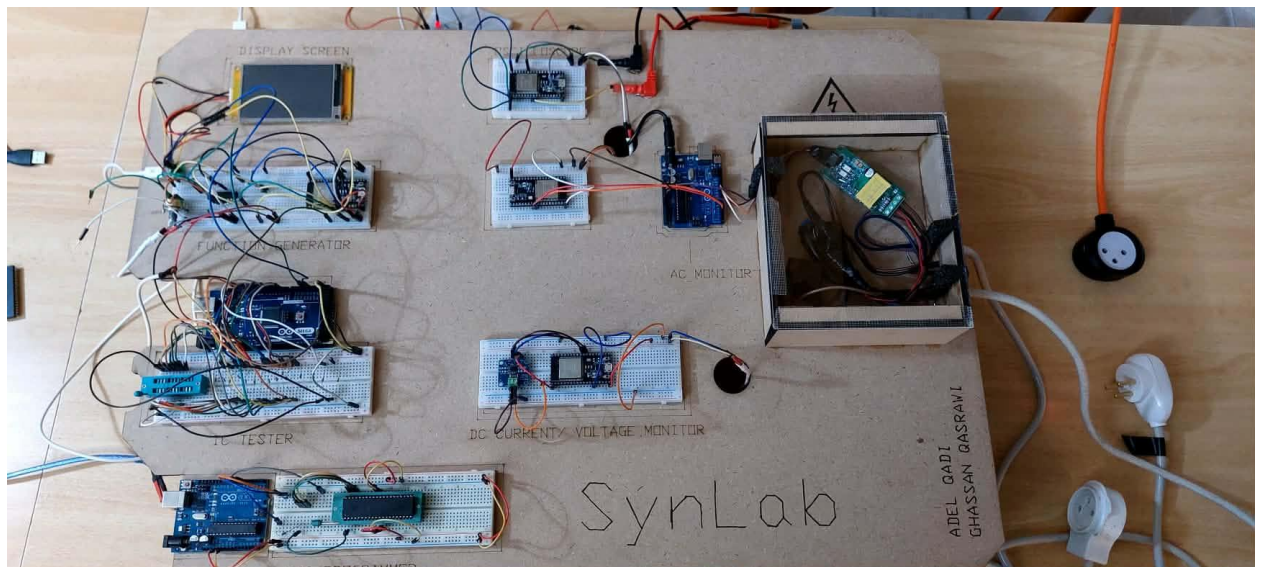


Figure 1: SynLab Overall Design

4.1.2. System's structure and modules

The system includes multiple modules that communicate with each other and with the mobile application. These modules are as follows:

4.1.2.1. Function generator

The function generator module consists of a single ESP32 development board that can generate sine, square and triangle waves using the DAC and the PWM it provides, it is also responsible for the Nextion display UI management and connecting to WIFI.

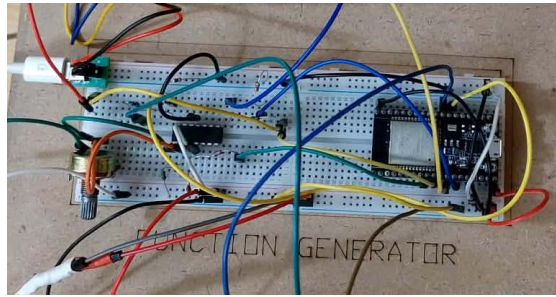


Figure 2:Function generator module

It's connected with the IC tester module too, so we developed two voltage dividers for the RX Serial pins of it each of them consists of one 10KΩ and one 22KΩ resistors to output a 3.3V to the RX pins since the Nextion and Mega TX pins transmit 5V as the following equation suggests:

$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

Substituting values where R2 = 22KΩ and R1 = 10KΩ, Vin = 5V, gives Vout = 3.4375V ≈ 3.3V

A voltage amplifier is connected to the output of the sine / triangle wave generating pin with a 20KΩ POT to control amplitude. The frequency can be controlled using the Nextion display.

4.1.2.2. IC Tester

Supports CMOS and TTL ICs with IC numbers 74xx and 40xx. The Arduino Mega 2560 is used for testing different ICs in the IC tester module, it's connected via serial with the function generator's ESP32 to enable communication between them and enable it to use the nextion display which is controlled by it.

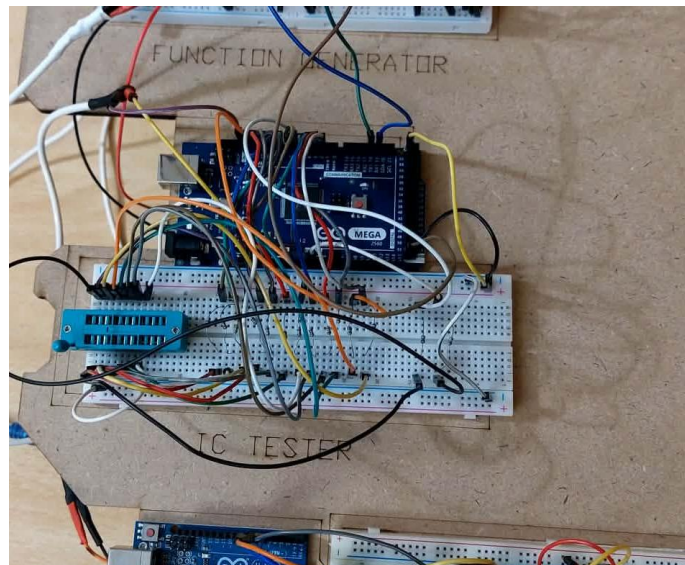


Figure 3: IC Tester module

The IC Tester module is designed to test 14 and 16 pins ICs, it can operate in two modes, “Auto” mode where the IC tester module compares and tests the attached IC to the ZIF automatically. And the manual mode in which the user enters the code for the IC so the module checks if it’s valid or not then proceed to manual testing page. The manual mode has a special “Detailed mode” where it shows tests done to the entered IC in detail.

4.1.2.3. PIC Programmer

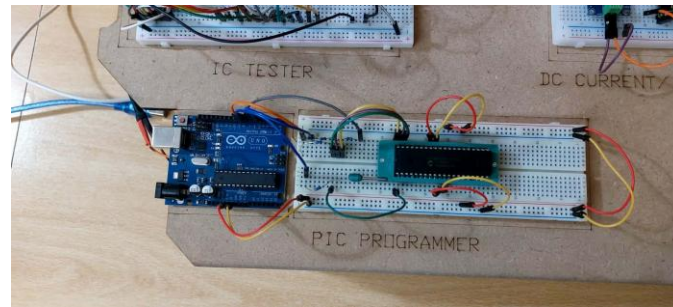


Figure 4: PIC Programmer module

We implemented an in-circuit programming system for the **PIC18F4xx microcontroller family** using an Arduino as the programmer, in accordance with **Microchip’s ICSP specification**. The Arduino communicates with the PC over a serial connection, receives programming commands and data, and programs the PIC by directly controlling the ICSP hardware lines: **PGC** (programming clock), **PGD** (programming data), **PGM** (low-voltage programming enable), and **CLR** (reset).

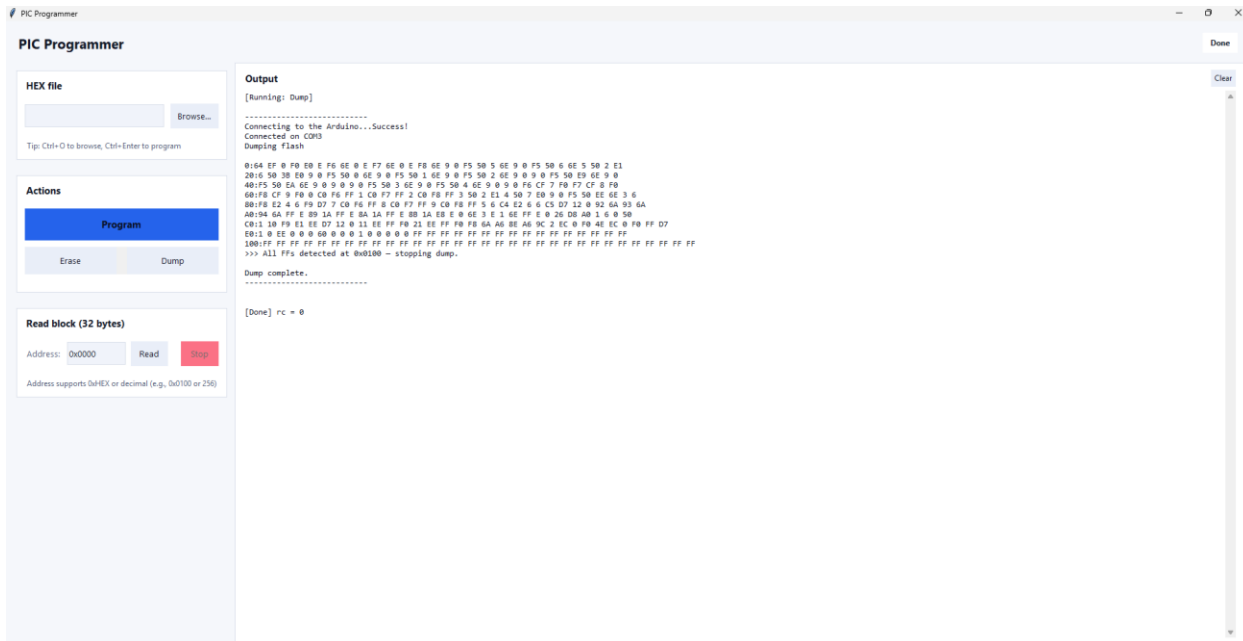


Figure 5: PIC Programmer Interface

To support this hardware, we developed a desktop programming interface with a **C++ backend** and a **Python-based frontend**, which was compiled into a standalone executable. This interface allows the user to **upload HEX files** to the PIC, **erase the device**, **read individual lines of Flash memory**, and **dump the entire Flash memory** for verification and debugging purposes.

4.1.2.4. Oscilloscope

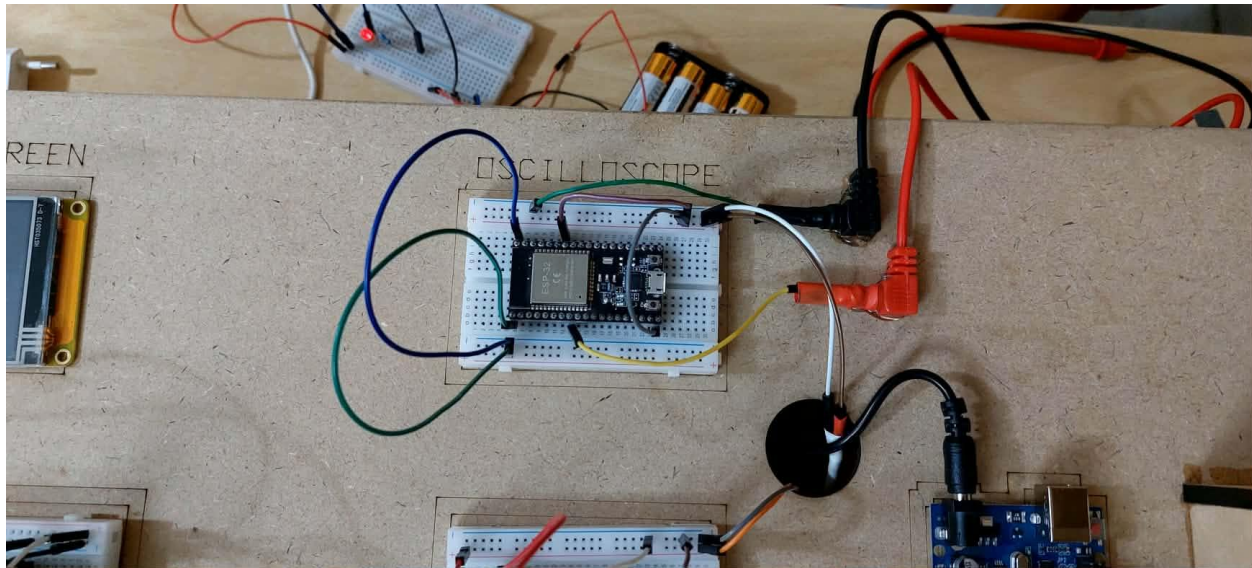


Figure 6: Oscilloscope module

We implemented a simple oscilloscope acquisition node using an **ESP32**. The ESP32 samples an analog waveform using its internal **ADC1** on **GPIO33 (ADC1_CHANNEL_5)**. The ADC is configured for **12-bit resolution (0–4095)** and **11 dB attenuation** to support a wider input range. For each capture cycle, we collect **256 raw samples** at a target sampling rate of **20 kHz** using microsecond timing from the ESP32 high-resolution timer.

To reduce bandwidth and keep transmission reliable, we down-sample the captured frame by selecting **15 evenly spaced points** from the 256-sample buffer. Each selected point is scaled from 12-bit to an **8-bit value (0–255)** to match the display pipeline and minimize payload size.

The sampled points are transmitted wirelessly using **ESP-NOW**. The ESP32 is configured in **Wi-Fi station mode**, paired with a specific receiver ESP32 using its **MAC address**, and sends each data point as a small ASCII command in the format:

```
add <wave_id>,<channel>,<value>
```

In our design, this sender node performs only acquisition and transmission. A **second ESP32 receiver node** listens for these ESP-NOW packets and forwards the reconstructed stream to the

TFT/Nextion display over serial, where the waveform is drawn in real time. This split architecture keeps the oscilloscope sampling fast and isolated, while the receiver handles display communication and UI updates.

4.1.2.5. DC Monitor

We implemented a DC monitoring module using an **ESP32** and the **INA219 high-side current sensor**. The INA219 measures **shunt voltage** and **bus voltage**, then provides derived **current** and **power** readings over **I2C**. In our setup, the INA219 is connected to the ESP32 using **SDA = GPIO16** and **SCL = GPIO17**, and the sensor is accessed using the Adafruit INA219 library (default I2C address **0x40**).

On each update cycle, we read: **Bus voltage (V)**, **shunt voltage (mV)**, **current (mA)**, and **power (mW)** from the INA219.

For visualization, we format the results as **Nextion/TFT serial commands** (e.g., `tV.txt="..."`) and send them to the display interface using **ESP-NOW**: we buffer outgoing display bytes and transmit them in compact packets to a paired ESP32 receiver which is directly connected to the TFT.

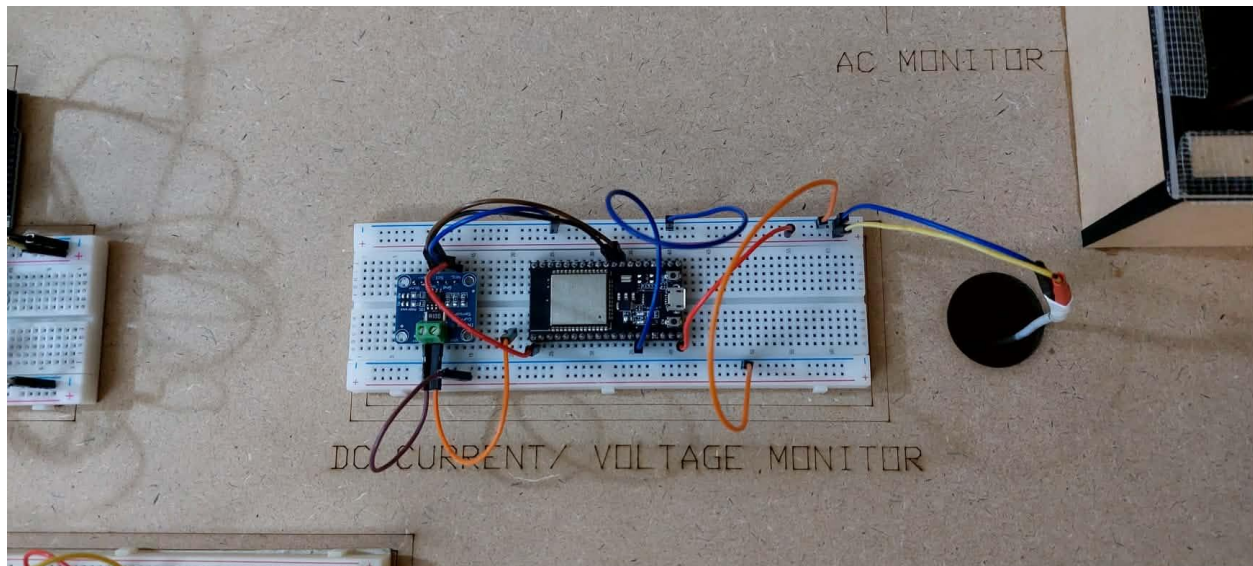


Figure 7: DC Monitor module

4.1.2.6. AC Monitor

We implemented an **AC power monitoring module** using the **PZEM-004T energy measurement sensor**, controlled by an **Arduino Uno**. The PZEM-004T measures **AC voltage, current, active power, frequency, and power factor** from a **220 V mains-connected load** and communicates these measurements to the Arduino over a **UART interface**.

Because the PZEM-004T operates directly on **mains voltage**, it presents a **significant electrical safety risk** during operation. For this reason, the entire PZEM-004T and high-voltage wiring assembly was **fully enclosed in a protective casing** to prevent accidental contact and to ensure safe handling during testing and use.

The Arduino Uno acts as the local controller and data formatter. It periodically reads the measured electrical parameters from the PZEM-004T and transmits the formatted data over a **direct serial connection** to an **ESP32**. This ESP32 then forwards the data wirelessly using **ESP-NOW** to another ESP32 responsible for driving the **TFT display**.

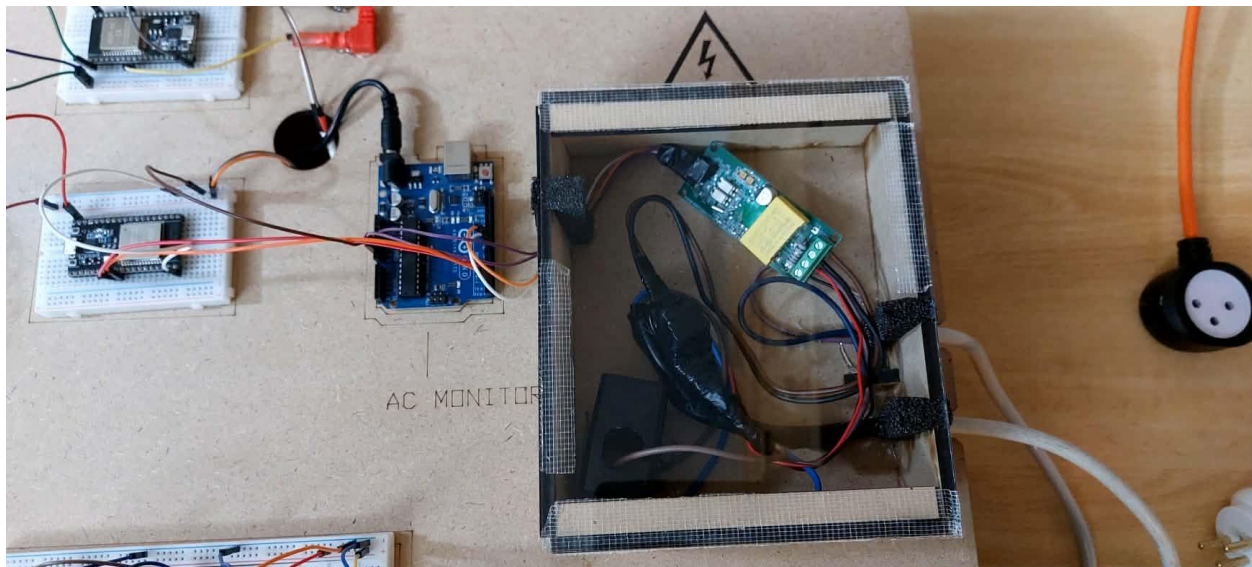


Figure 8AC monitor module:

4.1.3. Screen interface

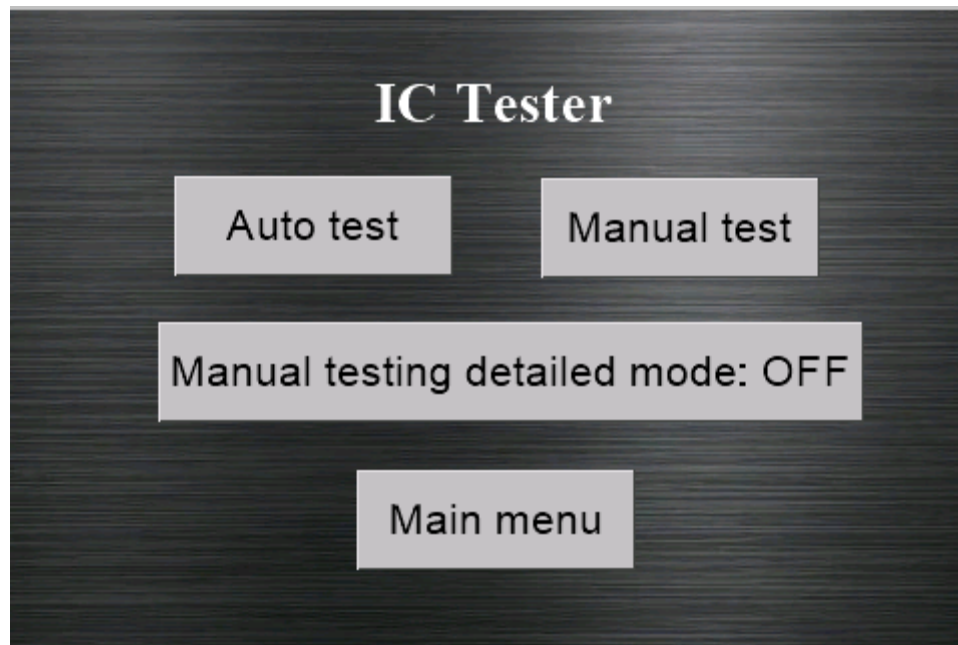


Figure 9: Main interface

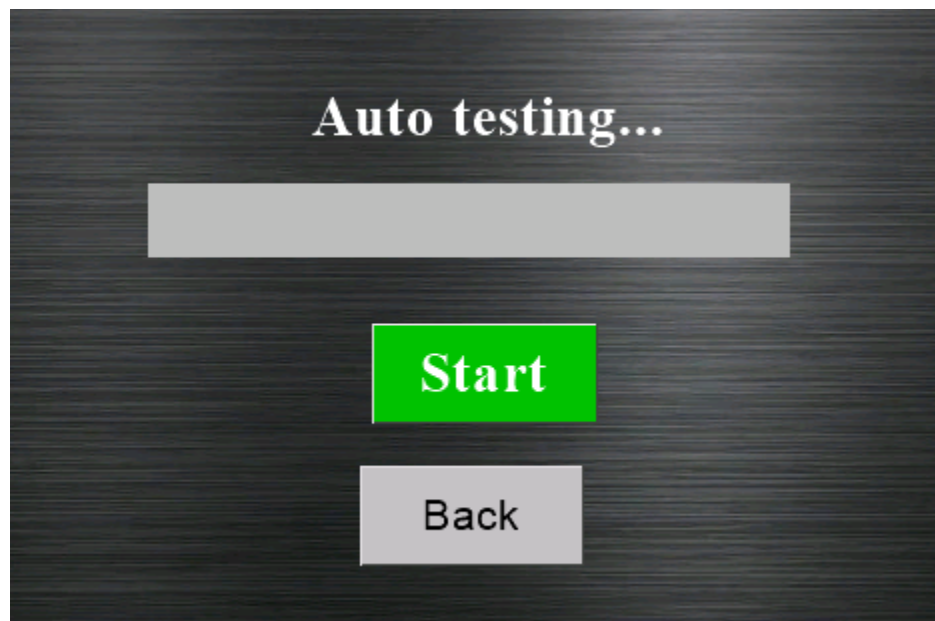


Figure 10: Auto testing interface

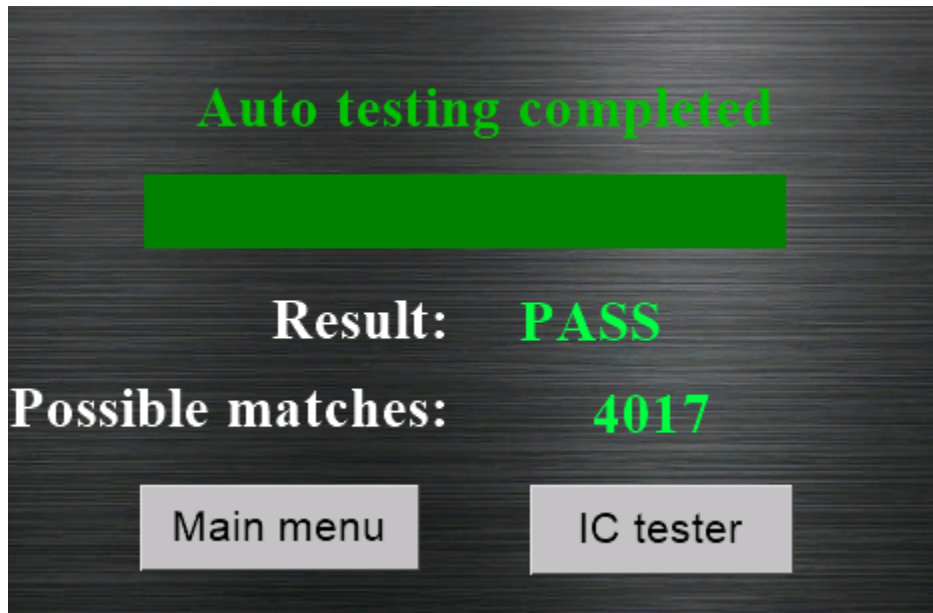


Figure 12:Auto testing interface 2

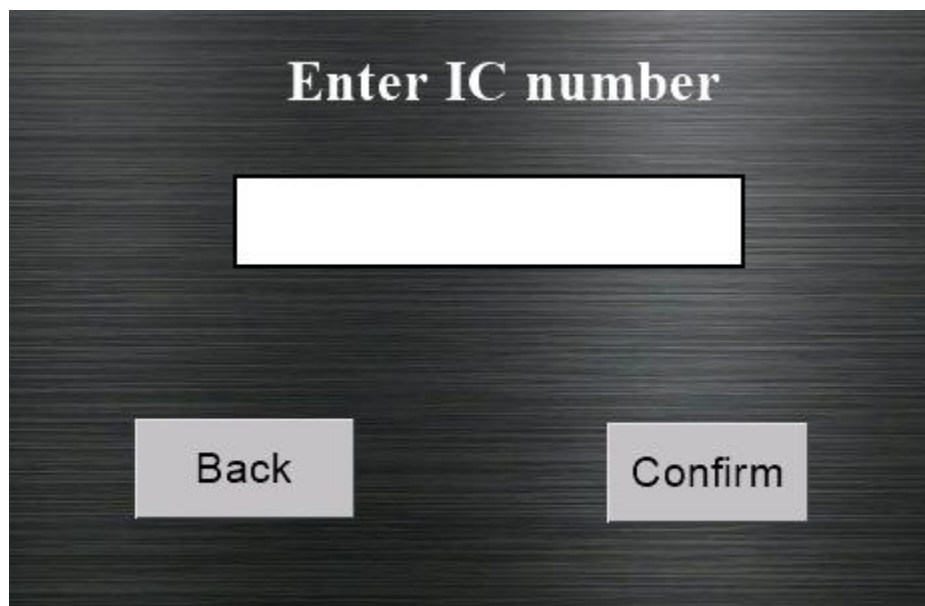


Figure 11:Manual test interface

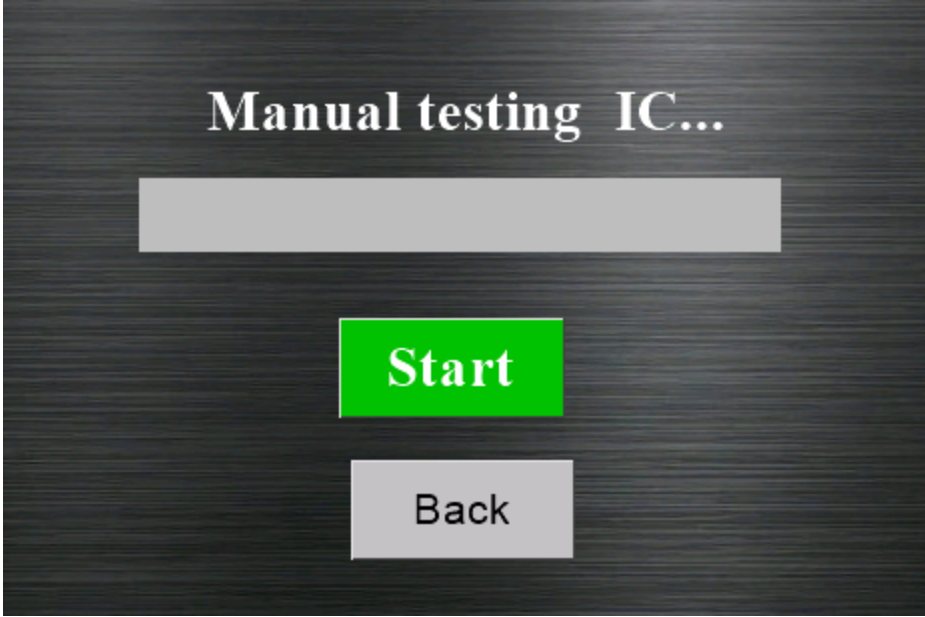


Figure 13: Manual test interface 2

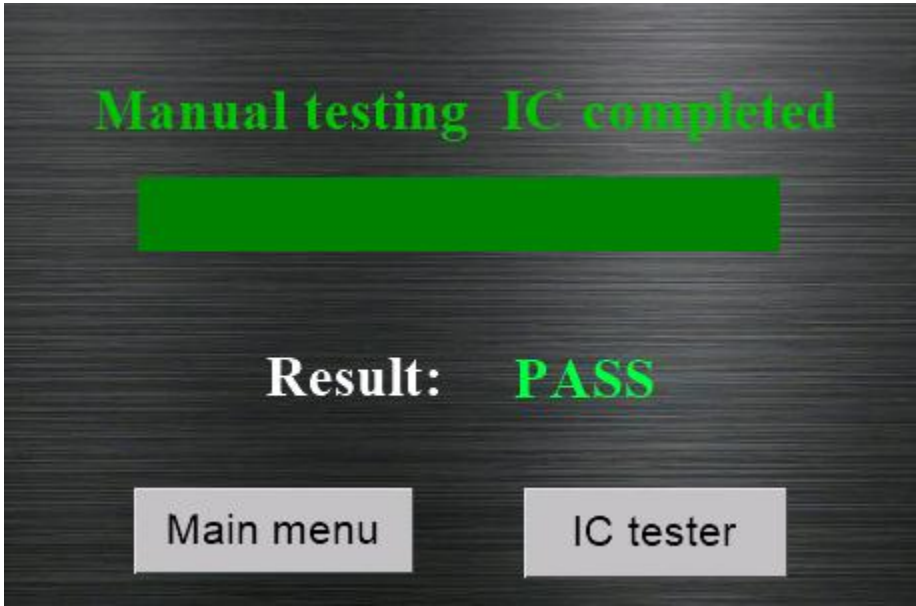


Figure 14: Manual testing interface 3

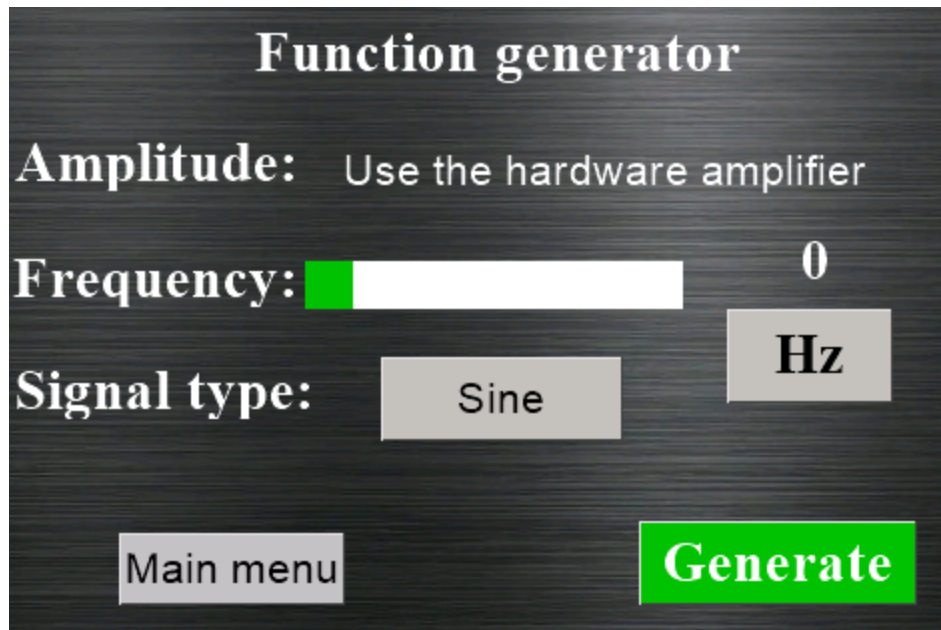


Figure 16: Function generator interface

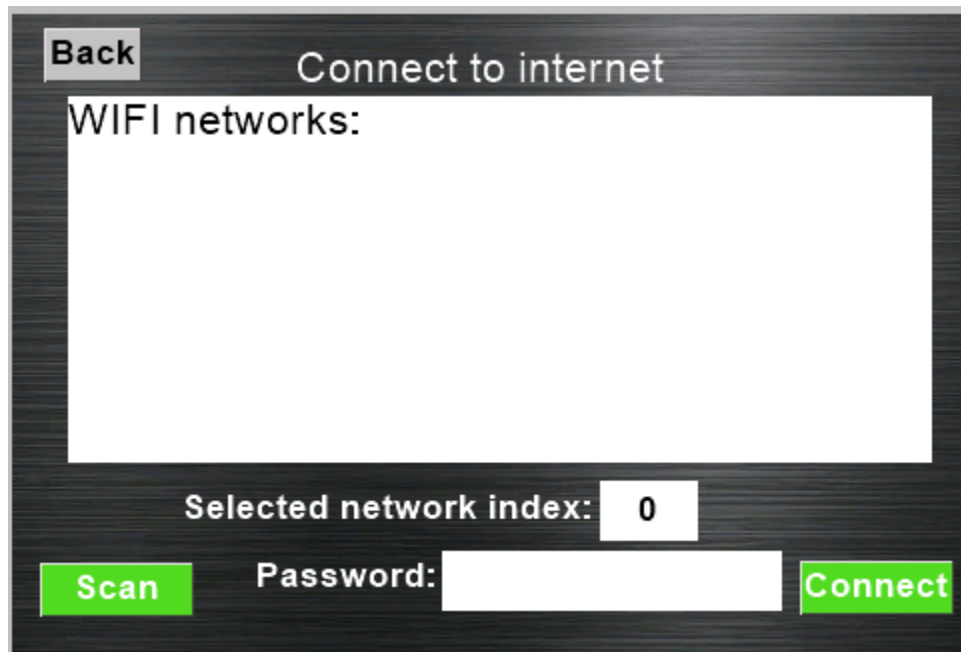


Figure 15:Wifi networks interface

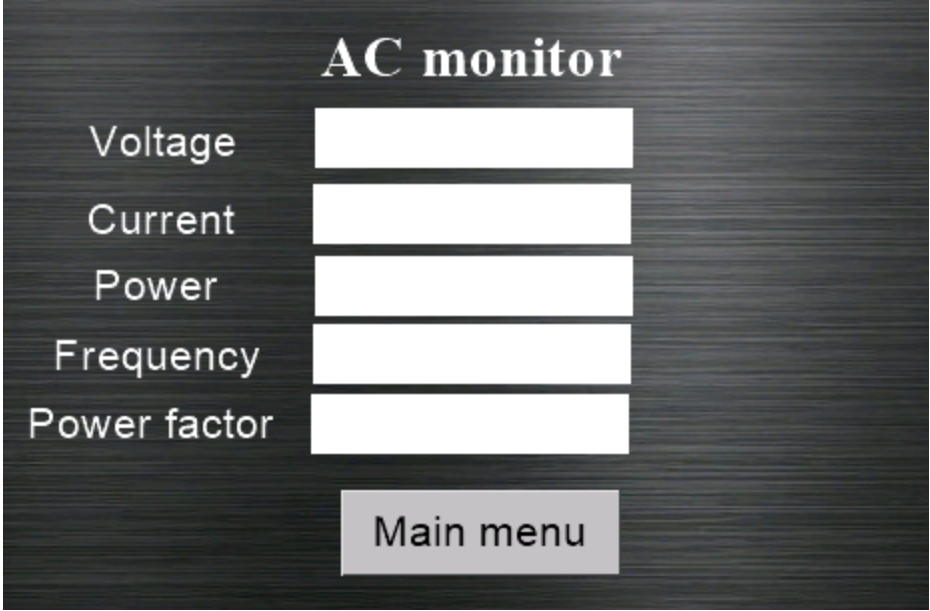


Figure 17:AC Monitor interface

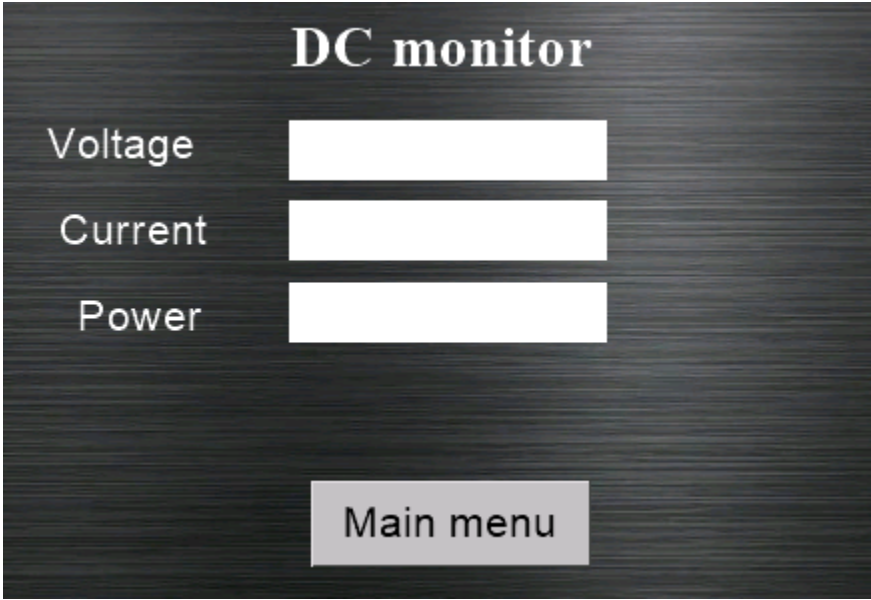


Figure 18:DC Monitor interface

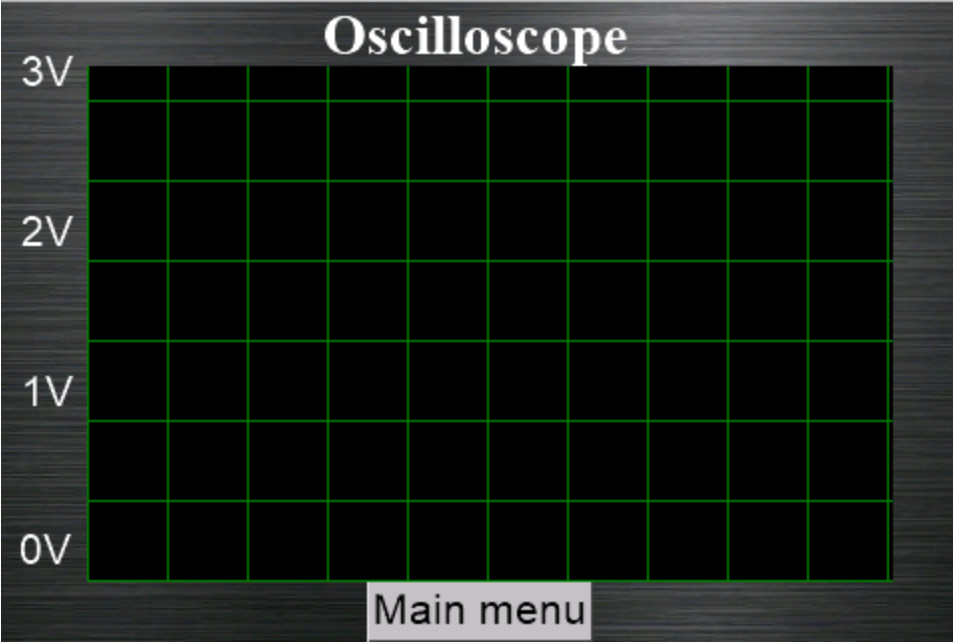


Figure 19: Oscilloscope interface

4.2. Hardware components

This section describes in detail the hardware components and pieces we used in building SynLab.

4.2.1. Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on ATmega2560. It has 54 digital I/O pins, of which 15 are PWM and 12 analog inputs, which can be used as PWM outputs, 16 Analog Input Pins, 4 UART (Hardware Serial ports), 16 MHz Crystal Clock frequency oscillator, a USB port, a power jack, an ICSP connector, and a reset button. It has all that is required to support the microcontroller. We used it to function mainly as the IC tester due to the big number of digital pins it can have and also to communicate with other modules of SynLab.



Figure 20:Arduino Mega 2560

4.2.2. Arduino Uno R3 microcontrollers

Arduino Uno R3 is a microcontroller based on the ATmega328P. It consists of 14 digital I/O pins, 6 analog inputs, as well as a USB interface.

We used the Arduino Uno R3 in the PIC programmer module and the AC monitor module.



Figure 21:Arduino Uno R3

4.2.3. NodeMCU ESP32 Dev Boards

Powerful ESP32 is integrated with Wi-Fi and Bluetooth SOC and usually integrated with a USB-to-serial converter (e.g. CP2102 or CH340), it is ideal for compact (open source) growth and prototype board advanced IOT and built-in system.

It supports a double-core 32-bit processor, operates up to 240 MHz and includes 2.4 GHz for 802.11 B/G/N Wi-Fi as well as inherent support for Bluetooth 4.2 (classic and bl.)

It has an integrated TCP/IP stack, +20.5 dbm output power, several GPIOs, ADC, DACS, SPI, I2C and UART interface and a high performance PCB or external antenna.

The board also includes a Micro USB port, boot and reset buttons, and it can be fully programmed via Arduino Idea, Micropython or Espressif's ESP-AIDF.

In our project, we used mainly as the function generator due to it's powerful DAC and PWM modules, we also connected it with the Nextion display to control the UI for it and to scan for WIFI networks in order to connect to the internet and use MQTT for IoT communication between modules and the mobile application. We used it in the Oscilloscope and the DC measurement modules too.

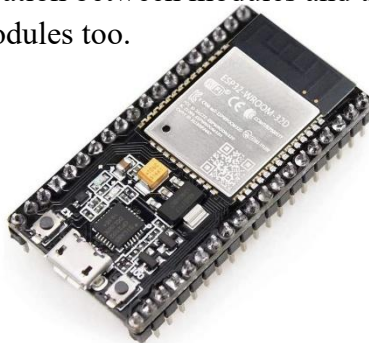


Figure 22: ESP32 Development board

4.2.4. Nextion 3.5" Discovery Display

The Nextion display is a cutting-edge hybrid graphic user interface (HMI) made especially for Internet of Things (or IoT) and embedded machinery applications. With an internal memory, a resistive or capacitive touchscreen, and an onboard processor, it functions as a stand-alone graphical user interface. Microcontrollers like the ESP32 are communicated with via dependable serial UART (TTL) communication.

We chose the Nextion display to be our main interface for controlling and monitoring the system to provide easy user experience and easier handling with different modules.



Figure 23:Nextion display

4.2.5. Zero Insertion Force (ZIF) sockets

The ZIF socket is a version of an IC socket that was designed to make it easy to insert and remove the integrated circuits without the use of forces, which could easily lead to damage of the pins. Within SynLab, the ZIF socket forms part of the IC tester and PIC programmer modules and is used to hold microcontrollers or other ICs during testing or programming. This provides the capability for fast swapping of components while ensuring reliable electrical contact, simplifying the workflow in experiments and device programming.



Figure 24: IC ZIF Sockets

4.2.6. PZEM-004T V3 Power measurement module

The PZEM-004T V3 is a digital module developed for measuring any type of power flow, such as voltage, current, power consumption, and energy consumption of AC circuits. SynLab uses this module with an Arduino Uno R3 as the AC Monitor Moudle, this module is utilized for observing and analyzing the characteristics of a given circuit. This module helps users see the real-time power behavior of the circuit, and which enables performance analysis of the circuit within the smart lab environment.



Figure 25: PZEM-004T V3 module

4.2.7. INA219 Current and voltage sensor

INA219 is a highly accurate digital sensor that can be used to measure DC voltage, current, and power using an I²C bus interface. INA219 is used in SynLab to observe the electrical characteristics of low-voltage and DC circuits, which enables users to observe real-time current consumption and the supply voltage in DC circuits. Therefore, INA219 can be used to improve the understanding and safety of DC circuit experiments in real-time so we used it along with an ESP32 in the DC current and voltage monitor module.

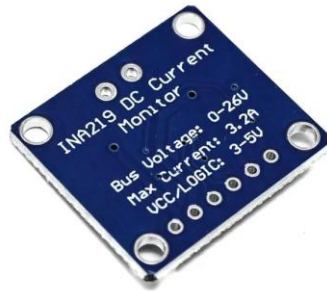


Figure 26: INA219 sensor

4.2.8. LM324 Operational Amplifiers IC

The LM324 is a low-power quad operational amplifier IC. It contains four independent op-amps in a single package. We used it in the function generator to amplify the generated wave signals.

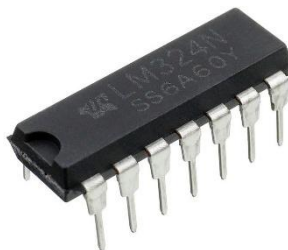


Figure 27: LM324

4.2.9. 20 K Ω Potentiometer

The 20 K Ω potentiometer is a type of variable resistor designed to assist in the regulation of voltage levels within electronic circuits. We used it in the function generator module to control the amplitude of the generated wave signals.



Figure 28:20K Ohms POT

4.2.10. Carbon resistors (Different Ω values)

We used multiple carbon resistors across the system to ensure safety of the microcontrollers and to build multiple voltage dividers for the ESP32 boards consisting of 10 K Ω and 22 K Ω resistors, other values include 680 Ω and 3.3K Ω resistors.



Figure 29:10K ohms carbon resistor

4.2.11. Breadboards

Solderless boards, also known as breadboards, are reusable prototyping boards that are used for prototyping electronic circuits without the need for soldering. In SynLab, these prototyping boards create a flexible working framework for prototyping analog and digital electronic circuits, and is used as the base for different measurement modules, oscilloscopes, power monitors, the IC tester, etc. The internal connection pattern of the prototyping board facilitates a structured wiring plan, thereby becoming an important part of the SynLab system.

We used total of 7 breadboards (3 Medium and 4 Small)

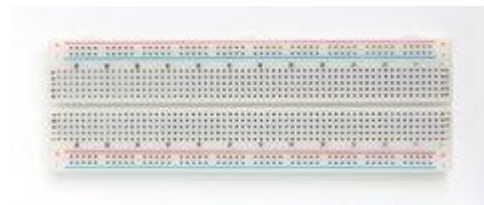


Figure 30: Breadboards

4.2.12. Jumper wires

We used them for the internal connections of each module with the microcontrollers and some for serial communication between some of the modules.



Figure 31: Jumper wires

4.2.13. Female DC Power Jack Adapter Connector Plug Button Switch

Used to enable 12V adapter connection with the amplifier in the function generator module.



Figure 32: Female DC Power Jack Adapter Connector

4.2.14. Power adapters from AC 220V to DC 12V and 5V

We used multiple 5V power adapters to power the modules separately which enable users to choose which module they want to work with and use to save electricity. We also used a 12V power supply to power on the amplifier for the function generator.



Figure 33: 12V and 5V DC Power adapters

4.3. Mobile application

The mobile application allows users to monitor all activities on the system in real time, it also enables them to track the results of each module.

4.3.1. Main page

Presents the home page of the application, it features a grid of 4 buttons at the center of the screen to access each module in the system.

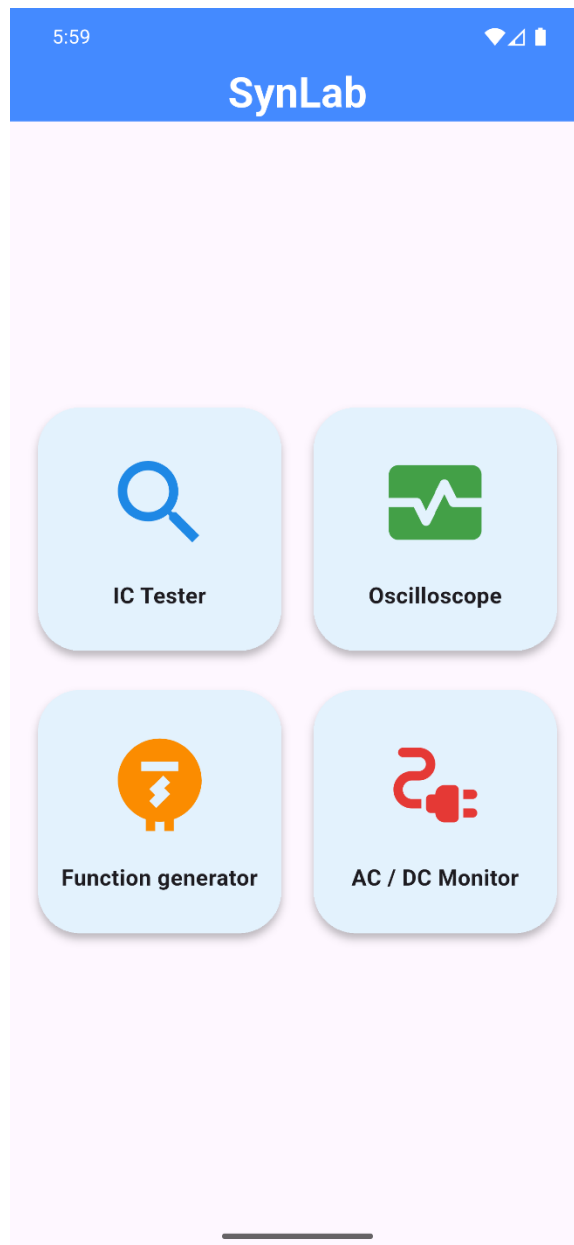


Figure 34: Mobile main page

4.3.2. IC tester page

Shows the IC tester module results in real time and maintains them for the user with the ability to search for specific IC.

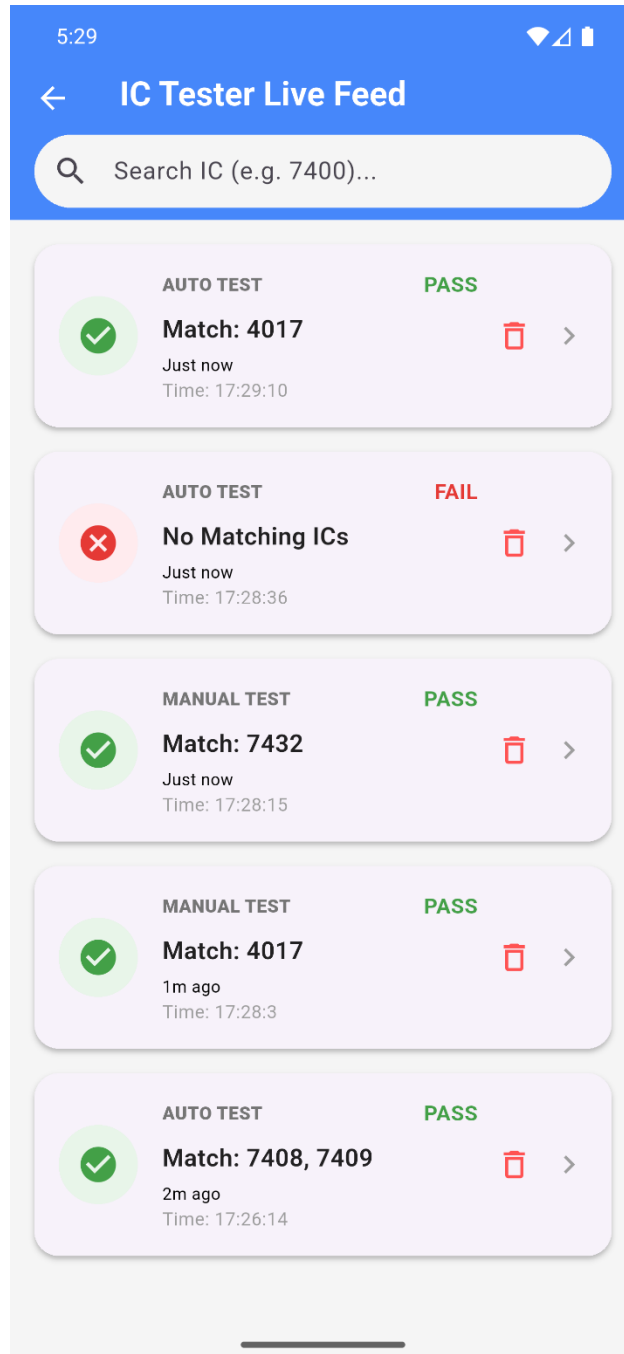


Figure 35: IC Tester page

4.3.3. Test details page

Shows the details of an IC test when clicking on one of the tests in the IC tester page.

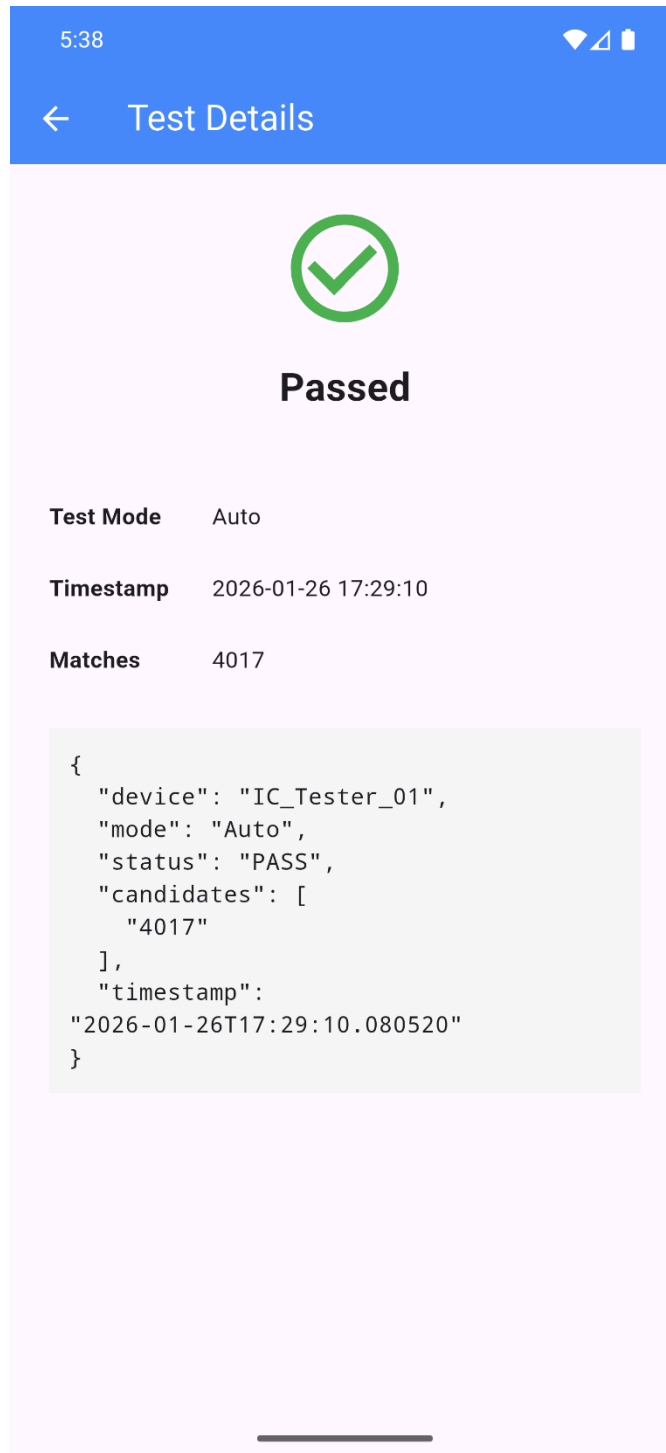


Figure 36: IC test details page

4.3.4. Function generator page

Shows the status (Standby or Active) of the function generator along with the frequency, wave type, and real time visualizer / plotter for the generated wave.

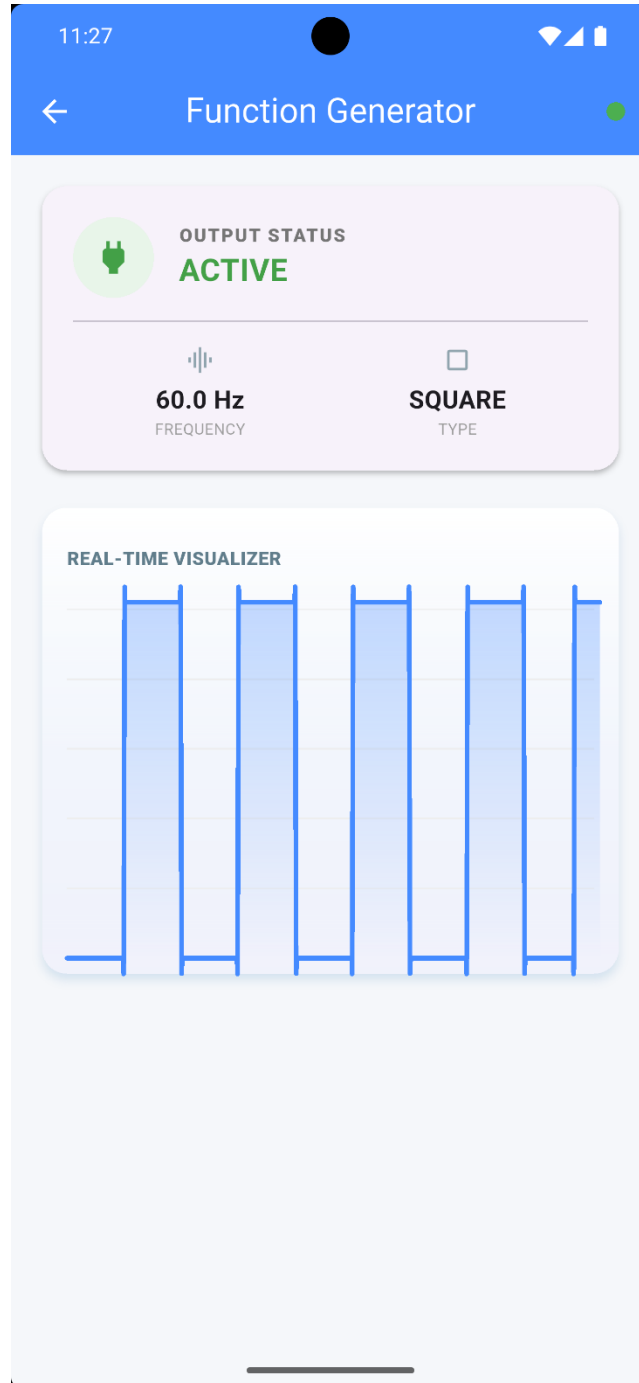


Figure 37: Function generator page

4.3.5. Oscilloscope page



Figure 38: Oscilloscope page

4.3.6. AC / DC Monitor page

Allows the user to choose between the AC monitoring module or the DC one.

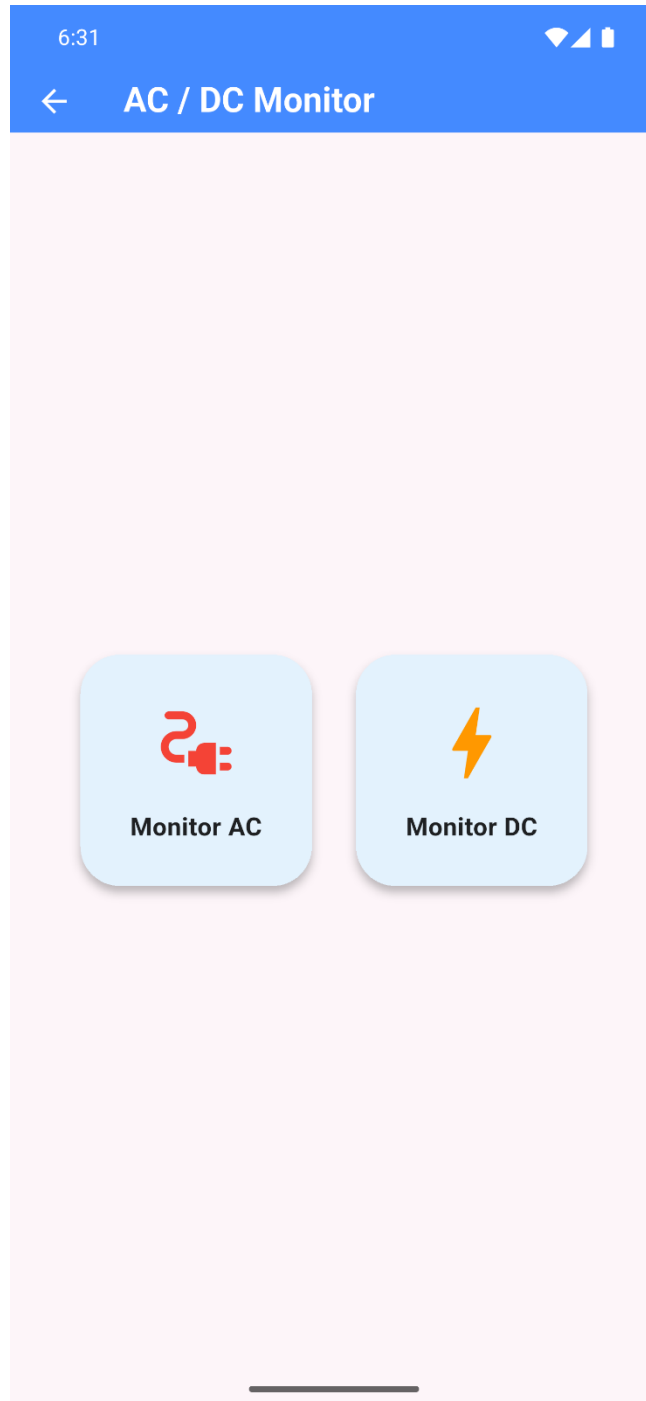


Figure 39:AC / DC monitor page

4.3.7. AC Monitor Live feed page

Shows analysis of the AC monitor module which includes Voltage, Current, Power, Energy and Frequency.

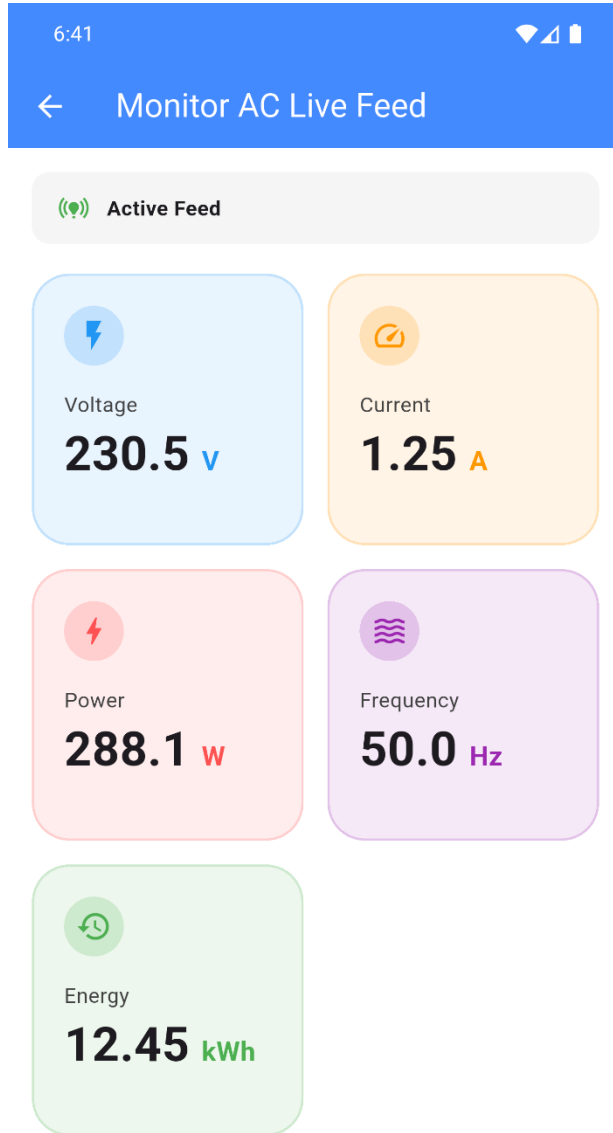


Figure 40: AC monitor page

4.3.8. DC Monitor Live feed page

Shows analysis of the AC monitor module which includes Voltage and Current.

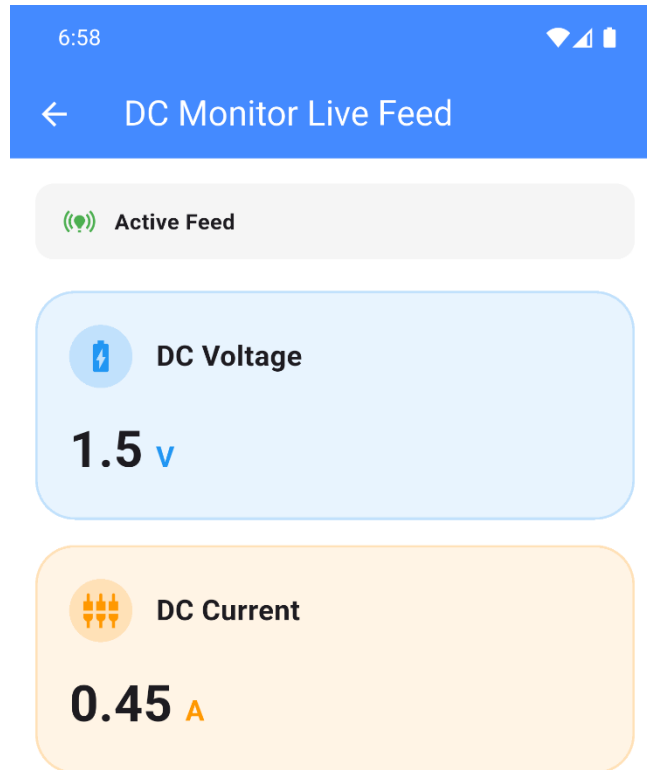


Figure 41: DC Monitor page

Chapter 5: Discussion and Results

This section discusses and analyzes the experimental results obtained from the implementation and testing of the SynLab modular electronic laboratory. The individual components of the system were tested separately and collectively in order to assess their functionality, accuracy, and reliability in facilitating electronics experiments in a practical manner.

➤ IC Tester

The IC tester module was able to identify and verify logic ICs. The process involved inserting ICs into the ZIF socket and choosing the IC type via the software interface. The system then used test vectors and checked the output responses. 74xx and 40xx series ICs, were identified correctly, and errors such as stuck-at outputs or missing responses were also identified.

➤ Function generator

This function generator was successful in generating sine, square, and triangle waveforms over a wide range of frequency and amplitude. The waveform generation using ESP32 and outputting it through a DAC was a success and helped in fine-tuning and real-time control of the waveforms using the software provided by our project.

In order to ensure that the voltage levels were accurate and stable, an RC filter and an operational amplifier was integrated into the output stage. This helped in ensuring that the output signal was not distorted due to impedance matching with the load circuits.

Additionally, it helped in ensuring that the output signal was safe and accurate by using a voltage divider to scale down the output signal to desired levels.

All these factors helped in ensuring that the output waveform was clean and stable, and it was verified using an oscilloscope module that the output signal generation was of laboratory grade.

➤ Oscilloscope

The oscilloscope module enabled the observation of voltage signals in real time with a resolution sufficient for prototyping and educational use. The ESP32 microcontroller transmitted waveform data to the Nextion interface in the system for graphing after sampling input signals using the ESP32 microcontroller's ADC.

The waveforms from the function generator and external circuits were determined to be accurately captured by the oscilloscope module in terms of frequency, peak-to-peak voltage, and waveform type. Although it had a lower bandwidth compared to commercial bench oscilloscopes, it was sufficient for microcontroller experiments, analog circuits, and digital

circuits. The use of graphing in the same software environment eliminated the need for display instruments.

➤ **PIC Programmer**

This module was used for verifying and programming PIC microcontrollers, the programmer received HEX files uploaded via a pc for the need of a flash drive which cannot be connected to the Nextion interface, and verification feedback verified that flashing was successful.

➤ **AC Monitor**

Voltage, current, power, frequency, and energy consumption were measured in real time by the AC monitoring module using the PZEM-004T V3 sensor. After being sent to the central hub, the data was shown on the user interface.

Measurements using resistive and inductive loads were consistent and repeatable. This module is an important educational and safety feature of SynLab because it allows users to safely analyze real-world AC behavior without being directly exposed to high-voltage wiring.

➤ **DC Monitor**

The DC monitoring module provided precise real-time readings of DC power consumption based on the INA219 current and voltage sensor. This made it possible for users to keep an eye on the power usage of microcontroller boards and test circuits.

The module is useful for debugging power problems, evaluating circuit efficiency, and verifying design assumptions in embedded and analog systems because the results showed high consistency and resolution.

When we integrated all modules into the project through the central hub and synchronized via the IoT communication framework, it operated as a unified digital lab system. Data flowed reliably between the ESP32 nodes and the software interface, allowing users to control instruments, visualize measurements, and record experimental data in real time.

The system achieved its primary objectives of providing an interactive, connected, and multifunctional laboratory environment. Compared to traditional standalone instruments, SynLab offered improved usability, reduced hardware redundancy, and greater experiment coordination. The results confirm that SynLab successfully delivers a modern, efficient, and intelligent electronics laboratory suitable for education, research, and development.

Chapter 6: Conclusion

6.1. Conclusion

SynLab successfully implemented an IoT based unified synchronized laboratory system which features multiple modules used in any electronics and digital systems labs and handles real time data. It provides a suitable interactive environment for experimenting and learning. Although commercial laboratory instruments may offer higher precision or performance, our system provides a cost-effective, integrated, and flexible alternative that significantly enhances usability and educational value and combines different modules.

6.2. Future work

- **Custom-designed PCBs** can replace breadboard-based implementations to improve reliability, reduce noise, and enhance the overall physical layout and durability of the system.
- **Additional laboratory modules** such as a logic analyzer, programmable DC power supply, or digital multimeter can be integrated to expand system functionality.
- **Higher-resolution ADCs and DACs** may be used to improve the accuracy and performance of the oscilloscope and function generator modules.
- **Enhanced software features**, including advanced waveform analysis, data logging, and experiment history tracking, can further support educational use.

6.3. References

- [1] V. Smolaninovs and M. Terauds, “Microcontroller-Based Electronic Laboratory Measurement Device for Distance Education,” **Electronics**, vol. 14, no. 3, p. 438, Jan. 2025.
- [2] D. *et al.*, “Improving Learning Outcomes in Microcontroller Courses Using an Integrated STM32 Educational Laboratory: A Quasi-Experimental Study,” **Education Sciences**, vol. 16, no. 1, p. 157, 2025.
- [3] A. Zekovic and P. Pejovic, “Integrating Instrument Networking and Programming into Electronics Curricula: Design, Implementation, and Impact,” **Information**, vol. 16, no. 12, p. 1024, 2025.
- [4] D. Tsiplanitis, A. Misirli, K. Lavidas and V. Komis, “IoT Devices and Their Impact on Learning: A Systematic Review of Technological and Educational Affordances,” **IoT**, vol. 6, no. 3, p. 45, Aug. 2025.
- [5] Syed A. F. W. Syed Ridza and S. M. A. Motakabber, “IoT-Based Lab System for Teaching Methods in Times of Crisis,” **Asian Journal of Electrical and Electronic Engineering**, vol. 1, no. 2, pp. 14–19, Sep. 2021.