Thesis title:

RFID Diagnostic module

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Abstract:

This thesis presents the design and development of an RFID Diagnostic Module, which is intended to improve the understanding of the errors in the RFID sensor which the REER SPA research team working on it. The project involves the creation of multiple prototypes, laboratory measurements and tests, and the realization of the final prototype. The module utilizes Radio Frequency Identification (RFID) technology to streamline the diagnostic process, allowing for more precise and reliable testing results. The design process involved careful consideration of the specific requirements of the module, including the selection of appropriate components and circuitry design. The creation of multiple prototypes allowed for iterative improvements and optimization of the module's performance. Laboratory measurements and tests were conducted to evaluate the module's effectiveness and to identify areas for further improvement. The final prototype was then realized, incorporating all the necessary components and features to achieve optimal performance. The results of this thesis work demonstrate the potential for RFID technology to revolutionize diagnostic testing in a variety of industries, and provide a valuable contribution to the field of diagnostic technology.

Acknowledgements

I express my gratitude to **Professor Graziano Mariagrazia**, to be my advisor for providing me with the opportunity and great support in writing my thesis.
I am also thankful to **Carlo Pautasso** & **Jucimar Cabral** from **REER SPA** for their crucial role in guiding and patiently supporting me throughout the whole process of thesis and internship time period.

I would like to acknowledge my family and friends with deep appreciation for their unwavering support and constant encouragement throughout my years of study, as well as throughout the process of researching and writing this thesis. This accomplishment would not have been possible without their invaluable help.

"Thankyou"
Best Regards
Muhammad Talha Farooq

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Introduction

1.1 Overview:

This whole thesis project is the development of the RFID diagnostic module that aims to enhance the comprehension of errors in the RFID sensor on which REER SPA research team is working. The project involved the development of various prototypes, laboratory experiments, and assessments, culminating in the creation of the final prototype. As it is the RFID module so this module leverages Radio Frequency Identification technology to facilitate the diagnostic process, resulting in more accurate and dependable test outcomes.

1.2 Radio Frequency Identification (RFID) technology:

In Radio Frequency identification (RFID), radio waves are used in a wireless communication system to identify and track objects. An **RFID tag** and an **RFID reader** make up its two primary parts. In order to identify and extract data from the tag, the reader sends radio waves, to which the tag reacts.

1.2.1 RFID Tag:

An RFID tag is a tiny electrical gadget with a microchip and an antenna. The antenna allows for communication with an RFID reader, while the microchip stores data. To identify and track an object using radio waves, the tag is often fastened to an item like a product, piece of machinery, or container.

RFID tags come in **passive** and **active** varieties. The Tag Without a power supply are passive one. **Passive RFID** tags rely on the energy sent by an RFID reader to function. The tag's antenna picks up the energy from the reader's radio waves and utilizes it to power the microchip, which then transmits data to the reader. Although passive RFID tags are less costly and smaller than active tags, they cannot be utilized in all situations and have a reduced read range.

On the other hand, **Active RFID tags** have a battery inside that powers the antenna and microprocessor. They have a larger range of uses and can send data over greater distances. The average size and cost of active tags are higher than those of passive tags.

Many sorts of data, including product details, serial numbers, and position information, can be stored on RFID tags. They may be used to increase productivity and automate procedures in a number of sectors, including manufacturing, shipping, healthcare, and retail.

1.2.2 RFID Reader:

An RFID reader is a tool that interacts with RFID tags by transmitting radio waves and responding to the tags' responses. An antenna, a transceiver, and a micro-controller are the usually the main component of the Reader.

An RFID reader emits a radio signal when an RFID tag is brought within range of the reader's antenna. The signal is picked up by the tag's antenna, which then utilizes it to power the microchip and relay data back to the reader's antenna. The processor decodes the data and transfers it to a computer or other processing device for additional analysis once the reader's transceiver catches the response from the tag.

RFID readers come in fixed and portable varieties. To track the movement of products, fixed readers are often deployed at specified places like warehouses or retail establishments. Workers, on the other hand, can use handheld scanners to read RFID tags on equipment or items while out in the field.

RFID readers can work with low-frequency (LF), high-frequency (HF), and ultra-high-frequency (UHF) frequencies (UHF). The type of RFID tags being used and the application determine the frequency. For instance, LF RFID is generally used for tracking animals, but UHF RFID is frequently employed in applications for retail and logistics.

1.2.3 Applications:

RFID technology has wide range of application including:

- **Healthcare:** Hospitals and other healthcare institutions utilize RFID to track patients, medications, and assets, enhancing patient safety and operational effectiveness.
- **Industrial:** RFID is used in manufacturing facilities to track components, works-in-progress, and finished goods, enhancing inventory management and quality assurance.
- **Supply chain and logistic management**: By tracking the movement of items along the supply chain, RFID enables businesses to streamline their processes and cut waste.
- **Commercial:** In retail stores, RFID is utilized for inventory control, product monitoring, and theft prevention.
- **Transport:** In the transportation sector, RFID is used to track commodities and assets including trailers, cars, and shipping containers.
- **Security:** RFID is used in buildings and other restricted locations for access control, enabling only authorized workers to enter and depart.
- **Sports:** Athletes are tracked, performances are analyzed, and injuries are prevented using RFID in sports.
- **Libraries:** RFID is used in libraries for self-checkout, inventory management, and theft prevention.

RFID technology is a significant tool in a variety of applications due to its adaptability and use.

1.3 Problem Statment:

The REER SPA research team is currently facing difficulties in understanding and diagnosing errors in their RFID sensors. The main problem in the RFID sensors is that after development as per standard requirement the sensor is filled with the specific material (resign). So after filled with resign it not possible to diagonise the faulty sensor as we have no access to the pcb to perform different testing .And also the current diagnostic process is time-consuming and unreliable, resulting in delays and increased costs. Therefore, there is a need for a diagnostic module that can streamline the diagnostic process, provide more precise and reliable testing results, and help the research team to identify and troubleshoot errors in the RFID sensors more efficiently. The **aim of this project** is to design and develop an RFID Diagnostic Module that can meet these requirements and provide a solution to the current challenges faced by the REER SPA research team.

Hardware Design and Development:

2.1 Demodulator:

The demodulator, which separates the modulated signal from the carrier wave of the RFID sensor, is a crucial part of the RFID Diagnostic Module. The data signal is then transmitted to the microcontroller for processing and analysis after the demodulator circuitry filters out the carrier frequency.

As mentioned in the previous topic of RFID technology, the data is modulated into a carrier wave and transferred by the RFID tag in RFID technology. The data signal is conveyed by modifying the amplitude, frequency, or phase of the carrier wave, which has a defined frequency. The modulated signal is received by the RFID reader, which then demodulates it to recover the original data signal.

The RFID Diagnostic Module's demodulator is made to operate with the precise carrier frequency that the RFID sensors under test employ. It must have the sensitivity to distinguish between weak signals and remove any interference or noise from the signal. Depending on the needs of the RFID sensor being tested, the demodulator circuitry may employ techniques like envelope detection, synchronous detection, or phase-locked loop (PLL) demodulation.

Overall, the demodulator is essential to the functioning of the RFID Diagnostic Module because it allows the module to separate the data signal from the carrier wave of the RFID sensor and deliver precise and trustworthy diagnostic data.

2.1.1 Block Diagram:

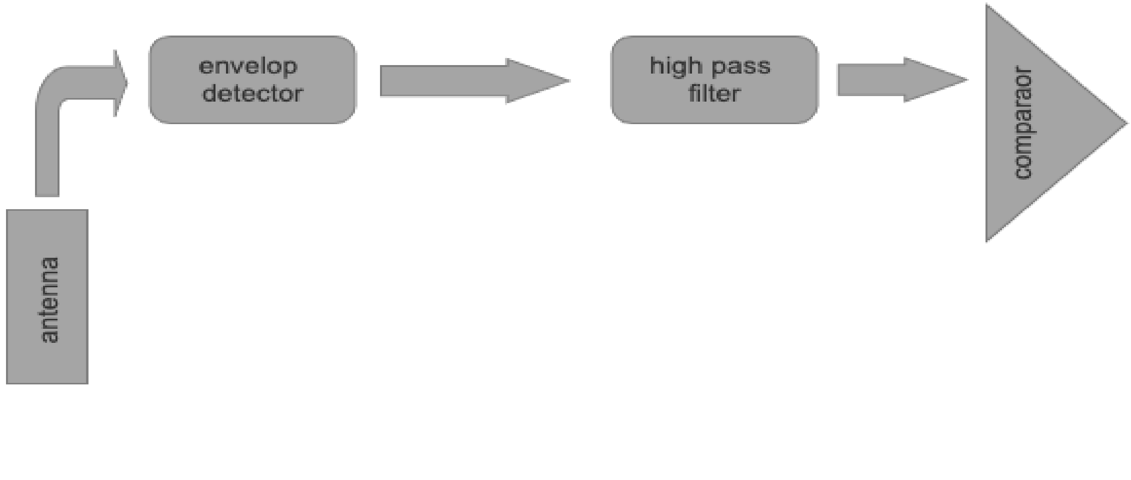


Figure no. 1 Block Diagram

As shown in the block diagram there are different main block of demodulator performing their task

2.1.2 Antenna:

The interface between the RFID sensor and the demodulator circuitry in the RFID Diagnostic Module is done by antenna of the demodulator. Its job is to receive the modulated signal sent by the RFID sensor and turn it into an electrical signal that the demodulator can process.

2.1.3 Envelop Detector:

The RFID Diagnostic Module's demodulator circuitry employs the envelope detector demodulation approach. It is employed to separate the amplitude modulation (AM) signal from the RFID sensor under test's carrier wave.

In envelope detection, the high-frequency carrier wave is filtered by a diode and a capacitor, which then extracts the low-frequency envelope signal. Just the positive half of the carrier wave may travel through the diode's rectifier function, and the capacitor filters out the high-frequency components, leaving only the envelope signal.

2.1.4 High pass filter:

The high pass filter plays a crucial role in the RFID Diagnostic Module's demodulator circuitry. Its purpose is to eliminate any low-frequency interference or noise from the received signal so that the high-frequency components can proceed on to the next demodulator stage.
Depending on the needs of the RFID sensor being tested, the high pass filter in the demodulator may be implemented using a variety of circuit designs, such as RC filters, active filters, or digital filters. But we are using the RC filter to maximize filtering performance for the targeted frequency range of interest, the filter's cut-off frequency can be changed.

2.1.5 Comparator:

A crucial element of the demodulator circuitry of the RFID Diagnostic Module is the comparator. It is used to determine if the modulated signal is present or absent by comparing the modulated signal's amplitude to a reference voltage and producing a binary result.

The comparator then receives the signal from the filter and measures its amplitude against a predetermined reference voltage.
The comparator output turns high, indicating the presence of the data signal, if the signal's amplitude exceeds the reference voltage. The comparator output decreases if the amplitude is less than the reference voltage, indicating the lack of a data stream.

Then microcontroller receives the comparator's output and processes it further before analyzing it. The comparator's binary output may be interpreted by the microcontroller to ascertain the data that is encoded in the modulated signal and to offer diagnostic data about the RFID sensor that is being checked.

2.2 Microcontroller:

The microcontroller is the main processing unit of the RFID Diagnostic Module. It is responsible for controlling and coordinating the different components of the module, processing the data received from the RFID sensor being tested, and generating diagnostic information.

The microcontroller has a built-in analog-to-digital converter (ADC) that is used to convert the analog signals from the demodulator into digital signals that can be processed by the microcontroller. The microcontroller also has a digital signal processing (DSP) unit that can be used to filter, analyze, and decode the data signal received from the RFID sensor.

The microcontroller runs software that is specifically designed for the RFID Diagnostic Module. The software provides a user-friendly interface that allows the user to configure the module, initiate diagnostic tests, and view the diagnostic results. The software may also include algorithms for decoding and interpreting the data signal received from the RFID sensor and generating diagnostic information.

The microcontroller can communicate with other devices, such as a computer or a smartphone, via wired or wireless communication protocols such as USB, Bluetooth, or Wi-Fi. This allows the diagnostic information generated by the module to be transmitted to a remote device for further analysis and interpretation.
In this diagonistic module the microcontroller after processing all things mentioned above communicate with the lcd display we are using in this project and showing the error no. and the detail accordingly.

2.3 Display:

Real-time updates on the status and outcomes of the diagnostic tests being run on the RFID sensor are shown on the display of the RFID Diagnostic Module. A tiny LCD screen or LED display that can show alphanumeric letters, symbols, and images is frequently used in these devices.

The display might provide details like the RFID sensor's frequency, the strength and quality of the modulated signal, whether a data signal is there or not, and any error or warning signals. The diagnostic test's progress and the final findings may be displayed on the display as well.

The microcontroller drives the display, which gets real-time updates when the diagnostic tests are run. The user may start tests, choose different settings, and check the diagnostic findings by interacting with the display using buttons or a touch screen.

The RFID Diagnostic Module's display is a crucial part of the device since it gives the user fast feedback and makes it easy for them to see any problems or faults with the RFID sensor under test. It facilitates the diagnostic procedure and gives the user the information they need to assess the effectiveness and dependability of the RFID sensor.

2.4 Power management:

Power management is an important aspect of the RFID Diagnostic Module, as it ensures that the module operates efficiently and reliably while conserving battery life. The power management system typically consists of several components, including:

- **Power supply**: The power supply supplies the required current and voltage to run the various parts of the RFID Diagnostic Module. A battery, a power adapter, or a combination of the two may serve as the power source.

- **Circuitry for power management**: To maintain optimum performance and efficiency, the power management circuitry regulates the power consumption of the various module components by tracking the voltage and current of the power supply. Features like overvoltage protection, undervoltage protection, and overcurrent protection may also be present in the power management circuitry.

- **Low power components**: To save energy, the RFID Diagnostic Module is employ low power elements such low power wireless communication modules, LCD screens, and microcontrollers.

Component Selection:

When selecting components for an RFID diagnostic module, there are several key factors to consider e.g. antenna, comparator, diaode, microcontroller.

While choosing components, it's crucial to carefully analyze the unique needs of your RFID diagnostic module application. Making the appropriate component choices can assist guarantee dependable performance and precise diagnostic findings.

3.1 Antenna:

Figure no. 2 Antenna Neosid

Selecting an appropriate RFID antenna for a diagnostic module depends on various factors such as the frequency range of the RFID system, the distance at which the tags need to be read, the type of tags being used, and the operating environment. Here are some steps that can help in the selection of an RFID antenna:

- Determine the frequency range: RFID systems operate in different frequency ranges such as low-frequency (LF), high-frequency (HF), and ultra-high-frequency (UHF). Select an RFID antenna that is designed for the frequency range of the RFID system.

- Determine the read range: The distance at which the RFID tags need to be read will help in selecting an appropriate antenna. Antennas with higher gain can read tags from a longer distance.

- Determine the type of tags: Different types of RFID tags have different characteristics and require different types of antennas. For example, passive tags require a stronger signal from the antenna to be read, while active tags have their own power source and require a lower signal strength.

- Determine the operating environment: The operating environment can affect the performance of the RFID system. For example, metal objects can interfere with the RFID signal, so an antenna designed for use around metal objects may be necessary.

- Consider other factors: Other factors to consider include the size and shape of the antenna, the mounting options available, and the cost.

Based on the above factors, you can select an RFID antenna that is suitable for your diagnostic module. Neosid is a manufacturer of RFID antennas and offers a range of products for different frequency ranges and applications. We use two antennas in the series of values **4.15mH & 3.3mH**. You can consult their product catalog or contact their sales team for assistance in selecting the right antenna for your module.

3.1.1 Specification:

In the following table there are the specification of the antennas we are using from the series of the NEOSID.

L (mH)	Q>=	$f_{L.Q}$ (KHZ)	F_{res}>= (MHZ)	R_{DC} (ohm)	I_{MAX} (mA)
3.3mH	55	125	0.6	26	50
4.7mH	40	125	0.45	40	50

Table 1 specification of antenna

3.1.2 Dimension and Footprint:

When selecting electronic components, it is important to consider the dimensions and footprint of the component to ensure proper fit and compatibility with the circuit board and other components.

When selecting electronic components, it is important to consider the dimensions and footprint of the component to ensure proper fit and compatibility with the circuit board and other components as show in the figure its dimension are very ideal for designing a RFID sensor.

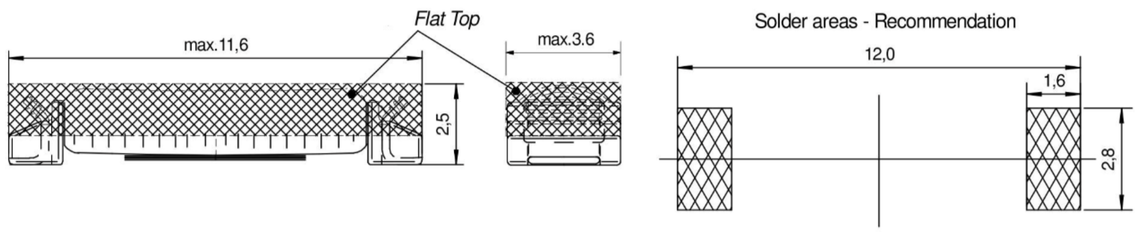


Figure no. 3 Dimension and Footprint

3.1.2 Applications:

Neosid inductor coils are used in a variety of applications where high performance and reliability are required. Some common applications of Neosid inductor coils include:

- **Power Electronics**: Neosid inductor coils are used in power electronics to filter out unwanted frequencies, smooth out the output voltage, and store energy. They are commonly used in DC-DC converters, voltage regulators, and other power supplies.

- **RF and Telecommunications**: Neosid inductor coils are used in RF and telecommunications applications to filter out unwanted frequencies, impedance matching, and tuning. They are commonly used in filters, matching networks, and resonant circuits.

- **Automotive:** Neosid inductor coils are used in automotive applications for power electronics, RF and telecommunications, and sensing applications. They are used in various systems such as ignition systems, electronic fuel injection, ABS systems, and various sensors.

- **Industrial:** Neosid inductor coils are used in various industrial applications for power electronics, RF and telecommunications, and sensing applications. They are used in systems such as motor drives, variable frequency drives, and various sensors.

- **Medical:** Neosid inductor coils are used in various medical applications for sensing, filtering, and tuning applications. They are used in various medical devices such as MRI machines, pacemakers, and various sensors.

3.2 Comparator:

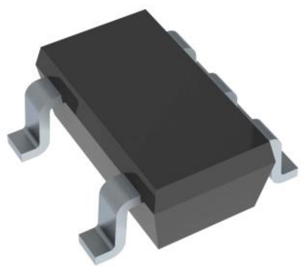


Figure no. 4 LMV331_1G

When selecting an LM331 for the demodulator in the RFID Diagnostic Module, the following factors should be considered:

- Frequency range: The LM331 should be able to operate within the frequency range required by the RFID Diagnostic Module.

- Accuracy: The LM331 should have high accuracy and low drift to ensure precise frequency detection and measurement.

- Sensitivity: The LM331 should have high sensitivity to detect even small changes in frequency.

- Output voltage level: The LM331's output voltage level should be compatible with the input voltage requirements of other components in the system. Which is **200 mV Typical**

- Power consumption: The LM331 should have low power consumption to minimize the overall power consumption of the system. Which ranges from **2.7 V to 5.5 V**.

- Availability and cost: The LM331 should be readily available from reputable suppliers and fit within the budget of the project.

3.2.1 Specification:

There are some tables that shows the different attribute of the specification of the LMV331_1G. through which it become to understand it selection for the demodulator of our Diagnostic module.

Absolute Maximum Ratings:

V_{CC}	Supply voltage[2]			5.5	V
V_{ID}	Differential input voltage[3]			±5.5	V
V_I	Input voltage range (either input)		0	V_{CC+}	V
	Duration of output short circuit (one amplifier) to ground[4]	At or below T_A = 25°C, V_{CC} ≤ 5.5 V		Unlimited	
T_J	Operating virtual junction temperature			150	°C
T_{stg}	Storage temperature range		–65	150	°C

Table 2 absolute max. rating

Recommended Operating Conditions:

V_{CC}	Supply voltage (single-supply operation)	2.7	5.5	V
V_{OUT}	Output voltage		V_{CC+} + 0.3	V
T_A	Operating free-air temperature	–40	125	°C

Table 3 Operating conditions

Electrical Characteristics, VCC+ = 2.7 V

PARAMETER	TEST CONDITIONS	T_A	MIN	TYP.	MAX	UNIT

V_{IO}	Input offset voltage		25°C		1.7	7	mV
α_{VIO}	Average temperature coefficient of input offset voltage		–40°C to 125°C		5		μV/°C
I_{IB}	Input bias current		25°C		15	250	nA
			–40°C to 125°C			400	
I_{IO}	Input offset current		25°C		5	50	nA
			–40°C to 125°C			150	
I_O	Output current (sinking)	$V_O \leq 1.5$ V	25°C	5	23		mA
	Output Leakage Current		25°C		0.003		μA
			–40°C to 125°C			1	
V_{ICR}	Common-mode input voltage range		25°C		–0.1 to 2		V
V_{SAT}	Saturation voltage	$I_O \leq 1.5$ mA	25°C		200		mV
I_{CC}	Supply current	LMV331	25°C		40	100	μA
		LMV393 (both comparators)	25°C		70	140	
		LMV339 (all four comparators)	25°C		140	200	

Table 4 Electrical characteristics

3.2.2 Application:

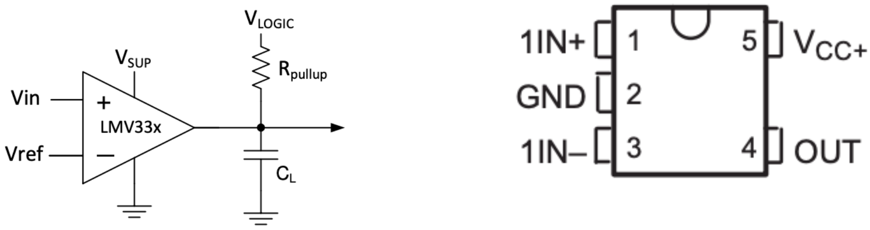


Figure no. 5 circuit and Pinout diagram

LMV331 is a low-voltage, single-supply, low-power comparator IC (integrated circuit) that is commonly used in various applications where precise and fast comparisons are required. Here are some of the most common applications of LMV331:

- **Battery-powered systems**: LMV331 is commonly used in battery-powered systems due to its low voltage and low power consumption. It can operate on a supply voltage as low as 2.7V and consumes only 60µA of current, making it an ideal choice for low-power applications.

- **Signal detection**: LMV331 can be used for signal detection, such as detecting the presence or absence of a signal or comparing two signals. It is commonly used in audio, video, and communication systems.

- **Threshold detection**: LMV331 can also be used for threshold detection, where it compares an input signal to a predetermined threshold level and outputs a high or low signal accordingly. This is useful in applications such as overvoltage and undervoltage protection.

- **Level shifting**: LMV331 can be used as a level shifter to convert a low-voltage signal to a higher voltage signal or vice versa. This is useful in applications such as interfacing low-voltage microcontrollers with higher voltage circuits.

- Oscillators and timers: LMV331 can be used to create oscillators and timers by using positive feedback to create a Schmitt trigger circuit. This is useful in applications such as pulse generators, oscillators, and timers.

3.3 Microcontroller:

Figure no. 6 ESP32-C3

For the microcontroller I use ESP32-c3. It is a powerful and highly integrated Wi-Fi and Bluetooth MCU (microcontroller unit) that is designed for low-power and cost-sensitive IoT (Internet of Things) applications. It can be a good choice for a diagnostic module and it meets the following requirements:

- Wi-Fi connectivity: If the diagnostic module needs to be connected to a Wi-Fi network to transmit data or receive commands, ESP32-C3 can be a good choice. It supports 2.4GHz Wi-Fi and provides up to 150 Mbps data rate, which is sufficient for most IoT applications.

- Low power consumption: If the diagnostic module needs to operate on a battery or a low-power source, ESP32-C3 can be a good choice. It is designed for low-power applications and provides multiple low-power modes to optimize power consumption.

- Cost-effective: If the diagnostic module needs to be cost-effective, ESP32-C3 can be a good choice. It is a highly integrated MCU that combines Wi-Fi and Bluetooth connectivity, a powerful CPU, and various peripheral interfaces, which can reduce the overall system cost.

- Processing power: If the diagnostic module needs to perform complex data processing or machine learning algorithms, ESP32-C3 may not be the best choice. It has a single-core CPU with a clock speed of up to 160 MHz and limited RAM and Flash memory.

- Other requirements: If the diagnostic module requires other features such as Bluetooth connectivity, high-speed data transfer, or real-time processing, other MCUs or SoCs (system-on-chip) may be more suitable.

- Overall, ESP32-C3 can be a good choice for a diagnostic module if it meets the specific requirements of the application, especially if Wi-Fi connectivity and low power consumption are the main priorities.

3.3.1 Block Diagram:

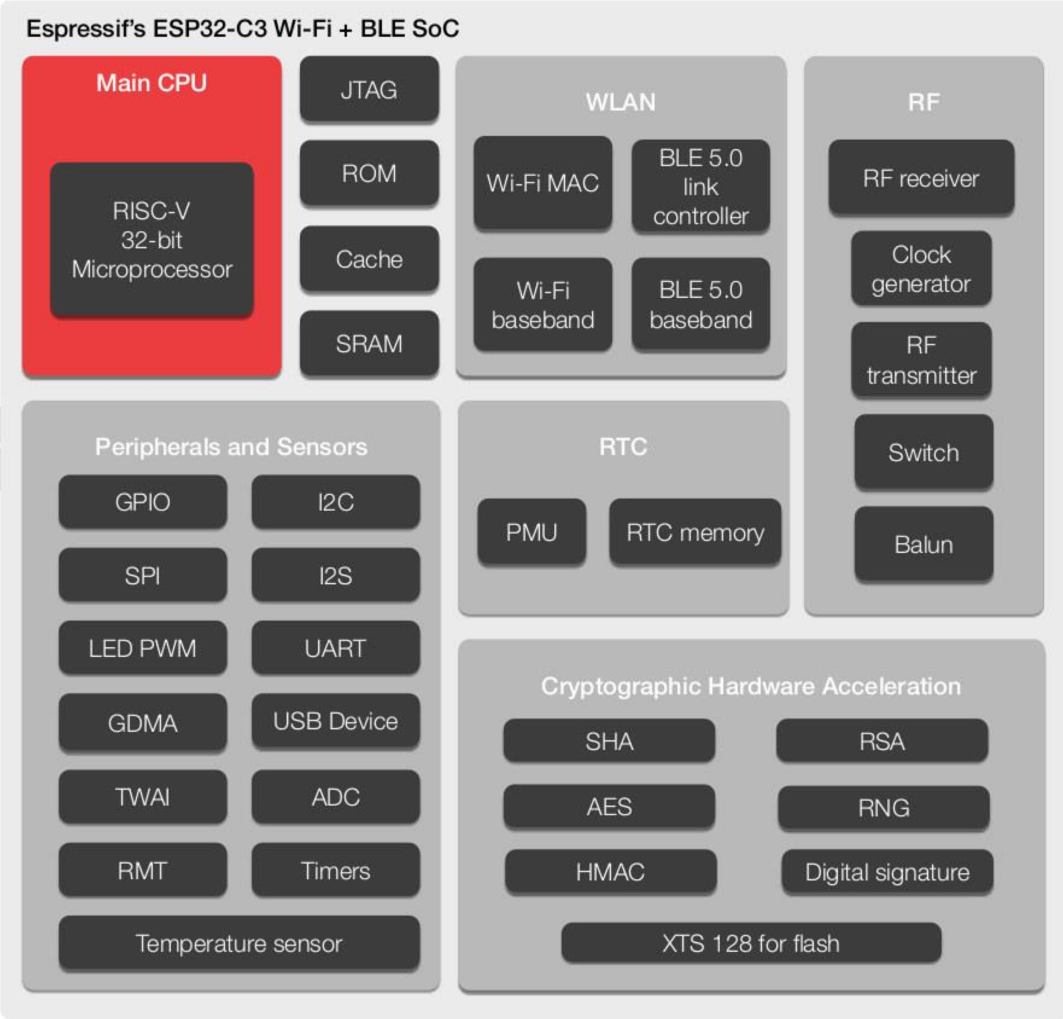


Figure no. 7 Block Diagram

3.3.2 Internal Memory:

The internal memory of the ESP32-C3 consists of: 384 KB of ROM for booting and core operations And which is very handy for our fireware Also.

• 400 KB of on-chip SRAM with a programmable frequency of up to 160 MHz for data and instructions. 16 KB of the 400 KB SRAM are set aside for the cache.

• RTC FAST memory: 8 KB of SRAM that the primary CPU may access. In deep sleep mode, it can save data.

• eFuse 4 Kbit: Your data, including the device ID and encryption key, are reserved for 1792 bits.

3.3.3 Schematic Information:

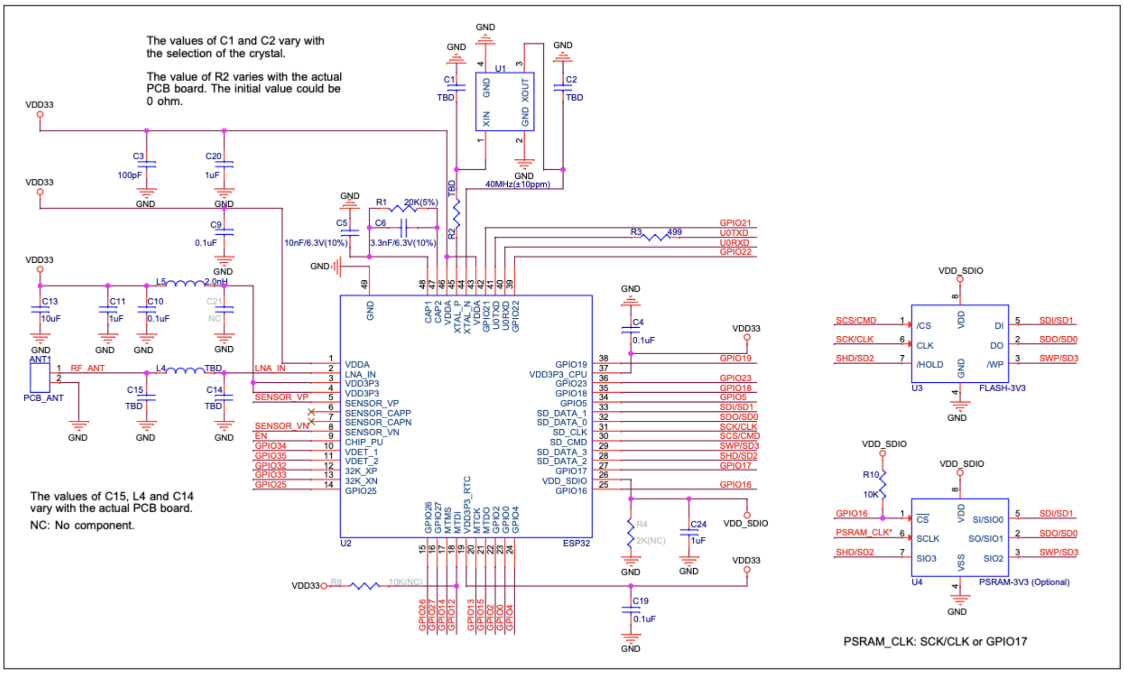


Figure no. 8 Schematic Information

The schematic information for ESP32 can vary depending on the specific variant and the application circuit. However, here are some of the key components and connections that are typically found in an ESP32 schematic:

- Power supply: The ESP32 requires a stable power supply voltage of 3.3V to operate. The power supply can be provided by a voltage regulator that converts the input voltage (usually 5V) to 3.3V, or it can be provided directly from a battery or a low-power source.

- Crystal oscillator: The ESP32 requires a 40 MHz crystal oscillator for accurate timing and clock generation.

- USB-to-UART interface: The ESP32 can be programmed and debugged using a USB-to-UART interface. The interface typically includes a USB connector, a UART transceiver, and a reset circuit.

- Wi-Fi and Bluetooth antenna: The ESP32 requires an antenna for Wi-Fi and Bluetooth communication. The antenna can be an external chip antenna or an onboard PCB antenna.

- GPIO pins: The ESP32 provides a large number of general-purpose input/output (GPIO) pins that can be used to interface with various sensors, actuators, and other components. The GPIO pins typically support functions such as digital input/output, analog input, PWM output, and interrupt input.

- SPI, I2C, and UART interfaces: The ESP32 provides multiple serial communication interfaces such as SPI, I2C, and UART, which can be used to interface with various peripheral devices such as sensors, displays, and communication modules.

- Flash memory: The ESP32 typically includes onboard flash memory for program storage and data storage. The flash memory can be programmed and erased using an external programmer or through a bootloader.

- Power and ground connections: The ESP32 requires multiple power and ground connections to ensure stable operation and to reduce noise and interference.

The schematic information for ESP32 can be found in the datasheet and reference designs provided by the manufacturer, and it can also vary depending on the specific application requirements and design choices. It is important to carefully review the schematic and ensure that it meets the requirements and specifications of the application.

3.3.4 Application:

It can be used in a wide range of applications that require wireless communication and low power consumption, including:

- Internet of Things (IoT) devices: ESP32-C3 can be used in IoT devices such as smart home devices, wearables, and sensors that require wireless connectivity and low power consumption.

- Industrial automation: ESP32-C3 can be used in industrial automation systems that require wireless communication and low power consumption, such as remote monitoring and control systems.

- Consumer electronics: ESP32-C3 can be used in consumer electronics devices such as smart TVs, home audio systems, and gaming consoles that require wireless connectivity and low power consumption.

- Healthcare: ESP32-C3 can be used in healthcare devices such as medical sensors and remote patient monitoring systems that require wireless communication and low power consumption.

- Automotive: ESP32-C3 can be used in automotive applications such as remote monitoring and control systems, infotainment systems, and telematics systems that require wireless communication and low power consumption.

- Agricultural automation: ESP32-C3 can be used in agricultural automation systems that require wireless communication and low power consumption, such as remote monitoring and control systems for irrigation, crop monitoring, and weather sensing.

Overall, ESP32-C3 is a versatile MCU that can be used in various applications that require wireless communication and low power consumption. Its small form factor and low cost make it a popular choice for IoT and other wireless applications.

3.4 Crystal:

ESP32-C3 requires an external 20 MHz crystal oscillator for accurate timing and clock generation. The crystal oscillator is used as a reference clock for the system's internal oscillator and for the Wi-Fi and Bluetooth subsystems. As the suggest in the hardware design guidline.

When selecting a crystal oscillator for ESP32-C3, there are several factors to consider, including:

- **Frequency stability:** The frequency stability of the crystal oscillator determines how accurately the system can maintain the desired clock frequency over temperature and other environmental conditions. A stability of ±10 ppm (parts per million) or better is recommended for ESP32-C3.

- **Load capacitance:** The load capacitance of the crystal oscillator should match the input capacitance of the ESP32-C3. The input capacitance is typically around 8-10 pF, so a crystal oscillator with a load capacitance of around 8-10 pF is recommended.

- **Operating temperature range:** The crystal oscillator should be able to operate reliably over the temperature range required for the application. ESP32-C3 is rated for a temperature range of -40°C to 85°C, so the crystal oscillator should be able to operate within this range.

- **ESR (Equivalent Series Resistance) and Drive Level:** ESR of crystal must be low as ESR can change the crystal frequency, and drive level of oscillator must be high enough to drive the load capacitance of the crystal and also must be within the specification of the crystal being used.

- **Aging rate:** The aging rate of the crystal oscillator determines how much the frequency drifts over time. A low aging rate is desirable for applications that require long-term accuracy and stability.

Overall, a 20 MHz crystal oscillator with a frequency stability of ±10 ppm, load capacitance of around 8-10 pF, low ESR and drive level, and low aging rate is recommended for use with ESP32-C3. It is important to consult the datasheet and reference designs provided by the crystal oscillator manufacturer to ensure that the selected crystal meets the requirements and specifications of the application.

So, to keep the above information in mind we select HC-49USX QUARTZ CRYSTAL

Figure no.9 HC-49USX QUARTZ CRYSTAL

3.4.1 Features:

HC-49USX is a commonly used SMD type quartz crystal oscillator. Some of its key features are:

- **Frequency stability:** HC-49USX quartz crystals are available in a wide range of frequencies, typically from a few kilohertz to 125 MHz. The frequency stability of HC-49USX quartz crystals varies depending on the operating temperature range and the crystal's fundamental frequency.

- **Load capacitance:** HC-49USX quartz crystals are designed to operate with a specified load capacitance, typically between 12 and 32 pF. The load capacitance is used to stabilize the oscillation frequency and ensure accurate timing.

- **Operating temperature range: HC**-49USX quartz crystals can operate over a wide temperature range, typically from -40°C to 85°C. However, the frequency stability of the crystal may vary depending on the temperature range.

- **Aging rate:** The aging rate of HC-49USX quartz crystals is typically low, which means the frequency of the crystal is likely to drift only slightly over time.

- **Resonant resistance:** The resonant resistance of HC-49USX quartz crystals is typically low, which means the oscillator circuit can be designed with a lower drive level and consume less power.

- **Size:** HC-49USX quartz crystals are available in a compact through-hole package, making them easy to mount on printed circuit boards (PCBs) and suitable for use in a wide range of applications.

3.4.2 Application:

Some of the common applications of HC-49USX quartz crystals include:

- **Microcontroller-based systems:** HC-49USX quartz crystals are widely used in microcontroller-based systems such as microprocessors, microcontrollers, and digital signal processors. These devices require accurate timing to synchronize their internal clocks with the external world.

- **Digital circuits:** HC-49USX quartz crystals are used in digital circuits such as counters, flip-flops, and shift registers. These circuits require precise timing to perform their functions correctly.

- **Communication systems:** HC-49USX quartz crystals are used in communication systems such as radio transmitters and receivers. These systems require accurate timing to ensure that data is transmitted and received at the correct time.

- **Timing applications:** HC-49USX quartz crystals are used in timing applications such as clocks, watches, and timers. These applications require accurate timing to keep track of time and ensure that events occur at the correct time.

- **Industrial automation:** HC-49USX quartz crystals are used in industrial automation systems such as programmable logic controllers (PLCs) and motor control systems. These systems require accurate timing to control the timing of various events and ensure that the system operates correctly.

3.5 Battery:

Figure no. 10AAA alkaline battery

When selecting a 3V battery for an RFID diagnostic module, there are a few factors to consider:

- Capacity: The capacity of the battery determines how long it can power the RFID diagnostic module. You should choose a battery with a capacity that is sufficient for your needs.

- Size: The size of the battery should be appropriate for the module and the space available. You may need to choose a smaller battery if space is limited.

- Voltage: The battery voltage should match the voltage required by the module. In this case, a 3V battery is required.

- Chemistry: There are several types of batteries available, such as lithium-ion, alkaline, and nickel-cadmium. The chemistry of the battery should be appropriate for the module and your specific application.

Based on these factors, some suitable options for a 3V battery for an RFID diagnostic module include:

- CR2032 lithium coin cell battery
- AAA alkaline battery
- 1/3N lithium battery
- CR123A lithium battery

- It's important to carefully consider your requirements and the specifications of your module before selecting a battery to ensure proper operation and longevity. And to consider the above factor and the need of my Diagonistic module we select **AAA alkaline battery.**

3.6 Display (1.8inch LCD module):

Figure no. 11 1.8inch LCD module

For this Diagnostic module we made the selection of waveshare 1.8inch OLED Module. When selecting this Display for an RFID diagnostic module, there are a few factors to consider:

- **Compatibility:** The LCD module and the RFID diagnostic module you're using must be compatible. To fit with your RFID diagnostic module, confirm that the LCD module has the necessary interface, resolution, and dimensions. And both the Microcontroller and the are capable to interface with each as the the display support the SPI protocol that's fine for the microcontroller also.

- **Size:** The LCD module's size needs to be suitable for the product and the application. In this situation, a small RFID diagnostic module that is 1.8 inches wide might work.As we want the module in between the 46(W) & 29(H)(mm) width and length respectively. And to consider this factor this module is the best choice.

- **Display caliber:** A clear and accurate depiction of the RFID data depends on the LCD module's display caliber. Think about things like viewing angle, contrast, and resolution.

- **Power consumption:** To reduce the drain on the RFID diagnostic module's battery, the LCD module's power consumption should be low. And for our system of 3V this Display work as it also need 3V power supply.

Based on these factors, the Waveshare 1.8 inch LCD module may be a suitable option for an RFID diagnostic module. This LCD module has a resolution of 128x160 pixels, an SPI interface, and low power consumption.

3.6.1 Specification:

- **Operating voltage:** 3.3V/5V (When using 5V power supply, the logic voltage is 5V, when using 3.3V power supply, the logic voltage is 3.3V)
- **Interface:** SPI
- **LCD type:** TFT
- **Driver:** ST7735S
- **Resolution:** 128 * 160 (Pixel)
- **Display size:** 35.04(W) * 28.03(H)(mm)
- **Pixel size:** 0.219(W) * 0.219(H)(MM)
- **Dimension:** 56.5 * 34(mm)

3.6.2 Interface Description:

SYMBOL	DESCRIPTION
VCC	Power (3.3V/5V input)
GND	Ground
DIN	SPI data input
CLK	SPI clock input
CS	Chip selection, low active
DC	Data/Command selection (high for data, low for command)
RST	Reset, low active
BL	Backlight

Table 5 Interface description

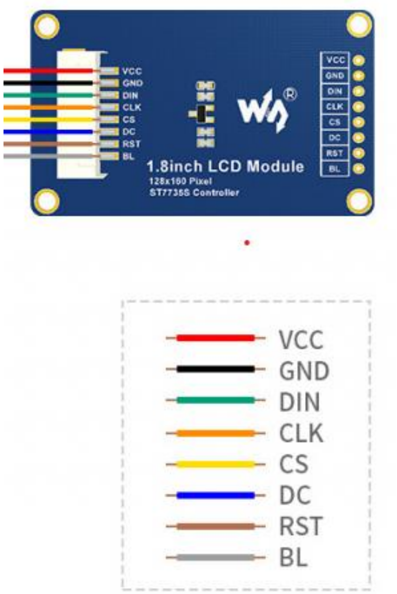


Figure no. 12 Interface pinout

3.6.3 Dimensions:

Figure no. 13 Dimension

3.6.4 Application:

There are many uses for the Waveshare 1.8-inch LCD module, including:

- **Diagnostic tools that are portable:** The LCD module can be used as a display for RFID diagnostic tools that are portable to show the information gathered by the RFID reader.
- **Wearable gadgets:** Due to the LCD module's compact size, wearable gadgets like smartwatches or fitness trackers can utilise it.
- **Educational kits:** The LCD module can be used in educational kits to instruct students in the fundamentals of programming and LCD display technology.
- **IoT devices:** To provide users with information or feedback, the LCD module can be embedded into IoT devices.
- **Gaming devices:** Small gaming devices, including handheld gaming consoles, can employ the LCD module as a display.

Firmware:

As we discussed in the introduction section that through this diagnostic module we try to find the error in the RFID module so keep this in mind there are two main part in this firmware:

- **Receiving Data**: Microcontroller receive the data from the Demodulator.
- **Processing the values** taken from the demodulator to get correct information about the error.
- **Display Data:** Show the name and the code of the error on the TFT led display.

4.1 Receiving Data :

The microcontroller receive the data from the demodulator through UART protocol

4.1.1 UART Specification:

- start bit 1
- stop bit 1
- parity bit 1
- Baud rate 600
- Data frame 8 bit long

Code:

As I program the micro-controller through Arduino Ide so write following lines for the code to receive the data from on the receiving pin of the Microcontroller:

```
const int BUFFER_SIZE = 3;
char buf[BUFFER_SIZE];
Serial.begin(600, SERIAL_8N1, 20, 21);
while (Serial.available()>0)
{
  Serial.readBytes(buf, BUFFER_SIZE);
}
```

4.2 Processing Data :

After receiving the data from the demodulator then we have to process it in a way to compare it with all the all the list of the error by comparing the code of error we receive to the entire list

4.2.1 List of error:

various micro failures:

```
#define MICRO_FAILURE                            0u
#define DYN_OFF_LINE_TESTS_NOT_IN_SEQUENCE       0u
#define DYN_OFF_LINE_TESTS_NOT_EXECUTED          1u
#define DYN_ROM_TEST_FAILED                      2u
#define INI_MEM_CRC_EXCHANGE_FAILED              3u
#define DYN_VARIABLE_MEM_TEST_FAILED             4u
#define DYN_STACK_MEM_TEST_FAILED                5u
#define INSTRUCTIONS_TEST_FAILED                 6u
#define DYN_INT_SCHEDULER_TEST_FAILED            9u
#define INTERRUPT_TEST_FAILED                    10u
#define SCHEDULER_SAFETY_FLOW_NOT_CORRECT        11u
#define SECOND_MODULE_MICRO_FAILED               12u
#define DYN_END_OF_CODE_MEM_REACHED              13u
#define REGISTER_TEST_FAILED                     14u
#define MEMORY_CORRUPTED                         15u
#define DYN_AD_CONVERTER_FAIL                    17u
#define ANTENNA_OVERVOLTAGE_DETECTED             18u
#define OVERVOLTAGE_DETECTED                     20u
#define MAX_MICRO_FAILURE                        31u
```

OSSDs failure:

```
#define OSSD_FAILURE                             32u
#define INI_OSSD_IDENTIFICATION_FAILED           34u
#define SECOND_MODULE_OSSD_FAILED                36u
#define INI_OSSD_IDENTIFICATION_K_WRONG          37u
#define OSSD_DECISION_COUNTER_MAX                38u
#define DYN_OSSD_TEST_NOT_PERFORMED              39u
#define DYN_OSSD_FEEDBACK_WRONG                  40u
#define MAX_OSSD_FAILURE                         42u
```

various comm failures

```
#define COMM_FAILURE                             64u
#define INI_COMMUNICATION_TIMEOUT                64u
#define SECOND_MODULE_COMM_FAILED                65u
#define DYN_COMMUNICATION_MISSING                66u
#define MAX_COMM_FAILURE                         67u
```

external Contactors failure

```
#define EXT_RELAY_FAILURE                        96u
#define DYN_K_CONTACT_OPENED_WRONG               96u
#define DYN_K_CONTACT_CLOSED_WRONG               97u
#define SECOND_MODULE_EXT_RELAY_FAILED           98u
```

#define MAX_EXT_RELAY_FAILURE 99u

Transponder failure

#define TRANSPONDER_FAILURE 128u
#define TRANSPONDER_ID_WRONG 128u
#define MAX_TRANSPONDER_FAILURE 132u

various configuration failures

#define CONF_FAILURE 160u
#define INI_USER_CONFIGURATION_REJECTED 160u
#define INI_K1_K2_INPUT_WRONG 162u
#define SECOND_MODULE_USER_CONFIG_WRONG 165u
#define SECOND_MODULE_CONFIG_REJECTED 166u
#define DYN_CONFIG_CHANGE 172u
#define DYN_FIRST_SENSOR_CONFIG_CHANGE 173u
#define EEROM_CORRUPTED 180u
#define MAX_CONF_FAILURE 181u

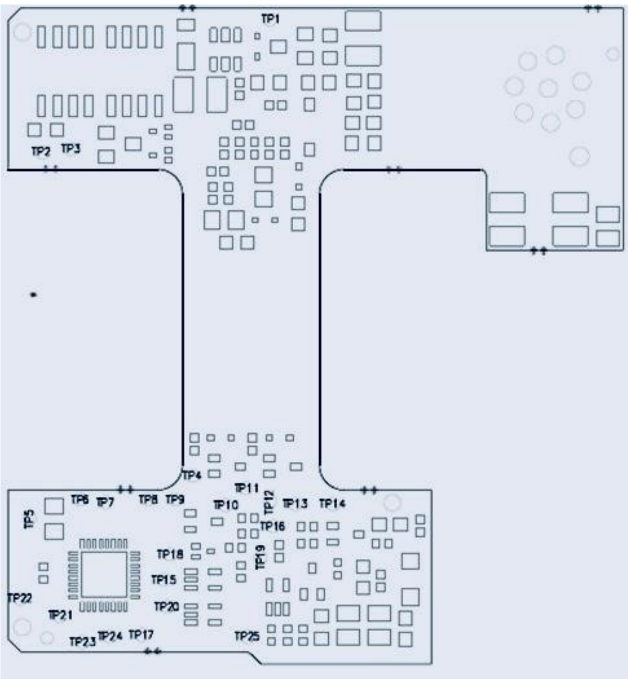
various safety inputs failures

#define SAFETY_INPUT_FAILURE 192u
#define DYN_SAFETY_INPUT_DISCREPANCY 192u
#define SAFETY_INPUT_CHANNEL_WRONG 193u
#define MAX_SAFETY_INPUT_FAILURE 197u

various board failures

#define BOARD_FAILURE 224u
#define INI_UNDERVOLTAGE_TEST_FAILED 224u
#define INI_WD_TEST_FAILED 225u
#define INI_START_INCONGRUENCY 230u
#define RFID_HW_TEST_FAIL 234u
#define SECOND_MODULE_BOARD_FAILED 236u
#define MICRO_ID_WRONG 237u
#define SECOND_MODULE_ALWAYS_MASTER 242u
#define MAX_BOARD_FAILURE 243u

To get all the values or code for this error we have to test all the test points on the PCB of the RFID sensor with failure of each and every point one by one. As shown the test points in the picture below:



TEST POINTS	
TP1	CJ1_IN_+24V_DC
TP2	N04083
TP3	N04067
TP4	N06550
TP5	SWD_DIO_MIDDLE_MCU1
TP6	SWD_CLK_MIDDLE_MCU1
TP7	N06554
TP8	SWD_CLK_MIDDLE_MCU2
TP9	SWD_DIO_MIDDLE_MCU2
TP10	DI_MCU1_NRESET
TP11	N27709
TP12	N10228
TP13	N09443
TP14	RFID_MCU_TX
TP15	GND
TP16	+5V_DC
TP17	N04748
TP18	DI_MCU2_NRESET
TP19	N06546
TP20	N06542
TP21	N08478
TP22	N08078
TP23	N08953
TP24	N04760
TP25	N14517480

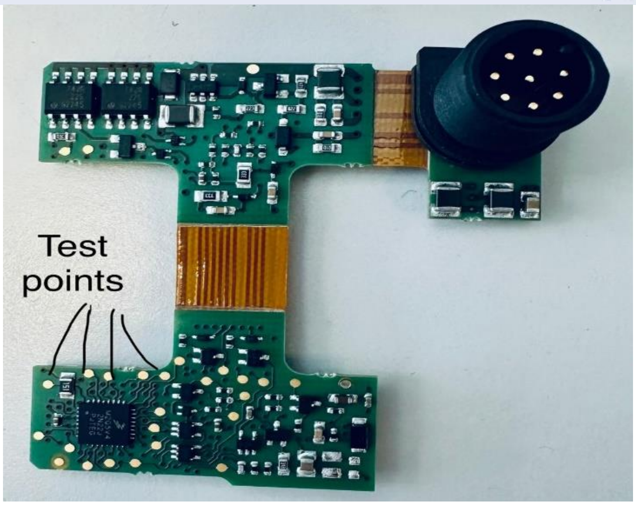


Figure no. 14 Testpoints

Code:

Following is the code for processing the value for the PWS voltage value and Antenna value in the BOARD FALIURE MODE as an example :

```
if( buf[0] == 255u)
{

  fnumber2=(float)buf[1]*0.4335+1.5;
  fnumber3=(float)buf[2]*0.039;

  tft.println("MAX_BOARD_FAILURE");

  tft.print("PWS VOLT: ");
  tft.println(fnumber2);
```

```
  tft.print("ANTEENA VOLT: ");
  tft.println(fnumber3);
  delay(500000);

}
```

4.3 Displaying Data:

Finally after processing the data and get the correct error name and the error code after processing the data receive from the demodulator of our RFID diagnostic module we are now in position to display this information on the Display module

Code:

Following is the code related to the displaying of the information:

```
tft.init();
tft.fillScreen(TFT_BLACK);
tft.setRotation(1);
tft.setCursor(0, 0, 2);
tft.fillScreen(TFT_BLACK);
tft.setTextColor(TFT_WHITE);
tft.setTextFont(2);
        tft.println("DYN_OFF_LINE_TESTS_NOT_IN_SEQUENCE ");
tft.print("ERROR: ");
tft.println((int)buf[1] , DEC);
tft.print("POSITION: ");
tft.println((int)buf[2], DEC);
```

4.4 Complete Firmware:

Following is the complete firmware of this RFID Diagnostic module but here in the report I copy the code only with few error as if I mention all the errors it will take a lot of pages:

```
#include <TFT_eSPI.h>       // Graphics and font library for ST7735 driver chip
#include <SPI.h>
#include "image.h"
TFT_eSPI tft = TFT_eSPI();  // Invoke library, pins defined in User_Setup.h
TFT_eSprite sprite = TFT_eSprite(&tft);
#define TFT_GREY 0x5AEB     // New colour
#include <HardwareSerial.h>
```

```
const int BUFFER_SIZE = 3;
char buf[BUFFER_SIZE];
int number;
float fnumber2;
float fnumber3;

void setup(void) {

  tft.init();
  tft.fillScreen(TFT_BLACK);
  tft.setSwapBytes(true);
  tft.pushImage(0,0,128,160,image);
  Serial.begin(600, SERIAL_8N1, 20, 21);
  }

void loop() {

while (Serial.available()>0)
{
  Serial.readBytes(buf, BUFFER_SIZE);
   tft.setRotation(1);
   tft.setCursor(0, 0, 2);
   tft.fillScreen(TFT_BLACK);                  // Set the font colour to be red with black
background, set to font 4
   tft.setTextColor(TFT_WHITE);
   tft.setTextFont(2);



if( buf[0] == 255u)
{

   fnumber2=(float)buf[1]*0.4335+1.5;
   fnumber3=(float)buf[2]*0.039;

   tft.println("MAX_BOARD_FAILURE");

   tft.print("PWS VOLT: ");
   tft.println(fnumber2);

   tft.print("ANTEENA VOLT: ");
   tft.println(fnumber3);
   delay(500000);

}
else if( buf[0] == 254u)
{


switch (buf[1]) {
```

```
  case 0:
  tft.println("DYN_OFF_LINE_TESTS_NOT_IN_SEQUENCE ");
  tft.print("ERROR: ");
  tft.println((int)buf[1] , DEC);
  tft.print("POSITION: ");
  tft.println((int)buf[2], DEC);

            break;
  case 1:
  tft.println("DYN_OFF_LINE_TESTS_NOT_EXECUTED");
  tft.print("ERROR no: ");
  tft.println((int)buf[1] , DEC);
  tft.print("POSITION: ");
  tft.println((int)buf[2], DEC);

            break;
  case 2:
  tft.println("DYN_ROM_TEST_FAILED");
  tft.print("ERROR no: ");
  tft.println((int)buf[1] , DEC);
  tft.print("POSITION: ");
  tft.println((int)buf[2], DEC);

            break;
  case 3:
  tft.println("INI_MEM_CRC_EXCHANGE_FAILED");
  tft.print("ERROR no: ");
  tft.println((int)buf[1] , DEC);
  tft.print("POSITION: ");
  tft.println((int)buf[2], DEC);

   break;
  case 4:
  tft.println("DYN_VARIABLE_MEM_TEST_FAILED");
  tft.print("ERROR no: ");
  tft.println((int)buf[1] , DEC);
  tft.print("POSITION: ");
  tft.println((int)buf[2], DEC);

            break;
  case 5:
  tft.println("DYN_STACK_MEM_TEST_FAILED");
  tft.print("ERROR no: ");
  tft.println((int)buf[1] , DEC);
  tft.print("POSITION: ");
  tft.println((int)buf[2], DEC);

            break;
 }

}  } }
```

Schematic Diagram

5.1 Demodulator:

As we discussed before this section cointain the antenna, envelop detector, filter, comparator as shown in the schematic below:

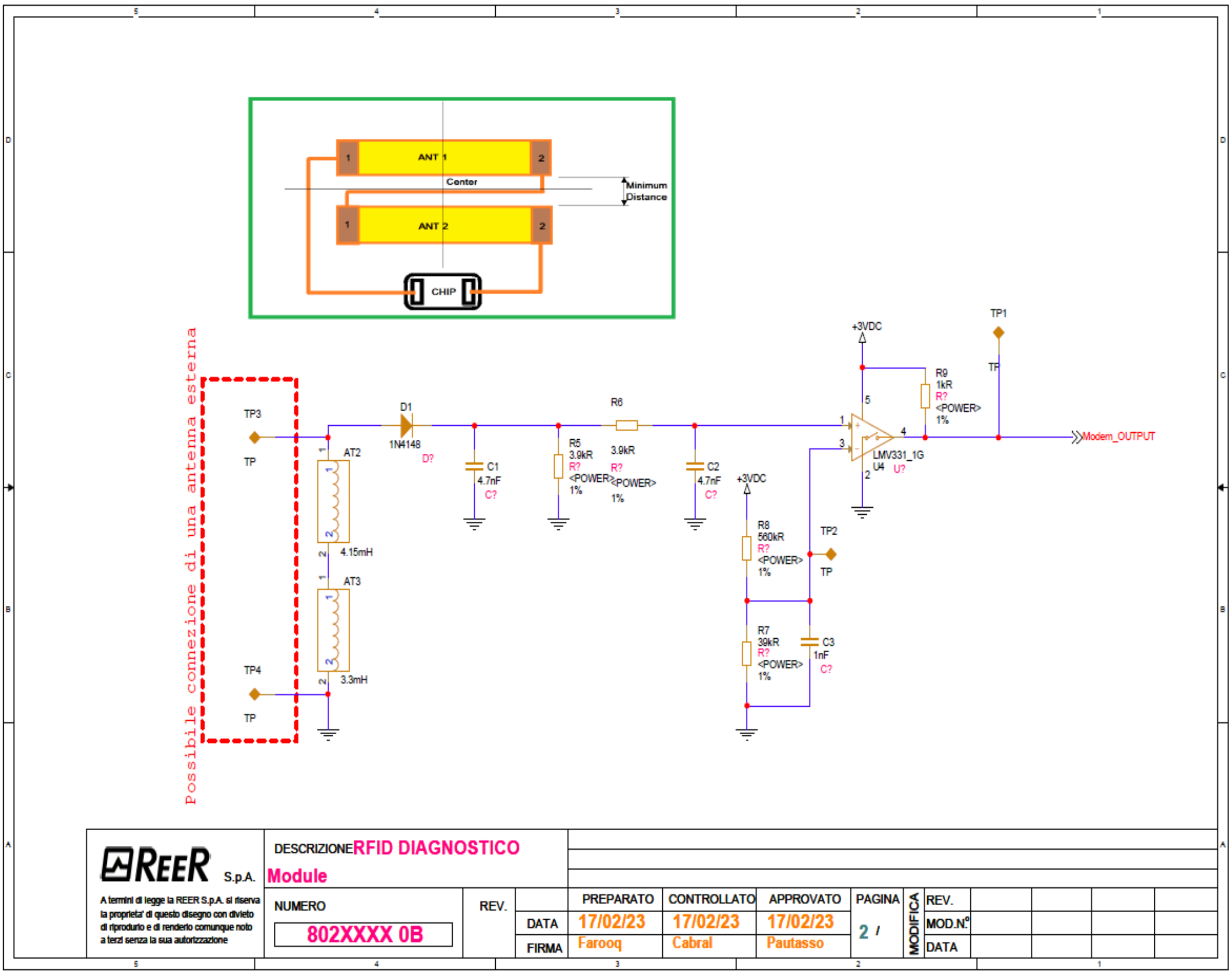


Figure no. 15 Schematic diagram (Demodulator)

5.2 MCU:

This section of schematic contain the micro-controller, power supply section, crystal, display (TFT led), Bluetooth antenna. As you can see in the schematic below:

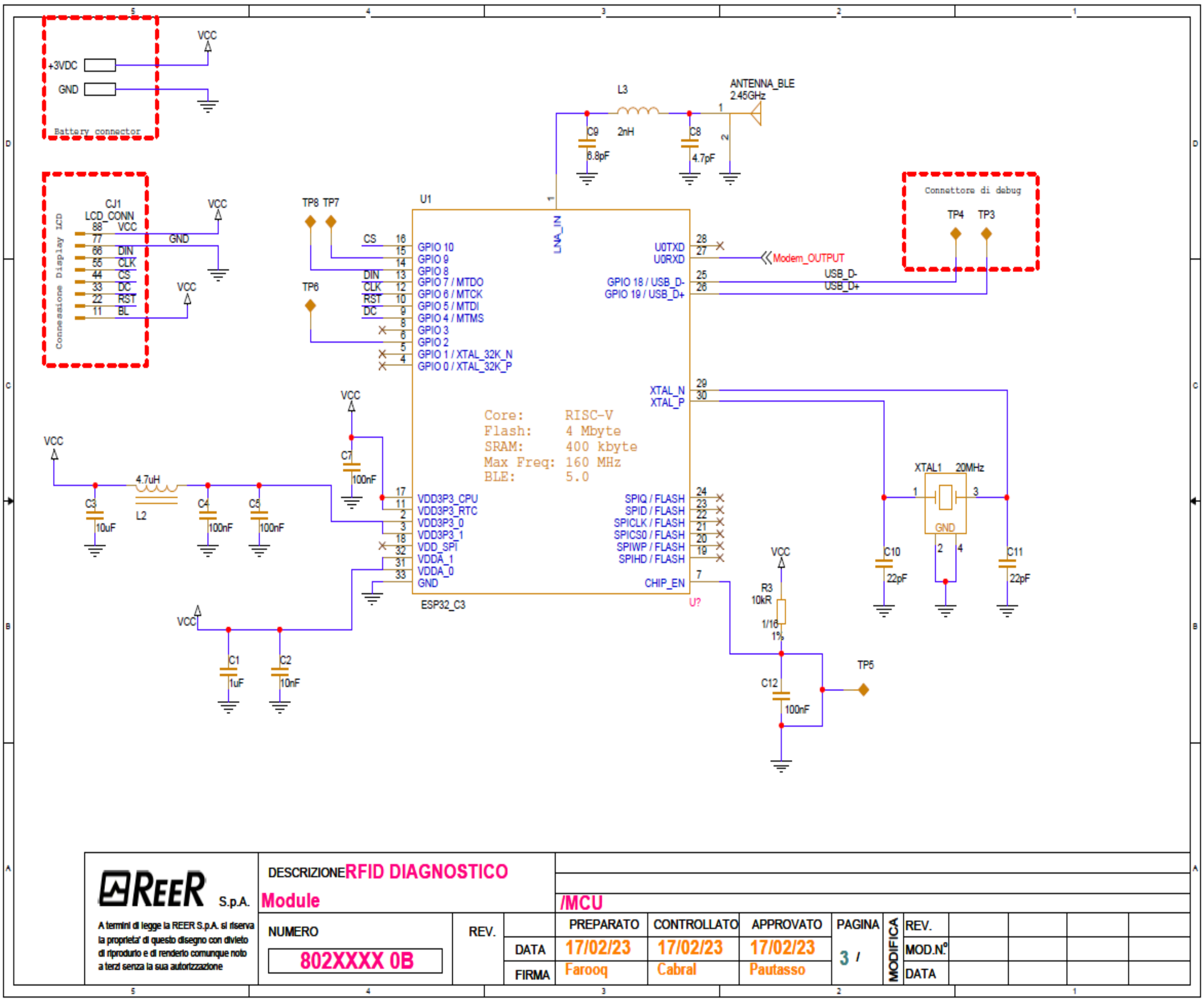


Figure no. 16 Schematic Diagram (MCU)

Validation & Testing of Prototype

Before going to start the PCB, First performed some test on each main section of the Diagnostic module. By making their circuit on the Breadboard.

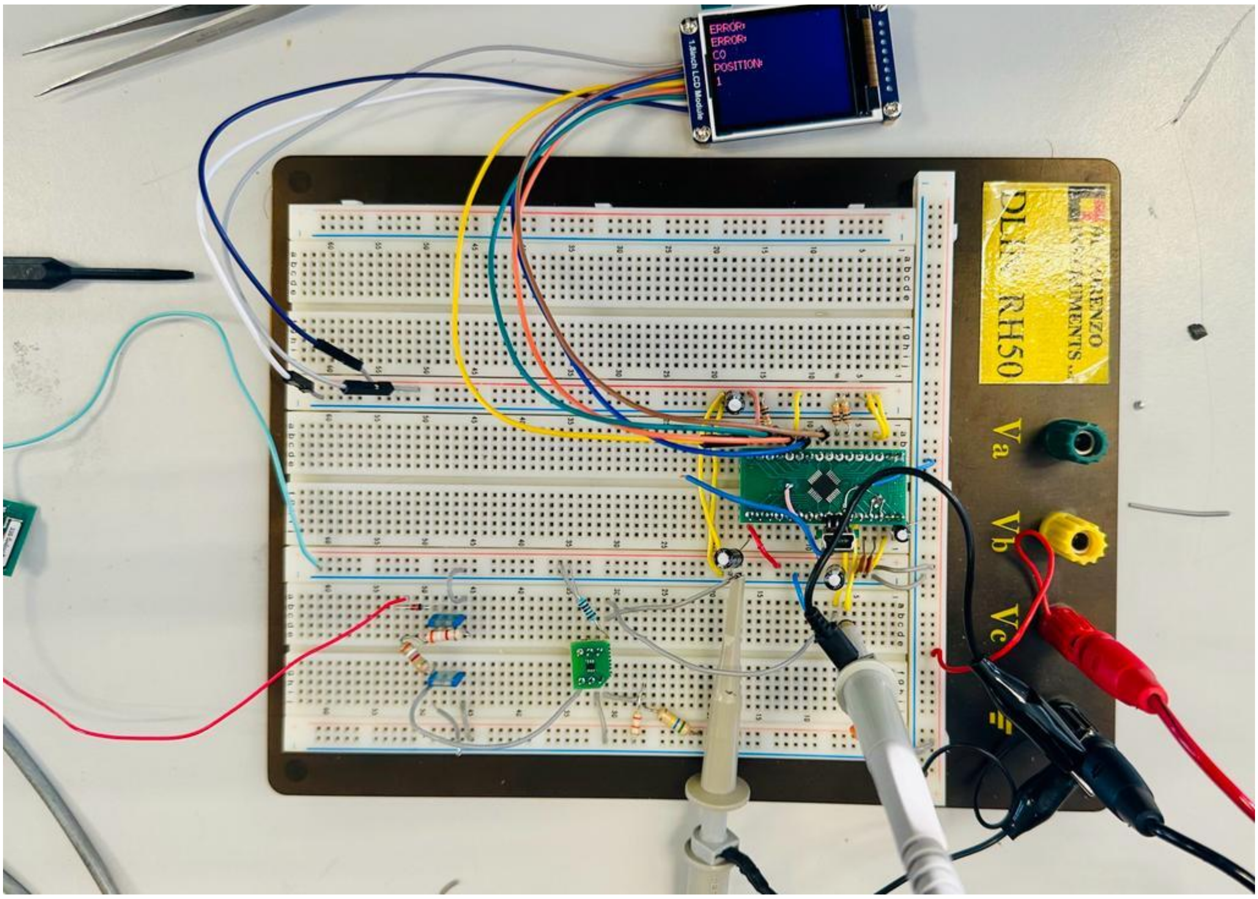


Figure no. 17 Prototype on breadboard

6.1 Demodulator Testing:

Following is the picture of the prototype of the demodulator on the breadboard to test is we got the correct signal from the RFID sensor.

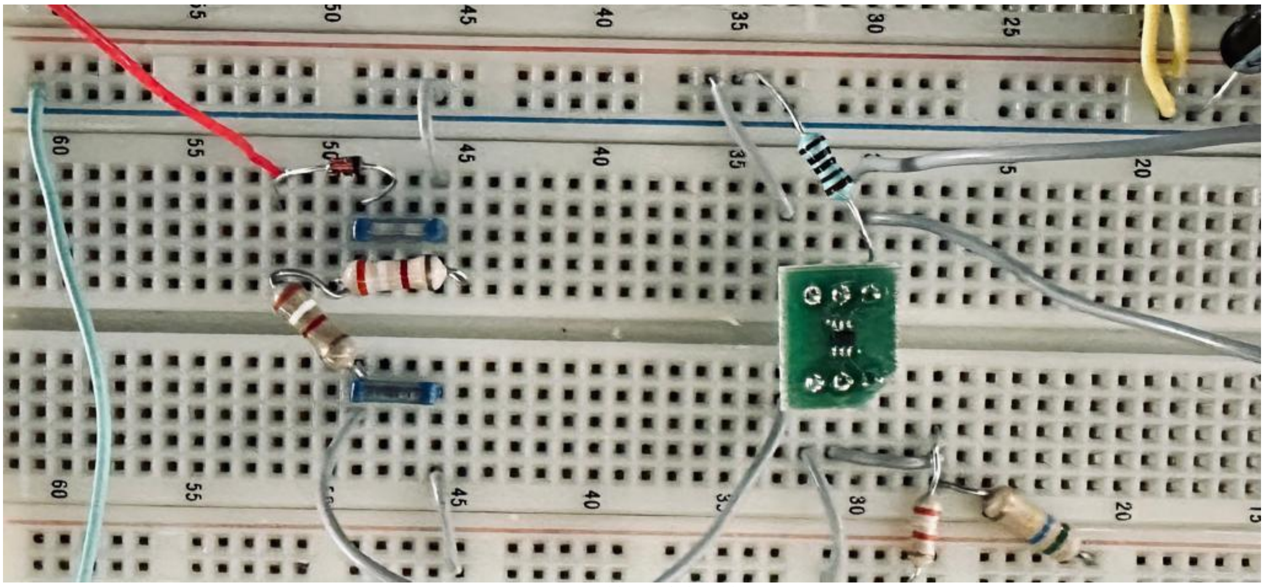


Figure no. 18 prototype (demodulator)

Perform making the small fault in the RFID sensor and check the signal through the oscilloscope. As shown in the picture below.

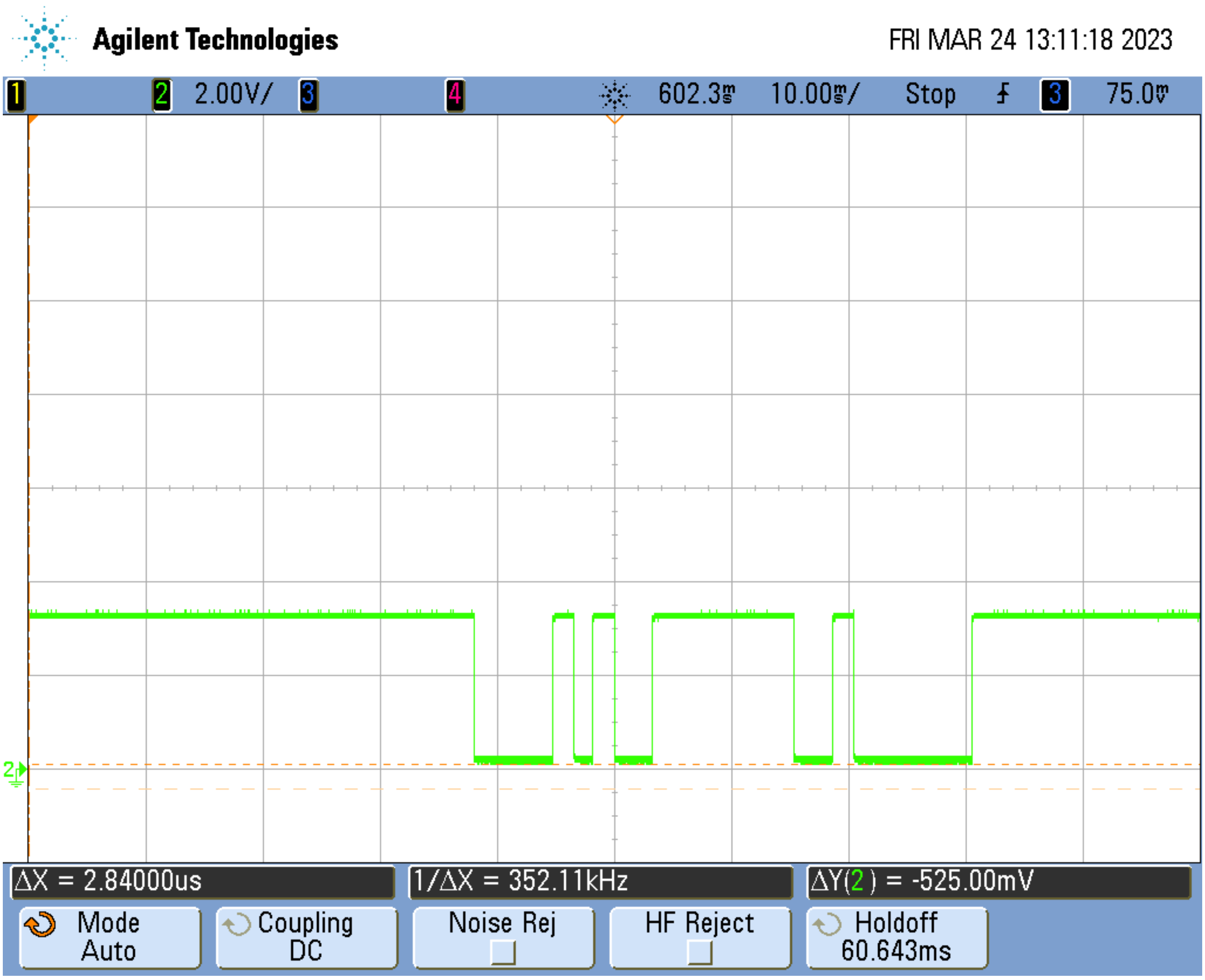


Figure no. 19 package signal

6.1 Microcontroller & Display testing:

After successfully taken the signal from the demodulator then communicate this signal to the microcontroller through UART communication protocol for processing the value and show on the display. To do the we made all necessary hardware design of the circuit for the Microcontroller as suggested by the manufacturer on the breadboard. As shown on the figure below:

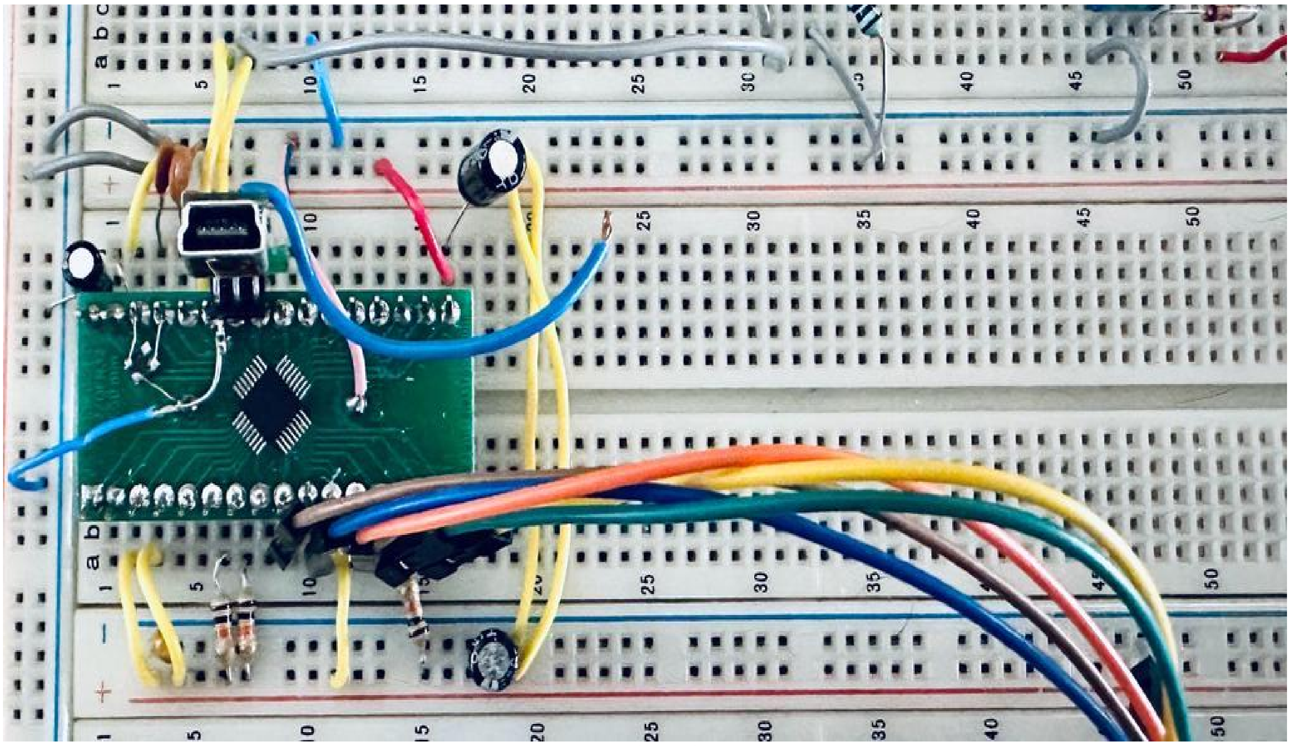


Figure no. 20 prototype(MCU)

After successfully receiving the values form the demodulator then microcontroller processing it and display it on the TFT LED through SPI communication pins. And shows the exact name of the error and the values, code, position of the error. As shown in the picture:

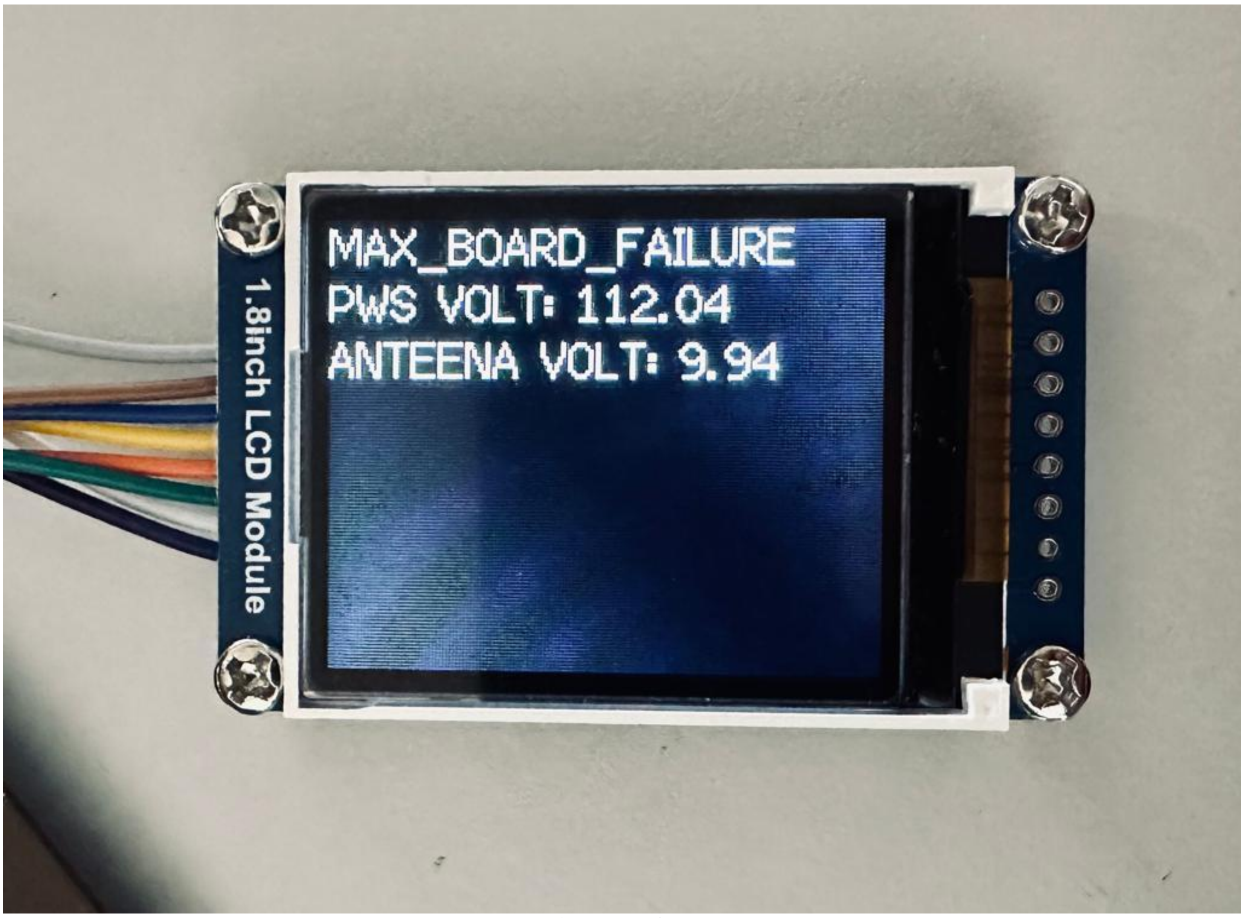


Figure no. 21 LCD showing information

PCB Layout

After testing the all main part of the prototype then we move on to the PCB layout. There are a number of important variables to take into account when designing the PCB layout for an RFID diagnostic module. These consist of:

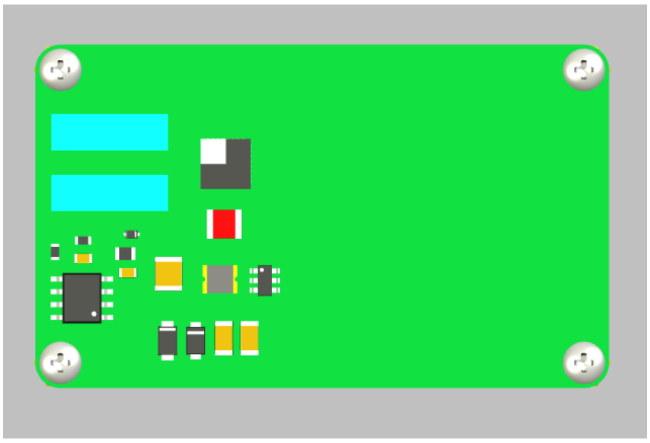
- **Component placement:** To guarantee optimum performance and reduce interference, components should be carefully placed on the PCB. It is important to position components so that they do not interact with one another or distort the signal.

- **Trace routing:** The PCB's traces must be routed properly for efficiency and signal integrity. High-speed signals should be routed with controlled impedance, and traces should be kept as short and direct as feasible.

- **Ground plane:** Maintaining transmission integrity and reducing electromagnetic interference (EMI) require a ground plane. The use of and connection of all components to a stable ground plane are required.
- **Power supply:** To avoid interference and guarantee precise readings, the power supply to the RFID diagnostic module should be clean and stable. Each component should have a bypass capacitor close to the power source pin.

- **EMI shielding**: The PCB should be enhanced with EMI shielding to prevent EMI from impairing the performance of the RFID diagnostic module. This can be accomplished by adding shielding around particular components or by encircling the entire PCB with a conductive shield.

In general, an RFID diagnostic module's PCB layout is crucial for guaranteeing precise and trustworthy readings of RFID readers and antennas. Build a superior RFID diagnostic module by paying close attention to the component placement, trace routing, ground plane, power supply, and EMI shielding.



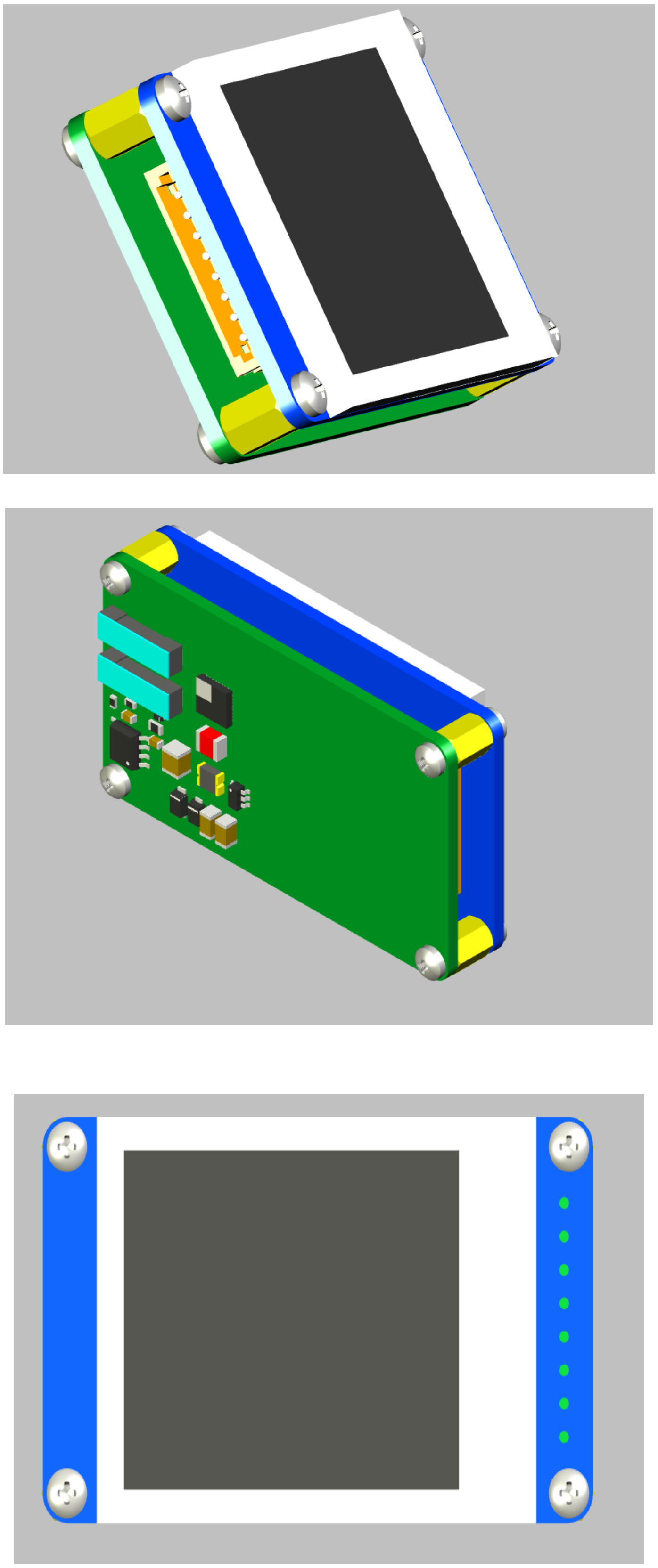


Figure no. 22 3D PCB

Conclusion

The earlier chapters provided a detailed account of the device's development, from the initial stages of functional definition to a functioning prototype that surpassed expectations. The model-based strategy attracted a lot of notice, with numerous tests and adjustments that guaranteed compliance with the desired outcomes while being straightforward, dependable, and simple to adjust as needed. The created firmware showed to be reliable and durable over time with no errors after the model was integrated and used.

The project calls for the development of several prototypes, measurements and tests in the lab, and the construction of the ultimate prototype. The diagnostic procedure is streamlined by the module's use of Radio Frequency Identification (RFID) technology, resulting in more accurate and trustworthy test findings. The selection of suitable components and the design of the circuits were all factors that had to be carefully considered during the design process. The performance of the module was optimized through iterative improvements made possible by the creation of numerous prototypes. To assess the success of the module and to determine areas for future development, laboratory measurements and tests were carried out. The final version was then created, including all the elements and functions required for the best performance.
The findings of this thesis project show how RFID technology has the ability to revolutionize diagnostic testing across a range of industries and make a significant contribution to the field of diagnostic technology.