HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY END ENGINEERING

FACULTY OF ADVANCED EDUCATION

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MECHATRONICS PROJECT REPORT

TOPIC: DESIGN OF AN INDOOR POSITIONING MODULE USING UWB TECHNOLOGY

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In particular, I would like to sincerely thank Mr. Bui Ha Duc for his dedicated supervision, support, and valuable professional feedback during the research, design, and implementation of this topic. His close guidance has helped me refine my thinking, develop a more scientific working methodology, and strengthen my practical problem-solving skills.

I also would like to extend my sincere appreciation to the University and the Faculty for providing a favorable learning environment, facilities, and reference materials that enabled me to conduct this project. Through the process, I had the opportunity to consolidate my specialized knowledge and improve essential skills in system design, electronic circuit design, embedded programming, and experimental validation. These experiences are important assets that have helped me form a clearer career direction and further develop myself in the field of mechatronics.

Although I have made every effort to complete this project with seriousness and responsibility, due to limited time and personal capacity, the report may still contain shortcomings. I respectfully welcome feedback and suggestions from the lecturers so that I can continue to improve and learn from this experience for future studies and professional work.

Sincerely thank you!

SUPERVISOR'S COMMENTS

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Ph.D Bùi Hà Đức

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CHAPTER 1. INTRODUCTION

1.1. RATIONALE FOR CHOOSING THE TOPIC

In the context of the strong momentum of the Fourth Industrial Revolution (Industry 4.0), automation systems, mobile robots, the Internet of Things (IoT), and smart homes are playing an increasingly important role in manufacturing and daily life. One of the core challenges in these systems is determining the precise position of an object in space, especially in indoor environments - where traditional positioning technologies such as GPS cannot operate effectively. [1]

Current indoor positioning systems are widely applied in:

- Autonomous robots in factories and smart warehouses.
- Asset tracking.
- Human monitoring in hospitals, schools, and industrial facilities.
- Navigation in large buildings (airports, shopping malls).
- Safety and rescue systems.

However, common indoor positioning methods such as WiFi, Bluetooth Low Energy (BLE), RFID, or ZigBee still have several limitations, including [2]:

- Low accuracy (typically an error of 1–5 m).
- Strong susceptibility to multipath interference.
- High latency and poor stability.

Meanwhile, **Ultra-Wideband (UWB)** has emerged as a next - generation positioning technology with the ability to provide [3]:

- Very high accuracy (centimeter-level error).
- Strong resistance to interference and multipath effects.
- Distance measurement based on signal time-of-flight (ToF) rather than signal strength.

Because of these outstanding advantages, researching, designing, and implementing an indoor positioning module using UWB technology is a topic that is :

- Highly practical.
- Aligned with current technology trends.
- Closely related to the Mechatronics field, integrating:
  - Electrical and electronics engineering.

- Embedded systems.
- Signal processing.
- Automation.

Therefore, I chose the topic **"Design of an Indoor Positioning Module Using UWB Technology"** as my mechatronics project.

1.2. PROJECT OBJECTIVES

1.2.1. General objective

To design and build an indoor positioning module using Ultra-Wideband (UWB) technology, capable of accurately measuring distances between nodes, serving as a foundation for an indoor positioning system.

1.2.2. Specific objectives

- Study the theoretical background of UWB technology and indoor positioning methods.
- Design the block diagram of the UWB positioning system.
- Select components and design the hardware circuit for the UWB module.
- Develop the schematic for the module.
- Perform simulation and validate the system's operation.
- Evaluate the accuracy and practical feasibility of the module.

1.3. SCOPE AND RESEARCH OBJECTS

1.3.1. Scope of the study

- The project focuses on indoor positioning.
- The measured distance range is from a few meters to several tens of meters.
- A complete 3D positioning system is not implemented; the work focuses on:
  - Accurate distance measurement (ranging).
  - Providing a foundation for future 2D/3D positioning systems.

1.3.2. Research objects

- Ultra-Wideband (UWB) technology.
- DWM1000 UWB module.
- ESP32 microcontroller.
- Time-of-Flight (ToF)-based ranging methods.

1.4. RESEARCH AND VALIDATION METHODS

This project employs the following methods:

- Reviewing documents, datasheets, and technical standards.
- Analyzing and comparing positioning methods.
- Designing schematics using KiCad.
- Performing validation measurements using a multimeter after the power supply is available.

CHAPTER 2. THEORETICAL BACKGROUND

2.1. OVERVIEW OF UWB TECHNOLOGY

2.1.1. Definition of Ultra-Wideband

Ultra-Wideband (UWB) is a wireless communication technology that uses a very wide bandwidth (typically greater than 500 MHz) with very low transmit power. [4]

Unlike traditional radio technologies that rely on narrowband sinusoidal waves, UWB transmits extremely short pulses (on the order of nanoseconds), enabling highly accurate measurement of signal propagation time.

2.1.2. Key characteristics of UWB

- High time resolution.
- Strong interference immunity.
- Less affected by multipath propagation.
- High positioning accuracy (centimeter-level).

2.2. PRINCIPLE OF DISTANCE MEASUREMENT USING UWB

2.2.1. Time of Flight (ToF)

The distance between two devices is determined based on the time it takes for a radio signal to travel from the transmitting device to the receiving device:

$$d = \frac{c \times t}{2} \text{ [4]}$$

Trong đó: d: Distance

c: Speed of light

t: Propagation time

2.2.2. Two-Way Ranging (TWR)

To reduce errors caused by clock offset, UWB commonly uses:

- Single-Sided TWR (SS-TWR).
- Double-Sided TWR (DS-TWR).

DS-TWR provides higher accuracy and is widely used in precise positioning systems.

2.3. UWB-BASED POSITIONING METHODS

2.3.1. Ranging (distance measurement)

- 1 anchor – 1 tag
- Output: distance

2.3.2. Trilateration (2D positioning)

- At least 3 anchors
- Determines coordinates (x, y)

2.3.3. Multilateration (3D positioning)

- At least 4 anchors
- Determines coordinates (x, y, z)

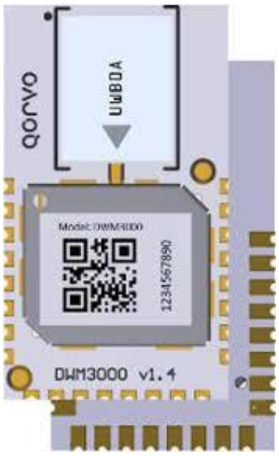
2.4. UWB MODULES AVAILABLE ON THE MARKET

2.4.1. DWM1000/DW1000

Picture 1:DWM1000

- Decawave DW1000 chip.
- High accuracy.
- SPI interface.
- Widely used in research.

2.4.2. DWM3000 / DW3000



Picture 2: DWM3000

- Newer generation
- Supports IEEE 802.15.4z
- Higher accuracy and better security

2.4.3. Comparison with Other Technologies

Technology	Accuracy	Applications
WiFi	$1-5\ m$	General indoor positioning
BLE	$0.5-2\ m$	IoT applications
RFID	$\sim 1\ m$	Tracking
UWB	$< 10\ cm$	High-precision positioning

Table 1: Comparison of UWB with other positioning technologies

CHAPTER 3. DESIGN OF THE UWB INDOOR POSITIONING MODULE SYSTEM

3.1. TECHNICAL REQUIREMENTS

Based on the project objectives and research scope, the indoor positioning module system using UWB technology must satisfy the following technical requirements.

3.1.1. Functional requirements

- Measure the distance between modules in an indoor environment.
- Support communication between modules via UWB technology.
- Allow expansion into a multi-node positioning system (2D/3D).
- Enable communication with a computer or a central control device.

3.1.2. Accuracy requirements

- Small distance measurement error (centimeter-level).
- Stable performance in multipath environments.
- Ensure measurement repeatability.

3.1.3. Hardware requirements

- Compact module size.
- Stable power supply and low power consumption.
- Clearly separated functional blocks for easy expansion and maintenance.

3.1.4. Software requirements

- Accurate ranging algorithm.
- Stable UART/SPI communication between the microcontroller and the UWB module.
- Easy firmware development and upgrades.

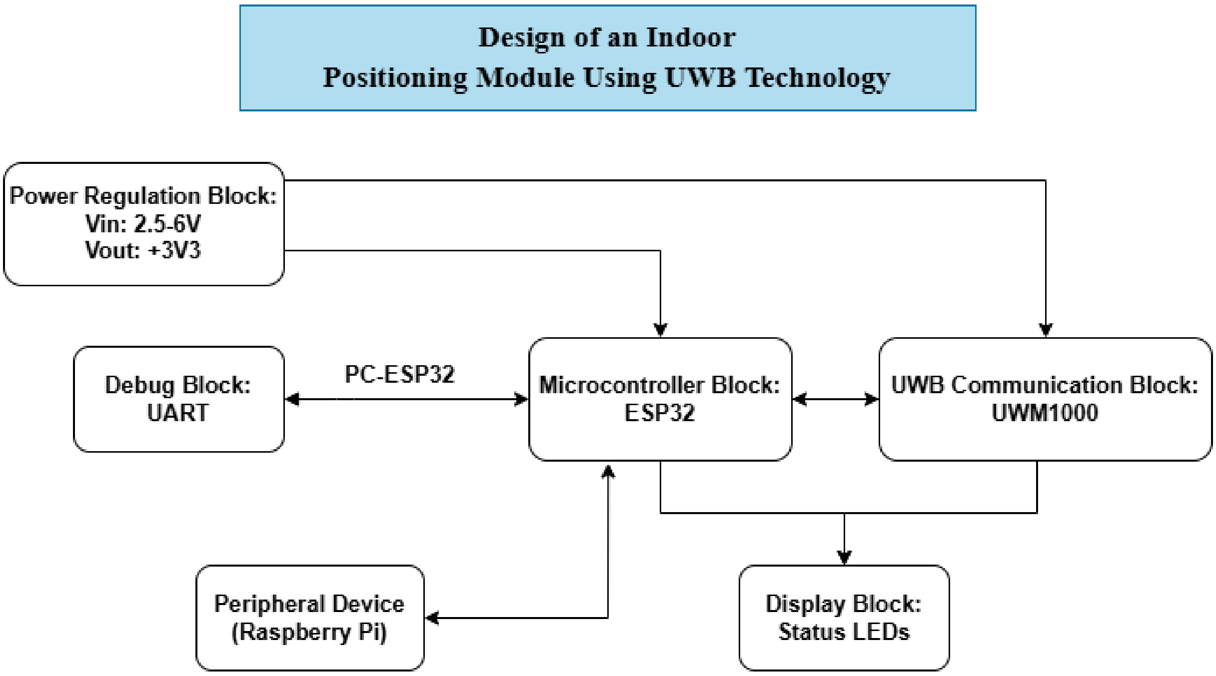
3.2. SYSTEM BLOCK DIAGRAM

The UWB positioning module system is designed with the following main functional blocks:

1. Power supply block.
2. Microcontroller block.
3. Peripheral interface block.
4. UWB communication block.

5. Display and debugging block.

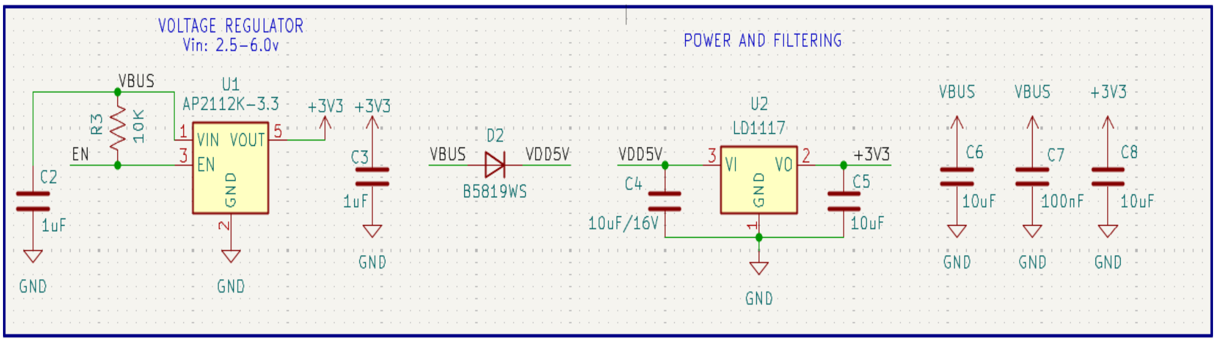
3.2.1. Overall block diagram



Picture 3: Overall block diagram

3.3. DESIGN OF THE POWER SUPPLY AND FILTERING BLOCK

3.3.1. Function of the power supply block



Picture 4: Power Supply and System Filtering Block

The power supply block is responsible for:

- Converting the input voltage (5V from USB or an external supply).
- Providing a stable 3.3V supply for the entire system.
- Ensuring clean power so that the UWB module can operate accurately.

3.3.2. Components

In the indoor positioning module system using UWB technology, both the ESP32 microcontroller and the DWM1000 UWB module operate at 3.3V and require relatively high current, especially during high-activity states.

- **The ESP32 and DWM1000** can draw **more than 300mA** at certain moments such as during startup, intensive processing, or when multiple peripherals operate simultaneously. In addition, during UWB transmission and reception, the DWM1000 can cause rapid current transients, which requires a stable power supply with good transient response.

Therefore, the power-supply design must not only provide the correct 3.3V level but also ensure sufficient current capability, minimize voltage drop, and reduce power-supply noise. Based on these requirements, the system uses two linear regulators (LDOs), LD1117-3.3V and AP2112K-3.3V, each serving a different role.

3.3.2.1. LD1117-3.3V Voltage Regulator IC (300–500mA)

The LD1117-3.3V is selected as the main 3.3V supply of the system due to the following advantages [5]:

- High output current capability, meeting the system’s total current demand when the ESP32 and auxiliary blocks operate simultaneously.
- Widely available and easy to source, making it convenient to replace during fabrication, common component suitable for PCB design and manufacturing.
- Simple application circuit and easy implementation.

In this module, the LD1117-3.3V converts the input voltage (5V) down to 3.3V to supply:

- The ESP32 microcontroller.
- Auxiliary circuits such as status LEDs, communication interfaces, and logic blocks.

However, the LD1117 is an older-generation LDO with several limitations:

- Relatively high dropout voltage as the load current increases.
- Lower efficiency when stepping down from 5V to 3.3V.
- Power-supply noise rejection that is not optimal for sensitive RF blocks.

Therefore, using only the LD1117 to power the entire system - especially the UWB module - may cause local voltage drops or supply noise, which can negatively affect ranging accuracy.

3.3.2.2. AP2112K-3.3V Voltage Regulator IC (400–600mA)

The AP2112K-3.3V is used as a secondary LDO to provide a cleaner and more stable 3.3 V rail for sensitive blocks [6].

Key advantages of the AP2112K-3.3V include:

- Low dropout voltage, helping maintain a stable output even under rapid load-current variations.
- Better noise rejection (higher PSRR) compared to the LD1117.
- Suitable for circuits that require high stability and low noise.

In this design, the AP2112K-3.3V is prioritized to power:

- The DWM1000 UWB module.
- Other circuit sections that require a highly stable supply.

Using the AP2112K reduces the impact of current fluctuations from the ESP32 and other blocks on the DWM1000 supply rail, thereby improving system stability and enhancing the accuracy of distance measurements.

3.3.2.3. Rationale for Using Two Voltage Regulators in the Same System

The simultaneous use of the LD1117-3.3V and AP2112K-3.3V regulators is driven by the system’s practical requirements, in which:

- The total current consumption of the ESP32 and DWM1000 can exceed 300mA.
- The DWM1000 is highly sensitive to power-supply noise.
- The ESP32 exhibits load-current variations depending on its operating mode.

A two-stage regulation design enables the system to:

- Provide sufficient current for the entire system.
- Separate the high-power rail from the low-noise rail.
- Reduce voltage drops and noise coupling between functional blocks.
- Improve the stability and reliability of the UWB positioning system.

All regulators are combined with input/output filter capacitors and local decoupling capacitors placed close to the power pins of the components to ensure a stable supply under all operating conditions.

3.3.2.4. Other Components

a) Schottky Diode - B5819WS
   - Prevents reverse current/backfeed (when another external supply is feeding VDD5V, it blocks current from flowing back into the USB port).
   - Provides simple reverse-connection protection.
   - Low forward voltage drop.

b) Capacitors and Resistors
- Connected to AP2112K-3.3V:
  - **Resistors R3-10K:** Pulls the **EN** pin high so the AP2112K is enabled by default. A 10 kΩ value is a common industry choice - strong enough to ensure a stable logic-high level, with negligible current consumption and good noise immunity.
  - **Capacitors C2-$1\mu F$:** Input decoupling capacitor to filter input noise and reduce transient voltage dips when the load changes. The 1uF value follows the LDO datasheet recommendation and should be placed close to the Vin - GND pins.
  - **Capacitors C3- $1\mu F$:** Output capacitor to stabilize the LDO control loop and reduce ripple/noise. The 1uF value is also datasheet-recommended and should be placed close to the Vout - GND pins.
- Connected to LD1117-3.3V:
  - **Capacitors C4-$10\mu F/16V$:** Helps reduce voltage sag during fast load-current spikes and improves LD1117 stability.
  - **Capacitors C5-$10\mu F$:** Stabilizes the LDO and reduces ripple, while supplying short transient currents.
- **Capacitors C6 ($10\mu F$ on VBUS) + C7 ($100nF$ on VBUS):**
  - **C6**: Mitigates voltage droop during plug/unplug events, load increases, or when using long USB cables.
  - **C7**: Suppresses high-frequency switching noise/EMI and fast edge transients.

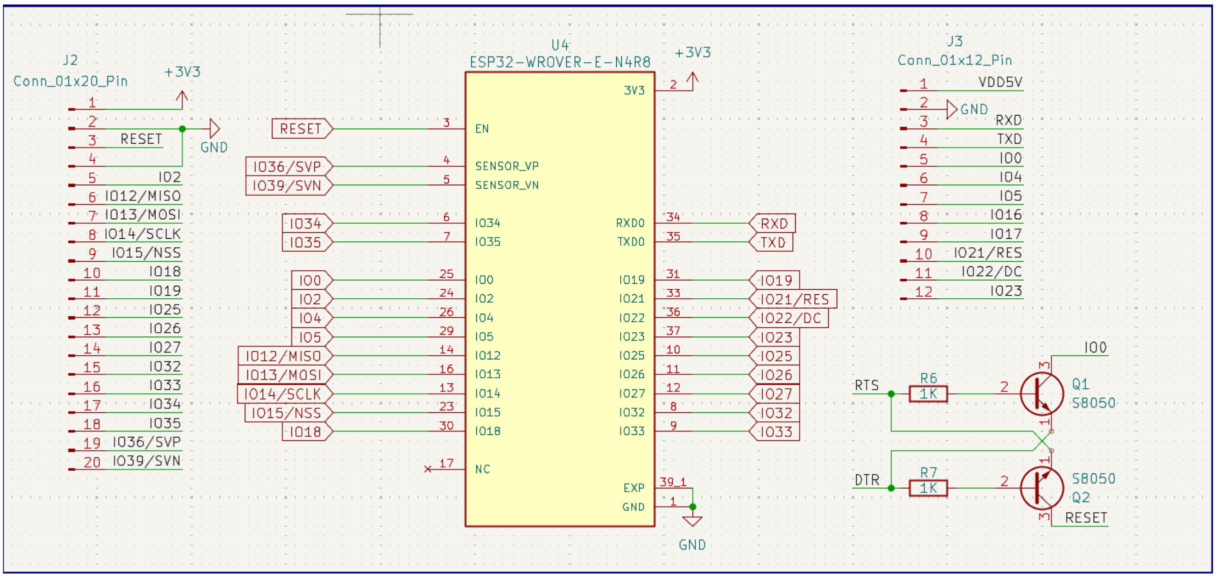
- **Capacitors C8 (10μF on +3V3):**
  - Absorbs large current transients when the ESP32 transmits Wi-Fi/BLE or when the UWB module transmits/receives (RF loads often draw “bursty” current).

3.4. DESIGN OF THE MICROCONTROLLER BLOCK

3.4.1. Overview of the microcontroller block

The microcontroller block serves as the processing center of the UWB-based indoor positioning module. It coordinates the overall operation of the system, including controlling communication with the UWB module, processing received data, interfacing with a computer for firmware uploading and debugging, and driving the status-indication components.

In this system, the selected microcontroller is the **ESP32-WROVER-E-N4R8**, an integrated module featuring Wi-Fi, Bluetooth, Flash memory, and PSRAM, which meets the requirements for real-time data processing and supports future expansion.



Picture 5: Microcontroller block

The microcontroller plays the central role and is responsible for:

- Controlling UWB transmission and reception (SPI protocol) via the communication module.
- Collecting, processing, and packaging positioning data.

- Communicating with a computer for configuration, debugging, and system monitoring, and interfacing with external devices (Raspberry Pi,…).
- Driving the display/status indication blocks to reflect the module's operating state.

3.4.2. Rationale for choosing ESP32 instead of STM32

In embedded systems, both ESP32 and STM32 are widely used microcontrollers in industry and research. However, for the project of designing an indoor positioning module using UWB technology, selecting the ESP32 offers several advantages that are more suitable than the STM32 - especially in the context of research and development for beginners.

Table 2: Comparison of the Advantages and Disadvantages of ESP32 and STM32

Criteria	ESP32	STM32	Remarks for the UWB Project
Design objective	IoT-oriented, rapid development, high integration	Industrial-oriented, wide product range, optimized for real-time applications	The project requires fast implementation → ESP32 is more convenient
CPU/ Performance	32-bit, good performance, sufficient for DS-TWR processing	32-bit, many series offer higher performance (depending on the family)	Both are sufficient for ranging; ESP32 is adequate for this project
Memory	Built-in Flash/RAM (depending on the module)	Depends on the MCU; many options, some require more configuration	ESP32 is easier to select and less likely to run into resource limitations

SPI interface (DWM1000)	Available, high speed, easy to use with libraries	Available, very powerful and flexible	Both are suitable; ESP32 is faster to implement with Arduino/PlatformIO
UART (debug/PC)	Available and very easy to use	Available, but typically configured via CubeMX/HAL	Fast debugging on ESP32 is a major advantage for students
I2C (peripherals)	Available	Available	Not a deciding factor (the DWM1000 does not use I2C)
Library ecosystem	Extensive, large community support (Arduino/ PlatformIO)	Large as well, but typically more “engineering-oriented” and dependent on HAL/LL	Beginners can more easily find examples and troubleshoot issues with ESP32
Development workflow	Quick setup and easy firmware flashing	More complex configuration (clock tree, startup, HAL)	The project requires rapid progress → ESP32 has an advantage
Difficulty for beginners	Low to medium	Medium to high	For beginners, STM32 users often get stuck on configuration steps
Real-time capability	Possible, but not its strongest point	A key strength (especially series with powerful timers/peripherals)	For an industrial RTLS system, STM32 may offer advantages

Power consumption	Has power-saving modes, but Wi-Fi/Bluetooth can be power-hungry	Many ultra-low-power series (L - series)	For long-term battery operation, STM32 can be more optimal
Integrated RF	Built-in Wi-Fi/Bluetooth (may introduce interference when enabled)	Typically no integrated RF (depending on the series)	UWB is noise-sensitive → Wi-Fi on ESP32 should be disabled during ranging
Project goal	Distance measurement, rapid prototyping, easy debugging	Deep optimization and industrial-grade product development	For an academic project → ESP32 is more suitable due to faster development and easier completion

Within the scope of the topic **"Design of an Indoor Positioning Module Using UWB Technology,"** I chose the **ESP32** because of its advantages in rapid development, convenient debugging, a rich library ecosystem, and strong suitability for beginners.

3.4.3. ESP32-WROVER-E Microcontroller Block

The **ESP32-WROVER-E** is a high-performance 32-bit microcontroller featuring a dual-core architecture. It supports multiple communication protocols such as UART, SPI, I2C, GPIO, and enables parallel processing. The WROVER variant integrates additional PSRAM, which increases memory capacity and is well-suited for applications that require temporary data storage, packet buffering, or positioning-algorithm processing. [7]

The microcontroller is powered by the system's 3.3V supply. Its power and ground pins are directly connected to the +3V3 and GND rails, ensuring stable operating conditions for the module.

3.4.4. Programming and Debug Interface (UART)

The ESP32 communicates with a computer via the UART protocol using two signal lines, **TXD** and **RXD**. This interface is used for:

- Uploading firmware to the microcontroller.

- Debugging and monitoring data during system development and testing.
- Retrieving status logs and measured data from the module.

The UART signals are routed to a connector and used together with an external USB-to-UART circuit, enabling direct connection to a computer without complex manual operations.

3.4.5. Reset Circuit and Automatic Programming Mode

To simplify the firmware upload process, the schematic uses an automatic reset and automatic bootloader-entry circuit controlled by the **DTR** and **RTS** signals from the USB-to-UART converter (**CP2104**). [8]

Two NPN transistors (**S8050**) and current-limiting resistors are used to control:

- The **EN (RESET)** pin of the ESP32: resets the microcontroller when required.
- The **IO0** pin: forces the ESP32 into programming mode when IO0 is held low during reset.

This circuit enables fully automated firmware uploading via software, eliminating the need to press reset/boot buttons manually and improving both usability and system reliability.

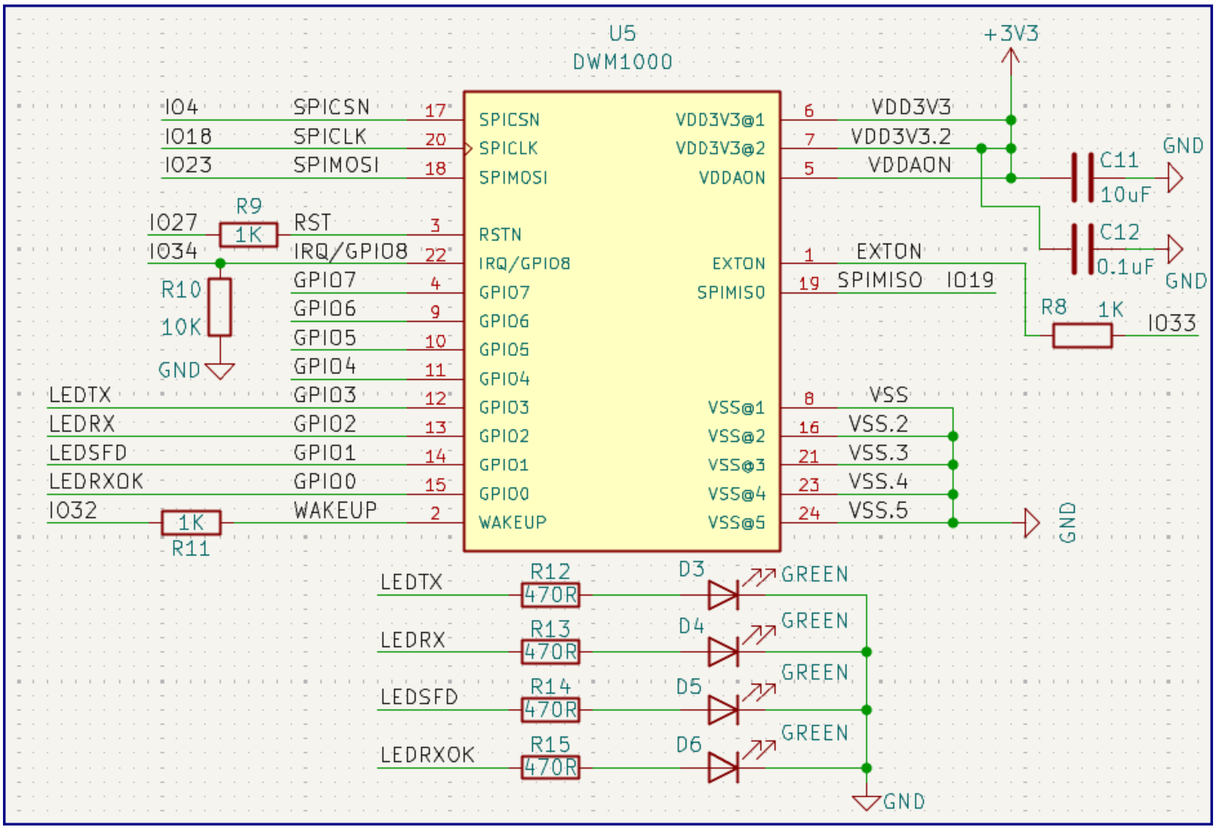
3.4.6. GPIO and Peripheral Interfaces

The ESP32 GPIO pins are routed to connectors to support:

- Connection to the UWB communication module via interfaces such as SPI or control GPIOs.
- Driving status LEDs to indicate the system operating state.
- Expansion to other peripherals during development or future upgrades.

Input-only pins (**IO34–IO39**) are used appropriately for signal reading, while general-purpose GPIOs are allocated reasonably for communication and control functions. [7]

3.5. DESIGN OF THE UWB COMMUNICATION BLOCK



Picture 6:The uwb communication block

3.5.1. Overview of the UWB Communication Block

The UWB communication block plays a key role in the indoor positioning system, responsible for transmitting and receiving Ultra-Wideband (UWB) signals to support distance measurement and high-accuracy positioning algorithms. In this design, the selected UWB module is the **DWM1000**, a widely used UWB solution capable of highly accurate Time of Flight (ToF) measurement, making it suitable for indoor positioning applications.

The UWB block interfaces directly with the ESP32 microcontroller via the SPI protocol and also uses control and interrupt pins to synchronize operation and handle events.

3.5.2. SPI Interface Between ESP32 and DWM1000

The DWM1000 is connected to the ESP32 through the SPI interface, which includes the following main signals [7], [9]:

- **SPICLK**: Clock signal for data transfer. (**Connected to GPIO18**, the default SPI clock pin on the ESP32, ensuring stability and compatibility with standard software libraries.)
- **SPIMOSI**: Data line from the ESP32 to the DWM1000. (**Connected to GPIO23**, the default MOSI pin, simplifying software configuration.)
- **SPIMISO**: Data line from the DWM1000 to the ESP32. (**Connected to GPIO19** to receive data from the UWB module, matching the standard SPI pin mapping on the ESP32.)
- **SPICSN**: Chip-select signal used by the ESP32 to enable communication with the DWM1000. (**Connected to GPIO4**, a free GPIO pin that allows the microcontroller to control UWB module selection during SPI communication.)

SPI is chosen because it provides high speed, low latency, and is well-suited for real-time data transfer between the microcontroller and the UWB module.

3.5.3. Control and Interrupt Pins

In addition to SPI, the DWM1000 uses several important control pins [7], [9]:

- **RSTN**: Reset pin of the DWM1000, controlled by the ESP32 through a current-limiting resistor, allowing the module to be restarted when necessary. (**Connected to IO27**, a general-purpose GPIO that is easy to use for hardware reset control.)
- **IRQ/GPIO8**: Interrupt pin used to notify the ESP32 when events occur (data received, transmission completed, errors, etc.). (**Connected to IO34**, an input-only pin, suitable for receiving interrupt signals from the UWB module.)
- **WAKEUP**: Wake-up pin that brings the DWM1000 out of low-power mode, enabling reduced power consumption when the system is not continuously active. (**Connected to IO32**, which supports wake-up functionality and is suitable for power-saving operation.)
- **EXTON**: External control pin (e.g., for external power/RF control), pulled to an appropriate level to ensure stable operation of the DWM1000. (**Connected to IO33**, allowing the ESP32 to detect when the DW1000 is active, supporting software synchronization and potential future hardware expansion.)

Other DWM1000 GPIO pins can be configured to drive status LEDs or support additional extended functions.

3.5.4. Power Supply and Filtering for the DWM1000

The DWM1000 operates from a 3.3V supply provided by the system's main power block. Due to its high-frequency operation and sensitivity to noise, the UWB block is equipped with local decoupling capacitors:

- **C11-** $\mathbf{10\mu F}$: Reduces voltage droop when the current consumption changes abruptly.
- **C12 -** $\mathbf{0.1\mu F(100nF)}$: Filters high-frequency noise and suppresses fast transients on the power rail.

These capacitors are placed close to the DWM1000 power pins to ensure a stable supply voltage and to minimize noise during UWB transmission and reception.

In addition, resistors **R8-1K, R9-1K, R10-10K, R11-1K** help protect the DWM1000 pins.

3.5.5. Status Indication Using LEDs

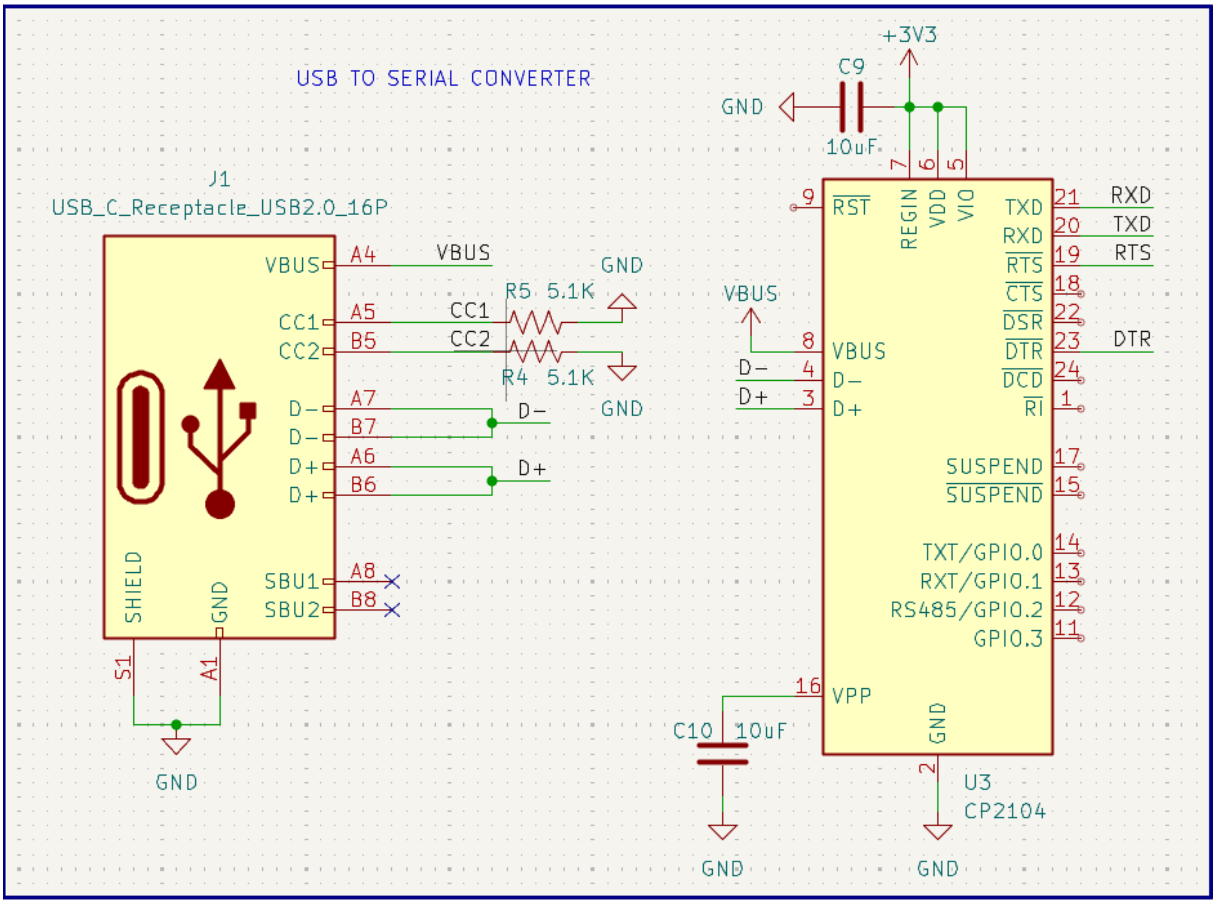
To support hardware monitoring and debugging, the system uses status LEDs driven directly by the DWM1000 GPIO pins [9]:

- **LEDTX**: Indicates data transmission status (GPIO3)
- **LEDRX**: Indicates data reception status (GPIO2)
- **LEDSFD**: Indicates detection of the start-of-frame delimiter (GPIO1)
- **LEDRXOK**: Indicates successful data reception (GPIO0)

Each LED is connected in series with a current-limiting resistor to ensure safe and stable LED operation, while preventing any negative impact on the IC's functionality.

3.6. DESIGN OF THE COMMUNICATION AND DEBUGGING BLOCK

3.6.1. UART Interface



Picture 7: The communication and debugging block

The UART interface is used in the system to support firmware uploading, debugging, and data monitoring for the ESP32 microcontroller during both development and operation of the module. Through this interface, system data and status information can be exchanged directly with a computer.

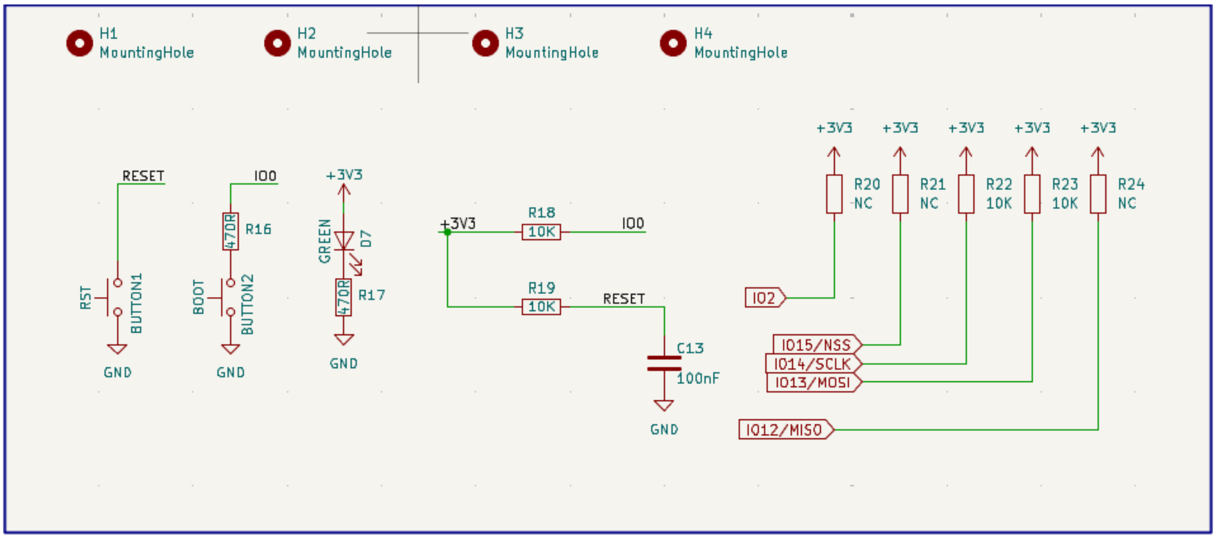
In this design, the **CP2104 USB-to-Serial** converter is used to convert the computer's USB signals into **TTL-level UART** signals. The CP2104 is selected due to its high stability, strong compatibility with common operating systems, and simple hardware requirements. The IC is powered directly from the USB **VBUS** line and is accompanied by filtering capacitors to ensure a stable operating voltage.

The **USB Type-C** connector serves as the physical interface to the computer. Pull-up/pull-down resistors on the two **CC** pins are used to configure the device in **USB Device** mode according to the standard, while the **D+** and **D−** data lines are connected directly to the CP2104 to enable USB communication.

The CP2104 **TXD** signal (data transmitted from the CP2104 to the microcontroller) and **RXD** signal (data transmitted from the microcontroller back to the CP2104) are connected to the ESP32 to perform UART data transmission and reception. In addition, the **RTS** and **DTR** control signals are used for the automatic reset and automatic bootloader-entry circuit, allowing firmware uploading to be performed conveniently and fully automatically. [8]

Overall, the UART communication block is designed to be compact, standards-compliant, and well-suited to the requirements for firmware uploading, debugging, and system verification in the UWB-based indoor positioning module.

3.6.2. Status LEDs and Push Buttons



Picture 8: Status LEDs and Push Buttons

The status LED and push-button block is designed to support operating-state indication and basic user control during both development and operation of the module. Through the LEDs and buttons, users can quickly identify the system status and perform actions such as resetting the system and placing the microcontroller into programming mode.

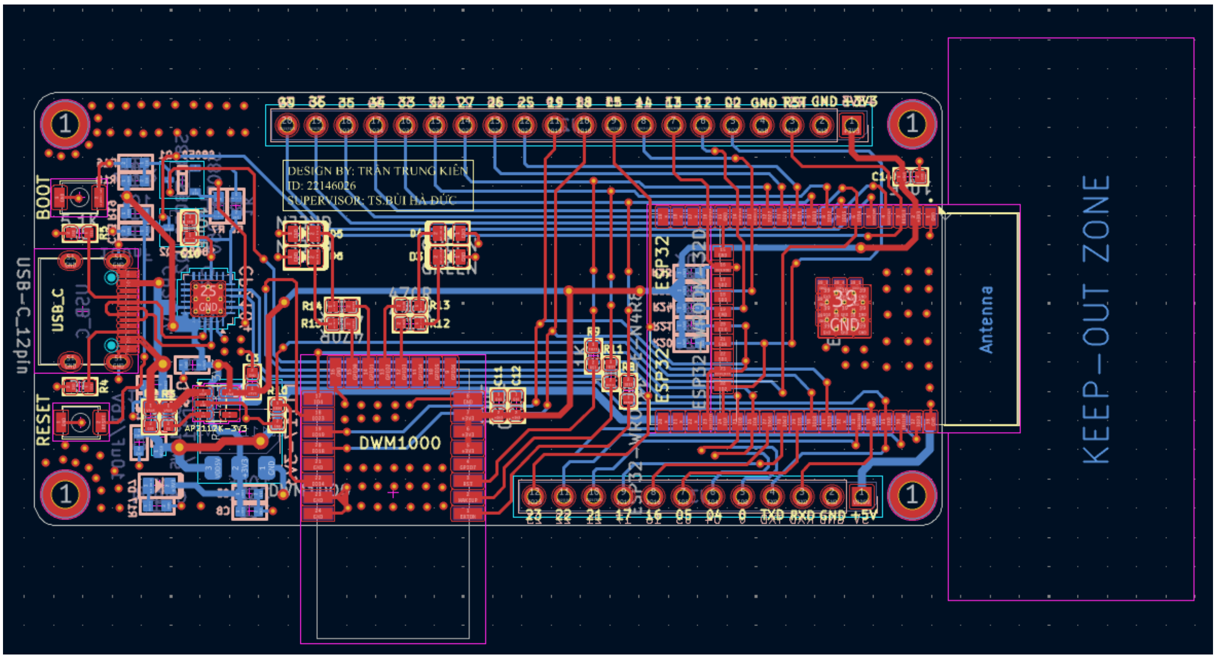
- **LED D7**: Indicates the power supply status.
- **RESET button**: Used to restart the ESP32 microcontroller when necessary. [7]
- **BOOT button**: Used to manually force the microcontroller into firmware upload mode by holding BOOT while resetting the device. [7]

The push buttons are connected to ground when pressed and used together with pull-up resistors to +3.3V to ensure a defined logic level when the buttons are not pressed. An RC network is applied on the RESET pin to filter noise and prevent unintended resets caused by short transient pulses.

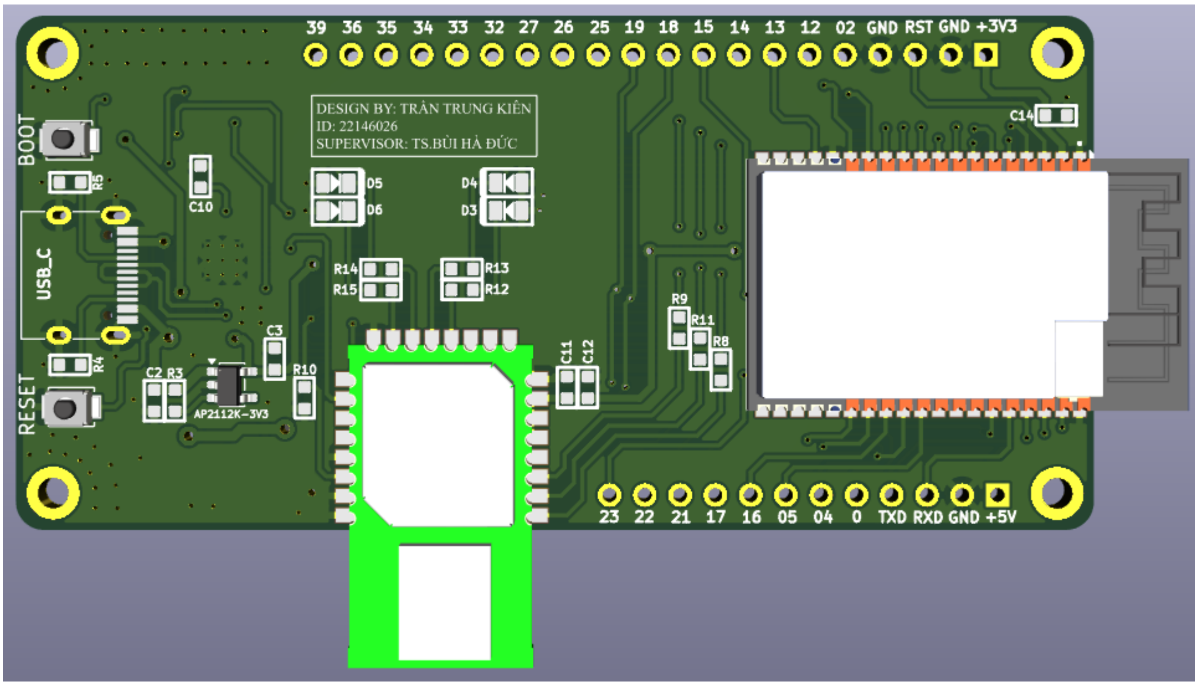
Pull-up resistors are placed on critical pins such as RESET, IO0, and several interface pins to maintain stable logic levels during startup. Some resistors are designed as optional (NC) components to facilitate configuration changes or functional expansion in future versions of the module.

CHAPTER 4. PCB FABRICATION AND VALIDATION

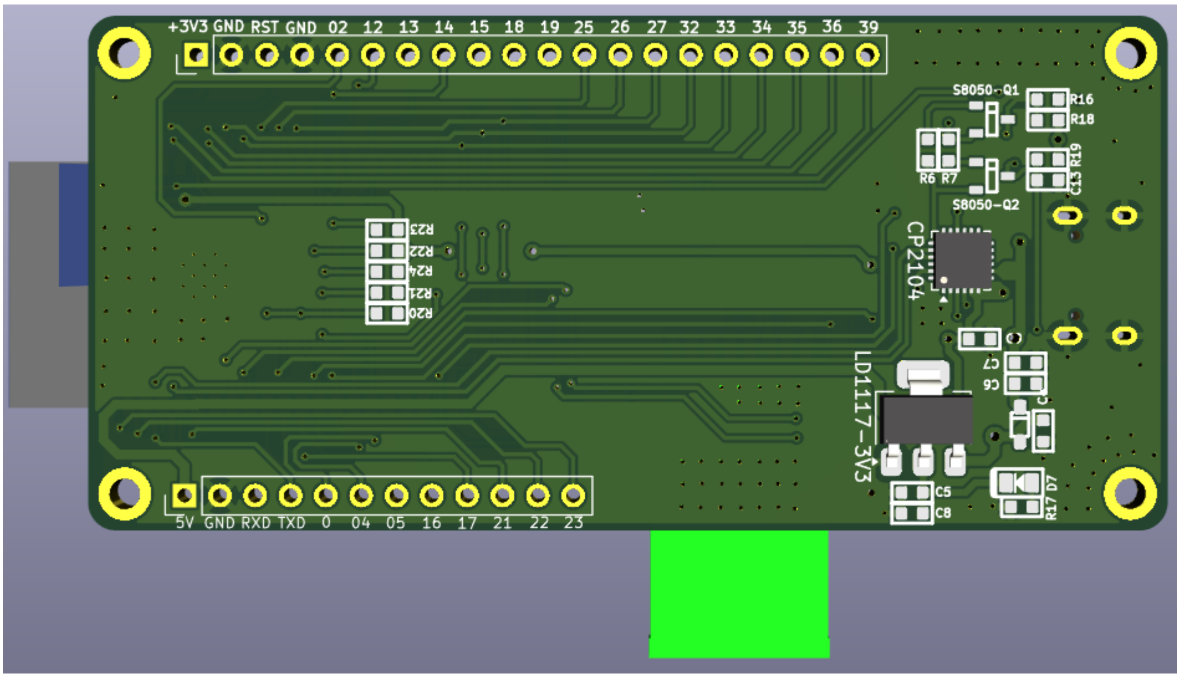
4.1. COMPONENT PLACEMENT AND PCB DESIGN METHODS FOR NOISE REDUCTION



Picture 9: PCB design (KiCad)



Picture 10: Front side of the PCB (KiCad)



Hình 11: Back side of the PCB (KiCad)

1. Clear functional partitioning
   - Power section: voltage regulators and filtering capacitors.
   - ESP32 microcontroller section.
   - UWB section (DWM1000 + antenna).
   - Peripheral interface section (USB-UART, headers).

   ➔ Reduced coupling noise between blocks.

   ➔ Easier control of current paths and ground return paths.
2. Placement of the ESP32 module, UWB module, and antenna
   - Keep them away from power ICs and crystal oscillators.
   - Route the antenna to the board edge and avoid copper pour under/around it (keep-out area).

   ➔ Reduce RF signal loss.

   ➔ Improve distance-measurement accuracy.
3. Clean power design for the system
   - Place decoupling capacitors ($100nF$) close to the power pins of each IC.
   - Add bulk capacitors ($10\mu F$) for each power rail/branch.
   - Keep power traces short and sufficiently wide.

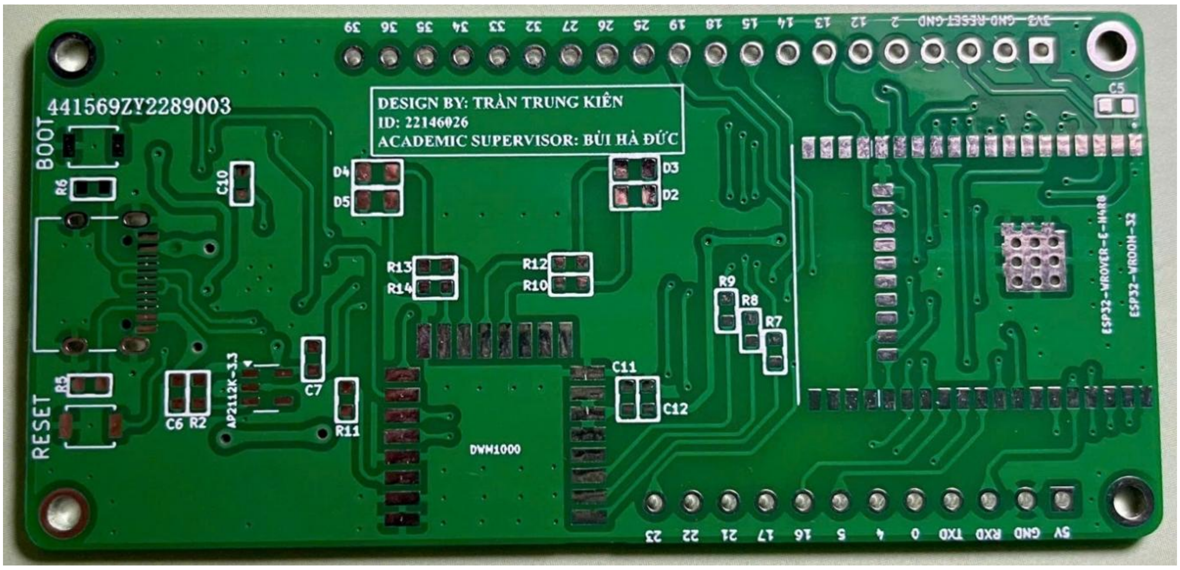
   ➔ Reduce high-frequency noise.

   ➔ Stabilize the supply during UWB transmission.

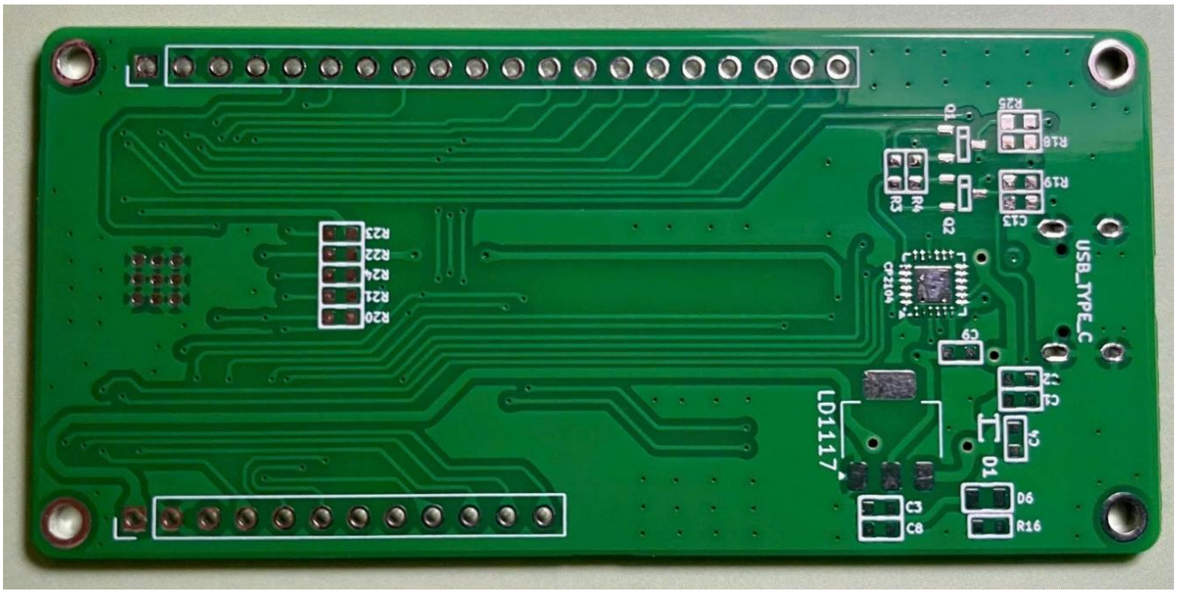
4.2. PCB FABRICATION

After completing the schematic design and component placement, the PCB layout was exported as Gerber files and manufactured according to industrial standards. The PCB was designed as a multilayer board with a continuous ground plane to reduce noise and improve system stability. The fabrication process ensured accurate pad dimensions, drill holes, and insulation clearances in accordance with the requirements of the selected components.

After receiving the PCB, a visual inspection was performed to identify basic defects such as open circuits, short circuits, incorrect pad sizes, or layer misalignment.



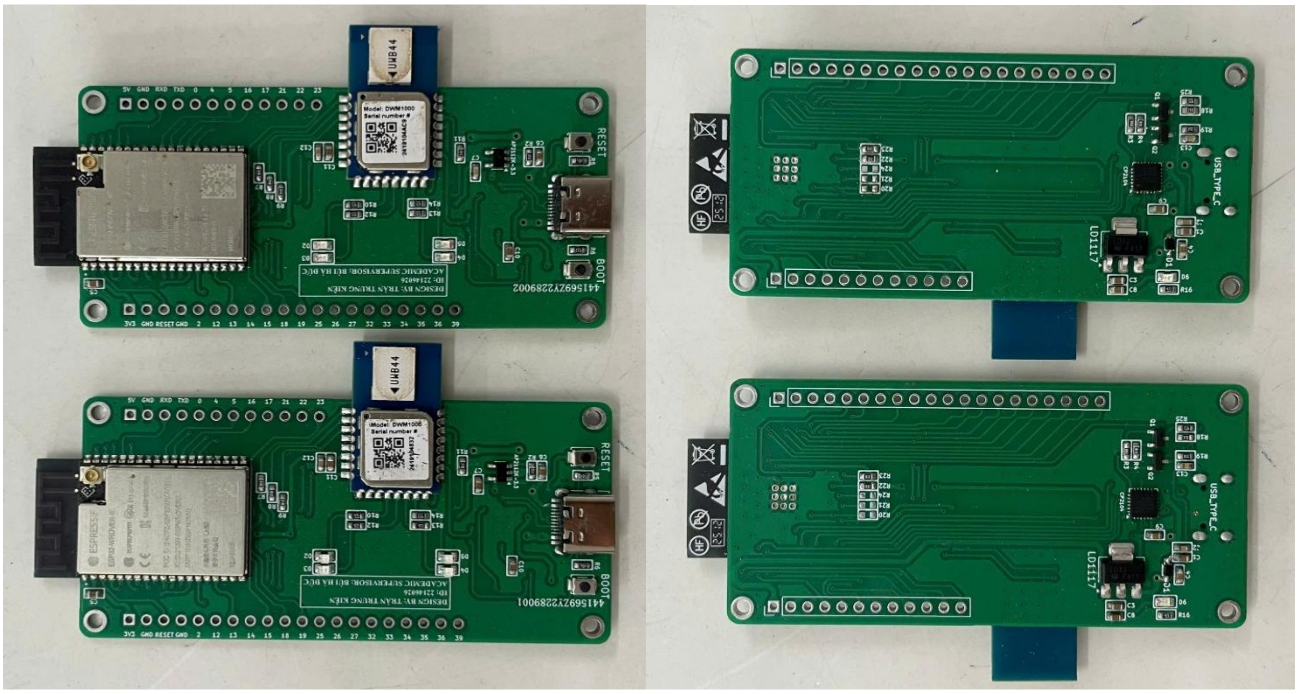
Picture 12: Front side of the PCB



Picture 13: Back side of the PCB

4.3. ASSEMBLY AND SOLDERING

Components were assembled in sequence, starting with surface-mount (SMD) parts. The soldering process was carried out carefully to ensure strong solder joints, with no cold solder joints or solder bridges. After soldering, the PCB was cleaned to remove excess flux, improving both the reliability and the appearance of the circuit.



Picture 14: PCB after component soldering

4.4. HARDWARE VERIFICATION

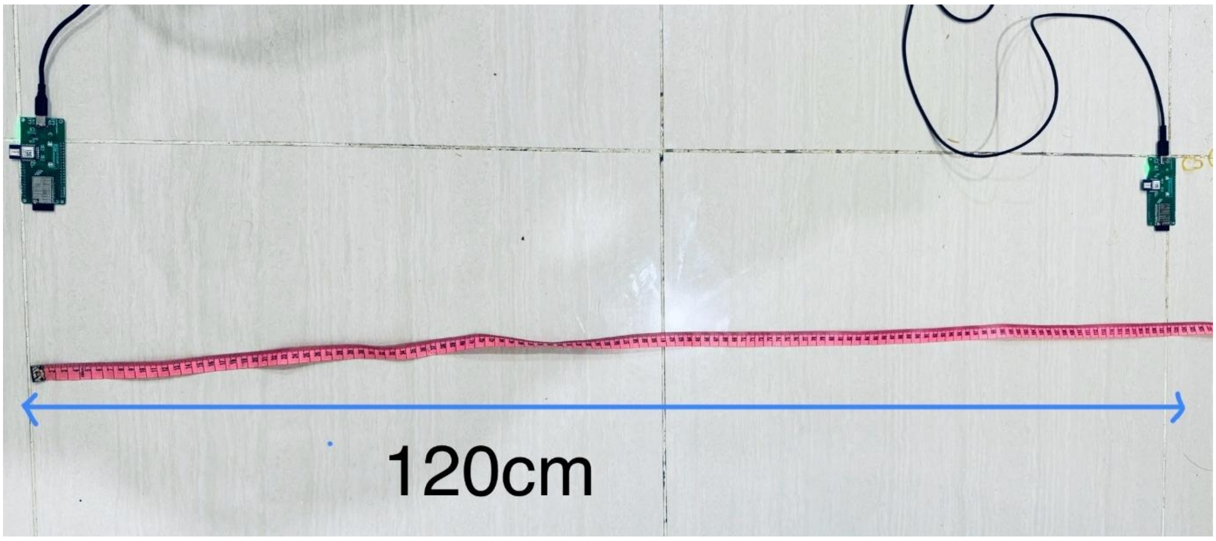
Before powering on, the PCB was checked for continuity and the resistance between the power rails and ground was measured to ensure there were no short circuits. The board was then powered up, and key voltage levels such as +3.3V were measured to confirm that the power supply block operated stably.

Next, the ESP32 microcontroller block was verified via the UART interface, including flashing a test program and observing responses through the debug port. The status LEDs and push buttons were also tested to ensure correct functionality.

4.5. SYSTEM FUNCTIONAL VALIDATION

After confirming stable hardware operation, functional validation of the UWB communication block was performed. The microcontroller was configured to communicate with the UWB module and execute basic transmit/receive tests. Status indications were observed via LEDs, and debug data was used to evaluate system stability.

Experiments were conducted at a fixed distance of **1.20m** to evaluate instantaneous measurement error and the effectiveness of the **UKF** filter.



Picture 15: Conducting the experiment

Parameter	Raw Data	UKF-Filtered Value
Minimum value	0.94 m	1.02 m
Maximum value	1.28 m	1.16 m
Fluctuation range	0.34 m (34 cm)	0.14 m (14 cm)

Table 3: Experimental results

Error relative to the ground truth (1.20m): approximately 4cm to 11cm.

```
... Still searching for Anchor ...
1.07,1.04
1.12,1.06
1.02,1.05
0.94,1.02
1.25,1.08
1.28,1.14
1.22,1.16
0.97,1.11
1.06,1.09
1.07,1.09
```

Picture 16: Results displayed on the Arduino IDE Serial Monitor

The validation results show that the module operates as designed and meets the requirements for communication, processing, and status indication in the UWB-based indoor positioning system.

4.6. COMMENTS

The PCB fabrication and validation process indicates that the circuit operates stably and meets the intended functional requirements. The power supply, microcontroller, UWB communication, and UART interface blocks all function as designed, providing a solid foundation for further software development.

In addition to the achieved results, several limitations remain in the circuit design. Specifically, the system does not include dedicated debug LEDs for the UART **TX** and **RX** signals between the computer and the ESP32. As a result, visual monitoring of UART transmission and reception status is limited and must mainly be performed through software.

CHAPTER 5. CONCLUSION

Within the scope of this project, I designed and built an indoor positioning module using UWB technology. The system was developed comprehensively, from schematic design, component placement, and PCB layout to fabrication and hardware validation. The main functional blocks - including the power supply, ESP32 microcontroller, UWB communication block, UART interface, status LEDs, and push buttons - were all designed and verified to operate in accordance with the defined requirements.

Validation results indicate that the module operates stably. Communication between the microcontroller and the UWB module is accurate, and the functions for firmware uploading, debugging, and status indication work as intended. The PCB design ensures stability, reduces noise, and is suitable for indoor positioning applications.

However, within the project timeframe, the system has been validated mainly at the hardware level and for basic functions. In the future, the system can be further developed by completing the positioning software, optimizing the ranging algorithm, expanding the number of UWB nodes, and integrating additional features for real-time monitoring and data visualization.

Overall, the project has achieved its objectives and provides a solid foundation for further research, development, and practical deployment of UWB-based indoor positioning systems.

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