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Beacon-Based Localization and Emergency Communication System: Design and Implementation

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Abstract

Rapidly locating and rescuing survivors and retrieving the black box after civil aircraft crashes on land or at sea is a critical requirement in modern aircraft design. Addressing the limitations of traditional fixed Emergency Locator Transmitters (ELTs), such as insufficient positioning accuracy and the lack of emergency communication capabilities in the black box, this paper proposes a beacon and emergency communication system integrating multi-band signal transmission, BeiDou/GPS dual-mode positioning, and satellite/wireless heterogeneous communication. Initially, the functional and performance requirements, system design scheme, and component composition are presented. Subsequently, the hardware and software design of the system is detailed, followed by the functional verification process.

Keywords: Beacon; Emergency Communication; BeiDou/GPS Dual-Mode Positioning; Satellite Communication

0. Introduction

The fixed Emergency Locator Transmitter (ELT) is an essential emergency communication device onboard civil aircraft, used for locating the aircraft after a crash. Upon aircraft distress, the system automatically activates and transmits signals at 121.5/243 MHz and 406 MHz. The COSPAS-SARSAT system [1] processes the 406 MHz signal to determine the crash location and relays this information to relevant search and rescue (SAR) authorities. In maritime accidents like Air France AF447 and Malaysia Airlines MH370, the Flight Recorder System (FRS), commonly known as the "black box," sank with the wreckage, creating significant difficulties or even rendering impossible its recovery and location. This severely hampered timely rescue efforts and accident investigation. The protracted, multi-national, and ultimately unsuccessful search for MH370, lasting several years, has intensified research into FRS-related aviation safety technologies [2-3].

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Zhang et al. proposed a separable aircraft emergency data recording and tracking system. Capable of rapid ejection and separation from the aircraft, operating independently of terrain or sea conditions, and enabling immediate alerting, positioning, and data transmission, this system is also known as the Harbinger (HBG) system [4]. The Beacon and Emergency Communication System (BECS) serves as a subsystem within HBG. The uniqueness of this system lies in the fact that it is no longer two passive, independent devices (ELT and FRS), but rather an intelligent, active emergency response terminal that integrates ejection capability, high-precision positioning, satellite communication, and data recording. It fundamentally transforms the passive situation after an accident from "waiting and searching" and "finding a needle in a haystack." It effectively addresses the core issues of traditional Emergency Locator Transmitters (ELT), such as insufficient positioning accuracy and the lack of real-time emergency data transmission capability, as well as the inability of Flight Recorder Systems (FRS) to transmit critical data in real time when an accident occurs. Designing a BECS that meets both system performance requirements and airworthiness regulations is a significant challenge in civil aircraft development and an urgent problem within the civil aviation sector.

1. System Functions, Performance Requirements, and Design

1.1 System Functional Definition

Upon aircraft power-up, the BECS, functioning as an emergency rescue communication system, enters standby mode. When the aircraft encounters an emergency, the BECS is triggered. Crucially, a failure of the BECS must not impede the crew's ability to operate the aircraft normally. Consequently, the Design Assurance Level (DAL) for the BECS can be defined as Level E. Functional definition follows a requirements-driven approach, referencing fixed ELT capabilities and ensuring functional completeness. The system functions are defined in Table 1.

Table 1: Functional Definition

No.	System Sub-function	System-Level Function
1	Transmit emergency locator signals during crisis	Provide positioning capability

No.	System Sub-function	System-Level Function
2	Transmit signals at 121.5MHz and 406MHz	Transmit aeronautical emergency/distress signals
3	Transmit emergency data during crisis	Provide satellite and wireless communication
4	Utilize internal battery power after aircraft power loss	Provide autonomous power

1.2 System Performance Requirements

The performance requirements for the BECS encompass operational performance and environmental qualification testing. Operational requirements include operating/storage temperature and altitude, output power and operating time, frequency accuracy, modulation schemes, power input, etc. Environmental qualification testing must comply with RTCA DO-160 [5] airworthiness standards, covering tests such as temperature-altitude, temperature variation, humidity, and waterproofing. Specific environmental tests must meet RTCA/DO-204A "Minimum Operational Performance Standards for 406 MHz Emergency Locator Transmitters (ELTs)" [6]. Lithium batteries must comply with TSO C142 "Non-Rechargeable Lithium Cells and Batteries" [7]. Software design must adhere to DO-178 "Software Considerations in Airborne Systems and Equipment Certification" [8], and hardware design must follow DO-254 "Design Assurance Guidance for Airborne Electronic Hardware" [9]. The equipment casing carries a battery expiration label; batteries typically require replacement every five years. Additionally, battery replacement is necessary if the BECS is activated (transmitting a distress signal) or accidentally triggered and remains in a transmitting state for an unknown duration or exceeding 1 hour.

1.3 System Operating Principle and Design Scheme

During an aircraft crash on land or at sea, the system acquires its position via the BeiDou/GPS module. This positioning information, along with emergency data, is then transmitted via the Tiantong satellite to a ground station. Simultaneously, the Emergency Position Indicating Radio Beacon (EPIRB) accesses the COSPAS-SARSAT satellite system. Signals relayed through these satellites are forwarded to ground station user terminals, where the distress

target's precise location is calculated. This information is sent to SAR authorities to initiate rescue operations. After establishing a wireless link, data is transmitted via a wireless module to a storage device on rescue aircraft. Components of the BECS include signal transmitters (ELT121 and ELT406), BeiDou/GPS positioning module, satellite/wireless communication module, microprocessor, power management unit (with internal battery pack), and antennas. The system design is shown in Fig. 1.

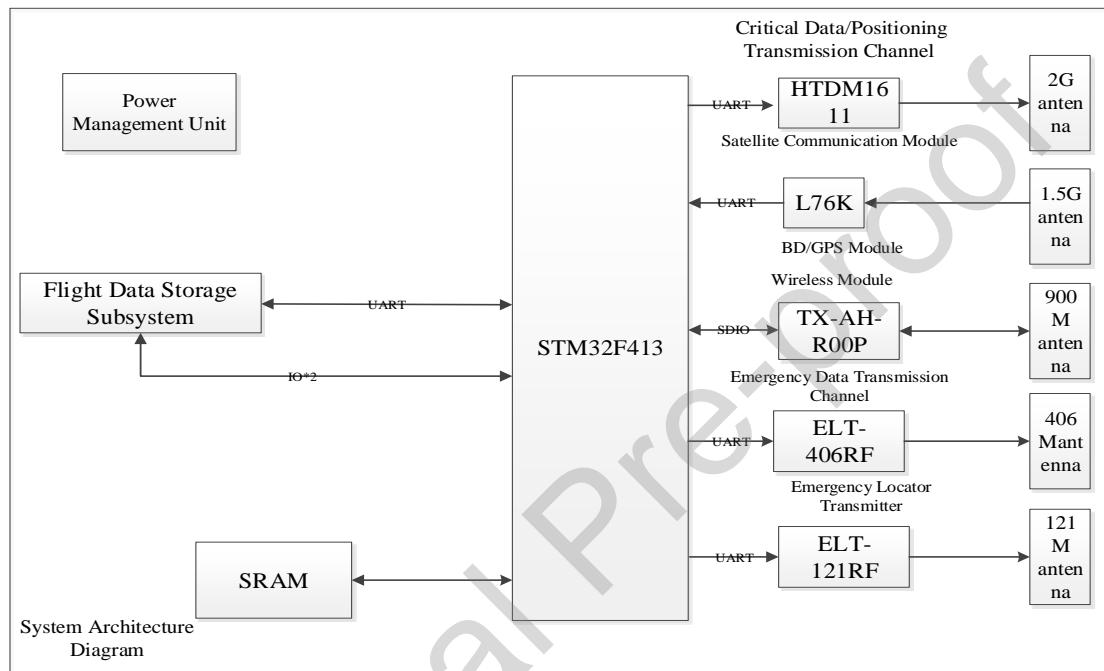


Fig. 1: System Block Diagram

Regarding electrical interfaces, the BECS primarily utilizes bus interfaces, discrete signal interfaces, RF transmit interfaces, and power interfaces. The bus interfaces facilitate data transmission between the BECS and the Flight Data Storage subsystem. Discrete interfaces output high/low logic level signals. RF transmit interfaces connect the various RF components to the antennas. The power interface connects to the battery pack (12.6AH) to supply the system.

2. System Design

2.1 Hardware Design

2.1.1 System Composition

To meet structural size constraints, the Beacon Positioning and Emergency Data Transmission subsystem employs a three-board design: a Main Control Board, a Satellite Communication Board (SatCom Board), and an Emergency Position Indicating Board (EPIRB Board), as shown in Fig. 2.

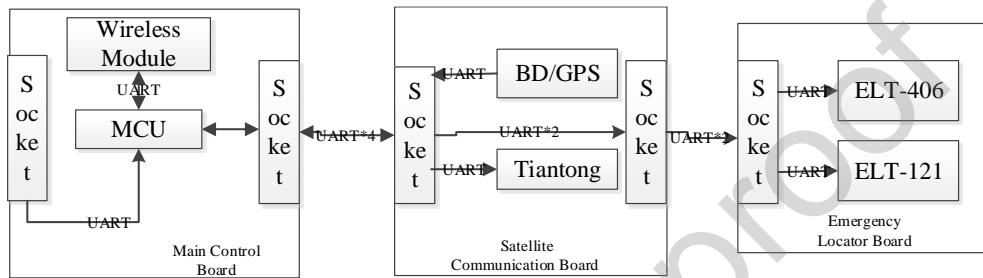


Fig. 2: System Composition Diagram

2.1.2 Main Control Board

- MCU Minimum System Circuit:** The MCU minimum system circuit comprises the power supply circuit, clock circuit, reset circuit, debug circuit, boot configuration circuit, and programming interface circuit. The schematic is shown in Fig. 3.

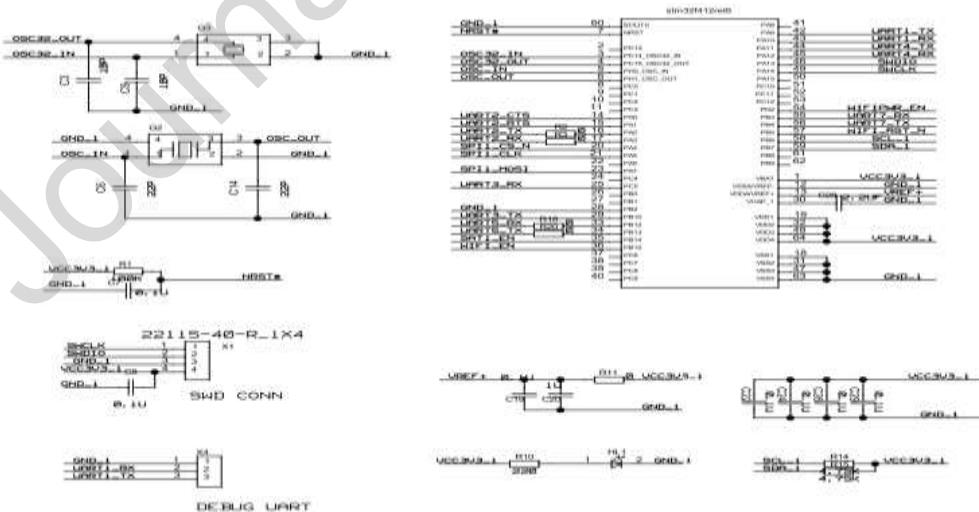


Fig. 3: MCU Circuit Schematic

2. **Wireless Transmission Circuit:** The TX-AH-R900P module loads firmware from an SPI NOR FLASH upon power-up. The MCU configures its operating mode and retrieves wireless link status via a UART interface. Once a wireless link is established, the MCU forwards emergency data via UART. The schematic is shown in Fig. 4.

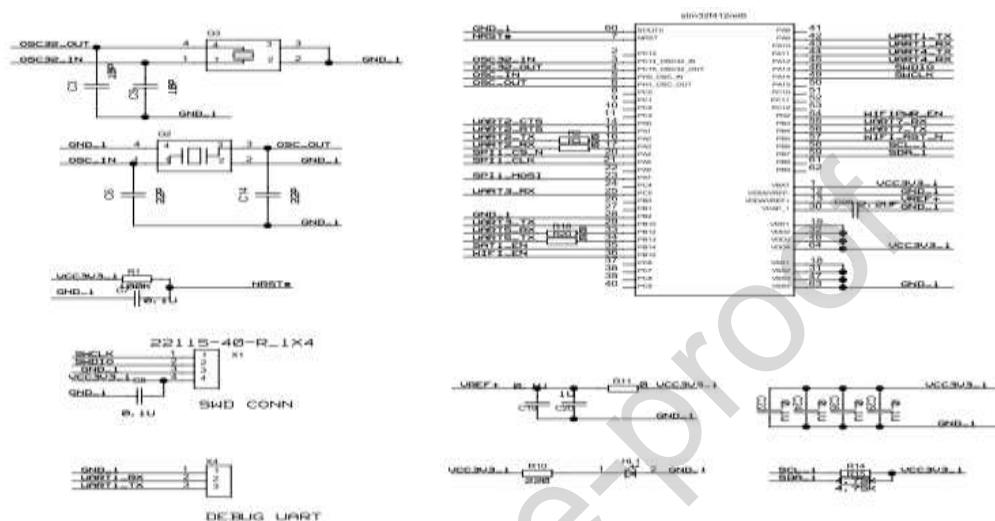


Fig. 4: Wireless Transmission Circuit Schematic

3. **Power Circuit:** A DC/DC converter chip (RT6286) steps down the 12V input voltage to 3.3V output. The MCU controls the power supply to the TX-AH-R900P module by toggling a PMOS transistor via a GPIO pin. The schematic is shown in Fig. 5

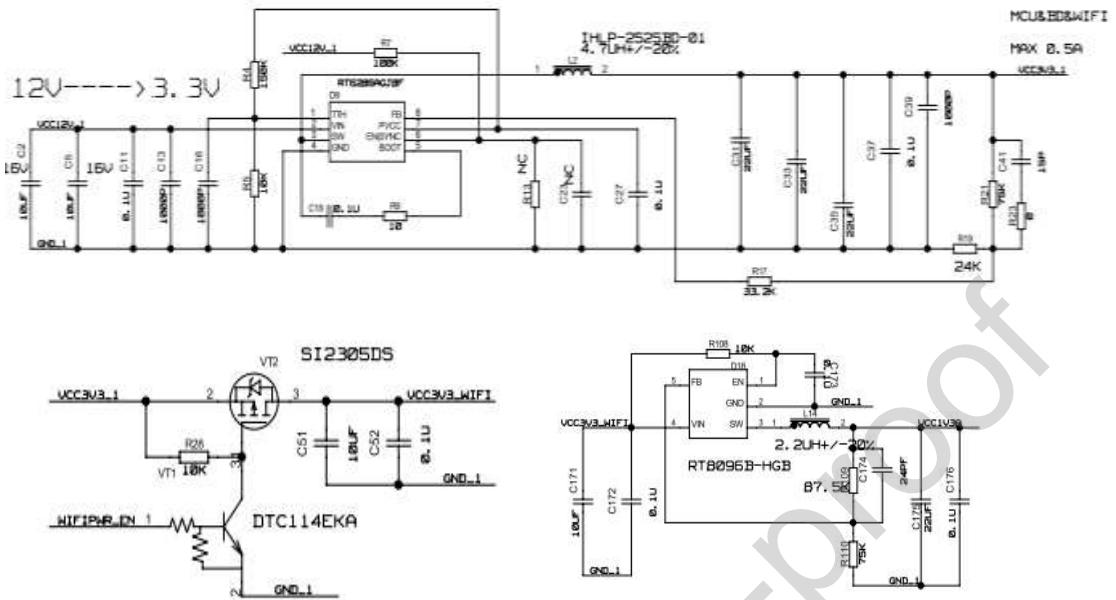


Fig. 5: Power Circuit Schematic

2.1.3 Satellite Communication Board (SatCom Board)

1. **Positioning Module Circuit:** The Quectel L76K BeiDou/GPS dual-mode positioning module is used. Its power (VCC), reset (RESET), and sleep mode (SLEEP) are controlled by General-Purpose Input/Output (GPIO) pins from the MCU on the Main Control Board. Communication between the module and MCU occurs via UART. The relevant schematic is shown in Fig. 6.

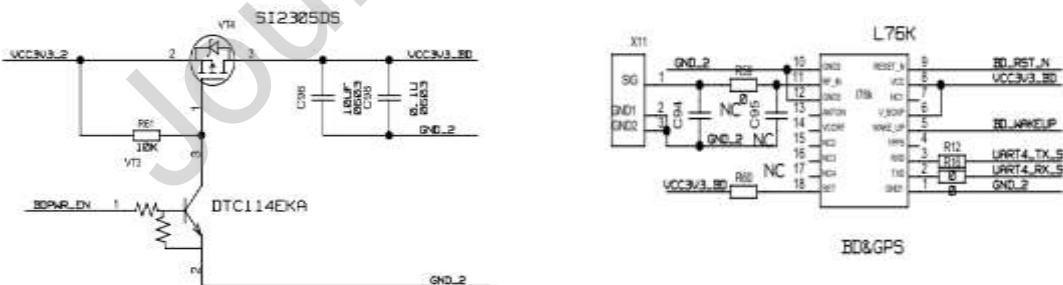


Fig. 6: BeiDou/GPS Module Circuit Schematic

- 2. Satellite Transmission Circuit:** The HDTM1611 Tiantong satellite data transmission module from Huahong Chuangtong is used. Its power (VCC), reset (RESET), and sleep mode (SLEEP) are controlled by the MCU via I²C through a PCA9535 GPIO expander. Communication between the module and MCU occurs via UART. A TXB0104 bidirectional level shifter converts between 3.3V and 1.8V logic levels. The schematic is shown in Fig. 7.

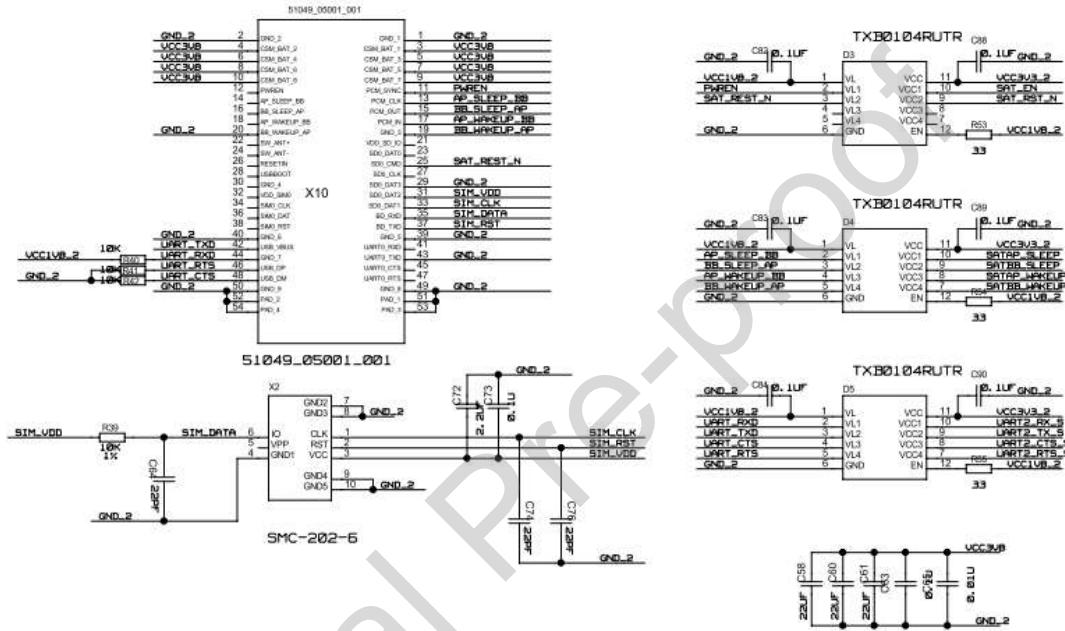


Fig. 7: Satellite Transmission Circuit Schematic

2.1.4 Emergency Position Indicating Board (EPIRB Board)

- 1. Position Indicating Beacon Circuit (121.5 MHz):** An Analog Devices AD9958 frequency synthesizer generates the 121.5 MHz sine wave. The MCU configures the AD9958's internal registers via SPI to output a 121.5 MHz differential sine wave signal. This differential signal is converted to a single-ended signal by an ADTT1-1 balun. The single-ended signal is then filtered by a TA1952A SAW filter and fed into an ADL5602 RF power amplifier. The AD9958's reset (RESET) and sleep mode (SLEEP) control signals, along with the ADL5602's power (VCC) control, are managed by the MCU accessing a PCA9535 GPIO expander via I²C. The schematic is shown in Fig. 8.

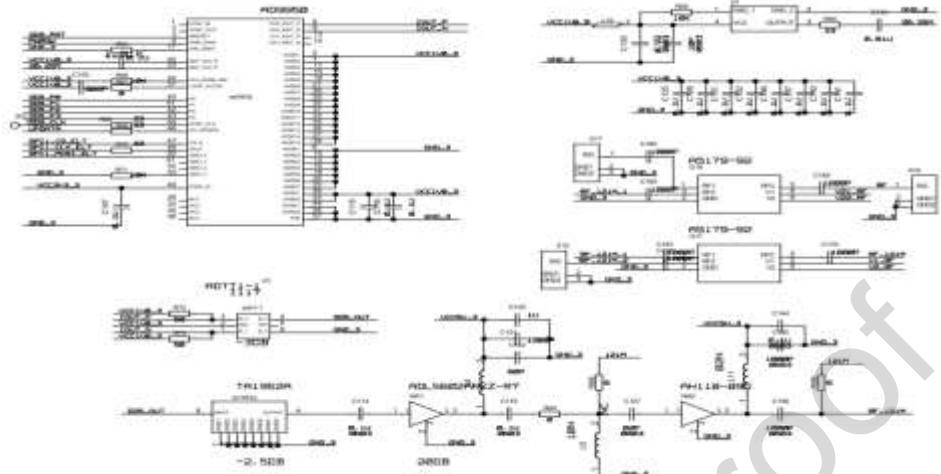


Fig. 8: Position Indicating Beacon (121.5 MHz) Circuit Schematic

2. **Distress Signal Circuit (406 MHz):** The ELT-406 RF module from China Electronics Technology Group Corporation (CETC) is used. Precise power management and operational state control are achieved by controlling the enable pin of a DC/DC converter chip (RT6286). The schematic is shown in Fig. 9.

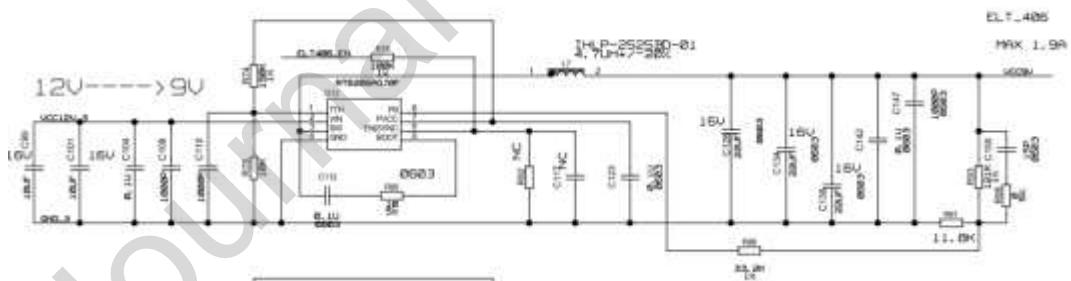


Fig. 9: ELT-406 Power Supply Circuit Schematic

2.2 Software Design

The software handles the initialization of UART, SPI, and I²C peripherals and controls the power enable, reset, and sleep modes for various functional modules. The 121.5 MHz transmission task uses a timer to execute a cycle of transmitting for 750 ms followed by shutting down for 1500 ms. The wireless transmission task performs minute-by-minute

polling of the link status. Once a wireless link is established, the storage subsystem card detects a logic-high signal and begins transmitting emergency data. After transmission is complete, the module's power is shut down. The software flowchart is shown in Fig. 10.

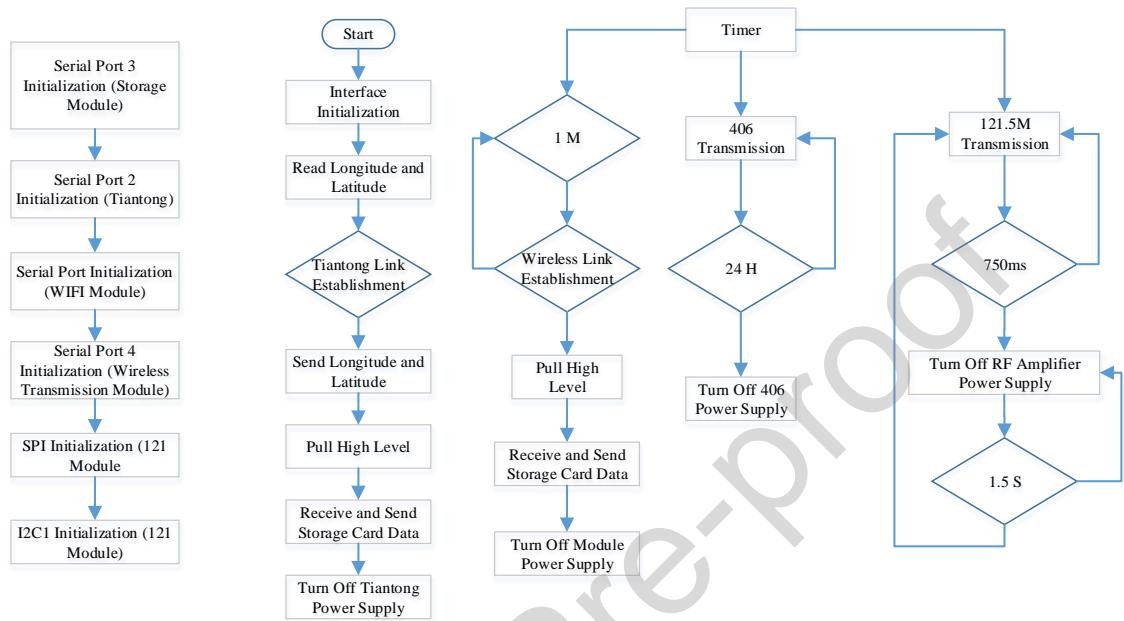


Fig. 10: Software Flowchart

3. System Functional Verification

3.1 Wireless Transmission Verification

Functional testing of the wireless transmission device aimed to verify its capability to receive and transmit data. The communication range reaches 1 km in an unobstructed environment. The test setup is shown in Fig. 11 and results in Fig. 12.

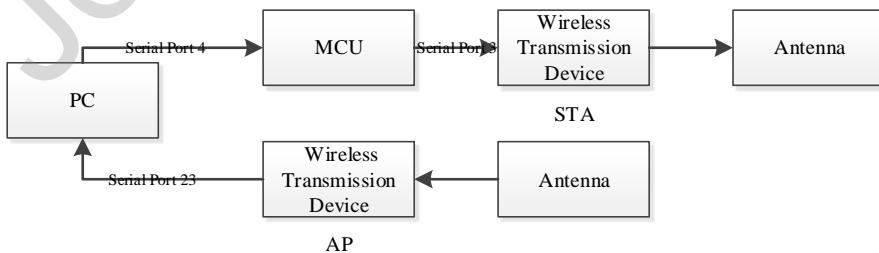


Fig. 11: Wireless Transmission Test Setup Diagram

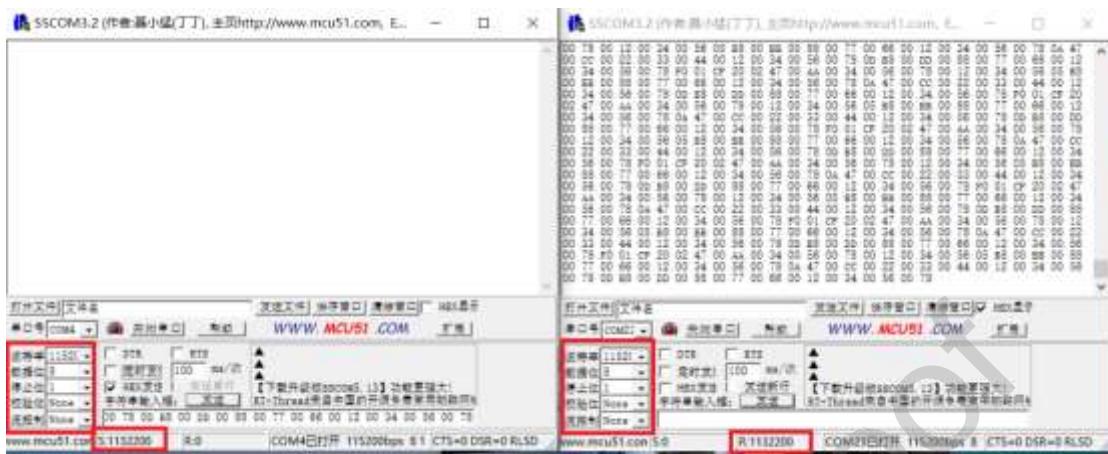


Fig. 12: Wireless Transmission Test Results

3.2 BeiDou/GPS Positioning Function Verification

Testing of the BeiDou/GPS positioning function aimed to verify the device's ability to stably receive location information. The test results show a positioning accuracy within 2.0 m. The test setup is shown in Fig. 13 and results in Fig. 14.



Fig. 13: BeiDou/GPS Test Setup Diagram

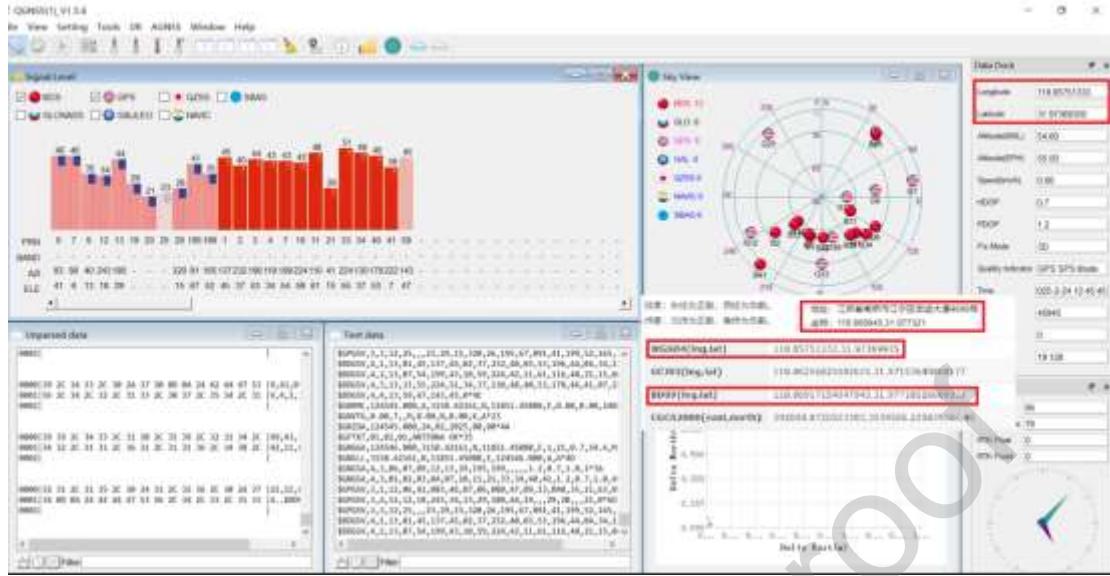


Fig. 14: BeiDou/GPS Test Results

3.3 Satellite Communication Function Verification

Testing of the satellite communication function aimed to verify the device's ability to stably receive and transmit data. The test setup is shown in Fig. 15 and results in Fig. 16.



Fig. 15: Satellite Communication Test Setup Diagram



Fig. 16: Satellite Communication Test Results

4. Conclusion

To address the limitations of traditional fixed ELTs, such as insufficient positioning accuracy and the lack of emergency communication in black boxes, a Beacon and Emergency Communication System (BECS) was proposed. This paper described the operating principle of the BECS, detailed its comprehensive design, and presented experimental verification of its wireless transmission, positioning, and satellite communication functions. The results demonstrate that the overall design scheme of the BECS is feasible and effective.

Future work should involve a more comprehensive evaluation of signal quality, stability, and communication range across various real-world scenarios, such as complex terrain, urban canyons, and adverse weather conditions.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.