Jomo Kenyatta University of Agriculture and Technology

College of Engineering and Technology

School of Mechanical, Materials, and Manufacturing Engineering

Department of Mechatronic Engineering

Design and Fabrication of a Reliable Dual Recovery System for the N4 Rocket with Extended Telemetry Range

(FYP22-4)

Project Proposal

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January 28, 2026

Declaration

We declare that this project proposal is our original work and has not been presented for examination in any other institution.

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Acknowledgment

We would like to express our sincere gratitude to the Nakuja Project team for providing the opportunity to work on this critical recovery system for the N4 rocket mission.

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Special thanks to the Department of Mechatronic Engineering, JKUAT, for providing the necessary facilities and resources for this research.

Finally, we thank our families and friends for their continuous encouragement and support throughout this endeavor.

Abstract

The N4 rocket mission represents a critical advancement in student rocketry, requiring a reliable dual recovery system capable of preserving flight data and hardware integrity. This project addresses three fundamental reliability challenges: telemetry range limitations leading to signal loss, uncontrolled heat generation from DC dump ignition methods causing single-use deployment systems, and absence of real-time pre-flight feedback on critical system parameters.

The proposed solution integrates the Digi XBee-PRO 900HP telemetry system for robust long-range data transmission exceeding 5km, implements a PWM-controlled ignition system to regulate Nichrome wire temperature and enable reusable deployment, and develops a comprehensive feedback monitoring system transmitting real-time battery voltage and igniter continuity to ground control. Additionally, a sealed explosion cap design prevents thermal damage to the parachute canopy while ensuring consistent deployment, and a custom 3D-printed avionics holder provides vibration isolation under high-G launch forces.

Expected outcomes include operational telemetry with less than 5% packet loss at 5km altitude, zero thermal damage to recovery systems, and automatic launch inhibit protocols for critical power failures. This comprehensive approach addresses identified research gaps in student rocket recovery systems and establishes a foundation for future high-power rocketry missions.

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1 Introduction

1.1 Background of Study

Rocket recovery systems represent the most critical subsystem for preserving flight data and hardware in high-power rocketry missions. The evolution of recovery systems has progressed from simple single deployment methods to sophisticated dual deployment architectures. Single deployment systems release a parachute at apogee, presenting risks of high drift radius and unpredictable landing zones. In contrast, dual deployment systems utilize a drogue parachute at apogee for stability, followed by a main parachute deployment at lower altitude for controlled soft landing, establishing the standard for modern high-power rocketry operations.

The Nakuja Project N4 mission builds upon previous experiences from the N3.5 mission, which employed a basic single-deployment piston-based system. The current N4 design implements dual deployment architecture but faces significant challenges in deployment reliability and telemetry signal integrity. Previous missions demonstrated critical vulnerabilities in both mechanical deployment mechanisms and communication systems, necessitating a comprehensive redesign approach.

1.2 Problem Statement

The N4 mission's recovery system faces critical reliability challenges including telemetry range limitations causing signal degradation during critical flight phases, uncontrolled ignition system temperatures exceeding 1000 degrees Celsius that create unreliable single-use deployment mechanisms, and absence of real-time pre-flight monitoring systems for battery voltage and igniter continuity, collectively threatening mission success through potential vehicle loss, deployment failures, and inability to validate system readiness before launch.

1.3 Aim

To design, fabricate, and validate a reliable dual deployment recovery system for the N4 rocket with extended telemetry range and comprehensive pre-flight monitoring capabilities.

1.4 Specific Objectives

The following four objectives capture the project focus areas:

1. **Long-Range Telemetry Implementation:** Deliver Digi XBee-PRO 900HP telemetry with verified 5km+ range and sub-5% packet loss so that the flight computer can stream live health and sensor data across the entire trajectory.

2. **Pyrotechnic Deployment System:** Engineer a PWM-driven ignition controller and sealed explosion cap that together ensure repeatable, temperature-regulated nichrome activation for both drogue and main parachute stages.

3. **Integrated Mechanical and Monitoring System:** Fabricate a PETG avionics bay that secures the flight computer and batteries with vibration isolation while providing continuous ADS1115-based monitoring of battery voltage, chute continuity, and launch inhibit status.

4. **System Validation through Testing:** Execute pop tests to confirm explosion cap containment and conduct telemetry range trials that demonstrate sustained connectivity beyond 5km as required by the mission profile.

1.5 Justification

The development of a reliable recovery system is paramount to mission success. Loss of the rocket vehicle results not only in hardware loss but also complete loss of flight data critical for mission analysis and future design improvements. The proposed improvements address documented failure modes from previous missions and implement industry-standard practices adapted for student rocketry applications.

The Nakuja Project represents a significant investment in student engineering education and practical aerospace systems development. Ensuring mission success through robust recovery systems validates this investment and provides valuable learning opportunities for future engineering professionals.

2 Literature Review

2.1 Recovery Systems in Student Rocketry

Recovery systems preserve flight hardware and recorded data [1]. Student rocketry projects face budget constraints requiring innovative, cost-effective solutions [2]. Dual-deployment architectures use staged recovery: drogue chute at apogee for stability, main parachute at lower altitude for soft landing [3, 4].

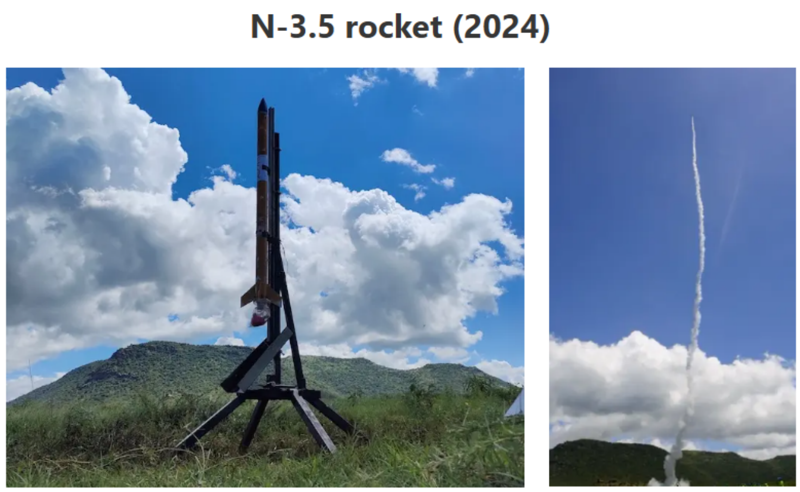

Figure 2.1: Full Nakuja N3 rocket showing the dual-deployment recovery configuration and component layout

The Nakuja Project's progression from N3.5 single-deployment to N4 dual-deployment architecture reflects industry evolution [5]. Previous missions identified critical improvements needed in mechanical reliability and telemetry range.

2.2 Telemetry Systems Analysis

Table 2.1 compares telemetry technologies for student rocketry applications [6, 7].

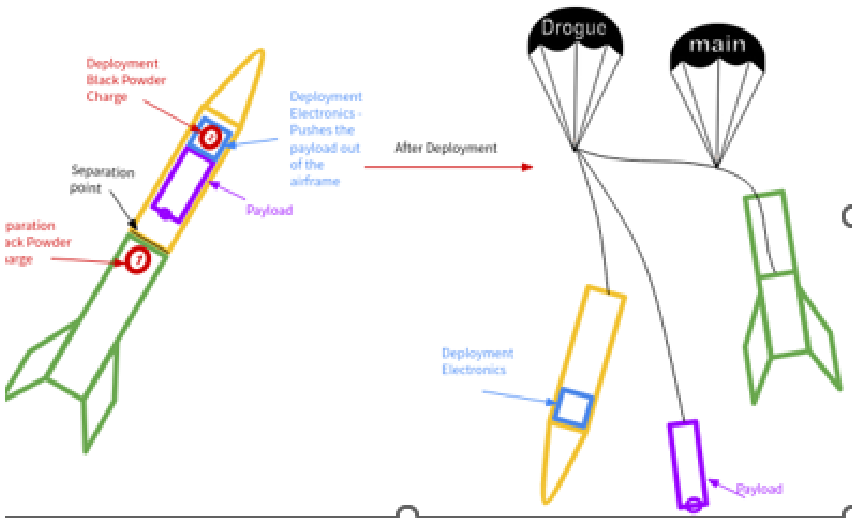

Figure 2.2: Rocket in flight demonstrating the dual-deployment sequence and aerodynamic stability during ascent

The XBee-PRO 900HP provides optimal balance between range, data capacity, and protocol reliability [8]. Its 900 MHz frequency offers superior penetration versus 2.4 GHz alternatives.

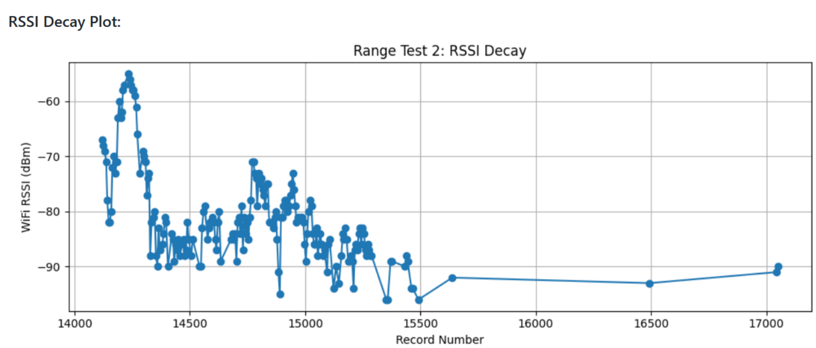

Figure 2.3: Beacon RSSI decay analysis showing signal degradation with distance and altitude

Table 2.1: Telemetry System Comparison for Student Rocketry Applications

Technology	Range	Data Cap	Strength	Limitation
433 MHz RF	5–10 km	Very low	Simple, long range	No ACKs
Beacon	4 km/0.8 km	Low–Med	Simple	Range drops
LoRa SX1278	2–15 km	Low	Low power	Low BW
XBee 2.4 GHz	<2 km	Medium	Easy integration	Short range
XBee-PRO 900HP	**5–15 km**	**Med–High**	**Reliable**	**Higher power**
ESP-NOW	<1 km	Medium	Low latency	Not long-range
Cellular LTE	Global	High	Unlimited range	Network dep.

2.3 Pyrotechnic Deployment Systems

Nakka's Crimson Powder research provides baseline data for pyrotechnic charges [9]. Proper formulation generates sufficient pressure while minimizing thermal output. Combustion temperatures exceed 2000°C, requiring thermal isolation to prevent parachute damage.

2.4 Electronic Control Systems

The ESP32 platform offers dual-core architecture for parallel sensor processing and communication [10, 11]. PWM ignition control enables precise thermal management, preventing wire burnout while enabling multiple tests [12].

2.5 Power and Structural Systems

LiPo batteries provide superior energy density but require BMS for safety. High-G launch loads cause battery disconnection in spring-loaded holders [13]. Custom avionics holders provide vibration isolation and battery retention.

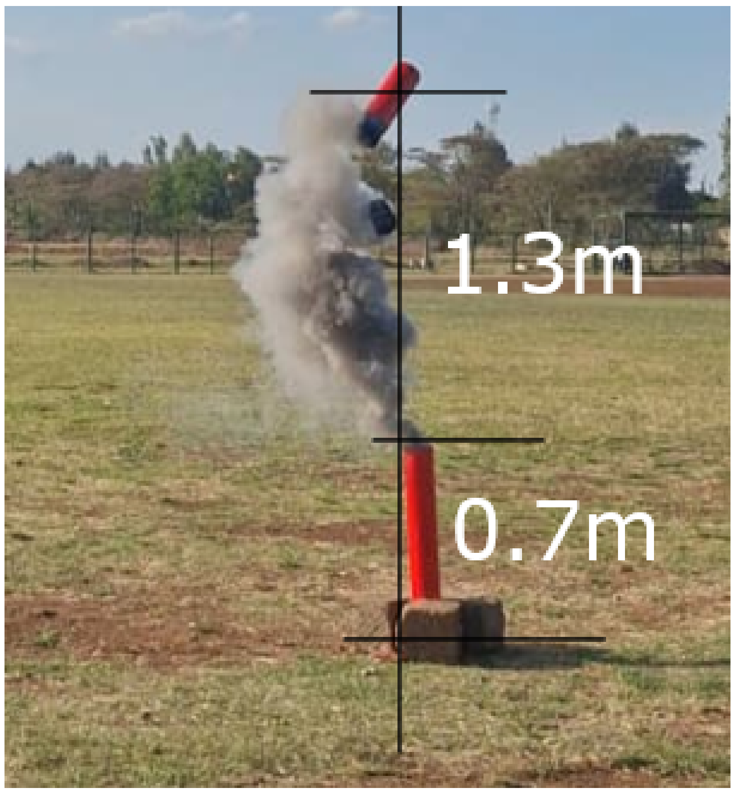

Figure 2.4: Excessive crimson powder deployment showing the need for precise charge control

Figure 2.5: Charge holder thermal damage from explosion highlighting thermal isolation requirements

2.6 Previous Nakuja Mission Analysis

Table 2.2 summarizes mission outcomes.

Table 2.2: Nakuja Mission History and Key Findings

Mission	**Date**	**System**	**Key Outcome**
N-1	May 2021	Single deploy	Baseline established
N-2	Nov 2022	Single deploy	Telemetry improved
N-3	2024	Enhanced	Range limits identified
N-3.5	2024	Piston deploy	Thermal damage observed
N-4	**Proposed**	**Dual deploy**	**This project**

Analysis shows telemetry loss at altitudes exceeding 2km [5]. The XBee-PRO 900HP directly addresses this limitation.

Figure 2.6: Post-deployment test showing charring effects and the importance of sealed containment

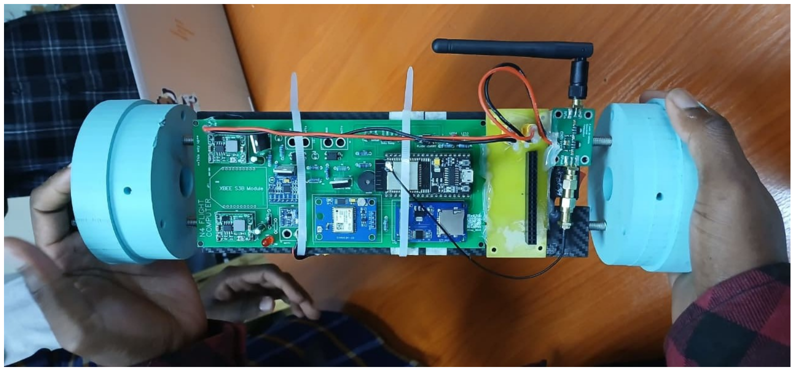

Figure 2.7: Assembled avionics bay with integrated battery retention and vibration isolation

2.7 Safety Standards and Guidelines

Amateur rocketry follows established safety protocols from organizations like Tripoli Rocketry Association. Key safety considerations include proper pyrotechnic handling, adequate descent rates for safe landing, and ground station monitoring capabilities.

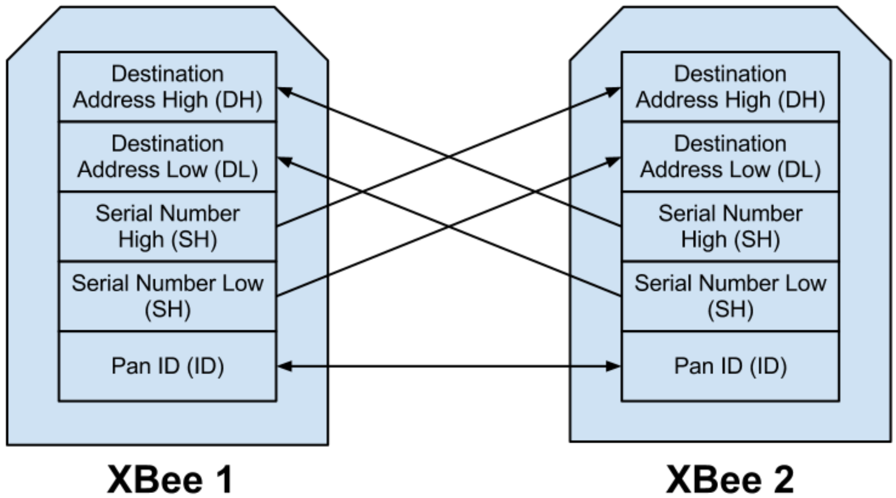

Figure 2.8: XBee-PRO 900HP telemetry system integration showing complete signal path

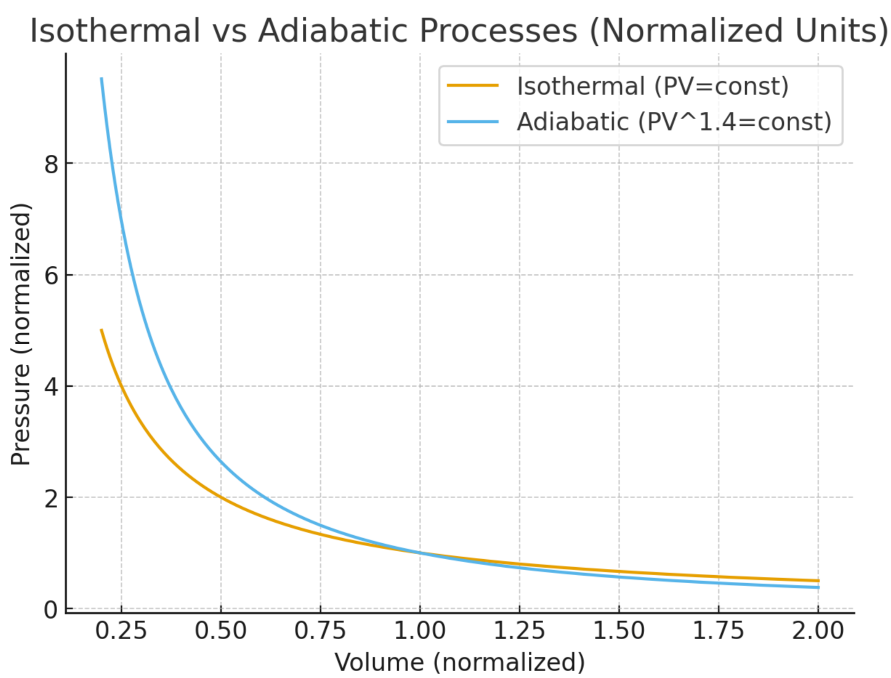

Figure 2.9: Adiabatic expansion analysis for parachute deployment system design

3 Design and Methodology

3.1 Design Approach

The project employs systematic design-build-test methodology [2]:

1. Requirements Analysis: Define system specifications based on N4 mission profile
2. Conceptual Design: Develop solution architectures
3. Detailed Design: Create CAD models and circuit schematics
4. Prototyping: Fabricate components
5. Testing and Validation: Conduct ground and flight tests
6. Iteration: Refine designs based on results

3.2 Implementation Methodology

3.2.1 Mechanical System Design

Sealed Explosion Cap Sealed explosion cap houses Crimson Powder pyrotechnic charge, containing combustion products while directing pressure for deployment [9]. High-temperature resistant materials withstand combustion while enabling multiple test cycles.

Avionics Bay Structure Custom 3D-printed PETG holder secures flight computer, LiPo batteries, and BMS with vibration isolation [13]. Design maintains center of gravity stability under high-G loads (see current design in Appendix D.3).

Figure 3.1 shows the CAD rendering of the avionics bay assembly with precise mounting features and component spacing requirements.

images/Current_CAD.PNG

Figure 3.1: CAD rendering of the avionics bay assembly showing component layout, mounting features, and dimensional constraints

3.2.2 Electrical System Architecture

Hardware Components ESP32 dual-core microcontroller processes telemetry data [10]. XBee-PRO 900HP module provides 5+km range at 900 MHz [8]. Custom PCB eliminates loose connections [11]. Current circuit implementation is detailed in Appendix D.2.

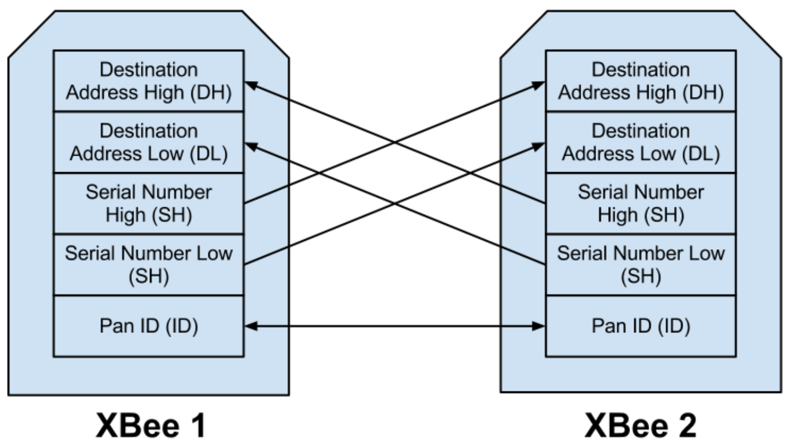

Figure 3.2: Proposed XBee-PRO 900HP telemetry system architecture

PWM Ignition Control MOSFET-based PWM driver controls nichrome wire heating, preventing burnout while enabling reusable testing [12].

Power Management BMS monitors LiPo battery health [14, 15]. Real-time feedback transmits battery voltage and igniter continuity. Launch inhibit activates below 14.0V threshold.

The battery management system employs an ADS1115 16-bit analog-to-digital converter for precise voltage and chute state monitoring. Battery voltage is acquired through a 47kΩ / 10kΩ voltage divider network providing a measurement range of 12V to 16.8V. The voltage measurement formula is calibrated as: $V_{battery} = V_{ADC} \times \frac{57.0}{10.0}$.

Chute detection utilizes dual analog inputs (channels 1 and 2) to monitor sensor states.

Figure 3.3: Nichrome wire demonstration showing thermal melting and cutting mechanism - illustrating the one-shot deployment characteristic

Signals exceeding 1000 counts indicate deployment readiness. The ADS1115 is configured with ±4.096V full-scale range gain for optimal resolution across all measured channels.

3.2.3 Electrical Design Concepts and Simulations

Figure 3.4 presents the conceptual design of the ground base station RF receiver architecture, integrating XBee-PRO telemetry with local data logging.

Figure 3.5 shows the XBee extension circuit design for the rocket avionics bay, demonstrating signal routing and antenna connection topology.

Figure 3.6 illustrates the detailed Proteus schematic and simulation of the battery management system, showing the ADS1115 ADC configuration, voltage divider network, chute detection circuits, and power distribution.

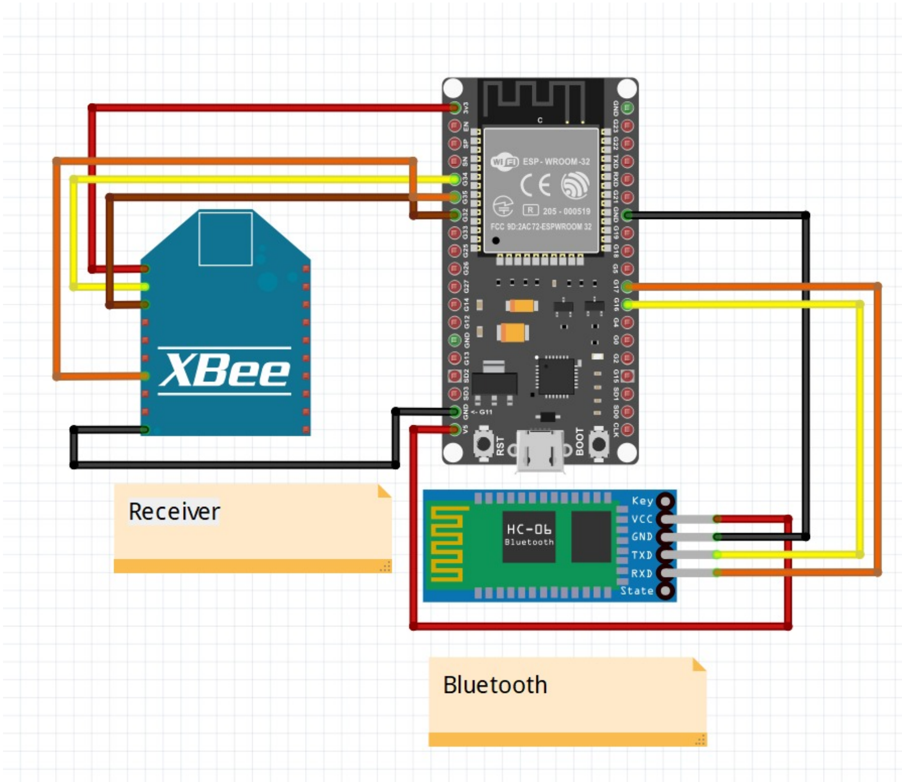

Figure 3.4: Base station receiver circuit concept showing XBee-PRO 900HP integration, RF filtering, and ground control processing elements

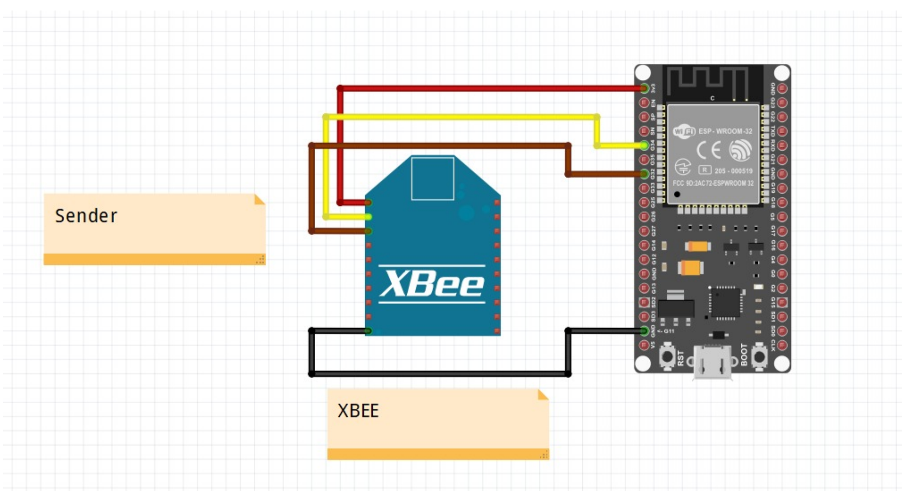

Figure 3.5: Rocket XBee extension circuit pinout and Fritzing layout illustrating power conditioning, antenna interface, and signal routing

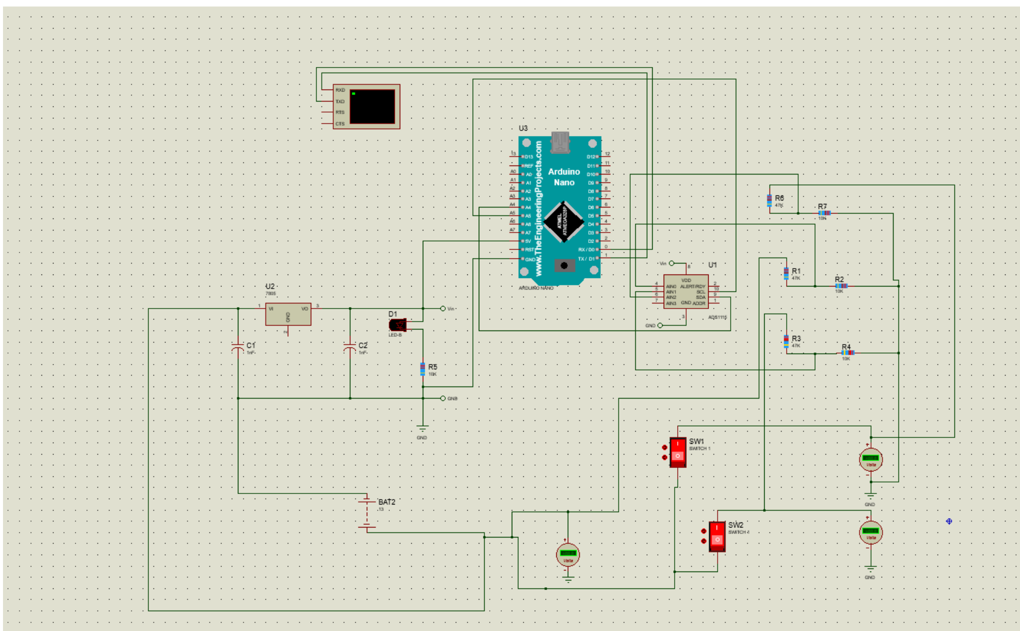

Figure 3.6: Battery Management System Proteus design showing ADS1115 ADC with voltage divider (47kΩ/10kΩ), dual chute detection inputs, and power distribution topology

3.3 Testing and Validation Plan

3.3.1 Ground Testing Protocol

- Telemetry range testing at 5+ km distances
- PWM ignition characterization with thermal imaging
- Explosion cap deployment force measurements
- Vibration testing on shake table (15G+)
- Full system integration verification

3.3.2 Flight Testing Protocol

Progressive testing: low-altitude validation flights before full mission profile.

4 Expected Outcomes

4.1 Technical Performance

- **Telemetry**: Continuous data up to 5 km altitude, ¡5% packet loss [8]
- **Recovery**: Zero thermal damage to parachute, controlled descent (¡5 m/s landing) [16]
- **Electronics**: Reliable PCB withstanding 15G+ vibration [13]
- **Mechanical**: Vibration-proof avionics holder, no component displacement
- **Safety**: Launch inhibit at ¡14.0V, dual-redundant ignition circuits

4.2 Project Timeline

15-week implementation: Planning/Design (Weeks 1-5), Procurement/Fabrication (Weeks 4-8), Integration/Testing (Weeks 9-12), Validation (Weeks 13-15). Detailed timeline in Appendix B.

4.3 Knowledge Contribution

Project documentation will provide:

- XBee-PRO 900HP performance validation in African high-altitude context
- PWM ignition characterization for student rockets
- Explosion cap design specifications
- Lessons learned for Nakuja Project and broader community

5 Conclusion

The proposed dual recovery system for the N4 rocket addresses critical gaps in current student rocketry recovery systems through comprehensive integration of advanced telemetry, controlled deployment mechanisms, and real-time monitoring capabilities. The implementation of XBee-PRO 900HP telemetry eliminates range limitations that have historically compromised mission success, while PWM-controlled ignition enables reusable deployment testing and eliminates thermal damage risks to recovery systems.

The sealed explosion cap design represents a significant advancement in deployment reliability, ensuring consistent performance while protecting critical parachute components. Integration of real-time feedback systems for battery voltage and igniter continuity provides ground operators with unprecedented visibility into system status, enabling proactive identification of potential failure modes before launch operations.

This project establishes a foundation for future high-power rocketry missions within the Nakuja project and contributes valuable empirical data regarding charge-to-ejection force relationships and ruggedized avionics design for student rocket applications. The modular system architecture enables future enhancements and adaptations for subsequent missions while maintaining core reliability improvements achieved through this development effort.

Successful completion of this project will significantly improve mission success probability for the N4 rocket while providing a validated design reference for future student rocketry recovery system development. The lessons learned and documentation generated will serve as valuable resources for the Nakuja Project and the broader student rocketry community.

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A Project Budget

Table A.1: N4 Recovery System Budget Breakdown

Item	Description	Qty	Cost/Unit (KES)	Total (KES)
Telemetry Modules*	Digi XBee-PRO 900HP	2	15,000	30,000
Antennas	900MHz High Gain Antenna	2	2,000	4,000
Copper Cladding	PCB Board (15 x 20 cm)	3	200	600
Microcontroller	ESP32 Development Board	1	1,800	1,800
Sensors	BMP180 + MPU6050 Module	1	4,710	4,710
Mosfets	IRL244N (Pack of 5)	1	1,000	1,000
Pyrotechnics*	Black/Crimson Powder	1	1,600	1,600
Mechanical Parts*	Threaded Rods & Hardware	1	1,000	1,000
Filament	PLA (1kg Roll)	1	3,000	3,000
Batteries	Lithium-Ion Cells (18650)	4	500	2,000
Total (With Purchased)				**49,710**
Total (Without Purchased)				**13,110**

*Components already available from Nakuja Project inventory. Out-of-pocket expenses: KES 13,110. Funding sources: Personal contribution (KES 7,000), Nakuja Project allocation (KES 6,110), university facilities for fabrication (in-kind).

B Project Timeline

Implementation follows a 15-week schedule with critical milestones:

- **Weeks 1-4:** Proposal presentation, continuous presentation, literature review and design phase
- **Weeks 5-8:** Mechanical, electrical, and control design with interim report submission

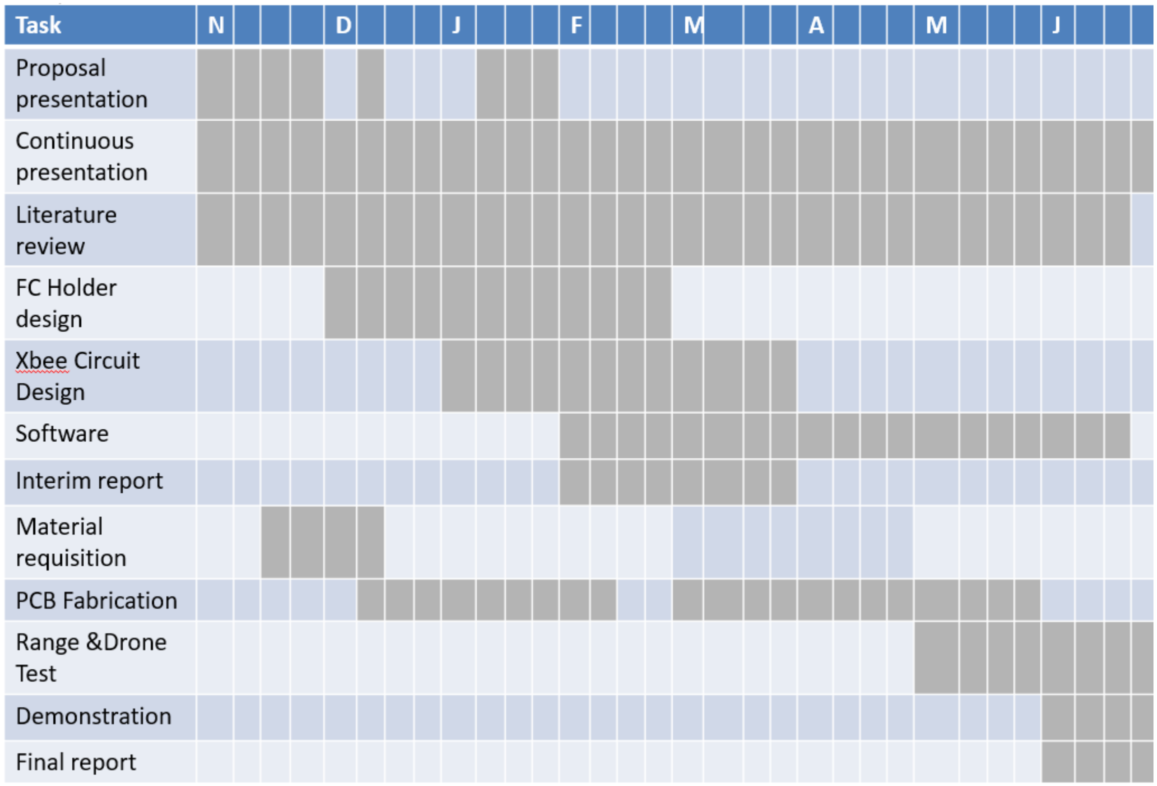


Figure B.1: 15-week project timeline showing task dependencies and critical path through design, fabrication, and testing phases

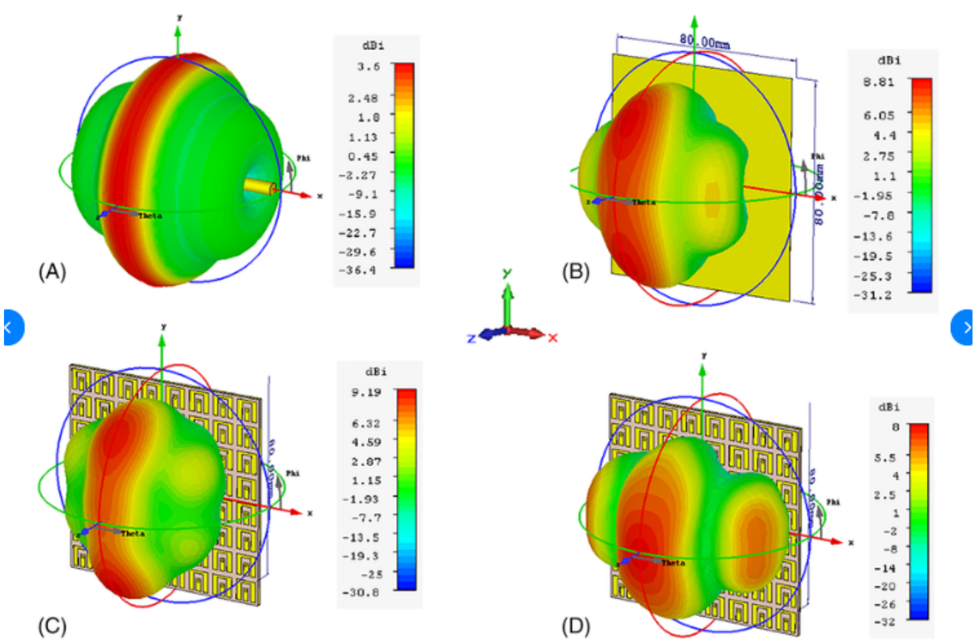
- **Weeks 9-11:** Material requisition, fabrication, and programming
- **Weeks 12-14:** Testing, demonstration, and final report preparation
- **Week 15:** Final report submission and project closeout

Critical path: PCB fabrication (2-week lead time), component procurement (3-week buffer). Risk mitigation: backup components ordered Week 4, 2-week weather contingency for launch operations.

C Antenna and RF Design Analysis

C.1 Null Space Signal Pattern

The XBee-PRO 900HP antenna radiation pattern exhibits directional characteristics with null spaces in certain directions. Understanding these null spaces is critical for ground station placement and receiver diversity architecture.



Radiation patterns in 3D form; (A) dipole antenna, (B) dipole antenna and metal plate with 6.9275 mm distance, (C) dipole antenna and EBG with 2 mm distance, (D) dipole antenna and EBG with 1 mm distance. EBG, electromagnetic band gap

Figure C.1: XBee-PRO 900HP antenna radiation pattern showing signal strength distribution and null space regions. The pattern demonstrates approximate omnidirectional coverage in the horizontal plane with defined null zones in vertical extremes

The null space analysis informs receiver antenna placement strategy, requiring minimum two-antenna diversity system at ground station to maintain continuous signal lock during all phases of the mission profile.

C.2 RSSI Signal Decay Characterization

Figure C.2 presents empirical Received Signal Strength Indicator (RSSI) measurements at various distances from the airborne transmitter. This data validates the 5+km effective range specification for the XBee-PRO 900HP system and informs link budget calculations for launch site selection.

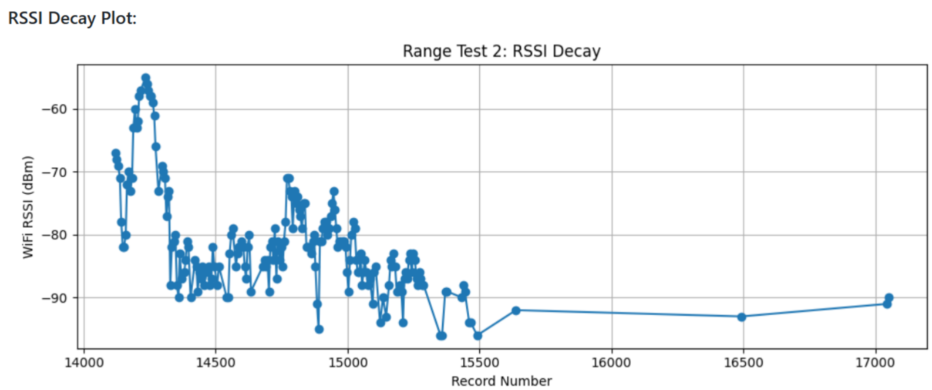


Figure C.2: RSSI signal decay plot showing measured signal strength attenuation with distance. Data confirms 5+km operational range with sufficient link margin (minimum -100 dBm receiver sensitivity) throughout nominal flight profile

The empirical RSSI decay curve provides quantitative validation for the telemetry system design and supports risk mitigation planning for boundary conditions (high-altitude drift, magnetic anomaly zones, etc.).

D Previous N4 Design References

Previous Nakuja missions (N1, N2, N3, N3.5) provide critical design heritage and lessons learned. The N3 single-deployment system identified key improvements needed for the N4 dual-deployment architecture, particularly in telemetry range extension (from 2km to 5+km) and pyrotechnic deployment reliability (see Figures D.2 and D.3).

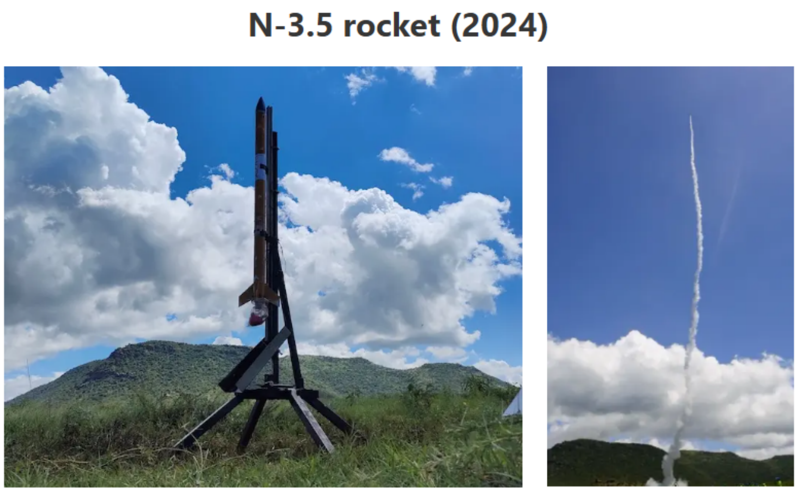


Figure D.1: Nakuja N3 rocket showing avionics bay configuration (reference design for N4 dual deployment architecture)

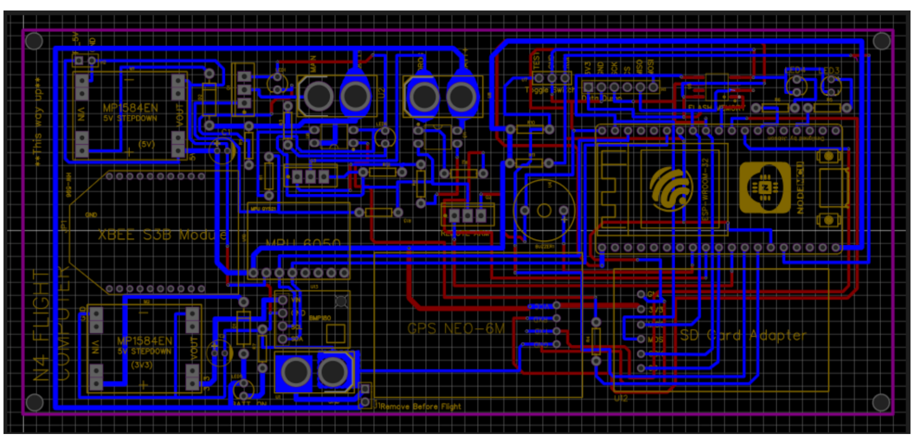


Figure D.2: Current N4 flight computer circuit design showing ESP32 microcontroller integration, XBee telemetry module, sensor interfaces (BMP180/MPU6050), MOSFET-based PWM ignition drivers, and power management circuitry

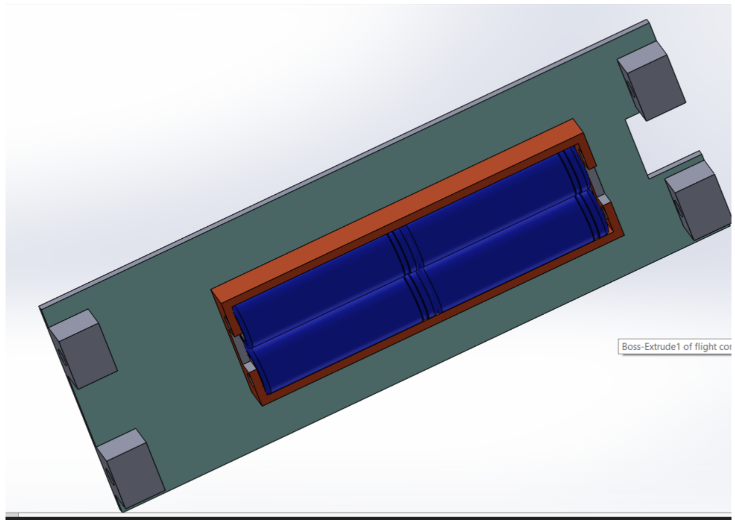


Figure D.3: Current flight computer holder design featuring 3D-printed PETG construction with integrated battery retention mechanism, vibration isolation mounts, and modular component placement for easy assembly and maintenance

The current design iterations (Figures D.2 and D.3) represent the latest improvements incorporating lessons from previous test campaigns, with enhanced vibration isolation and optimized circuit layout for reliability.

E Nakuja Project Resources

Project Website: `https://nakujaproject.com/`

GitHub Repository: `https://github.com/nakujaproject`

The Nakuja Project maintains open-source repositories for:

- Flight computer firmware (ESP32-based)
- Ground station telemetry software
- PCB design files (KiCAD format)

- Simulation and trajectory analysis tools
- Recovery system control algorithms

All documentation is available under open-source licenses to support the student rocketry community.