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MUNStar-1 A CubeSat Mission for Monitoring Climate Change in the North Atlantic Ocean

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Abstract

The Memorial University of Newfoundland (MUN) began developing the student-led MUNStar-1 CubeSat project in 2023. A successor to Killick-1, MUNStar-1 serves as MUN's submission to the Canadian Space Agency's CUBICS initiative. With a planned June 2026 launch, MUNStar-1 will be the province's second earth observation satellite, designed to monitor the North Atlantic Ocean and observe the effects of climate change through GNSS-R technology.

This presentation outlines the mission's primary objectives and requirements for MUNStar-1 and describes the payload and subsystems that were selected to best respond to the mission requirements. There are 4 key mission objectives for the project:

1. Spatially and temporally monitor the North Atlantic Sea State by detecting GNSS-R signals.
2. Provide open-access information on ocean conditions to the scientific community.
3. Establish an experiential learning approach for students in spacecraft systems and mission design.
4. Promote an interest in the space industry through various outreach events and social media platforms.

GNSS-R, or Global Navigation Satellite System Reflectometry, is a remote sensing technique where GNSS signals are transmitted from space and then collected after being reflected off a certain area of the earth's oceans. Using this technique, it is possible to determine the sea state of a given region, including sea level, mean square slope, and significant wave height. GNSS-R was selected for the MUNStar-1 mission due to its low cost and power consumption.

The quality of the reflected beams is influenced by sea characteristics such as surface roughness and wave height. The collected data is stored and represented using Delay Doppler Maps (DDM). Ocean scientists use this data to study trends and detect anomalies. MUNStar-1 will generate 1 image per second during data collection mode.

Listed below are some key subsystems of MUNStar-1 and their functions.

Nadir Antenna: A deployable 30cm x 30cm antenna array detects GNSS signals reflected off the earth's surface. Controlled using a burnwire mechanism and custom hinges.

Analog Front End: GNSS receiver for downconverting and digitizing signals.

UHF Transceiver: An onboard radio with deployable antennas that will downlink the acquired data during a communication pass.

Ground Station: A controllable antenna on the roof of the C-Core building at MUN tracks the satellite as it passes and collects/stores the downlinked data.

It is also important to recognize the educational benefits of this mission. By sponsoring student leadership and outreach activities, the MUNStar-1 team is proud to facilitate the training of the next generation of space professionals. There are currently 65+ students on the MUNStar-1 team. The satellite is being designed, built, and tested entirely by students. The project is a joint effort between Memorial University and C-Core, a research company affiliated with the university. Several professors and industry professionals from C-Core are advisors for the project. The audience is encouraged to visit the MUNStar-1 website or contact the team for more information.

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Acronyms/Abbreviations

Attitude Determination and Control System (ADCS)
Beginning of Life (BOL)
Controller Area Network (CAN)
Canadian Space Agency (CSA)
Commercial-Off-The-Shelf (COTS)
Critical Design Review (CDR)
Delay-Doppler Map (DDM)
Digital Signal Processing (DSP)
Electrical Power System (EPS)
End Of Life (EOL)
Federal Communications Commission (FCC)
Field Programmable Gate Array (FPGA)
Global Navigation Satellite System Reflectometry (GNSS-R)
Global Positioning System (GPS)
International Amateur Radio Union (IARU)
Inter-Integrated Circuit (I2C)
Low Earth Orbit (LEO)
Memorial University of Newfoundland (MUN)
On-board Computer (OBC)
Printed Circuit Board (PCB)
Random Access Memory (RAM)
Science, Technology, Engineering, Math (STEM)
Sun-Synchronous Orbit (SSO)
Two-Line Element (TLE)
Ultra-High Frequency (UHF)
Three Unit (3U)

1. Introduction

Climate change has significantly impacted the North Atlantic Ocean, leading to rising sea levels, record-high sea surface temperatures, and reduced sea ice [1]. Understanding these rapid changes, such as shifting ocean currents and rising sea levels, is critical, particularly for regions like Newfoundland and Labrador, where oceanic research and marine industries are key to the economy. However, monitoring vast ocean areas presents a challenge. The MUNStar-1 mission, developed at Memorial University of Newfoundland (MUN), aims to address this by utilizing Global Navigation Satellite System Reflectometry (GNSS-R) technology to study climate change effects on the North Atlantic Ocean [2].

Figure 1: Region of Interest

MUNStar-1 is MUN's submission to the Canadian Space Agency's (CSA) CUBICS initiative and follows the legacy of Killick-1 as the second Earth Observation satellite developed in Newfoundland [3]. The project is being designed, built, and tested by undergraduate students from engineering, science, and business disciplines, fostering interdisciplinary collaboration and experiential learning. It represents a collaborative effort between MUN and industry partners, C-Core and Solace Power. The team comprises of over 65 student volunteers, 4 co-op students, 10 faculty advisors, and 5 industry advisors [4].

2. Mission Objectives and Timeline

Four key objectives define the MUNStar-1 mission [4]:

1. Spatially and temporally monitor North Atlantic Ocean sea state conditions by detecting reflected GNSS signals.

2. Create and provide a publicly accessible dataset of ocean condition information relevant to climate change for the scientific community.

3. Facilitate the training and development of students in spacecraft systems engineering and mission design through hands-on experience and experiential learning.

4. Promote interest in the space sector within Newfoundland and Labrador through outreach activities and public engagement.

MUNStar-1 is expected to launch in June 2026 on Transporter-17 on SpaceX Falcon 9 with deployment at a 510 km Sun-Synchronous orbit. It will undergo regular mission operations for 3 years. In June 2029, mission operations will end, and the satellite will begin its deorbiting procedure [5]. Based on simulations conducted using the NASA Debris Assessment Software and the CNES Semi-analytic Tool for End-of-Life Analysis, MUNStar-1 is expected to deorbit within 4.8 years of mission completion, which complies with the FCC deorbiting regulations for Satellites in LEO [6].

3. GNSS-R Theory

Global Navigation Satellite System Reflectometry (GNSS-R) is a remote detection method that detects signals from high-altitude GPS satellites that reflect off the Earth's oceans. By analyzing their delay and Doppler characteristics, it's possible to determine sea state parameters such as sea level, mean square slope, significant wave height, and infer wind speed.

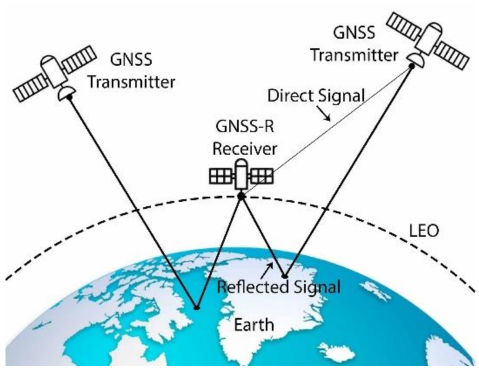

Figure 2: Example GNSS-R Satellite [2]

MUNStar-1 employs GNSS-R technology to monitor the North Atlantic Ocean sea state. GNSS-R was selected for its relatively low cost and power consumption compared to active sensing methods that require signal transmission and receiving. The use of L-band signals also allows for remote sensing, even in extreme weather conditions.

The quality and characteristics of the reflected signals are influenced by sea surface roughness and wave height. The reflected signal data is processed by the satellite and turned into Delay Doppler Maps (DDMs). A Delay Doppler Map is a 3D representation of signal power distribution across different code phase delays and Doppler frequencies. MUNStar-1 aims to generate one DDM image per second during its data collection mode. This data will contribute to the open-access dataset for ocean scientists to study trends and anomalies.

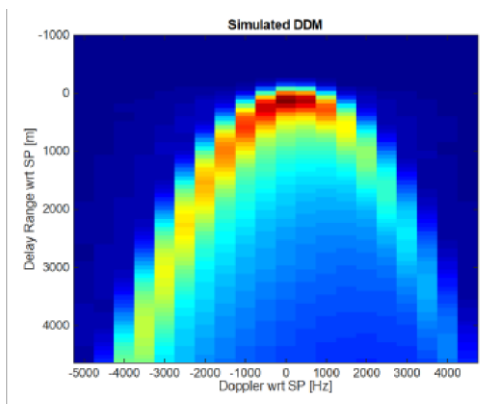

Figure 3: Simulated Delay-Doppler Map [2]

4. MUNStar-1 Payload

The payload consists of several key components [4]:

Nadir Antenna: A 10x30 cm panel with a 1x3 array of patch antennas designed to detect the reflected GNSS signals. The deployable panels are controlled using a burnwire mechanism and custom hinges.

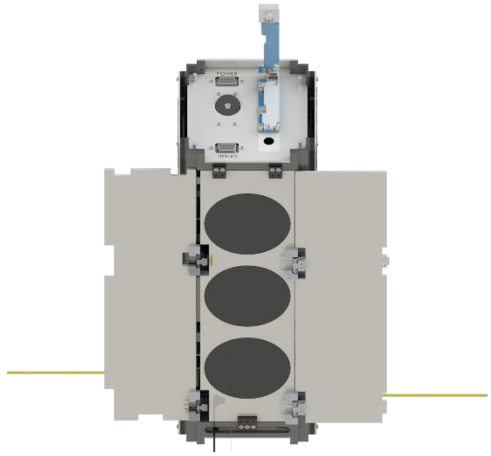

Figure 4: MUNStar-1 Nadir GNSS-R Antenna Panel [4]

Analog Front End: The Analog Front End GNSS receiver is responsible for down-converting and digitizing the received signals. Students have completely designed and tested this aspect of the payload.

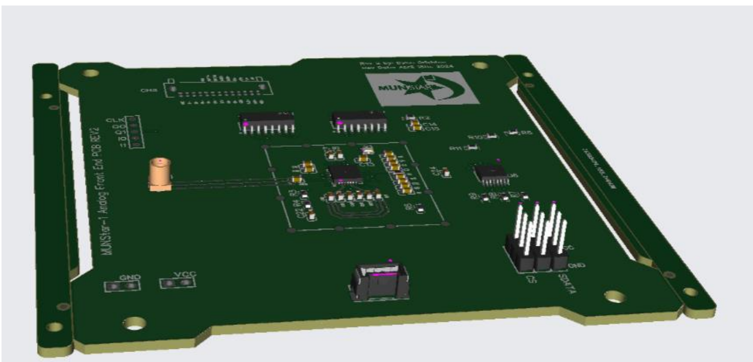

Figure 5: Custom GNSS-R Receiver Payload PCB [4]

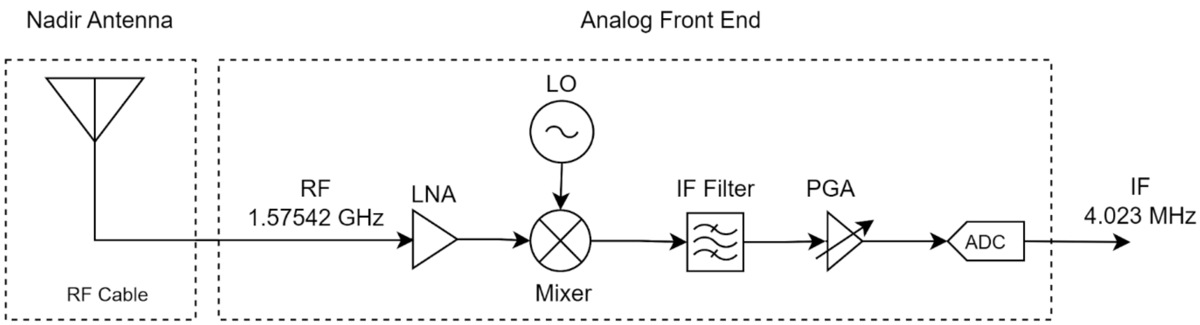

Figure 6: Analog Front End PCB Flow Chart [4]

Digital Back End: Performs Digital Signal Processing (DSP) on the digitized signals from the Analog Front End to generate the DDMs, implemented on an FPGA integrated within the OBC.

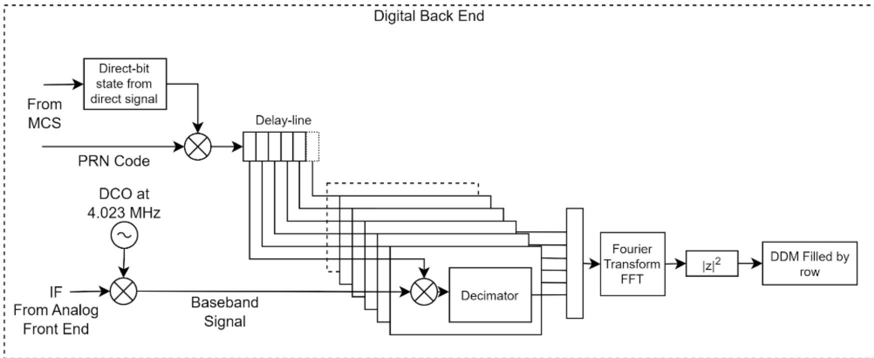

Figure 7: Digital Back End Flow Chart [4]

5. Satellite Subsystems

5.1 Structural/Mechanical

The primary structure consists of four main pieces machined from Aluminum 6061-T6, chosen for its space-grade properties and machinability [4]. The design prioritizes maximizing internal volume while adhering to the CubeSat standard dimensions for 3U satellites (10 x 10 x 34.05 cm) and interfacing correctly with the launch deployer, the ExoPod from Exolaunch. Key considerations include internal pathways for harnessing, accessibility for assembly and integration, and structural stability confirmed through simulation.

Figure 8: MUNStar-1 Structure [4]

MUNStar-1 features two deployable panels, initially designed as additional antenna panels but now primarily utilized to increase the drag area for passive deorbiting compliance. Deployment relies on custom hinges and a burn wire release mechanism. Prototyping using 3D printing has been used for fit checks and assembly procedure validation. Engineering and flight models have been machined by a local machine shop and anodized for surface protection. Mass, center of gravity, and moments of inertia are continuously tracked and managed in the MUNStar-1 Interface Control Document.

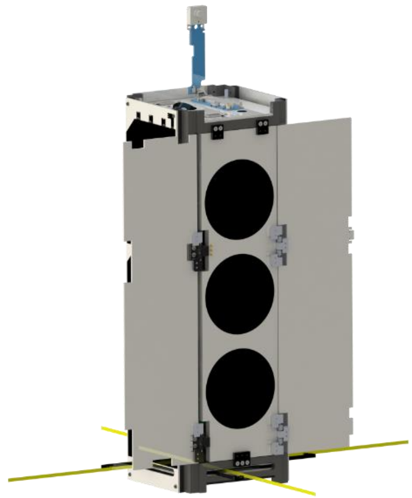

Figure 9: MUNStar-1 Deployed Configuration [4]

5.2 Attitude Determination and Control System (ADCS)

The ADCS utilizes components like magnetometers, magnetorquers, reaction wheels, a sun camera, and a horizon camera to determine and control the satellite's orientation while in orbit [4]. MUNStar-1 uses a Commercial-Off-The-Shelf (COTS) ADCS system. The CubeSpace ADCS Gen 2 was selected for its ease of use and integration. The ADCS is centrally located within the CubeSat stack for optimal control. Its primary function is to ensure the Nadir-pointing payload antenna is oriented toward the Earth's surface during data collection periods.

The ADCS also enables other pointing modes like Sun-pointing for optimal power generation or a high drag configuration to increase the drag area and increase the rate of deorbiting. Pointing budgets have been established, and performance has been verified through simulation and component-level testing.

5.3 Command and Data Handling C&DH)

The GOMSpace Nanomind HP MK3 is MUNStar-1’s onboard computer (OBC) [4]. It is responsible for executing the flight software, managing the different operational modes (e.g., Standby, Sun Pointing, Data Collection, Safe Hold), processing commands received from the ground station, collecting and storing telemetry data, and managing the payload operations, including the processing of DDMs using its integrated FPGA.

The OBC interfaces with other subsystems primarily via I2C and CAN protocols through the PC104 bus. Budgets for processing power, RAM, and data storage (ensuring sufficient capacity for DDM data) are carefully managed and tracked. Zedboards are being used in conjunction with a mezzanine board for initial software development and FlatSat testing before transitioning to the flight model OBC.

5.4 Communications

The Communications subsystem facilitates two-way communication between MUNStar-1 and the ground station [4]. The EnduroSat UHF Transceiver II is used for uplinking commands and downlinking payload data (DDMs) and satellite telemetry. It operates in the amateur UHF band, requiring coordination and licensing through IARU and relevant authorities. The system includes deployable antennas released after deployment that communicate with two Yagi Antennas during scheduled communication passes, which have been assembled on the roof of the C-Core office in St. John’s. These antennas have been designed to track passing satellites given their TLE data.

Figure 10: Assembled M2 Yagi Antennas on the roof of C-Core Office in St. John's, NL [7]

5.5 Electrical Power Subsystem (EPS)

The Electrical Power Subsystem manages power generation, storage, and distribution throughout the satellite. Power is generated by body-mounted solar panels affixed to the exterior faces of the CubeSat. These solar panels have been custom-designed by the MUNStar-1 team to maximize power generation and minimize cost [4].

Power budgets accounting for consumption in different operational modes and energy generation based on orbital parameters are maintained to ensure sufficient power throughout the mission lifetime, including considerations for beginning-of-life (BOL) and end-of-life (EOL) performance. The system includes redundant deployment inhibit switches (RBF pin and roller switch) to ensure the satellite remains unpowered inside the deployer until orbit insertion, complying with launch provider requirements.

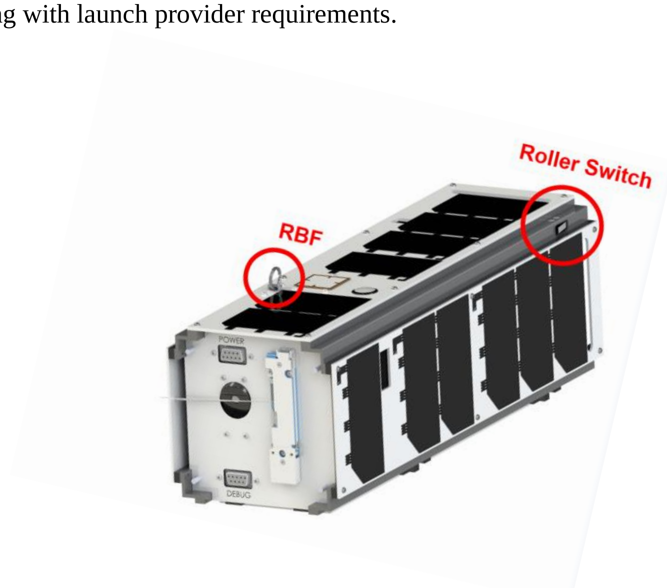

Figure 11: MUNStar-1 Solar Cell Configuration and Inhibits [4]

6. Results and Discussion

6.1 Scientific Impact

Upon successful deployment and operation, MUNStar-1 will contribute valuable data to the scientific community. The acquired DDMs, will be made freely available as an open-access dataset. This resource is intended to benefit climate scientists, oceanographers, and research institutions by providing crucial information for monitoring ocean conditions related to climate change. The temporally and spatially relevant data aims to enhance the accuracy of sea state condition predictions and support broader climate modelling efforts.

6.2 Educational and Industry Impact

MUNStar-1 and similar university CubeSat projects provide students with unparalleled experiential learning opportunities. These projects train the next generation of space professionals by immersing students in all the complexities of a real-world space mission. The MUNStar-1 team has gained hands-on experience across the mission lifecycle, including mission and systems design, subsystem-level electrical and mechanical design, manufacturing, assembly, integration, testing, validation procedures, and cleanroom protocols.

Furthermore, students develop crucial skills in interdisciplinary collaboration, systems engineering, navigating design reviews, and engaging with the wider space industry through events like this conference. University CubeSat programs like MUNStar-1 also foster collaboration between academic institutions and industry partners like C-Core and Solace Power.

Figure 12: ADCS Testing in MUN Cleanroom Lab

6.3 Public Engagement and Outreach

The MUNStar-1 team is committed to promoting interest in space science and engineering within Newfoundland and Labrador and beyond. The MUNStar-1 team actively engages in outreach programs for high school students across the province, showcasing pathways into STEM fields and highlighting space systems engineering.

Significant media attention, including interviews and news stories, has raised the project's profile in the province. The team also maintains an active social media presence (Instagram, LinkedIn) to share progress and engage the public. Ongoing media campaigns like "MUNStar Mondays" highlight different aspects of the team's work and foster sustained interest in the mission and the Canadian space sector.

Figure 13: MUNStar-1 Team at a High School High Achievers Event

6.4 Conclusions

MUNStar-1 represents a promising advancement in the use of CubeSat platforms for Earth observation and climate monitoring, specifically through the application of GNSS Reflectometry (GNSS-R). The satellite will provide valuable sea state data by detecting reflected GNSS signals across the North Atlantic Ocean. Creating an open-access dataset will enable researchers worldwide to analyze spatial and temporal trends in ocean surface conditions.

Beyond its scientific contributions, MUNStar-1 promotes experiential learning and collaboration by allowing students to gain hands-on experience in satellite systems engineering and mission design. MUNStar-1 trains the next generation of space professionals and fosters a growing interest in the Canadian space sector.

Acknowledgments

The MUNStar-1 team gratefully acknowledges the significant support provided by the Canadian Space Agency and the Government of Newfoundland and Labrador through the CUBICS initiative and the Research Innovation Fund. We extend our sincere appreciation to Memorial University of Newfoundland (MUN), particularly the Faculty of Engineering and Applied Science, for providing the facilities, resources, and academic environment essential for this project.

We thank our industry partners, C-CORE and Solace Power, for their invaluable collaboration and expertise. We are also deeply grateful to the dedicated supervisory team, faculty members, and industry advisors who have generously shared their time and guidance throughout the mission's development.

Finally, this project would not be possible without the hard work, dedication, and enthusiasm of the numerous undergraduate students who form the MUNStar-1 team. Their contributions across all subsystems and project phases are the driving force behind this mission.

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