Simulation of the RIDU- Sat 1 GMSK TT&C Link using GNU Radio

1st Rendi Dwi Rusti
Military Electrical Engineering
Republic of Indonesia Defense University
Bogor, Indonesia
rendidwirusti@gmail.com

2nd Sayyid Hasan Harahap
Military Informatics
Republic of Indonesia Defense University
Bogor, Indonesia
sayyidhassan195@gmail.com

3rd Erlangga Aryo Prastya
Military Electrical Engineering
Republic of Indonesia Defense University
Bogor, Indonesia
aryoprasss8@gmail.com

4th De Shepherd Guella Winisia Zega
Military Electrical Engineering
Republic of Indonesia Defense University
Bogor, Indonesia
dsgwzega@gmail.com

5th Maulana Ali Arifin
Research Center for Satellite Technology National Research and Innovation Agency Bogor,Indonesia
maul016@brin.go.id

6th Dananjaya Ariteja
Republic of Indonesia Defense University
Bogor, Indonesia
dananjaya.ariteja@idu.ac.id

7th Sembada Denrineksa Bimorogo
Republic of Indonesia Defense University
Bogor, Indonesia
denri5693@gmail.com

8th Wahyudi Hasbi
Research Center for Satellite Technology National Research and Innovation Agency
Bogor,Indonesia
wahyudi.hasbi@brin.go.id

***Abstract*— Ensuring reliable satellite communication is critical for mission success, particularly for nanosatellite operations where power and resource constraints pose significant challenges. This paper validates the required ground station (GS) transmit power for the RIDU-Sat 1 TT&C uplink by combining theoretical analysis with dynamic simulation. A link budget was first calculated to determine the minimum required power, showing that a GS with an Effective Isotropic Radiated Power (EIRP) of 23.19 dBm is theoretically needed to meet the satellite's -126 dBm sensitivity threshold. To verify this and account for operational margins, a higher operational EIRP of 39 dBm was chosen for simulation. An end-to-end GNU Radio simulation modeling a full Low Earth Orbit (LEO) pass was then developed. The simulation results confirm that transmitting at 39 dBm successfully maintains the received signal strength at the satellite well above the -126 dBm threshold, thereby validating the link budget calculation and confirming the viability of the chosen operational power.**

Keywords*— *GNU Radio, GMSK, TT&C, Nanosatellite, LEO Simulation

I. Introduction

RIDU-Sat 1 is a nanosatellite developed for educational and emergency communication (CORE) missions in Indonesia, designed to provide a resilient communication channel when terrestrial infrastructure is unavailable [1], [2], [3]. For such a mission, a reliable Telemetry, Tracking, and Command (TT&C) link is fundamental. The success of the uplink, in particular, depends on a critical question: how much power must the ground station transmit to ensure the satellite can reliably receive commands? Answering this requires a robust and validated link budget.

To ensure mission success and mitigate risks associated with orbital operations, rigorous pre-flight validation of the communication link is essential [4]. Simulation provides a cost-effective and low-risk method to validate performance before hardware integration, allowing for the analysis of link dynamics under realistic Low Earth Orbit (LEO) conditions, which include significant Doppler shifts and large variations in free-space path loss [5], [6].

For this study, GNU Radio was selected as the simulation platform due to its flexibility, modular design, and comprehensive libraries for signal processing and channel modelling [7], [8]. While previous studies have used GNU Radio to analyze GMSK performance under various conditions [9], [10], a gap exists in presenting a complete verification workflow that directly correlates a formal, theoretical link budget with results from a dynamic LEO pass simulation. This paper addresses that gap by presenting a methodology to first calculate the required uplink power theoretically, and then use a detailed simulation to verify that the calculation holds true under realistic orbital conditions.

The main contributions of this paper are:

- The establishment of a theoretical uplink link budget to determine the required Ground Station EIRP needed to meet the satellite's receiver sensitivity.
- The development of an end-to-end GNU Radio simulation that models the RIDU-Sat 1 TT&C link with realistic LEO channel impairments using the gr-leo toolkit.

- The validation of the theoretical link budget by simulating a full satellite pass and confirming that the received signal strength consistently remains above the -126 dBm receiver sensitivity threshold.

II. RIDU-Sat 1 System Specification

The TT&C communication system of RIDU-Sat 1 uses Gaussian Minimum Shift Keying (GMSK) as its primary modulation scheme. This choice was driven by GMSK's constant amplitude characteristics, which ensure high power efficiency when using non-linear power amplifiers a critical factor in power-constrained nanosatellite missions [11], [12]. The communication system is designed to operate at a carrier frequency of 145.925 MHz in the VHF amateur satellite band, by international frequency allocations for educational and amateur missions [13]. A data rate of 1200 bps was selected to balance bandwidth efficiency and link reliability in Low Earth Orbit (LEO) conditions. The bandwidth-time product of the GMSK filter is set to 0.5, a standard setting that provides an optimal balance between spectrum and modulation complexity. These parameters together ensure that the RIDU-Sat 1 TT&C link achieves robustness and energy efficiency while complying with regulatory and operational constraints.

The primary requirement for the uplink is to ensure that the signal arriving at the satellite is strong enough to be correctly demodulated. The satellite's GMSK receiver has a specified sensitivity threshold of -126 dBm, which serves as the critical performance benchmark for the link. Therefore, the main objective of the link budget calculation and subsequent simulation is to verify that the power transmitted from the ground station is sufficient to overcome all path losses and deliver a signal of at least -126 dBm to the satellite's receiver.

The key parameters for both the theoretical link budget and the GNU Radio simulation are summarized in Table 1.

TABLE I. RIDU-Sat TT&C Link Parameter

Category	Parameter	Value	Unit
Link	Uplinnk Frequency	145.925	MHz
	Modulation	GMSK	-
	Data Rate	1200	bps
	GMSK BT Product	0.5	-
Satellite	Orbit Altitude (Nominal)	518	km
	Antenna Type	Monopole	-
	Receiver Sensitivity	-126	dBm
	Receiver Noise Figure	8	dBm
Ground Station	Location	Sentul, Indonesia	-
	Latitude	-6.1	Degree
	Longitude	106.49	Degree
	Antenna Type	Yagi	-
	Antenna Gain	7.6	dBi

III. Simulation in GNU Radio

To validate the theoretical link budget, an end-to-end simulation of the RIDU-Sat 1 uplink was developed in GNU Radio. The design and implementation are divided into three main sections: the Ground Station Transmitter (TX), the LEO Channel Model, and the Satellite Receiver (RX).

A. Transmitter

The transmitter flowgraph, shown in Fig. 1, was designed to emulate the RIDU-Sat 1's packet-based communication system. The process begins with a Socket PDU block, which allows external data (e.g., from a command system like YAMCS) to be injected into the simulation. This data payload is passed to a PDU Air Frame Formatter block, which prepends the necessary headers such as the sync word and callsign. The complete data packet is then converted into a tagged stream by the PDU to Tagged Stream block.

This stream is fed into the GMSK Mod block, which performs the modulation with a samples-per-symbol (sps) of 10 and a bandwidth-time product (BT) of 0.5. Finally, a Multiply Const block adjusts the signal's amplitude to set the transmitter's Effective Isotropic Radiated Power (EIRP) to the operational value of ~39 dBm before the signal enters the channel model.

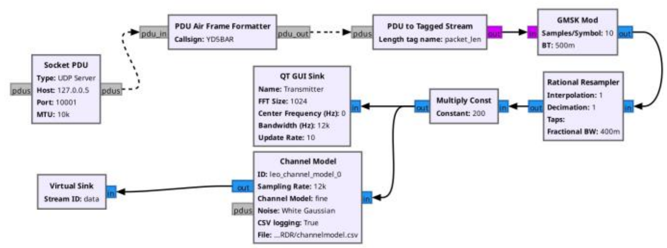

Fig. 1. Transmitter Flowgraph

B. LEO Channel Model

Conducting communication simulations in low Earth orbit (LEO) requires adjustments to reflect actual conditions. Therefore, a channel model that takes various important factors into account is used. The ground station's configuration is defined in the Tracker block, which represents its location at the Indonesian Defense University (-6.1° S, 106.49° E). To identify the RIDU-Sat 1 satellite, the Satellite block is configured with the satellite's specific TLE data.

These components are integrated by the LEO Model Definition block, which provides a realistic LEO environmental simulation using the gr-leo toolkit. For this simulation, the model is configured to include critical parameters such as Doppler shift and Free-Space Path Loss (FSPL), which are continuously updated throughout the pass. Atmospheric attenuation and pointing loss are also enabled according to ITU Recommendations. This channel model is highly comprehensive and aligned with real-world standards for LEO satellite communication.

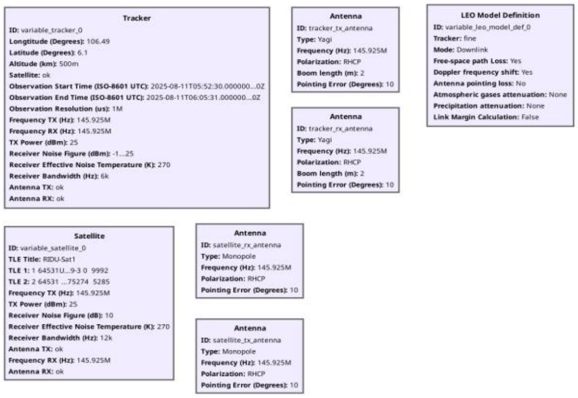

Fig. 2. Channel Model Specification

C. Receiver

The receiver flowgraph, shown in Fig. 3, is designed to demodulate the GMSK signal and decode the data packet. The signal from the channel model first passes through a Low-Pass Filter and a Frequency Xlating FIR Filter to isolate the signal of interest and correct for frequency offsets. A Quadrature Demod block then converts the signal to a baseband representation.

The core of the digital receiver consists of the Symbol Sync block, which recovers the symbol timing, and a Binary Slicer, which makes the final 0-or-1 decision on each bit. The resulting bitstream is reassembled into a packet PDU using the Unpacked to Packed and Tagged Stream to PDU blocks. Finally, this PDU is passed to the PDU Air Frame Parser, which strips the headers, validates the packet, and outputs the original data payload.

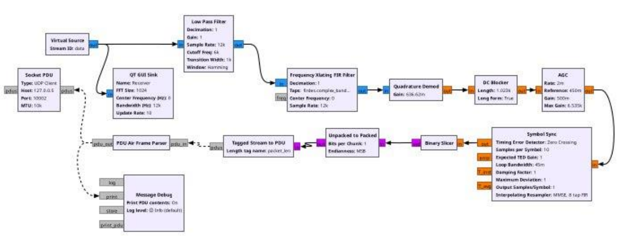

Fig. 3. Receiver Flowgraph

IV. Result and Discussion

This section validates the RIDU-Sat 1 uplink design by first establishing a theoretical link budget to determine the required ground station transmit power, and then using a GNU Radio simulation to verify that this power is sufficient under near realistic orbital conditions.

A. Theoretical Link Budget Calculation

The first step in validating the communication link is to perform a theoretical link budget calculation. This analysis accounts for all gains and losses in the signal path, from the ground station transmitter to the satellite receiver, to determine the required transmit power. The objective is to ensure the final received power at the satellite (Pr) remains above its sensitivity threshold of -126 dBm, especially in a worst-case scenario where the satellite is at its maximum slant range (lowest elevation). For a 518 km orbit, this corresponds to a slant range of approximately 2,620 km. The detailed link budget for this scenario is presented in Table 2.

TABLE II. Link Margin Calculation

Parameter	Value	Unit
Required Received Power (Pr)	-126	dBm
Free-Space Path Loss (fspl)	144.09	dB
Atmospheric Loss (La)	0.1	dB
Pointing Loss (Lmisc)	3	dB
Total Losses	147.19	dB
Satellite Antenna Gain (Gr)	2	dBi
Required Signal at Antenna	-124	dBm
Required GS EIRP	23.19	dBm
Operational GS EIRP	39	dBm
Link Margin	15.81	dB

The link budget calculation shows that a minimum Ground Station EIRP of 23.19 dBm is theoretically required to close the link when the satellite is at its furthest point. To provide a robust operational margin, a much higher transmit power of ~39 dBm was chosen for actual operations and for this simulation. This provides a healthy link margin of +15.81 dB in the worst-case scenario.

B. Simulation Validation

To verify the link budget, the GNU Radio simulation described in Section III was executed for a full satellite pass. The GS transmitter was configured with an EIRP of ~39 dBm. The signal of the transmitter is shown in the fig. 5.

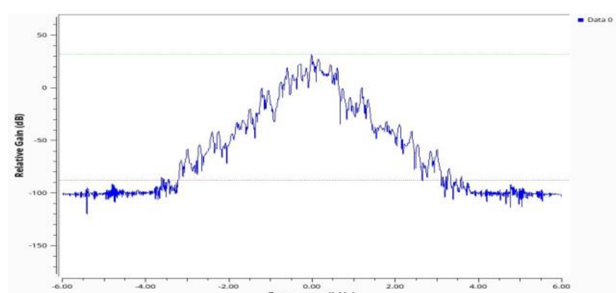

Fig. 4. Transmitter Signal

The simulation results strongly validate the theoretical link budget. The measured power of the received signal, as shown in Fig. 6, is approximately -107 dBm. This measured value is in excellent agreement with the -108.1 dBm power predicted by a similar link budget calculation for a 2,620 km slant range.

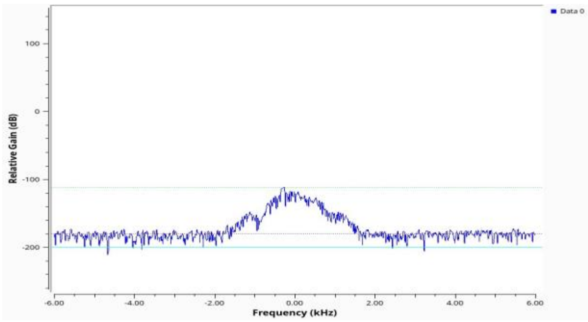

Fig. 5. Received Signal

This close correlation between the calculated and simulated values confirms that the GNU Radio model is accurately representing the real-world channel conditions. Most importantly, the measured signal power of -107 dBm is +19 dB above the critical -126 dBm sensitivity threshold, confirming that a Ground Station EIRP of 39 dBm is sufficient to maintain a robust and reliable uplink to the RIDU-Sat 1 satellite.

To better understand which challenges most affect the link, a series of tests were run where specific channel impairments were turned on one by one. The results are shown in Table 3.

TABLE III. LINK MARGIN CALCULATION

Free-Space Path Loss (FSPL)	**Doppler Shift**	**Antenna Pointing Loss**	**Atmospheric/Precipitation Attenuation**	**Result**	**Packet Receive**	**BER / PER**
Yes	No	NO	None	SUCCESS	100/100	0.00e+00 / 0.00
Yes	Yes	No	None	FAILURE	5/100	~1.0 / ~0.95
Yes	No	Yes	None	SUCCESS	100/100	0.00e+00 / 0.00
yes	No	Yes	Atmospheric Only	SUCCESS	100/100	0.00e+00 / 0.00
yes	No	Yes	Atmospheric & Precipitation	SUCCESS	100/100	0.00e+00 / 0.00

The results in Table 3 reveal a key finding: the Doppler shift is the most critical challenge for the communication link. Test 2 shows that when the Doppler shift is active but not corrected by the receiver, the link fails almost completely, with a 95% packet error rate. In contrast, Tests 3, 4, and 5 show that the link easily handles other issues like pointing errors and atmospheric losses without any packet loss. This analysis proves that while the system has a large power margin to overcome signal loss, the receiver's ability to correct for frequency changes caused by the Doppler effect is absolutely essential for successful communication.

V. CONCLUSSION

This paper presented the pre-flight validation of the RIDU-Sat 1 nanosatellite's TT&C uplink. The study successfully demonstrated a workflow that connects theoretical analysis with simulation by first establishing a formal link budget and then using a GNU Radio simulation to verify its performance under realistic LEO conditions.

The finding is the successful validation of the uplink power requirements. The theoretical link budget determined that an operational Ground Station EIRP of 39 dBm would be sufficient , predicting a received signal strength of approximately -108.1 dBm. The GNU Radio simulation strongly corroborated this prediction, showing a received signal strength of approximately -107 dBm. This is well above the satellite's -126 dBm sensitivity threshold, confirming a robust link. Furthermore, the analysis identified the Doppler shift as the primary challenge, confirming that the receiver's frequency correction capability is essential for successful operation.

This agreement between theory and simulation validates the RIDU-Sat 1 TT&C uplink design and provides high confidence that the system is ready for mission operations. The methodology presented offers a low-cost, reproducible framework for other academic and resource-constrained nanosatellite programs to verify their own link budgets prior to launch

AI USAGE DECLARATION

We declare that we used ai tools, specifically chatgpt by OpenAI, during the preparation of this manuscript for purposes such as grammar checking and paraphrasing suggestions. all ai- assisted outputs were carefully reviewed, edited, and verified by the authors to ensure accuracy, clarity, and academic integrity.

ACKNOWLEDGMENT

The Republic of Indonesia Defense University (RIDU) through the RIDU-Sat 1 program and the Research Center for Satellite Technology, National Research and Innovation Agency (BRIN) supported this work, entitled *Simulation of the RIDU-Sat 1 GMSK TT&C Link Using GNU Radio*

REFERENCES

[1] A. Khan *et al.*, "RDSP: Rapidly deployable wireless ad hoc system for post-disaster management," *Sensors (Switzerland)*, vol. 20, no. 2, Jan. 2020, doi: 10.3390/s20020548.

[2] K. Hazra *et al.*, "Designing efficient communication infrastructure in post-disaster situations with limited availability of network resources," *Comput Commun*, vol. 164, pp. 54–68, Dec. 2020, doi: 10.1016/j.comcom.2020.09.019.

[3] S. Waharte and N. Trigoni, "Supporting search and rescue operations with UAVs," in Proceedings - EST 2010 - 2010 International Conference on Emerging Security Technologies, ROBOSEC 2010 - Robots and Security, LAB-RS 2010 - Learning and Adaptive Behavior in Robotic Systems, 2010, pp. 142–147. doi: 10.1109/EST.2010.31.

[4] R. Sanchez-Pkrez, F. J. Casajus-Quir6s, E. T. S. I. Telecomunicaci6n, and S. Pasupathy, "Branch-Dependent Metric for Viterbi based Receivers for GMSK in Frequency Selective Fading Channel."

[5] O. : Benny and J. Sinurat, "Model Pembelajaran Simulasi."

[6] B. Lucia, B. Denby, Z. Manchester, E. Ruppel, and A. Colin, "Editor: Shadi Noghabi COMPUTATIONAL NANOSATELLITE CONSTELLATIONS: Opportunities and Challenges," 2021.

[7] V. T. Nguyen, F. Villain, and Y. Le Guillou, "Cognitive radio RF: Overview and challenges," 2012. doi: 10.1155/2012/716476.

[8] Y. Ren, "Analysis and Implementation of Reinforcement Learning on a GNU Radio Cognitive Radio Platform."

[9] S. Biddlestone and K. A. Redmill, "A GNU Radio Based Testbed Implementation with IEEE 1609 WAVE Functionality," 2009.

[10] M. Sever and B. Tavli, "Use of GNU Radio as a Validation and Visualization Tool in Communications Electronic Support Project," in *2020 28th Signal Processing and Communications Applications Conference, SIU 2020 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Oct. 2020. doi: 10.1109/SIU49456.2020.9302461.

[11] S. Mariyanto and A. Sasongko, "ANALISIS PENGARUH PENAMBAHAN KODE PENEBAR PADA MODULASI GMSK TERHADAP DSCDMA DAN OFDM DITINJAU DARI BER SISTEM," 2007.

[12] R. Muhida, J. D. Setiawan, A. Rahmono, H. A. Yanto, E. Edwar, and A. Budiyono, "Nanosatellite Applications in Indonesia: Status, Challenges and Future Prospects." [Online]. Available: https://www.researchgate.net/publication/365838731

[13] B. Klofas, "Frequency Allocation for Government-funded CubeSats: NSF Paves the Way," 2011.