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Implementation of GMSK Modulation Using GNU Radio for Cube Satellite

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Abstract

The CubeSat platform has evolved to support a wide range of space missions, modulation schemes, and frequency bands, leading to a need for dependable ground-to-satellite communication systems. Software-defined radio (SDR) has become the modern RF communication system chosen method. The goal of this research is to be able to communicate with a satellite using a configurable SDR and GNU Radio. Other research has conducted GMSK signal simulations, SDR-to-SDR testing, or receiver-side validation only, while this study evaluates GMSK modulation using a CubeSat Engineering Model (EM). Signal was conducted with 276-byte data packets. Unpadded SDR transmissions failed to communicate, whereas a conventional RF signal generator achieved 100% success. Review of the RF generator revealed that it produces 1000 transmission symbols by default, including the data packet. Considering the longer transmission symbols, extra null symbols (zero-padding) were added to the end of the SDR packet in increments of 5 to 50 bytes. Symbol adjustment attempt led to a 100% packet-rate success of the GMSK communication link between the SDR and the EM. Findings revealed that consideration of signal factors such as transmission length, flowgraph configurations, and hardware compatibility is critical for communication performance.

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Introduction

Over the years, space technology has shifted from large, expensive satellites to compact, cost-effective solutions, enabling broader participation in space exploration by universities, research institutions, and companies. (Liddle et al., 2020). CubeSats have transformed practical space research due to their low development and launch costs (Chiu et al., 2022; Dalbins et al., 2023; Doyle et al., 2022). Standardized in “Units” or ”U” (1U = 10 cm × 10 cm × 10 cm, 1–1.33 kg) (Areda et al., 2022; Sri & Sashendra, 2024; Zosimovych, 2020) and can be configured in multi-unit assemblies such as 3U, 6U, or 12U to accommodate more complex subsystems (Yaqoob et al., 2022). With this kind of configuration versatility, CubeSats can support a diversity of space mission needs (Contreras-Benito et al., 2024; Melaku & Kim, 2023). These small satellites support a wide range of missions, including Earth observation, communication, scientific experiments, technology demonstrations, and even interplanetary exploration. The affordability and versatility of this technology make it suitable for academic institutions and emerging space ventures, allowing for more frequent and accessible satellite launches.

Despite the advantages of CubeSats, establishing reliable communication between the satellite and its ground station remains a major challenge. Telemetry, Tracking, and Command (TT&C) subsystem are critical for satellite functionality, encompassing data transmission from the satellite, position tracking, and command delivery from the ground (Gupta et al., 2020; Zhan et al., 2020). Conventional systems, typically used for larger satellites, rely on complex, costly, and rigid hardware, which limits flexibility in frequency allocation and modulation schemes and is often unsuitable for the adaptive requirements of CubeSats. In response to this challenge, Software Defined Radio (SDR) technology has gained significant traction as a flexible and cost-effective solution for CubeSat communication systems (Deekshitha et al., 2024; Gummineni & Polipalli, 2024; S et al., 2025). SDRs are radio systems that use software to define signal processing functions, enabling operation across a broad range of frequencies and modulation schemes without requiring hardware modifications (Sahoo et al., 2025; Wangsa et al., 2019). By leveraging SDR technology, developers can design and implement communication systems due to its ability to support a wide range of modulation schemes without the need for hardware changes (Baktybekov et al., 2024; Perera et al., 2021; Xu & Guo, 2025). In developing SDR frameworks, GNU Radio, a popular open-source tool, is used to generate signals and design configurable flowgraphs for CubeSat communication systems. It offers a wide variety of signal processing blocks that can be combined to create complex flowgraphs, making it an ideal tool for designing CubeSat communication systems (K H & M V, 2024; S et al., 2025; Xu & Guo, 2025).

Building on the importance of reliable CubeSat TT&C operations and the flexibility offered by SDR platforms such as GNU Radio, previous studies have explored GMSK modulation for small satellite communication with promising results, yet several limitations remain. (Harshavardhini et al., 2024) focused on simulation-based evaluation, analyzing GMSK performance in the UHF band using parameters such as in-phase, quadrature, frequency offset, phase offset, and amplitude. While these simulations demonstrated the theoretical viability of GMSK modulation, they did not provide practical validation on actual CubeSat hardware, leaving the real-world performance of uplink communication untested. (Hudhajanto et al., 2018) implemented a low-cost nano-satellite communication system using HackRF and Raspberry Pi with GNU Radio, showing basic GMSK data transmission and system reconfigurability. However, their work was limited to small-scale hardware. It did not involve a CubeSat Engineering Model (EM) or address challenges such as burst effects and packet framing for reliable uplinks. (Abbas & Asami, 2021) proposed an adaptable packet communication system with feedback-controlled modulation rates tested under simulated channel noise. Yet, it remained simulation-based and did not explore padding strategies or single-packet burst effects that can cause decoding failures. In contrast, this study experimentally validates a GNU Radio-based GMSK uplink using a USRP B205mini-i SDR with a CubeSat EM, incorporating packet framing and incremental zero-padding to mitigate burst transmission effects, providing measurable improvement in packet success rates and demonstrating that even minor adjustments can decisively impact communication reliability. This work bridges the gap between simulation-focused research and operational CubeSat communication, offering practical insights for robust uplink design.

Addressing these gaps, this research focuses on experimentally validating a GNU Radio-based GMSK uplink for CubeSat communication under real operational conditions. This study systematically tests signal transmission under multiple methods to identify conditions that lead to errors and to develop strategies, such as zero-padding and packet framing, to ensure reliable communication. The research focuses on examining key factors affecting signal performance, including modulation parameters, the effects of single-packet transmissions that can produce burst-induced data loss, and practical solutions for failed transmissions. By analyzing these elements, the study provides a detailed assessment of how signal characteristics and transmission design interact to influence the success of SDR-based CubeSat uplinks. This approach enables both practical validation and quantitative evaluation, measuring packet success rates across different transmission configurations. The results offer actionable insights for improving packet reliability, optimizing transmission design, and ensuring consistent uplink performance in CubeSat systems, highlighting the importance of aligning hardware parameters, flowgraph configuration, and signal strategies to achieve robust satellite communication.

Methods

The aim of our research is to develop and prove the experimental performance of an SDR-based GMSK transmitter for CubeSat communications in the VHF frequency band. There are several important steps in our research methodology, starting with system design, followed by the implementation of the communication system using GNU Radio, the setup of the experimental framework, and the execution of comparative tests to evaluate the performance of the proposed SDR-based transmitter.

System Design

The system design emphasizes that all SDR parameters must mirror the CubeSat operational characteristics to guarantee signal compatibility, minimize distortion, and maintain packet integrity. By structuring the flowgraph to reflect these specifications, the transmitted GMSK signal remains fully compliant with the EM receiver, providing a robust foundation for reliable CubeSat uplink communication.

Table 1. Hardware Specification

Component	Parameter	Value
CubeSat EM	Frequency	145.925MHz
	Modulation	GMSK
	Baud Rate	1200
	Symbol Rate	100-10,000sym/s
	BT	0.5
	OBW	1.5 KHz
	Receiver Sensitivity	-120 dBm
USRP B205mini-i SDR	Frequency Range	70 MHz – 6 GHz
	Max. Bandwidth	56 MHz
	Max. Sample Rate	8 MSps
	TX Power	>10 dBm
Data Packet	Command Data	255 bytes
	Airframe Data	21 bytes
	Total Packet Size	276 bytes

The SDR-based CubeSat communication system was designed to implement a GMSK uplink at VHF frequencies, ensuring compatibility with the CubeSat Engineering Model (EM) and its operational parameters as shown in Table 1. Hardware Specification. The system parameters were designed based on the CubeSat specifications and the capabilities of the USRP B205mini-i SDR. The CubeSat EM is configured to receive GMSK-modulated signals at a frequency of 145.925 MHz, with a symbol rate between 100 and 10,000 symbols per second, a BT of 0.5, an OBW of 1.5 kHz, and a receiver sensitivity of –120 dBm. The data packets consist of 255 bytes of command data and 21 bytes of airframe information, totaling 276 bytes for each transmission.

The USRP B205mini-i SDR was selected for its broad operational specifications, which support a wide frequency range, high sample rates, flexible modulation schemes, and sufficient transmit power, making it suitable for reliable CubeSat uplink testing. Its operational capabilities include a maximum sample rate of 8 MSps, output power greater than 10 dBm, frequency coverage from 70 MHz to 6 GHz, and instantaneous bandwidth up to 56 MHz (Ettus Research, 2025). These specifications allow the SDR to accurately generate a GMSK signal that matches the EM requirements. Key parameters, including baud rate (1200), samples per symbol (10), BT (0.5), and operating frequency (145.925 MHz), were configured in the GNU Radio flowgraph to ensure precise alignment with the EM.

GNU Radio Implementation

The designed communication system was implemented in GNU Radio as the signal-processing framework for the SDR-based CubeSat uplink. GNU Radio was selected because it provides a modular environment for constructing, configuring, and testing digital communication flowgraphs while allowing direct integration with SDR hardware. In this study, the transmission chain was organized into four main stages: command data input, airframe data packet formatter, GMSK modulation, and USRP transmission interface, as illustrated in Figure 1. Signal Processing Diagram.

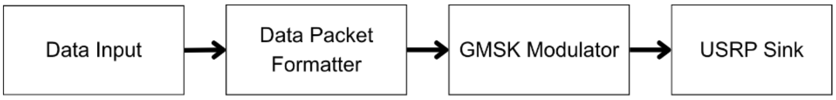

Figure 1. Signal Processing Diagram

The process begins with the command data input, which contains the command information to be sent to the CubeSat. This command data represents the primary operational message intended for the satellite subsystem. The command is then combined with the airframe data through the packet formatter block. At this stage, the formatter arranges the transmission packet according to the communication structure required by the CubeSat Engineering Model (EM). The formatted packet includes the command field, airframe information, and the required packet structure so that the transmitted signal can be correctly interpreted by the receiver. When required, zero-padding is added at the end of the formatted packet to extend the transmission duration and reduce the possibility of burst-induced decoding failure. After packet formation, the output is passed to the GMSK modulator. This block converts the digital packet stream into a GMSK-modulated baseband signal according to the CubeSat communication specification. The modulation parameters in GNU Radio were configured to match the CubeSat requirements, particularly the operating frequency, baud rate, and BT value. Accurate configuration at this stage is essential because the SDR-generated signal must be fully compatible with the CubeSat EM receiver. Finally, the modulated signal is forwarded to the USRP transmission interface, where GNU Radio sends the processed signal to the USRP B205mini-i for RF transmission. The USRP block functions as the hardware bridge between the software flowgraph and the physical communication channel. Through this implementation, GNU Radio serves not only as a signal generation platform but also as an environment for controlling packet structure, modulation behavior, and transmission readiness. This implementation framework enables systematic evaluation of how packet design and padding strategies affect the success of SDR-based CubeSat communication.

Experimental Testing Setup

The experimental setup for testing the SDR-based CubeSat communication system involves two main components: the SDR transmitter (USRP B205mini-i) and the CubeSat EM. This section outlines the setup for the transmitter and receiver, along with the testing procedure.

The CubeSat EM is used to represent a real CubeSat's communication subsystem, providing a realistic testing environment for the SDR-based transmitter. The EM consists of hardware that have the actual communication system of a CubeSat, including the RF front end, receiver, and demodulator. The CubeSat EM is capable of receiving and decoding the GMSK-modulated signal transmitted by the SDR-based ground station. It is used to assess the performance of the SDR-based transmitter in a realistic satellite communication scenario. To validate the SDR-based transmitter's performance, a conventional RF signal generator is used as a reference. The signal generator is configured to output a GMSK-modulated signal at the same frequency as the SDR transmitter. This setup allows a straightforward comparison between an SDR-based transmitter and a conventional RF signal generator. The signal generator serves as a benchmark for evaluating the reliability and accuracy of the SDR-based system.

The testing procedure involves two transmission schemes, in which data packets are transmitted using both the SDR-based transmitter and a conventional RF signal generator, as shown in Figures 1 and 2. The purpose of this test is to evaluate the success of developing an SDR-based GMSK modulator, with validation from a conventional RF signal generator that also transmits a signal with the same parameters to the CubeSat. Additionally, the test is conducted with and without padding to assess the impact of the padding strategy in mitigating burst transmission effects.

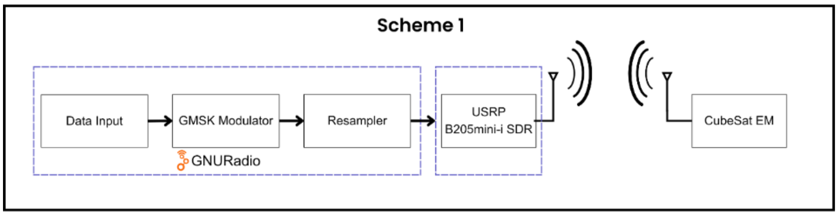

Figure 2. Scheme 1

Figure 2. Scheme 1 illustrates the experimental setup where data packets are transmitted from the SDR-based transmitter (USRP B205mini-i) to the CubeSat EM. In this setup, the GMSK-modulated signal is generated in GNU Radio and transmitted to the CubeSat EM at the specified VHF frequency (145.925 MHz). The CubeSat EM is configured to receive and decode the transmitted signal. If the modulated signal aligns with the CubeSat EM's specifications, the EM will respond by transmitting a telemetry signal back to the transmitter, indicating successful reception and decoding. The experimental test is conducted in two conditions: with padding and without padding. In the first scenario, padding is applied to data packets to smooth transitions between bursts. In contrast, in the second, the transmission is conducted without padding to observe the effects of burst transmission. Padding is crucial in communication systems to reduce burst effects, which occur when data is transmitted in short, high-power bursts that can distort the signal and cause data corruption. By comparing the system's performance with and without padding, the experiment aims to highlight the role of padding in improving the reliability and robustness of the communication link. The success of the test is measured by the CubeSat EM's ability to decode the transmitted packets. If the EM transmits the telemetry signal back, it confirms that both the SDR-based transmitter and the communication method are viable for real satellite communication. This response validates the experimental setup and demonstrates that the SDR-based system can establish reliable communication with the CubeSat.

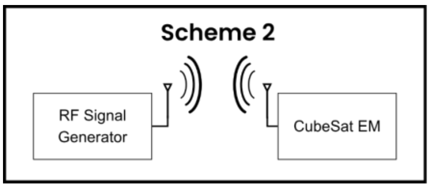

Figure 3. Scheme 2

Figure 3. Scheme 2 shows an alternative transmission scheme in which a conventional RF signal generator transmits data packets to the CubeSat EM. In this setup, the RF signal generator is configured to output a GMSK-modulated signal at the same frequency as the SDR transmitter (145.925 MHz). This scheme serves as a benchmark to compare the performance of the SDR-based transmitter with that of a traditional RF system. The RF signal generator outputs a stable, continuous GMSK-modulated signal, which is transmitted to the CubeSat EM to mimic the SDR-based system's transmission process. As with the SDR-based transmission, the CubeSat EM attempts to decode the transmitted data and sends back a telemetry signal if the signal meets its specifications. This setup helps to evaluate the reliability of the SDR-based system by providing a reference point for comparison. A conventional RF signal generator is used to assess whether the SDR-based system performs equally well in terms of signal quality, reliability, and packet integrity. In this case, the performance comparison is based on key metrics such as packet loss, signal strength, error rates, and overall communication reliability. Additionally, as in Figure 1, the effectiveness of the padding strategy is assessed by comparing the system's performance with and without it. This test provides valuable insights into how padding impacts the signal quality and the robustness of the communication channel, especially when considering burst transmission effects.

The experimental test setup, as described, involves transmitting data packets using both an SDR-based transmitter and a conventional RF signal generator. The CubeSat EM plays a crucial role in the test by receiving and decoding the transmitted signals and providing feedback through telemetry. The success of the communication system is determined by whether the CubeSat EM correctly decodes and responds to the transmitted data. The effectiveness of the padding strategy is evaluated through this experiment. Padding helps to mitigate burst transmission effects that can cause signal distortion and data corruption. By comparing the system's performance with and without padding, the experiment assesses how padding improves the reliability of the communication link. Additionally, comparing the SDR-based system with a conventional RF signal generator helps evaluate the feasibility of SDR for CubeSat communication and provides a performance benchmark. The findings of this study will provide insights into the potential of SDR-based communication systems for CubeSat missions, highlighting the importance of signal modulation, padding strategies, and overall system performance.

Results and Discussion

The following section discusses the results of experimental tests evaluating the performance of an SDR-based GMSK transmitter for CubeSat communications. The tests were designed to assess the system's effectiveness under real-world conditions, with a particular focus on the role of padding in mitigating transmission burst and ensuring reliable communication. This result analysis is divided into three main segments: the implementation of the GNU Radio flowgraph, the transmission test procedure, and the final results, including a discussion of the key findings.

The first part of the discussion focuses on the design and implementation of the GNU Radio flowgraph, which is central to the development of the GMSK modulation system. The flowgraph is explained in detail, highlighting the key blocks and the configuration that allowed the system to generate and transmit the GMSK-modulated signal to the CubeSat EM. The second part of the discussion examines the transmission tests conducted using both the SDR-based transmitter and a conventional RF signal generator. These tests provided a comparative analysis of the performance of both methods in terms of signal reliability and communication success. The results of the communication tests were analyzed to identify the factors leading to successful signal transmission in satellite communication. The final section presents the test results, focusing on the effectiveness of the padding strategy and its ability to improve the reliability of the communication link. The test findings are analyzed to provide a comprehensive understanding of the factors that influence the success of SDR-based CubeSat communication systems. This experimental communication test validates the use of SDR systems for CubeSat communication.

GNU Radio Flowgraph Implementation

The design and implementation of the CubeSat communication system in GNU Radio is a fundamental part of this research. The aim is to develop a GMSK 1200 modulator to match the CubeSat communication system's specifications as shown in Figure 4. GNU Radio Flowgraph.

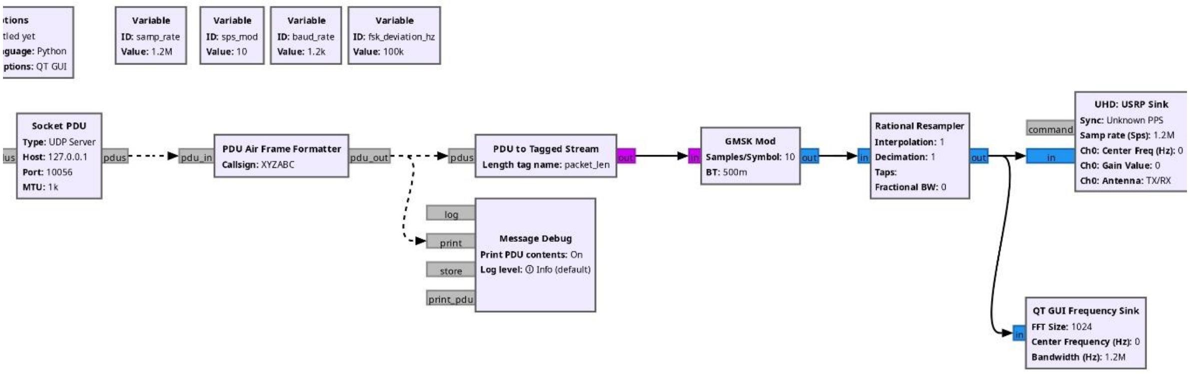

Figure 4. GNU Radio Flowgraph

The implementation of the GNU Radio flowgraph for the CubeSat communication system involves a more detailed block arrangement tailored to the experiment's specific requirements. The flowgraph comprises several key blocks that ensure data is transmitted efficiently and in accordance with the CubeSat's communication specifications. The flow begins with the Socket PDU (Protocol Data Unit) block, which serves as the system's data input. This block simulates the reception of data, such as telemetry or commands, in a PDU format. The PDU format is used because it efficiently handles both fixed and variable-length data packets. The Socket PDU block receives the data and prepares it for further processing. Next, the Packet Formatter block takes the incoming data and formats it according to the CubeSat's communication protocol. Additionally, zero-padding is applied to the packets in this block. Padding helps mitigate transmission burst effects by smoothing packet transitions, ensuring the signal is transmitted without distortion or abrupt changes. This additional symbol is especially important in satellite communication, where maintaining a continuous, stable signal is crucial. The PDU-to-Tagged Stream block then converts the data packets into a tagged stream format, enabling efficient processing and transmission. The tagged stream format helps maintain the integrity of the packet structure, ensuring that data is transmitted without errors.

Following this, the data passes through the GMSK Modulator, where it is modulated into a GMSK signal suitable for transmission. The GMSK modulator is configured with the CubeSat specifications, including a symbol rate of 1200 symbols per second. This block uses the GMSK technique to generate a constant-envelope signal, ideal for power-limited communication systems such as CubeSats. After modulation, the signal is processed through the Rational Resampler block. The resampler helps adjust the sample rate to match the required symbol rate for GMSK modulation. The USRP platform operates at a sample rate of 1.2 MSps, which is adjusted by the rational resampler to achieve the 1200 symbols per second rate required for GMSK modulation. The resampler also reduces the system's computational load, ensuring the process runs smoothly without overloading the PC. Once the signal is properly modulated and resampled, it is transmitted through the UHD: USRP Sink block. This block interfaces with the USRP B205mini-i hardware, enabling the modulated signal to be transmitted at 145.925 MHz. The signal is then sent to the CubeSat EM for reception and decoding. Finally, the QT GUI Frequency Sink block provides real-time spectral visualization of the transmitted signal. This block allows for monitoring of the signal's spectral characteristics, including its bandwidth utilization and spectral shape. The frequency sink provides valuable insights into how well the GMSK modulation fits within the allocated frequency spectrum and helps ensure that the signal meets the CubeSat's communication requirements.

Transmition Test

The core objective of this study is to assess the effectiveness of the GMSK modulator in an SDR-based CubeSat communication system using GNU Radio. To achieve this, transmission tests were conducted under various conditions to evaluate the system's performance. These tests were performed using both the SDR-based system and a conventional RF signal generator to validate the SDR system's reliability and to understand the role of transmission burst length, especially in terms of padding, in ensuring successful communication with the CubeSat EM.

The initial phase of the experiment involved transmitting data packets using the SDR-based GMSK transmitter to the CubeSat EM. The data packets included the necessary command and airframe structures as specified by the CubeSat communication protocol. In this first test, we deliberately did not apply any padding to the transmitted data packet. The GMSK-modulated signal was generated using GNU Radio and transmitted to the CubeSat EM at the specified VHF frequency (145.925 MHz). In this configuration, the goal was to observe how the system would perform without any modifications to the transmitted data. The modulated signal was expected to be received by the CubeSat EM and decoded, with the EM responding by transmitting telemetry data back to the transmitter. However, contrary to expectations, the CubeSat EM did not respond to the transmitted signal. The lack of response was perplexing at first, as all the key parameters, including frequency, modulation, and packet structure, appeared to be correctly configured. Upon further analysis, we hypothesized that the issue was related to the transmission burst duration. In communication systems, single transmissions can result in signal burst. The absence of transmission symbols likely caused the CubeSat EM's receiver to fail, leading to communication failure.

To validate this hypothesis, a second test was conducted using a conventional RF signal generator configured to output the same GMSK-modulated signal. In this second test, the RF signal generator successfully transmitted the modulated signal to the CubeSat EM, which then transmitted telemetry data back to the ground station. This response confirmed that the CubeSat EM's receiver subsystem was functioning correctly and that a successful communication link could be established with the appropriate transmission parameters. The successful transmission using the RF signal generator provided a point of comparison with the SDR-based system. Upon closer inspection of the RF signal generator's signal, it became apparent that it was much longer than the signal transmitted by the SDR. The RF signal generator produced a transmission burst lasting approximately 1000 symbols, significantly longer than the SDR system's burst. This extended symbol duration allowed the CubeSat EM's to receive the command signal and successfully decode the transmitted data. This finding shows that symbol duration is a critical factor for reliable communication in satellite systems. When the transmission signal is too short, the receiver may fail to fully transmit the data, leading to missed data and communication failure. This result confirmed that the SDR-based transmitter, which initially transmitted a shorter signal, needed to be adjusted to match the RF signal generator's symbol length to establish reliable communication with the CubeSat EM.

After observing the difference in burst lengths between the SDR-based system and the RF signal generator, we decided to introduce padding into the SDR-based transmission to extend the burst duration. Padding involves adding extra bits to a data packet to increase the transmission burst length artificially. The padding strategy was implemented to address the burst transmission issue and ensure the transmission burst was sufficiently long to allow proper synchronization and data decoding. Initially, we applied zero-padding to the end of the data packet in the SDR-based system, with an initial padding length of 5 to 50 symbols. This additional padding was designed to replicate the RF signal generator's extended burst length, providing the CubeSat EM's receiver with the right signal data. The modified transmission was then repeated under identical conditions, using the same data packet structure and transmission parameters. The results of this modified transmission were significant. After applying the padding, the CubeSat EM successfully received the transmitted command and returned telemetry data, confirming that the communication link had been established. This outcome demonstrated that the introduction of padding effectively mitigated the burst transmission effects, allowing the CubeSat EM's receiver to detect and decode the signal. The success of this transmission confirmed that the padding strategy was a crucial modification to the SDR-based system, helping to address the issue of insufficient transmission burst length.

Result and Discussions

The transmission tests, summarized in Table 2. Result, clearly illustrate the effect of padding on the reliability of SDR-based GMSK communication with the CubeSat EM. Initial SDR transmissions without padding, using 276-byte data packets, failed to establish communication, achieving a packet success rate of 0%. This indicates that the single-packet transmission generated too short a burst for the EM receiver to synchronize and decode the signal. In comparison, a conventional RF signal generator, producing 1000-symbol bursts by default, successfully transmitted all packets to the EM with a 100% success rate. This confirms that burst duration is a critical factor for reliable uplink communication, providing sufficient time for the receiver to lock onto the signal and process the incoming data accurately. The results highlight that signal continuity and adequate burst length are essential for successful GMSK uplinks, particularly in SDR-based systems transmitting single packets.

Table 2. Result

Transmission Method	Data Packet	Zero-padding	Packet Success Rate (%)
SDR	276 bytes	0	0
RF Signal Generator	1000 symbol	(system default)	100
SDR	276 bytes	5	100
		10	100
		15	100
		20	100
		25	100
		30	100
		35	100
		40	100
		45	100
		50	100

Incremental zero-padding was then applied to the SDR-based packets to systematically extend the transmission duration and mitigate burst effects. Padding was added in 5-byte increments from 5 to 50 bytes at the end of each 276-byte packet. Each padded transmission achieved 100% packet success, demonstrating that even minimal padding can significantly improve reliability. These findings confirm that careful alignment of SDR parameters, GNU Radio flowgraph configuration, and transmission design directly impacts communication performance. By extending the burst length through padding, the SDR-based system achieved performance comparable to the RF generator, providing a practical solution for mitigating single-packet burst effects and ensuring robust CubeSat uplink communication. This study therefore quantifies the importance of packet structure, burst management, and parameter alignment in SDR-based satellite communication, offering a framework for future CubeSat uplink design.

Conclusion

This research experimentally implemented a GMSK modulator using GNU Radio to establish reliable satellite communication with a CubeSat, validated on a CubeSat Engineering Model under controlled VHF conditions. Initial SDR transmissions without padding failed due to burst effects and insufficient symbol duration, while comparative testing with a conventional RF signal generator demonstrated that longer transmission bursts enabled successful decoding, highlighting the critical role of burst length. Introducing zero-padding to the SDR packets extended the effective transmission duration, achieving 100% packet success and confirming that padding mitigates burst-induced errors, ensures signal continuity, and enhances decoding reliability. These results provide quantitative experimental evidence of the effect of padding on uplink performance, demonstrating that SDR-based ground stations can deliver robust, cost-effective, and reconfigurable CubeSat communication. Limitations of the study include the use of ideal indoor channel conditions, a fixed 1-meter testing range, and the absence of orbital or long-range space link evaluation. Future work should explore adaptive packet length, real-time SDR optimization, and testing under dynamic or space-like conditions to further enhance the reliability and scalability of SDR-based CubeSat uplinks. Overall, this study establishes a practical, experimentally validated framework for designing reliable SDR-based GMSK communication systems for small satellites.

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