Thesis

System Analysis of a Cube Satellite Communication Link

Area: Microwave Engineering
Advisor: Prof. Dr. Sören Peik
Duration: 6 Month
Prerequisites Microwave Engineering, Microwave Office, Lab Experience

Context und Motivation

The Institute of Aerospace Technology is planning to launch a 3-unit CubeSat, named Vibes Sat, with the primary mission of researching microvibrations in microgravity environments. Vibes Sat is equipped with an onboard processor based on the Pynq platform, which integrates both a programmable logic FPGA and a processing system. The baseband processor for the telemetry link is implemented within the FPGA and is currently capable of generating an IQ (In-phase and Quadrature) data stream for modulation in the RF section. The ground station is equipped with a 1.9-meter dish antenna that receives the transmitted signal, which is then processed through an RF frontend and a digital receiver.

Given the importance of reliable and efficient communication between the satellite and the ground station, a thorough system analysis is essential to optimize the communication link's performance. This thesis aims to analyze and improve the overall signal processing chain, from the generation of the binary data bitstream on the satellite to the reception and decoding of the bitstream on the ground.

Problem Statement

While the IQ data stream generation has been successfully implemented, the end-to-end performance of the communication link, including all intermediate stages of signal processing, has not been comprehensively analyzed. Issues such as signal degradation due to noise, path attenuation, and other channel impairments need to be understood and mitigated to ensure the integrity and reliability of the data received on the ground.

Objective

The primary objective of this thesis is to conduct a detailed analysis of the CubeSat communication system, with a focus on improving the overall signal processing chain. This analysis will encompass the entire signal path, starting from the binary data bitstream generated by the satellite's onboard processor, through its transmission over the RF link, to the final reception and decoding at the ground station.

The specific objectives include:

- **Spectrum Analysis:** Evaluate the frequency spectrum of the transmitted and received signals to ensure optimal use of available bandwidth and to identify potential sources of interference.

- **Bandwidth Considerations:** Analyze the bandwidth requirements of the communication link and investigate ways to optimize it for the given channel conditions.
- **Power Considerations:** Assess the power efficiency of the signal transmission, including considerations of signal-to-noise ratio (SNR) and energy per bit.
- **Frequency Stability:** Assess the effect of phase noise and frequency offsets in the transmit path, requirements on the local oscillator frequency stability
- **Nonlinear Distortion:** Nonlinearities in the power amplifier may causes vector errors in the modulated signal. Assess the effects of the chosen amplifier
- **Eye Pattern Analysis:** Analyze the eye pattern of the received signal to evaluate the quality of the signal and to identify timing errors, jitter, and other issues.
- **Error Vector Magnitude (EVM):** Measure the EVM to quantify the modulation accuracy and to identify any distortions introduced during transmission.
- **Bit Error Rate (BER) Analysis:** Calculate the BER under various conditions, including the presence of additive white Gaussian noise (AWGN), to evaluate the robustness of the communication link.
- **Path Attenuation:** Study the signal attenuation due to distance and other factors, and evaluate the impact on the received signal strength.
- **Polarization and Pointing Mismatch:** Investigate the effects of polarization and antenna pointing errors on the received signal quality.
- **Multipath Effects:** Analyze the impact of multipath propagation on the signal integrity and explore mitigation techniques.
- **Doppler Effects:** Evaluate the effects of Doppler shift due to relative motion between the satellite and ground station, and propose solutions to compensate for these shifts.
- **Overall Link Budget:** Create a detailed link budget upon the data generated from the analysis above

Methodology

To achieve the objectives outlined above, the analysis will be conducted using three complementary approaches:

1. **Python Script-Based Analysis:** Develop and implement Python scripts to simulate and analyze the communication system. This will include the generation of synthetic data, application of channel models, and evaluation of signal processing algorithms.
2. **Simulation Using AWR Virtual System Simulator (VSS):** Utilize AWR VSS to simulate the communication link in a virtual environment, allowing for detailed analysis of the RF and baseband signal processing, including the impact of various impairments.
3. **Hardware-Based Measurements:** Perform actual measurements on the prototype hardware, including the satellite's onboard systems and the ground station receiver. These measurements will validate the simulation results and provide insights into real-world performance.
4. **Comparison of approaches:** Compare the results of the three different methods, explain variations and mismatches

Expected Outcomes

The expected outcomes of this thesis include:

1. A comprehensive analysis of the CubeSat communication system, identifying potential areas for improvement.
2. Optimized signal processing algorithms and techniques to enhance the reliability and efficiency of the communication link.
3. Detailed documentation of the analysis process, including Python scripts, simulation models, and measurement data, which can serve as a reference for future satellite missions.

References

A preliminary list of references will be compiled during the literature review phase, focusing on relevant topics such as CubeSat communications, RF signal processing, and satellite-ground link analysis. Starting points may include:

1. ITU Handbook on Satellite Communications, Third Edition, Wiley & Sons Ltd
2. Gerard Maral, Michel Bousquet , Zhili Sun, Satellite Communications Systems: Systems, Techniques and Technology, Wiley, 2020
3. M. Swartwout, "Small Satellite Communication Systems: An Overview," Acta Astronautica, vol. 91, pp. 317-329, 2013.
4. E. Calle, M. E. Villarreal, and A. Medina, "Design and Implementation of a Communication System for CubeSats," in Proc. IEEE Aerospace Conf., Big Sky, MT, USA, 2017, pp. 1-10.
5. S. Vaccaro, RF and Microwave Circuit Design for Small Satellite Systems. Norwood, MA, USA: Artech House, 2020.
6. C. Lopez, J. Fernandez, and L. Quintana, "Performance Analysis of CubeSat Communication Systems with Ground Stations," IEEE Trans. Aerosp. Electron. Syst., vol. 55, no. 2, pp. 703-713, Apr. 2019.