DVB-S/2/X Transmission Methods

Brandon Beaver[a], Matthew Nelson[b]

Abstract

For the 2023-2024 Eclipse, a 5.8 GHz Wi-Fi link was proposed to live stream video from a high-altitude balloon. However, challenges were faced with this system that resulted in inferior performance than expected. A new system was then explored to create a more reliable digital video transmission system. This system would use the existing Digital Video Broadcast (DVB) standard and specifically the DVB-S (Satellite) standard, of which there are now three generations including DVB-S2 and DVB-S2X. Project Heimdall seeks to challenge the 5.8 GHz video transmission system by utilizing these standards of amateur television transmission via a 1.2 GHz band using DVB-S, of which there are several generations to work with, i.e. DVB-S2 and DVB-S2X. In this paper, we will explore how this system works and the benefits and expected improvements. We will also discuss what testing we have done and our plans to implement this system in a high-altitude balloon. The Project Heimdall implementation process will utilize software-defined radio (SDR) boards as hardware transceiver devices, such as Analog Devices' PlutoSDR or Great Scott Gadgets' HackRF SDR programmable via GNURadio, a free software using user-defined code blocks, and a receiving software such as SDRangel as user-friendly tools with minimal learning curves to ensure easy accessibility.

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1. Introduction

The October 2023 solar eclipse saw attempts from many entities at various academic and professional levels attempting to capture as much data as possible from the rare opportunity provided by the eclipse. The collection of data ranged from atmospheric, telemetric, and visual data in various forms, thought the focus will be on visual data for the scope of this manuscript. Particularly, live video broadcasting. The October eclipse, as well as the more recent April eclipse, the implementation of a 5.8GHz Wi-Fi link was tested in a broad scope of several universities based on the Ubiquiti Rocket M5 Point-to-Point antenna.

2. Motivation

The universities that would take advantage of the Ubiquiti antenna's high-frequency signal noticed two major issues. The first of these issues was the short distance at which prime functionality would be possible. The second issue would be the necessary line-of-sight connection required for the same functionality. These two issues combined would rarely result in complete live video feed even just after the launch of the high-altitude balloons equipped with this very system. One of the teams using this system, High-Altitude Ballon Experiments in Technology (H.A.B.E.T.), another Iowa State University organization, would note the first major issue would cause breakdown of the signal at around 50 km away from the Mission Control location, that is, if the signal was not blocked as noted in the second issue. After the two eclipse missions, combined with many test

[a]Undergraduate student, Iowa State University

[b]Professor of Aerospace Engineering, Iowa State University, https://orcid.org/0000-0002-7026-3178

Author to whom correspondence should be addressed: Matthew Nelson mnelson@iastate.edu

flights utilizing this system, another system would be looked upon to guarantee a more successful and sustainable live video feed. Enter Project Heimdall, a lower frequency, longer range alternative using amateur television as a method of delivery.

3. Requirements, Constraints, and Standards

3.2. Standards

Project Heimdall follows several standards, such as Federal Communications Commission (F.C.C.), Institute of Electrical and Electronics Engineers (I.E.E.E.), Federal Aviation Administration (F.A.A.), and Digital Video Broadcast Generation 2 (DVB-S2). The explicit standards are defined as follows:

- FAA Regulations for Unmanned Balloons
  - CFR Title 14, Chapter I, Subchapter D, Part 101, Subparts A,D [1].
- FCC Radio Frequency Devices
  - CFR Title 47, Chapter I, Subchapter A, Part 15 [2].
- FCC Amateur Radio Service Operators
  - CFR Title 47, Chapter I, Subchapter D, Part 97 [3].
- DVB-S/S2 Standards [4]
- IEEE Wi-Fi Technology Standards
  - IEEE 802.11[5]

While all of these standards apply, and the sources provide excellent reading, Project Heimdall focuses heavily on the DVB-S/S2 standards. DVB-S standards, per ETSI, makes use of QPSK modulation schemes, concatenated convolution, and Reed-Solomon channel error correction coding to compound the original DVB modulation schemes to target satellite use. These are used to increase capacity gain at given bandwidths depending on sample rates and modulation. DVB-S2, the second generation of the DVB-S system, improves upon these capacities by allowing stronger flexibility as an input stream adapter for one or more input streams of different formatting, more code rates ranging from quarter-wavelength to 9/10ths-wavelength, more constellations, and low-density parity check (LDPC) based FEC systems and near-error-free operation with BCH close to the Shannon limit. These, combined with the DVB-S's Variable Coding and Modulation make it the prime choice for Project Heimdall to replace the previous video broadcasting system noted previously.

3.3. Requirements & Constraints

The success of the Heimdall project relies on a thorough understanding and definition of its requirements, constraints, and adherence to engineering standards. This section outlines those constraints that guide the development of Heimdall, focusing on the functional requirements and resource constraints. By defining these parameters, the project team can ensure Heimdall meets its objectives of improving the video quality of transmissions from high-altitude weather balloon payloads while complying with expected performance standards. From functional requirements that specify the system's essential capabilities to resource constraints that define its limitations, each aspect plays a crucial role in shaping the design and development of Project Heimdall.

3.3.1. Functional Requirements

Heimdall's functional requirements define the essential tasks and operations it must perform to achieve high-quality video transmission. This section outlines these requirements, guiding the development of Heimdall to meet the project's objectives effectively.

- **Video Transmission Reliability:** The Heimdall system shall be capable of streaming and recording video reliably for extended periods (roughly 2 hours or longer) that is clear and decipherable.
- **Software-Defined Radio (SDR) Integration:** The system shall integrate SDR technology to control phase and frequency modulation for video transmission to allow for cheap customizable configuration of the system in the long term.
- **Easily Maintainable:** Heimdall's design and choice of tools must allow for future changes to be made with a minimal learning curve to suit the needs of HAB and other amateur television broadcasting systems at a low cost.
- **Frequency of transmission:** The targeted frequency range of transmission for the scope of this project will be at the 1.2 GHz carrier frequency band while avoiding interference with positioning systems and other satellite transmission systems.
- **Distance:** The signal must be capable of clearly transmitting video distances greater than 100km

3.3.2. Constraints

Similar to functional requirements, constraints define the limitations and boundaries within which Heimdall must operate. This section details the specific constraints that influence the system's development, guiding the design process to meet these limitations effectively.

- **Weight:** The overall spacecraft shall weigh less than 12 lbs. to comply with FAA regulations for high-altitude balloon payloads, therefore requiring Heimdall's addition to be as light as possible.
- **Power:** The system shall operate with as minimal of a power budget as possible and must be constantly monitored and controlled by either pre-programmed or remote access intervention.

4. Design

4.2. Equipment

The primary design elements lie in software in the form of a GNURadio Block diagram on the transmission end and an open-source receiving software titled SDRangel, both of which are visual software that encode and modulate on the transmission side and decode and demodulate on the receiving side of the system. Hardware utilized includes SDR devices such as the Analog Devices PlutoSDR mentioned previously and the HackRF device by Great Scott Gadget's. A single-board computer (SBC), such as a Raspberry Pi, operates the camera(s) and is loaded pre-launch with the proper GNURadio transmission script, which is then transmitted via the SDR device of choice. Once transmitted, a receiver will then skim the signal at the 1.2GHz frequency band via a similar, secondary SDR device and transcribe the signal via SDRangel. Once decoded and demodulated, a live video feed will be streamed to the output where it can be stored for future use.

4.2.1. Software

4.2.1.1. Transmission

GNURadio is a visual code utilizing code-backed blocks as a method of building scripts that can be easily altered with a low learning curve for anyone taking advantage of the system. The transmission end of the system is built entirely in GNURadio so necessary changes can be made quickly and easily. These changes are made in two ways, the first of which involves diving into the diagram itself and adjusting the value to the suit the user's needs. This way, as most experienced coders know, is a bit inefficient. Thankfully, GNURadio developers thought of this to give the second, much easier method of making adjustments via global variable blocks as seen in **Fig. 1**.

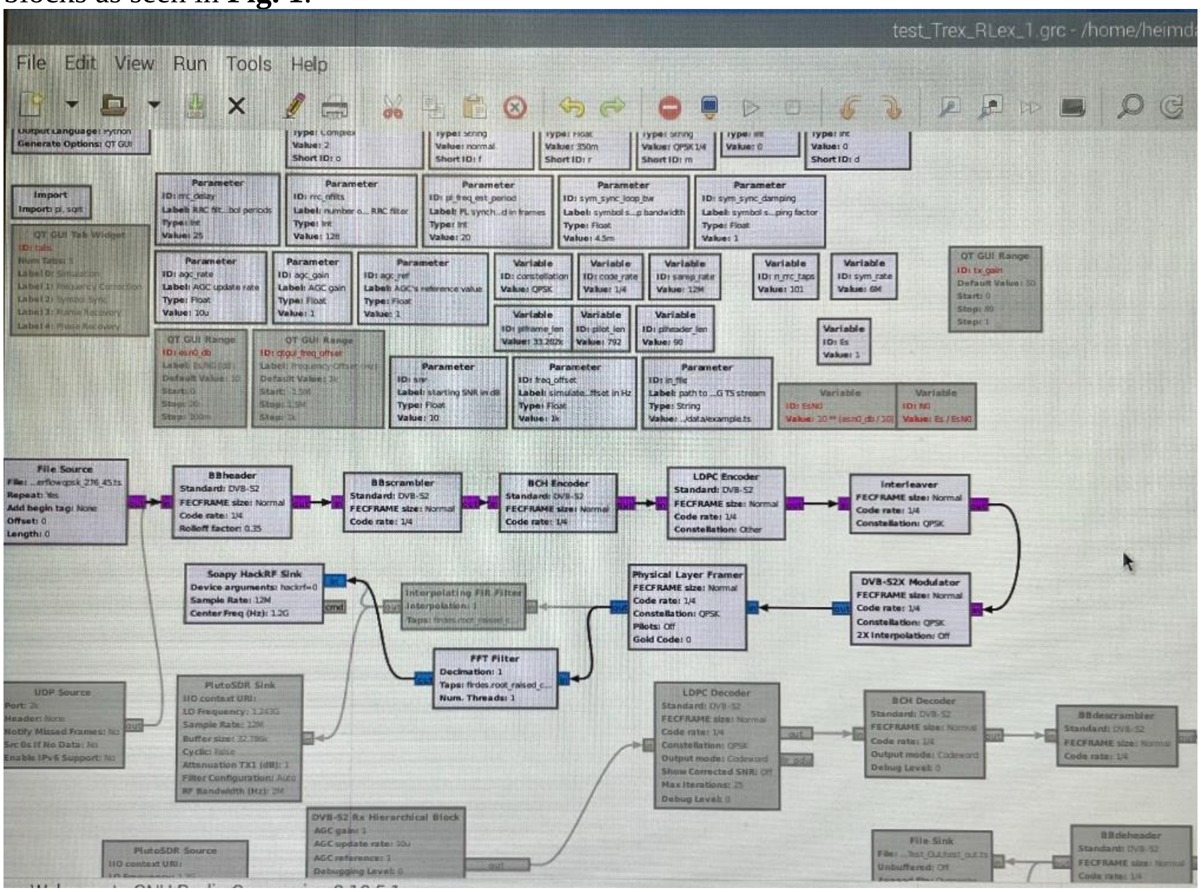

Fig. 1. While appearing complex due to the number of blocks, this is a fairly simple example of the transmission of a test video file. Most of the blocks seen here are variable blocks, specifically placed so users do not need to delve into every block to make adjustments such as Bandwidth, carrier frequency, sample and symbol rates, and so on. [Primary]

A key aspect of this visual code is the encoder in use, also seen in **Fig. 1**, which is a low-density parity-check (LDPC). This is paired with the QPSK modulation scheme chosen to make the best use of the set bandwidth for better performance. Later instances of MATLAB simulation show these benefits at different noise levels and bandwidths in **Section 5**.[6-7]

4.2.1.2. Reception

After attempts to pair GNURadio with other software failed to bear fruit, a simpler solution was sought. This simpler solution manifested in the form of SDRangel, an open-source software that would require little more than driver updates to handle all the receiving end work after proper hardware usage. This particular setup shown in **Fig. 2** is the result of the proper block diagram with the LDPC decoding enabled. Thought the figure does show functionality, there were issues, as noted in the description. These issues came from poor bandwidth options in the GNURadio diagram. With SDRangel, these issues were easily spotted with little effort. Third-party drivers for other SDR devices are also plentiful, which is what makes SDRangel the primary choice for this project.[6]

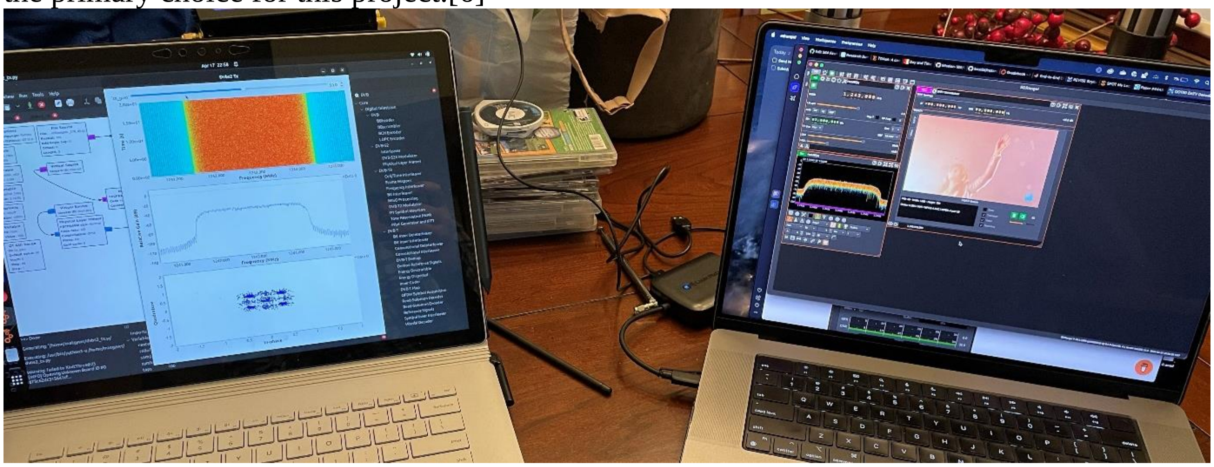

Fig. 2. While this image shows a successful transmission, the issue not seen is frame loss and choppy feed. This is directly related to bandwidth issues to be adjusted later.

4.2.2. Hardware

If GNURadio is the synapses of the system, the Raspberry Pi is the brain of Project Heimdall. The GNURadio diagram is loaded onto the Raspberry Pi running Linux as the main operating system for the SBC. Simultaneously, the Raspberry Pi operates two cameras as inputs to the system, which is fed into the GNURadio diagram as a live video feed. This transmission system is capable of multiple inputs, though the current setup only utilizes one video feed at a time. Upon further testing, a second feed will be introduced to enhance visual data collection.

The SDR devices in use at the time of testing are the ADALM-Pluto SDR board, though due to a lack of support for this device, another SDR was sourced. The Great Scott Gadgets' HackRF SDR device seen in **Fig. 4** is similar in operation to the PlutoSDR device, but has much more community support behind operation than the Analog Devices board. This support allows for better troubleshooting during operations that avoids stop processes during testing and implementation, making the cost increase from the PlutoSDR device worthwhile. More testing is required to determine if functionality is improved upon in the HackRF SDR device, though from recent tests the outlook is positive and a switch to these devices as a primary implementation is warranted and currently in process.

Fig. 3. The hardware configuration if the PlutoSDR board is used. This specific setup relies on a Power-Over-Ethernet (POE) custom board by the HAB students at the University of Montana to power a Raspberry Pi 4B CamArray hat for multi-camera video feeds.

Fig. 4. A photograph of the replacement SDR board, the HackRF One by Great Scott Gadgets. This new device has a wider range of standard operation starting as low as 1 MHz and as high as 6 GHz, a much higher sample rate capacity of 20 MSPS. This device has a slightly higher power draw than the PlutoSDR because of these improvements, [8]

5. Simulation In MATLAB

Taking advantage of the MATLAB Satellite Communications Toolbox, simulated data can be obtained at various modulation settings, symbol rates, sample rates, channel bandwidths, and carrier frequencies with different phase noise levels. These phase noise levels, however, are estimates based on the table in **Fig. 5** at different frequencies from 100 Hz to 1 MHz.

Frequency	100 Hz	1 KHz	10 KHz	100 KHz	1 MHz
Low	-73	-83	-93	-112	-128
Medium	-59	-77	-88	-94	-104
High	−25	-50	-73	-85	-103

Fig. 5. MATLAB Satellite Communications Toolbox DVB-S2 Bit Error Rate Example noise generated to apply at three given levels determined by the carrier frequency.

The modulation scheme of choice is QPSK ¼, or Quarter-Length Quadrature Phase-Shift Keying with a roll-off factor of 0.35, a normal forward error correction (FEC) framerate, and a samples per symbol rate of 2. The energy per symbol to noise ratio is set to 20 decibels (dB) for the purpose of these simulations, though this does not accurately display the effects of the noise floor at high-altitude, which requires further testing to determine an accurate value.

The following simulations were run at each of the phase noise levels listed in **Fig. 5**, ranging from 0 ppm to 10 ppm at a step size of 2.5 ppm between each test. The purpose of these tests were to observe how the bandwidth of the channel in Hz affects these noise levels at the 1.243 GHz carrier frequency.

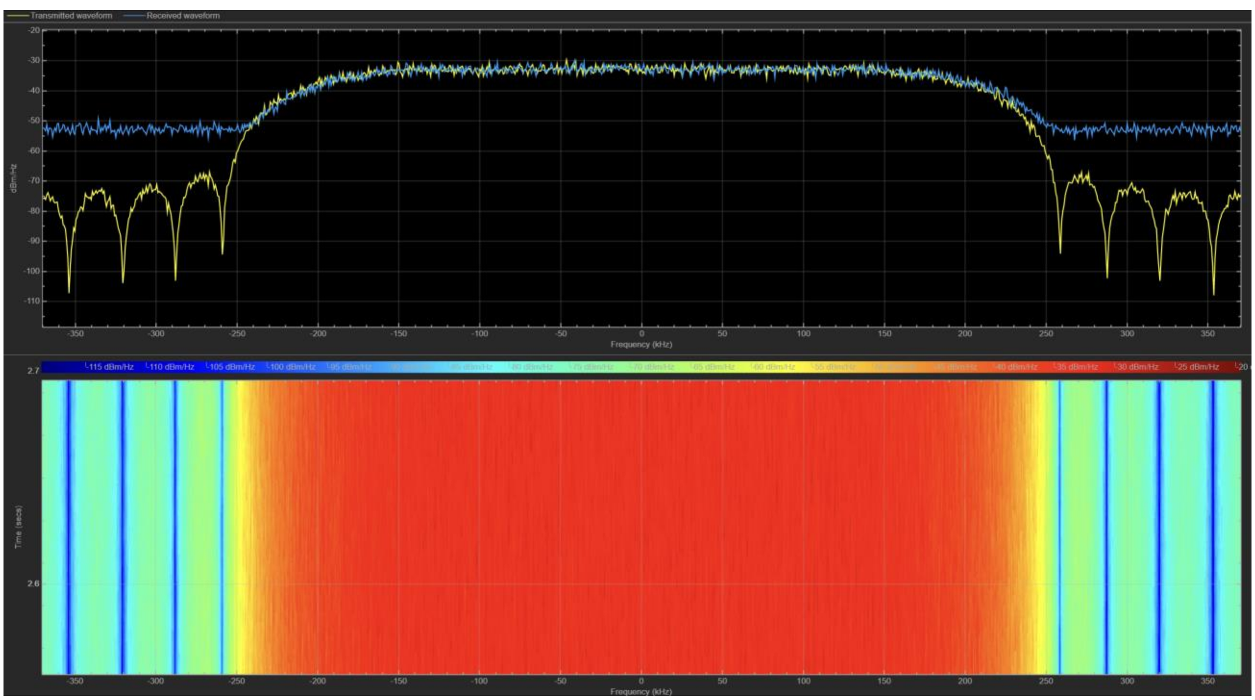

Fig. 6 Spectrum and Power Density spectrogram at 0 ppm SCO and a 500 kHz bandwidth

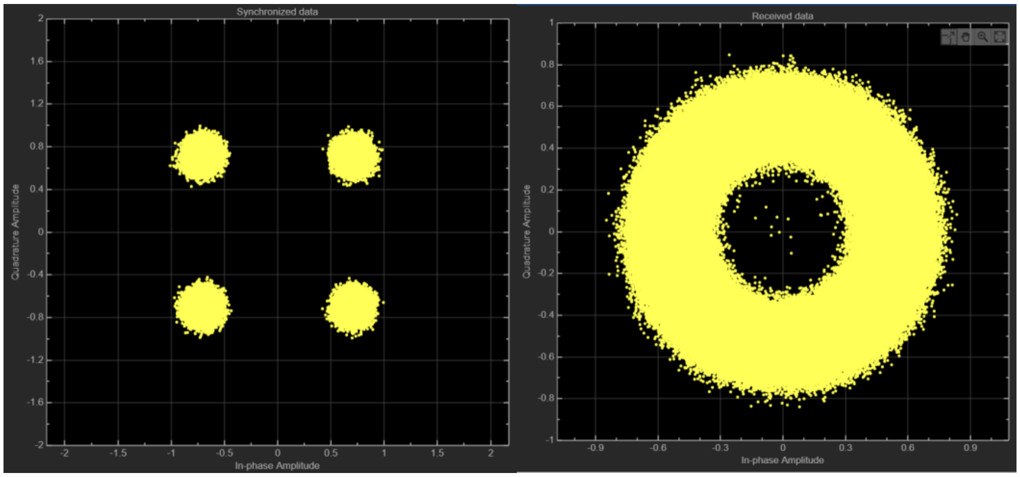

Fig. 7 Constellation plots for simulation in **Fig. 6**

While the first constellation shows a clear QPSK in-phase amplitude and the power density spectrum is clear, a better signal can be found. The following are at an SCO of 10 ppm and a 500 kHz bandwidth and a 20dB energy per symbol to noise ratio with a high phase noise level to show best transmission conditions with the worst possible noise at reception.

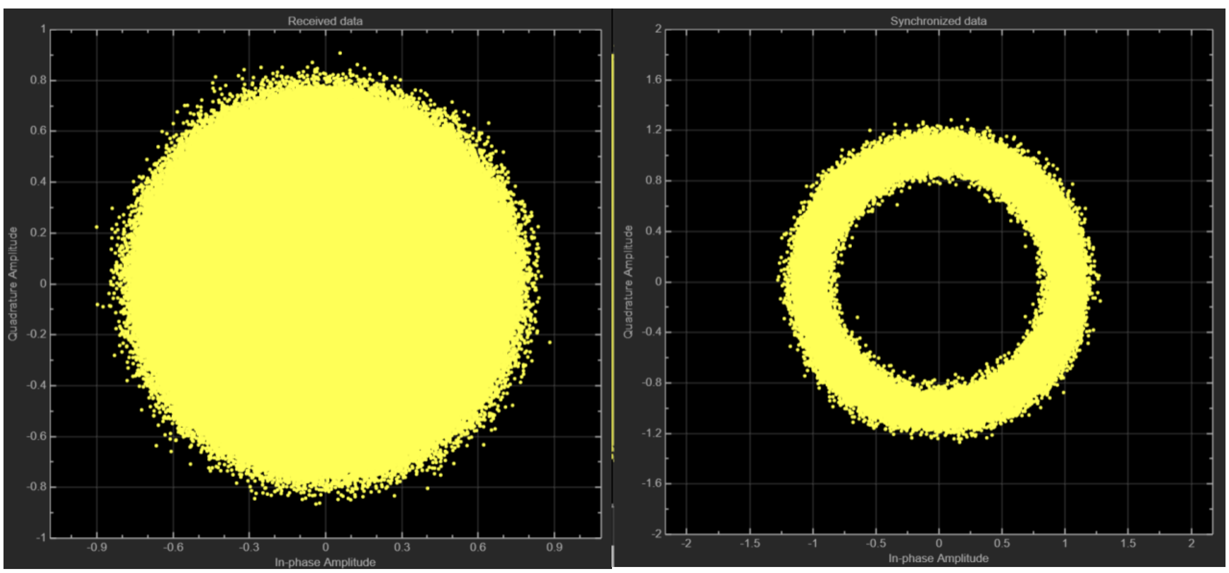

Fig. 8 Constellation plots for high phase noise. Note the first plot isn't split, but one large conglomeration of samples, a huge indication of the amount of interference in the system.

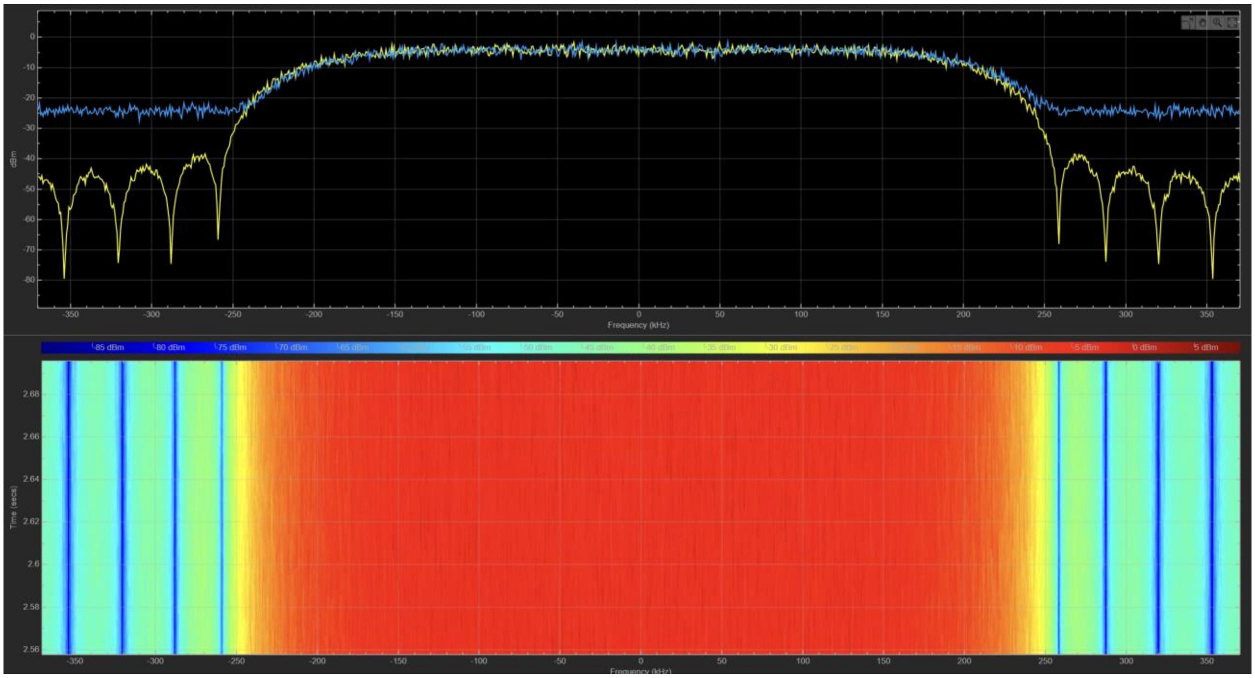

Fig. 9 Spectrum and Power Density spectrogram at 10 ppm SCO and a 500 kHz bandwidth

While not much is different in the spectral plot of the power density with the given changes, the constellation plots are displaying the greatest changes. This level of noise can distort the signal even with prime operating conditions. The major question requiring further tests is what altering the bandwidth at this noise level can achieve in realistic settings. In simulation these make much more sense, though much can still change.

6. Future Work

Further field testing to assure what issues will arise from real noise floor interference at altitude is needed, and this will require much collaboration with H.A.B. teams, both local to Iowa State University and across the country as they relate to high-altitude data collection. The primary focus on these tests is finding a bandwidth and energy per symbol to noise ratio that will ensure clear visuals on the receiving end of the DVB-S2 system. Other possible sample rates and modulation techniques may also be required for further testing.

Conclusion

A properly sourced device can mean the success or failure of a project thought meeting deadlines, proper testing capabilities and field test scenarios, all of which can be affected by improper hardware. The 5.8GHz frequency has a large bandwidth at short distances with minimal interference from noise and physical obstructions, but that isn't something the high-altitude ballooning world sees very often in the best of conditions. Longer flights require overcoming line-of-sight obstructions via signal penetration while meeting long distance capabilities for a strong connection. H.A.B. projects at Iowa State University relied on amateur radio previously as a primary transmission system and those roots proved reliable, even when testing more recently. Video transmission through Project Heimdall's amateur television setup will return to these roots and provide clear visual data reliably through open-sourced software and devices.

Acknowledgments

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