Reception of GOES-East Satellite Services: HRIT and GRB

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Abstract

Software Defined Radio (SDR) has democratized access to radio-based systems by reducing reliance on proprietary hardware and software. We present two practical SDR implementations for acquiring imagery and data from GOES satellites, relevant to educational and institutional applications. First, we describe a High Rate Information Transmission (HRIT) reception system using a repurposed Wi-Fi antenna and SatDump software, providing a simple, low-cost entry point suitable for educational purposes. Second, we detail a more complex GOES Rebroadcast (GRB) system, with higher bandwidth and dual-polarization requirements, employing a 3.9 m parabolic dish, self-made Septum feed, LNA, USRP B200 mini SDR, and SatDump. This setup enables meteorological institutions and research groups to autonomously access satellite data. Together, these cases highlight SDR's versatility in satellite data reception and its potential to provide cost-effective, independent access to Earth observation information.

1. Introduction

The Geostationary Operational Environmental Satellites (GOES), operated by the National Oceanic and Atmospheric Administration (NOAA), deliver high-resolution imagery and critical meteorological data for Earth observation. These data can be accessed via online platforms such as Amazon Web Services (AWS) (NOAA, a), rebroadcast systems like GEONETCast (GNC) (NOAA, b), or by directly receiving transmissions from the satellites. Although direct reception requires more complex infrastructure, it is often preferred by meteorological agencies and early warning systems (Casa Rosada; INPE). GOES provides two services: GOES Rebroadcast (GRB), delivering the complete high-resolution dataset, and High Rate Information Transmission (HRIT), offering a smaller, lower-resolution subset of products.

Access to GOES-East data is particularly important for the Uruguayan Institute of Meteorology (INUMET) and the Solar Energy Laboratory (LES) at the Universidad de la República (UdelaR), which currently rely on Internet access to obtain GOES data due to limited resources for building and maintaining a reception system. This reliance creates a critical vulnerability during severe weather events, making direct reception systems essential to ensure continuity and to strengthen national response capacity. By contrast, HRIT is a simpler service, easier to receive and not specifically intended for meteorological institutions, as it excludes much of GOES-East data. Instead, it serves as a basic emergency channel, delivering forecasts and alerts to remote areas with limited connectivity. Its simplicity makes it particularly suitable for educational applications.

Traditional reception systems are costly and rely on proprietary software. In contrast, Software Defined Radio (SDR) (Grayver, 2012), combined with open-source tools like GNU Radio and SatDump (GNU Radio, a; SatDump), offers a flexible, affordable, and powerful alternative, enabling robust signal processing without the restrictions of proprietary systems.

This work presents two SDR-based implementations for GOES reception. For HRIT, a low-cost setup was built using an Adalm-Pluto SDR (Analog Devices) and a modified Wi-Fi antenna, complemented with a balun and an LNA. For GRB, a more complex system was implemented at ANTEL's Manga Ground Station (IMM, 2023) featuring a USRP B200mini SDR (Ettus Research), a 3.9 m dish, and a custom dual circular polarization Septum Feed.

By combining SDR flexibility with open-source accessibility, these implementations offer cost-effective alternatives to conventional reception systems, demonstrating the value of open-source software for education, research, and resource-limited institutions.

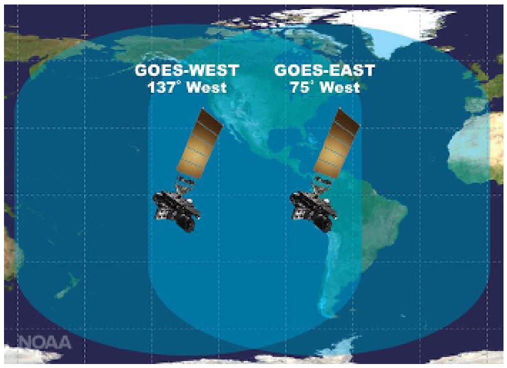

Figure 1. Coverage areas of GOES-West and GOES-East satellites (NOAA, a).

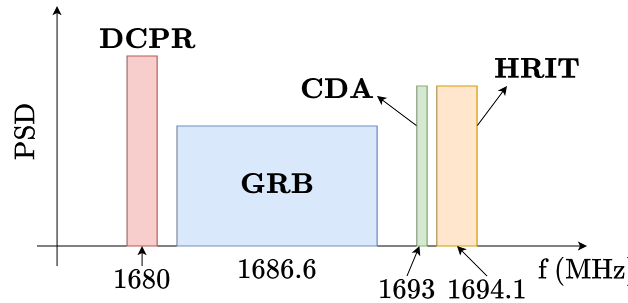

Figure 2. Transmission spectrum of GOES-East (NOAA, 2019).

2. GOES Satellites

NOAA currently operates two GOES satellites over the Americas: GOES-West and GOES-East. Their locations and coverage areas can be seen in Figure 1. Given that Uruguay lies within the footprint of GOES-East, our work focused on the reception of data provided by this satellite.

GOES satellites broadcast data collected by their six main instruments through two primary services: HRIT and GRB. These instruments are the Advanced Baseline Imager (ABI), the Space Environment In Situ Suite (SEISS), the Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS), the Solar Ultraviolet Imager (SUVI), the Magnetometer (MAG), and the Geostationary Lightning Mapper (GLM) (NOAA, 2019). Among them, the ABI is the primary instrument, providing high-resolution images of the Earth in 16 spectral bands. Similarly, SUVI captures images of the Sun in the extreme ultraviolet (EUV) range, allowing the monitoring of solar activity.

Apart from HRIT and GRB, GOES satellites also provide the Data Collection Platform Relay (DCPR) and the Command and Data Acquisition (CDA) services. CDA allows NOAA to operate and control the satellite, while DCPR relays environmental data from numerous ground-based stations distributed across the Americas. The full transmitted spectrum of the GOES satellites is shown in Figure 2.

2.1. High Rate Information Transmission (HRIT)

The HRIT service provides Earth imagery with lower spatial resolution compared to that transmitted by GRB, including Full-Disk and mesoscale views captured by the ABI. It also integrates the NWS's broadcast forecasts and emergency alerts through EMWIN (Emergency Managers Weather Information Network), along with the retransmission of meteorological data from other agencies and information collected by weather stations via the GOES DCS (Data Collection System). By consolidating this information, HRIT offers an accessible alert system for regions with limited connectivity and functions as a backup when Internet-based services are disrupted.

To fulfill this role, HRIT was designed for reception with relatively small and simple ground stations. The signal is transmitted at $1694.1\,\mathrm{MHz}$ with vertical polarization, a bandwidth of $1.205\,\mathrm{MHz}$, and a symbol rate of 0.93 Msps. It employs BPSK modulation along with a FEC rate of $1/2$, combining a simple modulation scheme with robust error correction (NOAA, 2019).

2.2. GOES-Rebroadcast (GRB)

GRB is the primary service through which current GOES satellites disseminate their data. It provides access to all data generated by the satellite, including Full-Disk, mesoscale, and Continental US (CONUS) or Pacific US (PACUS) (depending on the satellite) imagery from the 16 ABI channels, along with data from the other onboard instruments. Compared to HRIT, GRB offers imagery with higher spatial and temporal resolution, ranging from $0.5\,\mathrm{km}$ to $2\,\mathrm{km}$ depending on the channel, and from 5 to 15 minutes depending on the scanning mode (NOAA, 2019). As a result, the service delivers a very large data volume, typically between $1.5\,\mathrm{TB}$ and $2\,\mathrm{TB}$ per day (NOAA, c), which poses significant challenges for low-cost reception systems.

To support this transmission, GRB employs dual circular polarization: left-hand (LHCP) and right-hand (RHCP) (NOAA, d). Both signals occupy the same frequency but carry different data streams, making it essential that the receiving antenna separate them correctly to avoid interference.

GRB is broadcast at $1686.6\,\mathrm{MHz}$ with a bandwidth of $10.9\,\mathrm{MHz}$ and a symbol rate of 8.67 Msps (NOAA, 2019). To maximize throughput, it uses a forward error correction rate of $9/10$ and QPSK modulation under the DVB-S2 standard. The adoption of DVB-S2 simplifies system design, as it is a widely adopted standard with broad hardware support and extensive documentation (ETSI, 2009).

GRB is primarily targeted at institutional users and research centers capable of deploying and maintaining more complex reception systems. However, direct GRB reception offers a unique advantage: it allows users to achieve sovereignty over meteorological and environmental satellite data, reducing reliance on Internet-based sources.

3. Reception of High Rate Information Transmission (HRIT)

The first stage of this project focused on HRIT reception. Compared to GRB, HRIT requires less demanding equipment, making it both an accessible starting point for this work and a practical introduction to satellite reception.

3.1. Reception System

The reception chain consists of an antenna that captures the signal, followed by filtering, amplification, digitization with an SDR, and final processing and decoding on a PC. The implemented system is shown in Figure 3, with the following main components:

- A repurposed parabolic **Wi-Fi antenna**, originally designed for $2483.5\,\mathrm{MHz}$ and adapted for HRIT reception at $1694.1\,\mathrm{MHz}$.
- A **low-noise amplifier and bandpass filter** (SAWbird+GOES by Nooelec (Nooelec)).
- An **Adalm-Pluto SDR** from Analog Devices.
- A laptop running **SatDump**, an open-source software for reception and decoding.

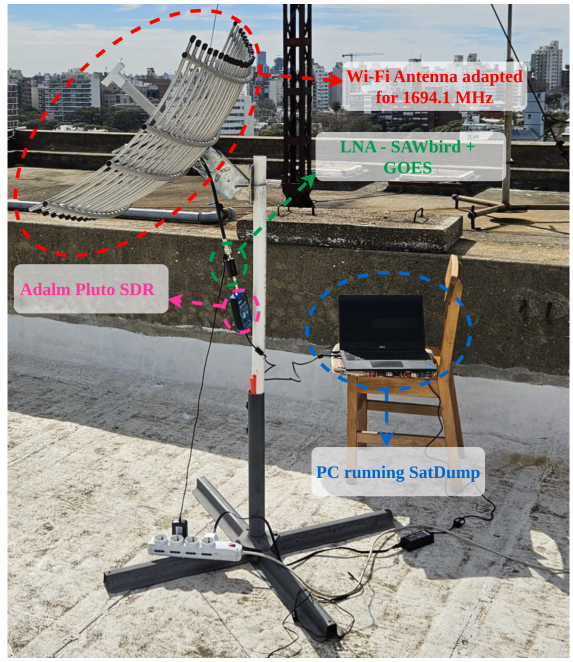

Figure 3. Implemented HRIT reception system.

3.2. Antenna Modifications

Given that HRIT is broadcast at $1694.1\,\mathrm{MHz}$, it was necessary to modify the Wi-Fi antenna in order for it to be capable of receiving the HRIT service. The antenna's dipole was enlarged by $35\,\mathrm{mm}$, for a final length of $88\,\mathrm{mm}$. The modification was carried out while measuring the $SWR(S_{11})$ parameter of the antenna, using a Vector Network Analyzer (VNA). Initially, the $SWR(S_{11})$ at the HRIT frequency was 8.67; after the modification, it was reduced to 1.6.

During system assembly, it was observed that the reception signal-to-noise ratio (SNR) improved significantly when the coaxial cable was hand-held, indicating the presence of common-mode current. This is a common issue in RF systems, where a balanced component (the antenna dipole) couples poorly with an unbalanced one (the coaxial cable), introducing noise and interference (DxEngineering).[1] To mitigate this, a Pawsey Stub balun was added (Huggins, 2010). Implemented as a coaxial cable segment, it presents high impedance to common-mode currents, effectively isolating the antenna and improving signal quality.

Figure 4 shows the final configuration of the modified Wi-Fi antenna. The red marks indicate the extended dipole segments, adjusted to operate at HRIT's frequency. The green ones show the added balun, which reduces the negative effects of common-mode currents. With these modifications, successful reception of the HRIT signal was achieved.

3.3. Final Setup

The final HRIT reception setup, shown in Figure 3, was installed on the rooftop of the School of Engineering building. This location offered a clear view of the sky, enabling precise antenna alignment toward GOES-East, assisted by the mobile application *Satellite Director* (Andlar).

On the software side, SatDump was used for signal processing and product generation. SatDump is an all-in-one, open-source satellite software that integrates the entire processing workflow into a single platform. It includes au-

[1] In a balanced component, current flows with equal amplitude and opposite direction along the conductors, whereas in an unbalanced one, current flows through a single conductor with the other acting as ground reference.

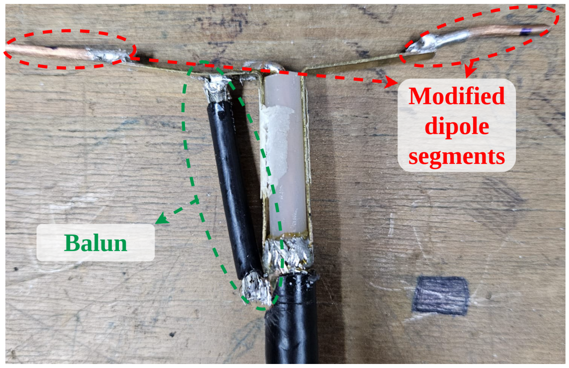

Figure 4. Modified Wi-Fi dipole antenna adapted for HRIT signal reception.

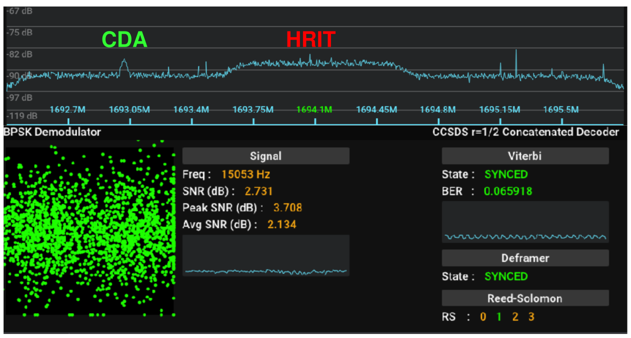

Figure 5. SatDump user interface during HRIT reception. HRIT and CDA signals are visible in the spectrum.

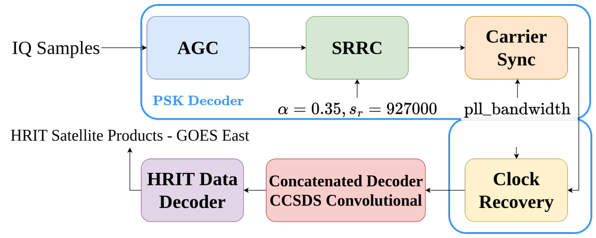

Figure 6. SatDump processing pipeline for HRIT data decoding.

tomatic satellite tracking, decoding, data reassembly, and LUT application for imagery. With these tools, SatDump can produce derived products such as land and ocean surface temperatures, or quarter-hour precipitation rates. All results can be viewed directly in the application, without additional software. Figure 5 shows the SatDump user interface, highlighting the HRIT and CDA signals in the spectrum, along with the corresponding constellation plot.

3.4. HRIT Reception Pipeline

SatDump's HRIT reception pipeline is illustrated in Figure 6. Each block performs a specific function in the decoding chain:

- **Automatic Gain Control (AGC):** Normalizes the amplitude of the incoming signal.
- **Square Root-Raised Cosine (SRRC) Filter:** Shapes the signal using a pulse-shaping filter.
- **Carrier Synchronization:** Corrects frequency offsets using a Costas Loop (GNU Radio, b).
- **Clock Recovery:** Synchronizes symbol timing with the Mueller and Mueller algorithm (GNU Radio, c).
- **CCSDS Concatenated Decoder:** Recovers transmitted bits with Viterbi decoding (Viterbi, 1967), in compliance with the CCSDS protocol standard (CCSDS, 2020).
- **HRIT Data Decoder:** Reconstructs HRIT products from the decoded bitstream.

4. Reception of GOES Rebroadcast (GRB)

The second stage of this project focused on the reception of GRB, which required specialized equipment, advanced technical knowledge, and greater effort compared to the HRIT system. Nevertheless, GRB reception offers a valuable alternative for enhancing autonomous access to satellite data, particularly for institutions with limited resources.

4.1. Reception System

Compared to HRIT, the GRB broadcast requires a more complex reception system due to its polarization scheme and bandwidth demands. The SDR interface must support high data rates and fast storage capabilities to prevent data loss.

The reception chain consists of a parabolic antenna, a dual circular polarization feed, filtering and amplification stages, digitization with a high-end SDR, and final processing and decoding on a PC. The implemented system is shown in Figure 7, with the following key components:

- A repurposed $3.9\,\mathrm{m}$ **parabolic dish**, originally used for satellite TV reception by ANTEL.
- A **Septum Feed**, responsible for receiving GRB and separating the LHCP and RHCP polarizations.
- A **low-noise amplifier and band-pass filter** (SAWbird+GOES by Nooelec).

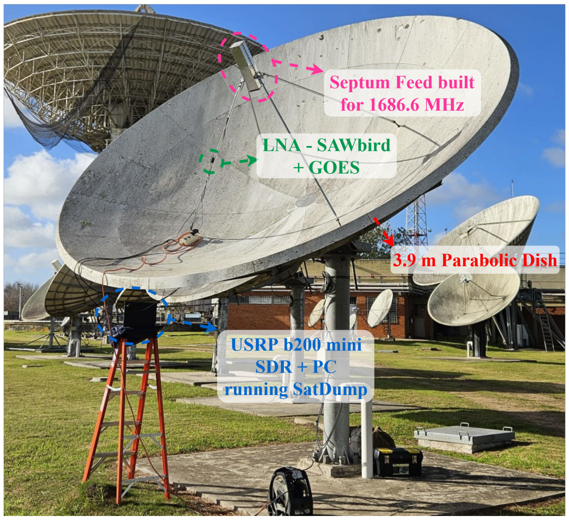

Figure 7. Implemented GRB reception system at ANTEL's Manga Ground Station.

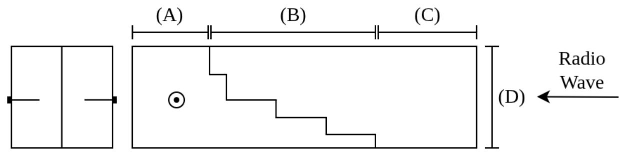

Figure 8. Structure of the Septum Feed. (A) Waveguide–coaxial connectors, (B) polarizer, (C) waveguide, and (D) radiator.

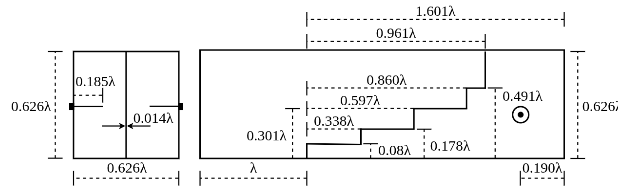

Figure 9. Dimensions of the implemented Septum Feed.

- A **USRP B200mini** SDR by Ettus Research.
- A laptop running the Ettus UHD utility `rx_samples_to_file` and **SatDump** for data decoding and product generation.

4.2. Septum Feed

GRB transmits two overlapping signals, one in RHCP and the other in LHCP, making effective polarization separation by the feed essential for successful decoding. Although NOAA provides suitable commercial feeds (NOAA, b), their high cost and limited availability led to the exploration of alternative designs such as helical antennas, canntennas, and septum feeds. Helical antennas offer circular polarization with good axial ratio but require precise construction, whereas canntennas are simpler and low-cost, though limited in bandwidth and cross-polarization performance.

The Septum Feed, originally proposed in 1973 by M. Wi Chen and G. N. Tsandoulas (Chen & Tsandoulas, 1973), enables reception of circularly polarized waves with high cross-polarization discrimination (XPD). Its structure is shown in Figure 8. This design was selected because it allows simultaneous reception of RHCP and LHCP signals through separate output ports, labeled Rx and Tx. It also provides high isolation between polarizations and can be fabricated at relatively low cost. The implementation followed OK1DFC's design (Samek, 2002; Wade, 2003), with dimensions illustrated in Figure 9.

Accurate manufacturing is critical for proper operation, as small deviations in the polarizer section or waveguide asymmetry can significantly reduce polarization isolation (Wade, 2012). Initial tests revealed several issues that impaired system performance. In the first Septum Feed prototype, asymmetry in the radiator caused poor polarization isolation; this was corrected by adding a "mouth" structure over the radiator to restore symmetry. Misaligned mounting steps in the polarizer were also identified as a source of degradation, prompting the construction of a new polarizer with precisely aligned screws. Figure 10 shows the final functional version. These modifications enabled effective separation of the two circular polarizations.

4.3. System Mounting and Operation

According to NOAA, a $4.5\,\mathrm{m}$ antenna is recommended for GRB reception in Uruguay (NOAA, c). The available parabolic dish (Figure 7), with a diameter of $3.9\,\mathrm{m}$, is slightly smaller but still provided reliable signal reception. This antenna, part of ANTEL's Manga Ground Station in Uruguay, was repurposed for this project in addition to its regular satellite TV reception tasks.

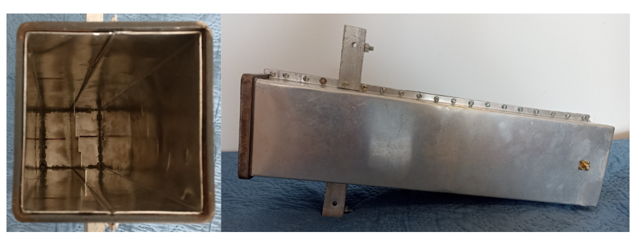

Figure 10. Front (left) and side (right) views of the final version of the Septum Feed.

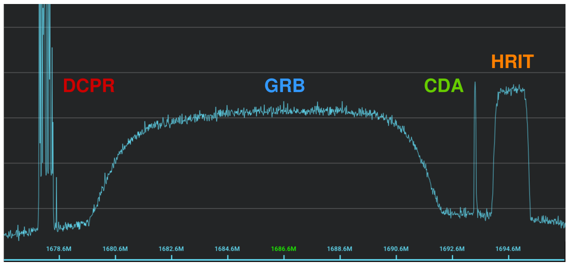

Figure 11. Spectrum of GOES-East at ANTEL's Manga Ground Station, measured at the Septum Feed Tx port.

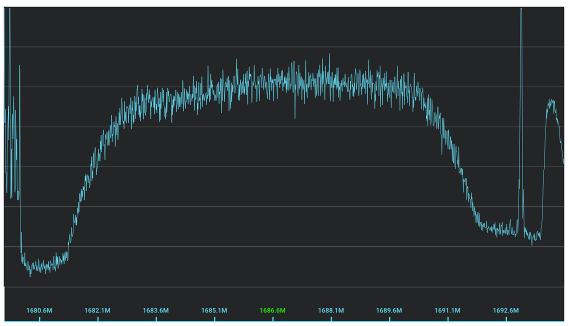

Figure 12. Spectrum received by the GRB system with a faulty LNA power supply.

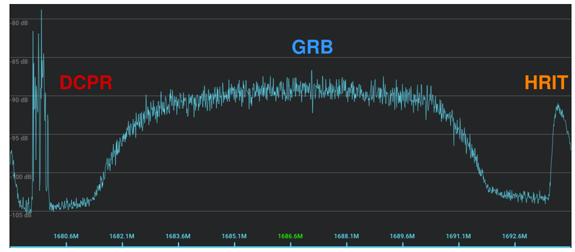

Figure 13. Spectrum of GOES-East at ANTEL's Manga Ground Station, measured at the Septum Feed Rx port.

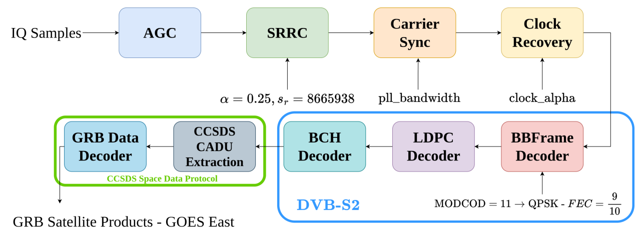

Figure 14. Processing pipeline implemented in SatDump for decoding GRB data.

Because only a single SDR was used, only one polarization could be received at a time. To ensure proper operation of the Septum Feed during testing, the unused port was terminated with a $50\,\Omega$ load to suppress reflections that might otherwise degrade system performance.

The spectrum received at port Tx is shown in Figure 11, where four distinct signals transmitted by GOES-East are visible: DCPR, CDA, HRIT, and GRB.

Although the system achieved proper polarization separation, information decoding was initially unsuccessful due to low SNR. A closer inspection of the spectrum revealed an asymmetry in the noise floor, most evident at higher frequencies. As shown in Figure 12, the noise floor on the right side of the spectrum (between the CDA and HRIT signals) is elevated compared to the left side.

The issue was traced to the LNA power supply, which introduced distortions and fluctuations in the signal level. Replacing the faulty supply restored normal operation, yielding the expected flat noise floor across the spectrum, as shown in Figure 11 for the Tx port and Figure 13 for the Rx port. The Rx port, which receives the LHCP signal, shows no CDA component. Since the CDA signal is transmitted with RHCP polarization, it should not appear in the LHCP reception. This confirms that the Septum Feed effectively separates the two incoming circular polarizations while introducing minimal cross-interference.

For baseband acquisition, a USRP B200mini SDR was used together with the UHD utility `rx_samples_to_file`. The resulting data was subsequently processed using SatDump.

4.4. GRB Reception Pipeline

The GRB reception pipeline implemented in SatDump is shown in Figure 14. The primary functions of each processing block are as follows:

- **Automatic Gain Control (AGC):** Normalizes the amplitude of the received signal.
- **Square Root-Raised Cosine (SRRC) Filter:** Acts as a typical matched filter receiver, reducing intersymbol interference.
- **Carrier Synchronization:** Aligns the frequency of the received signal using a Costas Loop (GNU Radio, b).
- **Clock Recovery:** Achieves symbol timing synchronization using the Mueller and Muller algorithm (GNU Radio, c).
- **BBFrame Decoder:** Extracts DVB-S2 baseband frames, configured with QPSK modulation and a $^9/_{10}$

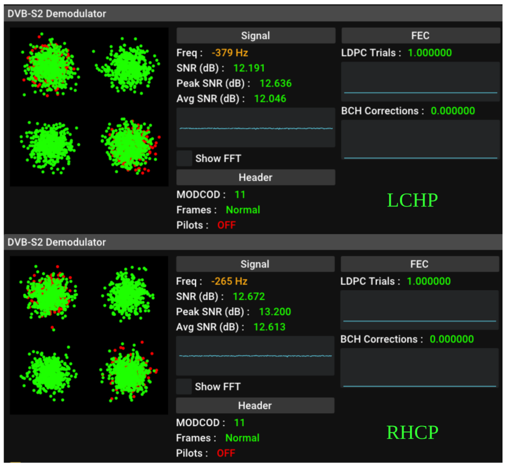

Figure 15. QPSK constellations decoded in SatDump for the LHCP GRB signal (top) and the RHCP signal (bottom).

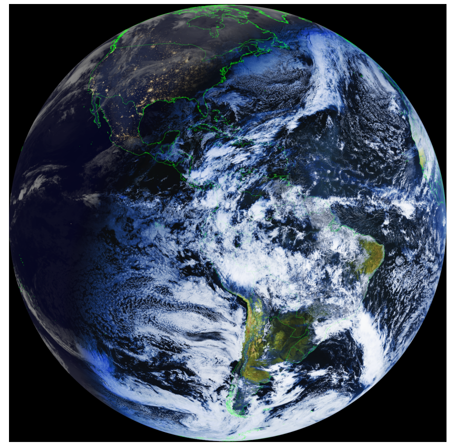

Figure 16. False-color Full-Disk composite generated from HRIT broadcast imagery, dated December 23, 2024.

FEC rate (MODCOD 11).

- **LDPC Decoder:** Performs the first stage of error correction. Low-Density Parity-Check (LDPC) coding is used as the inner code in DVB-S2 broadcasts.
- **BCH Decoder:** Performs the second stage of error correction. Bose–Chaudhuri–Hocquenghem (BCH) coding serves as the outer code in DVB-S2 broadcasts.
- **CCSDS CADU Extraction:** Assembles the DVB-S2 payload into Channel Access Data Units (CADUs) compliant with the CCSDS Space Data Protocol.
- **GRB Data Decoder:** Recovers the satellite products from the extracted CADUs.

For successful decoding, two parameters in the SatDump pipeline needed to be adjusted from their default values:[2]

- `clock_alpha` $= 3.5 \cdot 10^{-4}$ (default: $2.5 \cdot 10^{-3}$).
- `pll_bandwidth` $= 2.0 \cdot 10^{-3}$ (default: $5.0 \cdot 10^{-3}$).

The resulting QPSK constellations for both LHCP and RHCP signals are shown in Figure 15. In both cases, the constellations remained stable and well-defined throughout the reception.

5. Reception Results and Product Examples

The implemented reception setups allowed the successful acquisition of both HRIT and GRB. This section presents the measured performance of each system and provides example products obtained from the decoded signals.

[2]SatDump stores the GRB pipeline configuration at `pipelines/GOES.json` under the `goes_grb` section.

5.1. HRIT Reception Results

Table 1 summarizes the performance of the HRIT reception system. The average SNR at decoding was 2.1 dB, sufficient for stable reception. The energy-to-noise ratio (E_B/N_0) of 3.24 dB indicates performance close to the theoretical limit for error-free BPSK decoding with $^1/_2$ FEC, demonstrating efficient use of the modulation scheme. The carrier-to-noise ratio (C/N) of 0.39 dB reflects the narrow link margins, making the system sensitive to atmospheric attenuation or antenna misalignment. Overall, these results confirm the practicality of the setup while highlighting its limitations, rendering it most suitable for educational or low-cost amateur applications.

SNR (dB)	E_B/N_0	C/N
2.1 dB	3.24 dB	0.39 dB

Table 1. Measured performance metrics for the HRIT reception system. Metrics include the average SNR at the SatDump decoding stage, the symbol energy-to-noise ratio (E_B/N_0), and the carrier-to-noise ratio (C/N).

An example of the products broadcast by HRIT is shown in Figure 16. The image corresponds to a Full-Disk false-color composite generated from GOES-East ABI channels 2, 7, and 13. It was created using SatDump, which offers the possibility of editing the received data to create various meteorological products.

Figure 17. False-color Full-Disk composite generated from GRB RHCP broadcast imagery using ABI channels 1, 3, and 5, dated July 5, 2025.

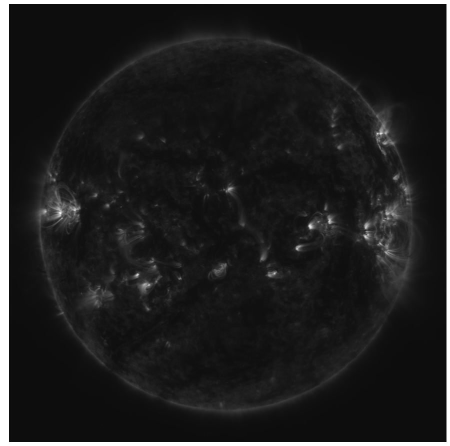

Figure 18. SUVI image captured in the 171 Å channel.

5.2. GRB Reception Results

Reception tests were conducted by acquiring one polarization at a time. The corresponding performance metrics are presented in Table 2. The results align with expectations for a larger antenna, which provides significantly higher gain. This increased gain translates into a greater link margin, ensuring reliable data reception even under adverse weather conditions.

Polarization	SNR (dB)	E_B/N_0	C/N
LHCP	12.0 dB	12.6 dB	4.77 dB
RHCP	12.6 dB	13.2 dB	

Table 2. Measured performance metrics of the GRB reception system.

An example of an RGB composite is shown in Figure 17. It depicts a Full-Disk image of the Earth generated from channels 1, 3, and 5 of the RHCP signal. In addition to ABI imagery, the GRB broadcast also includes SUVI products. An example from the 171 Å channel is shown in Figure 18.

6. Conclusion and Future Work

This project successfully demonstrated practical SDR-based reception systems for both HRIT and GRB meteorological services from the GOES satellites. HRIT reception proved to be accessible and robust, making it particularly well-suited for educational applications in wireless communications and remote sensing courses. The low-cost approach, which leverages SDR technology and open-source tools such as SatDump, provides an excellent entry point for students and researchers to gain hands-on experience.

During the course of this work, several practical challenges highlighted key factors essential for the reliable deployment of reception systems. Early tests revealed that effective suppression of common-mode current was critical, as it significantly degraded HRIT reception performance until a balun was introduced. The implementation of the GRB system demonstrated that feed design is often the most complex and time-consuming aspect of satellite reception projects, requiring multiple iterations and careful validation to achieve satisfactory performance.

Overall, this work validates two practical and well-documented SDR solutions for complete GOES-East service reception, making a significant contribution to accessible meteorological monitoring across the Americas. Furthermore, it demonstrates that open-source solutions can reliably receive both HRIT and GRB services, opening opportunities for broader educational and institutional adoption.

Future Work

Several avenues remain open for extending this work. Among them, we highlight two directions:

- **Educational use of HRIT reception:** The system's straightforward implementation makes it particularly well-suited for introductory engineering courses (Belcredi et al., 2020; González-Barbone et al., 2018).
- **Permanent GRB deployment:** The reception system is nearly ready for permanent installation at ANTEL's Manga Ground Station. Key requirements include weatherproofing, server integration, dual-polarization capability to access all meteorological products, data storage strategies, and enhanced SatDump visualization features to support operational workflows.

Acknowledgements

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