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Enhancing Satellite Operations through DATASAT: A Study on Noise Mitigation Systems within the ADA Framework

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***Abstract* – A Brazilian ground station network, DATASAT, utilizes Automatic Directional Antennas (ADA) for satellite communication. This research explores noise elimination within the ADA framework, focusing on Surface Acoustic Wave (SAW), helical, and cavity filters. By comparing signal-to-noise ratios with and without filters, the aim is to optimize ADA performance for reliable data transmission. This is crucial in today's environment with an increasingly crowded satellite population. Effective noise reduction improves communication efficiency, benefiting both DATASAT and the broader satellite operations community.**

***Keywords* – Ground station, antenna, satellite telemetry**

I. INTRODUCTION

Small satellites, or SmallSats for short, have become a game-changer in the space industry. These tiny spacecrafts, typically under 500 kg, are revolutionizing everything from who gets to play in space to the kind of missions that can be accomplished. First, let's break down the SmallSat world. They come in various sizes, with picosats starting at a mere 1 kg and microsats topping out at the 500 kg mark. This variety allows for the development of standardized components and launch vehicles, further contributing to the cost-effectiveness of SmallSat missions, as explored by Swanson [1]. This standardization makes it easier for new players to enter the space industry and reduces the barrier to entry.

Several factors have fueled this SmallSat surge. Launch costs have plummeted thanks to new vehicles built specifically for these miniature marvels. This affordability opens the door for universities, startups, and even high schools to join the space club. A study by Andrews [2] highlights how launch costs for SmallSats have decreased by an order of magnitude in the past decade, making space more accessible than ever before.

Technology has also played a starring role. Electronics, sensors, and even propulsion systems are shrinking rapidly, allowing SmallSats to pack a bigger punch. Better batteries mean they can stay operational for longer, too. Miniaturization of these critical components is an ongoing area of research, with promising advancements reported in [3] on miniaturized ion thrusters for SmallSat applications.

Another perk of SmallSats is their lightning-fast development cycles. Compared to their hulking cousins, SmallSats can be designed, built, and launched in a fraction of the time. This agility is perfect for fields like disaster monitoring, where a quick response can make all the difference. A research paper by [4] explores the benefits of rapid prototyping and iteration cycles enabled by SmallSats for Earth observation missions.

The commercial sector is increasingly leveraging SmallSats to create constellations that provide internet to remote regions, monitor environmental conditions like crop health, and test new space technologies. The rise of SmallSats is transforming the space industry, sparking innovation and attracting new players. These compact, cost-effective satellites are ideal for building networks that offer global coverage for communication and environmental monitoring. Additionally, they serve as platforms for validating emerging technologies, setting the stage for future space missions, as noted in recent industry reports [5].

Of course, with great power comes great responsibility. As the SmallSat population explodes, issues like space debris and regulations need to be addressed to ensure this exciting era continues to thrive.

Small satellites are no longer the little guys of the space world. They're transforming the industry, making space more accessible, enabling groundbreaking missions, and pushing the boundaries of technology. As the SmallSat revolution unfolds, we can expect even more amazing applications and advancements in the years to come.

The ever-growing number of satellites orbiting Earth necessitates advancements in ground station technology for efficient operation, tracking, telemetry and command (TT&C). DATASAT, a pioneering Brazilian initiative, addresses this challenge with its open-source Automatic Directional Antenna (ADA) network. ADASERVER software controls these ADAs, offering a unique platform for education, research, and innovation in satellite operations.

This paper focuses on a critical aspect of DATASAT – the role of noise elimination systems in optimizing ADA performance. The study by Alves [6] explores the impact of various filter types, including Surface Acoustic Wave (SAW), helical, and cavity filters. However, the quest for optimal noise reduction extends beyond these three options. This review delves into a wider range of filter technologies and their potential applications within the DATASAT framework.

A. SAW Filters: A Strong Contender

SAW filters have emerged as a leading contender for noise suppression in satellite communication due to their unique properties. These filters operate on the principle of converting electrical signals into acoustic waves that propagate on the surface of a piezoelectric substrate [7]. The interaction between these acoustic waves and the electrical signals leads to selective frequency filtering. SAW filters offer several advantages for ADA applications:

- **Compact size:** Their miniature design allows for efficient integration within the limited space constraints of ground stations. This is particularly important for DATASAT's focus on open-source hardware accessibility, where cost-effective and space-saving solutions are paramount. Studies like the one by Huang [8] demonstrate the miniaturization capabilities of SAW filters, making them ideal for modern communication systems with space constraints.
- **Excellent selectivity:** SAW filters exhibit exceptional selectivity, enabling them to precisely pass desired signal frequencies while significantly attenuating unwanted noise at other frequencies. Research by Zhang [9] and Mosteller [10] highlights their effectiveness in enhancing signal-to-noise ratio (SNR) in communication systems by targeting and eliminating specific noise frequencies. This improved SNR translates to clearer and more reliable data transmission between satellites and ground stations.
- **Remarkable temperature stability:** SAW filters maintain consistent performance across a wide range of operating temperatures. This characteristic is crucial for satellite communication equipment, which often experiences significant temperature fluctuations due to environmental factors. A study by Rebeiz [11] explores the design of SAW filters with improved temperature stability, ensuring reliable performance in various operating conditions. This stability is vital for DATASAT, as it guarantees consistent performance regardless of the climatic conditions where the ground stations are deployed.

B. Beyond SAW Filters: Exploring the Filter Landscape

While SAW filters offer a compelling combination of size, selectivity, and temperature stability, they may not always be the ultimate solution. Here's a look at some alternative filter technologies and their potential benefits for ADA systems:

- **Helical filters:** Renowned for their exceptional out-of-band rejection, helical filters excel in suppressing noise outside the desired signal bandwidth. Research by Shao [12] explores the design of miniaturized helical filters for radio frequency (RF) applications, showcasing their potential for integration within ADA systems while maintaining superior noise suppression. However, helical filters can be larger and more complex to manufacture compared to SAW filters.
- **Cavity filters:** These filters boast exceptional narrowband filtering characteristics, allowing for the precise isolation of the desired signal frequency. A study by Wang [13] investigates the application of cavity filters in satellite communication, demonstrating a significant improvement in SNR through precise noise filtering. This narrowband filtering can be advantageous in scenarios with high levels of closely spaced interfering signals. However, cavity filters can be bulky and expensive compared to SAW filters.
- **Interdigital filters (IDFs):** These planar filters offer a unique combination of compactness and sharp filtering characteristics. Research by Chen [14] explores the design of miniaturized IDFs for microwave applications, demonstrating their potential for size-constrained ADA systems while maintaining good filtering performance. However, IDFs may not offer the same level of out-of-band rejection as helical filters.

C. The Road Ahead: Selecting the Optimal Filter and Beyond

The comparative analysis proposed in [6] will be instrumental in identifying the most suitable filter type for ADA systems by evaluating the impact of each filter on SNR with and without their implementation. This analysis should consider not only SNR improvement but also factors like:

- **Filter size and weight:** For DATASAT's open-source, cost-effective approach, filter size and weight play a crucial role. While some filters, like SAW filters, offer miniaturization, others may introduce size constraints that need to be weighed against their noise suppression capabilities.
- **Power consumption:** The power requirements of different filter technologies should be factored in, especially for remote ground stations with limited power availability.
- **Manufacturing complexity:** DATASAT's focus on open-source hardware necessitates filters that are relatively easy and cost-effective to manufacture.
- **Specific application requirements:** The optimal filter choice may vary depending on the specific application of the ADA system. For instance, in scenarios with exceptionally high signal density and closely spaced interfering signals, cavity filters' narrowband precision might be advantageous, even if it comes at the expense of size or complexity.

By carefully considering these factors and pursuing ongoing research, the DATASAT project can leverage the power of noise elimination systems to optimize ADA performance and ensure reliable, efficient satellite communication in an increasingly crowded orbital environment. The open-source nature of DATASAT further emphasizes the importance of finding a balance between performance and cost-effectiveness, paving the way for wider adoption of this innovative ground station technology.

II. GROUND STATIONS DEVELOPMENT

The immense expansion of the New Space market has forced the development of improvements in the ground sector of space exploration. Thus, companies in this segment are in a rush to produce new technologies capable of meeting the needs of this new market.

While there is something magic, at least amazing, about launchers vehicles and satellites, none of them or their missions would have a purpose without communication with a ground station. The increasing number of institutions, as Universities or private companies that build their own satellites, boost all segments of spatial market.

How can we communicate to them, though? How do we get their information? Our expertise allows us to know that a satellite with a polar orbit as ITASAT-1, for instance, with a 100 minutes period, built and owned by ITA, has no more than 4 passes per day. That means, at the most, 60 minutes of daily connection.

Being a member of a ground station network would permit ITA to have more passages. Consequently, much more time of communication with ITASAT-1.

Aware of this market, big players known in other areas, as Amazon and Microsoft, have accelerated the development of ground stations and formed ground stations network around the globe, which is known as GSaaS, Ground Station as a Service. These, among other projects, represent the marvels of technology and goal to every satellite developer to work with, though the costs can be prohibitive for some of them.

There are also some free of a charge ground stations network like SatNOGS – Satellite Network Open Ground Stations and Network.

SatNOGS is a platform where members of the community, beginners or experts, exchange information about manufacturing and deploying of low-cost ground stations and other related subjects. Users can also publish their knowledge and information about manufacturing and deploying of low-cost ground stations. Besides that, they can publish decoded signals captured with their ground stations.

III. DATASAT

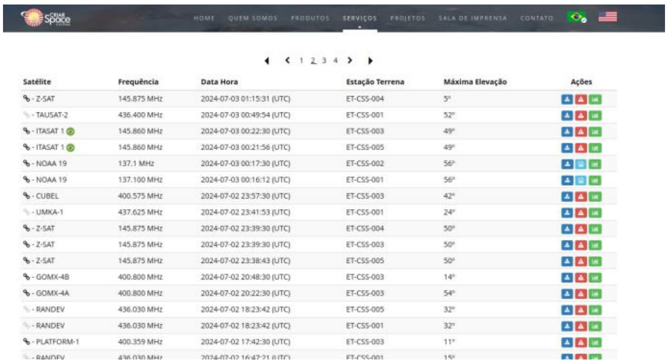
DATASAT shall be built by several ground stations standardized equipment that CRIAR SPACE SYSTEMS company has designed and developed in Brazil since 2018 named ADA. The goal is to send the ADA to the partners institutes together with a commodate contract, especially to those that are satellite users. Thus, they are going to be able to capture its satellite´s signals through an ADA antenna located at their place as well as all other ADAs around the globe. All of these benefits fully free of charges.

ADA, DATASAT and ADASERVER compose a full system of satellites TT&C and can be used by institutions that have courses and disciplines related to engineering, telecommunications, astronomy, astrophysics, among others.

All three components above are part of an open-source software and hardware development system. Every time someone who is related to the partners institutions or simply a user of published data has a suggestion, it will be analyzed by CRIAR SPACE SYSTEMS´s board. If it´s a pertinent suggestion, it will be provided an update by the Company.

In order to reduce the idle time of each ADA, GRUPO CRIAR, controller of CRIAR SPACE SYSTEMS Company, will use ADA's resources while it´s not being used by any course, discipline or capturing any satellite signal.

There are three ADAs operating at GRUPO CRIAR and CRIAR SPACE SYSTEMS' headquarters in Brazil and one in Portugal, where the Company also has a subsidiary.



Satélite	Frequência	Data Hora	Estação Terrena	Máxima Elevação	Ações
- Z-SAT	145.875 MHz	2024-07-03 01:15:31 (UTC)	ET-CSS-004	5°	
- TAUSAT-2	436.400 MHz	2024-07-03 00:49:54 (UTC)	ET-CSS-001	52°	
- ITASAT 1	145.860 MHz	2024-07-03 00:22:30 (UTC)	ET-CSS-003	49°	
- ITASAT 1	145.860 MHz	2024-07-03 00:21:56 (UTC)	ET-CSS-005	49°	
- NOAA 19	137.1 MHz	2024-07-03 00:17:30 (UTC)	ET-CSS-002	56°	
- NOAA 19	137.100 MHz	2024-07-03 00:16:12 (UTC)	ET-CSS-001	56°	
- CUBEL	400.575 MHz	2024-07-02 23:57:30 (UTC)	ET-CSS-003	42°	
- UMKA-1	437.625 MHz	2024-07-02 23:41:53 (UTC)	ET-CSS-001	24°	
- Z-SAT	145.875 MHz	2024-07-02 23:39:30 (UTC)	ET-CSS-004	50°	
- Z-SAT	145.875 MHz	2024-07-02 23:39:30 (UTC)	ET-CSS-003	50°	
- Z-SAT	145.875 MHz	2024-07-02 23:38:43 (UTC)	ET-CSS-005	50°	
- GOMX-4B	400.800 MHz	2024-07-02 20:48:30 (UTC)	ET-CSS-003	14°	
- GOMX-4A	400.800 MHz	2024-07-02 20:22:30 (UTC)	ET-CSS-003	54°	
- RANDEV	436.030 MHz	2024-07-02 18:23:42 (UTC)	ET-CSS-005	32°	
- RANDEV	436.030 MHz	2024-07-02 18:23:42 (UTC)	ET-CSS-001	32°	
- PLATFORM-1	400.359 MHz	2024-07-02 17:42:30 (UTC)	ET-CSS-003	11°	
- RANDEV	436.030 MHz	2024-07-02 16:47:21 (UTC)	ET-CSS-001	15°	

Fig. 1. Examples of signals captured by ground stations for a better understanding.

Source: https://criarspacesystems.com.br/site/services/datasat, access on jul 5, 2024

IV. ADA

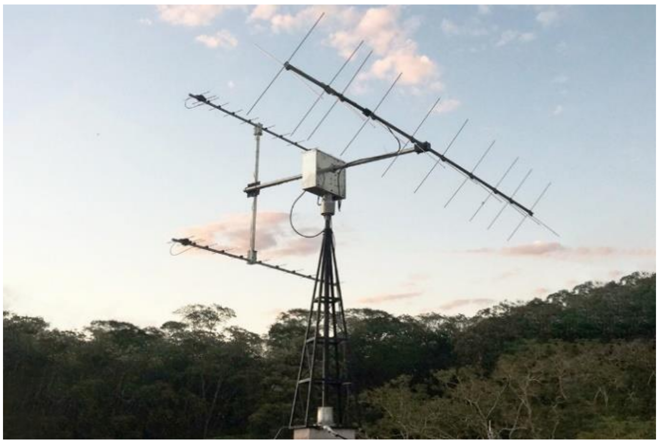


Fig. 2. One of operating ADAs installed in CRIAR SPACE SYSTEMS´s headquarters Source: https://criarspacesystems.com.br/site/, access on jul 5, 2024

Therefore, the ADA project is born as a solution to this market 'pain'. The equipment is capable of commissioning satellites, checking their health, tracking their passages, and capturing signals, among other applications.

Another important factor is that commercial ground stations have a high market value. On the other hand, the equipment described in this article was developed with the intention of satisfying the requirements raised with the lowest possible cost. The entire project was developed based on open-source software and hardware development philosophies, with the exception of some electronic and mechanical components.

V. ADASERVER

The operations between software and hardware take place through the ADA-Server system, which is composed of the integration of three softwares: Ada-server application (with a Plan13 implementation), GQRX and WXTolmg.

In order to perform satellite forecasts, the TLE (two line elements) file of the satellite of interest is searched for in the Celestrak database, Plan13 is activated with the information, and the coordinates and time of the passage are obtained. Soon after, a file of the scheduled satellite is generated.

The system checks the schedule of the next pass, sends the azimuth and elevation coordinates to the microcontroller via serial, and at the same time sends the frequency data to the SDR. The frequencies need to go through a script that does the Doppler effect correction calculation. The SDR records the received signals in a wave file.

DATASAT shall be built by several ground stations standardized equipment that CRIAR SPACE SYSTEMS Company has designed and developed in Brazil since 2018 named ADA (Automatic Directional Antenna).

A. Operational Diagram

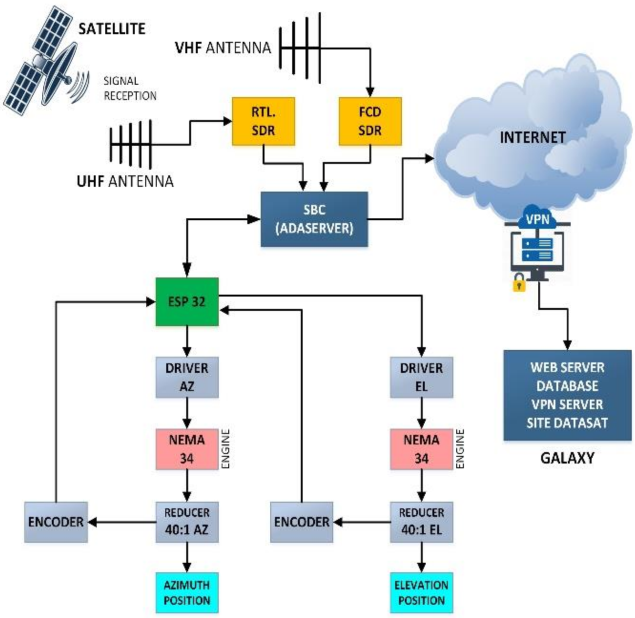


Fig. 3. Operational Diagram of the ADA equipment

B. Example of satellite communication

All information obtained from the communication between an ADA ground station and a satellite is saved on the CRIAR SPACE SYSTEMS server and made available to the public on the startup's website (https://datasat.space).

Today there are four ADA stations working, three of them in the company's headquarters in Brazil and the fourth one in its branch in Portugal (as shown in Fig. 4). This equipment receives signals and sends them to the site, and much of the data refers to meteorological control.

The NOAA - National Oceanic and Atmospheric Administration - has three satellites in low orbit (NOAA 18 and 19), all of which have a downlink frequency in the VHF range (near 137MHz). After decoding the signal, meteorological images are obtained, which are used to infer weather forecasts. Below is an example image taken from one of the ADA stations, located in the city of Ribeirao Preto - Sao Paulo - Brazil.

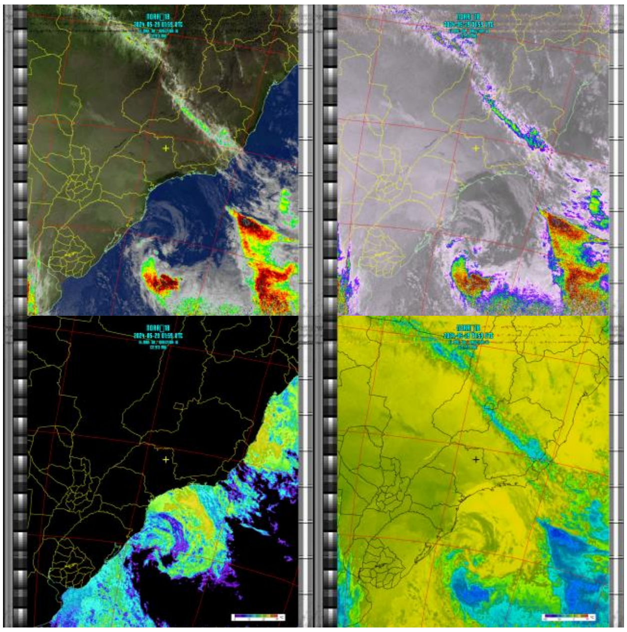


Fig. 4. Examples of images captured from the NOAA-19 satellite representing the 'MCIR' (Map Color Infra-Red) view and the thermal imaging view of the ocean.

VI. FILTER RESULTS

The reception quality of the LUSAT satellite signal (Norad Id: 20442) on the 437.1253 MHz frequency was compared using the LFA 11 Element UHF Yagi antenna.

The LUSAT satellite (20442) signal was received by the ground station during a pass with a maximum elevation of 72 degrees on December 20, 2023, with AOS at 16:52 Brasilia time. Two transmission lines were used:

- LFA 11 element Yagi antenna, connected to a 433 MHz BPF SAW filter with an insertion loss of 2.8 dB and connected to an RTL-SDR via an RG-400 coaxial cable;
- LFA 11 element Yagi antenna, connected directly to the RTL-SDR via an RG-400 coaxial cable.

During the pass, the satellite signal reception levels were simultaneously collected through the two transmission lines using the gqrx software version 2.14.5, which utilizes gnuradio version 3.7.13.4.

The difference between the software setups used was related to the RTLs LNA. Without a filter, the signal had to be amplified due to spurs, and a 24 dB LNA was used. With the filter, the signal was not attenuated, so a maximum 50 dB LNA was applied.

We have the following images with the gqrx screen for the two transmission networks and, in the center, the elevation angle at the moment. The data collections were performed for:

- AOS 5 degrees elevation;
- AOS 20 degrees elevation;
- AOS 50 degrees elevation;
- TCA 72 degrees elevation;
- LOS 50 degrees elevation;
- LOS 20 degrees elevation; and
- LOS 5 degrees elevation.

Note: AOS (Acquisition Of Signal) which sets the beginning of the pass; TCA (Time of Closest Approach) which sets the moment of maximum elevation and LOS (Loss Of Signal) which sets the end of the pass.

The Fig. 5 illustrates the methodology used for comparison of the results, and below are Tables 1 and 2 which summarize the results.

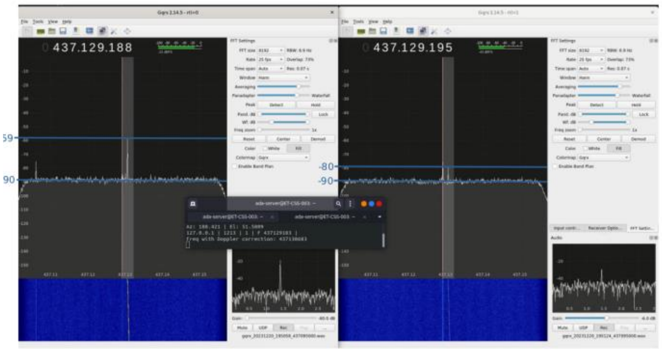


Fig. 5. Right: Gqrx with reception from setup with filter and in Left: Gqrx with reception from setup withou filter.

TABLE 1. LEVEL OF SIGNAL RECEIVED FORM A SETUP WITH FILTER

		AOS		TCA		LOS	
Elevation	5°	20°	50°	72°	50°	20°	5°
Azimuth	171°	174°	188°	230°	325°	338°	341°
Signal (dB)	-82	-60	-59	-71	-62	-61	-70
Noise (dB)	-90	-90	-90	-90	-90	-89	-90
Signal/ Noise	**8**	**30**	**31**	**19**	**28**	**28**	**20**

TABLE 2. LEVEL OF SIGNAL RECEIVED FORM A SETUP WITHOUT FILTER

		AOS		TCA		LOS	
Elevation	5°	20°	50°	72°	50°	20°	5°
Azimuth	171°	174°	188°	230°	325°	338°	341°
Signal (dB)	-90	-80	-80	-89	-81	-80	-86
Noise (dB) ɟo	-95	-98	-90	-89	-90	-90	-92
Signal/ Noise	**5**	**18**	**10**	**0**	**9**	**10**	**6**

It can be observed that the noise floor remains close to -90 dB, except for the transmission line without a filter for an azimuth of 170° at low elevation (less than 20°), where the noise floor was -95 dB for 5° elevation and -98 dB for 20° elevation.

It is noteworthy that the highest dB levels were computed for elevations of 20° and 50°, while at the TCA of 72°, the reception levels were lower, being 19 dB of signal-to-noise ratio for the case with a filter and for the system without a filter, the signal was not detected.

VI. FINAL REMARKS

The noise floor refers to the level of background noise present in a radio receiver system. A lower noise floor indicates a quieter reception environment.

Signal levels, on the other hand, represent the strength of the desired signal being received. Higher signal levels generally translate to better signal quality and stronger reception.

The provided observations highlight the impact of elevation and filter usage on noise floor and signal levels. At lower elevations, the signal is weaker and more susceptible to noise interference, leading to a higher noise floor. The use of a filter helps mitigate noise and improve signal-to-noise ratio, as evident in the higher signal levels observed with the filter at 20° and 50° elevations.

Interestingly, the signal was not detected for the system without a filter at the TCA (Time of Closest Approach), despite being the point of maximum elevation. This suggests that the signal was too weak to be received even with the advantage of the highest elevation angle, emphasizing the importance of noise reduction techniques like filtering.

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