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Sardinia Aperture Array Demonstrator: Measurement Campaigns of Radio Frequency Interferences

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ABSTRACT

Measurement campaigns of radio frequency interferences (RFIs) represent a fundamental aspect to optimize data collected by radio astronomical observations. In order to monitor the state of unwanted man-made signals, every radio telescope needs to have a radio frequency map in the frequencies range of its receivers. The Sardinia Aperture Array Demonstrator (SAD) is an Italian aperture array demonstrator composed of prototypical Vivaldi antennas designed to work at frequencies below 500 MHz. The antennas are located at the Sardinia Radio Telescope (SRT) site and they are arranged with a versatile approach that is able to provide different array configurations. In this paper, we present the results of measurement campaigns conducted with the SAD antennas at the SRT observing site with the aim to monitor the evolution of RFI scenario from 2016 to date. The signal acquisition chain and the software tool used for RFI detection are, also, presented.

Keywords: radio frequency interferences, Sardinia aperture array demonstrator, Vivaldi antenna.

1. INTRODUCTION

Radio telescopes, characterized by high sensitivity for optimizing the ability to measure weak sources of radio emission, represent instruments for radio astronomy applications such as stars, galaxies, and quasars observations. In recent years, particularly as concerns low frequencies observations, the design of modern radio telescopes was focused on the use of large numbers of antennas without any mechanical moving parts, concentrated in stations, electronically combined using digital backends, which perform beam-forming and beam-steering. The Low-Frequency Array (LOFAR)[1], the Long Wavelength Array (LWA)[2], the Murchison Widefield Array (MWA)[3] and the Square Kilometer Array (SKA-low)[4,5] are among the most famous examples of systems based on this technology.

In the wake of these instruments, thanks to a dedicated technological and scientific project funded by the Sardinian Regional Government, the Italian National Institute for Astrophysics (INAF) is developing a new radio telescope that will add to the already existing Italian ones (i.e. the Sardinia Radio Telescope, the Northern Cross telescopes and the VLBI dishes in Medicina and Noto), named Sardinia aperture Array Demonstrator (SAD)[6,7,8,9]. The SAD radio telescope is an Italian aperture array demonstrator constituted by Vivaldi antennas designed to operate with high efficiency across the 50-500 MHz frequency range. The array consists of 128 dual-polarized antennas[9,10] randomly distributed in an area with a diameter of about 64 meters and it is located in the Sardinia Radio Telescope (SRT) site, on a mountain valley 35 km from Cagliari (see Figure1).

By taking advantage of high-performance and high-sensitivity antennas, SAD might offer a technological and scientific testing ground to acquire experiences for digital beam forming[11,12,13], data acquisition, system calibration, sky imaging, space debris monitoring as receiver in a P-band bi-static radar configuration[14], radio frequency interferences mitigation and, given the closeness to the SRT, the possibility to correlate aperture array and single-dish data.

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Figure 1. A picture of the Sardinia aperture Array Demonstrator (SAD).

Being a low-frequency instrument, SAD is particularly vulnerable to all radiofrequency signals and, in particular, to strong and unwanted artificial signals, known as radio frequency interferences (RFIs). Despite the International Telecommunication Union (ITU)[15] and the Italian government defined the interference threshold level over which an RFI is considered harmful for a radio astronomy experiment in each regularly allocated frequency band, the continuous evolution of the RFI scenario represents a not insignificant issue for radio telescopes. For this reason, a RFI monitoring system represents a crucial point at the telescope site. In fact, the knowledge and the monitoring of unwanted and sometimes strong man-made RFI signals in the surrounding electromagnetic environment are very important for preventing to mask weak cosmic signals detected by the telescope. Therefore, it is necessary to have an up-to-date radio frequency map that, in the case of the SAD telescope, implies the preparation of a dedicated system for RFI mitigation. Thus, we have developed a RFI monitoring system that uses a SAD Vivaldi antenna, with a dedicated receiver chain, in order to combine both dual polarizations and to amplify the received signals, specifically front-end and a spectrum analyzer, which is employed as back-end. By analyzing the data collected by this system, we are able to filter away the unnecessary artificial signals in which it is not possible to perform scientific observations and, on the other hand, we can re-design the hardware of the telescope receiving system when the power level is high enough to lose the linearity performances.

In this paper, we present a detailed description of the front-end and the back-end, the dedicated software that we used our RFI monitoring system (Section 2) and the analysis of the RFI measurement campaigns results (Section 3). In detail, we illustrate the measurement campaigns setup, with their main achievements, conducted at the SRT observing site to monitor the evolution of RFIs scenario, starting from a general large frequency observation window in the range 10-1010 MHz and focusing on a more aimed range of 50-500 MHz. We will also summarize the performance of the future SAD telescope.

2. MATERIALS AND METHODS

A dedicated RFIs monitoring system has been developed with the purpose of acquiring and processing data in order to update the RFIs scenario at the SAD telescope. In order to have a system with high performances for RFIs analysis, a dedicated receiving chain was designed and developed. In this way, the RF signal detected by the antenna is sent to the dedicated back-end (i.e. the spectrum analyzer), for data acquisition and elaboration. The signal acquisition chain is described in sub-section 2.1 and the dedicated software for the data acquisition and elaboration is explained in sub-section 2.2.

2.1 The front-end of the RFIs monitoring system

The RFIs monitoring system uses only one of the 128 SAD antennas, deployed on the ground and aligned to the vertical axis with the wings oriented toward North-South and East-West directions, a signal acquisition chain and a dedicated software tool (see Figure 2).

Figure 2. One of the 128 Vivaldi antennas used as front-end of our RFI monitoring system.

The antennas that compose SAD are based on Vivaldi antenna, version 3.1, proposed by the Italian team for SKA-LFAA[4,5], whose main characteristics are listed in the following[7,8,9]:

- Operating frequency range: 50-500 MHz;
- High flexibility: the mechanical design is based on a mesh steel structure to reduce the weight (16 kg, 962x962x1370 mm) and the wind resistance (484 N with a wind speed of 130 km/h); four tiles (500x500x40 mm and 21 kg each) are placed at the base of the antenna in order to guarantee enough robustness and stability. By removing the tiles, we can easily change the array configuration;
- Half power beam width (HPBW) of about 45 degrees: the radiation pattern of the Vivaldi, measured with the UAV-based system[10], show an antenna gain at the zenith between 7.8 dBi at 250 MHz and 8.6 dBi at 450 MHz;
- Unbalanced 50-ohm excitation by using two coaxial cables directly connected to the radiators: the inner part of the coaxial connector is attached to one wing, while the external one is embedded in the opposite wing. In this way, there are no coupled currents on the cable and we can avoid inserting a balun;
- Linear dual-polarization;
- Low cross-polarization on the principal axes: with the aim of reducing construction costs, there is no ground plane under the antennas. In order to reduce the noise coming from the ground, which can provide a significant contribution to the temperature of the antenna, a cubic cavity under the four wings was made. In this way, the back lobes are reduced, the directivity is enhanced and the sensitivity is improved;
- Reflection coefficient (S11) of about -9dB in the frequency range above 250 MHz: the choice to carry out the antenna with a fine mesh structure increases the overall antenna impedance, but the level of the S11 is still acceptable.

The front-end of our RFI monitoring system consists of a dedicated acquisition chain that connect the Vivaldi antenna to the back-end based on a spectrum analyzer. In particular, the acquisition chain is composed of a low noise amplifier (LNA) for each polarization channel, a bias tee and a power combiner centered at the desired frequency, as is shown in Figure 3.

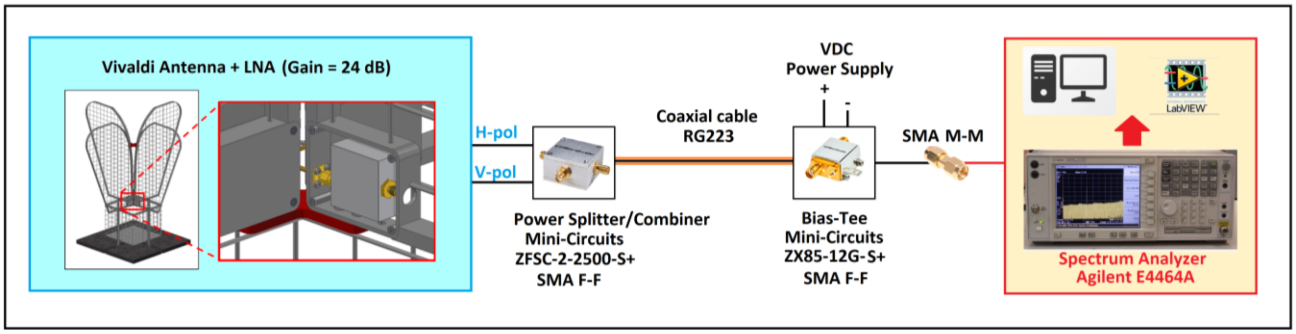

Figure 3. Schematic of the RFI monitoring system.

The LNAs are placed inside metallic enclosures, located in the bottom part of the antenna wings, close to the probes, one for each polarization channel. Despite the LNAs are housed in a waterproof aluminum box, this metallic enclosure guarantees an additional protection from atmospheric agents both for the device and above all, for the Sub-Miniature Version A (SMA) connectors used in input and output. The amplifier designed for the SAD is a one-stage 50 Ω single-ended LNA based on a Monolithic Microwave Integrated Circuit (MMIC) amplifier (SPF-5122Z model from Qorvo[17])[16]. The LNA presents a gain of 23 dB ± 1dB in the SAD operative bandwidth (250-450 MHz), a noise temperature below 40 K, a 1 dB compression point (oP1dB) greater than +18dBm and an output 3rd order intermodulation point (OIP3) greater than +30dBm, guaranteeing a high dynamic range. Furthermore, the amplifier is powered through the coaxial cable attached to the output connector and, for this reason, a bias tee in the acquisition chain is needed. We chose the commercial ZX85-12G-S+ Bias-Tee model from Mini-circuits[18] with a maximum attenuation less than 0.5 dB.

As shown in Figure 3, between the LNA and the Bias-Tee there are both a power combiner and a 20-m low-loss cable (RG223 model) that complete the RFI monitoring chain. In particular, the power combiner (ZFSC-2-2500-S+ model from Mini-Circuits[18]) mixes both linear polarization channels of the Vivaldi antenna in order to increase the sensitivity of the receiving system, since the two polarizations are present at the same time, and to find even very weak artificial signals. Table 1 summarizes the attenuation and the gain of all receiving chain components.

Table 1. Gain and attenuation of the RF receiving chain in the SAD's operative band.

Receiving Chain components	**Max Attenuation**	**Gain**
LNA	-	23 dB ± 1dB
Coax cable 1 (1.5m) RG223	0.4 dB @450 MHz	-
Power combiner ZFSC-2-2500-S+	3.6 dB @450 MHz	-
Coax cable 2 (20 m) RG223	5.7 dB @450 MHz	-
Bias Tee ZX85-12G-S+	0.4 dB @ 450 MHz	-

2.2 The dedicated software of the RFIs monitoring system

An ad-hoc software has been developed, in LabView programming language[21], with the aim to make the best of performances of the RFIs monitoring system. The software is analyzed considering a simplified block diagram, depicted in Figure 4. This diagram is composed of two main blocks: the Data Acquisition block and the Data Elaboration block. The first one has the functionality to set the main functions of the Spectrum Analyzer (see Spectrum Analyzer Setup block in Figure 4). In particular, thanks to this part of the software, it is possible to choose and set the following parameters, as shown in the toolbar in the low part of Figure 5:

- start and stop frequencies of the observation window;
- the resolution bandwidth (RBW);
- the video bandwidth (VBW);
- the sweep time (SWT);
- the input attenuation of the instrument (expressed in dB);
- the number of points employed for the representation of each acquired spectra;
- the total number of the spectra;
- the duration of the temporal acquisition window (expressed in seconds).

After setting the instrument parameters, the data acquisition starts and the max hold function of the spectrum analyzer is enabled, for the entire duration of the acquisition window (i.e. 10 seconds). After the time of the acquisition window, the function clear/write of the spectrum analyzer is turned on and the system restarts to acquire new data, with the max hold function enabled, for a new acquisition window, and so on. The acquired spectrum is plotted as part of the spectrogram of Figure 5, which is made visible with the aim to do a preliminary check in acquisition phase.

The Data Elaboration block of Figure 4 is dedicated to the data elaboration and it is used in post-processing when there is a good quantity of available data. This part of the software returns, as a result, three plots (i.e. spectrogram plot, AVG plot and VAR plot) useful in order to view the RFIs situation of the considered frequency range. In detail, the spectrogram plot is a visual representation of a certain number (based on user needs) of spectrum frequencies as it varies with time. Each spectrum is lasted an established time according with the duration of the pre-set acquisition window. The AVG plot, which acronym stands for averaged plot (in dBm), is useful to detect all continuous signals. It is achieved from an integration on the temporal duration of the spectrogram, where a sum of all the spectra and a division by the number of spectra is done. The latest plot, named VAR plot, allow us to detect all of the impulsive signals and it is achieved by plotting only the bin variance (the bin is the ratio of frequency span and the number of points used for the representation). In this way, during the processing, only the new signals that do not appear continuously are considered and plotted.

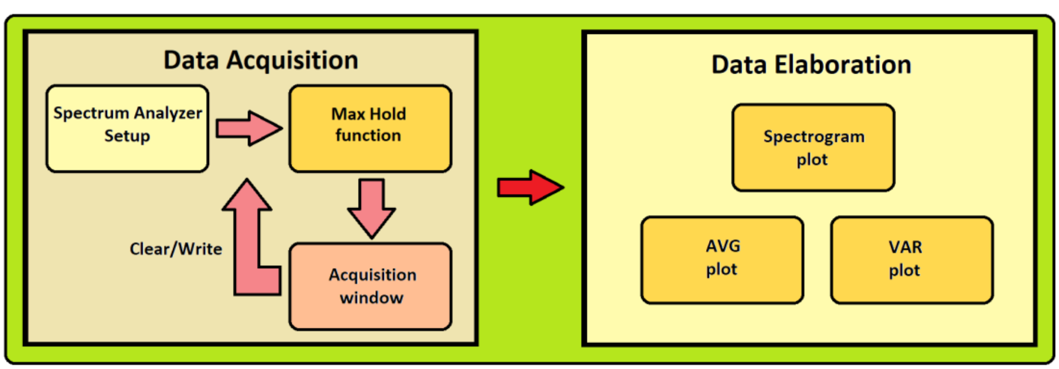

Figure 4. Block diagram of the dedicated software for data acquisition and elaboration.

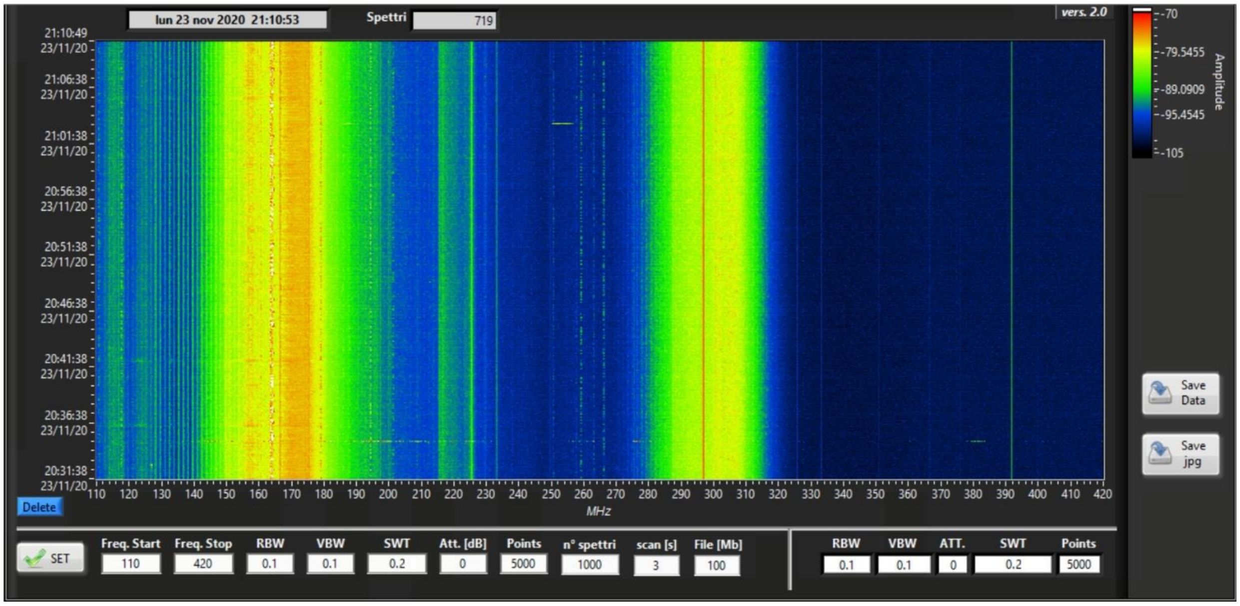

Figure 5. Screenshot of the graphical interface of the Data Acquisition software.

3. RESULTS

Several measurement campaigns were carried out with the goal of searching the RFI "free zones" in the SAD band. The first RFI campaign, which was the preliminary campaign performed on a wide frequency bandwidth according to the LNA bandwidth, it was addressed to monitor the radio spectrum up to 1010 MHz. The settings of main Spectrum Analyzer parameters are reported in Table 2. The results of this first preliminary measurement are reported in Figure 6. As shown in the spectrogram plot, where the signal power levels are visible, the highest signals are derived from the FM radio services in the frequency range 80-110 MHz. Other significant signals are imputable to:

- Security services (160-185 MHz);
- Digital Video Broadcasting (DVB) services (203.5 MHz);
- Terrestrial Trunked Radio (TETRA) in use by the Italian Ministry of Defense (385-395 MHz);
- Sardinia emergency department (460 MHz)
- Radio TV link signals (470-828 MHz);
- Weather balloons (402 -405 MHz, but it is also possible to detect them in the RAS band 406.1-410 MHz).

It is worth noting that most of these interferences do not change in frequency, thus they are easily recognizable, as can be seen in the VAR plot of Figure 6.

Table 2. The settings of main Spectrum Analyzer parameters.

Measurement campaign ID	Start and Stop frequencies of the observation window [MHz]	RBW/VBW [MHz]	SWT [ms]	Input attenuation [dB]	Number of points	Total number of the spectra
#1	10-1010	0.1/0.1	120	0	8000	1656
#2	110-500	0.05/0.1	150	0	5000	816
#3	270-420	0.05/0.1	150	0	2000	816

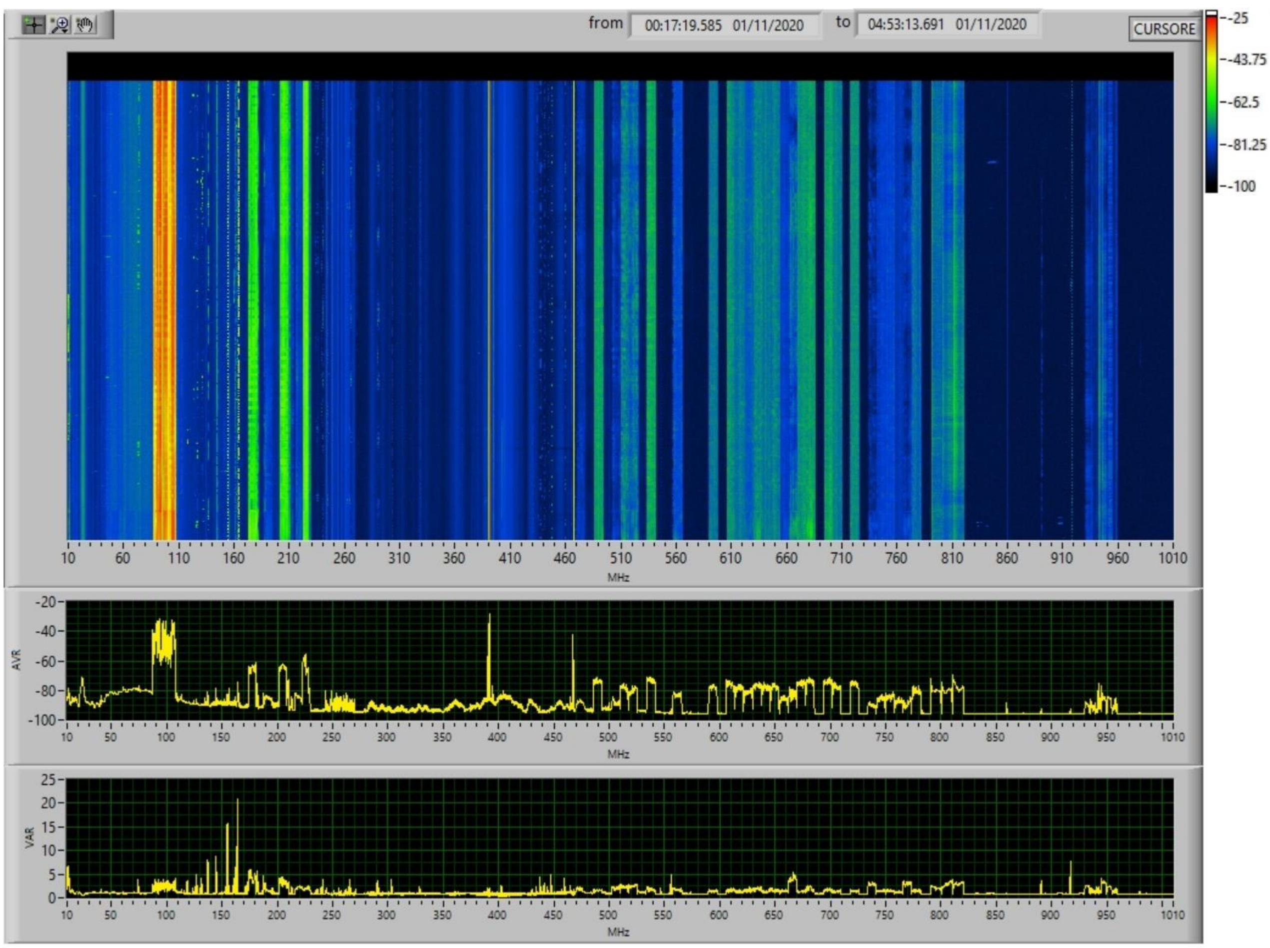

Figure 6. Screenshot of the graphical interface of the Data Elaboration software, with the Spectrogram plot, AVG plot and VAR plot. These plots are related to the frequency range 10-1010 MHz.

After these preliminary results, another campaign was performed in the bandwidth 110-500 MHz. As shown in Figure 7, the frequency band between 280 to 350 MHz is suitable for the astronomical observations; it seems to be the best frequency for observing with the SAD. In addition, it is worth noting that the bandwidth 400-420 MHz is also poorly affected by RFI occurrences. This represents an important aspect in order to consider SAD telescope useful as receiver in a P-band multi-static radar configuration for space debris observations (at 410-415 MHz)[19], with the other Italian radars based on a radio telescope as receiver (i.e the BIRALET[14,19] and BIRALES[20] radars). The AVG plot shows that the power level of the strongest signals in Figure 7, due to the TETRA services, might saturate the subsequent amplification stages of the acquisition chain or the future back-end based on Field Programmable Gate Array (FPGA) board. For this reason, a band-stop filter to reject and/or attenuate sufficiently the TETRA signals might be required before any further amplification stage after the LNA.

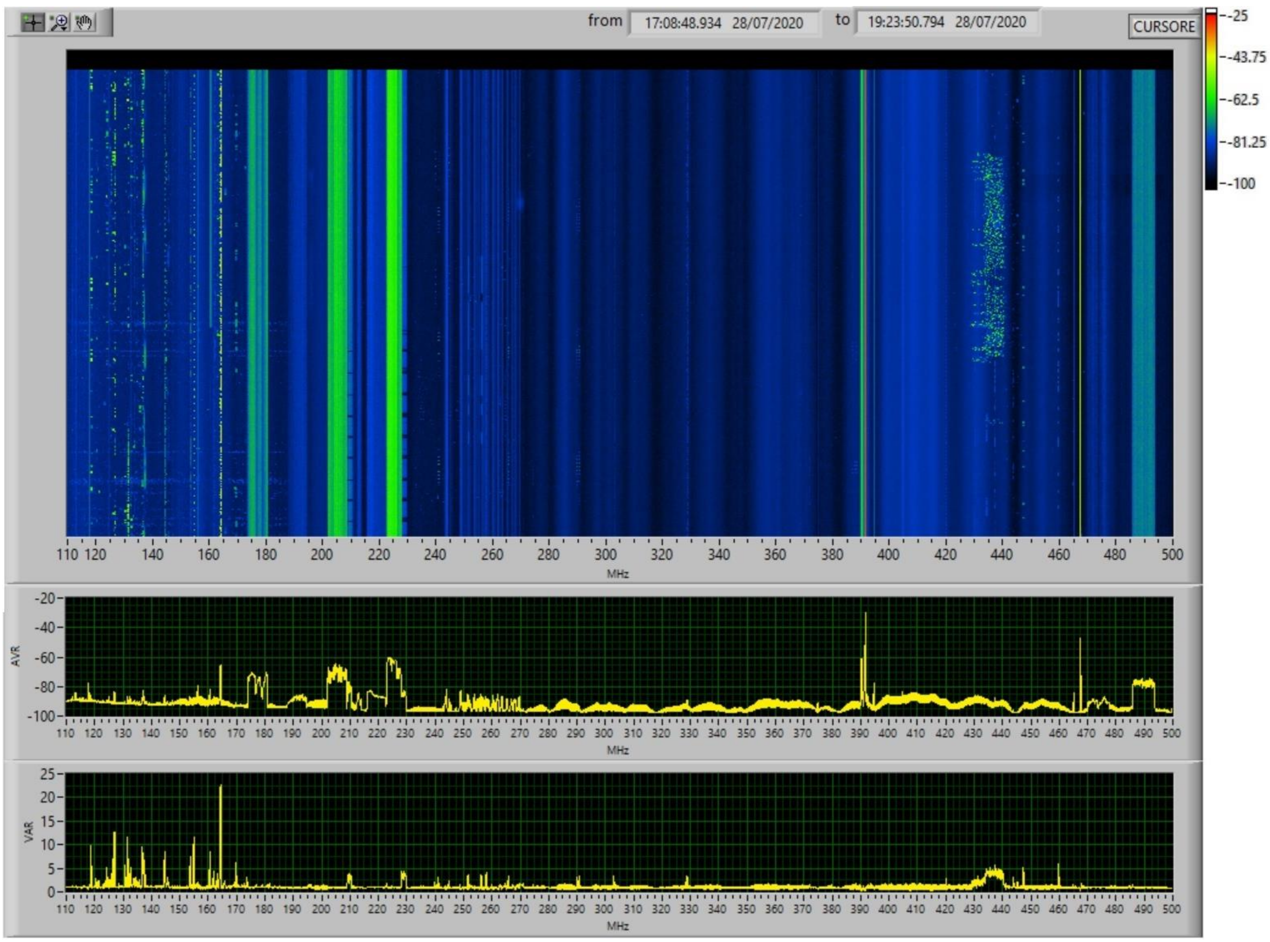

Figure 7. Screenshot of the graphical interface of the Data Elaboration software, with the Spectrogram plot, AVG plot and VAR plot. These plots are related to the frequency range 110-500 MHz.

After the results shown in Figure 7, another measurement campaign was performed in the bandwidth 270-420 MHz (see Figure 8). The analysis of the collected data confirms that, at least at the sensitivity level of these measurements, this frequency range (excluding the frequency range between 385 and 395 MHz (TETRA signals)) appears to be relatively free of RFI, thus it results the most promising one for scientific and space debris observations with SAD.

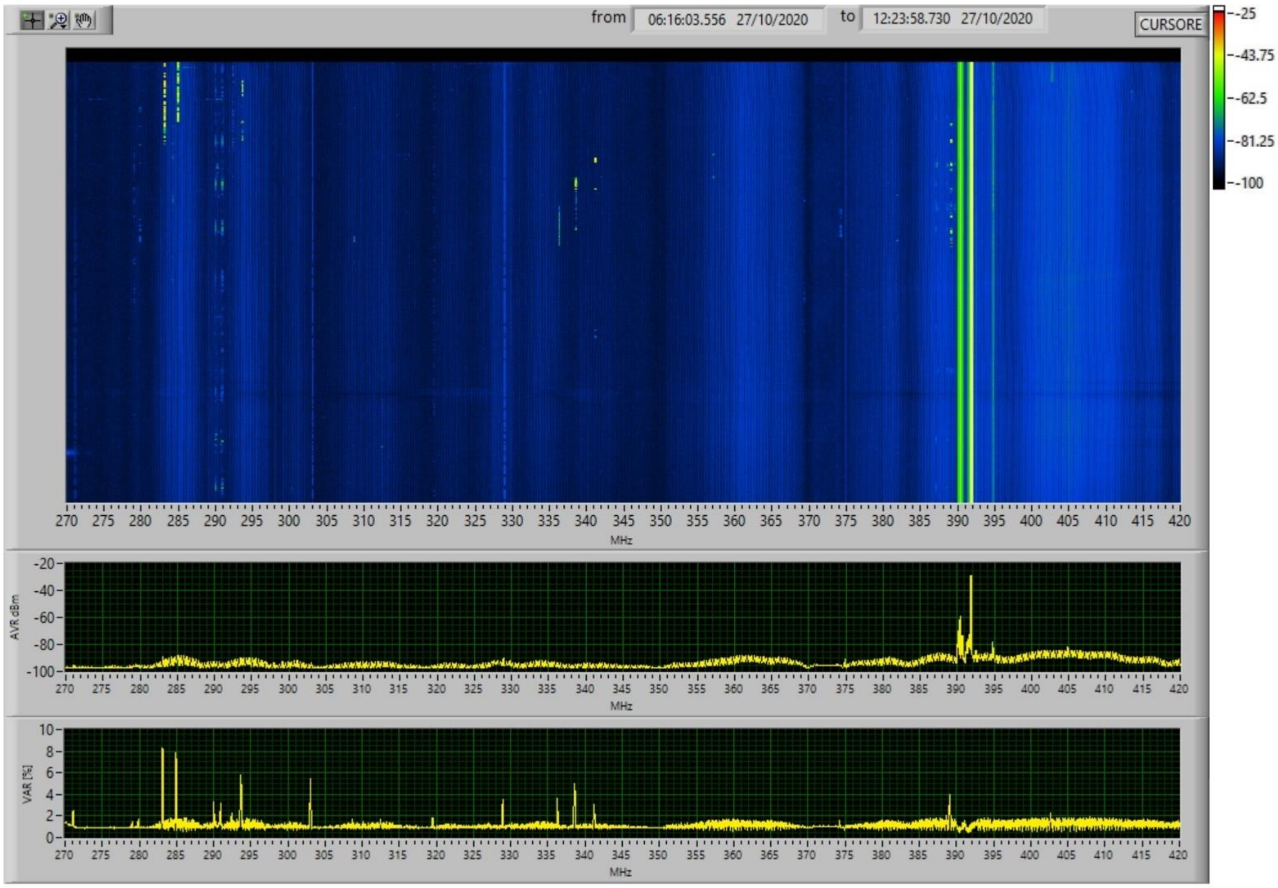

Figure 8. Screenshot of the graphical interface of the Data Elaboration software, with the Spectrogram plot, AVG plot and VAR plot. These plots are related to the frequency range 270-420 MHz.

4. CONCLUSION

SAD radio telescope is an Italian aperture array demonstrator constituted by128 dual-polarized Vivaldi antennas designed to operate with high efficiency across the 50-500 MHz frequency range. One of the most important aspect, when a new radio telescope is in developing phase, is represented by the study and knowledge of the continuous evolution of the RFI scenario in the territory where it is located. For this reason, a RFI monitoring system has been developed and presented in our paper. The front-end of the system is composed of a SAD Vivaldi antenna equipped with a dedicated receiver chain in order to send the received signal to a dedicated back-end based on a spectrum analyzer. Regarding this back-end, an ad-hoc software has been implemented with the purpose of setting the main parameters of the spectrum analyzer, acquiring, saving and elaborating the collected data. The results of the measurement campaigns performed by our system have been reported in the results section. From the analysis of these results, it appears that the bandwidth 270-420 MHz, excluding the frequency range between 385 and 395 MHz (TETRA signals), is relatively free of RFI and thus results the most promising for scientific and space debris observations with SAD.

5. ACKNOWLEDGMENTS

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