Preliminary tests to design an ad hoc signal acquisition chain for the Sardinia Aperture Array Demonstrator

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Abstract

The Sardinia Aperture Array Demonstrator (SAD) is an Italian facility, which is composed of 128 prototypical Vivaldi antennas, specifically designed to operate across the 50-500 MHz frequency range. As well known, one of the major burden at low frequency are the radio frequency interferences, thus after several accurate measurement campaigns we realized that a specific signal conditioning is needed in order to feed the digital beamformer with the proper signal level. In this paper, we report the results of the preliminary tests that we carried out in order to design an ad hoc receiving chain for the SAD array.

1 Introduction

Digital backends plays a key role in radio astronomy, especially at low frequency due to the strong radio frequency interference (RFI). Although single-dish solutions are often the only option, the worldwide trend is moving towards large arrays (for examples the LOFAR array [1], the MWA array [2], the LWA array [3] and the SKA-low array [4]). This can be achieved by electronically combining all the elements of the array; modern digital back-ends allow to do that.

In the framework of the SKA, the Italian National Institute for Astrophysics (INAF) designed the Sardinia Aperture Array Demonstrator (SAD), a project funded by the Sardinian Regional Government that is composed of 128 dual-polarized Vivaldi antennas. The SAD is located in the Sardinia Radio Telescope (SRT) site, at about 35 km from Cagliari [5-7]. It works, with a high efficiency, at frequencies below 500 MHz, all of the antennas are randomly distributed in a 64 meter-wide diameter area.

Being a low-frequency instrument, SAD is particularly vulnerable to all radio frequency signals and, in particular, to the strong and unwanted artificial ones, aka RFIs. A deep knowledge of the RFI environment at the site where the SAD is placed is essential, thus we carried out different measurement campaigns with the aim to detect all RFI signals [8]. According to the results achieved during these campaigns, we will design a proper signal conditioning system to prepare all the signals for the next stage of processing, the digital backend indeed.

By exploiting the reconfigurability provided by the FPGA technology, as well as the experience gained from working on thePHAROS2 project [9-12], we have decided to use the same iTPM-based backend for the SAD as well. The iTPM board consists of the Analog Digital Unit (ADU) and of two pre-ADU boards. The ADU is a 6U board containing sixteen dual-inputs Analog to Digital Converters (ADC) and two FPGAs (Xilinx Kintex Ultrascale XCU40) capable of digitizing and processing up to 32 RF input signals with a maximum bandwidth of 500 MHz [11-14]. As a consequence, a single iTPM features are suitable for a sub-array of the SAD with only 16 Vivaldi elements, in view of the final version of the system with all 128 elements.

In this paper, the results of the preliminary tests to design an ad hoc receiving chain for a single Vivaldi antenna of the SAD array are reported. In particular, two acquisition chain setups are described, whose results are intended as precursors to develop a receiving system suitable with the future iTPM back-end requirements.

2 Materials and methods

As mentioned earlier, the design of the signal acquisition chain is strongly influenced by the RFI scenario of the environment around the telescope. Moreover, the power level before feeding the iTPM back-end has to be -3 dBm at least, in order to guarantee an optimal functioning of the device [11-14].

By taking into consideration these technical needs, along with the level peak of all high undesired signals, it is possible to design a front-end that allow us to carry the radiofrequency signal, detected by the telescope, to the iTPM digital back-end.

The typical RFI scenario, evaluated in several measurement campaigns by using a dedicated RFI monitoring system described in [8], can be summarized with the spectrum depicted in the following Figure 1.

As evidenced in the red rectangle, the 270-420 MHz is relatively free of RFIs and is definitely promising for scientific purposes as well as for space debris observations [15] if it were not for the TETRA signal (385-395 MHz).

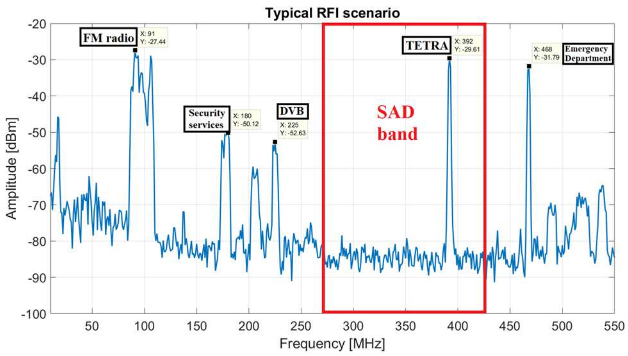

Figure 1. Spectrum of the RFI scenario at the SAD telescope. The SAD band (270-420 MHz) is highlighted with the red block. The significant RFIs, reported in [8], are labeled.

Therefore, a notch filter (also known as a band-stop filter or reject filter) centered at 392 MHz, seems to be essential for mitigating the TETRA signal and for avoiding any signal saturation after the low noise amplifier. In this way, we can obtain the aforementioned total power level of about -3 dBm by inserting additional components to the acquisition chain used during the RFI measurement campaigns and described in [8].
In order to test the performance of SAD array followed by the iTPM digital backend, we decided to use an acquisition chain based on the custom front-end that is used for the Medicine Northern Cross BEST demonstrator (see Figure 2) [16-17]. It is composed of a low noise amplifier, a band pass filter centered at 408 MHz with a bandwidth of about 25 MHz, and a second amplifier block that guarantee a total gain of about 60 dB. The BEST main features are listed in Table 1.

Figure 2. Photo of the box containing two BEST front-end (FE#7 and FE#40), one for each Vivaldi antenna channel. Each BEST front-end is directly connected to a Bias-Tee that provides the 12 V power supply [16-17].

Gain	60 dB
Frequency bandwidth	25 MHz @ 408 MHz
OIP3	> +33 dBm
Input RL	15 dB
Output RL	15 dB
Noise Figure	0.45 dB
Power Supply	(10 − 15) Volt @ 245 mA

Table 1. Main features of the BEST front-end [16].

The S-parameters of the BEST front-end are shown in Figure 3. The S21 curve (red curve) shows the BEST front-end gain as function of the frequency. In particular, it is possible to appreciate that the BEST front-end confines the signal in the 3-dB bandwidth 399.5-417.5 MHz. The S21 red curve shows a maximum gain of about 60 dB, which matches with the overall gain of the BEST front-end (Table 1).

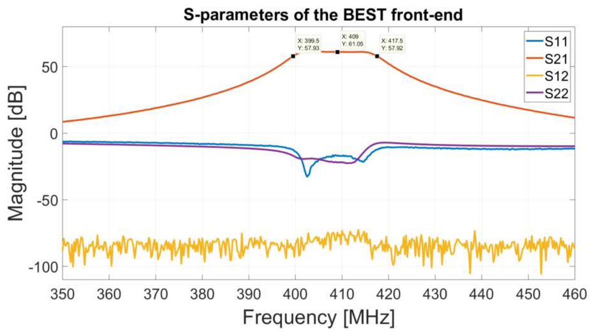

Figure 3. S-parameters of the BEST front-end (FE#7).

A further configuration, based on the use of a tunable band pass filter downstream of the acquisition chain described in [8], has been evaluated. The band pass filter employed in this case is the 3TF-50/500-5S model provided by the Lorch Microwave, which has a bandwidth that is the 5% of the central frequency. The central frequency of the filter was set at 360 MHz. After the filter, three low noise amplifier (ZX60-P103LN+ model from Mini-Circuits) are added in order to achieve an acceptable gain in the receiver chain. The main features of the chain -with the Lorch filter and the three ZX60-P103LN+ amplifier- are listed in Table 2.

Total gain	60 dB @ 350 MHz
Frequency bandwidth	16MHz @ 342 MHz
OIP1	22.5 dBm @ 350 MHz
Noise Figure	0.4 dB @ 350 MHz
Power Supply	5 Volt @ 95 mA

Table 2. Main features of the chain based on the Lorch filter and the three ZX60-P103LN+ amplifiers.

3 Results and discussion

Once properly assembled the receiving chain based on the BEST front-end, we got the spectrum shown in Figure 4: the measured power density in a bandwidth of 90 MHz, centered at 405 MHz, is -12 dBm. The TETRA signal at 392 MHz heavily affects this result; even though it is partially filtered by the BEST front-end filter (see S21 red curve of Figure 3), it results still too high.

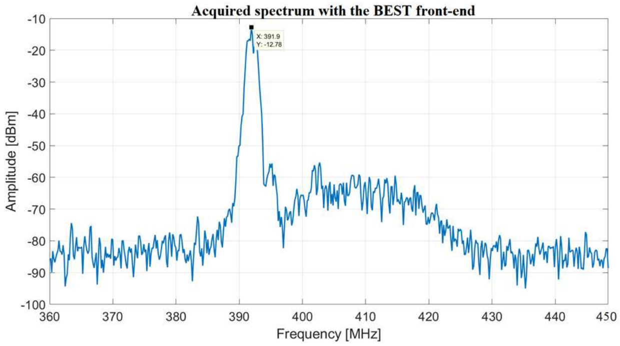

Figure 4. Spectrum acquired using the acquisition chain based on the BEST front-end (FE#7).

The second configuration was based on the tunable band pass filter and the same three low noise amplifiers; it shows a power density of -24.6 dBm within a bandwidth of 30 MHz, centered at 345 MHz. The corresponding acquired spectrum is shown in Figure 5. In this case, thanks the tunable filter, we chose a frequency range devoid of RFIs signals (338 -347 MHz) so that the measurement is not conditioned by unwanted signals. For this reason, the power density is better than the one measured with the BEST front-end. Moreover, this result is more profitable because the digital back-end does not receive any undesired signals and the bandwidth can be considered free of RFIs. The optimal power level (about -3 dBm [11]) can be achieved using further amplifiers in the receiving chain.

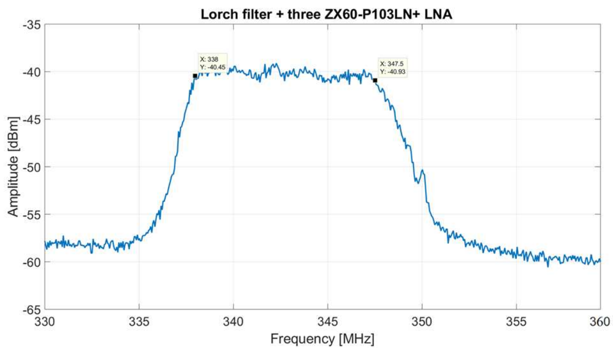

Figure 5. Spectrum acquired using the acquisition chain based on the Lorch filter and the three ZX60-P103LN+ amplifiers.

4 Conclusion

In this paper, we outlined how the best signal acquisition chain for the SAD telescope needs a notch filter centered at 392 MHz. In this way, it is possible to mitigate the highest RFI signal and to amplify the remaining bandwidth by avoiding any back-end saturation. The filter is going to be designed and developed in the near future.

Alternatively, a preliminary configuration of the receiving chain based on the BEST front-end may be used. This allow to operate in the 399.5-417.5 MHz frequency range with a gain of 60dB; nevertheless, the TETRA signal at 392 MHz is not completely filtered. Consequently, it is possible to test the iTPM back-end, bearing in mind that there is a strong RFI signal that has to be filtered.

A further preliminary configuration taken into consideration consists of a tunable band pass filter and of three low noise amplifiers placed downstream of the first LNA in the chain described in [8]. The filter allows to cut the undesired RFIs and consequently work in a specific portion of band (338-347 MHz) with the iTPM back-end. The power density that we measured with this receiving chain is about -25 dBm; thus, an additional amplifier is needed to achieve the proper signal level for the digital back-end.

5 Acknowledgements

The Sardinia Aperture Array Demonstrator is funded by the Sardinian Regional Government, L.R. 7 agosto 2007, N.7: “Promozione della Ricerca Scientifica e dell’innovazione Tecnologica in Sardegna”, Progetti di ricerca fondamentale o di base annualità 2012; CRP-60151, PI M. Murgia.

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