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UPGRADING THE SARDINIA RADIO TELESCOPE TO A BISTATIC TRACKING RADAR FOR SPACE DEBRIS

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ABSTRACT

In order to prevent the harmful impacts for spacecrafts deriving from the presence of space debris, many surveillance and monitoring programs of the space environment have been started in recent years. The Sardinia Radio Telescope is a new comer in such a scenario, but it has already showed its potential. However, since the actual receiving chain is not optimized for the reception of the echoes scattered from the debris, some modifications has been planned to upgrade the telescope and made it suitable for these types of observations.

INTRODUCTION

Space debris represent an increasing problem for the ongoing space operations and they are the primary reason of the space environment pollution [1]. The study and monitoring of the known objects, as well as the detection of new ones, is essential to prevent the risk of collision between debris and spacecraft but also between debris themselves. Radar measurements are often used to detect debris in the Low Earth Orbit (LEO) between 200 and 2000 km from the Earth’s surface [2]. In recent years, the Sardinia Radio Telescope (SRT), a fully steerable wheel-and-track 64-m dish located near San Basilio in Sardinia (Italy), has been employed, as a receiver in a bistatic radar system, for space debris monitoring purposes in beam parking mode in P band (410 MHz) [1],[3]. Nevertheless, this structure is not provided with a space debris-dedicated receiving chain nor back-end. To fill this gap, the Cagliari Astronomical Observatory (OAC) research group has made an effort in two ways: designing a tailor-made receiving system for space debris and developing a specific algorithm to provide the pointing schedule for the SRT either in beam parking or tracking mode.

The design of the receiving system included: the upgrade of the L-P band receiver, installed in the primary focus of the antenna [4], the implementation of a performing back-end and contextually the development of the down-conversion system.

Optics	Gregorian (shaped) + BWG
Focal positions	Primary f/D = 0.33 Gregorian f/D = 2.34 2 x BWG I f/D = 1.38 2 x BWG II f/D = 2.81
Frequency range	0.3 ÷ 116 GHz
Primary and secondary reflector diameter	64 m and 7.9 m
BWG mirrors diameter	2.9 ÷ 3.9 m
Azimuth and Elevation Speed (wind speed < 60 km/h)	0.85°/sec Azimuth 0.5°/sec Elevation
Antenna gain and efficiency in P band at 410 MHz	46.6 dBi – 57.7 %

Fig. 1. Sardinia Radio Telescope characteristics and detail of P band receiver in primary focus.

UPGRADE OF THE SARDINIA RADIO TELESCOPE

The SRT (see Fig. 1) has recently showed its potential in the detection of relatively small objects orbiting near Earth. With its 64 meter dish, composed by a total of 1008 aluminum panels, the SRT is the second world largest radio telescope equipped with an active surface system [5]. The front-end used for the first experiments on the debris was the L-P receiver [1] (Fig. 1), a cryogenically cooled coaxial receiver with two channels, one for the P band (305-410 MHz) and the other one for the L band (1300 – 1800 MHz). However, during such experiments, the receiving chain was oversimplified, as it can be seen in Fig. 2. In this early configuration the two channels at the output of the L-P block – one for each circular polarization – were simply combined and sent to a spectrum analyzer.
Although the experiment described in [1] can be considered a success, the data processing was poor, due mainly to the limitations of the spectrum analyzer, i.e. the slow frequency sweep for low RBW and unobtainable real time data saving. For these reasons, the choice of a brand new back end was a key point of the upgrade. The P band is a spectral region largely used for radio communication services that can reduce the useful bandwidth and compress a lot the dynamic of the receiver. While radio-astronomical observations use very large bandwidths, radar signals are narrowband.

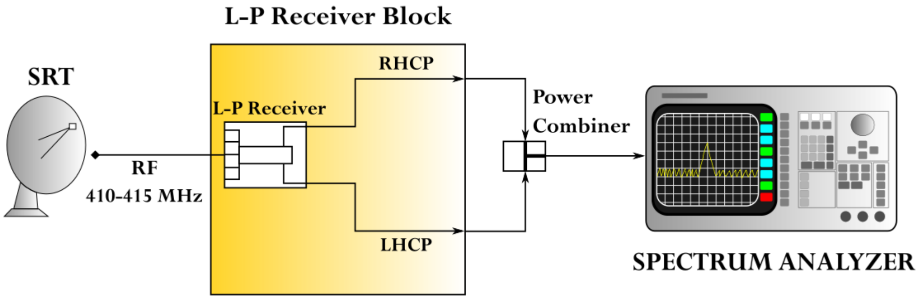

Fig. 2. Schematic of the receiving chain in the early space debris detection experiments.

For this reason the receiver block has been modified by inserting in the chain a band-pass filter (centered at 410 MHz with a 15 MHz bandwidth) to increase the signal to noise ratio, to mitigate the radio frequency interference (RFI) and to remove the image frequency interference, as shown in the schematic in Fig. 3. The insertion loss of this tubular BPF is equal to 1.1 dBa and its dimensions (99.06 x 31.75 x 31.75 mm) have been chosen due to the lack of space inside the L-P receiver block.
The 410 MHz RF signal, amplified and filtered inside the first block of the chain, is then down converted to an intermediate frequency (IF) at 30 MHz, an operation necessary to shift the input signal to the frequency of the dedicated back end, and further filtered with a band-pass filter centered at 30 MHz with 5 MHz bandwidth and an insertion loss of 0.9 dBa. The mixer chosen for the down conversion works in the bandwidth 100-2000 MHz with a isolation between the L-R ports of about 52 dB and an isolation of about 35 dB between the L-I ports. Since the signals scattered from the debris are very weak, an amplifier has been placed in the final part of the down conversion block. The main features of the amplifier are: an overall gain of about 40 dB, a noise figure of about 3 dB and an output power at 1 dB compression point of about 17 dB. The amplifier is followed by a wideband (up to 6 GHz) digital step attenuator, whit a resolution of 0.25 dB, a maximum attenuation of 31.75 dB, an input IP3 of 53 dB and a 7 bit parallel control interface that allows to change the level of the signal at the input of the last block.

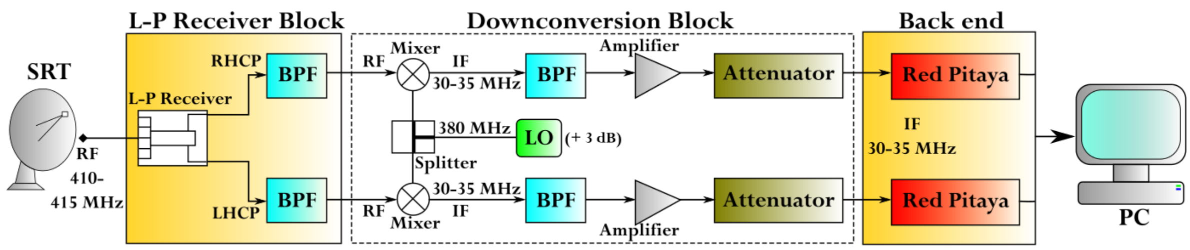

Fig. 3. Schematic of the new and upgraded P band receiving chain.

The IF signals go through the digital platform based on two Red Pitaya boards [6], one for each polarization. Each orthogonally polarized signal is sampled individually with an analog to digital converter, having a resolution of 14 bits and a sampling frequency of 125 MS/s. Once the data are digitized, they are sent to the Xilinx FPGA installed in the board and then properly processed. As already said, the frequency interval of interest starts from 30 MHz with a bandwidth of 5 MHz, the signal is down-converted and then filtered with a decimating digital filter in order to remove the unnecessary band and to minimize the output data rate. At this stage, since the

signal is mixed with a local oscillator generated by a DDS (Direct Digital Synthesizer) implemented in the FPGA, it is composed of complex-valued samples that are then sent to the PC. This base-band complex signal is stored and subsequently (or simultaneously) a Fast Fourier Transform (FFT) is applied to the data in order to break up the signal in several sub-bands. The FFT engine could be implemented in the FPGA as well, however the number of spectral points would be limited by the available memory on the FPGA, thus we opted to implement it in the CPU/GPU boards.
To track the debris, the SRT must be pointed and driven by a schedule, that contains the azimuth and elevation coordinates of the object. The schedule is generated by an algorithm that takes in input the observation epoch, the Two Line Element (TLEs) of the debris, the geographical coordinates of the radio telescope, the duration and time steps of the tracking.

CONCLUSION

The research field related to the monitoring of space debris is becoming more and more attractive. The SRT is moving its first steps in this area and has already shown its capabilities. This early and however encouraging experiments have been carried on with an oversimplified receiving chain though. For this reason, the research group of the OAC has designed an hardware and software upgrade of the SRT receiving chain, in order to optimize the use of the radio telescope as a receiver for space debris monitoring and tracking.

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