SPACE DEBRIS RADAR EXPERIMENTS AT THE MEDICINA VLBI DISH

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ABSTRACT

In 2007 three space debris detection tests were performed in the framework of a monitoring program carried out by the Istituto Nazionale di Astrofisica - INAF - in collaboration with the Italian Space Agency - ASI. The observations were made by using the bistatic radar technique. The INAF 32 m radiotelescope located at Medicina (Bologna, Italy) was used as receiver whereas the Ukrainian 70 m parabolic antenna located at Evpatoria was utilized as transmitter. The aim of the experiment was to test the sensitivity of the Medicina-Evpatoria radar system in space debris detection, and to validate and optimize the hardware setup. Measurements were mainly carried out on inactive satellites and catalogued space debris. However the search for new fragments in LEO was also performed during the campaign. This paper reports on results of these observations.

Key words: Bistatic Radar; Space Debris; Medicina-Evpatoria radar.

1. INTRODUCTION

The number of space debris orbiting around the Earth is constantly increasing and nowadays they pose a serious risk for overall human activity in space, as clearly demonstrated by the collision occurred in 1996 between the CERISE satellite and a fragment of the Ariane third stage [1] or the recent impact between Cosmos 2251 and Iridium 33 satellites. For this reason the characterization of the orbital debris environment has became a key issue for the worldwide space agencies. In order to achieve this goal a large number of ground based radars and telescopes have been employed. These two kinds of sensors cover complementary application fields. Optical observations reach very good performances in geostationary ring (GEO) and geostationary transfer orbit (GTO), whereas radar techniques outperform optical facilities in Low Earth Orbits (LEO). Radars do also have other important advantages: their measurements are not affected by weather, day-night conditions and are independent on the target illumination by sunlight.

Since 2006 the Medicina Radioastronomical Station of the Italian Istituto Nazionale di Astrofisica - INAF - has been involved in the ASI "Space Debris" program and in the international VLBR radar campaigns coordinated by the Keldysh Institute of Applied Mathematics. In 2007 three tests of space debris detection were performed by using a bistatic radar configuration composed by the 32 m antenna at Medicina (Italy) as receiver and the RT-70 parabola at Evpatoria (Ukraine) as transmitter (Figure 1).

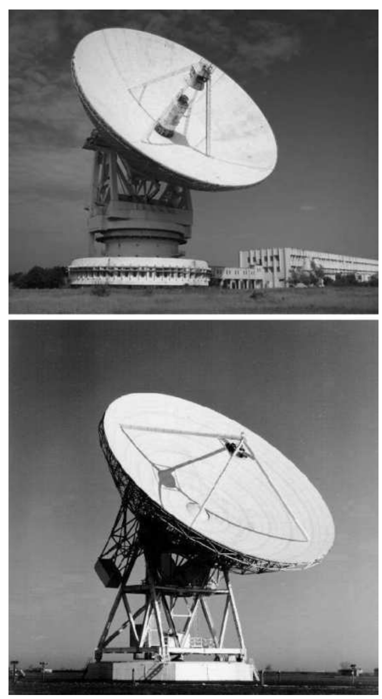

Figure 1. From the top: the RT-70 transmitting antenna at Evpatoria and the Medicina VLBI 32 m receiving antenna.

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2. THE MEDICINA-EVPATORIA BISTATIC RADAR

The Medicina 32 m antenna is a fully steerable dish developed to perform observations from 1.4 to 22 GHz in both single dish and network configuration together with other European VLBI (Very Long Baseline Interferometer) radiotelescopes. Since the antenna has been specifically designed for radioastronomical purposes, it is optimized to detect very faint radio signals from distant astronomical objects (e.g. quasars and radiogalaxies).
The Evpatoria RT-70 is a fully steerable 70 m parabolic antenna equipped with two high power sources (200 kW) in C-band. Since 2001 this antenna, developed for space research and radar astronomy, has been also utilized for space debris investigation at Geostationary (GEO) and High Earth Orbit (HEO) [2]. During the experiments, RT-70 transmitted a continuous right circularly polarized (RCP) signal at a frequency of 5010.024 MHz, and with a mean power of approximately 20 kW.
The scattered signals were received at Medicina in both circular polarizations by using the 5 GHz receiver located in the antenna Cassegrain focus. The receiver is cryogenically cooled by liquid helium and exhibits optimal performances in terms of noise temperature and antenna gain. Main parameters of the Medicina 5 GHz receiver are listed in Table 1.

Type	Cooled
Channels	2
Polarization	LCP - RCP
Central frequency (GHz)	5.05
Noise temperature ($^{\circ}K$)	12-14
Useful RF band (GHz)	4.3 $\div$ 5.8
RF filter width (MHz)	1500
IF filter width (MHz)	400 or 800
Instantaneous RF band (GHz)	4.85 $\div$ 5.25 *

Table 1. Standard parameters of the 5 GHz receiver. (with 400 MHz IF filter)*

Signals from receiver were acquired in parallel by an innovative multi-backend system consisting of two spectrometers and two time-domain data acquisition devices. The general scheme of the multi-backend is given in Figure 2.
Two fast programmable spectrometers (MSpec0 and SPECTRA-1) acquired the signal in real-time and performed data analysis in the frequency domain. Both spectrometers were developed in the framework of the ITASEL-ASI program for the detection of water maser emission lines in planetary atmospheres. Mspec0 and SPECTRA-1 exhibit complementary performances (Table 2). The MSpec0 spectrometer performs an FFT signal analysis and, according to the programmed settings, allows very high frequency resolutions. The poliphase filter bank installed on SPECTRA-1 assured both a better channel to channel rejection level (very useful in case of strong radio interferences or signals) and an improved time resolution.

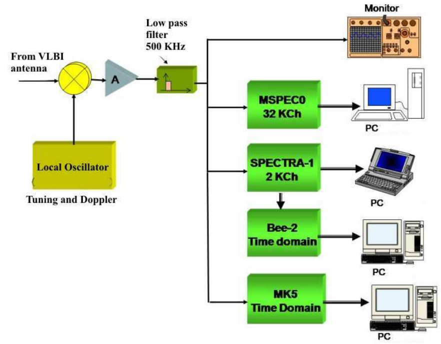

Figure 2. Scheme of the multi-backend data acquisition system utilized in the space debris observational campaigns.

	MSpec0	SPECTRA-1
Bandwidth (MHz)	0.5	2.5
N. of channels	32000	2000
Avg spectra	20	100
A/D	10 bit	14 bit
Domain	freq.	freq.
Freq. res. (Hz)	15.6	1200
Time res. (sec)	1.2	0.08

Table 2. The MSpec0 and SPECTRA-1 operating parameters utilized during the radar experiments

Parallel to the spectral analisys, signals were also digitized and recorded in time domain by the VLBI standard formatter MK-V and a BEE-2 (Berkeley Emulation Engine 2) FPGAs cluster (Table 3). Off-line data processing allowed a fine tuned analysis resulting in a optimized frequency and time resolution.

	MK-V	BEE-2
Bandwidth (MHz)	0.5	10
A/D	2 bit	8 bit
Sample-rate	1 MHz	20 MHz
Domain	time	time

Table 3. Operating settings of the time domain acquisition system: MK-V VLBI formatter and BEE-2 cluster

3. OBSERVATIONS

At the beginning of each observational session, some inactive geostationary satellites were pointed in order to check the overall operationality of the radar setup. The pointing accuracy was crucial because of the small fields of view of the antennas: at a wavelength of 6 cm the $-3dB$ beams of the Medicina and Evpatoria antennas were 7.5 arcmin and 2.6 arcmin, respectively. Observations of catalogued Low Earth Orbit (LEO) and Medium

Earth Orbit (MEO) debris having different radar cross sections (RCS) were performed to test the efficiency of the multi-backend system in detecting echoes coming from debris. The first and the second test campaigns were successfully carried out on July 17-19 and July 28-31, 2007. Almost all the selected debris were detected by the acquisition system. In particular some of the smallest space debris issued in the NORAD public catalog were detected with a very high signal to noise ratio. This result proved the efficiency of the data acquisition systems and the capability of the Medicina-Evpatoria radar to detect fast and small targets [3]. One of the echoes detected during the observational campaign is shown in Figure3.

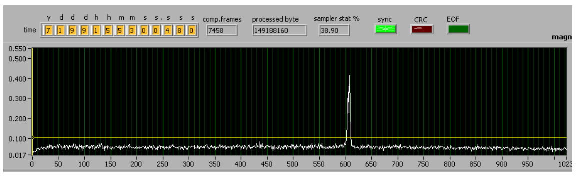

Figure 3. Signal spectrum of the echo coming from the small space debris 28068 (CZ-4 debris) recorded on July 18th, 2007 at 15:53:00 UT

Part of both observational sessions were dedicated to the search for new uncatalogued objects. The technique utilized in this case was the classical beam park: the transmitting and receiving antennas are kept fixed at a given position (determined by definite elevation and azimuth coordinates) while debris randomly pass within the common field of view. In order to increase the detection probability, a suitable LEO region was selected according to the PROOF-2005 space debris population model. The geodetic coordinates of the centroid of this region are listed in Table 4.

Height (km)	871.70
Latitude (deg)	47.800
Longitude (deg)	21.172
Range Tx (km)	1348.336
Range Rx (km)	1234.270

Table 4. Geodetic coordinates of the centroid and topocentric slant ranges (Tx and Rx) of the region observed in beam park mode.

During the beam park experiment several faint echoes from uncatalogued orbiting objects were recorded. Figure 4 shows the spectrum of a relatively strong echo coming from an object not correlated with the NORAD public catalogue. The echo was acquired in time domain by the MK-V backend and post-processed by a dedicated software. It is under development at Medicina a new software for the analysis of radioastronomical spectral data The software - called ASTRA (Advanced Spectra Tools for Radioastronomy) [4] - includes special routines for the decode of data stored in time and frequency domain and for the discrimination of faint signals with low S/N. It is therefore particularly suited for the identification of weak echoes.
The third test campaign was carried out on November 12,

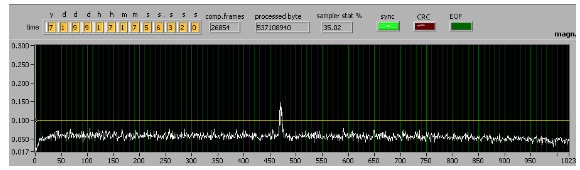

Figure 4. Echo from an uncorrelated debris orbiting at a geodetic height of 871.7 km detected during the beam parking session. The echo was recorded on July 18th, 2007 at 17:17:56 UT.

2007. The aim of this radar session was the validation of the results obtained during the previous one and the optimization of the backends settings. On this occasion all the selected objects were detected with an extremely high signal to noise ratio [5]. Some of the targets had been already observed during the first and second sessions, providing confirmation of the previous detections. Furthermore the comparison between different measurements of the same debris in terms of signal to noise ratio and frequency resolution proved that the new backends settings improved the sensitivity of the radar system. An example of the increasing of the peak intensity and of the S/N is given by the Debris 29040, having one of the lowest RCS of the NORAD catalogue at that time (Figure 5).

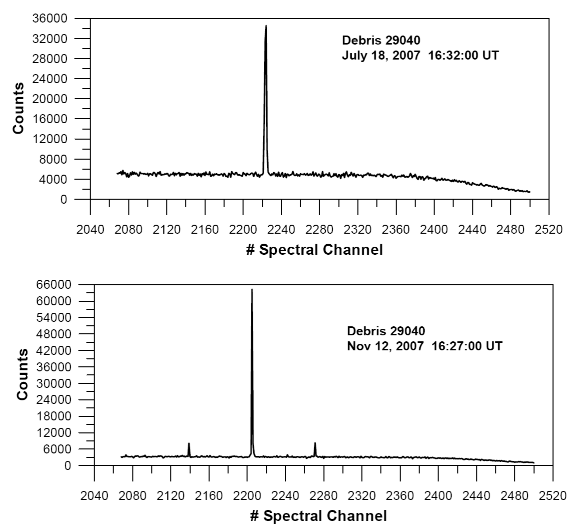

Figure 5. Signal spectra from the space debris 29040 recorded by SPECTRA-1 during the first (top) and the third (bottom) campaign performed in 2007. The two spectra were recorded at the same frequency resolution and in a similar observational geometry.

Further space debris observations were performed by the Medicina-Evpatoria bistatic radar in 2008 and 2009. Data coming from these campaigns are still under processing and the results will be therefore discussed elsewhere.

4. CONCLUSIONS

Three space debris observational tests were performed between July and November 2007 by using the Medicina-

Evpatoria bistatic radar. The successful results obtained during the experiment proved the extremely high performances of the system in detecting orbiting objects, as small sized debris in LEO and MEO. Data collection is still ongoing together with elaboration of recent observations. Although further work is necessary to calibrate and improve the system, Medicina-Evpatoria could be a powerful tool to characterize the orbital environment.

ACKNOWLEDGMENTS

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