A POTENTIAL INTEGRATED MULTIWAVELENGTH RADAR SYSTEM AT THE MEDICINA RADIOTELESCOPES

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ABSTRACT

Ground-based radars provide a powerful tool for detection, tracking and identification of the space debris fragments orbiting around Earth at different altitudes. The Medicina Radioastronomical Station is an Italian radio observation facility that is here proposed as receiving part of a bistatic radar system for detecting and tracking space debris at different orbital regions (from Low Earth Orbits up to Geostationary Earth Orbits).

Key words: Space Surveillance; Space debris; Observational Techniques: Bistatic Radar; Telescopes: Medicina VLBI antenna, Medicina Northern Cross.

1. INTRODUCTION

The Medicina Radioastronomical Station is located nearby Bologna, in Italy. It consists of two receiving antennas currently dedicated to the astronomical research at radio frequencies: the 32 m diameter parabolic dish performs observations from 1.4 to 22 GHz whereas the Northern Cross (a T-shaped array transit antenna) works at 408 MHz (Fig.1). Within the last few years the two antennas have been successfully used to perform space debris observational tests in the framework of the Italian Space Agency - ASI - space surveillance program [3]. The successful results suggested the possibility to perform a technological upgrade of the antennas in order to use them as receiving parts of a bistatic radar system.

2. THE MEDICINA RADIOTELESCOPES

2.1. The UHF Northern Cross Antenna

The Norther Cross antenna is one of the largest European radiotelescopes (30.000 sqm collecting area). It is a property of the Università di Bologna, Italy, and operates since 1970. The Norther Cross antenna was originally built to operate at UHF-band (408 MHz) with a bandwidth of approximately 2.5 MHz. It is a transit instrument, steerable in declination only, and therefore able to point at objects that transit over the local celestial meridian. The radiotelescope is composed of two perpendicular branches: the first arm is aligned in an E-W direction and the second one in a N-S direction. The E-W branch is a unique antenna with a 564 m long and 35 m wide cylindric-parabolic reflector surface. It is supplied with 1536 dipoles that lie out along the focal line. The N-S arm is composed of 64 parallel cylindrical-parabolic shaped antennas. Each antenna is 23.5 m long and 8 m wide. It is equipped with 64 dipoles for a total of 4096 receivers for the whole N-S arm. The parabolic shape of the reflector allows the incoming radiation to keep the phase and to converge on the antenna focus, if the radiowaves come along a direction that is parallel to the parabola axis. An accuracy of the mirror shape within the limit of 1/16 of the wavelength (including mechanical deformation effects, atmospheric influence, etc.) does not significantly affect the instrument performances. This

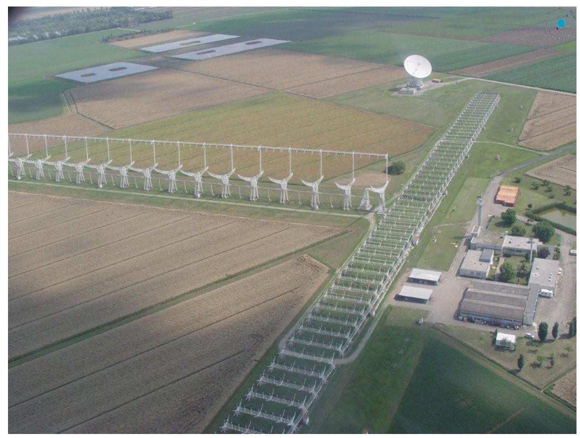

Figure 1. A top view of the Medicina radiotelescopes. In the foreground the T-shaped antenna Croce del Nord. In the background the 32 m diameter parabolic dish.

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tolerance allowed the use of steel wires aligned 2 cm parallel to each other instead of a filled surface for the reflector, since the operating wavelenght is 73.5 cm (Fig.2).

Figure 2. Schematic diagram of one N-S cylinder. The reflector surface is made of steel wires aligned parallel to each other.

The antenna resolution is approximately 4'-5' in a N-S direction, and 4' in an E-W direction. These values are due to the very large collecting area of the Northern Cross (30.000 square meters). Antenna's dipoles perform the conversion of the incoming electromagnetic waves into a measurable tension. This is successively transferred on the recording data devices through a system of rigid coaxial wires. The signal received at 408 MHz is first converted to an intermediate frequency of 30 MHz. This is performed in order to reduce signal attenuations due to wire "skin" effects that produce a reduction of the intensity which is proportional to the square root of the frequency. The intermediate frequency signal finally reaches the recording data system through underground coaxial wires. The cables are buried at 1.20 m from the soil in order to protect them from the rapid (daily) thermal variations that would alter the fragile relation phase-amplitudes of the incoming signal. The resulting signal is repeatedly amplified and filtered in order to remove possible radio interferences and increase the signal to noise ratio. The contributions coming from both the E-W and the N-S arms are finally equalized in phase and amplitude. The outcomes can be either individually elaborated or correlated. After an analog elaboration, the signal is digitized and sent to a computer which performs the final processing and storage of the data on a dedicated hard disk.

3. THE 32 METERS PARABOLIC DISH

The Medicina 32-m antenna is a Cassegrain radiotelescope that operates since 1983. It is managed by the Istituto di Radioastronomia of the Italian Istituto Nazionale di Astrofisica - INAF. The instrument is characterized by fast frequency switching (maximum time $\leq$4 min), fast secondary reflector wobbling (shifting time $\leq$1 sec at $\nu \geq 20$ GHz) and a complete automation and remote control of the observing settings. In Table 1 a summary of the main features of the telescope is shown.

Table 1. Medicina 32 m dish main characteristics.

Location	Medicina (BO), Italy
Coordinates	Lat. 44°31'15" N Long. 11°38'49" E Alt. 25 m f.s.l.
Optics	Cassegrain
Frequency coverage	1.4 ÷ 22 GHz
Primary reflector diameter	32 m
Secondary reflector diameter	3.2 m
Available foci	Primary F/D = 0.32 Cassegrain F/D = 3.04
Elevation range	0° ÷ 90°
Azimut range	±270°
Slew rates (wind speed $\leq$60 km/h)	48°/min Azimuth 30°/min Elevation
Surface accuracy	0.6 mm
Pointing accuracy	8 arcsec
FWHM Beamwidth	38.7 arcmin/f (GHz)
Gain	0.10 ÷ 0.16 K/Jy

The antenna primary reflector is made of 240 aluminium panels (RMS = 0.4 mm) sustained by a backup reticular truss. The housing of the Cassegrain focus feeds is at the mirror vertex. The primary reflector backup structure substains the secondary mirror, placed at a distance of 9 m, through $4\times45°$ inclined beams (quadrupod) (Fig. 3).

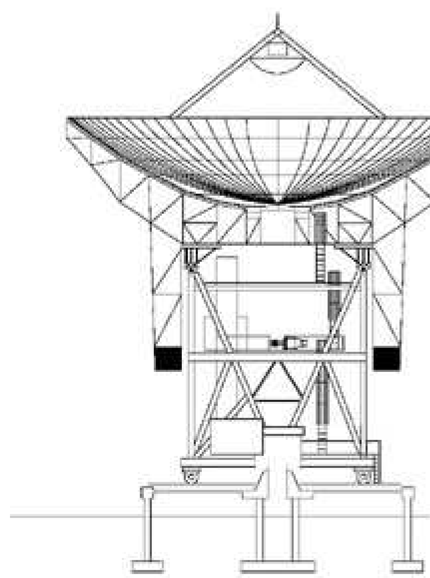

Figure 3. Schematic diagram of the Medicina antenna.

The secondary mirror is a hyperbolic reflector, 3.2 m in diameter, made of a single aluminium panel (rms = 0.35 mm). On the backup structure 3 mechanical actuators are

Table 2. Parameters of the Medicina 32 m antenna receivers.

Band	ν_0 (GHz)	λ (cm)	Receiver name	Beam (') N/S	Beam (') E/W	Lsky (GHz)	Hsky (GHz)	Receivers band (MHz)	Noise temp. (K)
L	1.4	21	lhp	31.0	31.3	1.35	1.45	2x80	50
L	1.6	18	llp	27.5	27.6	1.595	1.715	2x80	60
S	2.3	13	ssp	18.6	17.3	2.20	2.36	2x160	40
C	5	6	ccc	7.50	7.40	4.30	5.80	2x400 - 2x800	12-14
C	6	5	chc	7.00	6.50	5.90	7.10	2x400	57
X	8.3	3.6	xxp	4.80	5.00	8.18	8.98	2x800	25
K	22	1.3	kkp	2.00	2.00	21.86	24.14	2x800	80

installed and allow the mirror to tilt around the 3 axis. Besides the whole system can translate along the x and y axes. The system that rotates the secondary mirror has been optimized in order to enhance the number of receivers that can be installed at the Cassegrain focus. For the receivers installed in the external circumference, the same movement can be used for the Wobbling technique. The total reflector surface accuracy at 90° and 60° elevation is 0.8 and 0.6 mm respectively whereas a pointing accuracy of 0.13 arcmin (rms) is provided at normal observing conditions. The Medicina parabolic antenna covers a frequency range of $1.35 \div 24.1$ GHz. In Table 2 the main characteristics of the receivers are shown.

The connections between the radiotelescope's foci involve three different kinds of signal:

1) Local Oscillator: a single local oscillator can serve several receivers through a signal distribution system.

2) IF: the RF signals, once received and converted by the front-end, are sent to the back-end installed in the control room, at the base of the antenna.

3) Reference: 5 MHz H-maser signal, necessary for the local oscillator stability.

All the signals are distributed via coaxial cable. The back-end systems are installed in the control room, located at the antenna's base and are connected to the receivers through dedicated links. From the control room it is possible to act on receivers, antenna and sub-reflector movements. Observations are performed by using the Mark IV terminal and the "Field System" software. The Mark IV is made of two main parts: IF distributor (receiving the input from the front-end and splitting them in sub-bands) and videoconverters (14 units that operate the base-band conversion and the integration). Signals are finally stored in Mark V terminals.

The Medicina 32 m radiotelescope is part of the European Very Long Baseline Interferometry Network - EVN VLBI. The antenna operates in the framework of the EVN network for approximately 4 months per year. The remaining 8 months are dedicated to single dish observations performed within radioastronomical research projects and space debris tests performed in collaboration with national and international transmitting stations.

4. POTENTIAL USE OF THE UPGRADED INSTRUMENTS IN SPACE DEBRIS PROGRAMS

Recently, in the framework of the Square Kilometer Array Designs (SKADS) program 14 antennas of the Northern Cross N-S arm have undergone a technical upgrade mainly consisting of the development and installation of new low-noise, high-dynamic range receivers, vector modulators/mixers and low-cost digital optical links. In the framework of the Low Frequency Array (LOFAR) project a further upgrade was performed on one focal line of the E-W arm where eighteen 200 MHz log periodic antennas replaced the corresponding old dipoles and corner subreflectors. A completely upgraded Northern Cross would represent an ideal instrument for tracking debris and satellites larger than 6-7 cm in size. At 408 MHz the antenna would be characterized by a very wide field of view (FOV): from 60 up to 120 sq. deg. according to the number of dipoles per receiver that could be installed. This FOV can be plastered with 23000 up to 46000 beams 4'x4' wide. Such a geometrical distribution allows for the constant monitoring of the trajectories of a large number of space debris with a precision of the order of a few arcmin (Fig. 4).

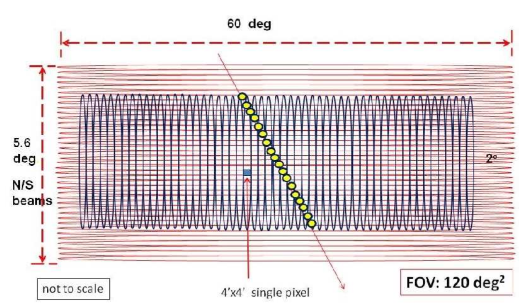

Figure 4. Debris tracked over a wide portion of sky through tens of thousands of 4'x4' beams (feeds).

Numerical simulations (Fig. 5) were performed by our group to obtain the maximum number of orbiting objects that pass into the Northern Cross FOV. The results showed that a detection of approximately 85% of the objects is possible for a FOV=120 sq deg (covered by 48000 feeds), whereas a detection of 80% of the objects is obtained for a FOV=60 sq deg (corresponding to 24000 feeds).

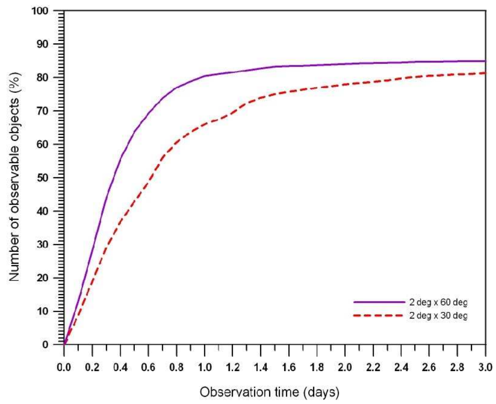

Figure 5. Percentage of objects crossing the Northern Cross FOV in different configurations. Solid line: number of objects detectable in case of 2x60 sq. deg. FOV. Dashed line: number of objects detectable with a 2x30 sq. deg. FOV.

Currently at the Medicina Radioastronomical Station data transmission from the receivers to the elaboration center occurs via optical link. Data coming from the two antennas can be contemporary acquired and analyzed in both frequency and time domain with several backends [1]. In particular the signal coming from the receivers can be digitized and stored in time domain by the VLBI standard formatter MK-V and by the new high performance Bee-2 (Berkeley Emulation Engine 2) FPGAs cluster, suitable to an on-line processing. Due to the capacity of performing a one Tera Ops/sec, this cluster is able to fulfill the computationally-intensive task of processing data coming from an extremely large number of receivers in real time. Fig. 6 shows a schematic diagram of a possible refitting of the whole Northern Cross, with SKADS technology, to obtain N beams on a wide FOV. In this case the space debris data acquisition and processing is planned to be implemented by using a cluster of Roach boards - an advanced version of the currently available BEE-2 cluster.

The frequency bands that are commonly used for space debris radar observations are 5.01 and 8.5 GHz. Observational tests performed at Medicina by using the parabolic antenna C- and X- band receivers coupled with the Evpatoria (Ukraine) 70 m transmitting station, have already demonstrated that the 32 m antenna can be successfully used as receiving facility to perform space debris detection down to a few centimeters in size [2]. The installation of appropriate transmitters on Italian 20 m class parabolic antennas, and therefore the creation of a potential Italian radar network, could open a new operational scenario for what concerns the high sensitivity fragments detection and tracking. Furthermore 24 hours-a-day debris observations at these frequencies could be performed if an independent receiver is mounted in one of the two feeds currently available. The new device should be able to work simultaneously together with the 7 existing

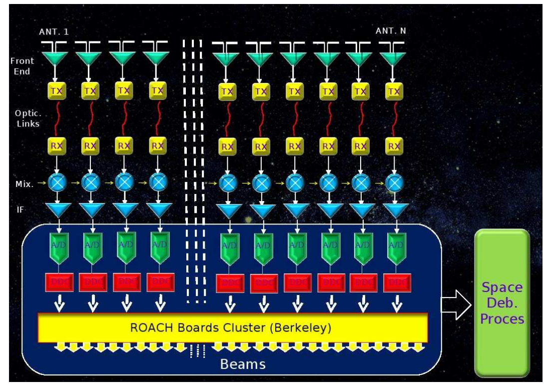

Figure 6. Schematic diagram of a possible Northern Cross refitting implemented with SKADS technology.

radioastronomical receivers operating from L-band (1.4 GHz) up to K-band (22 GHz). The new receiver should be implemented and installed in a way that the observations of space debris could be also performed in piggy back mode (i.e. not interfering with routine radioastronomical measurements). This feature would be particularly effective for the search of new space debris and for the statistical analysis of the debris environment.

5. CONCLUSIONS

The feasibility of a bistatic radar system using the Medicina radioastronomical antennas has been investigated and analyzed in this document. An appropriate refitting of the instruments together with the availability of appropriate transmitters (UHF and microwaves) would allow the construction of an integrated multifrequency system with improved debris monitoring performances. The UHF part of the system would be aimed to the accurate tracking on wider fields of view, whereas the national microwave network would be dedicated to high sensitivity fragments detection.

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