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The new transmitting antenna for BIRALES

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Abstract. In the last decades the increasing Resident Space Objects (RSOs) population is fostering many Space Surveillance and Tracking (SST) initiatives, which are currently based on the use of ground sensors. These can be distinguished in optical, laser and radar and categorized in tracking and survey sensors. In particular, the survey radars allow to determine the orbit of both catalogued and uncatalogued objects. Italy contributes to the European SST (EUSST) activities with the BIstatic RAdar for LEo Survey (BIRALES), whose transmitter is the Radio Frequency Transmitter (TRF), located at the Italian Joint Test Range of Salto di Quirra in Sardinia, and whose receiver is a portion of the Northern Cross Radio Telescope, located at the Medicina Radio Astronomical Station, near Bologna. The current sensor configuration is undergoing an upgrade process, including the receiver field of view extension and a new transmitter station. The purpose of the work is to present the new transmitting antenna of BIRALES, showing its technological progress and the potential for the monitoring of space debris. The final objective is to produce a high technological radar to improve the performance of the EUSST sensors network. In particular, the aim is to increase both the number of detectable objects and the sensitivity to detect fragments of a few centimetres up to an altitude of 2,000 km, with a remarkable improvement of orbit determination procedures and quality. The transmitting antenna has been designed to be very flexible for any type of observations, modifying its parameters depending on the observation needs and according to the service to offer (monitoring of fragments, re-entry or for collision avoidance). The work presents the system architecture and the transmitting antenna structure, and the performance are assessed through numerical simulations.

Introduction

Due to the growing complexity of the orbital environment, space-based assets are increasingly at risk of collision with other operational spacecraft or debris [1] [2]. At the same time, objects may re-enter the Earth's atmosphere and cause damage on the ground [3]. To address these concerns, the Space Surveillance and Tracking (SST) Consortium was established by the European Parliament and the Council in 2015. The EUSST system comprises a network of ground-based sensors aimed at surveying and tracking space objects, together with processing capabilities aiming at providing data, information and services [4].

BIRALES belongs to EUSST network, and this article focuses on the description of the transmitter and the final architecture of BIRALES, showing its capabilities.

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BIRALES architecture

BIRALES is a bi-static radar [5] [6] [7] which uses the North-South branch of the Northern Cross radio telescope (Fig. 1) located in Medicina (BO) as receiving antenna (RX).

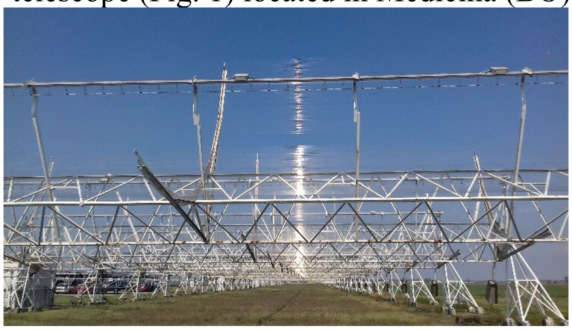


Fig. 1 BIRALES receiving antenna.

Fig. 2 BIRALES current (black) and future baseline (red).

The transmitting one is currently a parabolic dish located in Sardinia with a baseline of about 580 km. A new transmitter (TX), which will guarantee further performance increases, is under construction and will be installed closer to the receiver, forming a 250 km baseline. The new TX has been designed to work perfectly coupled with the RX and aligned as much as possible at the same terrestrial meridian of the RX, in order to maximize the overlap of the two antenna beams. The location identified for the transmitting antenna is 250 km southerly, as reported in the Fig. 2. The reduced baseline will also grant an increase in sensitivity. The receiving antenna has a collective area of about 11,000 m^2, and it is composed by 64 parallel parabolic cylindrical reflectors with 256 receivers installed on the focal lines (4 receivers per focal line).

Two types of observations are foreseen [8]: survey mode, for catalogue updating, observation of uncontrolled re-entry of large objects and monitoring to avoid collisions, and high-sensitivity mode, to observe fragmentations events and detect small objects (down to a few centimetres). The new TX is designed to adjust the Field of View (FoV) and gain according to the specific observation requested. In survey mode, the 64 cylindrical reflectors of the Northern Cross are collected in 8 groups of 8 cylinders, regularly spaced in elevation in order to obtain a coverage of the sky of about 45 deg in the N-S direction (each individual group of 8 antennas has a FoV of about 7x7 deg). Simultaneously, the TX is switched to the survey configuration mode, in order to have the same irradiated sky area of 7x45 deg (Fig. 3).

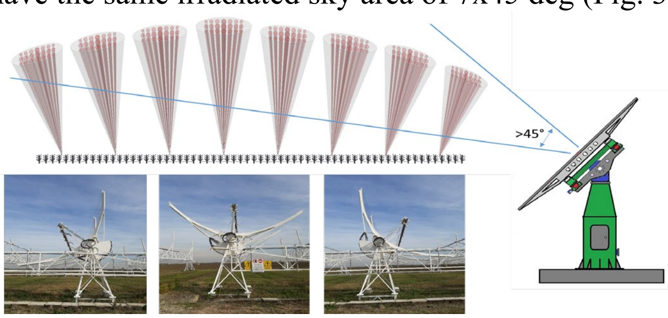


Fig. 3 BIRALES in survey configuration mode.

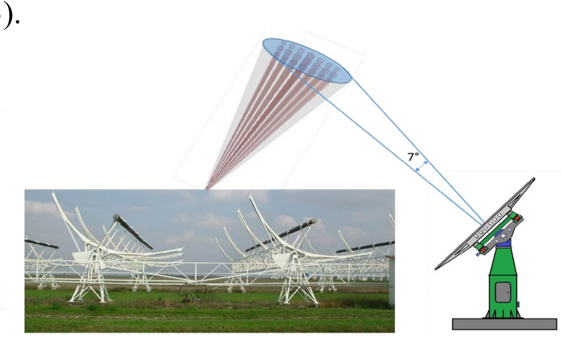
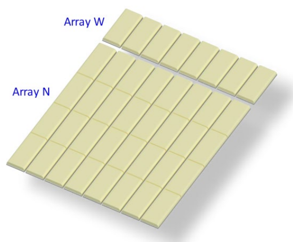


Fig. 4 BIRALES in high sensitivity mode.

In the high-sensitivity mode, the 64 cylindrical parabolic reflectors of the Northern Cross are pointed at the same declination to increase the antenna gain. At the same time, the transmitting antenna is switched to the high-sensitivity mode, increasing the gain and reducing the beam width at 7 deg (Fig. 4).

The selected architecture for the transmitting antenna is a patch array architecture (Fig. 5), composed of two sub-arrays which can be controlled to different beam apertures based on search and tracking operations (Fig. 6). The narrow beam sub-array is composed by a matrix of 8x4 antenna elements; each antenna element of the narrow beam array can sustain more than 312.5W in continuous wave (CW) mode. The wide beam sub-array is composed of a matrix of 1x8 antenna elements; each antenna element of the wide beam array can sustain more than 1.25KW of CW power. Considering the very demanding functional requirement for BIRALES, the antenna arrays and elements have been designed to optimize power factors, reflections, lobes, beam directivity and performance. The Antenna Control Unit (ACU) is installed on a two-axes pedestal able to tilt and rotate the antenna on azimuth and elevation axes. The implementation of a two-axes pedestal allows to relocate antenna beams and redirect monitoring and tracking waveforms to different sky areas (Fig. 7).



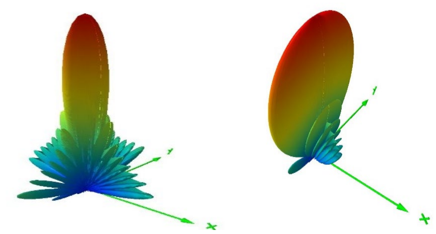
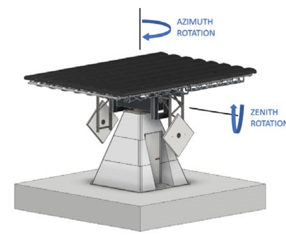



Fig. 5 Transmitting patch array antenna. Fig. 6 narrow (left) and wide (right) beams. Fig. 7 Transmitting antenna.

The new transmitting antenna will be fed by a power amplifier, able to provide an RF power up to 10 kW. Since the power amplifier is intended to operate continuously (24/7) in automatic and remote mode, the design needs to take into account the robustness and some redundancy criteria. The power amplifier will operate with two different modulations: continuous wave (CW) and pulse compression chirp modulation.

Radar performance

A simulation is carried out to evaluate the performance of the new configuration. In particular, it is fundamental to assess the importance of setting the transmitter station along the same meridian as the receiver one. To this purpose, the catalogue maintenance capability is examined in two configurations: the first configuration involves no misalignment (0 deg) between the transmitter and receiver meridians, while the second configuration introduces a misalignment of 0.2 deg between them. For both cases, a baseline of 250 km is considered. The study is conducted through the SpaceCraft and Objects Observation Planning (SCOOP) software, which, given a space objects catalogue, an analysis time window and the stations composing a survey sensor (like the ones involved in a bistatic radar), computes the observable transit. The space object catalogue is generally provided through the Two-Line Elements (TLEs), automatically downloaded from Spacetrack website, of the targets required by the user.

The simulation regards an analysis time window ranging from 00:00:00 of March 20th to 23:59:59 of March 26th, 2023 (according to a UTC time coordinate). The receiver station is considered pointed towards the zenith direction, with a FoV of 7x45 deg (7 deg in azimuth and 45 deg in elevation), that is in the survey operational mode. Both the transmitting stations are evaluated considering a 7x45 deg FoV, and three North pointing elevations are investigated: 45 deg, 60 deg and 75 deg. Results are shown in Table I and Table II, for the 0 deg and 0.2 deg offset from the receiver station meridian respectively. In particular, the number of detected objects, the number of transit and the median detection duration are reported.

Focusing on Table I it is possible to observe that the higher the pointing elevation, the larger the number of both detected objects and transits. Comparing Table I and Table II results, it is possible to observe that a 0.2 deg longitude offset with respect to the receiver meridian deteriorates the detection rate, that is the contribution to space objects catalogue maintenance.

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Tab.I 0 deg offset case.

Pointing elevation	Number of objects	Number of transits	Median duration
45 deg	738	1147	7.1 s
60 deg	968	1889	5.5 s
75 deg	985	2040	4.8 s

Tab.II 0.2 deg offset case.

Pointing elevation	Number of objects	Number of transits	Median duration
45 deg	722	1104	7.4 s
60 deg	788	1321	6.6 s
75 deg	739	1221	6.4 s

Conclusions

This article describes the transmitter architecture of BIRALES. Numerical simulations highlighted that placing the transmitter station along the same meridian as the receiver one would represent a remarkable plus in terms of contribution to the building-up and maintenance of the space objects catalogue.

Acknowledgement

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