ON THE USE OF LONG-RANGE RADARS FOR SPACE SITUATIONAL AWARENESS: AN EXPERIMENTAL TEST

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ABSTRACT

This paper reports on the results achieved in an experimental test conducted with the Selex ES RAT (Radar Avvistamento Terrestre) 31DL/M long range radar in February 2012. The objective of the test was to determine the capability of the radar of detecting and tracking Low Earth Orbit (LEO) satellites without modifications of the sensor hardware or software. The test have been prepared and conducted in the frame of the Company initiatives dedicated to the Space Situational Awareness (SSA) program and in particular for the development of a *dual-use* function for the detection and tracking of space or orbital debris.

1 INTRODUCTION

Space Situation Awareness (SSA) is a strategic capability for any space-faring nation.

Its main goals are:

- To protect national space assets from collisions with space debris.
- To monitor re-entry objects in order to provide alerts in case of danger.

Currently, Italy, as well as the rest of Europe, is strongly dependant on (North American Aerospace Defense Command) NORAD support to protect its main space assets.

The key national and European space agencies (ESA, ASI, etc.) are now facing the huge challenge of gradually becoming self-sufficient in the SSA task, cooperating with the US in producing an integrated international space surveillance network.

Selex ES is undertaking a large experimentation task, aimed to the following objectives:

1. Demonstrate some initial space sensing capability exploiting existing national radars produced by the company with minimal tweaks and adjustments. Specifically, a monostatic detection experiment of space object has been conducted using a RAT31D/L sensor, and will be described in the remainder of this paper.
2. Demonstrate an initial integration capability via cooperation with Istituto Nazionale di Astro Fisica (INAF), setting up a bistatic experiments exploiting national Radio-telescopes as receivers.
3. Illustrate key concept and guidelines, as well as a feasibility study, of a new sensor suite capable of granting, on the long run, some autonomous space surveillance capability.

The rationale for selecting the RAT 31DL/M sensor is essentially its capability of high elevation beam pointing, its flexibility in waveform management and the remarkable combination of antenna gain and transmitted power. It has to be noted that during the last years radars have became very important tools for planetary science and space debris investigation (see as an example [1]). In comparison with optical telescopes, radar measurements benefit of some advantages since they can operate independently of weather, day-night conditions and illumination of the target by the sunlight. Another advantage is given by the full control of the transmitted signal used to illuminate the target. While other astronomical techniques rely on passive measurement of reflected sunlight or naturally emitted radiation, radars are able to transmit a coherent signal of well-known characteristics. From the comparison between the characteristics of the transmitted signal and those of the received one, it is possible to deduce some physical and dynamical properties of the target.

2 TEST SETUP

The test was prepared and performed in the Rome site of the Company during an integration phase of the sensor and without any impact on the schedule of the radar program. The target selected for the trials was the International Space Station (ISS). To achieve the goal, the following activities have been accomplished:

1. A prediction tool, based on NASA published algorithms, has been realized In order to define a surveillance volume sector (and a set of elevation pointings) for the sensor. A description of this tool will be given section 3.
2. The prediction on range, azimuth and elevation of the ISS has been used to define a proper setup of the radar. The critical kinematics of the ISS required a specific setup, that will be detailed in section 4.

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3. The test was executed in the timeframe on 21-Feb-2012 and repeated on 24-Feb-2102. The radar plots were recorded using the sensor facility and stored on file for further analyses. Results are shown in section 5.

3 SSA-LAB SIMULATION SUITE

The test preparation has been supported by the performance predictions provided by a Selex ES proprietary analysis tool: SSA-Lab, which is a Matlab script, designed for this purpose, which incorporates orbital models as well as radar models.

The SSA-Lab tool is based on:

- NASA published algorithms (SGP4) for satellite orbital calculations
- Radar modelling equations scripts for radar performances predictions.

It allows for the space observation planning via properly defined radar systems, and produces helpful performance predictions in terms of detection opportunities and optimized beam pointings.

Fig. 1 describe the graphical user interface of the SSA-Lab tool. It allows for the direct download of the most updated Two Line Elemencts (TLE) from the NORAD catalogue; then, the selected space object are propagated, via NASA SGP4 orbital model, for the required timeframe. The radar sensor to be used for the detection can also be extensively modelled, thanks to the embedded radar simulation scripts, which originates from decades of experience of Selex ES in the radar engineering.

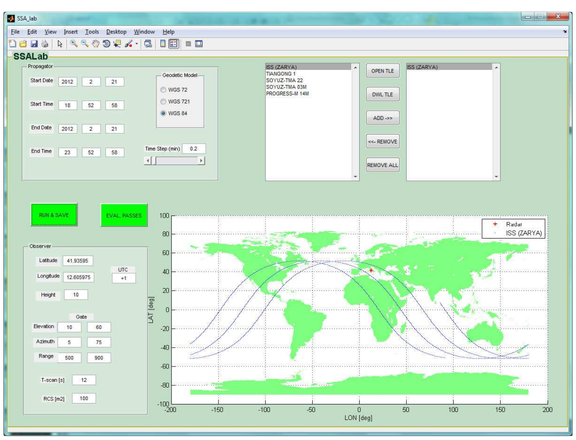

Figure 1. SSA-Lab user interface

Based on the sensor position, radiation constraints and Blake chart, the expected probability of detection of foreseen passes is calculated. Fig. 2 shows an example of output.

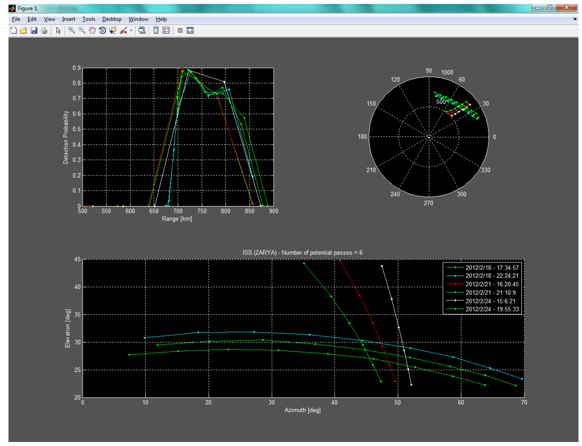

Figure 2. SSA-Lab output example

The preliminary performance prediction analysis is based on the following hypotheses:

- The RAT 31D/L timing, waveform and processing have been optimized for space objects detections
- The RAT 31D/L is placed in the Rome site
- The Radar Cross Section (RCS) and orbital parameters of identified targets are those currently contained in the NORAD Satellite Catalogue

For the first test, the International Space Station (ISS) has been selected, due to its large radar cross section which let us focus on the test procedure and algorithms optimization rather than on some detection issue.

Tab. 1 reports the ISS key orbital parameters.

Table 1. ISS orbital parameters.

Epoch start: 1998-11-20 06:40:00 UTC				
Orbital Parameters				
Periapsis	Apoapsis	Period	Inclination	Eccentricity
384.0 km	396.0 km	92.0 minutes	51.599998°	0.01538

Fig. 3 reports the results of the SSA-Lab performance prediction for the ISS passes, as seen from the Rome site in the March 2012 timeframe.

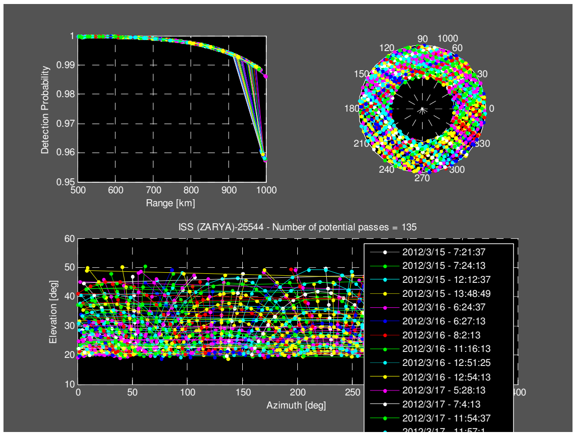

Figure 3. Detection probability of the ISS passes over the RAT 31DL/M site.

4 RADAR TUNING AND OPTIMIZATION

The scenario is composed by targets lying at distances longer than the RAT 31DL/M instrumental range.

The target expected radial speed is between 2000 m/s and 7000 m/s. It causes a range migration of several range cells during the dwell time. Furthermore, the Doppler mismatch causes a degradation of the pulse compression, which is shown in Fig. 4.

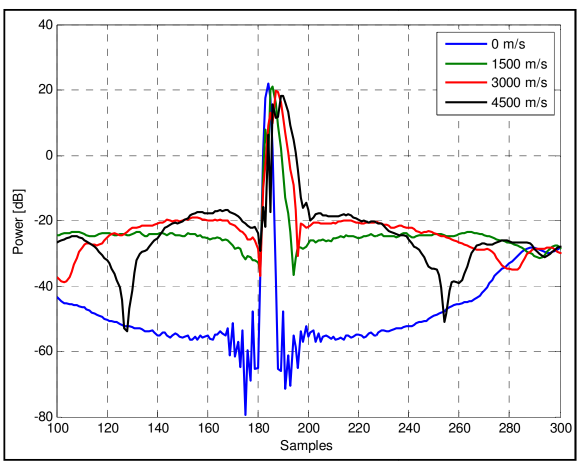

Figure 4. Pulse Compression degradation due to the target speed.

For these reasons the following radar mode has been selected:

- Radar operational mode: three bursts at three different Pulse Repetition Frequencies (PRF).
- Primary Threshold: Fixed (No clutter is expected).
- Secondary Binary Threshold (how many primary detections are needed to declare a target): 2 (The range cell migration does not allow to use higher values)

The combination of sub-optimal secondary threshold and pulse compression degradation causes an additional 5 dB of processing losses with respect to the radar performances against conventional targets.

The beam pointings have been optimized, based on outcomes from Fig. 3, and the obtained coverage volume is reported in Fig. 5.

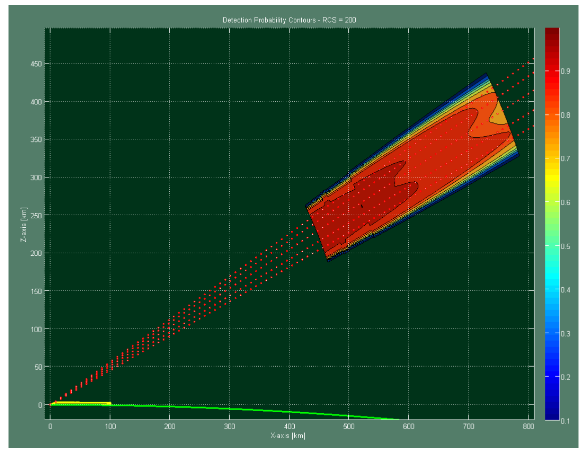

Figure 5.RAT 31DL/M coverage volume after specific "space-debris" setting up.

5 RESULTS

From a detection point of view, the test can be deemed successful. The ISS has been detected at the expected range-azimuth coordinates, consistently with radar expected performances. Evidence of this is provided in Fig. 6.

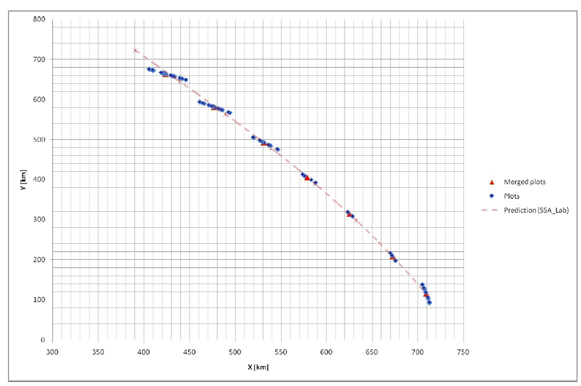

Figure 6. Measured Data versus expected coordinates.

Some issues have been observed on the recorded elevation: an altitude ceiling is currently implemented in the RAT 31DL/M processing, in order to discard detections that do not pertain to the air vehicles domain. This ceiling shall be removed in order to correctly manage orbiting targets.

The received signal power is also consistent with the ISS expected RCS, which is reported by many sources, as well as by the NORAD itself, as being close to 200 sqm.

RCS estimates based on the RAT 31DL/M measurements are depicted in Fig. 7.

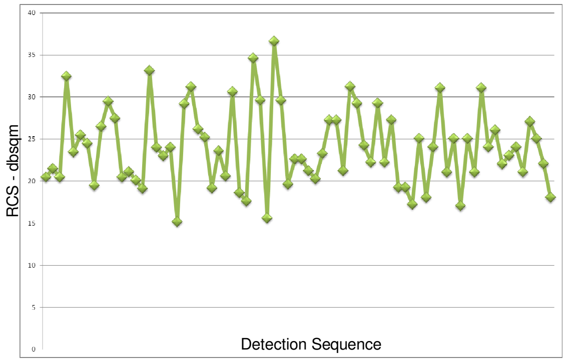

Figure 7. ISS RCS estimation.

6 CONCLUSIONS

The ISS detections are in accordance with the predictions. This shall be mostly regarded as a successful validation of the test procedure and approach.

New acquisitions shall be made in order to corroborate results. Moreover, there is a significant margin on the received signal, and smaller objects may be detectable.

In this context, Selex ES continuing efforts prove that the expertise and skills owned in the company and in the national academic and state agencies are adequate to support a significant Italian role in any future European SSA system.

7 REFERENCES

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