TECHNICAL ANNEX
FOR
Improvement of the BIRALES performance: data processing and system automatization
WP8 2-3SST2018-2020

Contest
The number of manmade objects orbiting the Earth has dramatically increased during the last years, posing a serious risk for space-based activities. Most of the objects currently orbiting the Earth are classified as “space debris”, that comprise inactive satellites, discarded launch stages and fragments originated from satellite breakups and collisions. An international effort is currently being devoted to monitoring and predicting the debris trajectories in order to avoid space collisions that could threaten space missions, i.e., operative satellites or manned spacecraft. Within this frame, an accurate estimation and propagation of space objects trajectory is instrumental to avoiding in-orbit collisions. In order to fulfil such an objective, accurate orbit determination procedures shall be performed, by processing measurements obtained through on-board and ground means, which can be split among optical, laser and radar sensors. Focusing on the last class, this can be subdivided between tracking and survey sensors: the former detects an object and move the pointing along the passage, in order to follow it; the latter instead keep the pointing fixed and just detects signals reflected by one or more objects entering the receiver field of view (FoV).
To meet this requirement, the European Commission has initiated the European SST (Space Surveillance and Tracking) Support Framework initiative. Besides monitoring the space environment, the European SST consortium is acting to provide Europe with the capacity to process the data resulting from the European network of sensors, with the aim of designing Collision Avoidance Manoeuvres (CAM), predicting the Re-Entry (RE) of orbiting objects in Earth’s atmosphere, and identifying the occurrence of satellites FraGmentations (FG).

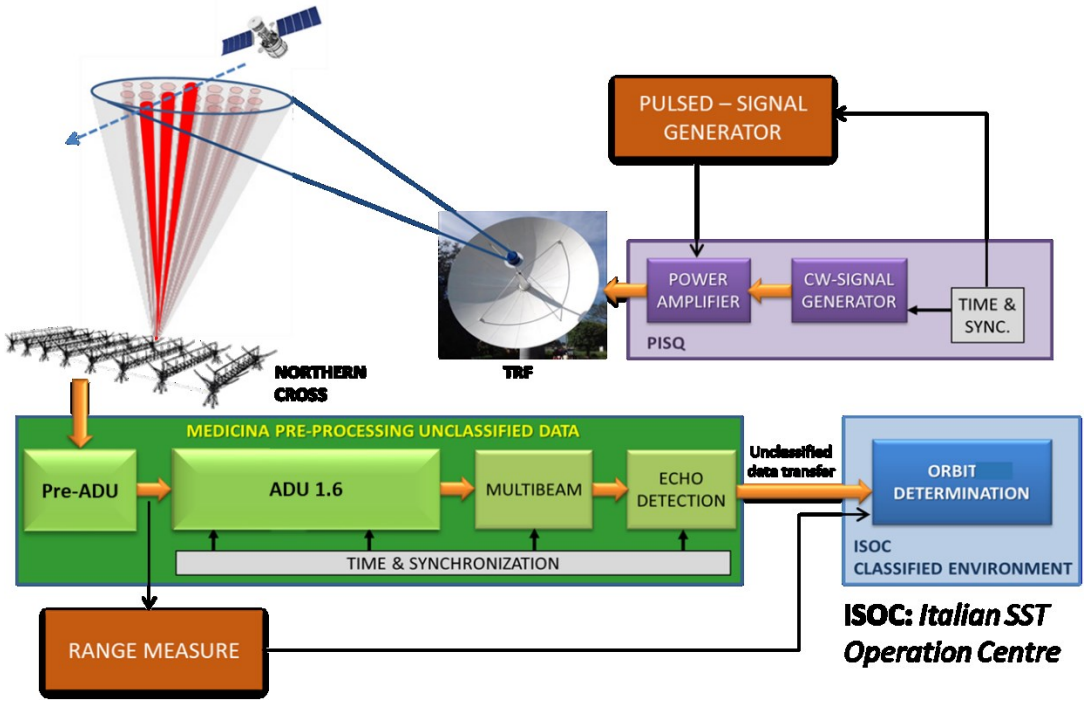
Introduction
BIRALES is a new radar for the monitoring of orbiting objects in LEO (Low Earth Orbit) in survey mode. The first two phases of the BIRALES upgrade were completed within the Grant Agreement N. 713762, 3SST2015 and Grant Agreement N. 785257, 2-3SST2016. The last phase of the BIRALES upgrade is described in the new Grant Agreement N. 952852, 2-3SST2018-20 and it provides an increase of the radar performance. New receivers have to be installed on the Northern Cross and the current back end (multibeam and space debris detection system) must be updated accordingly.
The subcontract described in the Grant Agreement provide the “Improvement of the BIRALES performance: data processing and system automatization”. In particular, after installing the new 128 receivers, the following activities must be carried out:

- Design a firmware for the new hardware based on TPM v1.6 boards.
- Design a multibeam to perform observation measure using half the N-S branch (128 antennas) of the Norther Cross;
- Update of the space debris detection system;
- Upgrade the signal processing architecture;
- Upgrade the calibration procedure of the system;
- Validate the new system and assess its accuracy and performance.

This document describes the actions to support the upgrade phases of the BIRALES Italian sensor as described in Grant Agreement N. 952852, 2-3SST2018-20.

System architecture
Due to the large numbers of receivers (256 = 4 receivers each focal line x 64 parabolic cylinder reflectors), the Field of View (FoV) can be populated with many independent beams. When an object transits inside the antenna FoV, beams are

illuminated by the reflected radio waves. By looking at the beam illumination sequence, it is thus possible to estimate the ground track of the transiting object, with a higher level of detail with respect to a single-beam system. The information about the sequence of illuminated beams allows to discern the trajectory of the object in terms of right ascension and declination (or alternatively in terms of azimuth and elevation). The acquired data should be processed by means of a data acquisition system, which digitally assembles measured radar echoes using an FFT in spatial domain in order to calculate the signal present in each beam. Doppler shift, the illumination time, and measured power intensity associated to each beam will be thus available.



Description of Work

According to the Grant Agreement N. 952852, 2-3SST2018-20, the purposed of this subcontract are:
P1) To improve the BIRALES performance and data processing;
P2) To design and realize a broadband multibeam, starting from the actual BIRALES configuration (8 antennas and 32 receivers);
P3) To extend it to the 512receivers (128 antennas) with the possibility to modify the architecture of the array modularly;
P4) The multibeam must be able to change the architecture according to the array configuration setup (see R4).
The schedule of the ACTIVITY with the major Milestones is as follow:
A1) To design the firmware for the TPM 1.6 ADU board similarly the one used with the TPM 1.2 board with the following capabilities:

- A Digital Down Conversion within the ADC chip;
- Channelize the time domain data to a frequency channels bandwidth of about 78kHz;

A2) To upgrade the Software MultiBeam to manage higher number of beams;
A3) To upgrade the data packet receiver to work with the newest Python 3 packages required by the TPM 1.6 and to manage the higher data rate due the increased number of Antennas/TPM boards;
A4) To manage dependent and independent BEAMs for the array as a function of the array configuration (this implies also to upgrade the initialization procedure to apply the desired array configuration);
A5) To upgrade the detection block according to the new multibeam system;
A6) To upgrade the BIRALES user tool to support multiple independent configurations, concurrent observations and new paramters;

A7) Implement an offline script which can read raw data and apply the following operations: calibration, channelization using a configurable number of channels, correlation using a configurable integration time and saving this data to disk for further processing.
A8) Include an additional processing block which generates a signal covariance matrix having predefined frequency resolution and integration time. This matrix should be generated per processing block and saved to disk if a space debris is detected in the detection stage
A9) To update the detection block to manage scenarios in which multiple targets are crossing the field of view simultaneously;
A10) Speed optimization of the detection block
A11) Design, implementation and testing of a ranging pipeline that use the same multipixel configuration to determine the range of detected echos. This pipeline must be capable of detecting the reflected modulated pulse of the transmitter within a 5 MHz range (probably through a timed channel selected mechanism in the firmware)

The following requirements must be satisfied:
R1) The system must be capable of packing and formatting the results to be sent to the Debris Detection Block;
R2) The system must be capable of detecting which Beam has been illuminated by the debris echo as a function of SNR and the Doppler Shift;
R3) The system must be capable of providing a text file containing the Observation Epoch, the Doppler Shift, Beams SNR and antenna's pointing angles (TDM format already implemented in the first version of the upgrade).
R4) The following configurations should be supported:

- R4.A) Multibeam formed by an array of 128 parabolic cylinder antennas and 512 receivers
- R4.B) Multibeam formed by an array of 64 parabolic cylinder antennas and 256 receivers.
- R4.B) Multibeam formed by an array of 32 parabolic cylinder antennas and 128 receivers;

R5) The system must be able to store covariance matrices associated to the detections. In particular, the following conditions must be met:

- R5.A) The user shall be able to modify both the sampling frequency and the integration time used to generate the signal covariance matrices
- R5.B) The data shall be saved in binary format, containing the covariance matrices and the corresponding time-tags.

R6) Range measures should be included in the TDM generated debris files.
R7) A procedure able to properly read the afore-mentioned binary data shall be provided in the system documentation.
Commissioning of the system are required, using dedicated days to test all the architecture. INAF will guarantee the use of the transmitter to perform these tests.
Periodic telecon will also be held to verify the activities progress.

List of deliverables		
Deliverable Number	**Deliverable Title**	**Due Date**
D1	Firmware for the TPM 1.6 ADU board similarly the one used with the TPM 1.2 board	T0+9
D2	Upgraded Software MultiBeam	T0+9
D3	Upgraded data packet receiver to work with the newest Python 3 and C++ libraries required by the TPM 1.6	T0+9
D4	Upgraded Detection block	T0+9
D5	Upgraded PBIRALES user tool	T0+9
D6	Commissioning report	T0+10
D7	System User manual	T0+10
D8	Software for the signal covariance matrix pipeline	T0+4