INITIAL OPERATIONS OF THE BREAKTHROUGH SPANISH SPACE SURVEILLANCE AND TRACKING RADAR (S3TSR) IN THE EUROPEAN CONTEXT

Rafael Casado Gómez(1), Jacobo Martínez-Villa Salmerón(1), Piermario Besso(2), Marco Alessandrini(2), Gian Maria Pinna(3), Maria Antonia Ramos Prada(4),

(1)Indra Sistemas, Crta Loeches 9, 28850 Torrejón de Ardoz, Madrid, Spain, Email: {rcasado, jmartinezv}@indra.es
(2) ESA/ESOC, Robert-Bosch-Str. 5, 64293 Darmstadt, Germany, Email: {Pier.Mario.Besso, Marco.Alessandrini}@esa.int
(3) ESA/ESAC, Camino bajo del Castillo, 28692 Villanueva de la Cañada, Madrid, Spain, Email: GianMaria.Pinna@esa.int
(4) Centro para el Desarrollo Tecnológico Industrial, C/ Cid 4, 28001 Madrid, Spain, Email: mariaantonia.ramos@cdti.es

ABSTRACT

The S3T Surveillance Radar (S3TSR) is a radar system developed by Indra within a project funded by Spanish Administration and technically managed by ESA. It is a ground-based radar, based in a close monostatic configuration, operating at L band and capable of providing positional information of orbital objects. The radar provides automatic surveillance and tracking of space objects in Low Earth Orbit (from 200 km to 2000 Km of orbit height above Earth). This is performed by continuously scanning the instrumented Field of Regard (FoR), generating track reports for all detected objects. Surveillance and tracking of LEO objects are activities with increasing strategic value.

Based on these tracks, the S3TOC (Spanish Space Surveillance and Tracking Operation Centre) is generating a catalogue in which objects are updated every pass. The radar architecture is scalable and the performances of the radar can improve by just adding building blocks (tiles). Both, transmission (Tx) and Reception (Rx) antennas are separated electronically scanning arrays (AESA). The Tx antenna has high power amplifier modules based in GaN technology to improve efficiency and reliability. The Rx modules use direct RF undersampling technology. Rx beamforming architecture is fully digital, each antenna input is digitized to maximize functional flexibility, and entirely over optical fibre, making possible the simultaneous formation of multiple Rx radiation patterns. The modular approach of the system allows a high reliability, robustness and resilience, due to the soft-failure design and the ease of maintenance, with the possibility of hot-plugging in key sub-systems.

Keywords:
Radar, Space Debris, Scalable Tile-based Architecture, Phased Array, Space Surveillance and Tracking (SST), Spanish SST (S3T), Spanish SST Surveillance Radar (S3TSR) AESA, Gallium Nitride (GaN), Digital Beamforming, Direct RF sampling.

1 INTRODUCTION

1.1 The space debris problem

The space debris population has drastically grown since the first launch of an artificial satellite in 1957 and it has become a serious threat to the security, safety and sustainability of space activities [1]. As of 1st January 2017, around 22,000 objects were tracked by the US Space Surveillance Network (SSN). Just a 4% of those objects are operational satellites while the rest are qualified as space debris. In addition, the number of particles between 1 and 10 cm in size is estimated to be around 500,000 and a figure of over 100 million particles smaller than 1 cm has been set.

Various detrimental consequences are currently taking place due to the proliferation of space debris, such as in-orbit fragmentations, collisions or the uncontrolled re-entry of objects into the Earth's atmosphere. This has, in turn, adverse effects on the ground- and space-based infrastructures, so that it has become necessary to permanently survey and track man-made space objects to provide satellite operators with early conjunction warnings, in order to manoeuvre operational satellites and reduce the collision risk, or to provide civil protection entities with information of uncontrolled re-entries of large objects which may not disintegrate in the Earth's atmosphere.

1.2 Spanish contribution

In this context, CDTI is coordinating the development and operations of the Spanish Space Surveillance and Tracking (S3T) system in collaboration with the Spanish Ministry of Defence, among others. In addition, the European Space Agency (ESA) is supporting CDTI in the development and procurement of the S3T System, via industrial contracts awarded to the Spanish Industry.

The present article focuses on the main LEO sensor of the S3TSN, the S3T Surveillance Radar (S3TSR), which has been developed by Indra with the collaboration of other

Spanish companies. The S3TSR is specifically designed for the detection of space debris in the LEO orbital regime (200-2000 km). It is an advanced scalable radar developed in Europe, by European industry, with full European know-how and key European technologies.

The S3TSR provided the first tracks at the end of August 2018, using in a reduced test configuration with full transmitter and one receiver module. The analyses of these first tracks confirmed the expected high performances of the final configuration regarding number of detected objects and accuracy, both in range and angular measurements. During the last quarter of 2018, an incremental installation approach was followed, with intermediate testing campaigns that corroborated the foreseen evolution in performance, in-line with the number of RX modules added, and, at the same time, proved the scalability and flexibility of the design by using the radar in various configurations. The S3TSR has successfully passed the final acceptance in December 2018 and is presently undergoing the operational calibration and validation campaign. It is already providing measurements of very high quality to the S3TOC and supporting the generation and maintenance of the catalogue of space debris.

2 S3TSR DESCRIPTION

2.1 Radar System Requirements

The S3TSR was designed to fulfill system requirements stated by ESA and summarized in the following points:

- It had to be a scalable system with straightforward upgrading evolution from a first configuration (the one that is currently in operation) to a Full Size (FS) configuration, in possible successive intermediate steps (see figure 2). All radar components for a given configuration must be reusable for subsequent upgrades.
- Track-While-Scan (TWS) capability for LEO objects passing through a Field of Regard (FoR) defined as a volume with a mean azimuth of 180º (toward South), a mean elevation of 60 degrees and swept angle span, referred to main antenna planes, not lower than ±43 degrees in left-right direction (U-angle), and not lower than ±15 degrees up-down direction (V-angle). See figure 3. The revisit time, that is the time used for exploring the full FoR, should be not greater than 10 seconds.
- The radar had be able to continuously work in an open-loop mode, detecting and providing tracks of objects with no a-priori information about their orbits. Tracks (collection of radar plots caused by a given object) are to be sent in real time to the S3TOC where they are to be processed as the main input of the LEO catalogue generation and updating process.
- Detection and tracking capability of the radar for the first and the full configurations has been specified by ESA with reference to a filtered version of MASTER Catalogue Model. Specifically, the FS version has to be able to provide tracks in a 24 hours period for at least the 78% of the reference catalogue. For the first version, the requirement is to provide tracks in this period for at least 1000 objects.
- Accuracy of raw object positional data (plots) was stated as 1-σ values for angle error (angle formed by the vectors from radar to real position and from radar to estimated position), range error and, as a goal, radial speed error.

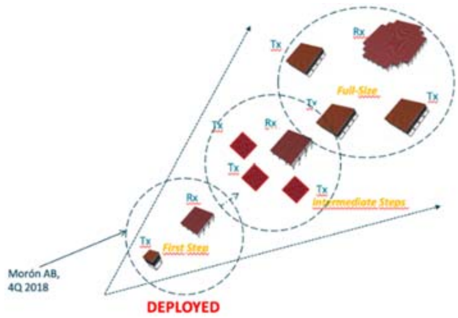

Figure 1. Roadmap of S3TSR, made possible by its scalable design.

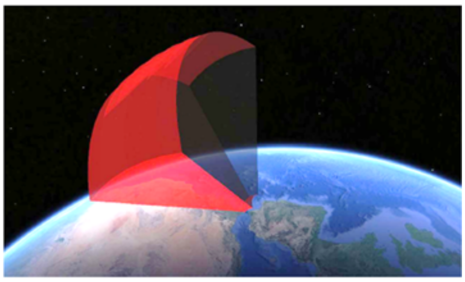

Figure 2. Scaled view of S3TSR FoR for its current configuration in Morón AB (near Seville).

The set of requirements imposed by ESA, including the operation in L Band, was the result a previous project led by ESA [2].

During the design phase, several detailed analysis were carried out based on specific catalogue propagation programs and a radar simulator able to estimate the detection and tracking performances for the different evaluated architectures and antenna size configurations. They were performed not only for radar design but also to assess the suitability of the specified FoR. For example, it was made clear that for a given FoR aperture in U-V angles, tracking capabilities are enhanced with a mean elevation of the FoR of 60 degrees with respect to a more vertical orientation of the FoR.

2.2 Design choices and main characteristics

Main decisions and features regarding S3TSR architecture are summarized below:

- **Close-monostatic architecture**: Transmitter and Receiver antennas are different, although their separation does not seek to achieve a bistatic radar operation. The reasons to employ different antennas for the two functions, Tx and Rx, are the overall reduction of losses (for example, duplexers are avoided), the reduction in mechanical, electronic and cooling complexity, and the flexibility for designing the two antennas with different characteristics.

  The Rx building holding the Rx Array also houses the Processing and Control Rack (PCR) and the facilities for a possible local operation. The Tx building supporting the Tx Array includes an associated Tx Distribution Rack (TXDR) and some auxiliary elements for Tx Antenna Calibration.

  The radar interfaces from Rx to Tx facilities are reduced to a redundant fiber optic Ethernet link for control and monitoring of all elements inside the Tx building and three RF cables, one to drive the low level Tx signal and two for auxiliary RF signals required for calibration. These signals are generated by the PCR as well as oscillator and test signals for the Rx array and its calibration.

  The separation between Tx and Rx sites is driven by the desired protection of receivers during the transmission time. In order to increase isolation, the Rx site is placed north of the Tx array, the transmitting direction being south.

  Specifically for the current configuration, housing of Tx and Rx elements has been solved with provisional infrastructure consisting of a 20 feet shelter mechanized for holding the Tx array and associated elements, and a modular metallic infrastructure of about 9 x 9 meters in plant, and maximum height of 7 meters (see figure 4). Separation between both arrays centers is about 90 meters.

  For the FS configuration the foreseen sizes of Tx and Rx Buildings are, respectively, 10 x 10 and 22 x 22 meters in plant, maximum height of about 8 (for the central Tx array) and 15 meters. Required separation is estimated not to be greater than 200 m.

Figure 3. Tx Building (shelter at left site) and Rx Building (right side) of current configuration of S3TSR at Morón AB.

- **L radar band operation**: The radar can operate at discrete frequencies (more than 250) spread over the L radar band ranging from 1215 to 1400 MHz. Operation in L band was a best choice decision in the trade-off considering hardware complexity, efficiency, cost, capability of achieving high transmission power, propagation losses and radar cross section for objects of interest.

- **Antennas design for very broad angular scanning angles**: Separation between antenna elements for both Tx and Rx Antennas has been selected for allowing a grating-lobe-free maximum scanning angle exceeding the specified FoR for the upper limit of the operation frequency band (1400 MHz). Since this scanning capability depends on the ratio S/λ, larger FoR, for example exploring ±60 degrees in U-angle, are possible by setting operation frequencies at the lower half of the band.

- **Optimized design regarding Tx/Rx Antenna sizes and number**: Radar equation states that detection capability is mainly driven by the combination of transmitted power, Tx and Rx antenna gains (or equivalently, antenna aperture) and the energy integration time, which is the product of the transmitted pulse length and the number of transmitted pulses integrated by signal processing techniques. For an active scalable Tx array with High Power Amplifier (HPA) modules directly plugged in the antenna frame, transmission power is proportional to the Tx antenna aperture, so both terms of radar equation are correlated. Since radar exploitation cost is mainly driven by electrical consumption, which is primarily caused by HPA modules, on one hand it is a goal to reduce Tx antenna size as much as possible, yielding a broad Tx antenna beam pattern. A wide Tx beam is good because it is possible to explore the whole FoR with a lower number of sequential Tx beam shootings, thus reducing the revisit time (or equivalently, for the same revisit time it can be increased the number of transmitted pulses). Low Tx power and gain must be compensated by designing an Rx antenna with very high gain, that is, very narrow beams, which has the additional advantage of enhancing angular accuracy and resolution. On the other hand, a very large Rx antenna implies a big number of receivers increasing cost and beamforming complexity. Additionally, great difference in Tx/Rx beamwidths causes high two-way beamshape losses unless several simultaneous Rx beams are synthesized and arranged to cover the angular coverage of one single Tx beam. The simultaneous beamforming of a large number of Rx antenna patterns is feasible with full digital beamforming, obviously up to some limit imposed by current FPGA capabilities and data throughput. Regarding pulse length, limitation is driven by duty cycle and minimum specified detection range. Increasing the number of pulses in the Tx beam burst is the cheapest way to gain detection capability, but it has the drawback of increasing the revisit time. A limit in the practical number of integrated pulses is also imposed by the movement of the objects.

For detection requirements not too demanding (as for example, those specified for the first version), it is possible to combine all previous terms arriving to a solution based on a single couple of Tx and Rx arrays. However, as the required detection capability increases it is necessary to get more Tx power and Tx antenna gain, so the beamwidth of Tx pattern is reduced making not possible to fulfill the revisit time constrain with a minimum reasonable number of integrated pulses. To overcome this problem, a first solution implemented in the S3TSR is the capability of operating with "double Tx Beams". This technique is based on generating transmission pulses consisting of two consecutive sub-pulses with a little gap between them, with different carrier frequency and/or modulation. The first sub-pulses of all transmitted pulses are steered toward a given direction and by changing phase shifters during the gap time, the second sub-pulses are emitted toward a different direction. During the reception time the Rx array synthesizes Rx beam bundles for receiving echoes from both directions, with the net result of cutting in half the number of Tx beams shootings for covering the FoR, and therefore, the revisit time.

For still more demanding detection capability, that is, narrower Tx beamwidth, the revisit time constrain cannot be met with double Tx beams. The choice of implementing "triple" or "quadruple" Tx beams is discarded because once the limit imposed by duty cycle or minimum detection range is met, increasing the number of sub-pulses implies a reduction of sub-pulse length. Therefore, the only practical possibility for achieving revisit time requirement with very narrow Tx beams is to arrange several Tx antennas transmitting at the same time toward different directions inside the FoR.

Specifically, the S3TSR has been designed to permit the operation with up to three Tx antennas emitting double Tx beams, that is, with up to 6 simultaneous Tx beams. This is the setting required for the foreseen FS configuration (see figure 5). Since Tx array has been designed for scanning the full FoR, theoretically all Tx antennas could be oriented southward, but a better arrangement for reducing deflection losses in U-angle is to dispose them with different heading so as each antenna explores a different region of the FoR. In order to reduce the crossover, the six Tx beams are transmitted with sub-pulses generated with different carrier frequency and/or modulation.

The goal in this approach is to keep a single Rx antenna, because the cost of duplicating the Rx array, due to its size and number of elements, is much higher than increasing the number of Tx antennas. Therefore, main design effort in S3TSR development project has been focused on the digital beamforming process of Rx antenna, with the goal of synthesizing a number of simultaneous Rx antenna patterns great enough for covering the six simultaneous Tx beams with six independently steered bundles of Rx beams. Specifically, the resulting beamforming process can arrange bundles of up to seven Rx beams for covering each Tx beam, that is, a total of 42 simultaneous Rx beams. For each Rx beam, three antenna patterns are formed, a Sum pattern, a Diff-in-U pattern and a Diff-in-V pattern, allowing the estimation of angular coordinates of object detections by monopulse technique. Additional beamforming channels are reserved for configuring omni-like patterns for side-lobe blanking function. In total, the implemented beamforming process of Rx Antenna can output more than 130 simultaneous Rx antenna patterns arranged in different frequency channels. Of course, this capability is only feasible with fully digital FW-based process.

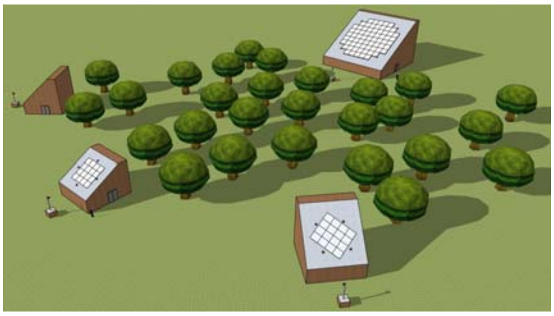

Figure 4. Layout of foreseen S3TSR Full Size configuration (3 Tx Antennas and a single Rx Antenna).

- **Modular and scalable design of Tx Antennas**: The Tx array is built-up by tiling the desired number of the so-called Tx Building Blocks (TxBB). See figures 6 and 7. Each TxBB is a self-contained subarray consisting of a mechanical frame supporting an antenna plane and providing fixings for the active modules, RF cables and passive elements for distributing Tx signal, fiber optic Ethernet cables for control and monitoring, AC distribution cables, hoses and pipes for coolant (water) distribution and cold plates for active modules refrigeration.

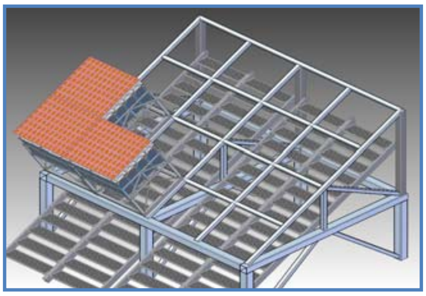

Figure 5. Tiling of 3 TxBB on a supporting structure for building up the FS Tx array.

Figure 6. View of a TxBB and installation of a TxBB on top of the Tx shelter of first configuration (single TxBB antenna).

The antenna plane is an aluminum plate holding the matrix of unitary antenna elements, which are double stacked circular patches inside a hollow cavity. A harmonic filter is incorporated to each radiating element for meeting radiated spectrum requirements. Each TxBB antenna plane is protected by a polycarbonate radome.

The active modules inside the TxBB are arranged in Tx Boxes (TxB). Each TxB comprises a Driver Module (DRVM) and two Dual High Power Amplifiers (DHPA). See figure 7. These two modules are the only LRUs of Tx array.

Both modules use GaN transistors for main amplification stages, with designs seeking maximum efficiency. The DRVM takes the low-level Tx signal resulting from the passive distribution network of the TxBB, and splits it in four ways that are amplified and phase-shifted as required by the control. Each DHPA receives two of the four medium level signal outputted by the DRVM and applies an independent high power amplification to each channel (two inputs-two outputs). Each output is connected to a radiating element of the antenna plane.

The DHPA has been designed for being fed directly with 230 V AC supply. In addition, the DRVM receives its DC supply in a redundant way from the two associated DHPAs, through the same cable used for control and monitoring. This approach simplifies power supply distribution, avoids external AC/DC modules and makes easier all test and maintenance operations on DHPAs.

The only control and monitoring interface required by each Tx Box is a fiber optic Ethernet link arriving to the DRVM. An RF codified trigger signal preceding the Tx pulse, and sent through the same Tx signal cable, is used for synchronizing the different Tx Boxes of the whole Tx antenna. This little trigger pulse is only processed by the DRVMs and is not driven at the input of DHPAs.

From the mechanical point of view, both modules has been designed for an easy and fast replacement, with floating connectors for output signals in the case of DHPAs.

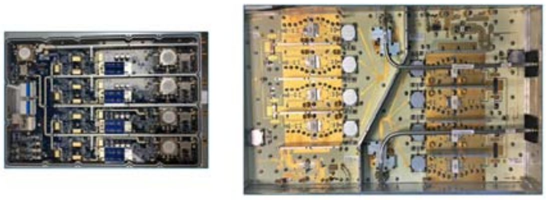

Figure 7. View of RF boards of DRVM (left side) and DHPA (right side).

As previously mentioned, besides the Tx array composed of TxBBs, each Tx antenna sub-system comprises a Tx Distribution Rack (TXDR), which is a standard 19” rack housing other elements related with transmission function: a dual redundant intermediate power amplifier, a 1:16 RF passive distribution network for providing a Tx signal replica for each possible TxBB, and a set of Ethernet switches for the interconnection of control and monitoring links. It also contains elements for Tx antenna calibration.

The TXDR is already prepared for successive scale-up upgrades of Tx array: Adding a new TxBB only requires the connection of a single Tx signal cable from the TxBB to the RF top panel, and the connection of the corresponding multifibre Ethernet cables to the patch panel.

In summary, the design of the S3TSR allows configurations regarding Tx array size from the one currently operating version (single TxBB) to the one foreseen for Full Size version. Finer control of antenna aperture can be performed by sub-populating in number of active modules the TxBBs of the contour.

- **Modular and scalable design of Rx Antenna**: As for Tx, the Rx array is built-up by tiling the desired number of the so-called Rx Building Blocks (RxBB). Each RxBB is a self-contained square subarray consisting of a mechanical frame supporting an antenna ground plane and providing fixings for the active modules, RF cables and passive elements for distributing test and oscillator signals, fiber optic ring cables, AC distribution cables, hoses and pipes for coolant (water) distribution and cold plates for active modules refrigeration. Each RxBB is also fitted with an individual radome.

Figure 8. Partial view of a Rx Building Block (without radome) fully populated with reception modules.

The only active module and LRU in Rx Array is the so-called Multichannel Reception Module (MRM), which provides reception function for four antenna elements. In order to reduce Rx losses for getting minimum noise figure, the antenna elements are directly attached to the mechanical box of the module (see figure 10). When the MRM is inserted in its receptacle by mean of sliding guides, the antenna elements pass through slots in the ground plane.

Since their number is very high and power handle is not an issue for them, a cost-driven design has been adopted for Rx antenna elements, resulting in a printed bow tie type solution.

Each MRM includes four independent RF stages for low noise amplification, filtering and equalizing the signal, as well as splitter and switches for injecting a test signal in the four channels from a common input. The test signal is used for synchronization, calibration and BITE purposes. The four amplified RF signals are A/D converted and the digital samples enter in a high performance FPGA for digital down-conversion and beamforming. Other analogue input of the MRM is a reference oscillator from which the sampling clock for A/D conversion is obtained.

The digital interfaces of the MRM are fiber optic links. All MRMs are interconnected through several redundant high throughput fiber optic links. Each MRM receives from previous MRMs of the same rings the data packages with their contribution to the different beamforming channels, adds the contribution corresponding to their associated four antenna elements, and passes the resulting data package to next MRMs in the ring. This “add-and-pass” method makes possible to grow up the size of the antenna, just by increasing the number of MRMs that are interconnected in a ring. The interconnection topology for all the rings is solved at RxBB level with input and output LCD connectors at left and right side for sewing up RxBBs just with little bridge fiber cables.

As for the DHPAs, it was decided to design the MRM for a direct 230 V AC supply.

Although the heat dissipated by the MRMs or Rx antenna is relatively low, it was considered more suitable a cooling system based on liquid cold plates as in the case of Tx Antenna. In both cases, redundant chillers are placed outside the buildings. The overall cooling solution provides a very silent environment inside Tx and Rx buildings.

Other Rx array design feature that is important for maintenance is the in-operation replacement of MRMs.

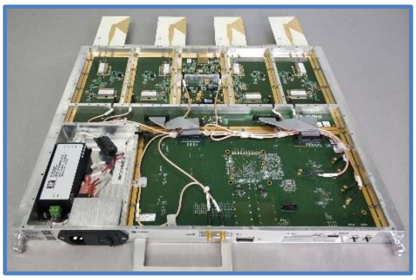

Figure 9. Multichannel Reception Module (single active module of Rx Array).

The Rx array interfaces with the Processing and Control Rack (PCR), which is standard 19” rack inside the Rx Building. It includes the sub-rack for the generation of all signals (Tx, test and reference oscillator) required by the Rx antenna and the up to 3 Tx antennas. It also contains power amplifiers for the reference oscillator and test signal used by Rx antenna, as well as passive splitting networks for both signals. The outputs from this network are available at the top panel of the PCR, ready to be connected to the successively integrated RxBBs.

With all these design choices, the Rx Array of S3TSR can grow up from the current implementation to the foreseen FS configuration (see Figure 11). In addition to tiling the required number of RxBBs, the finer shaping of antenna aperture is achieved by sub-populating in number of MRMs the RxBBs of the contour.

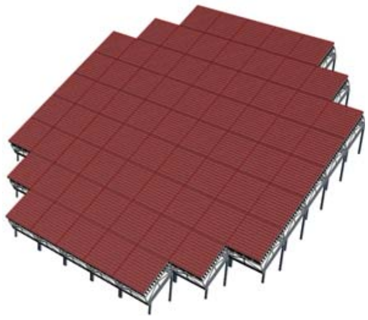

Figure 10. Foreseen arrangement of RxBBs for building up the FS configuration of S3TSR.

- **COTS-based Signal and Data Processor**: Signal and data processing resources are provided by COTS high performance workstations, the same model for both. They are integrated in the Processing and Control Rack.

  The signal processor for the current implementation is based on a single computer (two are required for FS configuration) fitted with a COTS PCIe board with fiber optic links and a high performance FPGA. This board interfaces with the Rx array controlling and receiving the beamforming channel samples from the MRMs. It performs the last stage of beamforming, i.e., the integration of samples from the different rings. Samples for all formed Rx antenna patterns are read and processed by the SW running on host processors through PCIe lanes.

  The output of the Signal Processor are target detections (raw plots) that are sent to the Data Processor (DP). First, a plot correlation process is applied by the DP for merging in an “elaborated” plot all detections for the same object and instant resulting from processing the different Rx beams of the bundle covering the same Tx beam.

  Plots resulting from correlation are the input of the “open loop” tracking process, which is the main task performed by the DP. It consists of identifying the set of plots that are caused by the pass of an orbital object through the FoR, rejecting false alarm plots caused by noise. A recursive Least Square Error minimization process is applied, with a refinement of the track state vector in each iteration.

  Once a track is formed, the collection of associated plot data (measured positions and radar cross section estimation) is formatted and sent to the connected clients.

  The DP also includes a continuous recording and off-line data distribution function. Clients connected to the radar through local or remote links can request raw plot and track data for any time interval within the recorded period.

  Both signal and data processing functions are programmed in standard C/C++ language and run on real time Linux.

- **Antenna Calibration**: Means for automatic (but commanded by user) calibration of all Tx and Rx antennas have been integrated in the S3TSR system (see figure 12). Pneumatic masts with a horn antenna on top are extended when the calibration is required. A test signal is emitted by the horn for calibrating Rx antenna, and in the case of Tx antenna, the Tx pulse successively emitted by each antenna element is received by the horn. Four additional auxiliary horn antennas, mechanically stabilized, are disposed around main antennas and are used for a fine estimation of actual mast horn position, compensating little displacements caused by wind. Calibration is only required as a monthly or even less frequent periodic verification and maintenance process. Time spent for calibration is mainly determined by mast extension and subsequent nesting.

Figure 11. Tx antenna calibration (left side) and Rx antenna calibration (right side) setups

- **Monitoring, Control and Evaluation Tools**: Two user applications, running on specific computers, have been developed for the S3TSR: the Monitoring and Control Workstation (MCW) and the Radar Console Workstation (RCW).

  The MCW is a web-like application for controlling and monitoring the radar. The very few actuations required for S3TSR control and setting (transmission activation, operative mode selection, sensitivity (false alarm rate) control, calibration activation, etc.) can be commanded from the MCW. A mimic-based HMI with several nested pages is used for displaying the status and relevant information for all active system components. Several MCW applications can be connected to the radar through local and remote links. A request/granting protocol has been implemented for giving control capability only to one of the connected MCW users.

The RCW is a tool mainly conceived for system engineers. It provides 2D and 3D visualization of on line and off-line (from recording files) radar data (raw plots and tracks) as well as propagated orbits loaded by means of TLE, OEM and SP3 files. It can perform detection and accuracy analysis by correlating propagated orbits with off-line track data.

It can also interact with the Signal Processor for requesting and displaying beam signal samples at different processing stages and for test target signal injection.

As the MCW, the RCW can operate in local or remote mode.

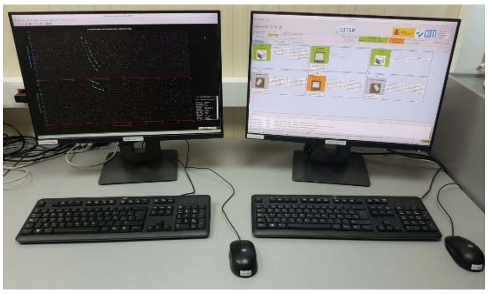

Figure 12. Radar Console Workstation (RCW) at left side, and Monitoring and Control Workstation (MCW) at right side.

3 INITIAL OPERATIONS

After passing Final Acceptance Test in December 2018, the first version of the S3TSR is currently undergoing the operational validation phase. However, already since September 2018, the radar has been set into continuous operation during long periods, which has made possible some preliminary evaluation of performances.

As an example of detection and tracking capability, figure 14 shows a collapsed view of all tracks reported by S3TSR during a 12 h period starting at 0 h UTC of November 20 (945 tracks). It corresponds to one of the double 2D views provided by the RCW, where in this case the common X-axis is range in km, the upper graph plots in Y-axis the V-angle coordinate and the graph below shows in Y-axis the U-angle, both angles in degrees. Figure 15 displays the same data in a different view: the common X-axis is azimuth relative to local north, upper Y-axis is elevation and Y-axis below is range.

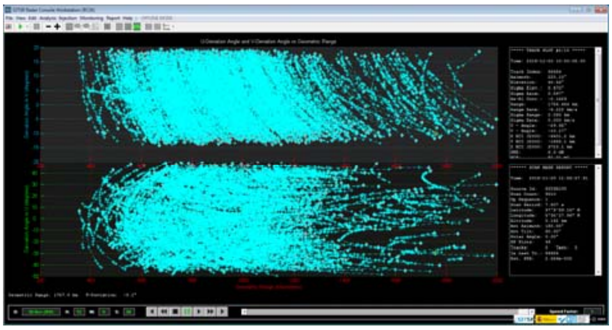

Figure 13. Collapsed view in U-V vs Range mode of all tracks reported by S3TSR in a 12 h period.

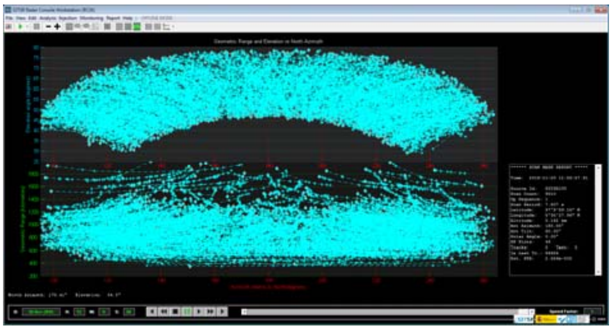

Figure 14. Same data but in displayed in Range-Elevation vs Azimuth mode.

These results show that the S3TSR, reporting more than 1800 tracks per day, fulfils in excess the detection and tracking requirements stated by ESA.

Accuracy analysis performed so far are based on some selected satellites for which very accurate orbit positions are known and provided by ESA. Preliminary results allow asserting that position error requirements are met in excess, especially in range coordinate for which the estimated standard deviation is more than three times lower than the specified value, being in the order of 8 meters. The angular accuracy is also exceeding the specified performance, being in the order of 0.15° in Δu and Δv.

4 CONCLUSIONS

S3T autonomous catalogue is created and maintained based on the data obtained from the S3T Sensor Network (S3TSN). The catalogue is growing steadily and it provides autonomy to the S3T system. As of beginning 2019, the S3T catalogue contains more than 800 confirmed objects, from which around 10% are UFOs (i.e. not included in public catalogues). The system is now receiving the tracks of LEO objects from the S3TSR and has starting building its own independent catalogue.

The LEO catalogue creation and maintenance is to be primarily supported by the S3TSR, an instrument specifically designed for the detection of space debris in the LEO orbital regime, and which is an operational radar developed in Europe, by European industry, with full European know-how and key European technologies. It has been designed and developed with scalability as main concept, allowing an easy, steady and cost-effective growth in size, power and performances.

5 REFERENCES

1. Inter-Agency Space Debris Coordination Committee, Space Debris. IADC Assessment Report for 2011, IADC-12-06, April 2013.

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