THE JOINT TERRASAR-X / TANDEM-X GROUND SEGMENT

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ABSTRACT

This paper recalls the essential elements of the joint TerraSAR-X and TanDEM-X ground segment. It elaborates on some topics which are usually not in the primary focus from a pure SAR technical point of view, e.g. the flight formation. Both commissioning and early routine phase results from operating the joint TerraSAR-X and TanDEM-X ground segment are given.

Index Terms— TanDEM-X, Ground Segment, Formation Flight

1. INTRODUCTION

Major achievement of the TerraSAR-X mission is the provision of high-resolution SAR data with an unprecedented geometric accuracy. Both science and commercial users may choose from a variety of SAR imaging and polarization modes to individually image their region of interest. The successful launch of the TDX-1 satellite at June 21, 2010, marked the beginning of the challenging TerraSAR-X add-on for Digital Elevation Measurement mission TanDEM-X. Its primary mission goal is the consistent generation of a world-wide global digital elevation model with high accuracy [1]. The satellites TSX-1 and TDX-1 are therefore flown in close formation to build a single-pass space-borne radar interferometer. The nominal TSX-1 / TDX-1 life-time overlap of three years is used to cover the complete Earth twice under different baseline configurations. Both satellites are used in parallel (one in receive-only mode) for the bistatic DEM data acquisitions. To counterbalance the interferometric usage of TSX-1, the data for the on-going operational TerraSAR-X mission have to be acquired by both satellites TSX-1 and TDX-1 whereby the appropriate one to fulfill a given user acquisition request is to be chosen by the ground segment.

2. GROUND SEGMENT EXTENSION

The TanDEM-X mission poses manifold technical challenges, e.g. in the areas of formation flight and baseline determination, bistatic radar instrument operation, mission planning, overall system calibration and interferometric data processing and thus required a major extension of DLR’s TerraSAR-X ground segment. Technically complex new subsystems had to be added to specifically fulfill the TanDEM-X requirements, existing ones needed significant add-ons to serve TanDEM-X on top of TerraSAR-X [2].

![Fig. 1: TerraSAR-X/TanDEM-X Ground Segment Overview (previous functionality grey, added functionality in black)](image-url)
3. COMMISSIONING THE JOINT GROUND SEGMENT

Commissioning of the challenging TanDEM-X mission on top of TerraSAR-X and thus the release of the joint TerraSAR-X / TanDEM-X ground segment for routine operation was done in parallel to the technical system verification in well-defined commissioning stages [3], [4].

3.1 LEOP and Drift Phase

TDX-1 was successfully launched at June 21, 2010 from Baikonur. At the moment of separation TDX-1 was 15,700 km behind TSX-1. After commissioning of the main AOCS sensors and actuators, a first orbit maneuver could be performed within 1.5 days after launch to adjust the along-track drift rate towards TSX-1 to about 630 km per day.

Reception and processing of the first SAR data was done only 3.6 days after launch in a fully automated manner using the operational PGS TerraSAR-X processing chain. A “blind” temporal overlay based on quicklook orbit information only, of the first TSX-1 image from 2007 with the early TDX image taken over the same Don river region on day 5 impressively demonstrated how well and precise both SAR instruments performed right from the beginning.

During LEOP, the German Antarctic Receiving Station (GARS) provided 24h/7d TT&C support for all visible passes. X-Band data compatibility was demonstrated.

One week after launch, the Kiruna ground station was checked-out and released for TDX-1 data reception during the commissioning phase including the online transfer of all acquired data to DLR for their further processing. This allowed to downlink a vast amount of commissioning data on top of the operational TerraSAR-X mission data whereby both types of data were processed using the operational PGS instance.

Finally, in the period from July 12 to 18 the TDX-TSX along-track drift was step-wise reduced and stopped at 20 km distance, where the formation for pursuit monostatic commissioning was acquired. The total TDX-1 velocity increment contained within 23 acquisition maneuvers performed during LEOP and in the drift phase was only 6.5 m/s out of a maximum budget of 18.5 m/s [5].

3.2 Pursuit Monostatic Commissioning Phase

On July 22, TDX-1 had reached a distance of 20 km to TSX-1 and started its helix formation flight, whereby the helix parameters where chosen such as to compensate the earth rotation within the 3s (20km) time difference and to ensure the same ground tracks as for TSX-1. This pursuit monostatic configuration was kept for 77 days to allow a thorough TDX-1 overall system verification. Close to 5000 TerraSAR-X data takes were acquired, received and processed. The (pursuit monostatic) TanDEM-X data take planning, commanding, acquisition and processing qualification was started also at July 22 leading to a first set of 700 data takes being processed into raw DEMs during this phase.

A further major event from a ground segment perspective was the operational replacement of the mission planning system with the new combined TerraSAR-X/TanDEM-X one [6] and the operational release of the TerraSAR-X mission based on the two satellites TSX-1 and TDX-1 in early October.

The Inuvik ground station underwent a thorough test and qualification phase for both TerraSAR-X and TanDEM-X data reception and TT&C support [7].

![Fig. 2: “Blind” overlay of historically first TSX-1 with the early TDX-1 data take. Images courtesy of T. Fritz.](image)

![Fig. 3: TanDEM-X Raw DEM acquired in pursuit monostatic configuration on August 10, 2010 over Mt. Egmont, New Zealand. Processed by PGS ITP.](image)
3.3. Bistatic Commissioning Phase

Finally, the close formation with its zero mean along-track separation was adjusted mid of October and the bistatic instrument operation period of the commissioning phase.

The precaution measures [2] to avoid a mutual illumination of the two satellites were activated, both on ground and in space. The successful exchange of synchronization signals between the two satellites in space using their sync horns is a prerequisite for any data taking. Exclusion zones in which the transmission of radar pulses is forbidden for one satellite have to be observed already during data take planning. Instrument commanding of a TanDEM-X data take differs in quite a few aspects from a TerraSAR-X one, e.g. w.r.t. to its start at a given and synchronized time instead of a given geographical position and their embedding of synchronization pulses.

As a consequence of the close formation flight, payload data from both satellites TSX-1 and TDX-1 are transmitted in a non-overlapping manner with a transition time of about 20 seconds only between the different replays, a situation which posed no problem at all for the ground station. The GARS station, which had its last Antarctic winter break in 2010, was available in time to provide important 24h/7d TT&C support during the transition into the close formation.

In only a few days, the complex interactions on ground and also between space and ground needed to perform the bistatic TanDEM-X operation on top of the operational TerraSAR-X mission using the two satellites TSX-1 and TDX-1 were mastered and the challenging bistatic SAR commissioning could be started. About 1800 TanDEM-X data takes were acquired, received by the TanDEM-X ground station network and processed into raw DEMs in this phase (see specifically [8] and [9] for details on the processing itself).

A thorough assessment of the formation control accuracy showed that by far better values then required could be achieved which is shown in Fig. 4.

4. FORMATION CONTROL

The TanDEM-X mission profile is particularly challenging from a flight dynamics point of view and posed new needs for spacecraft navigation and control as elaborated in [2]. The TSX-1 satellite is absolutely controlled w.r.t. its reference orbit which requires in-plane maneuvers of 1 to 5 cm/s size at a 2 day minimum and a 20 day maximum interval. Inclination maneuvers up to 30 cm/s are performed 3 to 4 times per year. The TDX-1 satellite simultaneously executes the same hydrazine maneuvers as TSX-1 to hold the close formation. On top of this absolute control, the TDX-1 performs additional cold-gas and hydrazine maneuvers to maintain the relative motion between TSX-1 and TDX-1 on a daily basis.

The biggest challenge as compared to previous experimental formation flying missions is the operational character demanding for continuously safe and robust operation with high control accuracy for at least three years. The remarkable control performance is depicted in Fig. 5. The achieved < 30 m R.M.S. along-track and < 5 cross-track (2D) R.M.S. accuracies clearly fulfill the mission requirements of 200 and 28.3 m, respectively [10].

6. TANDEM-X GROUND STATION NETWORK

A network of X-band ground stations [2], [7] located at appropriate geographical locations is needed to down-link the TanDEM-X data volume of about 350 TByte in 3 years. These data have to be consistently gathered before processing at the payload ground segment can start. Primary stations are DLR’s German Antarctica Receiving Station (GARS) O'Higgins on Antarctic Peninsula, DLR’s Inuvik Satellite Station in Canada and the partner ground station SSC ESRANGE Kiruna in Sweden. All stations provide S-band and TT&C services as well. DLR’s ERIS Chetumal station in Mexico is used to enhance the downlink capacity in peak orbits.
5. ROUTINE OPERATIONS PHASE

On December 12, 2010, the TanDEM-X routine bistatic data acquisition was started using the long-term data acquisition plan created by the IOCS segment. In the first four months, over 2000 TanDEM data takes were acquired, archived and processed by the Integrated TanDEM Processor ITP into raw DEMs leading to about 25000 raw DEM scenes. Currently, the final DEM processing chain including the DEM calibration and mosaicking is under completion.

For further details on the current mission status, see [11].

6. REFERENCES


The TanDEM-X project is partly funded by the German Federal Ministry for Economics and Technology (Förderkennzeichen 50 EE 1035) and is realized in a public-private partnership by DLR e.V. and Astrium EADS.