Overview and Status of TerraSAR-X / TanDEM-X Long Term System Monitoring

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Abstract

The TerraSAR-X and the TanDEM-X satellites are operated for two missions in parallel: the TerraSAR-X and the TanDEM-X missions for scientific and commercial applications, providing a multitude of SAR products of high accuracy and reliability. After launch the whole SAR system has been successfully calibrated and verified for both satellites during their commissioning phases: TerraSAR-X in 2007 and TanDEM-X in 2010. In order to guarantee a stable quality of SAR products and to monitor the correct operation of the entire SAR systems, both systems are regularly monitored. This paper presents an overview, the current status and some results of the long-term system monitoring (LTSM) tasks executed since launch.

1 Introduction

TerraSAR-X (TSX-1) and TanDEM-X (TDX-1) are Germany's first national remote sensing satellites implemented in a public-private partnership between the *German Aerospace Centre (DLR)* and *Airbus Defence and Space*. Both satellites have to support two missions in parallel: the TerraSAR-X mission for providing monostatic multi-mode X-Band SAR data in different operation modes [1] and the TanDEM-X mission in order to generate a new global digital elevation model with a 12-meter grid and a vertical accuracy better than two meters in bistatic operation [2].

The satellites feature an advanced high-resolution X-Band Synthetic Aperture Radar (SAR) based on the active phased array technology which allows the operation in Spotlight, Stripmap and ScanSAR mode with two polarizations in different combinations and elevation angles. For these various acquisition modes, their active phased array antenna electronically steers and shapes the patterns in azimuth and elevation direction. The antenna consists of 12 panels in azimuth direction, each panel consists of 32 sub-array radiators in elevation direction each fed by its own active transmit and receive module. It combines the ability to acquire high resolution images for detailed analysis as well as wide swath images for overview applications. The geometric resolution ranges from 25 cm (slant range) for Staring Spotlight and 3.3 m for nominal Stripmap to about 40 m for 6-beam ScanSAR products [3]. The respective image width ranges from few kilometers to about 200 km. There are over 1000 possible product variations, which result from the combination of different imaging modes, polarizations and elevation angles. The SAR performance and the calibration status of both systems is regularly analysed and monitored with respect to geometric and radiometric parameters like resolution and side lobe ratios. Long-term monitoring of system parameters like Doppler centroid or instrument characteristics verifies an excellent stability of both systems.

Long-Term System Monitoring (LTSM) covers the SAR system related parts of the combined TerraSAR-X and TanDEM-X system (space & ground segment). The detection of long-term SAR system performance changes is the primary subject of the LTSM. The main purpose of the LTSM is the collection and supply of information that can be used to initiate (if needed and feasible) dedicated actions to maintain the specified SAR product quality. Furthermore, the LTSM can help to reveal the causes for events that seem to be by chance (e.g. non-reproducible failure in command execution) by analysing similar cases (detection of coincidences with other events, operational or environmental conditions).

Over the mission time the LTSM system has been extended with the goal to have all relevant parameters and status information at hand. One major update resulted from the launch of the TanDEM-X mission. The following chapters shall provide a brief description of the monitoring system and an update of the current status. Additional results focusing on radiometric accuracy and stability are presented in [4].

2 Instrument Operations

Continuous monitoring of both SAR instruments in orbit is required to detect degradations of the satellite hardware and to compensate them by adapting the respective parameters. Therefore the instrument status of TSX-1 and TDX-1 is checked regularly. Main source is the telemetry data of the satellites, downlinked via S-Band. In addition, complementary ground segment data is evaluated in order to derive regular statistics on instrument load (commanded and executed acquisitions) etc.

Instrument-related telemetry is evaluated on-ground twice. First, dedicated Instrument Health Monitoring procedures evaluate the data directly after downlink, provide information about the actual state of the instruments and perform automatic checks of measurements against a mode dependent limit matrix, immediately initiating dedicated procedures in critical cases according to the instrument handbook. The Instrument Health Monitoring functionality is integrated in the Ground Segment's Monitoring and Control System (MCS) [5]. Second, the data is evaluated in the frame of LTSM, where the occurred events are summarized and visualized at regular intervals. All instrument-related data is stored in a central long-term data base (LTDB) and can be accessed for further offline analysis.

Besides the evaluation of voltage, current and thermal levels one major part is the (statistical) evaluation of on-board events like bit errors in the on-board memory and the monitoring of limited resources like the number of switching cycles of the Traveling Wave Tube Amplifier (TWTA), which is a central part of the X-band downlink unit. Two examples shall be described in the following sections: The monitoring of T/R module performance and front-end panel temperatures.

2.1 Monitoring of T/R Modules

For characterizing individual transmit/receive modules (TRMs) simultaneously a method based on orthogonal codes is applied [6]. Regular Antenna Health checks, based on the automated acquisition of special system datatakes at regular intervals, monitor the TRM transmit and receive gain, as well as transmit and receive phase for both instruments in-flight. Possible degradation or drifts can be found by depicting gain and phase trends over time. As an example, one of these 8 parameters, the phase deviation with respect to a reference value on receive on TSX-1 is plotted in Figure 1 versus datatake execution time for 383 of the 384 TRMs. The remaining TRM was deactivated prior to launch and is not monitored.

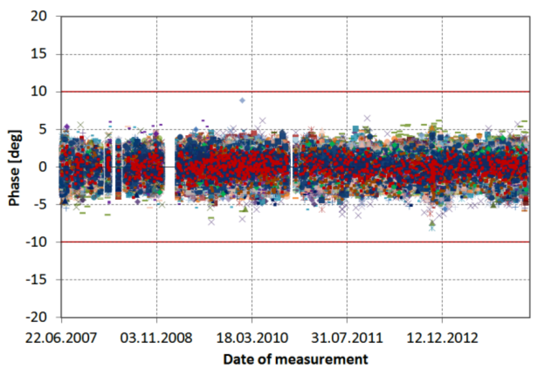

Figure 1: PN-Gating results of TSX-1 TRMs: Deviation of Rx phase of each individual T/R module from the reference value.

All active TRMs work within the established limits and no trend can be observed, indicating the stability of the TSX-1 instrument and the TRM settings respectively. The amplitude deviation (1 σ) stays below 0.1 dB and the phase deviation under 1 ° for all TRMs.

2.2 Monitoring of Front-End Temperatures

Monitoring the radar front-end temperatures shows that the instrument is operated in its space qualified thermal conditions. Figure 2 shows the daily maximum temperatures of the 12 front-end antenna panels of each instrument. The measured panel temperatures are far from the limit temperature of 30 °C for nominal performance. The temperature peak observed in both plots shows the instrument thermal behavior in extreme conditions during a Hot-Cold Test executed during the TDX-1 Commissioning Phase. Furthermore, the temperature plots clearly reflect the start of the operational TanDEM-X DEM acquisition phase in December 2010.

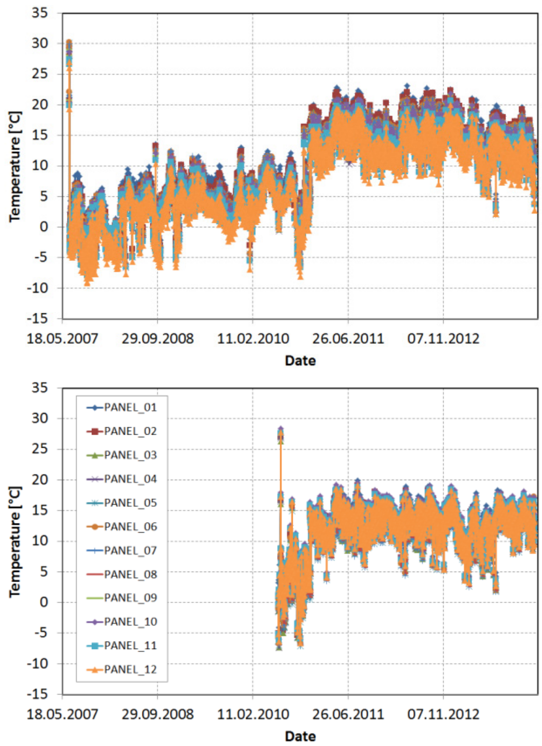

Figure 2: Maximum daily front-end panel temperatures (hot-spot) over time. Upper plot: TSX-1, lower plot: TDX-1.

3 Instrument Performance

SAR performance parameters are monitored continuously in order to provide long-term statistics and to prove the quality of the SAR data products [7]. In a first step each nominal datatake is checked immediately after screening of the raw data. In this screening process a number of limit checks is performed on selected statistical performance parameters. Limit violations will trigger immediate notifications.

Datatake Verification combines information from both the datatake ordering as well as the datatake reception and processing chain. It comprises a verification of:

- Completeness of raw data and correctness of source packet sequence
- Completeness of scene coverage
- Raw data saturation/clipping level
- Raw data statistics of in-phase and quadrature channel data
- Doppler Centroid estimation

The LTSM system is accessing the results of datatake verification and provides overall statistics and trend analyses. Similar to the handling of instrument operations data, occurred events are summarized and visualized at regular intervals. Two examples shall be shown in the following sections: The monitoring of Doppler Centroid and raw data statistics.

3.1 Doppler Centroid

SAR image quality is affected by the Doppler Centroid. The main contribution, an effective squint angle due to Earth rotation, is compensated by Total Zero Doppler Steering [8]. The residual Doppler Centroid is estimated for each data take by the operational SAR processors [9].

As the Doppler Centroid frequency of the SAR signal is related to the location of the azimuth beam centre, the evaluation of Doppler estimations over a number of datatakes can reveal antenna mispointing in flight direction. This sensitivity of the SAR system has been exploited in the monostatic commissioning phase of the satellites.

A long-term measurement of the Doppler Centroid is shown in Figure 3. The mean Doppler values are concentrated around 0 Hz mainly (95 % of the total acquisitions) in a tube of ±120 Hz providing a stable image quality over mission time. The data collected over the operational mission time does not show any trends. Outliers could be identified as non-nominal satellite conditions (e.g. GPS anomalies).

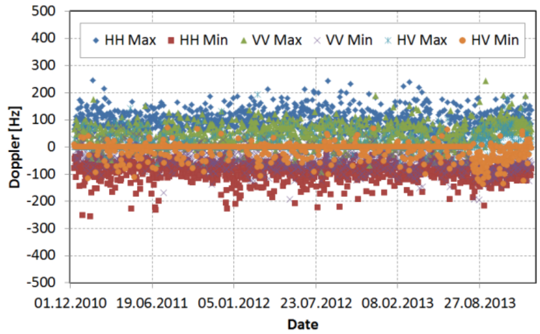

Figure 3: Maximum and minimum Doppler centroid for each datatake / polarization channel since 2011.

3.2 Raw data statistics

The complex data collected in in-phase (I) and quadrature-phase (Q) channels is not completely free of biases or cross-coupling (non-orthogonality) between the I and Q channels, introduced by the receiver electronics. This can be estimated by collecting statistics of the SAR raw data.

Figure 4 shows an evaluation of the bias in the I- and Q-channel of the TDX-1 SAR raw data. These results show once again the accuracy of the TSX-1 and TDX-1 SAR systems, as well as their high stability over the mission lifetime.

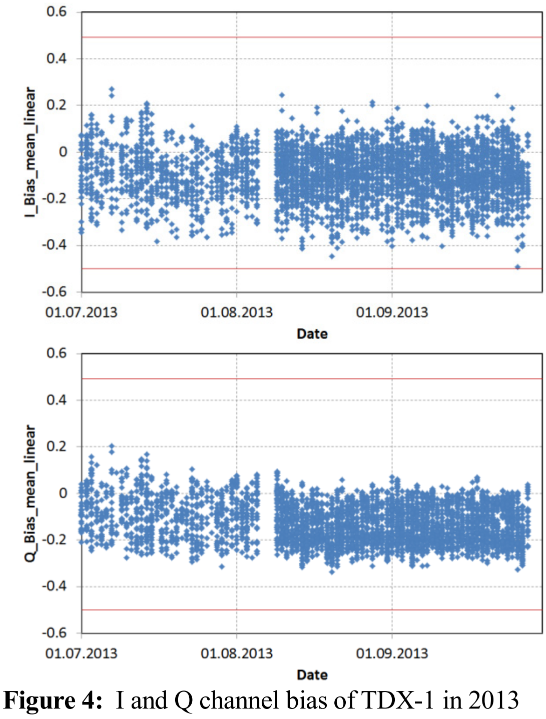

Figure 4: I and Q channel bias of TDX-1 in 2013

4 Conclusions

The measurements and the extended analyses performed for long-term system monitoring of both SAR systems TerraSAR-X and TanDEM-X show a very high stability of the instrument performance. Since launch of the respective satellite no degradation in the performance of both instruments has been observed. All parameters show a constant behavior. Hence, by all these measurements performed for LTSM it can be concluded that TerraSAR-X and TanDEM-X could be characterized and adjusted precisely, achieving at the end a highly accurate and stable SAR System.

For the design of future space borne missions like TanDEM-L the LTSM can provide a collection of valuable information (e.g. thermal & power behavior, reason of failure cases, performance degradation vs. mission duration etc.).

Acknowledgement

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