Long Term System Monitoring Status of the TerraSAR-X and the TanDEM-X Satellites.

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Abstract

The TerraSAR-X and the TanDEM-X satellites are operated to enable 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: the TerraSAR-X in 2007 and the TanDEM-X in 2010. In order to guarantee a stable quality of the excellent SAR products and to monitor the correct operation of the entire SAR systems, both systems are regularly monitored. This paper presents the status and results of all long-term system monitoring (LTSM) tasks executed since launch.

1 Introduction

TerraSAR-X (TSX) and TanDEM-X (TDX) are Germany's first national remote sensing satellites implemented in a public-private partnership between the German Aerospace Centre (DLR) and EADS Astrium GmbH. Both 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. Furthermore, both satellites have to enable both missions in parallel: the TerraSAR-X mission for providing single 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].

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 varies from 1 m for Spotlight, 3 m for nominal Stripmap and 16 m for ScanSAR products. The image width ranges from 10 km (Spotlight) to 100 km (ScanSAR). 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.

2 SAR Calibration Status

Continuous monitoring of both instruments in orbit is required to detect degradations of the satellites hardware and to compensate them by adapting the respective calibration parameters. Therefore the calibration status of TSX and TDX is checked regularly and is divided in three main parts: Internal Calibration, Antenna Pattern Verification and Radiometric Calibration [3] [9].

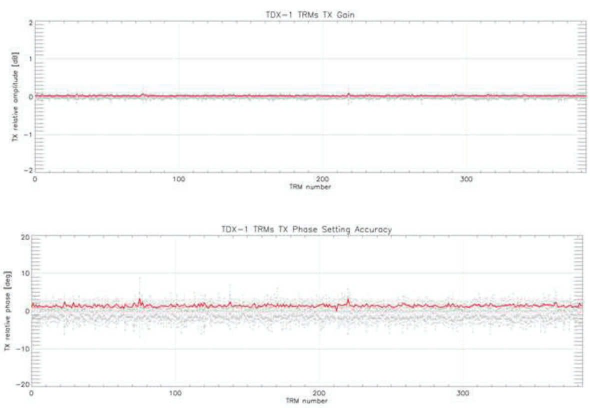

Figure 1: TDX statistical values of the amplitude and gain deviations on transmission measured for each of the 384 TRMs in flight during three months in 2011. The red curve shows the standard deviation of the amplitude (above) and phase (below).

For characterising individual transmit/receiver modules (TRMs) simultaneously, the PN-Gating method is applied

[4]. Regular PN-Gating checks monitor the TRM transmit and receive gain, as well as transmit and receive phase for both instruments in-flight. Possible drifts can be found by depicting gain and phase trends over time. For example in **Figure 1** the amplitude/phase deviations with respect to a reference value on receive are plotted for TSX versus datatake execution time for each of the 384 TRMs. All TRMs work within the established limits and no trend can be observed, indicating the stability of the TSX instrument and the TRM settings respectively. The amplitude deviation (1σ) stays under 0.1 dB and the phase deviation under $1°$ for all TRMs .
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 the lower plot shows the instrument thermal behaviour in extreme conditions during a Hot-Cold Test executed during the TDX Comissiong Phase.

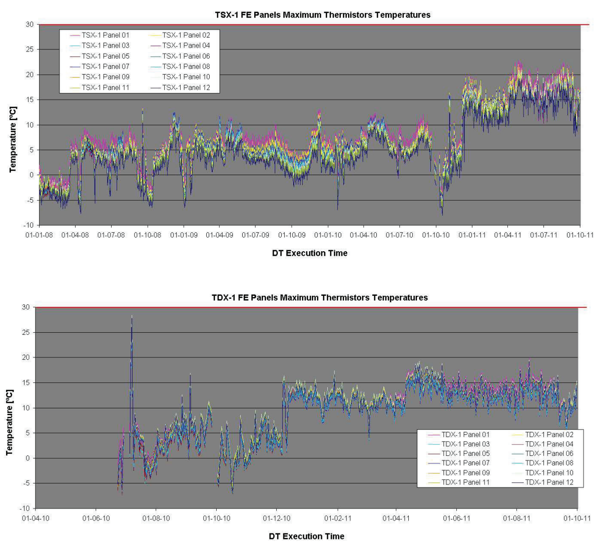

Figure 2: Maximal daily front-end panels temperatures (hot-spot) over time. Upper plot: TSX, lower plot: TDX.

The monitoring of the antenna patterns is required to detect degradation of the antenna front-end, especially the antenna wave guides as these are not covered by the internal calibration. For this purpose, ScanSAR data takes over the Amazon rain forest are acquired and evaluated [10]. Using ScanSAR data takes it is possible to estimate both the deviation of the pattern shape as well as the beam-to-beam gain prediction capability. The plot of **Figure 3** shows the relative deviation between the measured antenna patterns and the reference antenna patterns derived by the precise antenna model [5]. The values in blue correspond to TSX, green to TDX and they are referenced to their individual means, being the maximum deviation between the antenna model and the measurements less than ±0.2 dB.

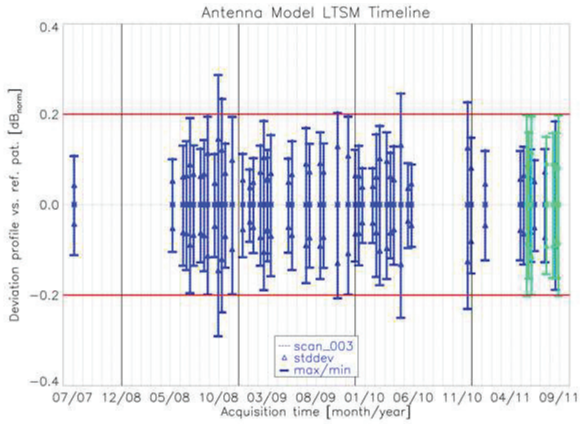

Figure 3: Antenna pattern statistic derived by acquisitions across the Amazon rainforest in ScanSAR operation, blue: TSX since 2007, green: TDX since 2011.

Monitoring the radar cross section (RCS) of corner reflectors permanently installed over time yields the radiometric stability of the whole SAR system. For this purpose TSX and TDX are operated in StripMap mode with different beams. By depicting the derived RCS versus mission time (as shown in **Figure 4**), trends of the radiometric stability of the entire SAR systems can be detected and monitored. In addition, the absolute radiometric accuracy of the corresponding satellite, which is defined by the standard deviation of the RCS measurements, can be determined.

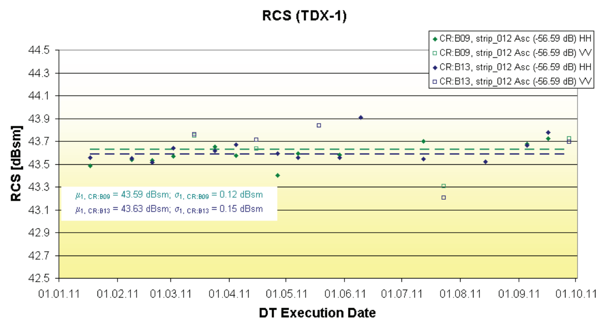

Figure 4: RCS derived from two Corner Reflectors (green CR:B09 and blue CR:B13, strip_012 ascending - middle incidence angle), both deployed for LTSM of the TDX satellite.

However, monitoring the TSX satellite over the first three years mission lifetime, a radiometric stability of better than 0.2 dB could be verified by a comprehensive re-calibration campaign executed in 2009 [7]. And as both satellites have achieved nearly the same accuracy [6], a similar stability can be expected for the second satellite TDX.

3 SAR 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 [8]. For this purpose, the impulse response function of reference point targets, like corner reflectors, has been analysed within a set of SAR images. The derived integrated side lobe ratio (ISLR, see **Figure 5**) and the peak-to-side lobe ratio (PSLR) are measures for the minimum possible detection of weak targets in the vicinity of strong neighbour targets. Statistical values of these measurements acquired between 2009 and 2011 over two corner reflectors are listed in **Table 1**.

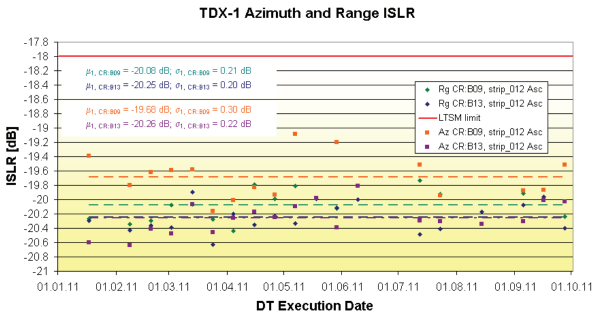

Figure 5: Azimuth and range ISLR of TDX Satellite measurements during mission time.

		TSX-1		TDX-1	
		μ	σ	μ	σ
ISLR	**Az**	-20dB	0.19dB	-19.68dB	0.30dB
	Rg	-19.55dB	0.21dB	-20.08dB	0.21dB
PSLR	**Az**	-30.07dB	0.77dB	-29.20dB	1.78dB
	Rg	-21.38dB	3.83dB	-29.45dB	0.80dB

Table 1: ISLR and PSLR mean/standard deviation values for TSX and TDX.

Also the geometric resolution in azimuth and in range are derived from point target responses, as shown in **Figure 6**. Both, the azimuth and the slant range resolutions are very stable.

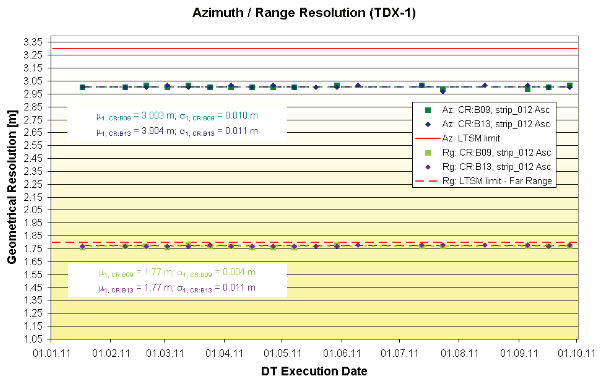

Figure 6: TDX-1 Geometric resolution in azimuth and in slant range measured in 2011 (red dotted line: product specification of 1.8 m in slant range, red solid line: product specification of 3.3 m in azimuth).

The further important performance parameter is the Doppler centroid, which is estimated from SAR data by frequent acquisitions. The mean Doppler values are concentrated around 0 Hz mainly (99% of the total acquisitions) in a tube of ±120 Hz providing a stable image quality over mission time (see **Figure 7**). Outliers could be identified as non-nominal satellite conditions (e.g. GPS Problems).

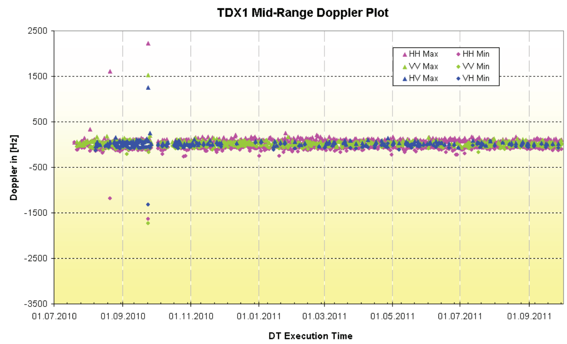

Figure 7: Maximum and minimum Doppler centroid for each datatake / polarization channel since 2010.

These results show once again the accuracy of the TSX and TDX SAR systems, as well as their high stability over the mission lifetime.

4 Conclusion

The measurements and the extended analyses performed for long-term system monitoring of both SAR systems TerraSAR-X and TandDEM-X show a very high stability of the instrument performance. Since launch of the respective satellite no degradation of both instruments have been observed. All parameters show a constant behaviour. Moreover, the measurements against corner reflectors and executed for TerraSAR-X approve a radiometric stability 20 times better then the requirements [3]. And as both satellites are nearly identically designed, a similar stability can be expected for the second satellite TanDEM-X. 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 estable SAR System.

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