TerraSAR-X Performance Status

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Abstract

TerraSAR-X is a satellite mission for scientific and commercial applications operating a highly flexible X-band Synthetic Aperture Radar (SAR) instrument with a multitude of different operation modes. The instrument and SAR performance have been successfully verified in the commissioning phase [1] and are monitored since start of the operational phase. This paper presents the results of the performance supervision over time, and confirms the stability of the excellent image quality delivered in the TerraSAR-X mission. It also describes the efforts to acquire images for the TerraSAR-X mission with the future TanDEM-X satellite and to preserve its reliable performance.

The paper shows system parameters and SAR image analyses over time to monitor the overall stability of TerraSAR-X SAR system performance.

Introduction

TerraSAR-X is Germany's first national remote sensing satellite being implemented in a public-private partnership between the German Aerospace Centre (DLR) and EADS Astrium GmbH [2]. The TerraSAR-X features 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 various combinations and incidence angles. For these various antenna beams, its active phased array antenna electronically steers and shapes the patterns in azimuth and elevation direction. The antenna consists of twelve panels in azimuth direction, each panel has 32 sub-array antennas in elevation direction fed by active transmit and receive modules [3]. It combines the ability to acquire high resolution images for detailed analysis as well as wide swath images for overview applications. The resolution varies from 1 m to 3.5 m for Spotlight (high resolution & single/dual), from 3 m to 6 m for Stripmap (single/dual)and 18 m for Scan SAR products. The image width ranges from 10 km (Spotlight) to 100 km (ScanSAR). There are over 1000 defined products, which result from the imaging mode, polarization and elevation angle combinations. The SAR performance of the system is analysed 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 confirms the continuous stability of the system. The specified product quality can be found in a public document of the TerraSAR-X mission [4] and the radiometric accuracies are presented in [3].

Performance Monitoring

TerraSAR-X was launched on June 15th, 2007, completed its commissioning phase in December 2007 and started the provision of high-resolution products from advanced SAR modes for both the scientific and commercial user community in January 2008. Since then over 28000 SAR images have been successfully commanded and acquired. Continuous monitoring of system parameters provides long-term statistics over the mission time to prove the product stability. Example statistics are shown in the following.

Doppler Variation

The quality of the images is affected by the Doppler Centroid. Its effect is reduced by Total Zero Doppler Steering to a minimum value [5]. A long-term measurement of the Doppler Centroid is shown in Figure 1, where every acquisition is represented by one point. The Doppler Centroid estimation is a result from the operational TerraSAR-X processor [6].

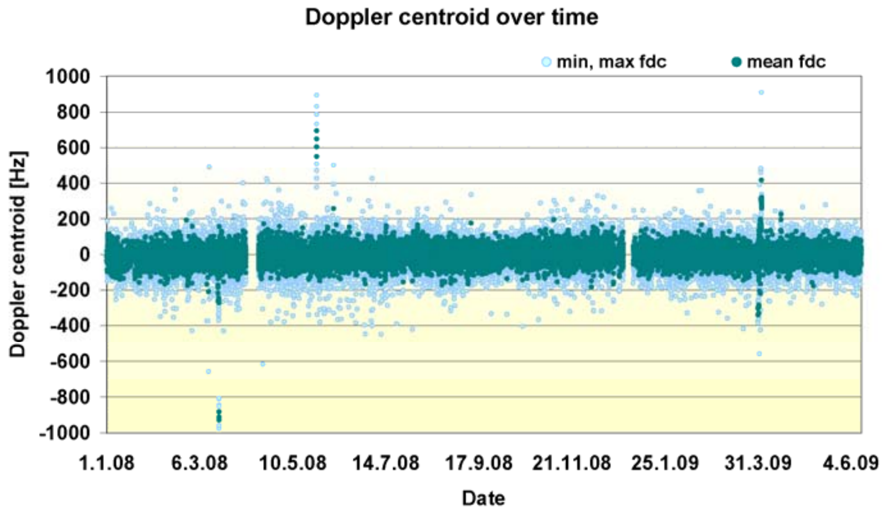

Figure 1: The maximal, minimal and mean Doppler Centroid of all SAR images over the complete mission time.

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. The outliers are assigned to non-nominal satellite conditions where each of it could be detected as single behaviour.

Radar Instrument Temperatures

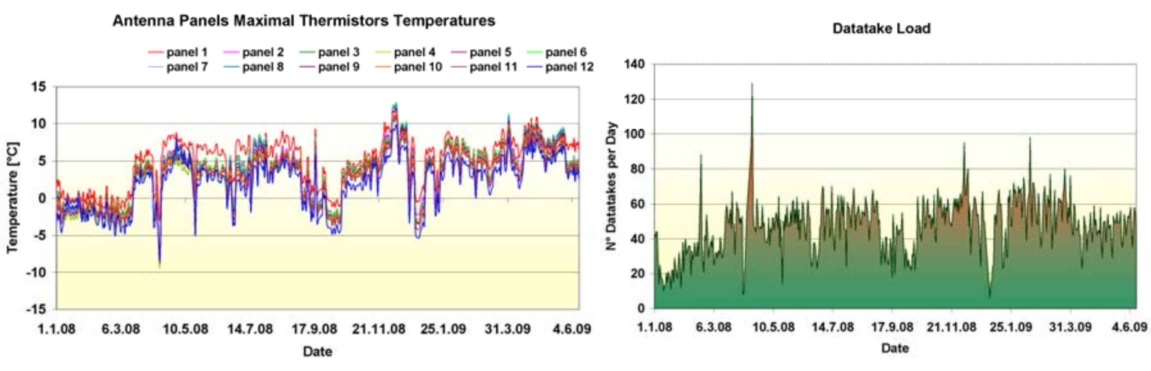

Figure 2: Left: Temperature of all twelve antenna panels over mission time. Right: Datatake Load.

Monitoring the temperature of the radar front-end shows that the instrument is operated in its space-qualified thermal conditions (see Figure 2 left). The temperatures on the twelve antenna panels are perfectly correlated with the varying instrument data load (right part Figure 2). No anomalies have been found. The limit temperature for the nominal performance, 67° C of the antenna is far from the measured panel temperature.

SAR Image Analyses

A set of 13 SSC images has been analysed for SAR performance parameters. The acquisitions are distributed in time between November 2008 and March 2009. They were commanded with two beams, each beam over one region. Near range images were acquired around 25° incidence angle and 150 MHz receive bandwidth (circles, in the following figures) and far range images around 38° incidence angle and 100 MHz receive bandwidth (squares, in the following figures). The measurements of *geometric resolution* and *peak to side lobe ratio (PSLR)* and *integrated to side lobe ratio (ISLR)* have been performed on a fixed 1.5 meter corner reflector per region. The *radiometric resolution* is derived from 4 distributed targets.

Geometric Resolution

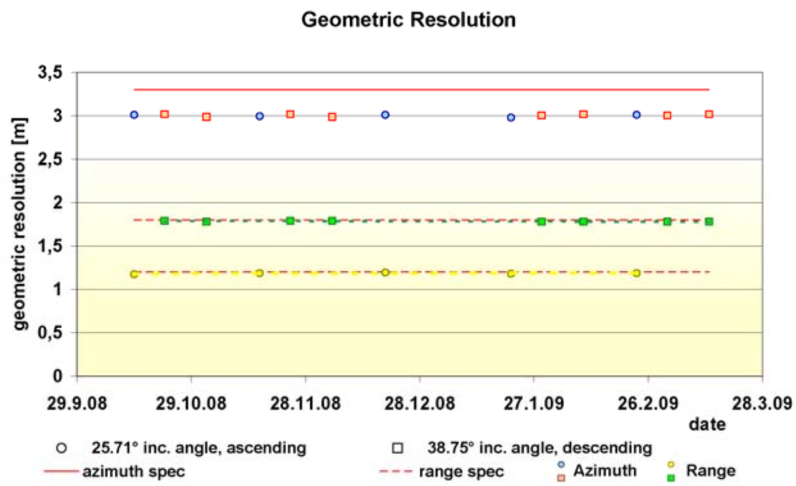

Figure 3: Geometric resolution in azimuth and in range.

Figure 3 shows the very stable measurements of geometric resolution in azimuth (blue and red) and in range (green and yellow). The specification for Stripmap images in azimuth is 3.3 meters (red line), the measured mean 3.00 meters and standard deviation 0.01 meters. For the ground range resolution near range images have a limit of 1.2 meters (lower dotted red line) and the far range images have a limit of 1.8 meters (upper dotted red line).

Integrated and Peak to Side Lobe Ratio

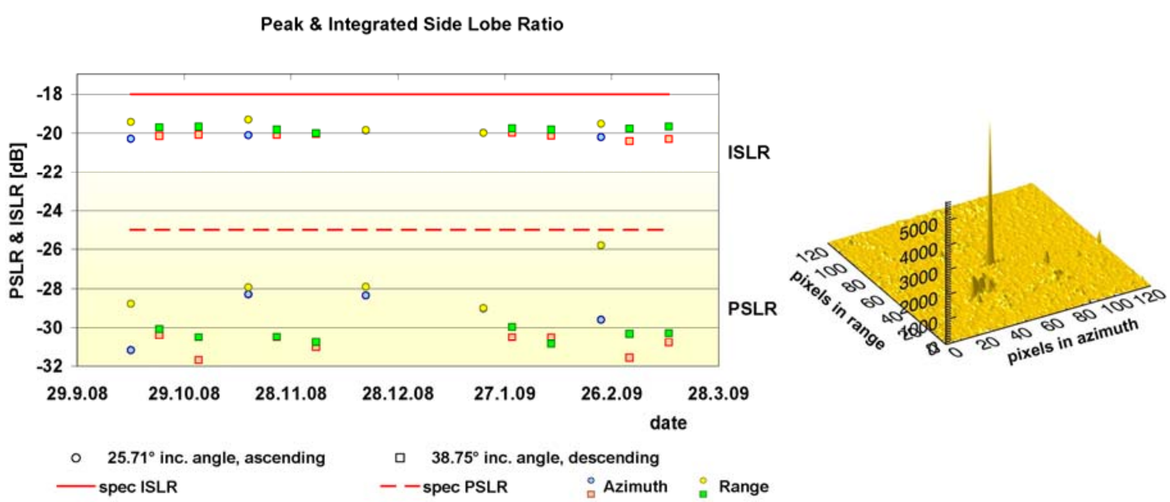

Figure 4: Left: Integrated and Peak Side Lobe Ratio in azimuth and in range. Right: One point target.

Figure 4 shows the ISLR (upper part) and PSLR (lower part) in azimuth (blue and red) and in range (green and yellow). ISLR and PSLR are always much better than the product specification -

18 dB (red line) and -25 dB (dotted red line), respectively, indicating the stable performance of the TerraSAR-X system. The mean value for ISLR is -19.92 dB and its standard deviation 0.27 dB. The mean value for PSLR is -29.84 dB and its standard deviation 1.34 dB.

Radiometric Resolution

The *radiometric resolution* is the expected spread of the variation in each scene reflectivity as an observed image [7]. For each image 4 distributed targets are selected and the radiometric resolution based on the image intensity is calculated as follows:

$$\gamma = 10 \cdot \log\left(\frac{\mu + \sigma}{\mu}\right)$$

, where μ is the mean and σ standard deviation of the image intensity.

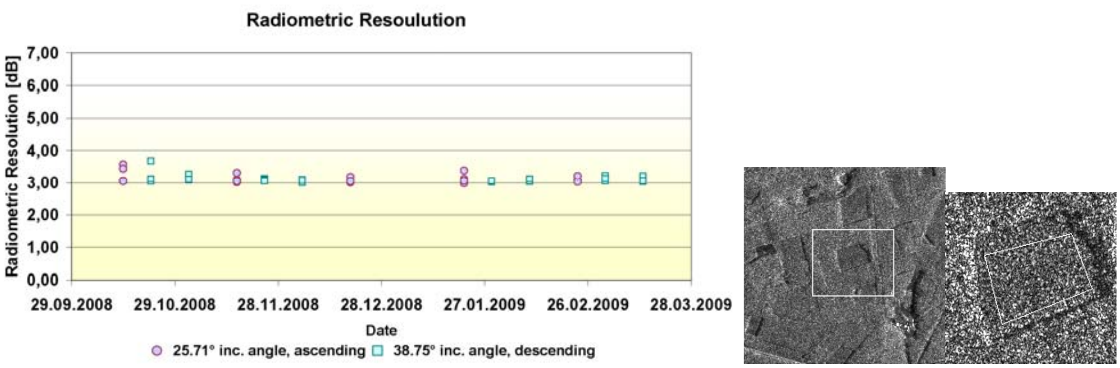

Figure 5: Left: Radiometric Resolution from statistic (4 distributed targets for each image). Right: Example of one of the 4 distributed targets around 38 ° incidence angles.

The mean value of the measured radiometric resolution is 3.1 dB, as specified for one look, and its standard deviation 0.13 dB.

TerraSAR-X Mission with TanDEM-X Satellite Performance

The future TanDEM-X mission will orbit two identical satellites (TSX and TDX) in a close helix formation in order to acquire bi-static SAR images and generate an accurate global digital elevation model (DEM). In addition, TanDEM-X has to be able to perform mono-static imaging on itself, so that both satellites can be used to continue fulfilling the TerraSAR-X mission [8].

The TSX satellite (which is in orbit since June 2007) has a fixed footprint to assure the possibility of repeating the same image across the time. The TDX satellite (launch goal is October 2009) has a horizontally and vertically displaced baseline referred to its TSX twin. The helix baseline is variable and typically between 200 and 600 meters. Baselines between 1 km and 10 km are only considered in special helixes. This causes that the TDX ground footprint is shifted with respect to the TSX footprint (left side Figure 6). The footprint shift in azimuth is compensated with the timing in order to acquire the desired scene.

However the antenna pattern is shifted, too, as a displaced part of the antenna look angle range sees the desired scene on ground (right side Figure 6). In order to preserve the quality of the images by acquiring those with the TDX satellite it is proposed to include a roll steering on the TDX to follow the TSX footprint. This baseline dependent roll steering adjusts the look angle of TDX to the reference footprint of the fixed TSX orbit.

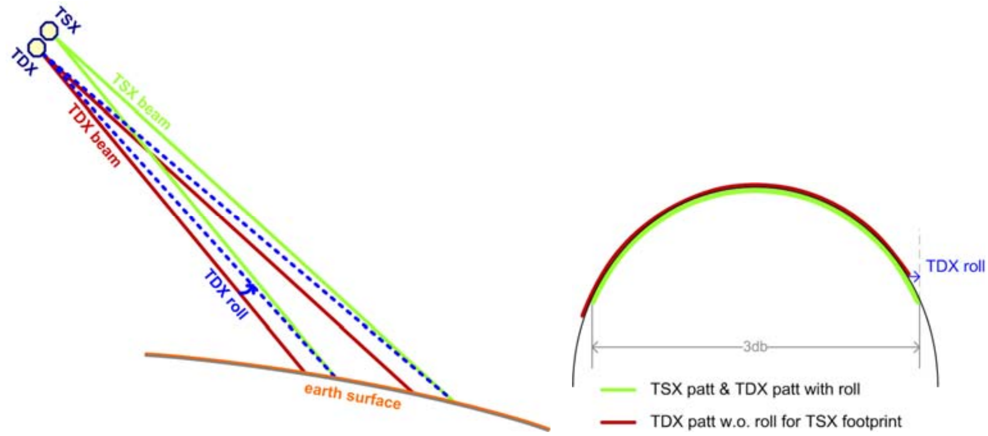

Figure 6: Left: Roll Steering of TDX to cover TSX footprint geometry. Right: Impact of Roll in the pattern overlap.

Conclusion

From the 5 years mission time TerraSAR-X is today over 2 years in orbit. Since start of the operational phase over 28000 images (01.01.2008 – 11.06.2009) have been successfully commanded and acquired. The SAR system has been monitored for its performance and instrument stability. The latest status from the SAR performance (ISLR/PSLR, geometric and radiometric resolutions) of TerraSAR-X is presented. The measurements are complemented with long-term monitoring Doppler Centroid and temperatures as shown in this paper. The radiometric accuracy is presented in [3].

The system shows no trends or performance degradation. An outlook on the future mission extension by the TanDEM-X satellite is given by the roll steering technique to keep the product performance.

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