TerraSAR-X System Performance & Command Generation

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Abstract

The paper starts with an overview about the TS-X data take command generation. The general approach of calculating particular instrument settings for each data acquisition is presented. Selected details are presented allowing a better understanding of presented results. The data take planning and commanding especially in the commissioning phase is resumed. The second part concentrates on the SAR system performance, i.e. obtained verification results are presented together with the resulting improvements in the data take commanding.

1 Introduction

TerraSAR-X launched at 2:14 UTC at June 15th, 2007. Only 5 days after launch, the first image was delivered, proving successful operation of the full SAR chain from data take (DT) commanding to SAR processing. During commissioning phase (CP), data take commanding and SAR system performance were optimized, characterized and verified. At 13th of December Stripmap and Spotlight products were released. ScanSAR products were released at 25th of February. The complete TS-X system was working excellent from the beginning. During the CP, all detected problems could be solved quickly and the SAR system performance was permanently optimized. Thus, high quality SAR products were released at CP end. The volume of this paper does not allow for a comprehensive discussion of all relevant topics of SAR system performance and command generation. However, it provides a quick overview and goes into details for selected topics. In the paper, data take and commissioning phase are abbreviated by DT and CP.

2 DT Command Generation

2.1 CP Data Take Planning & Execution

Figure 1 shows a simplified TSX command generation flow. The on-line path left applies for basic products. For the CP a planning tool was developed supporting flexible and cycle based ordering. It provided an excellent overview about planned, scheduled and executed DTs. Off-line command generation (right) supports experiments and maintenance by addressing the full instrument flexibility.

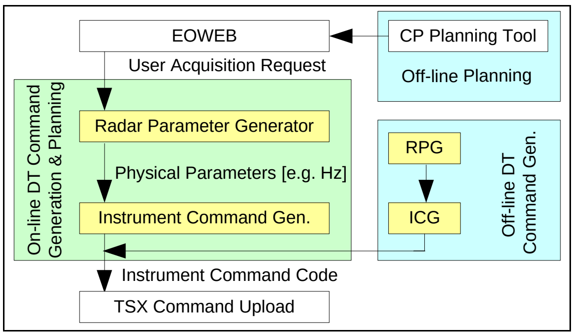

Figure 1: On/Off-line DT Command Generation & Planning

Before launch, more than 1000 data takes had been prepared and tested in the ground segment and with the Spacecraft. In the CP, more than 12000 DTs were finally executed. Figure 2 provides an overview about the executed DTs per day. Acquisition peaks resulted from statistical data take acquisition and load tests.

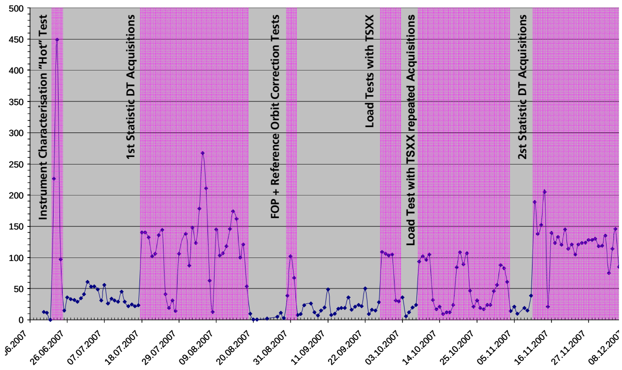

Figure 2: Number of executed data takes per day in the CP.

2.2 Rx Gain and Timing Parameters

In TS-X no automatic gain control is implemented. Thus, the Rx-Gain setting is calculated based on a σ_0 value and a target clipping degree of the signal standard deviation at the ADC input of 30% w.r.t. max. ADC voltage. The σ_0 value is taken from a σ_0 map with 1°x1° resolution in lat/lon, derived from a C-Band σ_0 map and a terrain classification map. Despite the rough sampling of about 110 km, the Rx-gain setting is adjusted within a data take. The BAQ setting is selected from a pre-defined table which is based on an upper limit of SNR degradation (using a backscatter map and NESZ). The table divides in mode, elevation beam and polarization. The high PRF values required in TS-X make the PRF selection a challenge. The principle is to respect transmit and nadir interferences and to select a PRF as close to a so-called target PRF which is optimized w.r.t. range and azimuth ambiguities. Nadir interferences are allowed in the echo window extension, i.e. the length of a transmitted pulse. In the CP it was verified, that nadir echoes do not saturate the receiver. PRF changes are allowed during a data take. In launch configuration, a nadir area of ±5° look angle was assumed.

3 SAR System Performance

3.1 Total Zero Doppler Steering - TZDS

TZDS [4] reduces the residual Doppler centroid down to the pointing accuracy level, in TS-X about +/-120 Hz. A series of Stripmap DTs from near to far range beams was acquired at different latitudes. The initial measurement is shown in Figure 3 on the left, where a dependency of incidence angle was found. There was no dependency on latitude.

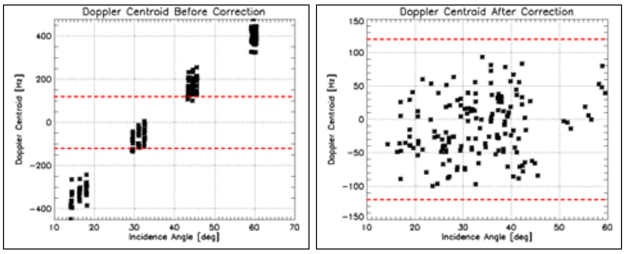

Figure 3: Doppler centroid before (left) and after correction

The conclusion was that there must be a bias in yaw and pitch angle steering which was corrected in the star sensor transformation matrix. After correction of 0.087° in yaw and 0.064° in pitch, the TZDS worked as expected as can be seen in the right plot. There is only a remaining constant bias of -40 Hz.

3.2 Along/Across-Track Orbit Accuracy

The TS-X reference tube of < ±250m was violated in the beginning of the CP and has been optimized. After October '07, the cross track deviation was within the foreseen limits. The absolute along track DT start position accuracy is, except for anomalies, within 100m. The dedicated analysis of repeat pass data takes resulted in a mutual along track separation of only 50 meters, i.e. 9% of ScanSAR the burst length, which is excellent for ScanSAR interferometry.

3.3 Receiver Gain Setting

The Rx-Gain setting was reduced twice, first one month after launch by -6dB based on visual saturation effects in the images and three month later after collection of sufficient data takes for raw data statistics [1] by another -4dB. The saturation in the raw data has been analysed dependent on the Rx-gain setting on a data basis of 230000 blocks of raw data. The result shown in Figure 4 is after the final Rx-gain setting.

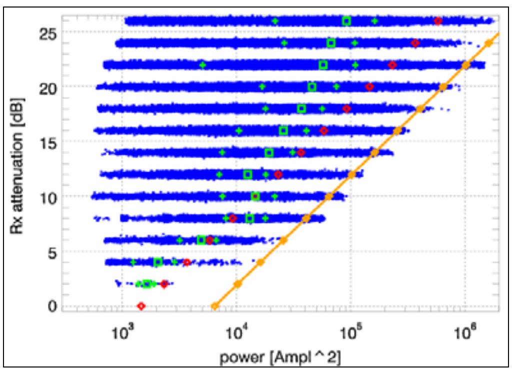

Figure 4: Measured signal power for different Rx-Gains

In the figure it can be seen that there is generally a high variation of the raw signal ADC input power. A raw data clipping of 3 percent has been considered as critical limit. This corresponds to a SNR degradation of 8dB@30dB and is represented by the orange line. The red diamonds represent the mean signal power for the desired clipping degree of 30% (section 2.2). The green symbols show mean power ± standard deviation of the measured signal. The position left of the desired power is intended since clipping causes a higher SNR degradation than quantization noise.

The same data basis was used to verify the BAQ setting strategy. The measured SNR values were used to re-calculate the BAQ degradation for the different modes and beams. The strategy was confirmed and for most combinations it was possible to increase the data compression by 1 or 2 levels.

3.4 Elevation Beam and Timing Margins

The pre-launch margin definition identical for gain and timing has been revised with the intention to relax the PRF selection constraints. By separating gain and timing margins, the contribution of pointing errors could be removed from the timing margins. On the other hand, timing margins have been made beam dependent, distinguished between near and far edge and DEM errors in the command generation were introduced up to 200m covering 80% of the land earth surface. Larger errors occur mainly at latitudes higher than ±60 . For those areas, there is the possibility of small deviations in the acquired product from the swath preview. The pre-launch gain margins have not been updated. Exemplarily, the final timing margins for Stripmap beams are presented in Figure 5. The full performance beams are from beam 03 to 14, i.e. 20°-45° incidence angle.

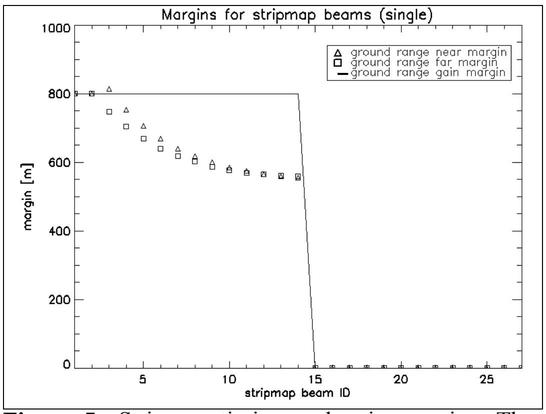

Figure 5: Stripmap timing and gain margins. The pre-launch timing margins had been identical to the gain ones.

3.5 Nadir Measurement

In 14 from 4300 operator checked DTs nadir echoes were identified, i.e. 0.33%. Mainly near beams were affected as is expected due to the weaker elevation pattern nadir suppression. Nadir echoes were only found in the far range of the images. This can be explained by the pre-launch nadir area definition, i.e.

±5° look angle, which works as a margin in nadir echo far edge only. Figure 6 shows a worst case measured nadir pulse which is range compressed and averaged over many range lines. After 1.5° the visible nadir vanishes and the nadir area in the timing was thus reduced to ±1.5° look angle. This corresponds to 1.2μs slant range time.

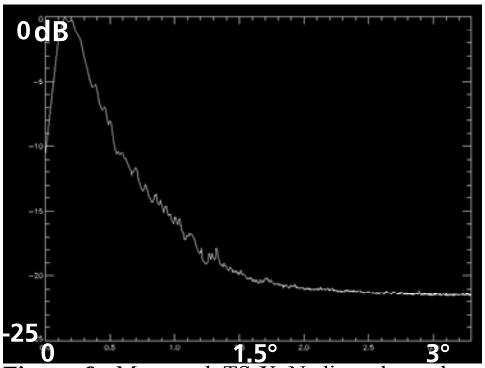

Figure 6: Measured TS-X Nadir pulse echo normalized (X-axis is look angle).

DEM errors have been identified as the main reason for observed Nadir echoes and a margin of 300m DEM error has been introduced in the nadir echo near and far edge, i.e. [2μs,2μs]. Considering the new nadir width of 1.2μs, the ± 5° pre-launch nadir can interpreted as no margin in nadir near edge but very high margin in nadir far edge. This explains why nadir echoes only occurred in image far range. The new definition resulted in a reduction of overall nadir extension by 6.8μs. This means a relaxation for the PRF selection combined with a reduction of the nadir echo events due to the margins. For DEM errors higher than 300m, nadir echoes are possible. However, the 0.33% occurrence of nadir echoes has been further reduced.

3.6 NESZ Measurement

For NESZ calculation both, sigma0 and SNR have been measured from the same data takes with 40 MHz Tx and 150 MHz Rx bandwidth. Rainforest scenes were chosen to achieve a homogeneous backscattering characteristic. For obtaining σ_0, the intensity was measured in the L1b *multi look ground range detected* images, combined with absolute and processing calibration factor, and assigned to the mean incidence angle of the scene. Figure 7 shows a typical rainforest scene. No masking of e.g. rivers was applied for better accordance with the measured SNR. The SNR measurement was done in raw data frequency domain by measuring the mean power of signal+noise (S+N) and noise (N) only. The SNR is then obtained by:

$$SNR = 10 \cdot \log_{10}\left(\frac{S+N}{N} - 1\right)$$

The subtraction of σ_0 by the SNR provides the NESZ in Figure 8. The variation along the beams is due the different PRF values in the beams and due to the fact that no statistical evaluation over many data takes was done.

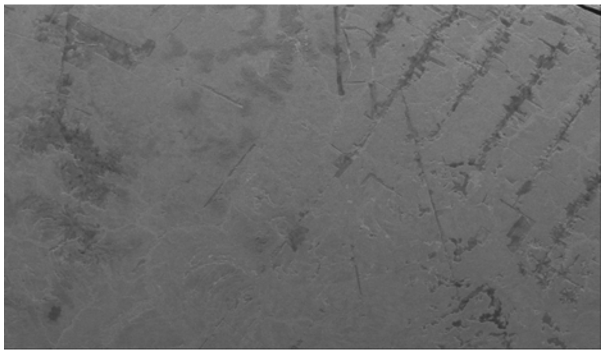

Figure 7: Rain Forrest Scene for NESZ measurement

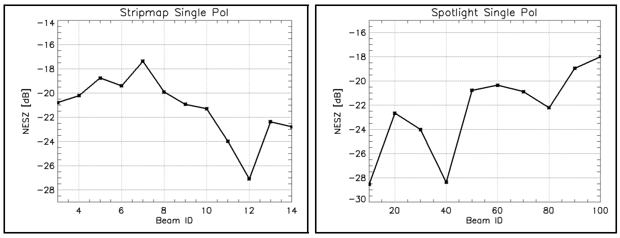

Figure 8: Measured NESZ for Stripmap and Spotlight

3.7 Ambiguities

In TS-X ambiguity control is a challenge due to the relatively short antenna and the resulting high PRF above 3 kHz. The TS-X ambiguity ratios are calculated with the model of equal σ_0 in ambiguity and target area, σ_t and σ_A, respectively. The ambiguous signal in the target area is suppressed mainly by the antenna pattern as shown in Figure 9. There are other models with ambiguous areas stronger than the target area. This is favorable for scenes with high contrast, e.g. land/see transmissions.

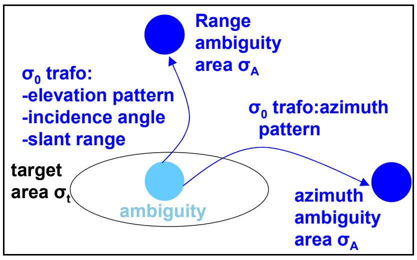

Figure 9: Target and ambiguous areas

Ambiguities were measured in order to relate a visual image impression to calculated ambiguity values. For the high contrast scene in Figure 10, the range ambiguity is considered acceptable for a high contrast scene and a ratio of 19.5 dB was measured in the image. Using elevation pattern and geometry the measured ratio was transformed into a σ_A/σ_t ratio of 52dB. This corresponds to a performance calculation value of -32dB using the equal σ_0 model, i.e. σ_A/σ_t=1.

Based on the above and other measurements, a range ambiguity ratio of about -25dB was established as recommendation for high contrast scenes. For azimuth ambiguities, a similar approach lead to a recommendation of -20dB. These values concluded in the recommended ambiguity range of Figure 11 for high contrast scenes, e.g. land/see transition.

Figure 10: Spot Image at 36° incidence with ambiguity

Mode	Pol Mode	Full Perf. Req. In Az & Rg	Full Perf. Beams	Incidence/ Look angle range	High Contrast Recommended Performance Beams (Criteria Rg -25 dB Az -20 dB)	Incidence/Look angle range
Stripmap	Single	-17 dB	strip_003-strip_014	19.7° - 45.5° 18.2° - 41.3°	strip_003 - strip_014	19.7° - 45.5° 18.2° - 41.3°
Stripmap	Dual-co	-16 dB	stripNear_003-stripFar_014	19.9° - 45.4° 18.3° - 41.3°	stripNear_003-stripFar_011	19.9° - 40.3° 18.3° - 36.8°
Stripmap	Dual-cross	-16 dB	stripNear_003-stripFar_014	19.9° - 45.4° 18.3° - 41.3°	stripNear_003-stripFar_011	19.9° - 40.3° 18.3° - 36.8°
Spotlight /HighRes	Single	-17 dB	Spot_010-Spot_100	19.7°-55.2° 18.2°-49.5°	Spot_010 -Spot_079	19.7°-49.7° 18.2°-44.9
Spotlight /HighRes	Dual-co	-16 dB (-9dB above 45°inc.)	Spot_010-Spot_100	19.7°-55.2° 18.2°-49.5°	Spot_010 -Spot_059	19.7°-43.3° 18.2°-39.4°
ScanSAR	Single	-15 dB	strip_003-strip_014	19.7° - 45.5° 18.2° - 41.3°	strip_003 - strip_014	19.7° - 45.5° 18.2° - 41.3°

Figure 11: Full performance range and recommended range w.r.t. ambiguity performance for high contrast scenes

3.8 ScanSAR and Spotlight Mode

The ScanSAR 1 azimuth look strategy was confirmed. Comparison with up to 4 look rain forest images did not show significant difference w.r.t. scalloping. Even for 1 look, the scalloping was measured below 0.2 dB. However, for an improved visual impression the burst image overlap was increased and is now in-between 3 and 10%, depending on subswath number.

In spotlight, apart from the verification of geometric resolution, the verification of the target integration time confirms the sliding spotlight command generation. One example measurement is shown in Figure 12, which also makes visible the TSX azimuth steering by switching different azimuth pattern.

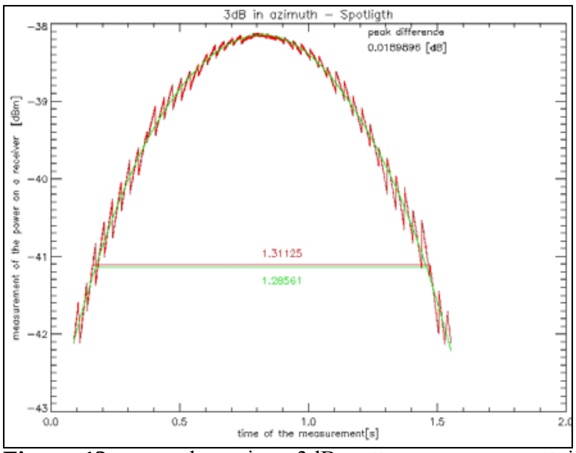

Figure 12: ground receiver 3dB pattern measurement in red, fit in green, time measured for DT 7553 1.285s, time calculated in command generation 1.278s.

3.9 Sidelobe Suppression

Image analysis made obvious that the high geometric resolution intensified the perception of point targets sidelobes too much. Thus, the sidelobe suppression was strengthened by changing the Hamming α value from 0.75 to 0.6. Details and image examples are shown in [2]. The corresponding 18% increase of geometric resolution could be almost compensated by reduction of processing margin and increase of processed bandwidth as well as steering range in azimuth.

4 Discussion

In the CP, many commanding and performance optimizations were performed. Two times the Rx-Gain has been reduced due to saturation and the BAQ compression could be increased by 1 or 2 bits. The Total Zero Doppler Steering works perfect and benefits the SAR processing. The image quality was enhanced by stronger sidelobe suppression below -30dB. The tight timing constraints for PRF selection have been reduced by optimization of nadir and swath margins. A recommended ambiguity range was defined for high contrast scenes. The commanding of spotlight and ScanSAR was verified. The ScanSAR 1 azimuth look strategy was confirmed and the visual scalloping performance has been improved by an increased burst image overlap. The measured along track repeat pass DT positioning is 50m, i.e. 9% of a ScanSAR burst. Successful verifications not explicitly mentioned in this paper are e.g. left looking in all modes, aperture switching mode for ATI or TOPSAR mode [3].

5 Acknowledgement

Hauke Fiedler calculated the yaw and pitch offsets in the TZDS verification.

6 References

[1] Marwan Younis, Johannes Boer, Carlos Ortega, Daniel Schulze, and Josef Mittermayer: *Determening the Optimum Compromise between SAR Data Compression and Radiometric Performance – An Approach Based on the Analysis of TerraSAR-X Data* –, submitted to IGARSS08.

[2] H. Breit, B. Schättler, T. Fritz, U. Balss, H. Damerow, E. Schwarz: *TerraSAR-X SAR Payload Data Processing: Results from Commissioning and Early Operational Phase*, proceedings of EUSAR 2008.

[3] Adriano Meta, Pau Prats, Ulrich Steinbrecher, Josef Mittermayer and Rolf Scheiber: *TerraSAR-X TOPSAR and ScanSAR comparison*, proceedings of EUSAR 2008.

[4] Hauke Fiedler, Elke Boerner, Josef Mittermayer, Gerhard Krieger: *Total Zero Doppler Steering—A New Method for Minimizing the Doppler Centroid*, IEEE Geoscience and Remote Sensing letters, 2005.