TerraSAR-X SAR Payload Data Processing: Results from Commissioning and Early Operational Phase

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Abstract

TerraSAR-X, the first national German radar satellite, was launched in June 2007. It carries an X-band high-resolution synthetic aperture radar instrument featuring the operational imaging modes Stripmap, ScanSAR and, particularly, Spotlight in a variety of different polarization modes. The TerraSAR-X mission 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 from January 2008 on.

The payload ground segment (PGS) is responsible for the reception of the SAR payload data, their archiving and processing and the distribution of the generated SAR basic products [2] to users. From the first mission day on, PGS was operated successfully using both its request workflow starting with the input of user orders and ending with the delivery of the generated product and its operational SAR data workflow for the reception and processing of the SAR payload data [9]. The central part of PGS is the TerraSAR Multi-Mode SAR Processor (TMSP) [3] focusing the SAR data in a unified way for the different imaging configurations. A wide range of processing options spanning from phase preserving complex products in slant range geometry to orthorectified terrain corrected intensity images lead to a comprehensive collection of SAR product types and variants. Together with instrument calibration [4] [6], checkout and tuning of the SAR processor was one of the major tasks of the commissioning phase with respect to product verification and validation. This paper summarizes the key activities and exposes the achievements obtained with respect to focusing quality.

1 Introduction

Instrument calibration and SAR processor validation depend on each other. A precondition for geometric and radiometric calibration is that the SAR processor itself does not falsify the measurements and provides relatively calibrated and geometrically undistorted image products. This essentially requires a correct implementation of the instrument internal calibration pulse evaluation and application, Doppler centroid estimation, processor normalization and in particular of the phase-preserving focusing kernel.

2 Essential Processing Aspects

Processor normalization has to ensure that the processor gain is independent of the:

- range spread,
- chirp length,
- azimuth aperture length,
- PRF and range sampling frequency,
- imaging mode,
- processed bandwidth and applied weighting,
- output sampling.

Despite the fact, that the normalization of the processor has been verified with simulated point target raw data prior to launch it is very satisfactory that the validation of the concept with real TerraSAR-X data finally results in a unique absolute calibration constant independent of the SAR imaging mode. It could be demonstrated that a mosaic of rainforest images acquired with different SAR modes fit seamless together with respect to radiometry (and of course geometry) [7].

One of the pre-conditions for the highly accurate determination and validation [6] of the various elevation gain patterns is the DEM based projection of the geometrically annotated patterns into the radar coordinates $t_{azimuth}$ and slant range R, respectively, carried out by the TMSP.

The high accurate determination of the range bandwidth dependent instrument internal electronic delays was supported by the TMSP's default evaluation and annotation of atmospheric propagation delays.

Proof was given, that not only the instrument is phase-stable but also the TMSP generates phase-preserving complex images in Spotlight and Stripmap mode [10]. Even in cases where a PRF change within a data take requires phase preserving interpolation and resampling of the SAR raw data an artefact-free interferogram has been generated. The fitness of the ScanSAR mode for interferometric applications will be demonstrated in the near future.

3 SAR Focusing Improvements

3.1 Range Reference Function Determination

Range focusing of satisfactory quality requires the precise knowledge of the transmitted and received chirp-type pulse. A typical approach being also initially considered for TerraSAR-X is the application of polynomial amplitude and phase fits of a reconstructed replica as the focusing reference function. Such fits are noise insensitive and robust against signal disturbances. However spectral analysis of a reconstructed chirp replica (Figure 1) reveals that a simple polynomial fit is an inadequate model to describe a chirp signal being affected by non-linearities in the system transfer functions of the instrument's transmit and receive electronics, i.e. up / down conversion. The power level of the mirror-frequency chirp and other chirp components is about 20 to 25 dB below the nominal chirp.

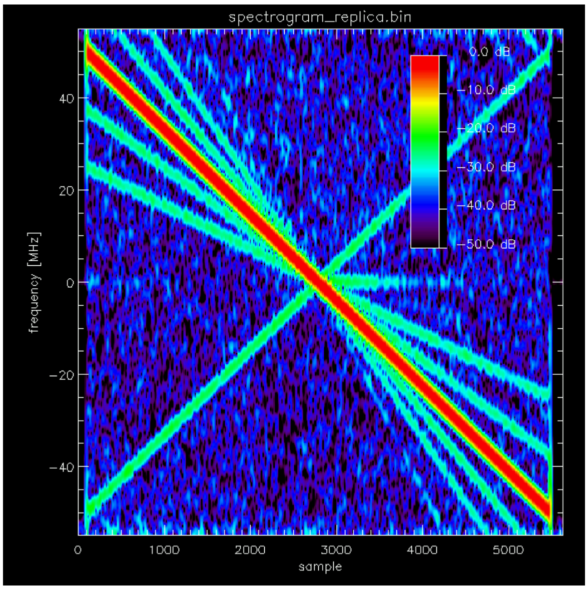

Figure 1: Spectrogram of a digital 100 MHz down-chirp replica reconstructed from the instrument's internal calibration loop measurements. Besides the nominal chirp additional chirp frequency rates are present. The colours represent a power range of 50 dB.

In high contrast parts of a SAR image as depicted in Figure 2 strong scatters leave objectionable range artefacts of several kilometres length, i.e. the chirp length. Applying the reconstructed chirp replica itself the energy of all chirp components is focused to the scatters' true locations, see Figure 3.

Figure 2: A 5th order polynomial replica fit being used as range reference function does not focus all range signal components. The given 2 km (az.) x 1.4 km (rg.) image detail depicts a container terminal located at Yokohama, Japan.

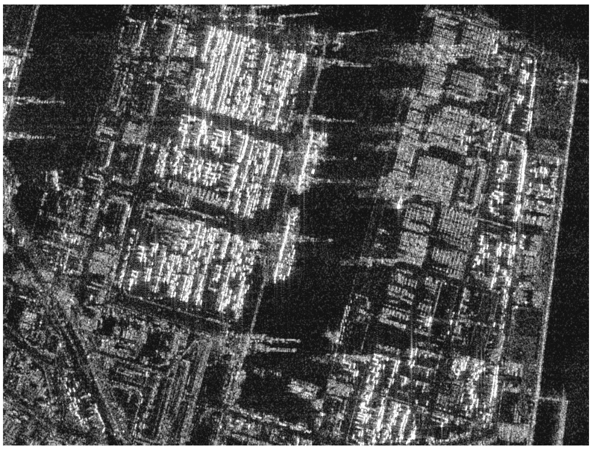

Figure 3: Direct use of a digital replica drastically improves the range focusing quality.

3.2 Sidelobe Suppression

Weighting of the complex signal spectrum by a Hamming like window function,

$$W(f) = \alpha + (1-\alpha)\cdot\cos(2\pi f/B)\cdot rect(f/B),$$

as implemented [3] suppresses side lobes on the expense of resolution. In contrast to the determination of an optimal range focusing reference function the trade-off between preferably high geometrical resolution on the one hand and an acceptable image degradation in terms of peak and integrated side lobe ratios (PLSR, ISLR), signal to azimuth ambiguity ratio (SAAR) and signal to noise ratio (SNR) one the other hand is always a compromise.

Comparing TerraSAR-X's best resolution of 1m with a typical value of 7m for operationally established civilian spaceborne SAR systems means that such a 7m resolution cell is broken apart into about 50 cells by TerraSAR-X. Larger objects especially in urban or industrial areas are thus decomposed into their single scattering constituents, e.g. individual structural elements of buildings. After inspection of the first high resolution TerraSAR-X images processed with a pre-launch defined side lobe suppression of α=0.75 (Figure 4) it seemed to be worthwhile reconsidering this parameter setting.

Figure 4: A 1.75 km x 1.5 km detail of a multi-look ground range image acquired in Strimap mode depicting the Oberpfaffenhofen test site. The processed azimuth bandwidth of 2500 Hz and range bandwidth of 100 MHz are weighted with α=0.75 respectively.

Figure 5: Weighting with α=0.6 effectively drops the unwanted side lobes of strong scatters. In azimuth direction an otherwise inherent decrease in resolution is counterbalanced by a slightly increased processed azimuth bandwidth of 2765 Hz.

A weighting factor of α=0.60 is a good compromise: Compared to the initial setting, PSLR improves by 10 dB and 1-D ISLR by 3.5 dB (Table 1). In contrast to range where the resolution is decreased by the theoretical value of 18% the effect is mitigated in azimuth by an increased processing bandwidth (+11%) in Stripmap mode. A total compensation is achieved in HS Spotlight mode (1.1m) by extended azimuth beam steering. In SL Spotlight mode the azimuth resolution is even improved (1.7m) [2].

weighting	resolution	PSLR	1-D ISLR
α=0.75	1.0	-21.4 dB	-16 dB
α=0.60	1.18	-31.6 dB	-19.5 dB

Table 1: Theoretical impulse response function properties

A welcome side effect is the improved signal to azimuth ambiguity ratio. Figure 6 reveals that even though the azimuth processing bandwidth has been increased the new setting, α=0.6, improves the SAAR by +2 dB for PRF values selected below 3600 Hz.

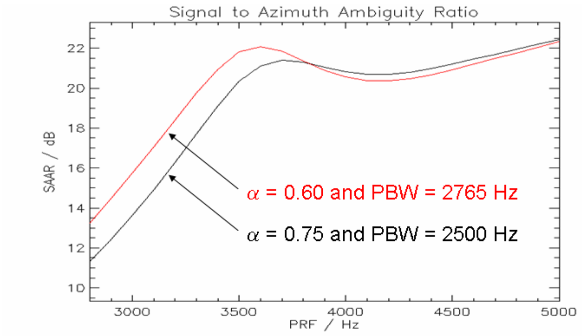

Figure 6: SAAR given as a function of PRF for two different settings of spectral weighting and azimuth processing bandwidth.

Figure 7 gives an image example demonstrating the SAAR improvement. The underlying Spotlight acquisition ($\theta_{incidence}$= 56°) being already executed outside of the full performance swath [2] with a very low PRF of 3000 Hz is not representative with respect to ambiguity strength to be expected in TerraSAR-X images. But the example nicely demonstrates the effect being theoretically derived in Figure 6.

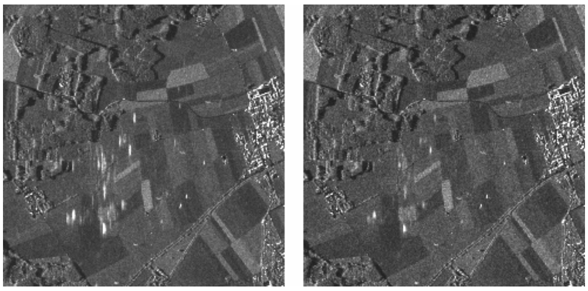

Figure 7: Image detail of a Spotlight acquisition showing agricultural land affected by azimuth ambiguities. Stronger spectral weighting (left: α=0.75, right: α=0.6) lowers the level of aliased energy.

Figure 8 presents a 300 MHz High-Resolution Spotlight scene processed with the final focusing settings.

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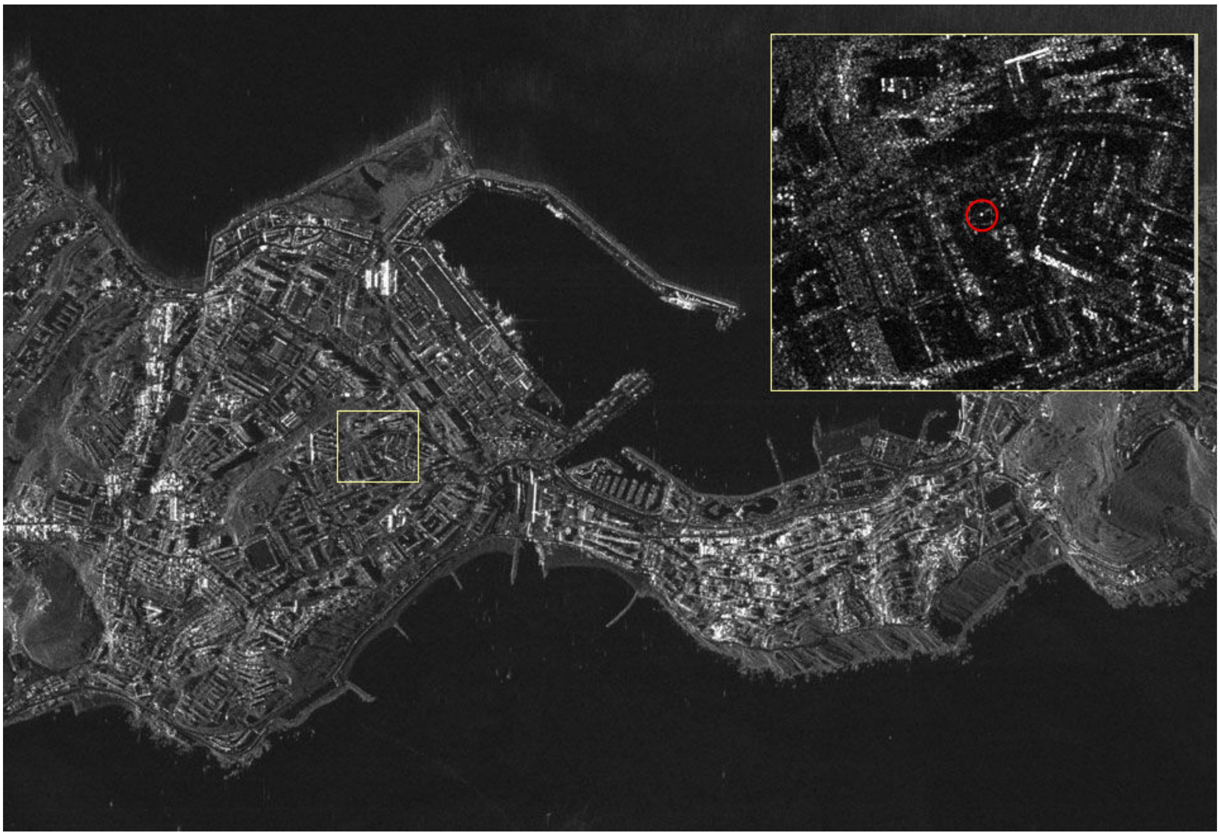

Figure 8: Ceuta, Spain acquired in High-Resolution Spotlight mode with 300 MHz range bandwidth. The data are processed to a spatially enhanced multi-look, ground range, detected level 1b product. A measurement on a natural point target, exposed by the red circle, resulted in an azimuth resolution of 1.1 m and a ground range resolution of 1.1 m corresponding to 0.6 m in slant range.

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