The External Calibration of TerraSAR-X, a Multiple Mode SAR-System

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Abstract

TerraSAR-X is a versatile X-Band SAR satellite operating in Stripmap, Spotlight and ScanSAR modes with selectable or dual polarisation. Additionally, experimental modes are possible, like wide bandwidth operation providing even higher resolution, or a left-looking mode. Consequently, cost and time effective concepts for external calibration are mandatory because of the large number of modes and possible antenna patterns.
External calibration meets the challenge of calibrating in a short time frame during commissioning. The paper describes the developed strategy planned for the TerraSAR-X commissioning phase and discusses its implementation. External calibration is presented as a part of the IOCS Calibration Section in the TerraSAR-X Ground Segment [1].

1 Introduction

The quality of the calibration process essentially depends on the inherent stability of the radar system and the capability to determine and monitor the radiometric and geometric characteristics of TerraSAR-X. SAR images require the transformation of recorded raw data into images with geophysical reference units like the radar cross section (RCS) of targets or the elevation for a Digital Elevation Models (DEM). The external calibration determines necessary parameters for the SAR processor to correct and scale the image data.

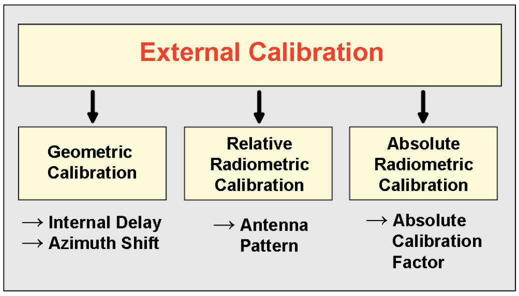

Figure 1: Scope of External Calibration.

As TerraSAR-X is a multiple mode system capable of switching between a multitude of beams, the requirements on external calibration are driven by the versatility of the instrument as well as the high demand on accurate geometric and radiometric calibration.
External calibration is the main driver of the commissioning phase schedule as extensive activities have to be performed. To account for the restricted time of calibration campaigns an advanced strategy for external calibration has been developed and is presented in the following.

2 Scope of External Calibration

Performed during commissioning of a SAR system, the objective of external calibration can be sub-divided into 3 major task:

- **Geometric Calibration:** to assign the SAR system to the geographic location on the earth surface.
- **Relative Radiometric Calibration:** for radiometric correction of SAR data within an illuminated scene.
- **Absolute Radiometric Calibration:** the measurement of the SAR system against standard targets with well known geophysical characteristics.

The corresponding calibration parameters required for SAR data processing and consequently for absolute calibrated SAR data products are shown in Figure 1.
Furthermore, a conventional calibration approach, i.e. the need of long-lasting antenna beam characterization using repetitive passes over rainforest for at least all performance beams as well as the measurement of TerraSAR-X against standard targets for all operation modes deriving the corresponding absolute calibration factors, is not feasible and new, more efficient, and affordable methods have been developed [2]. The key element of these methods and the new calibration concept is an antenna model. Thus, in addition to the tasks described above, the verification of this antenna model has to be performed in-orbit.

3 Strategy

In addition to the complexity of TerraSAR-X and the corresponding challenges described before, the main goal after launch of the satellite is to provide calibrated and verified SAR data products as far as possible at the latest by the end of the commissioning phase. Thus, a strategy for an efficient but robust calibration approach has been developed. The successive baseline calibration processes are:

1. Geometric Calibration
2. Antenna Pointing
3. Antenna Model Verification
4. Relative Radiometric Calibration
5. Absolute Radiometric Calibration

In the following the process steps of the external calibration are described in detail.

3.1 Geometric Calibration

The purpose of the geometric calibration is the geometric assignment of the SAR system to the earth surface. Two effects can influence the correct localisation of the product:

- systematic azimuth shifts and
- the internal electronic delay of the instrument

A time shift between the radar time and the orbit time yields an image shift in azimuth. By analysing the impulse response of a deployed point target within the SAR image, the difference between the orbit time and the annotated product time can be determined.
The round trip delay depends on the internal electronic delay of the instrument. By comparing the slant range of a deployed point target derived from the annotated SAR image and from the geometry, the difference in round trip delay yields the internal electronic delay of the instrument. For both effects, corner reflectors are deployed as they have no additional delay and consequently no additional source of error occurs.

3.2 Antenna Pointing

An important task is the determination of beam pointing errors coming from mechanical antenna offsets. These errors are measured in elevation and in azimuth using an appropriate notch pattern over rain forest and by ground receivers. But also a Doppler analysis is performed to evaluate the error in flight direction.

3.3 Antenna Model Verification

The characterisation of the antenna is based on a precise antenna pattern model, which has to be validated against precisely measured near field patterns on-ground before launch and verified in-orbit by in-flight measurements over homogeneous targets (rain forest) and deployed ground receivers.
The validation of the antenna model on-ground is performed by EADS Astrium [3] using a near field scanner. The strategy is based on the comparison between simulations and measurements whereby the model is validated first on sub-array level, then on panel level and finally on leaf level. The complete antenna can only be verified in-orbit.
The in-orbit verification will be performed by three selected beams with low, medium and high incidence angle. For this, the elevation patterns are measured over rain forest and compared to the pre-calculated patterns. Furthermore, the transmitted pulses are recorded on-ground by deployed ground receivers. With this method the transmit pattern of the TerraSAR-X antenna can be really measured in-flight verifying the one-way azimuth patterns.
One example of really measured antenna patterns is shown in Figure 2. The depicted pulses as function of time were measured for the ASAR/ENVISAT instrument in ScanSAR operation by one ground receiver [4]. The reduced amplitudes indicate the switching of the instrument from beam to beam and the envelopes represent the one-way azimuth pattern of the corresponding beam.

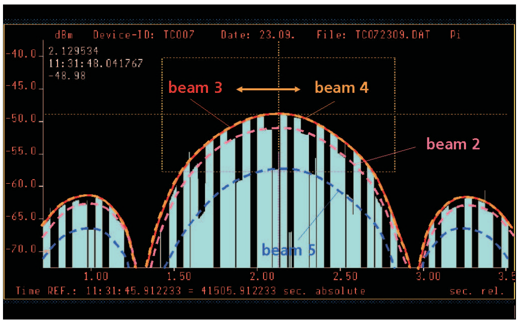

Figure 2: One-way (transmit) azimuth antenna patterns of the ASAR/ENVISAT instrument in ScanSAR operation measured by a ground receiver.

The relative gain variation from beam to beam will be characterised over homogeneous targets in ScanSAR operation. Thus, the effort of the absolute radiometric calibration can be reduced down to a few beams instead of measuring TerraSAR-X against deployed calibration targets for all operation modes.
The antenna model provides a software tool that accurately determines all beam patterns based on detailed characterisation of the antenna hardware and knowledge of the antenna control parameters. Beyond these capabilities the antenna pattern module also features a tool for generating optimised beam coefficients under given constraints. The major advantage of this beam optimisation is the dynamic re-calibration in the event of T/R Module degradations during the mission. An important input to the model are the actual beam coefficients of the active phased array which can be characterised in-orbit using the novel PN-Gating method [5].

3.4 Relative and Absolute Radiometric Calibration

After in-orbit verification of the antenna model the beam patterns required for radiometric correction of SAR data within an illuminated scene will be derived by the antenna model for all operation modes and all incidence angles.
In order to reduce calibration effort, the absolute radiometric calibration is likewise based on the antenna model, i.e. the real measurement is performed for the three selected beams described in chapter 3.3. The absolute calibration factors of all other beams and modes will be derived via the antenna model. Driven by the radiometric accuracy budget, each of the three beams will be measured against 12 calibration targets with well known RCS. The number of deployed calibration targets can be reduced by the number of passes.
Hence, by applying the antenna model, the effort for both the relative and the absolute radiometric calibration as well as the duration of the commissioning phase can be significantly reduced.

3.5 Background Activities

In addition to the required tasks for calibrating all full performance beams further activities will be performed to support the antenna model verification and the absolute radiometric calibration:

- SAR operation for different bandwidths
- Data acquisitions in Spotlight mode
- SAR operation in left looking mode

Although not time-critical in execution, these activities provide important information on the performance of the SAR system.

4 Calibration Sites

External calibration is based on SAR data acquisition over test sites with well-known calibration targets. Basically, these sites can be homogenous areas like the Amazonian rain forest or scenes with point targets like corner reflectors or active transponders. In case of point targets, the positions of these targets are precisely surveyed using the differential Global Positioning System (GPS).

4.1 Coverage

In order to obtain as many overflights as possible over calibration targets, test sites will be selected in the cross over points of ascending and descending passes. The coverage on the earth's surface needs to be evaluated with respect to the required number of point target and rain forest measurements assumed in the radiometric accuracy budget.

As single beams do not cover the complete globe, the selection of test sites is constrained to the availability of respective beams on ground. Figure 3 shows the coverage of the full performance beam 009 over Germany in right looking mode for a repeat cycle of eleven days.

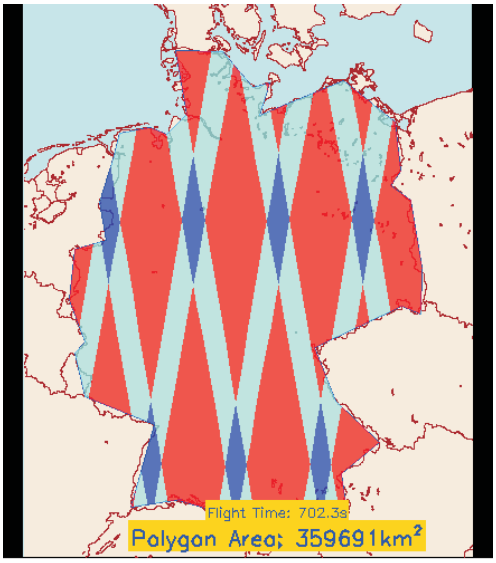

Figure 3: Coverage of StripMap beam 009 over a complete repeat cycle. Red areas: no coverage, light blue areas: once, and dark blue areas are covered twice.

4.2 Mega Test Site Configuration

To achieve a high number of passes during commissioning test sites are selected in areas where the same or different beams allow a re-use of one test site for several passes (e.g. ascending and descending).

Figure 4 shows how point targets are deployed in one of the so-called Mega Test Sites. There are seven fixed target positions, whereat the red crosses are covered in both descending and ascending orbit. Within one swath of 30 km range two targets are deployed in near range, in the swath centre and in far range, respectively. The targets must be sufficiently separated to avoid ambiguities in the image. However, by the Mega Test Site depicted in Figure 4 the required number of 12 target positions (compare with chapter 3.4) can be reduced down to 7 positions.

A Mega Test Site for ScanSAR operation is set up similar to that already deployed for calibrating the ASAR/ENVISAT instrument in wide swath operation [4]. Thus, the set up is accounted for four sub-swaths and their overlap regions instead of an overlap region between ascending and descending passes.

The number of overflights and places of test sites is optimised versus cost and time effort by calibrating several beams and polarisation modes with a few test sites.

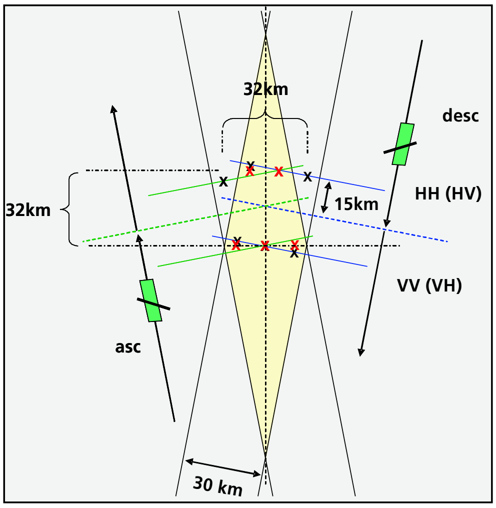

Figure 4: Mega Test Site configuration for TerraSAR-X StripMap calibration.

4.3 Calibration Facility Oberpfaffenhofen

Implementation of the above concepts requires a calibration facility that is well-equipped with ground calibration hardware as well as software tools for evaluating the measurements. As shown in Figure 5, three different types of calibration targets are used:

- Trihedral and dihedral **corner reflectors** as passive targets precisely surveyed (with differential GPS) and therefore well suited for geometric calibration.
- **Transponders** with high radar cross section providing accurately defined point targets within the scene.
- **Ground receivers** measuring the one-way azimuth pattern of the SAR antenna during an overflight

Mainly for logistic reasons test sites are selected which are operated and maintained near by Oberpfaffenhofen in South Germany.

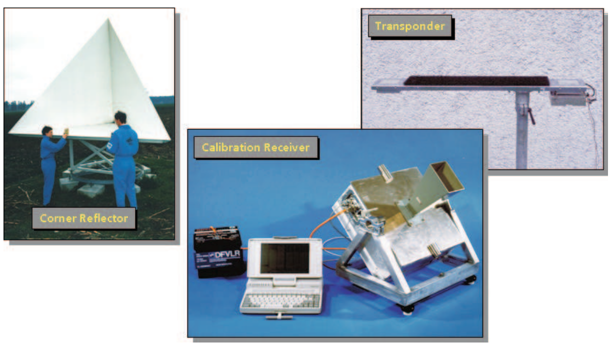

Figure 5: Calibration targets of DLR.

The existing infrastructure is well prepared for executing calibration campaigns over large test sites. Accordingly, reliable and accurate ground equipment is guaranteed during the whole mission life time.

5 Conclusion

External calibration planned for TerraSAR-X is based on DLR's experience on previous satellite SAR missions like XSAR-SRTM or ASAR/ENVISAT.

Innovative calibration techniques are established to cope with the multitude of beams to be calibrated. The developed antenna model provides a more efficient and faster calibration than the traditional beam by beam approach. Combined with the novel PN-Gating technique [5] the antenna model is also able to compensate for graceful degradation of the instrument throughout the mission lifetime.

Hence, by applying the antenna model as key element of the external calibration strategy, an efficient but accurate way to accomplish a short commissioning phase has been developed. The concept is applicable to other advanced SAR sensors coping with a multitude of operational modes as well as subsequent calibration campaigns.

References

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