On-Ground Testing of TerraSAR-X Instrument

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Abstract

The primary payload on TerraSAR-X is the Synthetic Aperture Radar using an active antenna operating in X-band. The SAR instrument architecture and its high performance have lead to refined approaches for verification. An outline is given herein together with examples for on-ground testing of primary instrument performance parameters.
TerraSAR-X is financed, built, launched and operated on a national basis in the scope of a public-private partnership between the German Aerospace Centre (DLR) and EADS Astrium GmbH.

1 Introduction

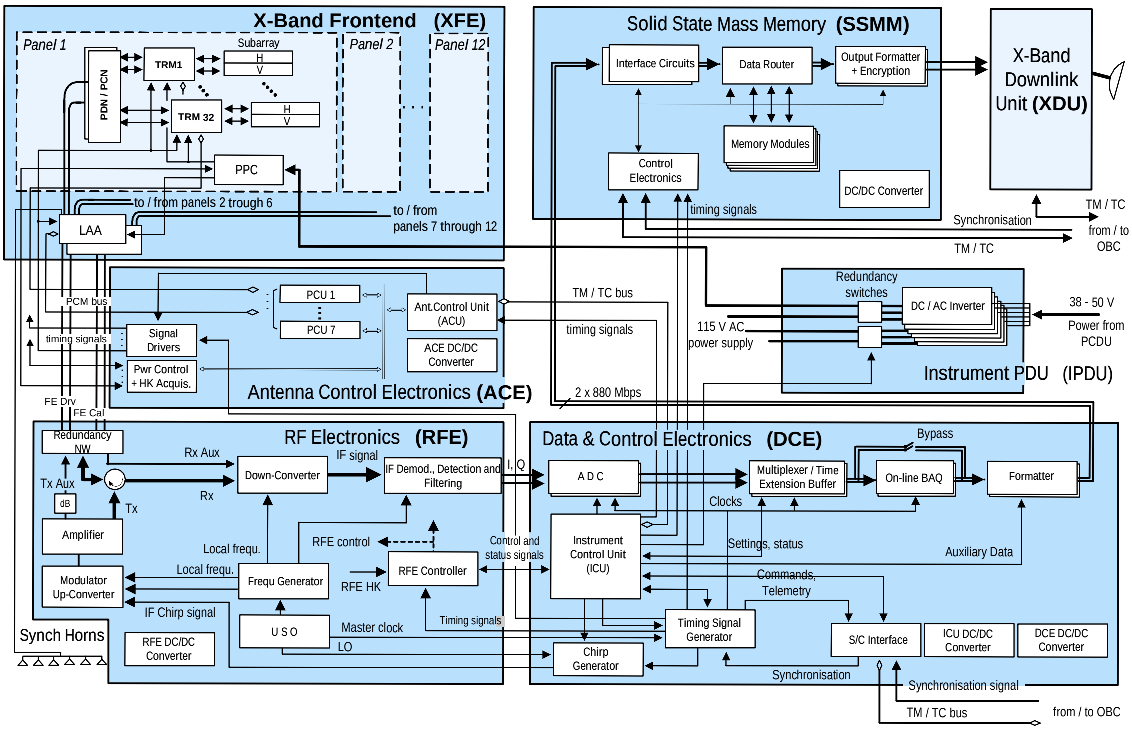
Background information is presented in parallel papers (EUSAR 2006).
An on-ground verification program for a space project aims to avoid the risk of finding problems in-orbit which obviously cannot be corrected. In-orbit verification of many image performance requirements is very difficult or even impossible for a high performance radar. Furthermore, TerraSAR-X also offers extreme operational flexibility which magnifies the need for a thorough on-ground verification program.

On-ground performance verification and testing is closely related to internal and external calibration and on-ground characterisation. This paper outlines these relationships.

2 SAR Overview

The SAR architecture is depicted in the block diagram in Figure 1.

Figure 1: SAR Block Diagram



X-Band Instrument - Functional Block Diagram

Transmit pulses are generated in the Digital Chirp Generator in the Digital Control Electronics. The Radio Frequency Electronics provides up-conversion and divides the pulses into 2 paths towards the antenna halves. Leaf Amplifier Assemblies pre-amplify and further divide to feed the 12 antenna panels. Each Panel Distribution Network further divides towards 32 Transmit Receive Modules. Each TRM feeds either a V- or an H-pol waveguide via its polarisation switch.
Reception is the reverse sequence to above as far as the RFE which then performs down-conversion, demodulation and filtering (1/3 selection). The DCE performs digitisation, time expansion, sub-sampling (matched to selected filter), Block Adaptive Quantisation. The Solid State Mass Memory provides data formatting, storage, replay with encryption. The X-band Downlink Unit provides data downlink to the ground station.

The SAR has the following key design aspects:

- Active antenna providing fast scanning in elevation (to cover the large range of incidence angle with minimal along track gaps between scenes) and in azimuth (to allow use of SpotLight technique to provide high resolution)
- Transmit & Receive Modules with polarisation switches and H/V-polarised pairs of slotted waveguides (to provide polarisation diversity)
- Metallised Carbon Fibre Reinforced Plastic radiating waveguides with high temperature stability because these elements are not covered by the internal calibration scheme
- Digital Chirp Generator and selectable receive filter bandwidths to allow efficient use of on board storage considering the ground range resolution dependence on incidence angle
- Block Adaptive Quantisation to allow efficient use of on-board storage and minimise downlink times with negligible impact on image noise
- RF-architecture which allows Dual Receive Antenna operation where use of nominal and redundant receiver chains with azimuth antenna halves effectively provides 2 SARs simultaneously to support Moving Target Indication
- Solid State Mass Memory which allows simultaneous image recording and replay/downlink.
- Synch Horn Antennas to radiate and receive signals to support a coherent multi-SAR (Tandem) mission with quasi-isotropic/spherical coverage

3 Verification, Calibration and Characterisation

The approach for on-ground verification of performance requirements is a combination of tests and analysis. The tests are typically done for so-called ‘technical parameters’, e.g. transmit power, noise figure. The analysis is a suite of algorithms which transform the technical parameters into ‘engineering parameters’ (i.e. image performance). Clearly these algorithms have to take into account the spacecraft Bus performance (e.g. pointing accuracy), and the Ground Segment performance (e.g. external calibration accuracy).
The performance algorithms are in fact used during the design phase. For this reason, they are structured first to use relevant parameters of unit specifications. Hence, they represent a design tool for defining the unit specifications and also a tool for processing any problems which occur during the development or production of the flight hardware.

Antenna performance dominates the radar image performance. An active antenna can provide an unlimited number of antenna patterns (via programmable amplitude and phase of the TRMs) which obviously cannot all be measured on-ground. The approach is to develop an Antenna Model and verify this on-ground by comparison with measurements of a limited number of typical antenna patterns. The Antenna Model is an algorithm which predicts the antenna gain and pattern depending on the programmable parameters. An important part of the in-orbit testing is to make a final conformation of the Antenna Model for the in-orbit configuration with the antenna mounted on the spacecraft structure and no-gravity conditions.

The SAR design includes an internal calibration scheme whereby transmit signals are routed into the receiver to allow monitoring of amplitude/phase during operation (either during on-ground testing or in-orbit). This scheme produces data which can be used by ground processing for radiometric and/or phase correction of the image data.
However, the internal calibration route is not exactly the same as the nominal radar transmit/receive path. On the one hand, some elements of the transmit/receive path are not fully covered, e.g. the internal calibration signals are coupled out at the Front-End TRMs (transmit side towards subarrays) hence undergo a different path than the radar signal itself. On the other hand, some elements of the internal calibration path are not part of the nominal radar path, e.g. the above internal calibration signals are routed back to the RFE via dedicated coax cables.

Temperature variations of those elements which are not fully covered or specific to the internal calibration loops result in instabilities which cannot be corrected by using the internal calibration data. On-ground measurements (i.e. characterisation) of these elements (viz. amplitude and phase variation with frequency and temperature) allow a second level of correction in the ground processing.

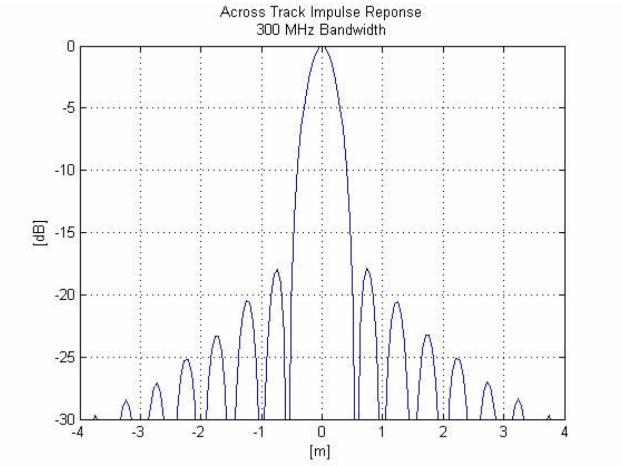
4 Testing of Geometric Resolution

The imaging quality of a radar is determined by characteristics of its Impulse Response Function, i.e. the appearance of a point target in an image. The IRF width determines the geometric resolution.

The internal calibration scheme of the TerraSAR-X SAR provides an ideal way to determine its IRF via Closed Loop measurements using the nominal configuration without external equipment. The measurement can be performed with a small section of the antenna and repeated at suitable stages during progressive antenna integration on the satellite. It can be performed during TV testing to prove performance at extreme environmental conditions.

A replica is built using internal calibration pulses. The Ground Processing is simulated by compression with a simulated point target echo provided by an internal calibration pulse measured at a later time being typical of the planned data take duration. Figure 2 shows a range IRF determined in this way for a 300MHz transmit chirp and the same value selected receive filter bandwidth.

Figure 2: Test Result for Range IRF (300MHz)



5 Testing of Stability

The internal calibration scheme of the TerraSAR-X SAR aims to monitor the product of transmit power and receive gain, the so-called PG product. The performance of this monitoring is a key contribution to the SAR radiometric stability.

A reference PG measurement is made using external equipment as depicted in Figure 3. Figure 4 shows the results of both measurements and their difference for the baseline planned operation using internal calibration every 60s and de-activation of the TRM automatic temperature compensation in between. The smooth drift allows the accurate interpolation of internal calibration measurements. This test proves the performance of the internal calibration scheme which then can be used (without external equipment) during TV testing with the complete antenna to prove performance at extreme environmental conditions.

Figure 3: Test Set-Up for Amplitude Stability

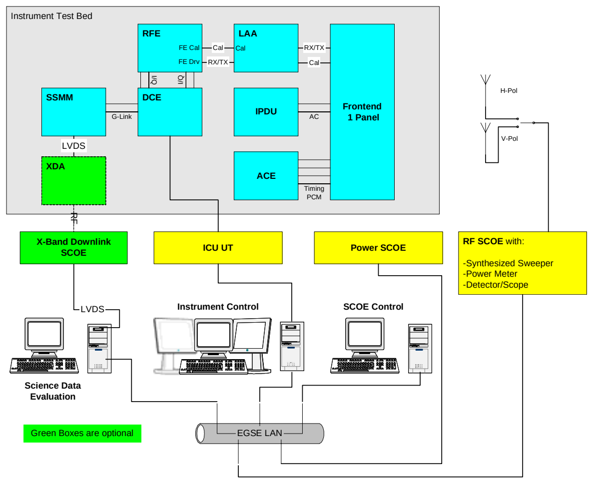


Figure 4: Test Result for Amplitude Stability