two Innovative Remote Sensing Stars for Space-borne Earth Observation

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**TerraSAR-X**  
**A National Science Mission with Commercial Potential**

## Public Private Partnership

<table>
<thead>
<tr>
<th><strong>DLR</strong></th>
<th><strong>EADS Astrium</strong></th>
<th><strong>Infoterra</strong></th>
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</thead>
</table>
| - Project Management  
- G/S Development & Ops  
- Science Coordination | - Platform Development  
- Instrument Development  
- Launch on Dnepr (2006) | - Service Infrastructure  
- Information Products  
- Commercial Exploitation |

### Main Mission Goals:
- Provision of TerraSAR-X data for **scientific applications** → public interest
- **Commercial exploitation** of TerraSAR-X data → by industry
TerraSAR-X
Application Areas

Agriculture
- Precision Farming Suite
- Crop Ripeness
- Crop Inventory
- Yield Prediction Cereals

Forestry
- Strategic Forest Inventory
- Reconnaissance Inventory
- Inventory Update

Cartography
- Topo Map Local
- Topo Map Regional / Macro
- Regional Planning Map
- Environmental Planning Map
- Infrastructure Planning Map

Risk
- Flood Damage Assessment
- Fire Damage Assessment
- Storm Damage Assessment

Utilities
- Telecom Planning
- Utility Planning

Security
- Reconnaissance Imagery (VHR-SAR)

Geology
- Geology Structure Map
- Geology Image Map
- Geological Elevation Map
- Oil Seep Detection

Marine
- Ship Detection Service
- Oil Spill Monitoring
- Sea Ice Monitoring
- Center frequency: 9.65 GHz (X-band)
- Tx bandwidth: up to 150 MHz (300 exp.)
- PRF: 3 KHz to 6.5 KHz
- Transmit duty cycle: 13-20%
- Radiated peak power: 2260 W
- System noise figure: 5 dB
- Antenna dimension in azimuth: 4.784 m
- Antenna dimension in elevation: 0.704 m
- Azimuth beamwidth: 0.33°
- Elevation beamwidth: 2.3°
- Scan angle azimuth: ± 0.75°
- Scan angle elevation: ± 19.2°
TerraSAR-X Orbit

dusk/down orbit
altitude at equator 514.8 km
inclination 97.44°
sun-synchronous repeat orbit:
repeat period 11 days
revisit time: 4.5 days (100%)
2.5 days (95%)
orbits per day 15 2/11
TerraSAR-X Mission Profile

- X-Band Downlink
  300 Mbit/sec
- DLR GS Neustrelitz
- DLR GS Weilheim
- S-Band TM & TC
- Raw Data Acquisition
- Mission Operations
  DLR
  Oberpfaffenhofen
TerraSAR-X Imaging Modes

**Stripmap Mode**

**ScanSAR Mode**

**Spotlight Mode (Sliding)**

**HighRes Spotlight Mode (Sliding)**

<table>
<thead>
<tr>
<th></th>
<th>Stripmap</th>
<th>ScanSAR</th>
<th>Spotlight</th>
<th>HighRes Spotlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>full perf. inc, angle range</td>
<td>20° - 45°</td>
<td>20° - 45°</td>
<td>20° - 55°</td>
<td>20° - 55°</td>
</tr>
<tr>
<td>scene size along track</td>
<td>acqu. length</td>
<td>acqu. length</td>
<td>10 km</td>
<td>5 km</td>
</tr>
<tr>
<td>scene size ground range</td>
<td>30 km</td>
<td>100 km</td>
<td>10 km</td>
<td>10 km</td>
</tr>
<tr>
<td>single look az. resolution</td>
<td>3 m</td>
<td>16 m</td>
<td>2 m</td>
<td>1 m</td>
</tr>
<tr>
<td>single look range resolution</td>
<td>3 m (ground)</td>
<td>16 m (ground) @ 5 looks</td>
<td>1.2 m (slant)</td>
<td>1.2 m (slant)</td>
</tr>
</tbody>
</table>
TanDEM-X

TerraSAR add-on for Digital Elevation Measurements
Primary Mission Goal:
Generation of a global HRTI-3 DEM
Comparison of DTED/HRTI-Levels: Example

DTED-2

HRTI-3

SRTM / X-SAR

E-SAR
Applications of Cross-Track Interferometry

- **Topography**
- **Navigation**
- **Urban Areas**
- **Crisis Management**
- **Glaciology**
- **Oceanography**
- **Geology**
- **Hydrology**
- **Land Use**
TanDEM–X HRTI-3 Spezification

- relative vertical accuracy 2 m (90% linear point-to-point error over 1° x 1° cell),
- absolute vertical accuracy 10 m (90% linear error),
- absolute horizontal accuracy 10 m (90% circular error), post spacing 12 m x 12 m

TanDEM-X provides a configurable SAR Interferometry Platform for Demonstrating new SAR Techniques & Applications
Applications ATI & New Techniques

- Ocean Currents
- Traffic Monitoring
- Glacier Mass Balance
- Bi-Static SAR
- Polarimetric InSAR
- Digital Beamforming
- InSAR Processing
- Super Resolution
- Formation Flying

Along-Track Interferometry

New SAR Techniques

- 64 km/h
- 56 km/h
- 68 km/h
**TerraSAR - X versus Tandem - X**

- **SAR System Parameters of both Systems fully compatible** allowing both
  - Independent TanDEM-X Operation in a **Monostatic Mode**
  - Synchronised Operation in a **Bistatic Mode**

**Main Differences**

- **More sophisticated Propulsion System** of TanDEM-X allows for **Constellation Control**
- **Additional S-band Receiver** enables for **Reception of Status & GPS Position Information** broadcast by TerraSAR-X
- **X-band Inter-Satellite Link** for **Phase Referencing** between both Radars (resp. Modifications on TerraSAR-X already implemented).
Calibration Concept for Multiple Mode High Resolution SARs like TerraSAR-X

M. Schwerdt, D. Hounam and T. Molkenthin

IRS 2003, Dresden Germany

1st October 2003
Introduction

- TerraSAR-X Features/Operation Modes
- Philosophy of Radar Calibration
- PN-Gating Method
- Concept of Antenna Pattern Model
- DLR Calibration Facilities
- Calibration / Validation Overview
Features/Operation Modes of TerraSAR-X

- Single/dual polarisation
- Wide range of swath positions (20° - 55°)
- 3 basic operation modes
  - Strip Map (26 look angles)
  - ScanSAR (WS à 4 SS)
  - Spotlight (123 look angles)
- Left/right looking SAR
- Experimental modes
  - Wide band width
  - Along track interferometry
- Large number of:
  - Operation modes
  - Antenna beams
    - 26 elevation beams
    - 123 elevation beams à 100 azimuth patterns
    - Active antenna array

Calibration major challenge costs affordable
Philosophy

- Calibrate image magnitude to physical units.

Radiometric Characteristics
- Calibration

- Stability
  - Internal Calibration

- Relative Accuracy
  - Antenna Pattern Compensation

- Absolute Accuracy
  - Bias Correction
New Calibration Concept

- Internal Calibration PN-Gating Method → In-Orbit Analysing of Individual TRMs
- Antenna Pattern Precise Model → Estimation of Actual Antenna Pattern
- Measurements as much as possible Sufficient Number of Ground Targets → Reliable Reference

(Index: PN = Pseudo Noise)
3 Calibration Pulses:

- 1 Transmit Path 1-2-4-5
- 2 Receive Path 6-4-2-1
- 3 Only RFE/DCE 6-5

controlling the instrument as a whole

individual modules?
PN-Gating: technique of characterizing individual T/R modules while all modules are operating, i.e. a characterization under most realistic conditions.

- Phase of each T/R module individually shifted about $\pm\pi/2$ (phase shift keying) between Cal-pulses according to a PN code sequence.
- Each T/R module has a different PN code or code shift.
Superposition of all T/R Signals

\[ S_c(t) = \sum_{i=1}^{N_{T/R}} s_i(t) \cdot c_i(t) \]

- correlation with the inherent Module code \( c_i \)
- extraction of individual module signal \( s_i \)
Standard Deviations versus Number of T/R Modules
S/N = 20db, 30 Modules, Codelength = 1023

For larger Number of T/R Modules code length would need to be increased correspondingly to achieve the same errors. But using of an ideally orthogonal code (Walsh sequence f.e.) the cross correlation of two distinct sequences is 0. Thus the code length can be reduced considerably down to 512 for 384 T/R modules.
Amplitude & Phase Error as function of SNR (TerraSAR, 384 Modules)

### Pseudo Noise Code

- **SCCR, PN Code**
  - Amplitude/dB
  - Phase/degree
  - S/N R [dB]
  - Error distribution:
    - red: constant
    - blue: random
    - green: linear
  - Standard deviation of amplitude error:
    - ~ 0.2 dB

### Walsh Code

- **SCCR, Walsh Code**
  - Amplitude/dB
  - Phase/degree
  - S/N R [dB]
  - Error distribution:
    - ~ 0.2 dB

- **ΔΦ, Walsh Code**
  - Standard deviation of phase error:
    - ~ 0.04°
Antenna Pattern Model

- Pre-Flight Characterisation
  - Synthesis
  - Analysis
  - On-Ground Measurements

- In-Orbit Verification
  - In-Flight Measurement
  - Rainforest Measurement

- Internal Calibration
  - PN-Gating
  - Module Stepping

- Module Failure
  - Antenna Optimisation
  - Synthesis

Estimation of Actual Antenna Pattern

Reference Pattern for Processing
Antenna Pattern Model

Goal: Derive all reference pattern required for SAR data processing; i.e. provide an accurate estimation of the actual antenna pattern with a minimum number of costly in-flight antenna pattern measurements.

- **Pre-flight Characterization**: calculating & analyzing antenna patterns of the different operation modes as well as on-ground antenna pattern measurements like those of a single radiation element or individual rows or panels.

- **In-Orbit Verification**: in-flight antenna patterns measured in use of ground receivers & by rainforest measurements (expensive!).

- **Internal Calibration**: PN-gating method, an antenna pattern can be calculated with the actual excitation coefficients of the individual modules.

- **Module Failure Analysis**: in case of contingencies, for example failed T/R modules, an optimization of the excitation coefficients of the remaining modules is intended in order to obtain the best beam of each operation mode.
Antenna Pattern Model

Verification accuracy determines the minimum number of inflight measurements

When developing the model, core attention has to be focused on two questions:

- What relevant beams have to be measured in order to verify sufficiently the antenna pattern model?

- How can the best estimation of the actual pattern be extracted from all inputs and information described above?
Essential TerraSAR-X calibration facilities

- Standard ground targets for bias correction
- Ground receivers for in-flight measurements
- Different analysis & evaluation tools, like
  - the presented antenna pattern model providing an estimation of the actual antenna pattern
  - SAR Product Control Software (SARCON) for target analysis of different calibration targets
- Appropriated SAR processor, as there are two types of calibration data that have to be processed:
  - SAR images covering deployed calibration targets,
  - Special calibration products like these of the presented
- PN-gating method.

In addition to the high demands, keeping the cost affordable is a major challenge for calibrating the TerraSAR-X instrument.
Challenge of Antenna Pattern Optimisation

- Drifted or failed T/R modules
- Optimization of remaining modules
- Best beam steering

Elevation Pattern and Template

- Side lobe region
- Main lobe region
Bias Correction

- On-Ground Calibration Targets with known RCS
- External Calibration

- SRTM 2000
- ENVISAT/ASAR 2002
Calibration Field for Scan SAR, ENVISAT/ASAR

- **Wide swath**: 405km
- **Enclosed Area**: ~ 405km
- **Sub-swath**: 65km - 108km
- **T**: transponder
- **ENVISAT**: Ascending
  - Passau
- **Descending**: Strasbourg
  - Salzburg

Simplified elevation pattern
ScanSAR Image of ASAR/ENVISAT, 12-10-02

- measured RCS
- adjusted RCS

absolute calibration constant
Measured Azimuth Antenna Patterns of ASAR/ENVISAT
Overview

- Verification
  - Specification
    - Pre-Flight Verification
      - Astrium
    - IN-Orbit Verification
      - IOCS
    - GS-Verification
      - PGS/MOS/IOCS
  - Acceptance/Monitoring

- Calibration
  - Specification
    - Characterisation
      - IOCS/Astrium
    - Internal Calibration
      - Astrium/IOCS
    - External Calibration
      - IOCS
    - Processor Calibration
      - PGS
  - Adjustment

- Validation
  - Requirements
  - Product Validation
    - IMF
  - Service Validation
    - InfoTerra
  - Product Control

Data Correction/Release

Calibrated & Validated Products

Users