Monostatic Calibration of both TanDEM-X Satellites

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TSX-1 / TDX-1 In-Orbit Calibration Plan

TSX-1 Launch (15.06.2007)  Summer 2007
TSX-1 Commissioning Phase
5 Months
- GS/SC Checkout
- Geo Cal
- Ant Point
- Ant Model Verification
- Radiometric Calibration

Operational Phase
- Spring 2009
  DRA Campaigns
  1 Month
  - Antenna Model
  - Cross Talk
  - Channel Imbalance
  - Radiometric Calibration

Summer 2009
- TSX-1 Re-Calibration
  1 Month
  - Geo Cal
  - Ant Point
  - Ant Model Verification
  - Radiometric Calibration

≈ Operational Phase ≈
- TSX-1 / TDX-1 In-Orbit Calibration Plan

≈ Operational Phase ≈
- TDX-1 Launch (21.06.2010)
- TDX-1 Comm. Phase
  5 Months
  (Mono + Bi: 3+2)
  - Geo Cal
  - Ant Point
  - ...
TSX-1 Calibration
Geometric Calibration TSX-1

Internal Delay: 208.09 ns

- 2m (requirement)

No trend since 2 years

- Pixel localization accuracy (range) 30 cm (1σ) (2 ns)
- Residual offset (in-flight ⇔ OGC) 3.75 cm (0.25 ns)

6 corner reflectors per pass
8 beams
Pointing Determination in Azimuth TSX-1

**Updates**
- Improved ground receiver position
- Re-adjustment between star trackers

**Improvements**

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement accuracy per pass</td>
<td>≤ 7.9 Hz</td>
<td>≤ 2.6 Hz (1σ)</td>
</tr>
<tr>
<td></td>
<td>&lt; 1.0 mdeg</td>
<td>&lt; 0.33 mdeg</td>
</tr>
<tr>
<td>Mean doppler</td>
<td>16 Hz</td>
<td>5.9 Hz</td>
</tr>
<tr>
<td>Residual pointing error</td>
<td>2 mdeg</td>
<td>0.74 mdeg</td>
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</tbody>
</table>

- Notch patterns with different look angles
- 4 ground receivers per pass
Antenna Pattern Monitoring TSX-1

- **Purpose**
  - Detect changes in the antenna front end and waveguides
  - 120 km range
  - 60 km azimuth

- **Antenna Pattern Monitoring TSX-1**
  - strip_003 strip_004 strip_005 strip_006

- **Quality parameters**
  - $\sigma_{\text{max}}$
  - $\mu$
  - $\sigma_{\text{min}}$

- **ScanSAR-mode:**
  - Several beams measured during one pass
  - Across an area of 750 x 750 km²

- **Gamma profile – scan_003**
  - Elevation look angle [deg]

- **Difference Meas / Model – scan_003**
  - Delta profile vs ref. patt. [dB]
Antenna Pattern Long Term Monitoring TSX-1

Shape deviation within the main beam

Beam-to-beam gain prediction

Requirement still fulfilled → stable, no trend

Δ < ± 0.2dB
Radiometric Calibration TSX-1

- **Antenna Model**
  \[ \mu \leq \pm 0.2 \text{dB} \]

- **Radiometric Stability**
  \[ \begin{array}{|c|c|}
  \hline
  \text{Abs. Cal Factor} & \mu = -56.43 \text{ dB} \\
  \hline
  \text{2007} & -56.58 \text{ dB} \\
  \hline
  \text{2009} & -56.43 \text{ dB} \\
  \hline
  \text{CR: corner reflector} \\
  \mu_{2009} = -56.53 \text{ dB} + 0.10 \text{ dB (CR)} = -56.43 \text{ dB} \\
  \end{array} \]

- **Radiometric Stability**
  \[ \text{TerraSAR-X is extremely stable} \]
  \[ \text{Requirement 0.5 dB (1\sigma) over 6 months !} \]
Calibration Tasks Performed in 2009 TSX-1

**TerraSAR-X in Dual Receive Antenna (DRA) Mode**

- 2 instrument chains on receive (main and redundant)
- 2 antenna halves
- Quad-pol mode
- Along track interferometry

**DRA Campaigns**

- Geometric calibration
- Antenna model verification
- Channel imbalance, phase
- Channel imbalance, amplitude → radiometric calibration
- Cross talk
Channel Imbalance: Amplitude TSX-1

QuadPol Transponder (45° constellation)

QuadPol Corner

Channel imbalance Abs. rad. accuracy during DRA campaigns

-0.18 dB antenna gain Correction, V-pol on receive

max. offset 0.44 dB

HH HV VH VV

μ = -56.05 dB
σ = 0.19 dB

μ = -56.25 dB
σ = 0.29 dB

μ = -56.49 dB
σ = 0.33 dB

μ = -56.46 dB
σ = 0.09 dB

μ = -56.65 dB
σ = 0.12 dB

0.26 dB 0.30 dB (1σ)
One-Way Cross Polar Isolation TSX-1

- Ground receivers aligned for V-pol
- 1-way azimuth pattern measured per pass

1-way cross polar isolation (on transmit)

> 34dB

Requirement ≥ 24dB (1-way, StripMap)
TerraSAR-X Calibration Tasks Performed in 2009

- DRA mode calibration
  - Channel imbalance: 0.26 dB / < 3 deg
  - Cross talk: < - 24.9 dB
- Pixel localization accuracy:
  - 31 cm (range)
  - 54 cm (azimuth)
- Pointing accuracy:
  - < 1 mdeg (azimuth)
  - < 4 mdeg (elevation)
- Radiometric stability:
  - 0.15 dB (over 2 years)
- Re-calibration 2 years after launch
- 213 acquisitions
  - 171 over rainforest
  - 42 cal-field (306 targets)
- 27 DLR colleagues
- Absolute radiometric accuracy:
  - 0.39 dB (StripMap)
  - 0.46 dB (DRA Quad-pol)

TerraSAR-X is stable with outstanding performance

TerraSAR-X Calibration Team
TDX-1 Calibration
TDX-1 Monostatic Calibration Strategy

2.5 months (summer 2010)
1. Geometric calibration
2. Antenna pointing
3. Antenna model
4. Radiometric calibration
   StripMap and ScanSAR

Cal test sites
* Rainforest: distributed field
* South Germany: 30 calibration sites from which 17 are permanently installed corner reflectors

Around 60 calibration campaigns with reference point targets: transponders and corners
More than 1000 datatakes will be analyzed
Calibration Field in South Germany near by Oberpfaffenhofen
First Results: Chirp Comparison of TDX-1 – TSX-1

- Receive pulses, BW = 150MHz, UP-chirp, pulse length = 32µs

TDX-1

Spectrogram of the REAL CHIRP (dB)

TSX-1

Spectrogram of the REAL CHIRP (dB)

Similar spectrograms → important for bistatic operation
First results TDX-1: TRM Characterization – PN Gating

**Transmit**
(normalised to max level) cold/hot

**Receive**
(normalised to max level) cold/hot

Warm instrument stability

**Transmit**
- Phase [degrees]
- Amplitude [dB]

**Receive**
- Phase [degrees]
- Amplitude [dB]

**blue**: measured in flight cold
**red**: measured in flight hot
First Results TDX-1: Antenna Pattern over Rainforest

Within requirements
First Results TDX-1: Antenna Pattern by Ground Receivers

- Measurements confirm simulated reference pattern
- Within requirements

Transmit pattern only
Relative accuracy $< \pm 0.1\text{dB}$
First Sequential Ground Receiver Acquisition

- Direct measurement of the satellite separation in along track → Pursuit monostatic phase

3s azimuth separation ≈ 20 km

- 1st absolute comparative measurement of transmitted power → <0.5dB difference TDX-1 – TSX-1
THE END

Questions?

TSX-1 DLR logo experiment: Oberpfaffenhofen, Bayern, Germany (19th June 2008)