Long Term System Monitoring of Performance Stability – Current Status of TerraSAR-X and TanDEM-X Satellites

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TerraSAR-X / TanDEM-X:
- German Earth observation SAR satellite
- X-band @ 9.65 GHz
- 514 km dusk/dawn orbit
- Multi-mode highly flexible operation
- Public Private Partnership (PPP)

StripMap Mode
- Resolution: 3.3 m x 3.3 m
- Swath width: 30 km

SpotLight Mode
- Resolution: 1.5 m x 1.5 m
- Swath width: 10 km

ScanSAR Mode
- Resolution: 17 m x 18 m
- Swath width: 100 km
TerraSAR-X / TanDEM-X Long-Term System Monitoring (I)

Purpose:
- Detecting long-term system SAR performance changes
- Monitoring correct operation of the SAR instrument and front-end
- Evaluating any degradation of the satellites hardware
- Guarantee a stable quality of the SAR products

Timeline for Long-Term System Monitoring (LTSM) periods

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch TSX-1 (06/2007)</td>
<td>2007/06</td>
</tr>
<tr>
<td>TerraSAR-X mission Commissioning Phase (6 month)</td>
<td></td>
</tr>
<tr>
<td>LTSM TSX-1</td>
<td></td>
</tr>
<tr>
<td>Launch TDX-1 (06/2010)</td>
<td>2010/06</td>
</tr>
<tr>
<td>TanDEM-X mission Commissioning Phase</td>
<td></td>
</tr>
<tr>
<td>LTSM TDX-1</td>
<td></td>
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<tr>
<td>2013/06</td>
<td></td>
</tr>
</tbody>
</table>
TerraSAR-X / TanDEM-X Long-Term System Monitoring (II)

Monitoring of SAR-transmission / receive modules (TRM)

Doppler centroid stability

Monitoring antenna characteristics over rainforest areas

Point target analysis
T/R-Module Monitoring

- Data takes using the **PN-Gating method**
- **Simultaneous characterization** of all 384 T/R-modules under normal operation conditions
- Evaluation of **gain** and **phase** for transmit (TX) and receive (RX) path for both satellites (TSX-1, TDX-1)
- “Error Matrix”: Gain and phase **deviations from a reference value** can be observed (first reference values were obtained from on-ground characterization data)

**Sample of Error Matrix** derived by PN-gating method (Gain for TSX-1 satellite in transmission mode).

“Out-of-range modules” can be easily detected
- Permanent monitoring of the gain and phase for each T/R-module.
- Regularly reported for periods over 3 months.
- July 2011: Phase anomaly on TSX-1 for TRM 359 (fixed).
- No SAR degradations detected.
### Monitoring of T/R-Modules – Statistics for full Life Time

<table>
<thead>
<tr>
<th>Mean over all $\sigma$-values of each module</th>
<th>TX</th>
<th>RX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gain [dB]</td>
<td>Phase [°]</td>
</tr>
<tr>
<td>TSX-1 (6 years)</td>
<td>0.08</td>
<td>1.97</td>
</tr>
<tr>
<td>TDX-1 (3 years)</td>
<td>0.03</td>
<td>1.68</td>
</tr>
</tbody>
</table>

#### Histogram: TSX gain TX

<table>
<thead>
<tr>
<th>Frequency</th>
<th>0.03</th>
<th>0.06</th>
<th>0.09</th>
<th>0.12</th>
<th>0.15</th>
<th>0.18</th>
<th>0.21</th>
<th>0.24</th>
<th>0.27</th>
<th>0.3</th>
<th>0.33</th>
<th>More</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin (Amplitude [dB])</td>
<td>1</td>
<td>33</td>
<td>280</td>
<td>59</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>More</td>
</tr>
</tbody>
</table>

$\sum$ 384 modules

Limit for Gain Deviation: **1dB**

#### Histogram: TDX phase RX

<table>
<thead>
<tr>
<th>Frequency</th>
<th>0.3</th>
<th>0.6</th>
<th>0.9</th>
<th>1.2</th>
<th>1.5</th>
<th>1.8</th>
<th>2.1</th>
<th>2.4</th>
<th>2.7</th>
<th>3</th>
<th>3.3</th>
<th>More</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin (Phase [°])</td>
<td>1</td>
<td>3</td>
<td>128</td>
<td>187</td>
<td>60</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>More</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\sum$ 384 modules

Limit for Phase Deviation **10°**
Daily Maxima Temperature of T/R Modules (Front end)

- Each panel is also observed for temperature variation
- Daily maxima temperatures are far from 30 °C limit
- Temperature increasing of around 10°C due to TanDEM-X mission
- Average temperatures of TSX-1 higher than temperatures of TDX-1 due to higher workload

**TSX-1**

**TDX-1**

Start of TanDEM-X Mission
Temp. increase of ≈ 10°C

Hot-Cold Test during TDX-1 Commissioning Phase
Antenna Pattern Monitoring (over Rainforest Region)

- Required to detect any degradation of the front-end (specially the antenna wave guides not covered by the internal calibration)
- ScanSAR data takes over the Amazon rain forest are executed and evaluated
- Deviation from reference antenna patterns (derived by the antenna model)
Antenna Pattern Monitoring – TSX-1 / TDX-1

Relative antenna patterns standard deviation stays within the limit of ±0.2dB.
Doppler Centroid Statistics – Timeline

- Total Zero Doppler Steering applied to compensate the Earth rotation
- Verification of the Doppler centroid estimation and stability
- Monitoring the stability of the satellite steering in azimuth

95% of the total acquisitions have a Doppler centroid within the goal of ±120Hz
Point Target Analysis
Evaluation of Impulse Response Function (IRF)

The following performance parameters are derived:

- Radar cross section (RCS)
- ISLR (Integrated Side Lobe Ratio)
- PSLR (Peak to Side Lobe Ratio)
- Geometric resolution

\[
\text{ISLR} = \frac{\text{Sum of energy in the side lobes}}{\text{Sum of energy in the main lobe}}
\]

\[
\text{PSLR} = \frac{\text{Peak intensity of most intensive side lobe}}{\text{Peak intensity of the main lobe}}
\]
Point Target Analysis: Image Area used for LTSM

DLR Neustrelitz

Permanently installation of additional corner reflectors (1.5m) near Neustrelitz (Germany):

- Advantage: no further work with manual alignment
- Disadvantage: only fixed beams are used
Point Target Analysis – Radiometric Stability

The standard deviation over life time of the target RCSs is a measure for the radiometric stability of both systems (TSX/TDX)!

High radiometric stability < 0.15dB for both satellites over monitored period (Req.: 0.5 dB over 6 month)
Point Target Analysis – Statistics for ISLR, PSLR and Geometric Resolution

ISLR (Integrated Side Lobe Ratio)

PSLR (Peak to Side Lobe Ratio)

Geometric resolution for point targets

Product Specification:
-18 dB in range and azimuth

Product Specification:
-18 dB in range and azimuth

Product Specification:
1.8 m in range
3.3 m in azimuth
TerraSAR-X is in orbit since 2007 / TanDEM-X since 2010

Both satellites are being monitored for their performance, instrument stability and health:

- T/R-module stability in gain (< 0.2 dB) and in phase (< 2 deg)
- Antenna pattern over the rain forest (+/- 0.2 dB)
- Doppler centroid statistics (< 120 Hz)
- Radiometric stability by evaluating point targets (< 0.15 dB)

Both systems are very stable and offering high quality SAR products

No performance degradations have been observed since launch