A Tandem TerraSAR-X Configuration for Single-Pass Interferometry

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TanDEM-X
Response to DLR Call for Proposals for the next National Earth Observation Mission
System and Mission Heritage

X-SAR

SRTM

DESA

TOPAS

CHAMP

GRACE

TerraSAR-X

TanDEM-X
TanDEM-X: Primary Mission Goal
Product comparison

Primary Mission Goal:
- DEM generation corresponding to HRTI-3 (DTED-3) standard with global coverage with minimum 3 years of nominal operation with TerraSAR-X
### Interferometry with TanDEM-X

<table>
<thead>
<tr>
<th></th>
<th>Spatial Resolution</th>
<th>Absolute Vertical Accuracy (90%)</th>
<th>Relative Vertical Accuracy (90%)</th>
<th>Absolute Horizontal Accuracy (90% circ.)</th>
<th>Relative Horizontal Accuracy (90% circ.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DTED-1</strong></td>
<td>90m x 90m</td>
<td>&lt; 16 m</td>
<td>&lt; 10 m</td>
<td>&lt; 60 m</td>
<td>&lt; 45 m</td>
</tr>
<tr>
<td><strong>DTED-2</strong></td>
<td>30m x 30m</td>
<td>&lt; 16 m</td>
<td>&lt; 10 m</td>
<td>&lt; 20 m</td>
<td>&lt; 15 m</td>
</tr>
<tr>
<td><strong>DTED-3</strong> (HRTI-3)</td>
<td>10m x 10m</td>
<td>&lt; 10 m</td>
<td>&lt; 2 m (4m, slope&gt;20 %)</td>
<td>&lt; 10 m</td>
<td>&lt; 3 m</td>
</tr>
</tbody>
</table>

*Other product specifications will be considered during phase A with respect to users requirements*
TanDEM-X: Orbit, Operation Modes and Performance
Interferometry with TanDEM-X

**2SAT Pendulum**
- horizontal baseline

**2SAT Helix**
- vertical baseline
- horizontal baseline

Digital Elevation Model (DEM) from SRTM Mission

**Single-Pass Cross-Track Interferometry with TerraSAR-X Tandem:**
- no temporal surface decorrelation (as opposed to repeat-pass interferometry)
- almost no atmospheric distortions (as opposed to repeat-pass interferometry)
- large interferometric baselines
**Operational Modes**

**Monostatic Mode**
- TerraSAR-X 1 and TanDEM-X transmit and receive independently.
- Large along-track separation (> 30 km) to avoid interference.
- Temporal decorrelation (~ 10 sec).
- Higher overall power consumption.
- More stringent requirements with regard to orbit accuracy (smaller interferometric baselines).

**Bistatic Mode**
- Only TerraSAR-X 1 transmits (or only TanDEM-X transmits).
- TerraSAR-X 1 and TanDEM-X receive simultaneously.
- Antenna footprints must overlap.
- Along-track displacement has to be small (< 2 km) (to ensure overlapping Doppler spectra).
- More stringent requirements on oscillator stability.
TerraSAR-X Imaging Modes

**Stripmap Mode**
Resolution: $3 \text{ m} \times 3 \text{ m}$
Scene Size: $100 \text{ km} \times 30 \text{ km}$

**ScanSAR Mode**
Resolution: $16 \text{ m} \times 16 \text{ m}$
Scene Size: $100 \text{ km} \times 100 \text{ km}$

**Spotlight Mode**
Resolution: $1 \text{ m} \times 1 \text{ m}$ ($2 \text{ m} \times 2 \text{ m}$)
Scene Size: $5 \text{ km} \times 10 \text{ km}$ ($10 \times 10 \text{ km}$)

- Incidence angle range from $15^\circ$ to $60^\circ$
- Dual polarisation data acquisition in all operational modes
- 300 MHz experimental mode with 0.5 m slant range resolution (1 m ground range @ 30 deg. incidence angle)
- Further experimental modes with Dual Receiving Antenna configuration (full polarimetric and along-track interferometry)
Three interferograms with two "effective baselines":

\[ B_{\text{monostatic}} = 2 \cdot B_{\text{bistatic}} \]

- good height accuracy (use large monostatic baseline)
- improved phase unwrapping (use smaller bistatic baselines)
- phase synchronization possible
- requires increased PRF (as in polarimetric mode)
**Interferometric Performance Estimation**

**Noise Equivalent Sigma Zero**

\[
\text{NEZ} = \frac{4^2 \pi^3 r_T^2 r_R^2 \sin(\Theta) kTBF}{P_T G_T G_R \lambda^3 c_0 \tau \text{PRF}}
\]

**Assumptions:**
- no antenna tapering for small incident angles
- swath width: 30km
- 6dB losses at swath border
## Interferometric Performance Estimation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>0.031 m</td>
</tr>
<tr>
<td>Chirp Bandwidth</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Peak Transmit Power</td>
<td>2260 W</td>
</tr>
<tr>
<td>Duty Cycle</td>
<td>18 %</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>Atmospheric Losses</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>Antenna Size (Tx, Rx)</td>
<td>4.8 m x 0.7 m</td>
</tr>
<tr>
<td>PRF</td>
<td>3500 Hz</td>
</tr>
<tr>
<td>Processed Bandwidth</td>
<td>2300 Hz</td>
</tr>
<tr>
<td>Co-Registration Accuracy</td>
<td>1/10 pixel</td>
</tr>
<tr>
<td>Quantization</td>
<td>3 bit (BAQ)</td>
</tr>
<tr>
<td>Sigma Nought Model (90% occurrence levels)</td>
<td>Ulaby (X-Band, HH, Soil)</td>
</tr>
<tr>
<td>Effective Baseline</td>
<td>1 km</td>
</tr>
<tr>
<td>Along-Track Displacement</td>
<td>1 km</td>
</tr>
<tr>
<td>Swath Width</td>
<td>30 km</td>
</tr>
<tr>
<td>Post Spacing</td>
<td>12 m x 12 m</td>
</tr>
</tbody>
</table>

Relative Height Accuracy (90%, Point-to-Point)

DTED-3 Specification

![Graph showing Relative Height Accuracy](image)
TanDEM-X Mission: Scientific Exploration
### Applications derived from across-track interferometry

<table>
<thead>
<tr>
<th>Area</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Environment</td>
<td>Topographic Mapping, Cartography, Urban Areas, Disaster and Crisis Management, Navigation, Archaeology, Change Detection</td>
</tr>
<tr>
<td>Hydrology</td>
<td>Ice and Snow, Wetlands, Morphology, Flooding</td>
</tr>
<tr>
<td>Renewable Resources</td>
<td>Land use mapping, agriculture, forestry and grassland</td>
</tr>
<tr>
<td>Oceanography</td>
<td>Wind and Waves, Ocean Dynamics, Ship Detection, Bathymetry</td>
</tr>
<tr>
<td>Geology</td>
<td>Geological mapping, Earthquake /Tectonics, Volcanoes, Landslides</td>
</tr>
</tbody>
</table>
# Scientific Areas

## Applications with Along-Track Interferometry

<table>
<thead>
<tr>
<th>Area</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceanography</td>
<td>Ocean currents, coastal zone mapping</td>
</tr>
<tr>
<td>Traffic</td>
<td>Traffic flow monitoring</td>
</tr>
<tr>
<td>Glaciology</td>
<td>Ice flow monitoring</td>
</tr>
</tbody>
</table>

## New Techniques

<table>
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<tr>
<th>Technique</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Pol-InSAR</td>
<td>Bi-static Processing</td>
</tr>
<tr>
<td>Digital beamforming</td>
<td>Super Resolution</td>
</tr>
<tr>
<td>Multi-Angle Observations</td>
<td>Formation Flying</td>
</tr>
</tbody>
</table>
Pol-InSAR
Single Pass
Polarimetric SAR Interferometry

Pol-InSAR

I Step:
Model and Validation Development

Observables
3 Interferometric Coherences
3 Interferometric Phases
for one baseline and three polarisation states

Coherent Scattering Model

Natural Scatterers
- Forest Parameters
- Surface Parameters
- Agricultural Parameters
- Land Ice Parameters
Single Pass
Polarimetric SAR Interferometry

Pol-InSAR

Observables
3 Interferometric Coherences
3 Interferometric Phases
for one baseline and three polarisation states

II Step: Model and Validation Inversion

Coherent Scattering Model

Natural Scatterers

Forest Parameters
Surface Parameters
Agricultural Parameters
Land Ice Parameters

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Single Pass
Polarimetric SAR Interferometry

L-band (Pol-InSAR)

E-SAR / Test Site: Oberpfaffenhoffen

Baseline=15m  HH  HV  VV
Single Pass
Polarimetric SAR Interferometry

L-band (Pol-InSAR)

Baseline=15m  HH-HH  HV-HV  VV-VV

E-SAR / Test Site: Oberpfaffenhoffen
Polarimetric Interferometric: Performance Estimation

Height Error and Height Bias

- $\mu_{\text{max}}$
- $\mu_{\text{min}}$
- $\Delta \varphi$

Parameter List:
- $\Lambda$: 3.1 cm
- Baseline: 1000.0 m
- $H_{\text{SAT}}$: 514.0 km
- Theta Inc.: 35.0°
- NESZ (HH): -17.9 dB
- Bandwidth: 150 MHz
- Rg Res: 30.0 m
- Az Res: 30.0 m
- Looks: 162.6
Along-Track Interferometry
Traffic Monitoring with Along Track Interferometry

SRTM/X-SAR data from the highway A-9 (7 meters along-track displacement, DLR-IMF)

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Traffic Monitoring with Along Track Interferometry

SRTM/X-SAR data from the highway A-9 (7 meters along-track displacement, DLR-IMF)
Summary
Scientific Opportunities

- DEM-based applications (DTED-3):
  - land environment, hydrology, geology, etc.
- polarimetric SAR interferometry
- along-track interferometry (e.g. mapping of ocean currents, moving target indication)
- super-resolution in azimuth and range
- Digital beam-forming with 4 phase centers
- multi-angle bistatic observations
- bi-static SAR polarimetry
- stereogrammetric applications
- Formation flying
Main challenges to be investigated in Phase A:

- PRF and Phase Synchronisation (design upgrade)
- Precise baseline determination using differential GPS and phase measurements
- Close formation flying capability
- Bi-static and interferometric data processing (DTED-3)
- Spotlight SAR interferometry
- Interferometric calibration (Ocean data takes, tie points)
- Scientific applications and opportunities