Sentinel-1 Antenna Model Verification and Validation

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ESA - ESTEC
Outline

- Introduction
  - Instrument Architecture
  - Sentinel-1 SAR Antenna Subsystem (SAS)
  - Tile Design
  - Sub-array Design
- Antenna Model Description
  - AM Inputs
- S1 SAS RF Pattern Test Campaign (Planar Near Field Scanner Facility)
- Antenna Model Validation Results
- Antenna Model Verification Results
- Conclusions
SAR Antenna Subsystem (SAS)
12.3 m x 0.84 m, 14 Tiles each with 20 dual polarized resonant waveguide sub-arrays
560 Transmit(15W)/Receive Modules

Size: 0.87 m * 0.85 m

2 Tile Amplifiera (TA)

Elevation Plane Distribution Network

40 Transmit(15W)/Receive Modules

20 dual polarized sub-arrays

2 Tile Control Units (TCU)

2 Tile Power Supply Units (TPSU)

TPSU1 and TPSU2 each feeding half a tile and both TAs.
- Mission Goal: attain accurately calibrated products
- Precise knowledge of the radiated patterns is needed
- AM provides the radiated patterns for:
  - Any set of excitation coefficients
  - Covering also potential changes such TRM failures or misalignments
- Reduce in-orbit commissioning phase (i.e. radiometric calibration of selected beam modes only)
- Accuracy maintained by use of RFC mode data
AM is based on the knowledge of the excitation coefficients for each of the radiators.

Subarray patterns are derived by characterization measurements on ground and are considered constant over the mission lifetime.

Azimuth and Elevation patterns are defined by the average phase and amplitude value over the 14 tiles or the 20 rows.
Planar Near-Field Scanner

- Room temperature was thermally controlled and active phase array was kept at a constant temperature by means of cryomats to ensure measurement stability.
- TRMs are equipped with Temperature compensation circuitries, but were deactivated to avoid phase & amplitude jumps during the measurement.

Orbit PNFS
Max Scan Area 15 m * 7 m
Rohde & Schwartz ZVA40
NSI Open Ended WG Probe
Control and data acquisition SW from March Microwave

Position accuracy:
\[ x \text{ and } y < 0.10 \text{mm} \]
\[ z < 0.13 \text{ mm} \]
Population - Raw Boresight Pattern Measurement

- Each signal within the SAS has a different path with different amplitude and phase coefficients.
- Coefficients were measured.
- Static offsets were uploaded to the SAS front-end.

untrimmed

trimmed
Operational Beam on-ground Validation
SM1 H-pol

(a) Comparison between PNFS Measurement and Antenna Model Prediction (large angular range)

(b) Comparison between PNFS Measurement and Antenna Model Prediction

(c) Pattern Comparison and Difference within Swath Width

(d) Pattern Difference and RMS value within Swath Width
Operational Beam on-ground Validation

EW V-pol

(a) Comparison between PNFS Measurement and Antenna Model Prediction (large angular range)

(b) Comparison between PNFS Measurement and Antenna Model Prediction

(c) Pattern Comparison and Difference within Swath Width

(d) Pattern Difference and RMS value within Swath Width
RMS results for all measured beams
EW1 was slightly out of the requirement (most complicated beam to synthetize due to large range of incidence angles)
Azimuth Pattern Verification – S1B

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>Absolute Error (dB (peak))</th>
<th>Stability (dB (peak))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>During Operations:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna Pointing</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Polarization Mismatch at 45°</td>
<td>0.116</td>
<td></td>
</tr>
<tr>
<td>Antenna Thermal</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Electronics Thermal</td>
<td></td>
<td>0.116</td>
</tr>
<tr>
<td>Waveguide Attenuator Thermal</td>
<td></td>
<td>0.054</td>
</tr>
<tr>
<td>Waveguide Circulator Thermal</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Other Waveguide Thermal</td>
<td></td>
<td>0.048</td>
</tr>
<tr>
<td><strong>External Calibration:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target Plate Flatness</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Target Plate Diameter</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Target Plate Thermal</td>
<td></td>
<td>0.01</td>
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<tr>
<td>Target Plate Pointing</td>
<td></td>
<td>0.033</td>
</tr>
<tr>
<td>Antenna Pointing</td>
<td>0.002</td>
<td></td>
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<tr>
<td>Range Measurement</td>
<td>0.0035</td>
<td></td>
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<tr>
<td>Target Illumination</td>
<td>0.01</td>
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<tr>
<td>Clutter</td>
<td>0.042</td>
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<tr>
<td>Multipath Correction</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td><strong>Total Error (peak value):</strong></td>
<td><strong>0.131</strong></td>
<td><strong>0.138</strong></td>
</tr>
</tbody>
</table>
Sentinel-1B in orbit Elevation Antenna Pattern Verification
Sentinel-1B Elevation Antenna Pattern Verification

S1B_IW_GRDH_1SDV_20160712T100355_20160712T100420_001130_000FAF_D254.SAFE
Beam-to-beam offsets are well predicted, except for EW1&5 VV where the gain is under-estimated.
Conclusions

On-ground Validation

- H-pol: RMS values < 0.06 dB
- Measured swaths RMS values < 0.05 dB, but non conformance with requirements for EW1 V-pol
- On-ground validation with an unprecedented accuracy

In-Orbit Verification

- For azimuth patterns, AM shows a close agreement with the measured patterns within the main lobe
- Elevation Antenna patterns and the beam-to-beam offsets of the received signals (raw data) for IW and EW modes are in good agreement with theoretical values
- Theoretical values were computed using the radar equation, observation geometry, mode settings and antenna patterns from the Antenna Model
- Remaining small Rx H/V gain imbalance (smile effect)
Instrument Architecture
SAR Antenna Subsystem (SAS)
12.3 m x 0.84 m,
14 Tiles each with 20 dual polarized resonant waveguide sub-arrays
560 Transmit(15W)/Receive Modules
### Elevation Patterns Verification – S1B

#### RMS gain error over each beam

<table>
<thead>
<tr>
<th></th>
<th>HH</th>
<th>HV</th>
<th>VV</th>
<th>VH</th>
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<tbody>
<tr>
<td>IW1</td>
<td>0.15</td>
<td>0.13</td>
<td>0.11</td>
<td>0.13</td>
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<tr>
<td>IW2</td>
<td>0.18</td>
<td>0.20</td>
<td>0.29</td>
<td>0.22</td>
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<tr>
<td>IW3</td>
<td>0.16</td>
<td>0.06</td>
<td>0.15</td>
<td>0.10</td>
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<tr>
<td>EW1</td>
<td>0.15</td>
<td>0.16</td>
<td>0.22</td>
<td>0.14</td>
</tr>
<tr>
<td>EW2</td>
<td>0.14</td>
<td>0.13</td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>EW3</td>
<td>0.09</td>
<td>0.09</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>EW4</td>
<td>0.14</td>
<td>0.14</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>EW5</td>
<td>0.20</td>
<td>0.19</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

#### Beam-to-Beam Gain Offsets

<table>
<thead>
<tr>
<th></th>
<th>HH</th>
<th>HV</th>
<th>VV</th>
<th>VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>IW1 - IW2</td>
<td>-0.22</td>
<td>-0.21</td>
<td>0.31</td>
<td>0.10</td>
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<tr>
<td>IW2 - IW3</td>
<td>-0.20</td>
<td>0.14</td>
<td>0.35</td>
<td>0.30</td>
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<tr>
<td>EW1 - EW2</td>
<td>0.10</td>
<td>-0.12</td>
<td>-0.51</td>
<td>-0.19</td>
</tr>
<tr>
<td>EW2 - EW3</td>
<td>0.12</td>
<td>0.10</td>
<td>-0.27</td>
<td>-0.11</td>
</tr>
<tr>
<td>EW3 - EW4</td>
<td>0.08</td>
<td>0.16</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>EW4 - EW5</td>
<td>-0.36</td>
<td>-0.33</td>
<td>0.17</td>
<td>0.05</td>
</tr>
</tbody>
</table>