Phase Requirements, design and validation of phase preserving processors for a SAR system

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• The need for a set of interferometric quality requirements for SAR processors has been recommended (CEOS Calibration meeting – Pasadena - 2009)

• The methods could serve as a basis for processor performances benchmarking

• Further, the definition of new acquisition modes (Sentinel-1 TOPSAR) requires the update and customisation of existing phase preservation tests

• Please note that only phase quality is here addressed (then being far from an overall suite of tests for SAR processing validation)
Outline

• Addressed SAR acquisition modes
  – Stripmap
  – SCANSAR
  – TOPSAR
  – SPOT
• Proposed phase preserving tests
  – Test definition and applicability
  – verification criteria
  – Brief procedural description
• Conclusions
“Not azimuth steered” modes

STRIPMAP

SCANSAR
“Azimuth steered” modes

TOPSAR

SPOT
Process two SLCs from the same raw data set and with the same orbit, but offset by 100 lines in azimuth and 100 sample in range. The interferogram formed from these two properly coregistered SLCs should ideally have a constant phase of zero and thus reveals processor induced artifacts.

Pass/Fail criteria:
- Mean of interferogram phase $\leq 0.1^\circ$
- Standard deviation $\leq 5.5^\circ$
- No discontinuity at block boundaries.

## Proposed SAR processor phase verification tests

<table>
<thead>
<tr>
<th>Purpose</th>
<th>STRIP</th>
<th>SCAN</th>
<th>TOPS</th>
<th>SPOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>‘Classical’ CEOS</strong></td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td><em>The purpose of the “CEOS offset test“([1]) is to verify the processor phase preservation performances with respect to range and azimuth shifts of the input RAW data. The test as it is defined can be applied to STRIPMAP and SCANSAR data</em></td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Extended CEOS offset</strong></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<tr>
<td><em>The extended CEOS has been introduced in order to verify the processor phase preservation with respect to shifts and scaling. Further the extended CEOS has been extended to TOPSAR and SPOT modes</em></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Inter Burst/Slice phase preserving</strong></td>
<td>YES*</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
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<tr>
<td><em>The purpose of this test is to verify the processor phase preservation performances when comparing the phase of adjacent bursts. For this purpose, targets in the burst overlapped area are exploited.</em></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Inter Swath phase preserving</strong></td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><em>Same as inter-burst test but applied to Sub-swaths overlapping areas</em></td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
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* For STRIPMAP the InterBurst test is simply performed considering overlapping processing blocks
PASS/FAIL criteria for the phase preserv. tests

Two main criteria can be used to verify the results of the generalised offset test:

1. **Time domain approach** (TDA) (classic CEOS offset criteria): the **mean and std** of the time domain interferogram compared with the given thresholds. Further **interferometric coherence** is computed. This approach requires distributed/noise input data.

2. **Frequency approach**: to be performed on **synthetic PT** it verifies that the 2D frequency phase difference is kept under control by the processor
   - 2.1: frequency domain interferogram (FDI): **mean and std** of the phase difference is compared with the given thresholds
   - 2.2: spectrum phase analysis (SPA): it includes
     - peak 2 peak in band phase error,
     - Mean spectral phase
     - in-band phase residual polynomial model
Applicable verification method

**TDA**: Time domain approach  
**FDI**: Frequency domain interferogram  
**SPA**: Spectral Phase comparison (PT)

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The extended CEOS offset test

• The extended CEOS offset test introduces the following enhancements:
  – it can be applied to all the processing modes by a proper data preconditioning step
  – It can be flexibly configured for what concern the overlapped block in terms of:
    • RG/AZ shifts
    • RG/AZ dimensions

The burst/slice B in the case of azimuth steered acquisition modes (TOPS and SPOT) shall be processed, suitably updating the doppler centroid information:

\[ DC_{shiftB} = k_a \Delta T_{az} \]

Where \( k_a \) is the data acquisition antenna steering rate.
The extended CEOS offset test is aimed at verifying the following SAR processing performances:

- phase preservation w.r.t. to azimuth and range shifts
- phase preservation w.r.t. to different RAW data blocks definition (i.e. verification of any block-wise phase artifact introduced by the processor)
- phase preservation w.r.t. changes to the processing block geometrical parameters (i.e. azimuth-adaptivity test)
Inter burst phase preservation test

• Accurate frequency domain phase preservation test for STRIPMAP (actually missing in the previous time domain tests)

• Range dependent processor phase aberrations in 2D frequency domain

• Phase preservation over different antenna sub-apertures (TOPSAR and SCANSAR case)

• Range dependent processor phase aberrations in 2D frequency domain
STRIPMAP inter “burst” test

- Processor features verified by this test:
  - capability to remain phase preserving moving along orbit → long data-takes processing
  - Correctness of the processor configuration in terms of azimuth processing block and overlaps
TOPSAR inter burst test

- Processor features verified by this test:
  - Phase preservation on extended azimuth spectral domain (e.g. up to 3 or 4 times the acquisition PRFs in the Sentinel-1 case)
  - Phase preservation in totally spectral decorrelated targets
  - Capability to remain phase preserving moving along orbit → long data-takes processing
Inter-swath phase preservation test

- The inter-swath can verify the same feature tested by the inter-burst test
- Further the processor phase preservation is checked also versus changes to the system acquisition parameters (i.e. same target acquired with different PRFs, Bandwidths, ...
Conclusions

• Phase quality performances for a SAR processor are a key point, especially for interferometric applications
• Future SAR mission, like ESA’s Sentinel-1 foresee interferometric dedicated acquisition mode based on new acquisition schemes (e.g. TOPSAR Interferometric Wide-swath Mode)
• Under these assumption update phase preserving tests for a SAR processor have been proposed introducing further specialised tests:
  – Extended CEOS offset test
  – Inter slice/burst phase preserving test
  – Inter swath phase preserving test
• These tests should guarantee an accurate screening of time-domain and frequency-domain phase aberrations of the investigated tool