The Sentinel-1 Radar Mission: Status and Performance

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Sentinel-1 Mission Objectives

Component of EU & ESA’s Global Monitoring for Environment and Security Programme (GMES)

- GMES Core Services
  - GMES Marine Services
  - GMES Land Monitoring Services
  - GMES Emergency Response Services
  - GMES Atmospheric Monitoring Services
  - GMES Security Services
- GMES Downstream services
We care for a safer world

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- Thales Alenia Space Italia as Prime Contractor
- EADS Astrium GmbH as Instrument Responsible
- First (S-1A) satellite launch 2012,
  S-1B 18 months later

Sentinel-1 Programme Status

2008  2010  2012  2014

S-1A Dev  LC  LC
S-1B Dev  LC
S-1C Dev  LC

3rd model launched in case of launcher failure

Storage
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Sentinel-1 System

Space Segment
- A constellation of two satellites
- Nominal lifetime in orbit of 7 years (consumables for 12)
- Global coverage
- Near-Polar Sun-Synchronous dusk-dawn orbit @ 693km.
- A second satellite in the same orbit but with a different Mean Anomaly
- C-Band Synthetic Aperture Radar Payload

Ground Segment
- Mission operations for a system of satellites over a period of 20 years
- S-Band station (Kiruna proposed), with a back-up for S/C contingencies
- Downlink currently assumes three X-Band receiving stations
Sentinel-1 System

- Sentinel-1 has two main operational modes, the Interferometric Wide Swath mode and the Wave mode, that:
  - satisfies most currently known service requirements
  - avoids conflicts and preserves revisit performance
  - provides robustness and reliability of service
  - simplifies mission planning & decreases operational costs
  - satisfies also tomorrow’s requests by building up a consistent long-term archive
- However
  - Mutually exclusive modes are provided for continuity reasons (w.r.t. ERS & Envisat) and for accommodation of emerging user requirements
  - Two other mutually exclusive dual polarisation modes are provided
Sentinel-1 SAR Acquisition Requirements

**Orbit Height**: ~700 km

**Flight Direction**: Sub-Satellite Track

**Wave Mode**: Interferometric Wide Swath Mode

**Strip Map Mode**: Extra Wide Swath Mode

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### Sentinel-1 Performance Requirements

<table>
<thead>
<tr>
<th>Mode</th>
<th>Access Angle</th>
<th>Single Look Resolution</th>
<th>Swath Width</th>
<th>Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interferometric Wide Swath</td>
<td>&gt; 25 deg.</td>
<td>Range 5 m Azimuth 20 m</td>
<td>&gt; 250 km</td>
<td>HH+HV or VV+VH</td>
</tr>
<tr>
<td>Wave mode</td>
<td>23 deg. and 36.5 deg.</td>
<td>Range 5 m Azimuth 5 m</td>
<td>&gt; 20 x 20 km Vignettes at 100 km intervals</td>
<td>HH or VV</td>
</tr>
<tr>
<td>Strip Map</td>
<td>20-45 deg.</td>
<td>Range 5 m Azimuth 5 m</td>
<td>&gt; 80 km</td>
<td>HH+HV or VV +VH</td>
</tr>
<tr>
<td>Extra Wide Swath</td>
<td>&gt; 20 deg.</td>
<td>Range 20 m Azimuth 40 m</td>
<td>&gt; 400 km</td>
<td>HH+HV or VV +VH</td>
</tr>
</tbody>
</table>

**For All Modes**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiometric accuracy (3 (\sigma))</td>
<td>1 dB</td>
</tr>
<tr>
<td>Noise Equivalent Sigma Zero</td>
<td>-22 dB</td>
</tr>
<tr>
<td>Point Target Ambiguity Ratio</td>
<td>-25 dB</td>
</tr>
<tr>
<td>Distributed Target Ambiguity Ratio</td>
<td>-22 dB</td>
</tr>
</tbody>
</table>
- 20 years continuous repeat observation by a C-band synthetic aperture radar constellation to completely cover:
  - the world’s land masses on a two-weekly basis
  - Arctic, Antarctic, coastal zones and shipping routes on a daily basis
  - open ocean continuously by imagettes

1. Arctic & Antarctic
2. Canada
3. European coastal waters and maritime transport zones
4. Europe
5. Rest of global land masses
6. Open ocean
Continuous SAR acquisitions over Land and Ice in IWS mode would need S/C operation capability longer than 50 minutes per orbit.

**S1 maximum operation capability per orbit is limited to 25 minutes in imaging mode + up to 74 minutes in wave mode**

Need for optimal coverage criteria in combination with an efficient data compression.
For each Sentinel-1 satellite:

- No coverage gap (apart from polar gaps)
- Minimise overlap between footprint of different acquisitions.

Sentinel-1B operates the same scenario as Sentinel-1A:

- all ROIs are acquired twice within one repeat cycle (12 days)
- shorter revisit time
- same ROIs for the two satellites
One satellite

- Complete earth coverage within one orbit cycle (12 days)

Two satellites

- All points are acquired twice within one orbit cycle
- Average revisit time performance increase
- Complete earth coverage after half orbit cycle (6 days)
### Coverage and Revisit Time

<table>
<thead>
<tr>
<th>Complete global coverage</th>
<th>After 12 days</th>
<th>S-1A Satellite</th>
<th>After 6 days</th>
<th>S-1A + S-1B Satellites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ice</td>
<td>MTZ</td>
<td>Europe</td>
<td>Canada</td>
</tr>
<tr>
<td>Number of acquisitions (range from - to)</td>
<td>1-9</td>
<td>1-6</td>
<td>1-5</td>
<td>1-4</td>
</tr>
<tr>
<td>Average Revisit Time [day]</td>
<td>8,0</td>
<td>3,7</td>
<td>5,5</td>
<td>8,2</td>
</tr>
</tbody>
</table>
On-board memory size: 1410 Gbits

SAR to PDHT link: link capacity up to 1280 Mbps (2 polarisation channels x 640 Mbps)

Net DL data rate: 520 Mbps (2 X-band channels @ 260 Mbps)

DL duty cycle: up to 30 min x orbit (20 min continuously), according to stations network

25 min imaging in IW mode -> 80 GByte/orbit (dual polarisation) compressed data

74 min in Wave mode -> 4 GByte/orbit compressed data
Data Compression

- Raw SAR data compression is used to reduce the instrument data rate to fit the available data downlink.
- Application of a BAQ like raw data compressor adds quantization noise to the raw data which degrades the data SNR.
- A BAQ that applies a constant bit rate independent of radar signal power is not optimal. It produces a degradation of the SNR which varies with the power of the detected radar signal.
- FDBAQ controls the bit rate in a flexible way as a function of the input radar signal power.
The FDBAQ Principle

- FDBAQ (Flexible Dynamic Block Adaptive Quantization) exploits a Variable Bit Rate (VBR) scheme.
- The number of quantization bits is selected according to a local estimate of CNR.
- FDBAQ principle:

  ![Diagram]

  → This approach leads to a Time variant bit rate
Non uniform quantization improves SQNR → using ECBAQ gives:

\[ SQNR = -1.65 + 6.02 \, R \, [dB] \]

FDBAQ: \( R \) selected applying the following criteria:

\[ \text{Thermal Noise} + \text{Quantization Noise} \leq f_{th} = -22 \, [dB] \]

\[
R(r) = \frac{\log_{10}\left(\sigma^2_c(r) + \sigma^2_z(r)\right) - \log_{10}\left(f_{th} - \sigma^2_c(r)\right) + 0.165}{0.602}
\]

\( R = \) number of quantization bits
Sentinel-1 Data Compression \( N_t = -24 \) dB Threshold = \(-22 \) dB

### Theoretical Performance - Total Noise Power

- Backscatter Coefficient (dB)
- Total Noise (dB)

**Graph:**
- FDBAQ
- ECBAQ
Theoretical Performance - Total Phase Noise

Sentinel-1 Data Compression Nt=-24 dB Threshold = -22 dB

![Graph showing the backscatter coefficient and phase noise in dB for FDBAQ and ECBAQ](image)

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Theoretical Performance - Total Noise Power

\[ P_{\text{noise}}(r) \]

\[ \sigma^2_c(r) = -10 \text{ [dB]} \]

\[ \sigma^2_z(r) \]

\[ \sigma^2_c(r) = 3.5 \text{ [dB]} \]
## Data Compression Analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mode</th>
<th>Data Rate [Mbit/s] One Polarisation Channel</th>
<th>Wind Speed [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Local Scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA East Coast scenario (land + sea)</td>
<td>IWS</td>
<td>216.04</td>
<td>0</td>
</tr>
<tr>
<td>Sahara Desert</td>
<td>IWS</td>
<td>189.4</td>
<td>0</td>
</tr>
<tr>
<td>Greenland (ice+sea)</td>
<td>IWS</td>
<td>241.59</td>
<td>0</td>
</tr>
<tr>
<td>East coast of China (rural regions, cities and sea)</td>
<td>IWS</td>
<td>202.7</td>
<td>0</td>
</tr>
<tr>
<td>Open Sea</td>
<td>IWS</td>
<td>186.53</td>
<td>2</td>
</tr>
<tr>
<td>Open Sea</td>
<td>IWS</td>
<td>190.37</td>
<td>8</td>
</tr>
<tr>
<td>Open Sea</td>
<td>IWS</td>
<td>200.97</td>
<td>14</td>
</tr>
<tr>
<td><strong>Global Scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>SM</td>
<td>220.09</td>
<td>0</td>
</tr>
<tr>
<td>World</td>
<td>IWS</td>
<td>205.30</td>
<td>0</td>
</tr>
<tr>
<td>World</td>
<td>EWS</td>
<td>52.54</td>
<td>0</td>
</tr>
<tr>
<td>World</td>
<td>WV</td>
<td>8.44</td>
<td>0</td>
</tr>
</tbody>
</table>

ECBAQ single polarisation:
- SM = 413.18 worst case
- IWS = 301.03
- EWS = 73.93
- WV = 29.63
Conclusions

- Sentinel-1 System introduced
- Operational scenarios are shown
- FDBAQ performances have been evaluated
  - A figure of merit (Total Noise Power) has been evaluated
  - FDBAQ satisfies the requirement of mean bit rate $\leq 260$ [Mbit/s] for a single channel
  - FDBAQ reduces mean bit rate by 25% wrt ECBAQ
Thank you for your attention