SAOCOM Calibration Strategy

M. Azcueta, J. Giardini, J. P. Cuesta González, M. Thibeault, T. Zajc

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1. SAOCOM SAR Instrument Main Characteristics
2. Calibration components
3. External Calibration Model
   - Overview
   - TopSAR modes
   - Calibration sites
4. Internal Calibration
   - Overview
   - Central Electronics Calibration - Scheme Fundamentals
   - Antenna Calibration
5. Summary
SAOCOM SAR Instrument

**MAIN CHARACTERISTICS**

- L-Band SAR
- Right looking SAR
- Left looking capability
- **10m x 3.5m** active phased array antenna with 140 TRMs
- TOPSAR & STRIPMAP acquisition modes
- Single, dual and quad polarization operative modes
- More than **2600 beams**
**Antenna model**

**Objectives**
- Antenna beams shape
- Beam to beam and pol to pol gain
- High number of beams

**Drivers**
- Radiometric accuracy optimization
- On-Orbit calibration effort reduction
- Pre-Launch extensive characterization

**Workflow**
- Pre-Launch validation (near field/int. Cal pulses)
- On-Orbit verification & monitoring (rain forest)

**Beam Coefficients**

- $S_{1HH}$
- $S_{2HH}$
- $S_{3HH}$
- $S_{1VV}$
- $S_{2VV}$
- $S_{3VV}$

**Int. Cal**

- Telemetry
SAOCOM Calibration Strategy
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External Calibration

- External Calibration
  - Antenna Model
    - Absolute Calibration constant
    - X-talks
    - Imbalances
  - Polarimetric Calibration
    - Range and azimuth Ant. pattern
    - Pointing
  - Antenna Pattern
    - Faraday
  - Ionospheric Correction
  - Geometric Calibration
    - Geolocation
    - Distorsión
  - Image Quality
    - Impulse response
    - Others

Internal Calibration

SAR Image

Antenna Model
Antenna Pattern shall be verify from External Calibration with a precisión of 0.2 dB.

Absolute calibration constant (K) shall be estimated from External Calibration measurements with an uncertainty equal or less than 0.2dB.

Crosstalk levels shall be estimated from External Calibration measurements and corrected so that the residual x-talks is less than -30dB.

Imbalance (f) shall be estimated with an uncertainty equal or less than 0.1dB.

Image geolocation error in STRIPMAP mode shall be less than 2 resolution cells.
Beams design

To limit the calibration effort, all the modes are based on a total set of 18 beams (in range):

- 9 Quad-Pol
- 9 Dual- Single Pol

TOPSAR mode was chosen to maximize coverage vs geometric and radiometric resolution.
Rely on the Antenna Model and the fact that the STRIPMAP beams are used to construct the TOPSAR mode

Computation of absolute constant using corner reflector for STRIPMAP then conversion to TOPSAR modes

Verification using Corners reflector over very low background

<table>
<thead>
<tr>
<th></th>
<th>STRIPMAP</th>
<th>TOPSAR W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration area [pixels]</td>
<td>20 x 20</td>
<td>20 x 20</td>
</tr>
<tr>
<td>Corner RCS $\sigma_{CR}$ [dB]</td>
<td>38.1</td>
<td>38.1</td>
</tr>
<tr>
<td>Background $\sigma_{B}^0$ [dB] $\sigma_{CR}$</td>
<td>-15</td>
<td>-25</td>
</tr>
<tr>
<td>Pixel area A [m²]</td>
<td>50</td>
<td>1000</td>
</tr>
<tr>
<td>Confidence error [%]</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Single Measurement error [dB]</td>
<td>0.2</td>
<td>0.27</td>
</tr>
<tr>
<td>12 Measurements error [dB]</td>
<td>0.05</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Salt Lakes for CR
Calibration Sites for Corner Reflectors

<table>
<thead>
<tr>
<th></th>
<th># Acquisitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQP-S1</td>
<td>60</td>
</tr>
<tr>
<td>SQP-S2</td>
<td>6</td>
</tr>
<tr>
<td>SQP-S3</td>
<td>16</td>
</tr>
<tr>
<td>SQP-S4</td>
<td>7</td>
</tr>
<tr>
<td>SQP-S5</td>
<td>6</td>
</tr>
<tr>
<td>SQP-S6</td>
<td>15</td>
</tr>
<tr>
<td>SQP-S7</td>
<td>6</td>
</tr>
<tr>
<td>SQP-S8</td>
<td>22</td>
</tr>
<tr>
<td>SQP-S9</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total QP</strong></td>
<td><strong>142</strong></td>
</tr>
<tr>
<td>SDP-S1</td>
<td>38</td>
</tr>
<tr>
<td>SDP-S2</td>
<td>9</td>
</tr>
<tr>
<td>SDP-S3</td>
<td>21</td>
</tr>
<tr>
<td>SDP-S4</td>
<td>50</td>
</tr>
<tr>
<td>SDP-S5</td>
<td>30</td>
</tr>
<tr>
<td>SDP-S6</td>
<td>72</td>
</tr>
<tr>
<td>SDP-S7</td>
<td>60</td>
</tr>
<tr>
<td>SDP-S8</td>
<td>0</td>
</tr>
<tr>
<td>SDP-S9</td>
<td>36</td>
</tr>
<tr>
<td><strong>Total DP</strong></td>
<td><strong>316</strong></td>
</tr>
</tbody>
</table>
Some sites are already operative for Airborne and satellites use.

Mores sites are planned in the near future.
- 55 Km² area.
- Background RCS of -10dB for X-band and -15dB for L-band.
- 1500 m height 2% of terrain slope.
Targets

- 750 m away of any other object
- 7 L band & 12 X band
• Antenna pointing will be verified using a special “notch” beam (1).
• A subset of beams will be validated: S1QP, S4QP, S8QP and S7DP (2).
• The validity of the model will be assumed for the rest of the beams.
• TOPSAR images correction will be verified as an end-to-end test (3).
Extended Targets

Amazon Rain Forest

Congo Rain Forest
Azimuth antenna pattern and pointing
SAOCOM Calibration Components

SAOCOM CALIBRATION COMPONENTS

ANTENNA MODEL

INTERNAL CALIBRATION

EXTERNAL CALIBRATION
SAOCOM Internal Calibration

INTERNAL CALIBRATION COMPONENTS

- Noise Acquisitions
- Central Electronics Cal Pulses
- Antenna Cal Pulses
- Instrument Telemetry
- On Ground Characterization

$\sigma$ bias estimation

Sensor drifts
Sensor Drifts

- Review of the needs for measuring drifts
- Sensor designed stable, however there will be drifts
- ICAL compensates for these drifts => Accuracy
**CE Calibration - Scheme Fundamentals (1/3)**

**Input and output signals from cal pulses**

**Paths in pulses A and B and nominal elements**

**Magnitude drift:**

\[
MD_{TX}^{10} = \frac{|K_{TX}(t = t_1)|}{|K_{TX}(t = t_0)|} = \frac{K_{TX}^1}{K_{TX}^0}
\]

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\[
MD_{TX}^{10} = \frac{|K_{TX}(t = t_1)|}{|K_{TX}(t = t_0)|} = \frac{K_{TX}^1}{K_{TX}^0}
\]
Scheme Performance

\[
\begin{align*}
\text{Actual:} & \quad \text{Without considering } F_{TX}:

\text{MD}_{TX}^{10} = \frac{K_{TX}^1}{K_{TX}^0} = \begin{vmatrix}
X_{CRX,B}^1 & X_{GSS,A}^1 \\
X_{GSS,B}^1 & X_{CRX,A}^1 \\
X_{CRX,B}^0 & X_{GSS,A}^0 \\
X_{GSS,B}^0 & X_{CRX,A}^0 \\
\end{vmatrix} \frac{F_{TX}^1}{F_{TX}^0}

\text{EMD}_{TX}^{10} = \begin{vmatrix}
X_{CRX,B}^1 & X_{GSS,A}^1 \\
X_{GSS,B}^1 & X_{CRX,A}^1 \\
X_{CRX,B}^0 & X_{GSS,A}^0 \\
X_{GSS,B}^0 & X_{CRX,A}^0 \\
\end{vmatrix}

\frac{1}{1 + \frac{\Delta F_{TX}^{10}}{F_{TX}^0}}

\varepsilon_{MD_{TX}^{10}} = \text{EMD}_{TX}^{10} / \text{MD}_{TX}^{10} = \frac{1}{1 + \frac{\Delta F_{TX}^{10}}{F_{TX}^0}}

\text{Performance depends on the relative change of } F_{TX}: \quad \Delta F_{TX}^{10} = F_{TX}^1 - F_{TX}^0
\end{align*}
\]
CE Calibration - Scheme Fundamentals (3/3)

- Scattering parameters
- Partial increments

\[
\begin{bmatrix}
A_{11} & A_{21} \\
A_{12} & A_{22}
\end{bmatrix}
\]

\[
\Delta F / F \approx \sum_i \frac{\partial F}{\partial \nu_i} \Delta \nu_i / F
\]

Two types of uncertainty sources:

- \( \frac{\Delta A_{21}}{A_{21}} \)
- \( -\frac{\Delta B_{21}}{B_{21}} \)
- \( \frac{1}{(1 + C_{21} \cdot C_{32} \cdot \Gamma_2 / C_{31})} \Delta C_{21} / C_{21} \)
- \( (C_{22} - C_{21} \cdot C_{32} / C_{31}) \Delta \Gamma_2 \)
- \( (-B_{22} + A_{22} + A_{21}^2 \cdot \Gamma_{GSS}) \Delta \Gamma_{CRX} \)
- \( (A_{11} + A_{21}^2 \cdot \Gamma_{CRX}) \Delta \Gamma_{GSS} \)

Instabilities of the ICAL NW

Changes in nominal HW

- AS A RESULT:
  - We obtain the ICAL performance in terms of measurable parameters
  - We understand the influence of each parameter on the total uncertainty
  - We can derive guidelines for ICAL NW design
Antenna Calibration

- Similar concept as for calibration of the CE
- In-flight measurements of TRMs (PCC)
- Models of passive devices (AM)

TRM Transmission Chain

TRM Reception Chain
1. The SAOCOM calibration strategy is built upon three features: 
   Antenna Model, External Calibration and Internal Calibration.

2. TOPSAR mode absolute Calibration made use of the 
   Antenna model and the STRIPMAP Calibration with CRs.

3. Many Calibration sites are planned or underway in Argentina 
   for Corner Reflector and use of both Amazon and Congo 
   Forest is envisaged as extended targets

4. Ground receptors are foreseen to be used for both validation 
   of some azimuth beams and pointing.
5. The SAOCOM ICAL Strategy was presented focusing on measurement accuracy, together with a proposed method for estimating the ICAL performance.

6. The method can be used to drive the ICAL network design, including requirements allocation to its components.

7. Potential error sources such as the effect of changes in the reflection coefficients of nominal elements were considered.

8. The method is planned to be used for the final version of the ICAL network.
Thank You
Back-Up Slides - CE Transmission Gain

Equation 1

\[ K_{TX} = \frac{X_{CRX,B}}{X_{GSS,B}} \times \frac{X_{CRX,A}}{X_{GSS,A}} \times F_{TX} \]

Where:
- \( X_{CRX,A} \), the voltage signal driving the CRX downconverter for pulse A
- \( X_{GSS,A} \), the voltage signal driving the GSS RF output section for pulse A
- \( X_{CRX,B} \), the voltage signal driving the CRX downconverter for pulse B
- \( X_{GSS,B} \), the voltage signal driving the GSS RF output section for pulse B
- \( F_{TX} \) is a function of the parameters of the calibration paths (described by scattering parameters) and input reflection coefficients seen from them, including:
  - \( \Gamma_{CRX} \), the reflection coefficient seen into the CRX RF input stage
  - \( \Gamma_{GSS} \), the reflection coefficient seen into the GSS RF output stage
  - \( \Gamma_{SP2,B} \), the reflection coefficient seen from port 2 of the splitter, for pulse B
  - \( \Gamma_{SP3,B} \), the reflection coefficient seen from port 3 of the splitter, for pulse B
  - \( \Gamma_{2,B} \), the reflection coefficient seen from port 2 of the DC, for pulse B
  - \( \Gamma_{3,B} \), the reflection coefficient seen from port 3 of the DC, for pulse B
  - \( A_{ij} \), the scattering parameters of the path marked as A in Figure 3, relating the reflected wave at port i for the incident wave at port j
  - \( B_{ij} \), \( C_{ij} \) and \( D_{ij} \), the scattering parameters of elements as B, C and D in Figure 4, relating the reflected wave at port i for the incident wave at port j.
Back-Up Slides - All Pulses

CE Transmission Chain

CE Reception Chain

TRM Transmission Chain

TRM Reception Chain