Raw Data-Based Internal SAR Instrument Calibration

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The SAR antenna consists of 448 radiators (antenna elements) for V and H polarization divided into 8 (azimuth) tiles.

Within the tile, the receive signals of 4x2 radiators are combined (analog combiner) and then digitized resulting in 7 digital data streams.

On-board the data streams are further combined forming time varying beams (SCORE/sweep-SAR operation).
Schematic of Instrument as Relevant for Calibration
Schematic of Instrument as Relevant for Calibration
Raw Data Driven Calibration
Instrument Schematic for Data-Based Calibration

- Utilize the received raw SAR data to estimate the phase and amplitude offset between the channels (channel alignment).
- Applied on-board (real time), or on-ground provided that the channels' data is available.
- Based on comparing the signals of the different channels.
- May be extended to yield an elevation/azimuth dependent correction (channel balancing).
Clutter Based Calibration

Properties of Spatial Correlation Func.

Under certain conditions –applicable for SAR– the spatial correlation function [1]:

- depends only on the separation and not on the absolute position
- is independent on the scene for homogeneous scenes

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Suitability for Calibration in Elevation and Azimuth

**Elevation Correlation Function**

Elevation correlation function with separation $[\lambda]$

**Azimuth Correlation Function**

Azimuth correlation function with separation $[\lambda]$
Suitability for Calibration in Elevation and Azimuth

**Azimuth Correlation Function**
- The minimum separation is given by the antenna element size
- Smaller elements result in a higher correlation
- Which also means that the signals contain more redundancies
- Elevation channels are better suited for clutter based calibration

**Elevation Correlation Function**

**Data Based Calibration Approaches**
- Clutter based calibration assumes a statistically uniform clutter like scene, i.e. are limited to the signal statistics
- Other methods based on contrast maximization utilizing e.g. entropy or p-norm as metric [2]

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Why use Data-Based Calibration?
Includes Complete Signal Path
Measures Coupling Errors

Causes for Coupling

- Coupling can occur at various points in the signal path: cal-components, switches, antenna, or SAR echo return.
- Coupling effects the calibration accuracy
Difference in ADC Load between Cal and SAR Signals

Standard deviation of phase error at ADC output versus the input signal power (≈ SNR)

- 6-bits
- 8-bits
- 10-bits
- 12-bits

Cal signal

SAR signal

8.4dB

DBU-to-CE Calibration

- By successively switching off all TRIMs but one
- The input signal power will be different from the SAR echo, resulting in an ADC error.
**Reflector Antenna versus Direct Radiating Arrays**

**Direct Radiating Array**
- Each antenna element measures a common wide angular segment; a single point target is seen by all elements.
- Patterns are separable (elevation and azimuth).

**Reflector Antenna**
- Each feed illuminates a distinct (narrow) angular segment; any point target is seen by few feeds.
- Patterns are non-separable (elevation and azimuth); complicated external calibration (elevation).
Reflector Antenna versus Direct Radiating Arrays

**Direct Radiating Array**
- Each antenna element measures a common wide angular segment; a single point target is seen by all elements.
- Patterns are separable (elevation and azimuth).
- Internal calibration measures all but short harness and radiators antenna elements.

**Reflector Antenna**
- Each feed illuminates a distinct (narrow) angular segment; any point target is seen by few feeds.
- Patterns are non-separable (elevation and azimuth);
  complicated external calibration (elevation).
- Internal calibration does not cover feed, reflector, nor feed-to-reflector path.
Calibration Errors
Data Driven Calibration Concept

Simulate SAR Signal  Introduce Phase Error  Cross-Correlation  Error Estimates  Residual Error Matrix
Residual Error Matrix

Residual phase error after data driven calibration vs. element separation

Residual phase error [degree]

separation in elements
Effect of Pulse Extension Loss on Calibration
The Pulse Extent

Non-Vanishing Pulse Extent

- An effect is the extent of the SAR pulse on the ground [3].
- The area contributing to the reflected (echo) power at any instance of time
- Proportional to the pulse duration divided by the sinus of the incidence angle

Angular pulse extent to beamwidth ratio versus the look angle for a pulse length of 50μsec

PEL and Modulation Depth

\[ PEL(\vartheta) = \frac{1}{\chi \vartheta} \int_{\vartheta_0 - \chi \vartheta/2}^{\vartheta_0 + \chi \vartheta/2} |C_R(\vartheta, \vartheta_0)|^2 \, d\vartheta \]

\[ M(\vartheta) = \frac{|C_R(\vartheta)|^2 - |C_R(\vartheta + \chi \vartheta/2)|^2}{|C_R(\vartheta)|^2} \]

**PEL Impact**

- The PEL = 0.65 dB and M = 39% at near range
- If not corrected this is an absolute calibration error
- Is not directly measurable
PEL in the Presence of Steering Error

Comments

• A constant steering error causes a PEL change which varies over the swath.
• TRM phase/amplitude errors can change the PEL even without steering error, because they influence the pattern shape.
• The PEL is not fully captured by the radar equation.

New Performance Parameters should be considered for Multi-Channel Calibration.
The conventional calibration methods currently used for spaceborne SAR systems may not be extended to multi-channel systems.

Raw data driven calibration includes:
- radiator and coupling
- the SAR Rx signal itself characterizes the instrument
- Requires data link between DBUs

New data driven approaches have been investigated and are promising.

It is suggested that raw data driven calibration will supplement the current methods.