Dr. Jacques Louet
ESA
The Netherlands

CALIBRATION

PRACTICAL EXPERIENCE WITH ERS-1

- Introduction
- Radiometric Calibration
- Geometric Calibration
- Phase Calibration
- Polarimetric Calibration
Introduction

Basic SAR measurement parameters are:

- Radar backscattering
- Target position
- Target speed
- Polarisation

SAR calibration facilitates *quantitative* measurements needed to derive geophysical parameters of the area under observation from basic SAR measurements (e.g. soil moisture, biomass, ocean wave energy, ocean currents, ice type, ice flow,.....)
Inversion Model

Sensor Calibration

Data Calibration

Geophysical Calibration

Direct Model

Geophysical Parameter

Geophysical Parameter Estimate

= ?

Geophysical Validation

© Geophysical Parameter Estimate
Radiometric Calibration

Radiometric calibration is relating the SAR output in terms of digital number to $\sigma^0$.

- Design for stability
- Sensor calibration
  - pre-flight characterisation
  - internal calibration
  - external calibration
- Data calibration
Characterisation parameters for ERS-1

- Transmitter Parameters
  - Frequency
  - Pulse power
  - Pulse duration
  - Chirp bandwidth
- Antenna Parameters
  - Relative azimuth pattern
  - Absolute elevation pattern
- Receiver Parameters
  - Sensitivity
  - Bandwidth
  - Power transfer function
- Calibration Parameters
  - Internal calibration stability
Instantaneous Amplitude

Center Frequency 5300 MHz

Instantaneous Frequency

Linear Up-Chirp

B = 15.5 MHz

37.12 µs

Amplitude of Spectrum

5300 MHz Center Frequency

B = 15.5 MHz

Corresponding to Peak RF Power
EXAMPLE OF 2-BIT CODE

EXAMPLE OF 5-BIT CODE
Internal Calibration

The objective of internal calibration is monitoring system parameter changes with time, such as

- Output power
- Receiver gain
- Linear distortion (amplitude & phase)
- Non-linear distortion (amplitude & phase)
- Noise level
- Level of spurious signals

Internal calibration methods include

- Calibration using transmit pulse sample (ERS-1 method)
- Reference signals: noise, cw
- Transmit power measurements
aft antennas

for

mid

aft

antennas

sar ant.

t/r

Calibrator

HPA

Upconv.

Wi. Generator

Saw

$5177 \text{ MHz}$

$123 \text{ MHz}$

Scatt Det.

A/D

Doppler

SAR Det.

A/D

$5177 \text{ MHz}$

$5177 \text{ MHz}$

$123 \text{ MHz}$

Pulse Comp.
ERS-1

CALIBRATION PULSE POWER SEQUENCE
COMMISSIONING PHASE (from 7-SEP-1991 to 6-DEC-1991)

CAL. PULSE POWER
Total Range = ± 0.1 dB

CALIBRATION PULSE POWER (in dB w.r.t. value on 06-SEP-1991)

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esa
ESRIN / ERS-1 PRODUCT CONTROL SERVICE
External Calibration

The objective of external calibration is to measure and monitor system components outside the internal calibration loop.

External calibration uses made-made or natural targets.

External calibration can be used to determine the radar image calibration factor either in combination or without reference to internal calibration.

AMI Transponder Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wind Mode</th>
<th>Image/Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar Cross Section</td>
<td>87.5dBm²</td>
<td>65.0dBm²</td>
</tr>
<tr>
<td>Adjustment Range</td>
<td>+0, −5dB</td>
<td>+0, −5dB</td>
</tr>
<tr>
<td>Calibration Accuracy</td>
<td>±.5dB</td>
<td>±.5dB</td>
</tr>
<tr>
<td>Cross-calibration Accuracy</td>
<td>±.2dB</td>
<td>±.2dB</td>
</tr>
<tr>
<td>Stability (Over 3 Years)</td>
<td>±.1dB</td>
<td>±.1dB</td>
</tr>
</tbody>
</table>
ERS-1 SAR CAL. TRANSPONDER #3

GAIN v TEMPERATURE

GAIN

TEMP

PLOT AV: 1
PULSE LEN: 37000 nS
PRF: 6800 Hz
CENTER F: 5300 MHz
AV TEMP:
BASEPLATE 25.7
CHAMBER 10.6
AV PwrIN: -35.7 dBm
AV PwrOUT: 9.4 dBm
AV GAIN: 45.09 dB

18 Jan 1991 19 Jan 1991

TEMPERATURE/TIME
ERS-1 Transponder Antennas

Gain Values for 12 Antennas

Average Gain = 27.81 dB
Standard Deviation = 0.06 dB
Transponder Error Model

[Diagram with labels: antenna errors, electronic gain error, coherent multipath, incoherent multipath, 'clutter']
Sidelobe structure in H-plane pattern (plane of offset).

Pointing evaluation E-plane, based on LMS curve fit.

E and H plane patterns, co and cross-polarisation.
FIGURE 2. RADAR CROSS SECTION CALIBRATION
## Transponder Calibration Accuracy

<table>
<thead>
<tr>
<th></th>
<th>SAR</th>
<th>SCATT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>full range</td>
<td>full range</td>
</tr>
<tr>
<td><strong>A</strong> Antenna Gain Error</td>
<td>0.028</td>
<td>0.032 dB</td>
</tr>
<tr>
<td>Pointing Error</td>
<td>0.53</td>
<td>0.56 deg</td>
</tr>
<tr>
<td><strong>B</strong> Electronic Gain Error</td>
<td>0.05</td>
<td>0.056 dB</td>
</tr>
<tr>
<td><strong>C</strong> Antenna Coupling Error</td>
<td>0.002</td>
<td>- dB</td>
</tr>
<tr>
<td>Transponder Stability A+B+C</td>
<td>0.08</td>
<td>0.088 dB</td>
</tr>
<tr>
<td><strong>D</strong> Transponder Stability</td>
<td>0.027</td>
<td>0.029 dB</td>
</tr>
<tr>
<td>$1 \sigma = (A+B+C)/3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>E</strong> Clutter &amp; Noise against $\sigma^0 = 0$ background</td>
<td>0.0495</td>
<td>0.0217 dB</td>
</tr>
<tr>
<td><strong>F</strong> Coherent Multipath</td>
<td>0.0207</td>
<td>0.0388 dB</td>
</tr>
<tr>
<td><strong>G</strong> Incoherent Multipath</td>
<td>0.0410</td>
<td>0.0767 dB</td>
</tr>
<tr>
<td>Single Transponder Observation Error</td>
<td>$\sqrt{D^2 + E^2 + F^2 + G^2}$</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>H</strong> Atmospheric Loss Uncertainty</td>
<td>0.07</td>
<td>0.07 dB</td>
</tr>
<tr>
<td>Combined Error =</td>
<td>$\sqrt{D^2 + E^2 + F^2 + G^2 + H^2}$</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>I</strong> Transponder Calibration Accuracy</td>
<td>0.2</td>
<td>0.2 dB</td>
</tr>
</tbody>
</table>
### Representative SAR Calibration Budgets

**SAR Radiometric Accuracy**

<table>
<thead>
<tr>
<th></th>
<th>1 σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Absolute Calibration Error</td>
<td>a 0.14 dB</td>
</tr>
<tr>
<td>B Cross Swath Calibration Error</td>
<td>b 0.08 dB</td>
</tr>
<tr>
<td>C Radiometric Stability Drift</td>
<td>b 0.25 dB</td>
</tr>
<tr>
<td>Nominal Calibration Accuracy</td>
<td>0.3 dB</td>
</tr>
<tr>
<td>D Radiometric Stability Drift Nominal Observation</td>
<td>c 0.25 dB</td>
</tr>
<tr>
<td>E Across Swath Characterisation Error</td>
<td>c 0.1 dB</td>
</tr>
<tr>
<td>F Across Dynamic Range Characterisation</td>
<td>c 0.1 dB</td>
</tr>
<tr>
<td>G Atmospheric Loss Uncertainty</td>
<td>c 0.07 dB</td>
</tr>
</tbody>
</table>

**Total Radiometric Error**

\[
\sqrt{A^2 + B^2 + C^2 + D^2 + E^2 + F^2 + G^2} = 0.6 \text{ dB}
\]

(a) Dominated by transponder calibration

(b) Single sample error, reduced by in-flight monitoring

(c) Random error per observation

**Absolute Calibration Error**

<table>
<thead>
<tr>
<th></th>
<th>Number of Samples</th>
<th>Single Sample Error (1 σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H Transponder Calibration Accuracy</td>
<td>3</td>
<td>0.2                       dB</td>
</tr>
<tr>
<td>I Antenna Gain Characterisation</td>
<td>3</td>
<td>0.1                       dB</td>
</tr>
<tr>
<td>J Single Transponder Observation Error</td>
<td>3</td>
<td>0.07                      dB</td>
</tr>
<tr>
<td>K Atmospheric Loss Uncertainty</td>
<td>3</td>
<td>0.07                      dB</td>
</tr>
</tbody>
</table>

**Combined Error**

\[
\sqrt{H^2/3 + I^2/3 + J^2/3 + K^2/3} = 0.14 \text{ dB}
\]
Figure 7: Transponder Sites Flevoland, Commissioning Phase Coverage
theoretical RCS of the calibrators

* 3 ESA Transponders

- JPL Corner Reflector
- FEL-TNO Corner Reflector

incidence angle \( \theta \) [degree]
ERS-1

TRANSPONDER & CORNER REFLECTORS ABSOLUTE R.C.S.

COMMISSIONING PHASE (from 25-OCT-1991 to 6-DEC-1991)

**ESA TRANSPONDER #2**
Nominal R.C.S. Value: 57.65 dBm2

**JPL CORNER REFLECTORS**
Nominal R.C.S. Value: 46.7 dBm2

**FEL/TNO CORNER REFLECTORS**
Nominal R.C.S. Value: 40.6 dBm2

SAME CALIBRATION CONSTANT USED
Reference: 13-OCT-1991 Transponder #2

ESRIN / ERS-1 PRODUCT CONTROL SERVICE
ERS-1
SAR CALIBRATION HISTORY
COMMISSIONNING PHASE & ICE PHASE (from 7-SEP-1991 to 11-MAR-1992)

R.C.S. VARIATION
(w.r.t. nominal values)
St.Dev. = 0.41 dB
Total Range = ± 0.75 dB

SAME CALIBRATION CONSTANT USED
Reference: 13-OCT-1991 Transponder #2

ESA TRANSPONDERS IN FLEVOLOND (COMPLEX DATA)
VARIATION OF THE MEASURED RADAR CROSS SECTION (in dBm2) AROUND THE NOMINAL R.C.S. (of each transponder)

07-SEP 06-OCT 06-NOV 06-DEC 11-JAN 10-FEB 11-MAR

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Calibration of other areas

The application of the calibration factor to other areas requires knowledge of geometry (range & antenna angle) and stability over time.

High resolution information about the antenna diagram can be obtained from imagery of extended uniform targets such as the tropical forest or ice shelves.

No absolute information is required for these 'targets of opportunity'. Stability over time and a smooth dependence of $\sigma^o$ on incidence angle is necessary.
Data calibration

Data calibration include the following steps

- Correct raw data for a number of system parameters
  - Linear distortion (amplitude & phase)
  - Non-linear distortion
  - Detector imperfections (DC-biases, amplitude & phase imbalance)
  - time variations as measured by internal calibration
  - noise bias

- Application of calibration factor to the entire image, taking into account geometry and antenna angle.
noise level in imaging mode

noise I and Q standard deviations

replica cross correlation peak width

cross correlation sidelobe and ISLR
Geometric calibration

Geometric calibration can be achieved following the same principles as for radiometric calibration.

- Design for stability
- Characterise SAR system in terms of delay, phase error and frequency offset
- Calibrate using point target with accurately known position

Geometric image calibration is carried out in the data calibration stage by correction for known system biases and applying geometry information (platform position & attitude and terrain models).
Phase calibration

During the formation of an intensity image the phase information in the radar data is lost. For applications in interferometry and polarimetry complex images are formed which provide two data points per pixel, amplitude & phase or real & imaginary parts of the complex signal.

Careful and elaborate phase characterisation of both the SAR sensor and the SAR processor are required. Time stability is critical for the above applications.
Polarimetric calibration

Polarimetric calibration can be treated essentially as a multi-channel extension of the methods discussed above. Polarimetric SAR differ from single channel SAR in the following ways.

- There are two orthogonal transmit channels to consider and four receive channels.
- Radiometric calibration can be separated into absolute calibration and relative between channel calibration
- Geometric calibration can be separated into absolute calibration and relative between channel calibration
- Phase calibration between channels is essential
- Crosstalk has to be taken into account