ENVISAT ASAR
Compensation of long-term gain and phase drifts on the Transmit/Receive Modules

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Overview

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Description of Antenna Sub-Assembly

- ASAR: C-Band SAR (5.331 GHz) onboard ENVISAT, in orbit since 1-Mar-2002.
- Deployed Planar Active Phased Array Antenna (1.3 m x 10 m).
- 32 rows (elevation) and 10 columns (azimuth).
- 20 Tiles with 16 T/R modules each.
- 24 dual-polarised radiating elements (annular slots) per T/R module.
Description of Antenna Sub-Assembly

- T/R Modules include two transmit chains (one for horizontal polarisation and one for vertical polarization) and one common receive chain.
- These chains are independently programmable in gain and phase to provide the required antenna beam patterns or calibration settings.
- 6 bits for Phase control (~5.6° step size) and 6 bits for Gain control (20dB non-uniform range, with step sizes between 0.15 dB and 1.15 dB).
- A calibration coupler is present before the antenna port of each T/R module.
Instrument Stability

Instrument Performance shall be achieved:
- anywhere in the orbit,
- at any temperature within the operating range [-10°C to 40°C],
- over the dynamic range and
- over the instrument lifetime.

Short and mid-term radiometric stability is accomplished by:
- On-ground compensation of the receive gain droop.
- Temperature Compensation scheme (onboard).
- Internal calibration pulses (onboard + Ground Processor).

Long-term stability also requires:
- Periodic updates of the antenna patterns based on measurements over suitable regions of the Amazonian rainforest.
- Monitoring and compensating for long-term T/R module drifts based on Module Stepping Measurements (MSM).
Instrument Stability

- On-ground compensation of receive gain droop:
  - Ground Processor routinely compensates echo data for temperature-dependent variation of the receive gain within the sampling window.
  - Based on pre-launch characterisation data.

- Temperature Compensation scheme:
  - Implemented onboard at antenna tile level (Tile Control & Interface Unit).
  - Gain and Phase corrections applied to each T/R Module.
  - Based on T/R Module temperature telemetry and pre-launch characterisation data.

- Internal calibration:
  - Row-by-row measurement of the Tx and Rx signal paths.
  - Requires calibration pulses and a calibration loop (signal distribution network and calibration couplers and switches).
  - Within-mode periodic measurements plus initial and end sequences.
Module Stepping Mode

- Calibration Mode routinely executed every day (one polarisation per day).
- Measures the Tx and Rx characteristics (gain & phase) of each TRM path individually.
- Allows detection of module failures and monitoring of long-term drifts.
- Mode execution takes less than 30 seconds.
Module Stepping Mode

- Measurements relative to a pre-launch reference.
- Failed T/R Modules and Power Supplies (groups of 4) in black.

![Tx H Gain ASA_MS__0PNPK20100818_081839_00000162092_00121_44263_0187.N1]

Tx Gain
H-pol

Tx Min, Mean & Max Gain: -0.88dB, 0.18 ± 0.48dB, 1.55dB

European Space Agency
Module Stepping Mode

- Measurements relative to a pre-launch reference.
- Failed T/R Modules and Power Supplies (groups of 4) in black.
Module Stepping Mode

- Measurements relative to a pre-launch reference.
- Failed T/R Modules and Power Supplies (groups of 4) in black.

Rx Gain

H-pol
Module Stepping Mode

- Measurements relative to a pre-launch reference.
- Failed T/R Modules and Power Supplies (groups of 4) in black.
Compensation of long-term drifts

- Most T/R Modules slowly drift in time in gain and phase. Specific commands can be uplinked to apply gain and phase offsets to each T/R Module, mode (Tx/Rx) and polarisation.

- During pre-launch tests, gain was observed to drift above the expected range, partly due to hydrogen content of the VGA package. An additional method to offset gain based on patching the first coefficient of the temperature compensation polynomial was introduced -> requires interruption of operations.

- T/R Modules drift differently. Some stayed for 4 years within +/- 0.4 dB, others drifted 5 dB in either direction:
Compensation of long-term drifts

Default = 1 MSM per day (1 pol)

Module Stepping Measurements dB

Average N latest relative MSMs

Calculate TRM drifts statistics (max, min, mean, stdev)

Stats < thresholds

Stats > thresholds

Calculate NEW Gain&Phase offsets

Failed TRMs dB

Gain&Phase Offsets

Stats < thresholds

Stats > thresholds

Calculate NEW K0 patches and Tile checksums

All gain offsets ∈ [-3.3, 5.2] dB?

Yes

No

Upload new Gain&Phase Offsets + Plan extra MSMs

Plan instrument interruption + Upload new Gain&Phase Offsets, K0 patches and Tile checksums + Plan extra MSMs
Results from maintenance 2005 and 2010

- Maintenance in two iterations.
- Tx Gain recovered (0.4 dB).
Results from maintenance 2005 and 2010

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- Phase normalised.
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+ Maximum
+ Minimum
- Mean
| Standard deviation
Results from maintenance 2005 and 2010

- Maintenance in two iterations.
- Tx Gain recovered (0.4 dB).
- Phase normalised.
- Bug on Rx Phase offset calculation was corrected.
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- Similar results for H and V pol chains.
- 2010 maintenance better than 2005.
- Worst-case stdev: 0.45 dB gain Tx
  0.35 dB gain Rx
  2.65° phase.

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<table>
<thead>
<tr>
<th></th>
<th>2005 (before)</th>
<th>2005 (after)</th>
<th>2010 (before)</th>
<th>2010 (after)</th>
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<tr>
<td><strong>Tx</strong></td>
<td></td>
<td></td>
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<tr>
<td>H-pol</td>
<td>Min -4.14</td>
<td>-1.15</td>
<td>-4.86</td>
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<td></td>
<td>Max 2.10</td>
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<td></td>
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<td>-1.04</td>
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<tr>
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<td>-0.23</td>
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<td>Max 2.71</td>
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<tr>
<td><strong>Rx</strong></td>
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<tr>
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<td>Max 8.63</td>
<td>1.36</td>
<td>6.15</td>
<td>1.07</td>
</tr>
</tbody>
</table>

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- Gain
- Phase
- 0.35 dB gain Rx
  2.65° phase.

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Conclusions and recommendations

- In September 2005 and March 2010, drifts in gain and phase of all operating T/R Modules were successfully compensated for by an iterative maintenance method based on Module Stepping Measurements.

- Residual errors after the maintenance (stdev 0.45 dB gain Tx, 0.35 dB gain Rx and 2.65° phase) are mainly due to the quantisation step size of the T/R Modules attenuators and phase shifters and to the MS measurement accuracy.

- Results from March 2010 were slightly better due to the availability of more MSM between the first and second iteration.

- The method could be improved for Tx Gain, as several TR Modules drifted beyond the 1dB compression point. These could be characterised by performing additional MSMs with lower output signal level from the RF sub-system. The correct (non-linear) compensation could then be commanded based on the degree of saturation.
Conclusions and recommendations

- In ASAR, the compensation of T/R Modules Gain and Phase offsets has an impact on operations:
  - instrument interruptions,
  - re-processing of products,
  - temporary delays to fully-calibrated products (measurements over rain-forest are required to estimate the new set of antenna patterns).

- This drawbacks can be overcome (as in Sentinel-1) by using:
  - an Antenna Model that accurately estimates all radiation patterns based on Module Stepping measurements, beam excitation coefficients and pre-launch characterisation data.*
  - a simplified commanding of Gain and Phase Offsets. **

* Not possible for ASAR as Embedded row patterns were measured with only 14 tiles and with insufficient control of the T/R modules.

** Not possible for ASAR as at a late stage of the instrument development, VGAs were found to drift in gain beyond the originally expected range. A solution was implemented based on patching coefficients of the temperature compensation coefficients and tile memory checksums.