GMES Sentinel-1 Transponder Development

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Outline

1. GMES Sentinel-1 overview
2. Sentinel-1 calibration
3. Transponder requirements
4. Transponder calibration
5. Deployment
6. Conclusions

Sentinel-1 Observation Geometry

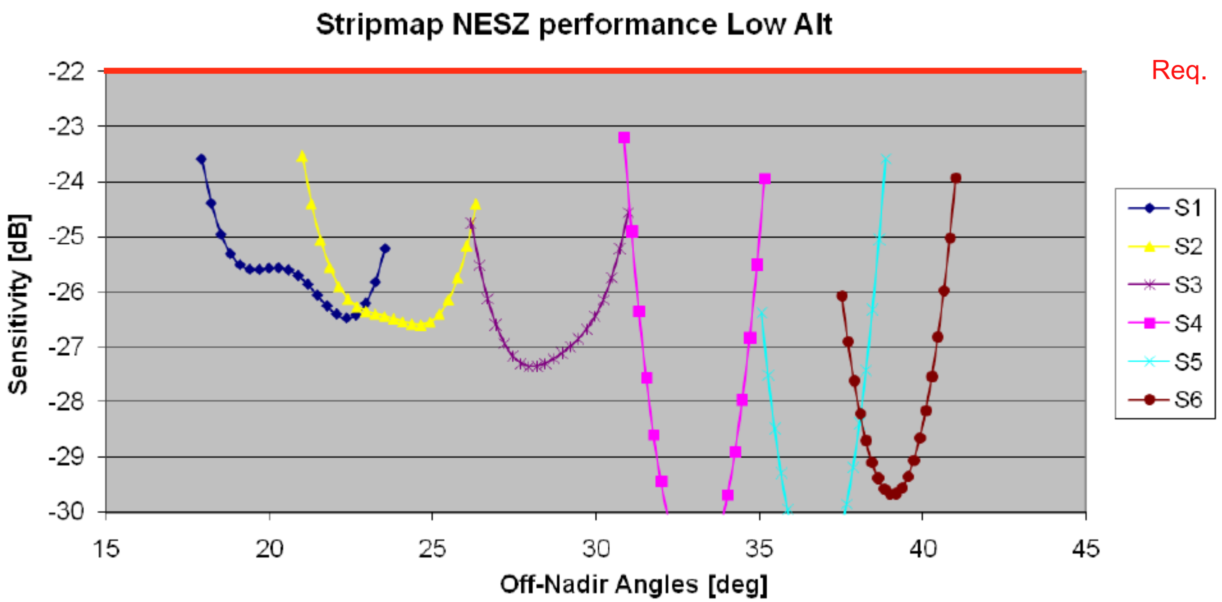
Sentinel-1 Performance

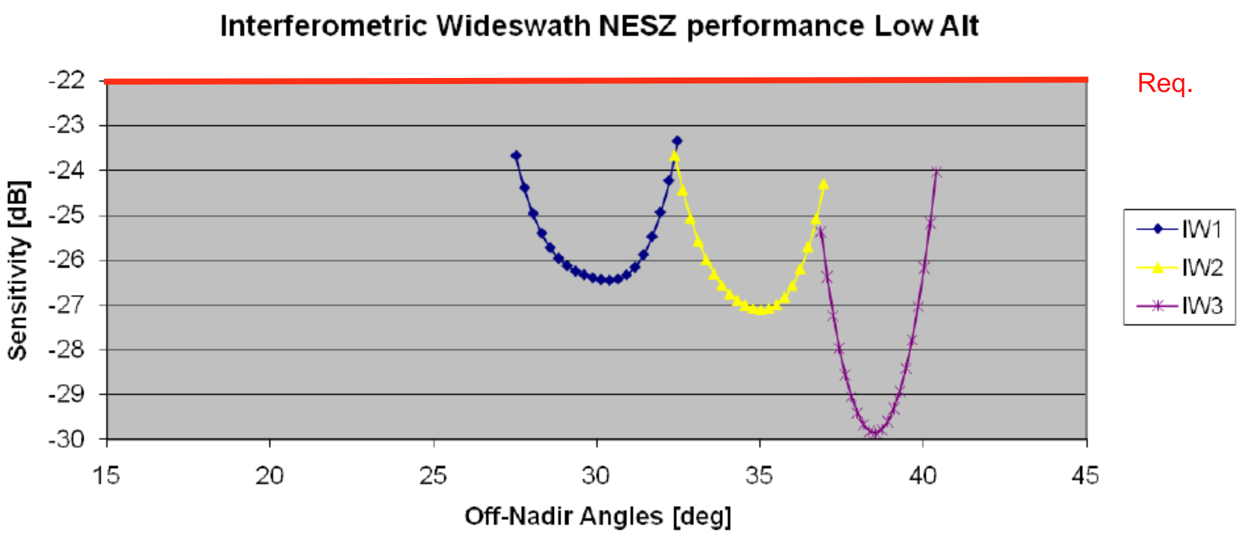
Mode	Access Angle	Single Look Resolution	Swath Width	Polarisation
Interferometric Wide Swath	**> 25 deg.**	**Range 5 m Azimuth 20 m**	**> 250 km**	**HH+HV or VV+VH**
Wave mode	**23 deg. + 36.5 deg.**	**Range 5 m Azimuth 5 m**	**> 20 x 20 km Vignettes at 100 km intervals**	**HH or VV**
Extra Wide Swath	> 20 deg.	Range 20 m Azimuth 40 m	> 400 km	HH+HV or VV +VH
Strip Map	20-45 deg.	Range 5 m Azimuth 5 m	> 80 km	HH+HV or VV +VH

Main modes

For All Modes	
Radiometric accuracy (3 σ)	**1 dB**
Noise Equivalent Sigma Zero	**-22 dB**
Point Target Ambiguity Ratio	**-25 dB**
Distributed Target Ambiguity Ratio	**-22 dB**

SAR Instrument Performance (NESZ)





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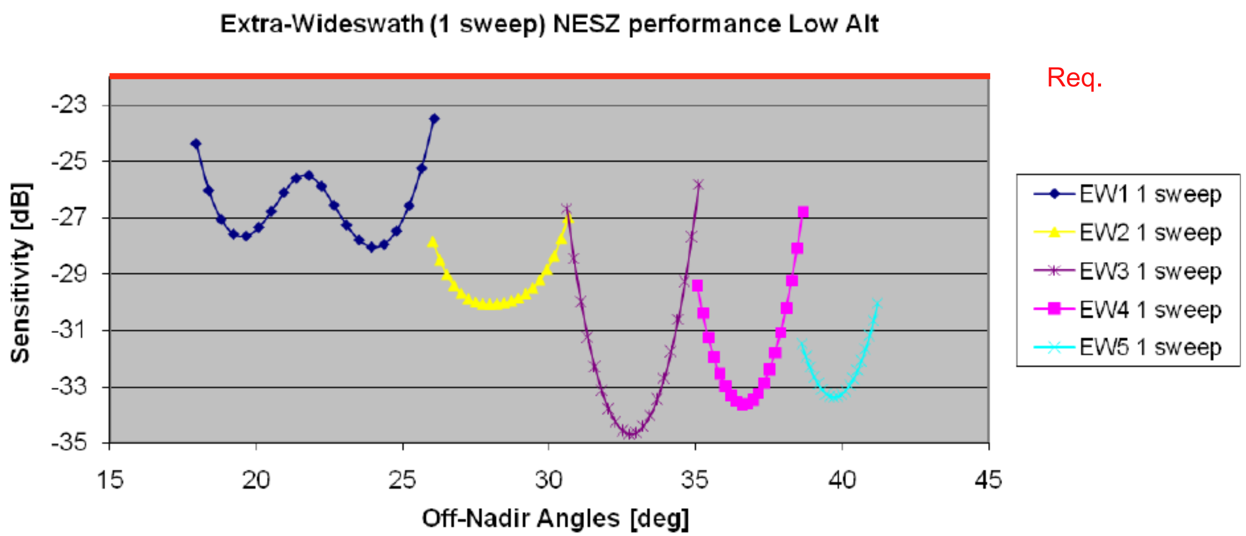
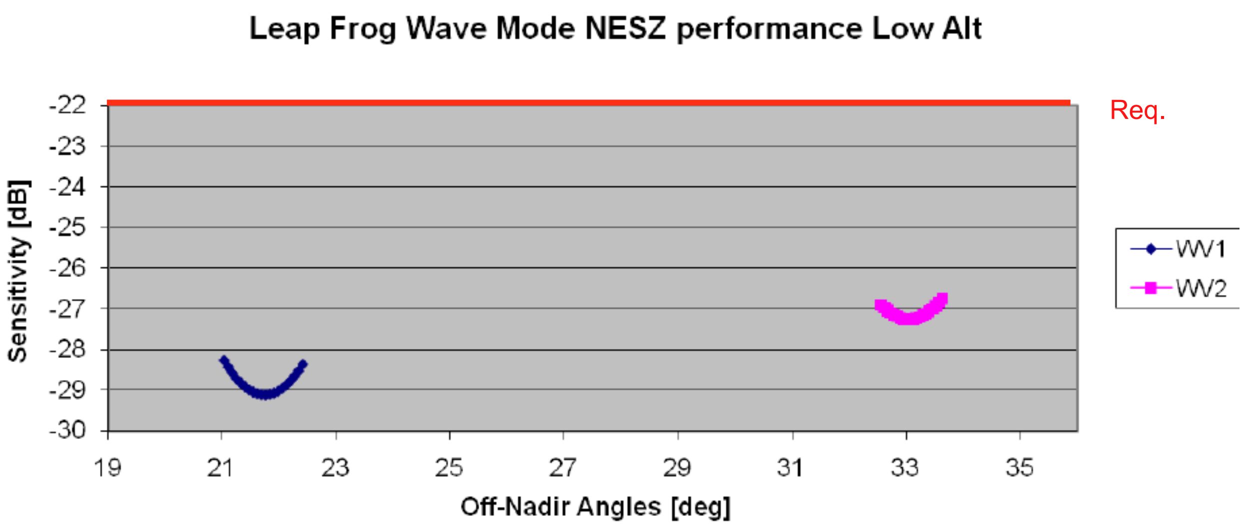




C-SAR Key Parameters

Parameter	Value
Centre Frequency	5.405 GHz
Instrument Mass	945 kg
DC-Power Consumption	3870 Watt (Interferometric Wideswath Mode, two polarisations)
Bandwidth	0 … 100 MHz (programmable)
Polarisation	HH-HV, VV-VH
Antenna Size	12.3 m x 0.821 m
RF Peak Power (sum of all TRM, at TRM o/p)	4368 W
Pulse Width	5-100 μs (programmable)
Transmit Duty cycle	
max	12%
Stripmap	8.5 %
Interferometric Wideswath	9 %
Extra Wide swath	5 %
Wave	0.8%
Receiver Noise Figure at Module input	3.2 dB
Pulse Repetition Frequency	1000- 3000 Hz (programmable)
ADC Sampling Frequency	300 MHz (real sampling) (Digital down-sampling after A/D conversion)
Sampling	10 bits
Data Compression	Variable according to FDBAQ

Internal Calibration and Antenna Model

- Internal Calibration
  - compensate for drift effects by measuring the power-gain product using internal calibration pulses
  - derive actual settings of the TRMs by pulse code technique (PCC) for tuning/optimising the antenna model
- Antenna Model
  - provide all reference patterns for radiometric correction of the SAR data
  - derive antenna settings for best instrument performance even for drifting and/or failed transmit/receiver modules (TRM) during the lifetime

Radiometric Calibration

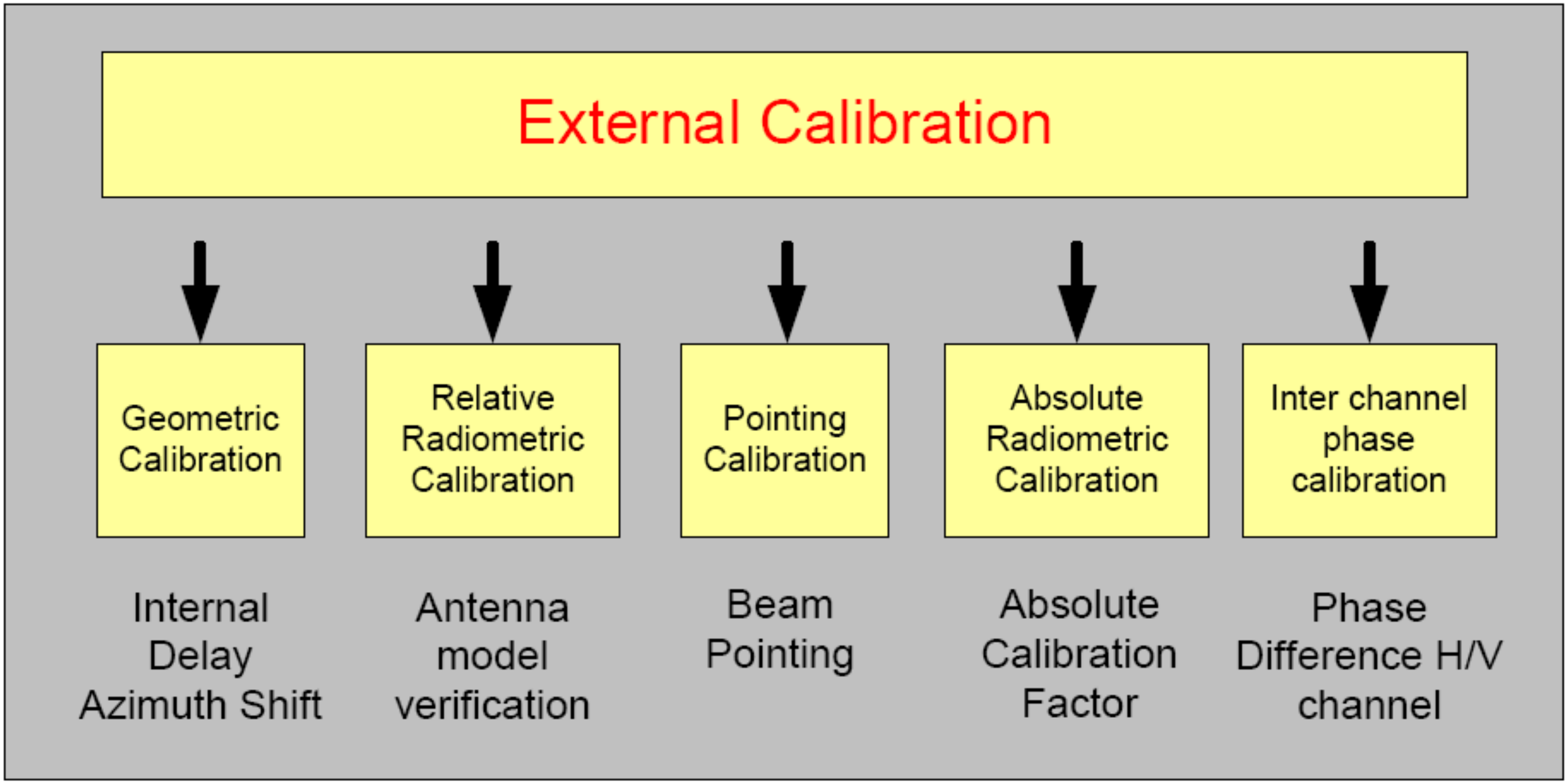
- External calibration is performed by use of transponders and by measurements over rain forest. Radiometric calibration is achieved by comparing the measured signal power over the transponders with their precisely known radar cross sections.

- Geometric calibration and pointing calibration:
  - Azimuth pointing can be estimated on basis of the "Doppler centroid". Estimation of this Doppler centroid across the swath allows also deriving the normal pointing.
  - Elevation pointing is estimated with dedicated Notch beams and from measurements with nominal beams over the rain forest.

- Inter channel phase accuracy is measured with transponders which return the signal in both H and V polarization at the same time and which allow a direct phase comparison between H and V channel.

- Antenna patterns are described by the antenna model which is to be derived on ground already with high accuracy. This antenna model is verified for a limited set of beams via measurements over a homogeneous target and using transponders.

In Orbit Calibration



C-SAR Requirements

Parameter	Requirement
Maximum Point Target Radar Cross Section	75 dBm^2
Receive polarisation	H and V
Transmit polarisation	H or V
H to V phase accuracy	15 degrees
Radiometric accuracy	1.0 dB (3σ)
Radiometric stability	0.5 dB (3σ)
Cross polar isolation	-30 dB
Accuracy of the antenna pattern estimation	0.1 dB within the swath 1.0 dB at -20 dB level with respect to the maximum 0.2 dB of absolute gain
Pixel localisation	2.5 - 10 m (3σ) depending on the mode

Transponder Requirements

Parameter	Requirement
Radar Cross Section as seen by the satellite	70 dBm^2
Receive polarisation	H or V
Transmit polarisation	Both H and V
Transmit H to Transmit V imbalance	Amplitude < 0.05 dB; Phase < 5 degrees
Radiometric accuracy of the RCS mode	0.1 dB (3σ)
Radiometric stability of the RCS mode	0.1 dB (3σ)
Time Delay	Adjustable from 1.0 μs to 1000 μs in increments of 0.01 μs
Accuracy of the receiver mode	0.05 dB in the main lobe of the received azimuth pattern relative to the peak value 0.5 dB at -20 dB level with respect to the peak value of the main lobe of the received azimuth pattern
Dynamic range of the receiver mode	The dynamic range shall be sufficient to reconstruct the azimuth pattern of the Sentinel-1 SAR antenna down to a side lobe level of – 40 dB.
Transponder position error	1 m (3σ)

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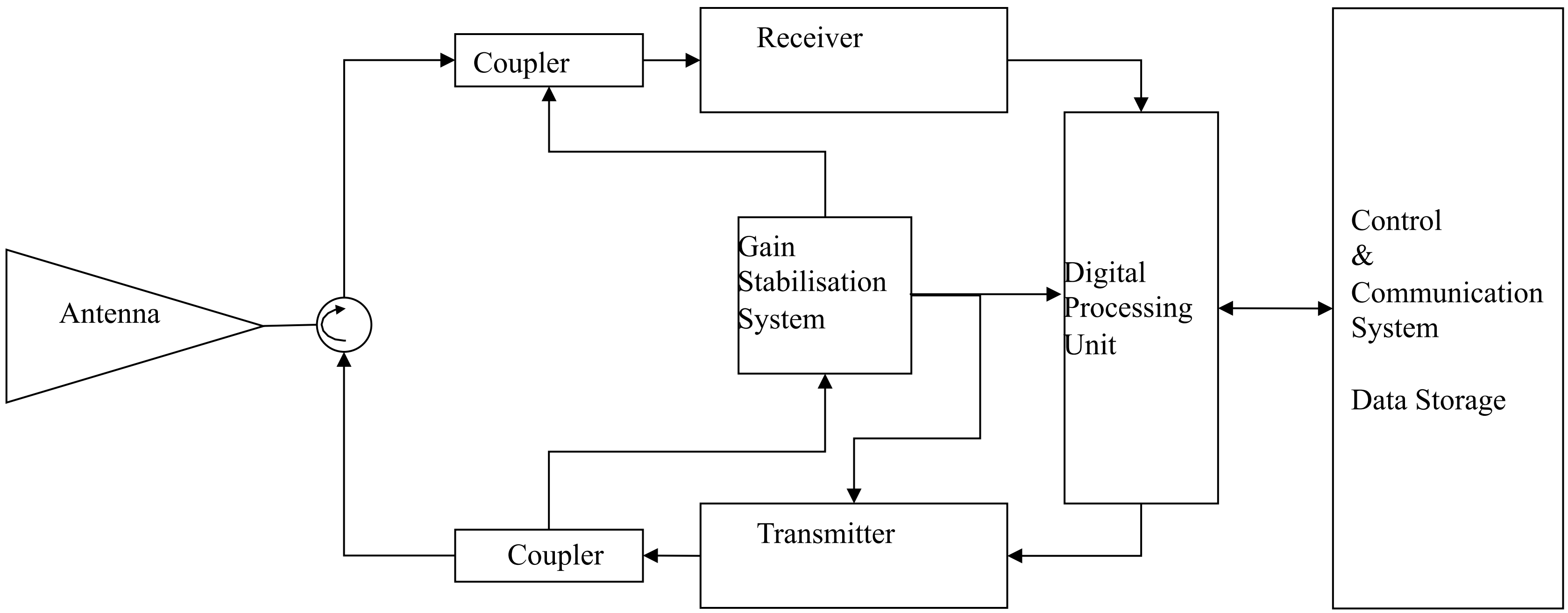
Transponder function

- Main function of the transponder is to act as a very stable high RCS target

- The transponder will also function as a receiver for the azimuth antenna pattern. The azimuth pattern receiver mode involves detection and measurement of the amplitudes of received SAR pulses. This mode will confirm the expected azimuth beam pattern for the C-SAR phased array. Pointing can be derived using an azimuth notch pattern on transmit.

Transponder layout

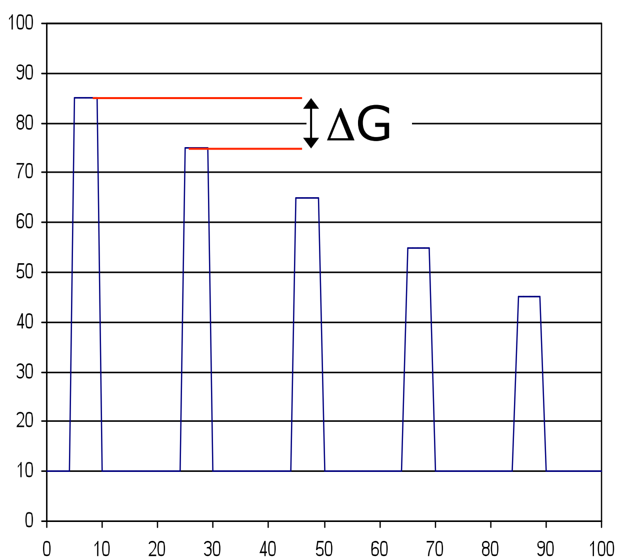


- Single antenna design → no potential coupling between TX-RX, but long delay required
- Gain stability achieved through:
  - detection of series of pulses, through RF & digital subsystem
  - amplitude compared with amplitude of original detected pulses in the gain stabilisation subsystem
  - Error compensated by controlled attenuator in DPU or Tx

Calibrating the Calibrator 1

Absolute calibration of the transponder will be determined on a test range using a flat metal plate of known radar cross section

- A test pulse is transmitted from the transponder to the plate which is then reflected back and received.
- This received pulse is once again transmitted to the plate after a suitable delay and the whole process repeated.
- The resulting series of decaying pulses can be used to determine the absolute RCS of the transponder through



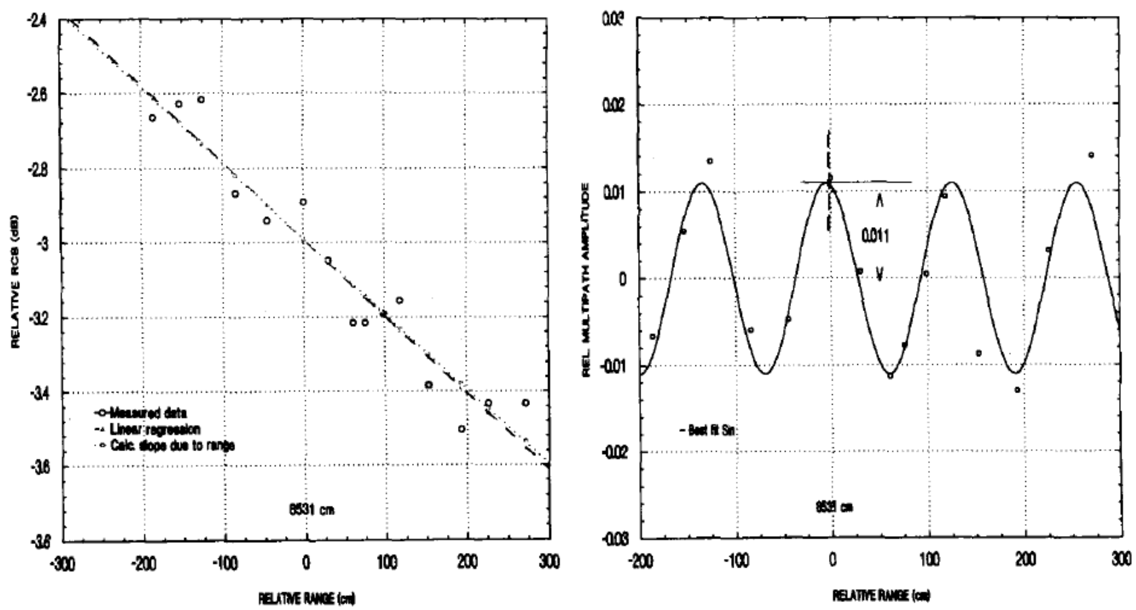
$$\Delta G = \frac{\sigma_{TP}}{4\pi R^2} \cdot \frac{\sigma_{plate}}{4\pi R^2}$$

$$\sigma_{plate} = \frac{4\pi A^2}{\lambda^2}$$

$$\sigma_{TP} = \frac{4\pi . \lambda^2 . R^4 . \Delta G}{A^2}$$

Calibrating the Calibrator 2

- No parallax due to the use of a single antenna
- Multi-path effects can be estimated by changing the distance between the transponder and the flat plate, measuring the change in transponder RCS and determining a correction factor



ERS-1 ARC Multi-path effect measurement

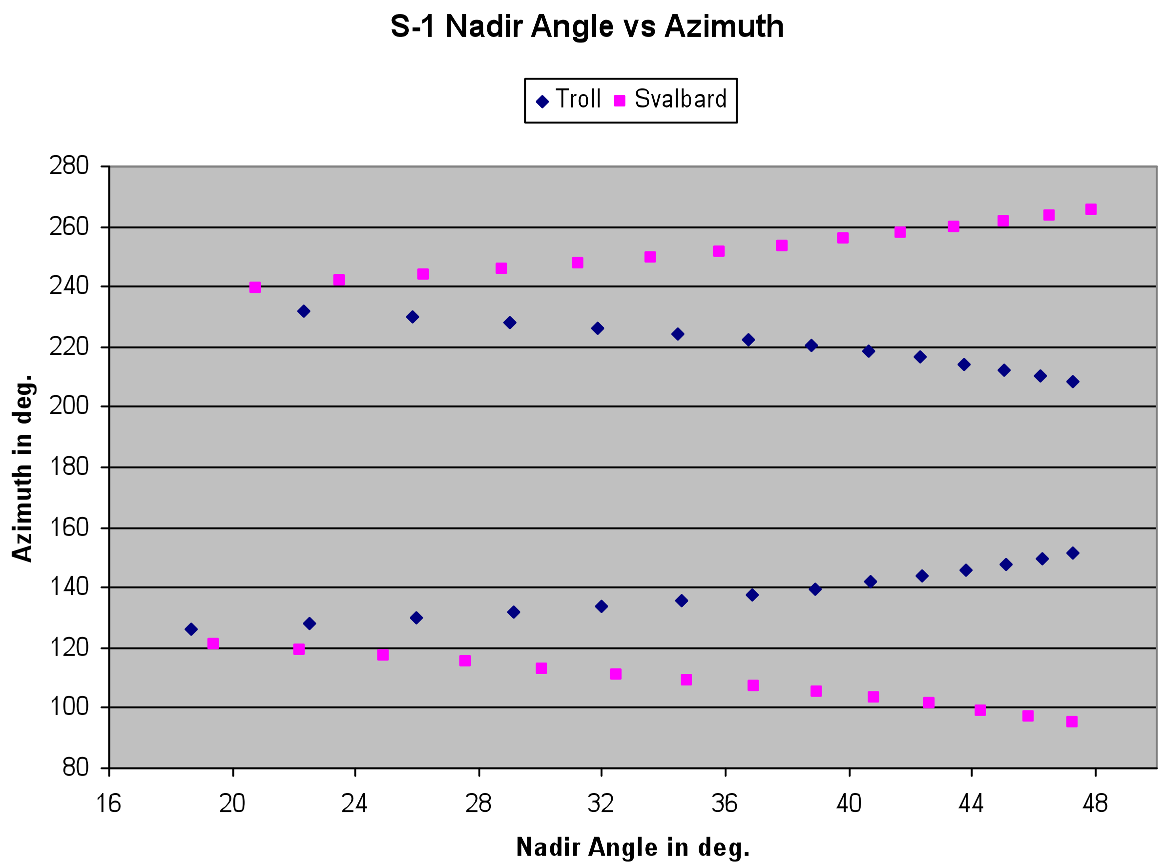
Calibrating the Calibrator 3

- Error budget to be calculated depending on for example:
  - Antenna pointing
  - Antenna gain stability (thermal)
  - Electronics stability (thermal)
  - Target plate flatness
  - Range measurement
  - Residual multi-path
  - Measurement accuracy decaying pulses

Transponder deployment 1

- High latitudes
  - Frequent revisit, 16-18 passes per cycle

  but
  - One transponder per site
  - Harsh environment

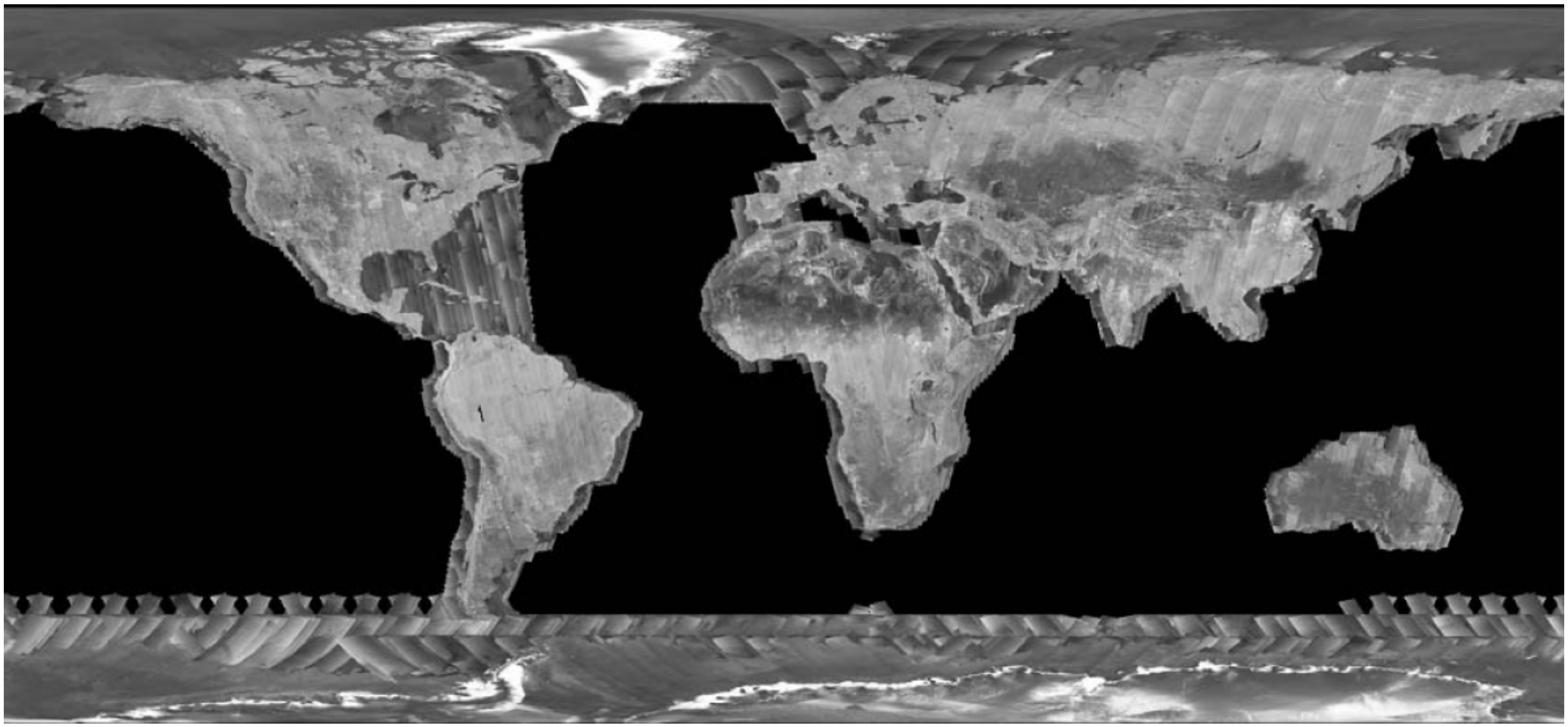


Elevation angle coverage for 12-day cycle of Sentinel-1 for Troll & Svalbard

Transponder deployment 2

- Mid-latitudes
  - Cross over region of beams in ascending and descending swaths
  - Use a limited number of beams
  - Three transponder in the same area
  - Easy deployment and maintenance

Questions



Global ASAR Global Monitoring Mosaic