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The 4th International Workshop on Advances in SAR Oceanography

Sentinel-1 Instrument Overview

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European Space Agency

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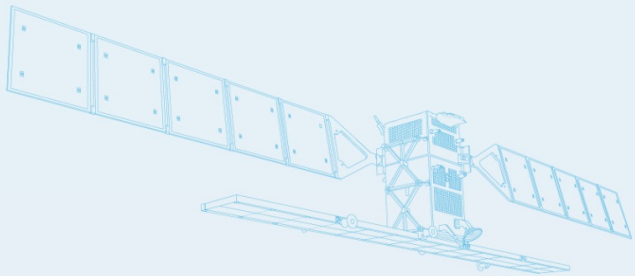
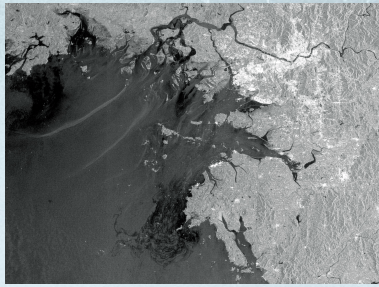
Outline

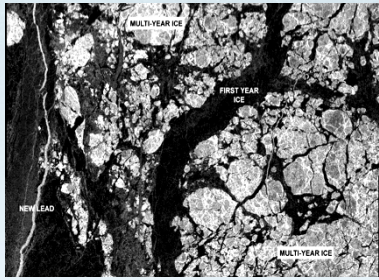
- Introduction
- Sentinel-1 System
- Acquisition modes and performance
- Sentinel-1 <-> ERS/ASAR comparison
- Instrument overview
- Conclusions

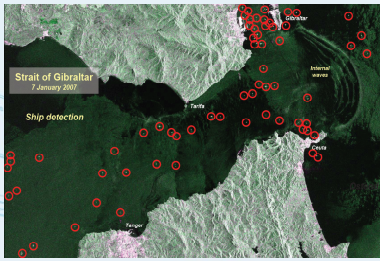


Sentinel-1 Mission Objectives and Requirements

- Provide routinely and systematically SAR data to GMES Services and National services
  - ✓ Marine Monitoring (e.g. oil spill, sea ice)
  - ✓ Land Monitoring (e.g. land cover, surface deformation)
  - ✓ Emergency Response
  - ✓ Climate Change (e.g. Polar caps incl. ice shelves and glaciers)
  - ✓ Security (e.g. vessel detection)
- Provide C-band SAR data continuity of ERS/ENVISAT type of mission
- Greatly improved coverage and revisit (i.e. as compared to ENVISAT)
- Conflict-free operations (wide swath and dual-pol modes)
- High system availability (SAR duty cycle and data latency)
- Data quality similar or better than ERS/ENVISAT (e.g. equalized performance across the swath)

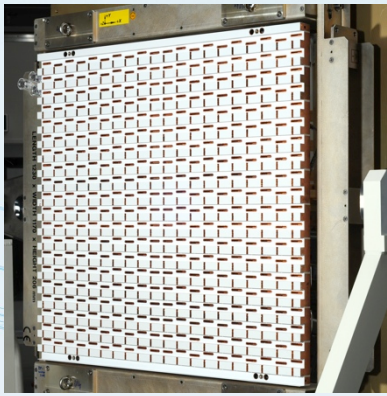






Sentinel-1 – Technical Overview

- Space Segment
  - ✓ A constellation of two satellites (same orbit with different Mean Anomaly)
  - ✓ Nominal lifetime in orbit of 7.25 years (consumables for 12 years)
  - ✓ Near-Polar Sun-Synchronous dusk-dawn orbit @ 693km, 98.6 min
  - ✓ Eclipse duration: 19 minutes during Southern Hemisphere Winter Solstice
  - ✓ Global coverage with a repeat cycle 12 days (175 orbits) or 6 days with S1A&B
  - ✓ Dual Pol C-Band (5.405GHz) Synthetic Aperture Radar Payload (CSAR)
  - ✓ On-board data compression using Flexible Dynamic Block Adaptive Quantization
  - ✓ On-board data storage capacity (mass memory) of 1410 Gbit
  - ✓ Data downlink in X-Band (2 x 260 Mbps) and laser link via GEO European Data Relay Satellite (ERDS) system (OCP)
  - ✓ Launch mass 2300 kg. Power 5900 W (EoL)
- Launch
  - Soyuz from Guiana Space Centre, Kourou in French Guiana.
  - S1A in 2013, S1B +18 months
- Ground Segment
  - Ground stations:
    3 X-band stations for SAR data, 1 S-band for TT&C, 1 EDRS station (OCP)
  - ESOC for mission control, management from ESRIN for mission planning, SAR data processing and distribution



Sentinel-1 – System Sizing

SAR Duty Cycle

- Up to 25 minutes in any of the imaging modes
- Rest (74 minutes) in Wave Mode
- Acquisitions in eclipse

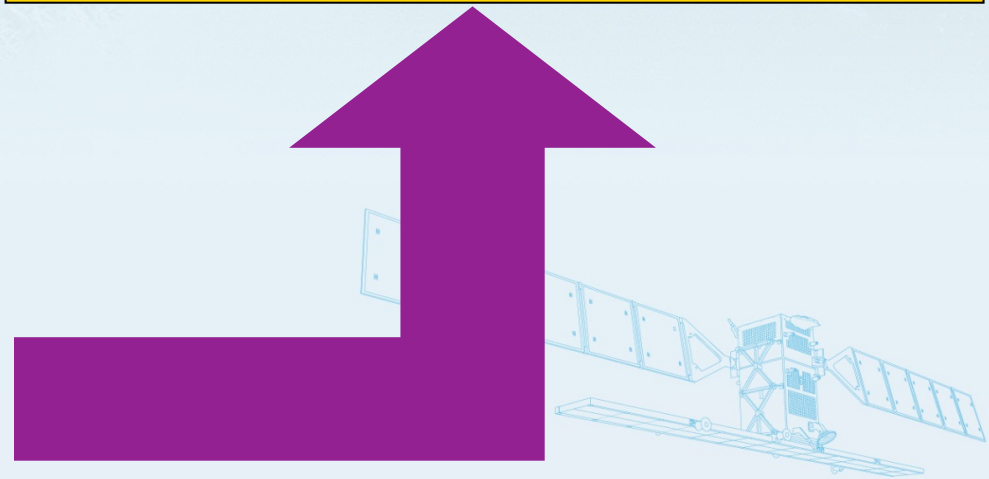
+

PDHT & Downlink Requirement

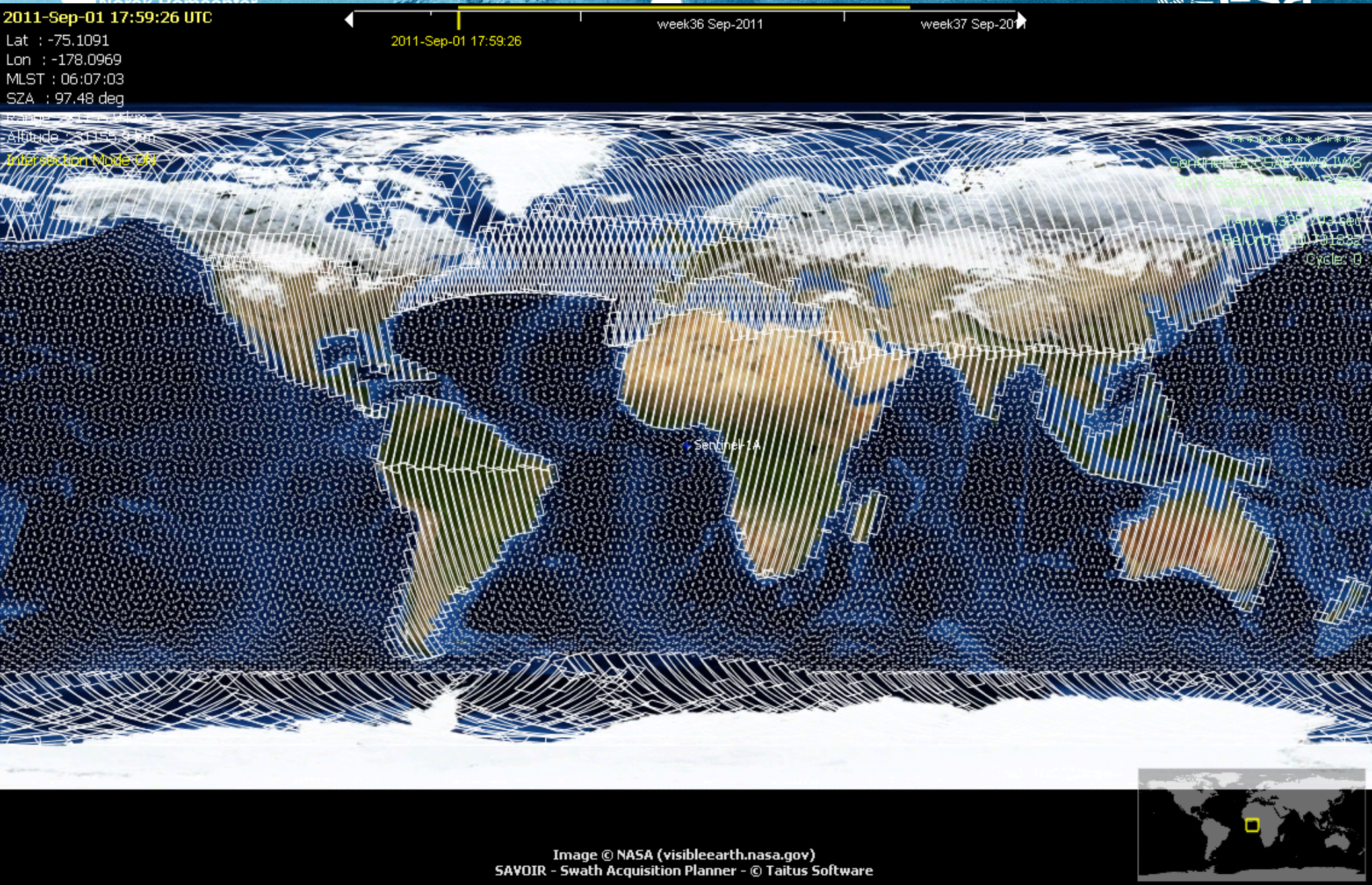
- Three X-band ground stations for payload data downlink
- No orbit without DL
- 20 minutes continuous DL
- Simultaneous SAR acquisition and downlink

On-board data latency

- NRT data one orbit from start of acquisition
- Non-NRT data two orbits from start of acquisition

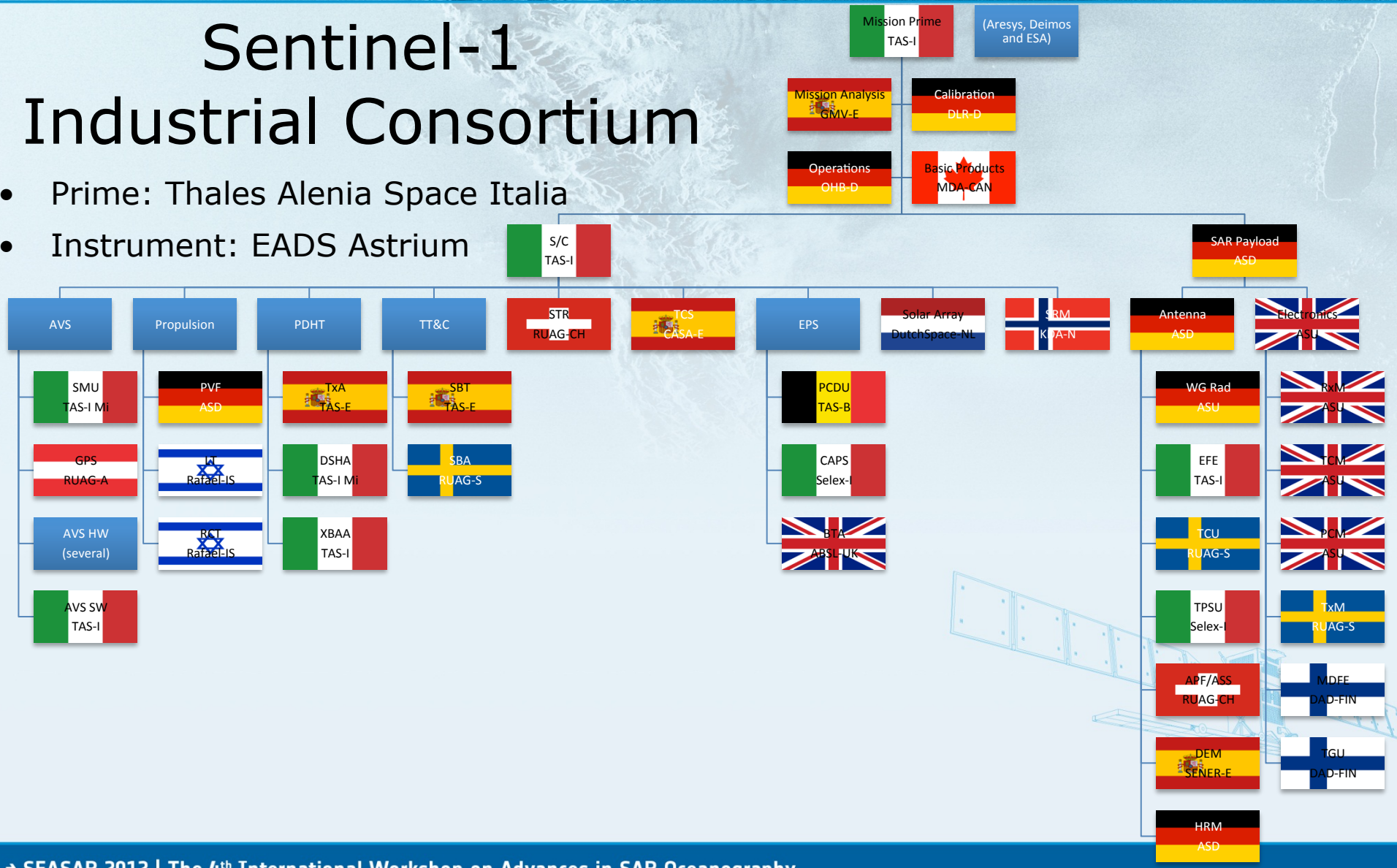


Sentinel-1A Capabilities IW and Wave mode every 12 days

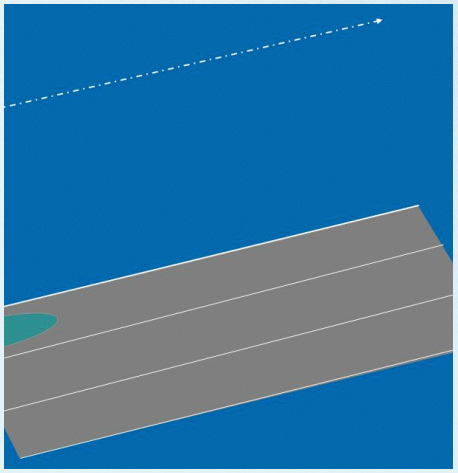


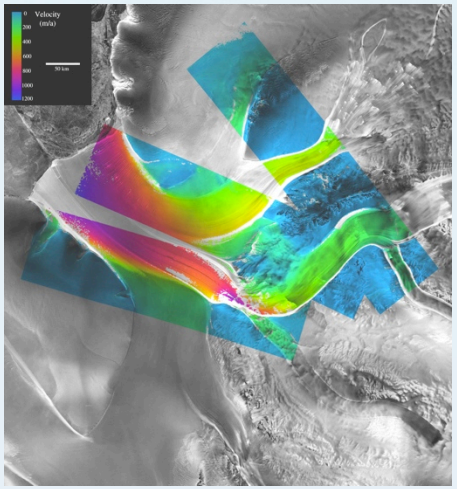
Sentinel-1 Industrial Consortium

- Prime: Thales Alenia Space Italia
- Instrument: EADS Astrium



Sentinel-1 CSAR Design Drivers



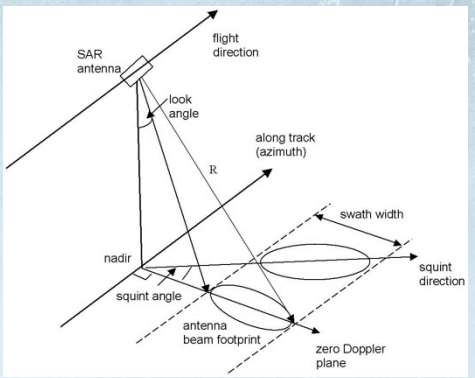


- High Sensitivity (NESZ : -22 dB):
  - Peak transmit power
  280 H and 280 V T/R units of 15W each
  - Low loss waveguide radiators
- 1dB radiometric accuracy and 0.5dB stability (3σ):
  - Extensive on ground characterization and internal calibration
- 5 meter ground range resolution:
  - 100 MHz bandwidth
- High Sensitivity & Low Ambiguity Levels:
  - 12.3 m x 0.84 m antenna aperture
- Dual Polarisation Capability:
  - One selectable Tx Chain and two parallel Rx Chains with low cross-coupling (< -35 dB)
- ScanSAR using TOPS Mode Implementation:
  ±12° elevation scanning and beam shaping capability
  ±0.8° azimuth scanning at PRI rate
- Minimise number of PRFs and SWL over the orbit:
  - Limitations to SAR Mode design
  - Roll-steering mode for S/C

Sentinel-1 Attitude Steering Modes

Total zero-Doppler steering mode

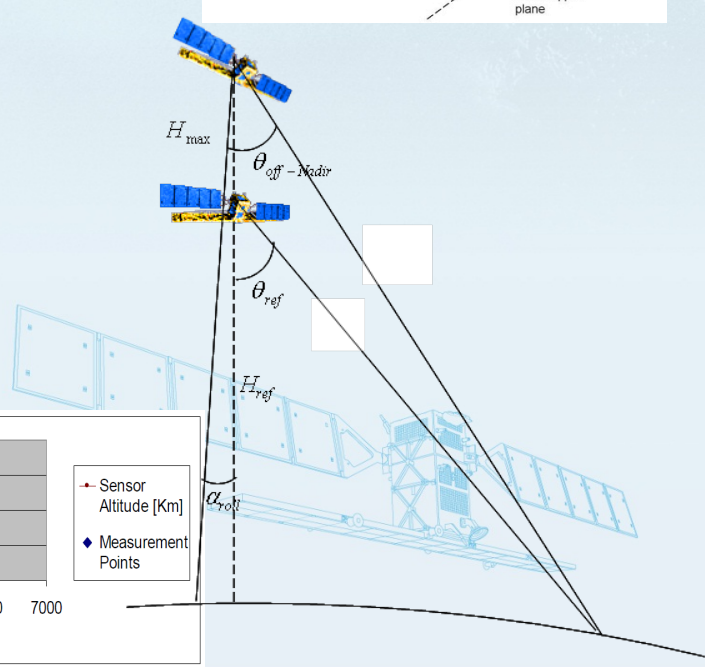
- Yaw and pitch adjustments around the orbit to account for Earth rotation effect
- Provides Doppler centroid at about 0 Hz – pointing knowledge <0.004°



Roll-steering mode

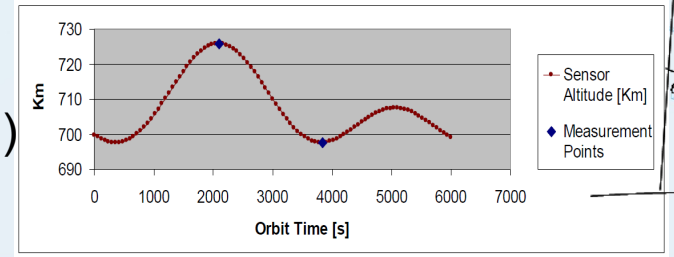
- Compensate for sensor altitude changes around the orbit
- Introduction of additional satellite *roll angle* depending on latitude to maintain a quasi "*constant*" *slant range*

at H_{min} = 697.6 km $\Rightarrow$ $\theta_{off\text{-}Nadir}$ = 30.25°
at H_{max} = 725.8 km $\Rightarrow$ $\theta_{off\text{-}Nadir}$ = 28.65°

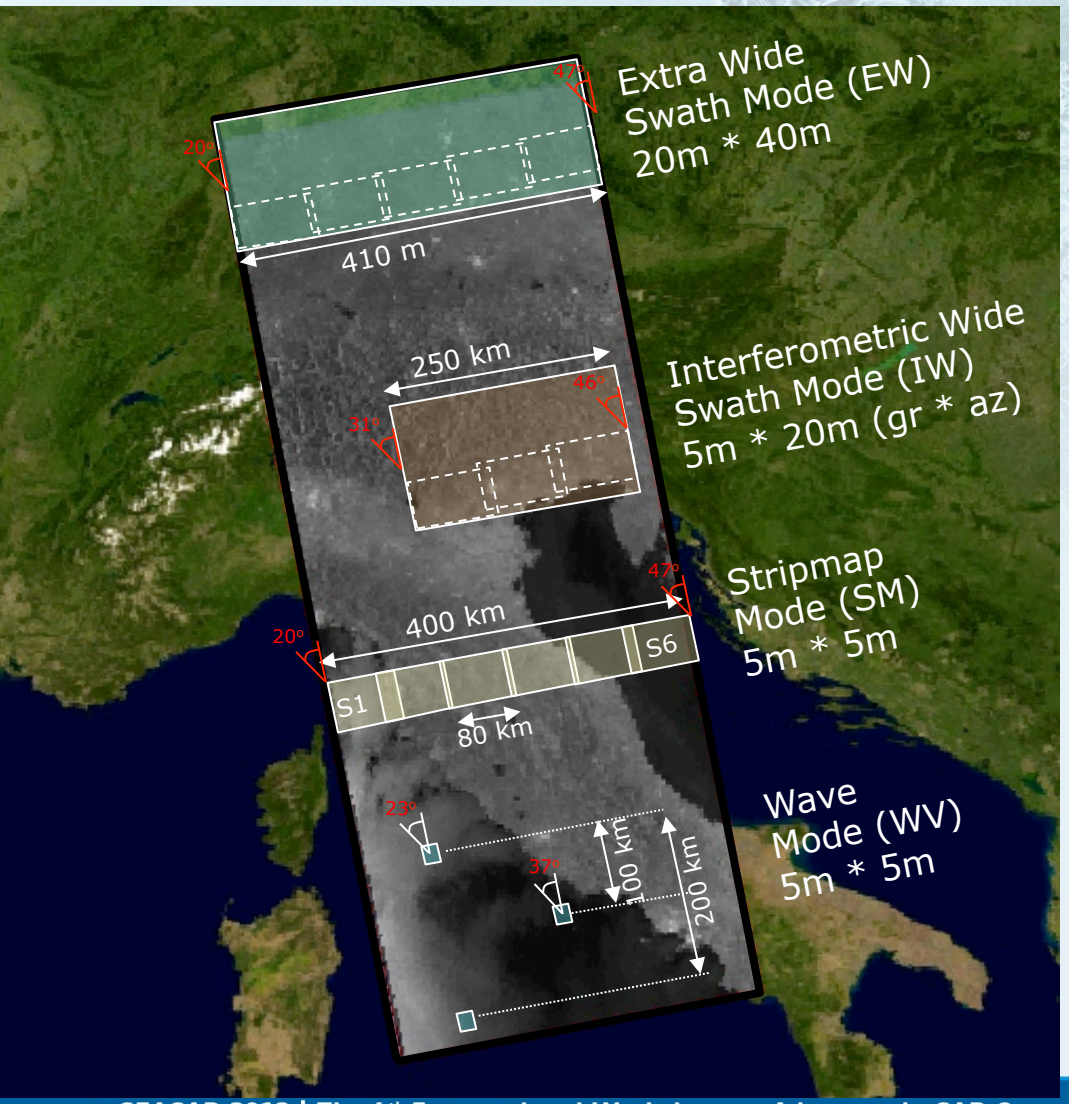


Advantages:

- *Single PRF* round orbit per swath or subswath (except for S5 (S5-N and S5-S)
- Fixed set of *Elevation beam patterns*



Sentinel-1 SAR Imaging Modes



Sentinel-1 SAR to be operated in 4 exclusive imaging modes with different resolution and coverage:

Interferometric Wide Swath (IW), Extrawideswath Mode (EW) and Strip Map (SM):

- single pol: HH or VV
- dual pol: HH+HV or VV+VH

For Wave Mode (WV)

- single pol: HH or VV

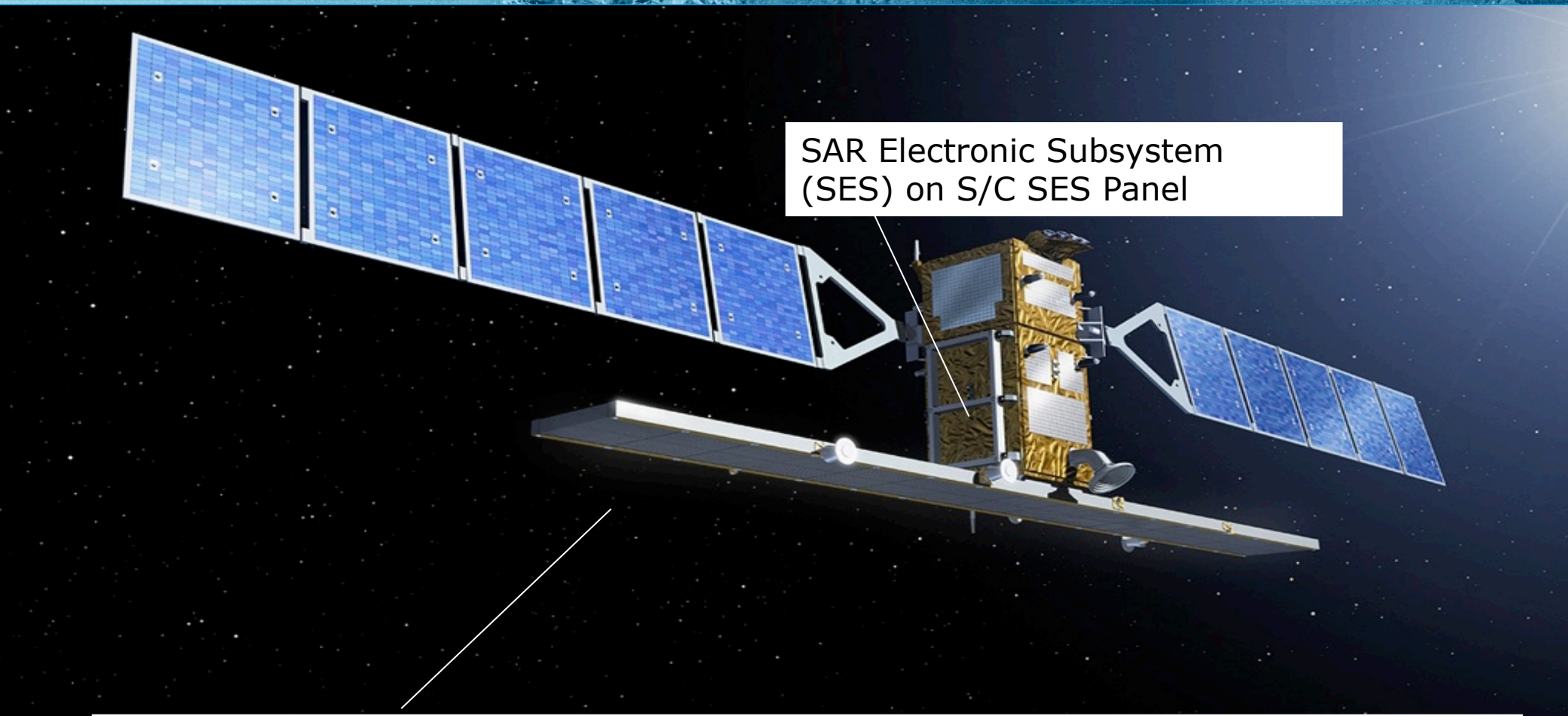
IW and WV main modes of operations

Image Quality Parameters for all Modes (worst case):

Radiometric accuracy:	1.0 dB (3σ)
Radiometric stability:	0.5 dB (3σ)
Sensitivity (NESZ) :	-22 dB
Ambiguities (DTAR) :	-22 dB

CSAR		ASAR / ERS
Orbit: 12 d (06:00 LTDN) 6 day repeat S-1A and S-1B		ASAR: 35 d (10:00 LTDN)
Maximum (continuous) imaging per orbit:	25 minutes	much better than ERS and ASAR
Stripmap Mode (SM)		
Swath:	80 km, 20° – 47°	comparable to ERS and ASAR
Resolution:	5x5 m (Az, GRg, 1L) (87.6 – 42.2 MHz)	better than ASAR capability
Extra-Wide Swath Mode (EW) - TOPS		ASAR - ScanSAR
Swath:	410 km, 20° – 47°	same as ASAR
Resolution:	40x20 (Az, GRg, 1L) (22.2 – 10.4 MHz)	better than ASAR capability
Wave (WV) - Leapfrog		BASELINE OVER THE OCEAN
Swath:	20x20 km at 100 km interval, 23° and 37°	better than ASAR
Resolution:	5x5 m (Az, GRg, 1L) (74.5 and 48.2 MHz)	better than ASAR
Interferometric Wideswath Mode (IW) - TOPS		NEW BASELINE MODE
Swath:	250 km, 31° - 46°	3 times ERS
Resolution:	20x5 m (Az, GRg, 1L) (56.5 – 42.8 MHz)	comparable to ERS
Sensitivity, Ambiguity and Radiometric Performance		comparable to ASAR

No separate AP mode but dual-pol on receive capability in all imaging modes without performance reduction



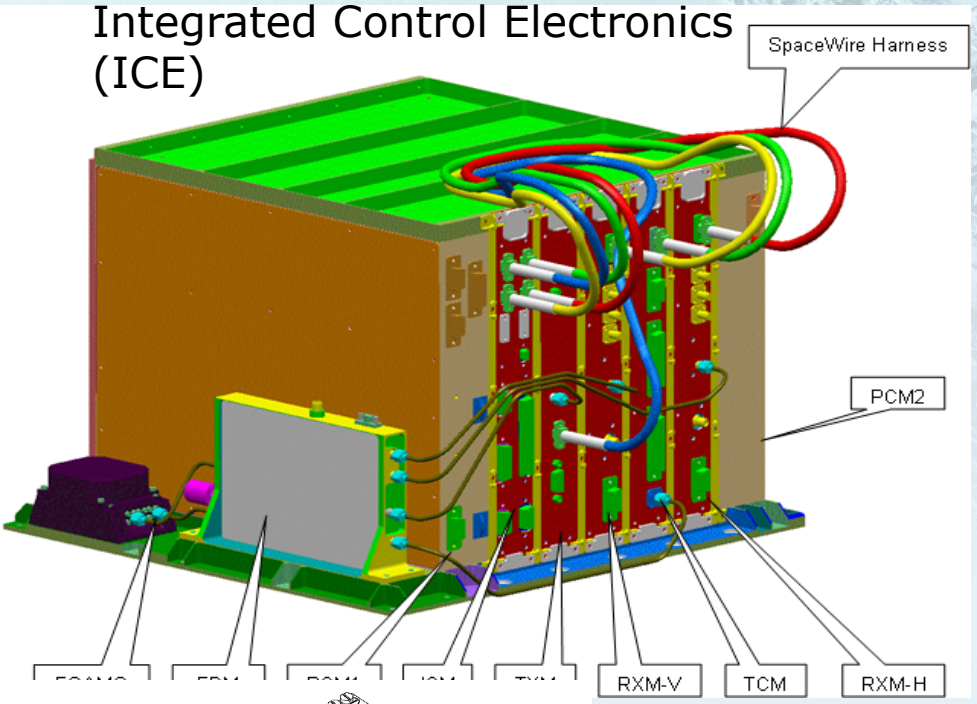
SAR Antenna Subsystem (SAS)
Aperture : 12.3 m x 0.84 m,
14 Tiles each with 20 dual polarized resonant waveguide arrays (5 SAS Panels)

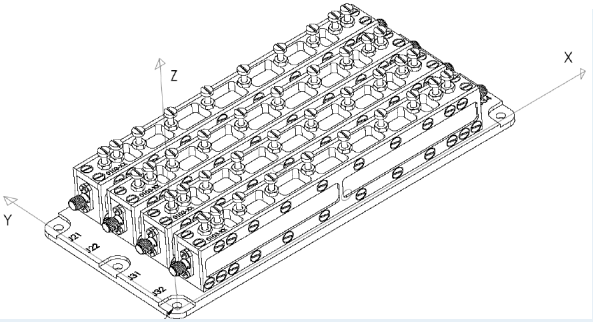
Sentinel-1 – Payload

- SAR Electronics
  - ENVISAT and RadarSAT-2 heritage
  - Real Sampling (digital I and Q demodulation)
  - High-efficient SAR data compression (FDBAQ)
  - Synchronisation of acquisitions with ground track
  - Self-standing data packets (GPS and AOCS)
- SAR Antenna (12.3 x 0.84 m) with 14 tiles in 5 deployable panels
  - Plated CFRP Waveguides (low-loss) - *TerraSAR-X heritage*
  - T-compensated T/R modules - *COSMO-SkyMed heritage*
  - Internal calibration for Radiometry – *ERS/ENVISAT heritage*

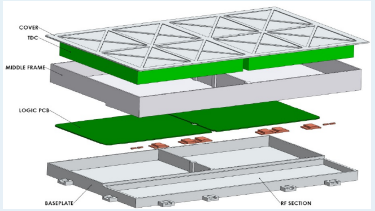
Sentinel-1 Electronics Subsystem

Integrated Control Electronics (ICE)





MDFE



TGU

TxM:
-Direct Digital Synthesis (up to 100 MHz chirp).

TGU:
- Redundant Tx Gain Unit cross strapped for SAS.

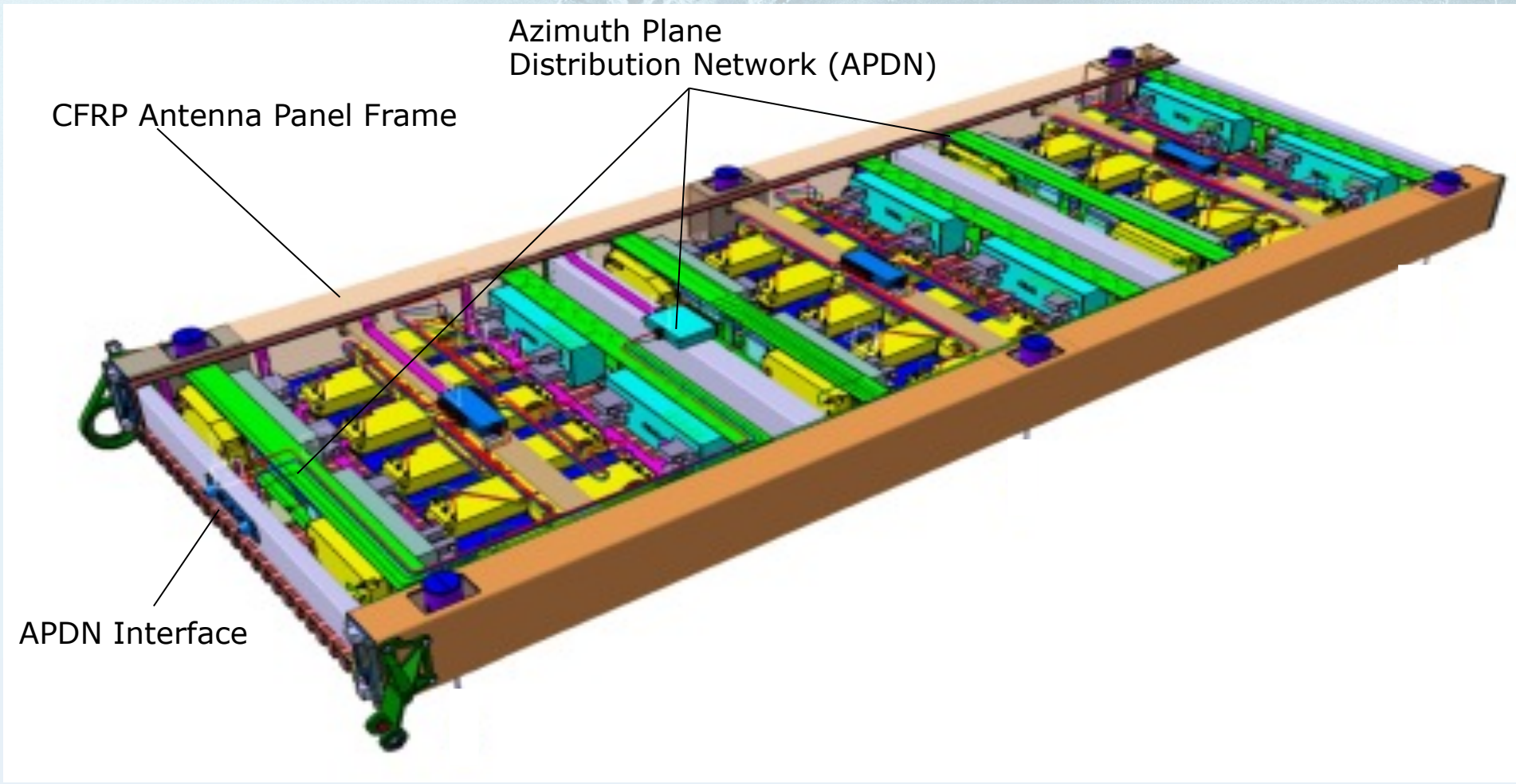
RxM:
- Two channels (H and V)
- Real sampling
- AD Converter (300Ms/s, 10 bits)
- Digital filtering (demodulation, down-conversion and decimation).
- FDBAQ SAR raw data compression

MDFE (Tx and Rx):
- Passive RF filters to control out-of-band transmission and limit interference.

ICM/TCM:
- Instrument and Timing Control of the radar

FDM/FOAMO:
- Frequency Distribution Module and STALO

SAR Antenna Wing Panel (Panel A)



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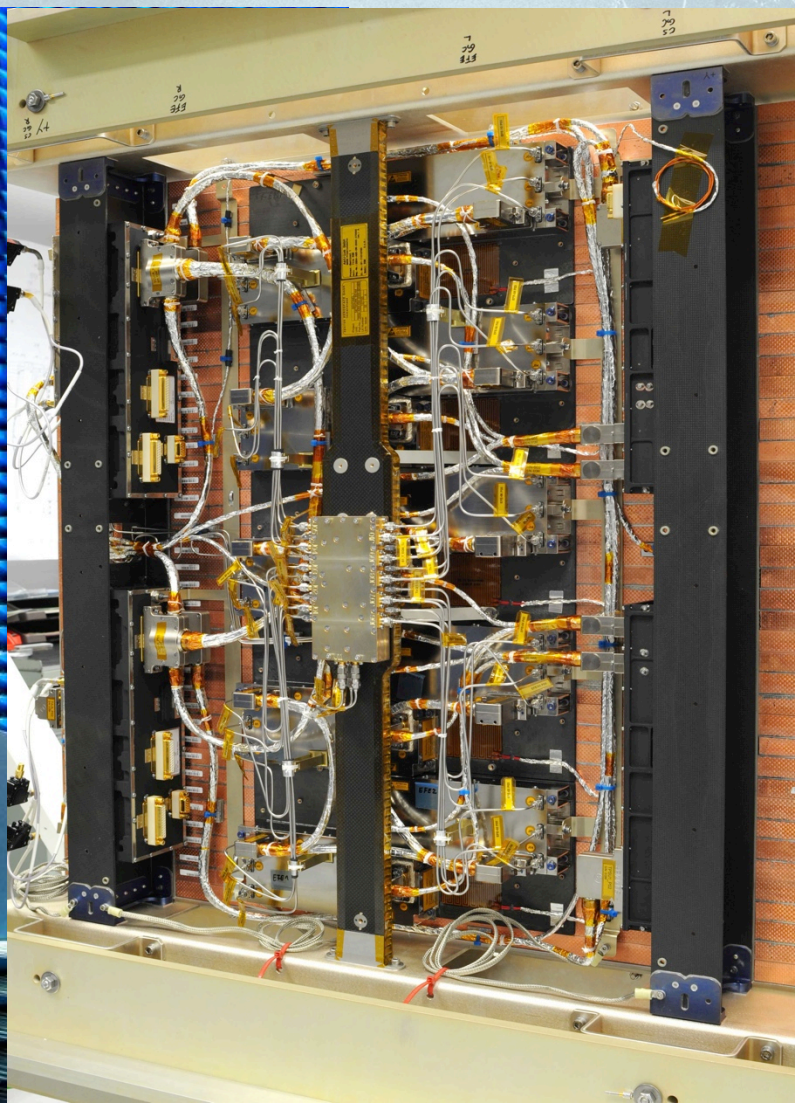
SAR Tile



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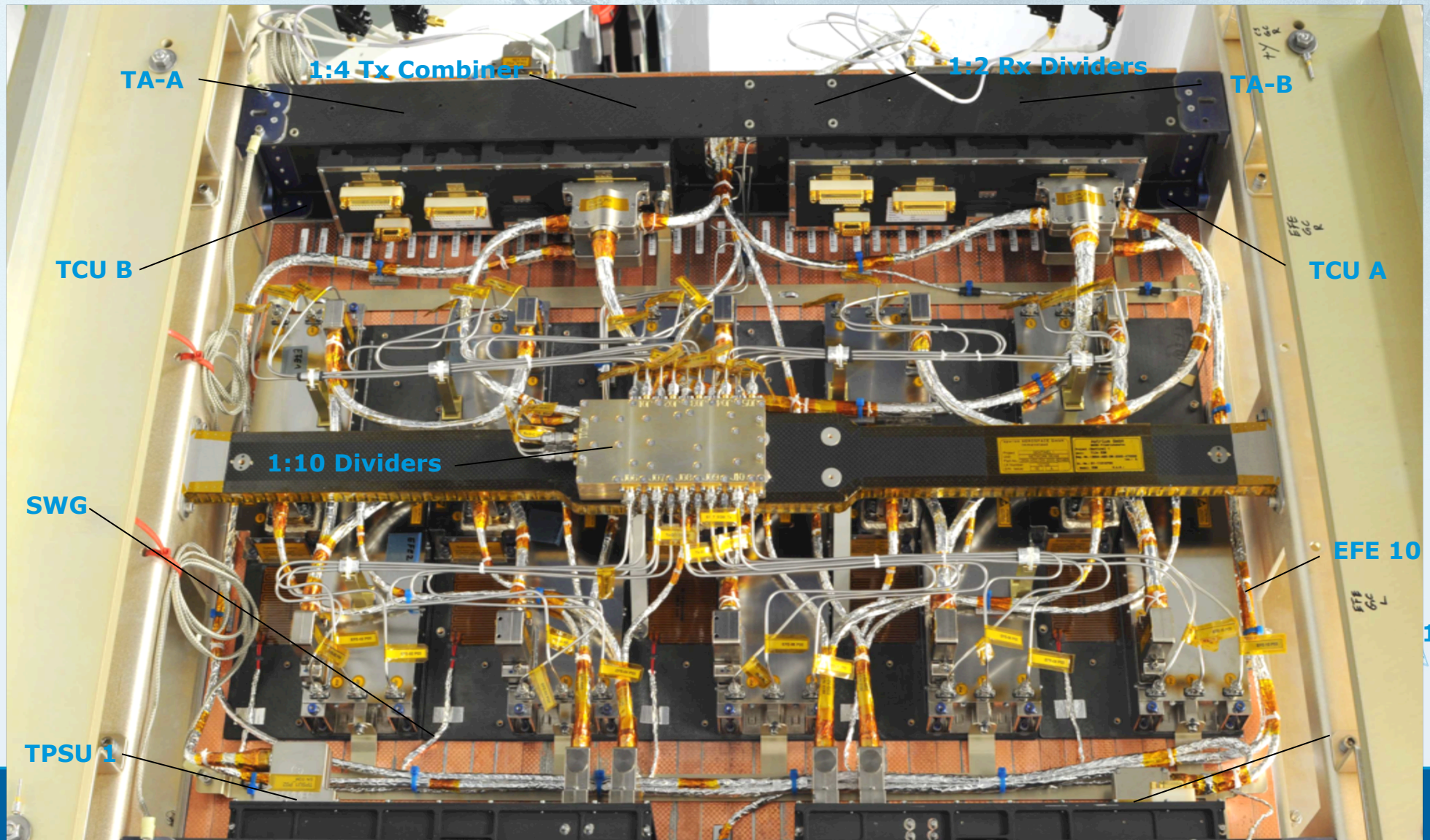
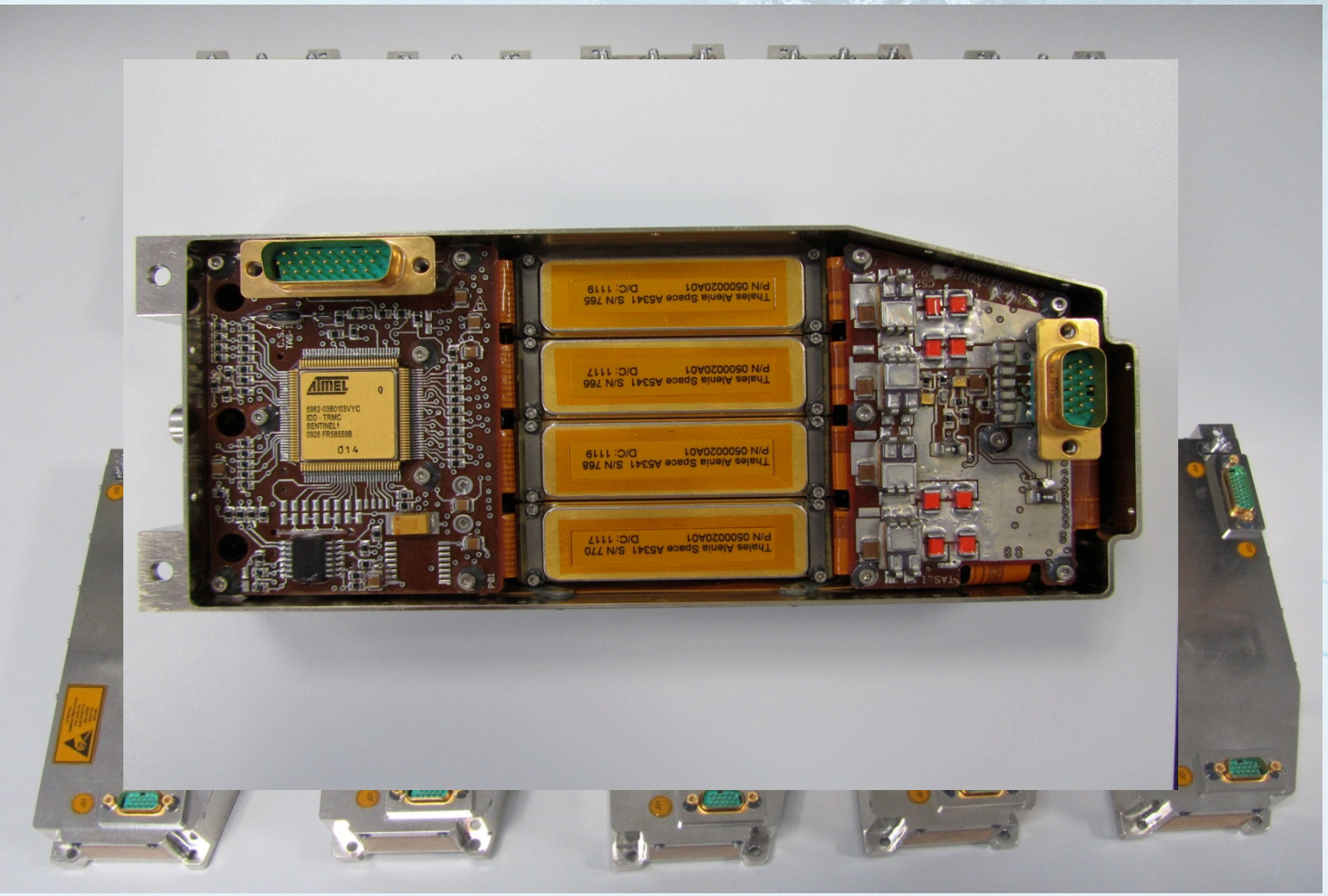
SAR Tile - Back



SAR Electronic Front-End - EFE

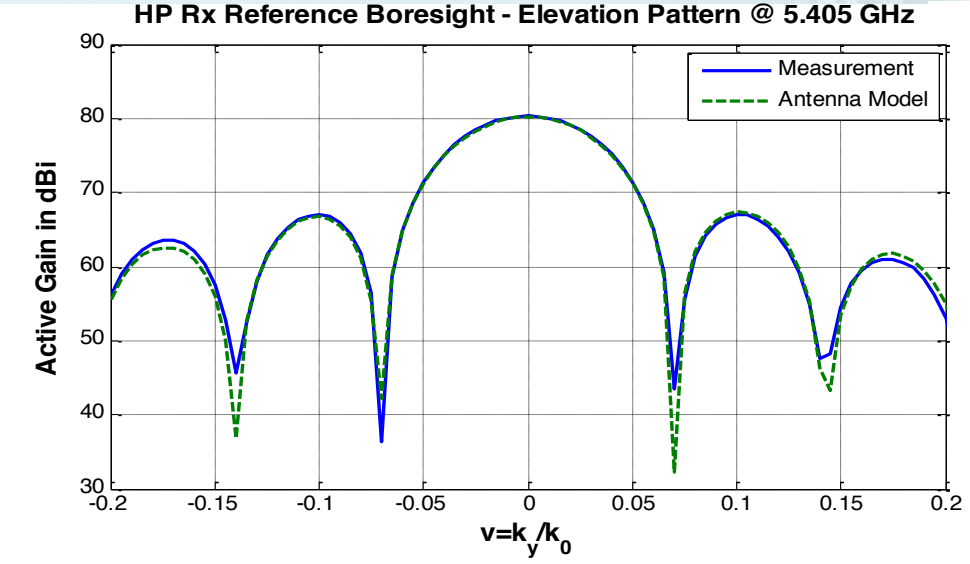


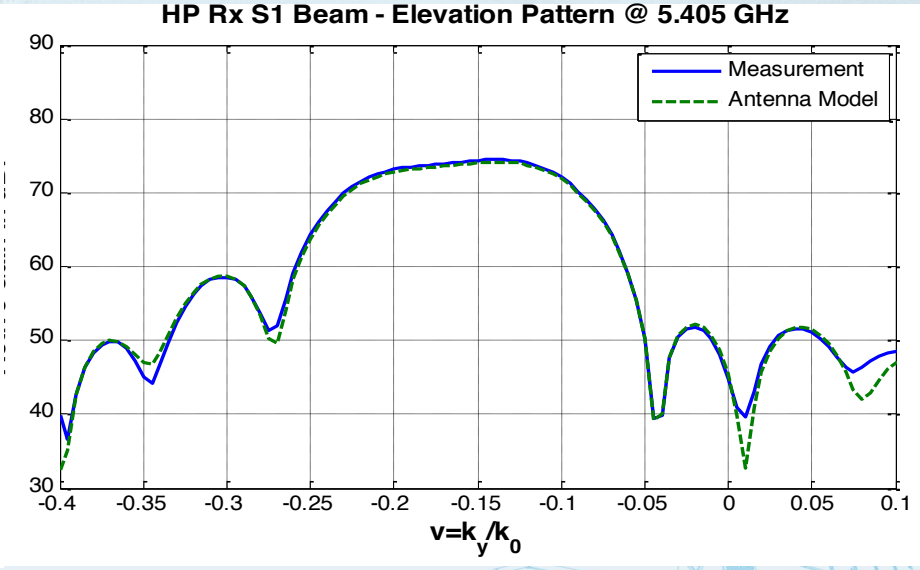
EFE features:

- In total 140 EFE
- 2 H and 2 V T/R modules
- 42 dBm (15.8 W) RF Power
- 11 dBm RF Input Power
- 3.2 dB Noise Figure
- 0.5 dB Gain (6bits)
- 5.6° Phase (6bits)
- Active/complex temperature compensation (TCU)
- Built-in calibration paths

Sentinel-1 Antenna Model

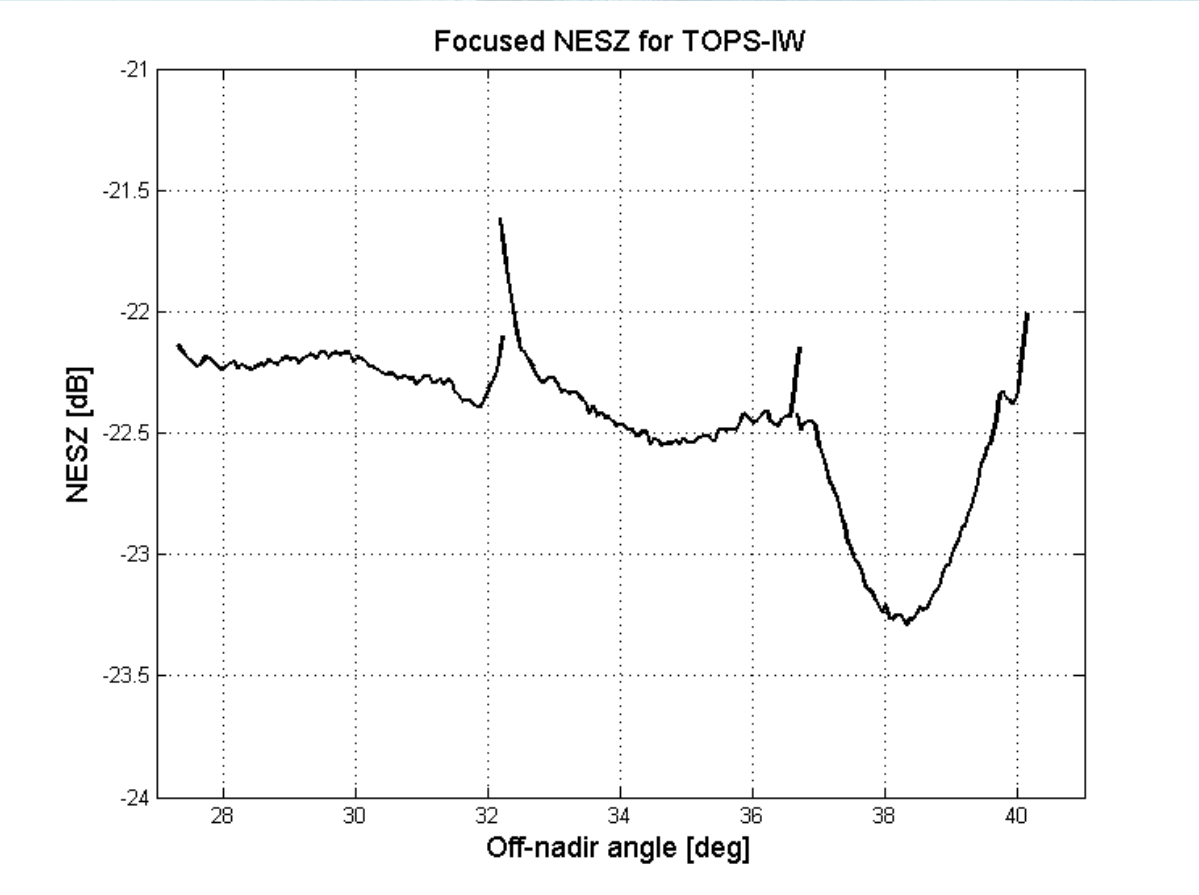
- Calculates Radiation Patterns based on Near-Field Measurements of single Sub-arrays
- RF Characterization
- Accurate Prediction of Radiation Patterns required for external Calibration (Commissioning Phase): 0.1dB two-way@ 3σ and 0.2dB absolute gain two-way@ 3σ.
- Mutual Coupling Effects are rigorously taken into account



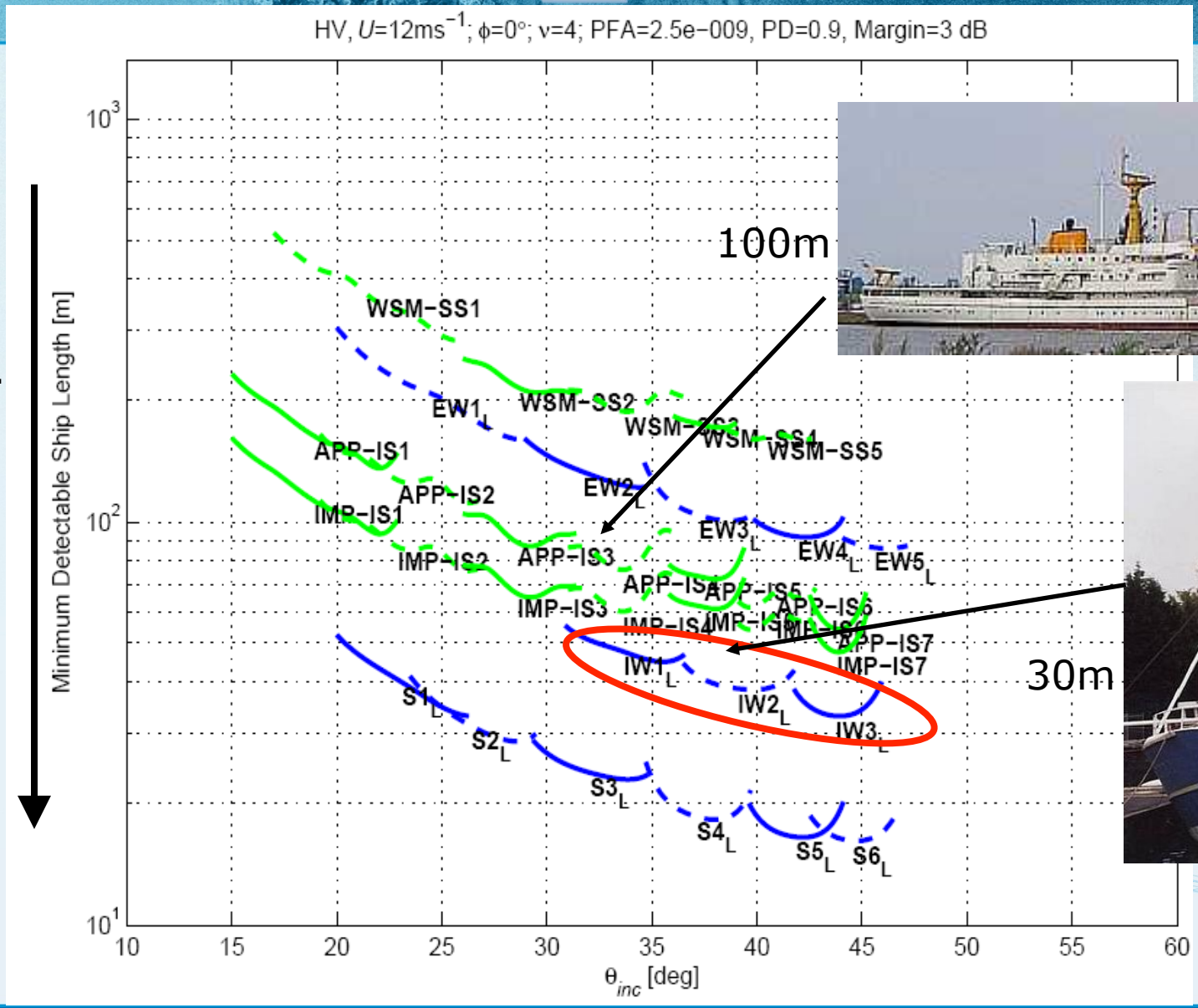


→ Preliminary Results of the Antenna Model agree well with Direct Pattern Measurements.

SAR Instrument Performance IW mode (Thermal and Quantisation Noise)



Smaller ships

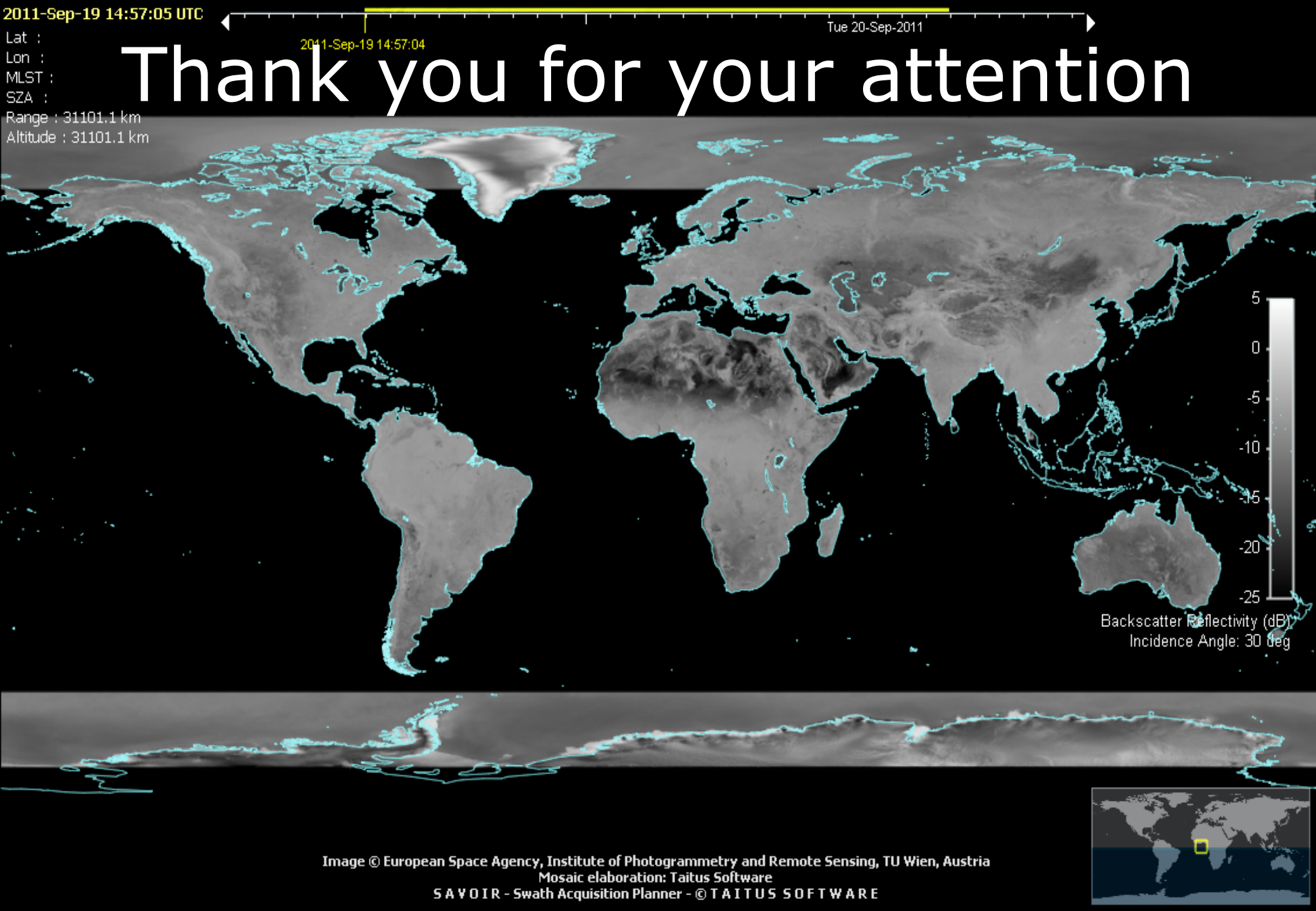


Summary

- Operational mission
- Maintains data quality of ESA's SAR ERS-1/-2, ENVISAT ASAR missions
- Substantial improvements
  - –Revisit frequency
  - –Coverage
  - –Timeliness and reliability of service
- C-Band SAR Instrument (5.405 GHz)

  - SAR Electronic Subsystem (SES)
  - SAR Antenna Subsystem (SES)

- C-Band Active Phased Array Antenna
- 12.3 m x 0.84 m Electrical Aperture
- 20 Rows (el.) and 14 Columns (az.)
- 4368 W RF Transmit Power
- 100 MHz Bandwidth
- Dual Polarisation Capability (HH-HV, VV-VH)
- High Sensitivity (NESZ<-22 dB)
- Low Ambiguity Levels (DTAR <-22 dB)
- Up to 410 km swath width
- Up to 5 m x 5 m resolution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Backscatter Reflectivity (dB)
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