Advanced Radiometer for Sea Surface Temperature Observations

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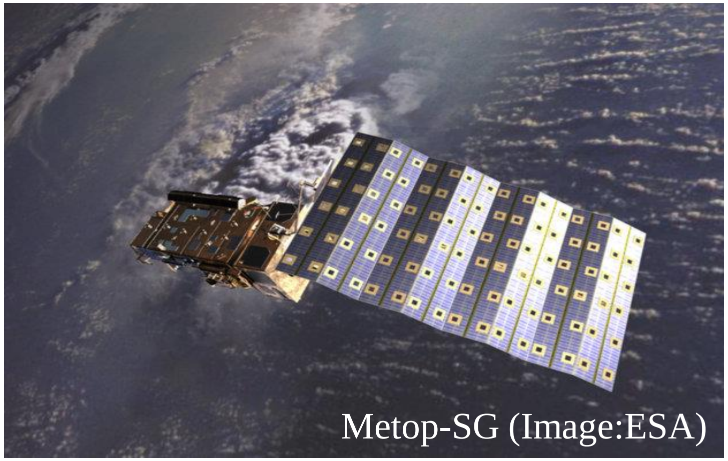
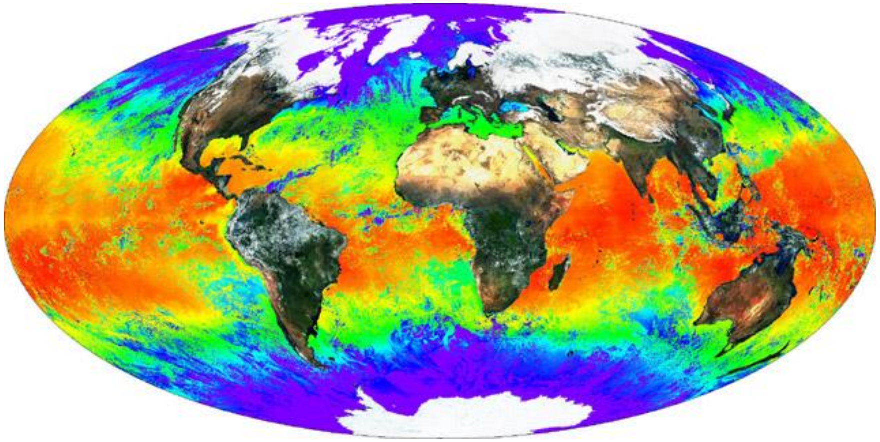
Finnish Remote Sensing Days 2014
Finnish Meteorological Institute, Helsinki, Finland
30.10.2014

Project rationale

- **Sea surface temperature (SST)**
  Ocean Vector Wind (OVW)
- SST is operatively measured with IR (clouds!), MW can be used, too.
- Additional access to OVW (currently measured with active instruments)
- No European low-MW mission (SMMR, SSM/I ,AMSR, WindSat, SMAP). Poor European heritage in MW radiometers (ERS + SMOS).

→ Low MW missions to complement METOP-SG in 2020-2040 timeframe.


Metop-SG (Image:ESA)


SST by MODIS (Image: NASA)

Study for Advanced SST Radiometer

- **Objective**: Propose a radiometer concept and preliminary design that meets the SST/OVW mission requirements

- **Consortium**: Harp Technologies (Finland)
  Terma A/S (Denmark)

- **Schedule**: 11/2013 → 1/2015

Study for Advanced SST Radiometer

- **TASK 1:** System Requirements Review
  Instrument concept definition
  Done!

- **TASK 2:** Preliminary design of instrument concepts
  Concept trade-off and selection of the candidate

- **TASK 3:** Preliminary design of the baseline concept
  Instrument and technology roadmap
  On-going

Identified Design Drivers

ID	System Parameter	Requirement	
22	Vega launcher		→ Parabolic antenna size of **~5m**? (6.9 GHz) → Foldable antenna? → Alternative measurement geometries?
7	Channels [GHz, pol]	6.9 H,V (10.6 H,V,3rd,4th) 18.7 H,V,3rd,4th	
20	Ground resolution for 6.9/10.65/18.7 GHz	20/20/10 km	
9	NEDT [K] for 6.9/10.65/18.7 GHz	0.30/0.22/0.25 K	→ Max. integration time → Multiple pixels simultaneously? → Enhanced cal. opportunities
10	Accuracy	0.25 [K]	
8	Bandwidths for 6.9/10.65/18.7 GHz	300/100/200 MHz	→ Receiver architecture → FPGA based DSP
12	RFI resistence	State-of-the-art	
13	Coastal regions [km] for 6.9/18.7 GHz	15/5	→ AP requirements → Side-lobe correction methods

Vega

- ESAs affordable intermediate capacity launcher.
- Dimensions of the payload module determine the S/C envelope. Radius 2.2 m, full height 5.5 m. Full radius height 3.1 m.
- Max. mass 1350 kg to the MetOp orbit.

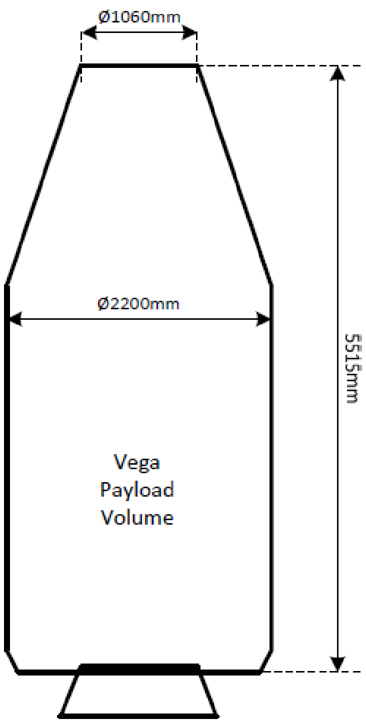


Image: ESA

Applicable microwave radiometer concepts

- Conical scanner
- 1D interferometer
- (Pushbroom)

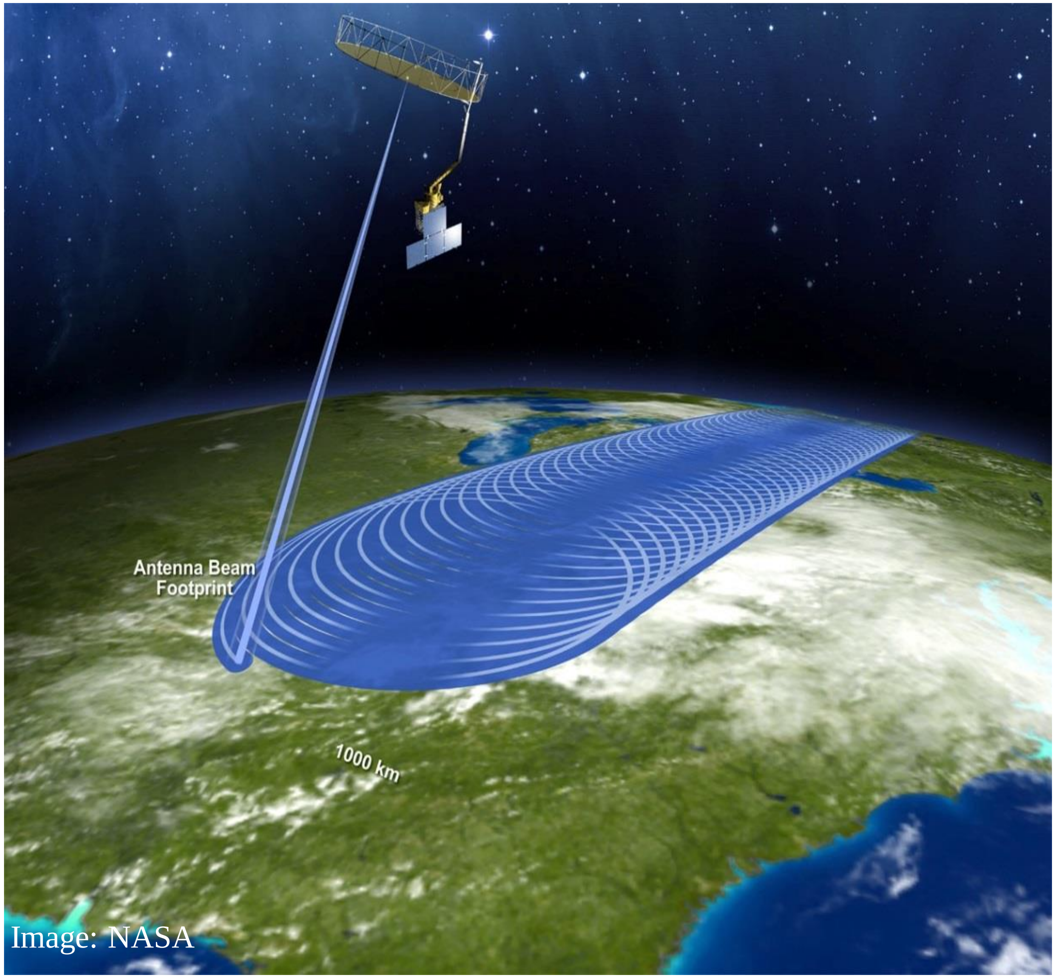
Along-track scanning

Profiling radiometer

2D interferometer

Conical scanning concept

- 1978→ SMMR, SSM/I, TMI, AMSR, SSMIS
- WindSat
- Newest generation: GMI, SMAP
- First European conical scanner: MWI onboard MetOp-SG in 2018?



Conical scanning SST/OVW radiometer

- Reflector: 4.6 x 4.9 m
- Focus lenth: 3.8 m
- Three frequencies
- Multiple feedhorns (2/4/8)
- 11.33 rpm
- Forward+after scan
- Ground res 20/20/10 km

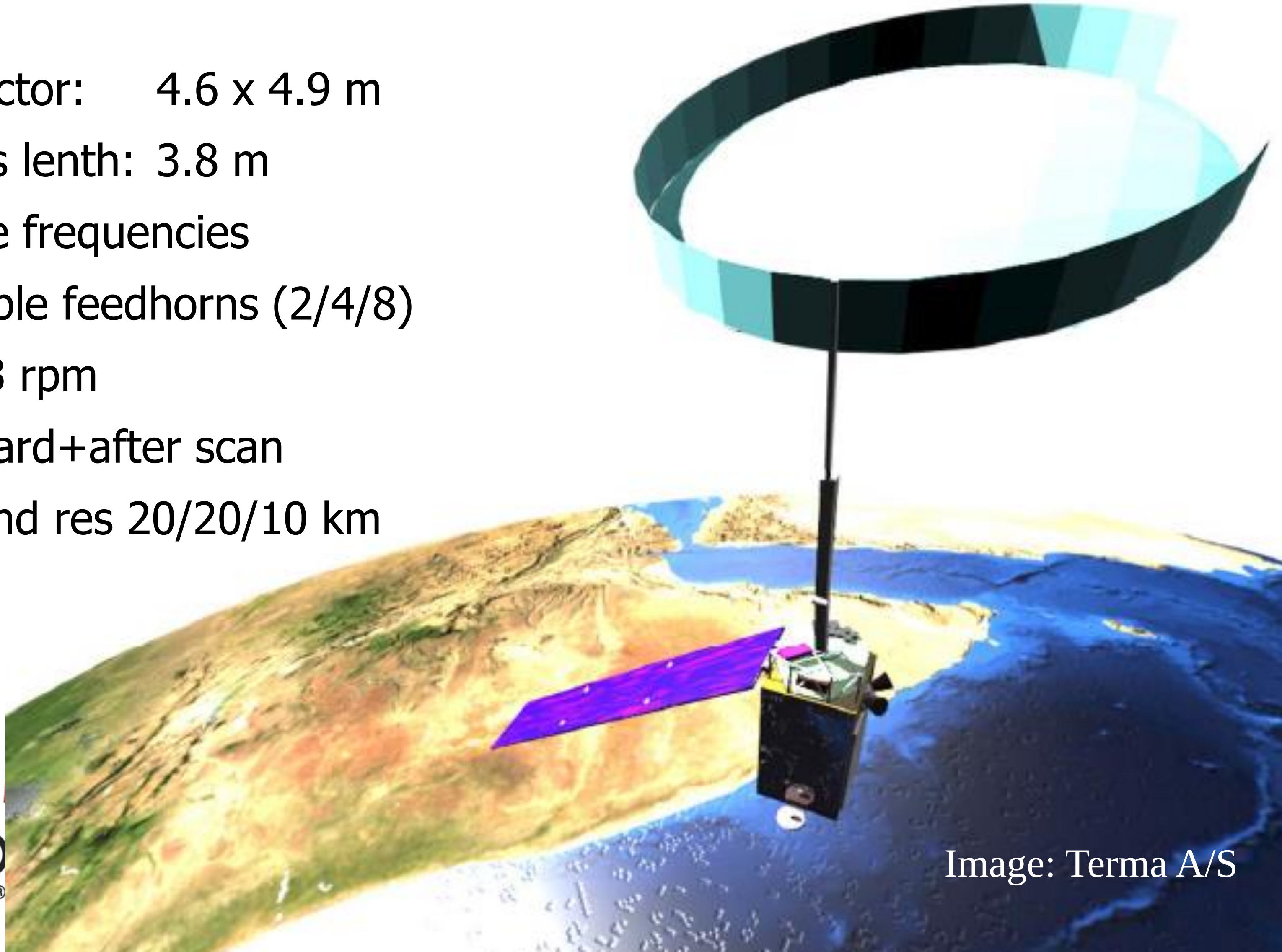
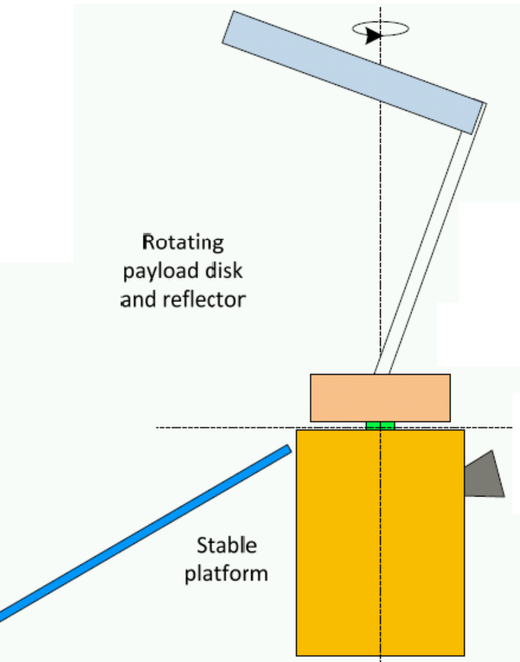
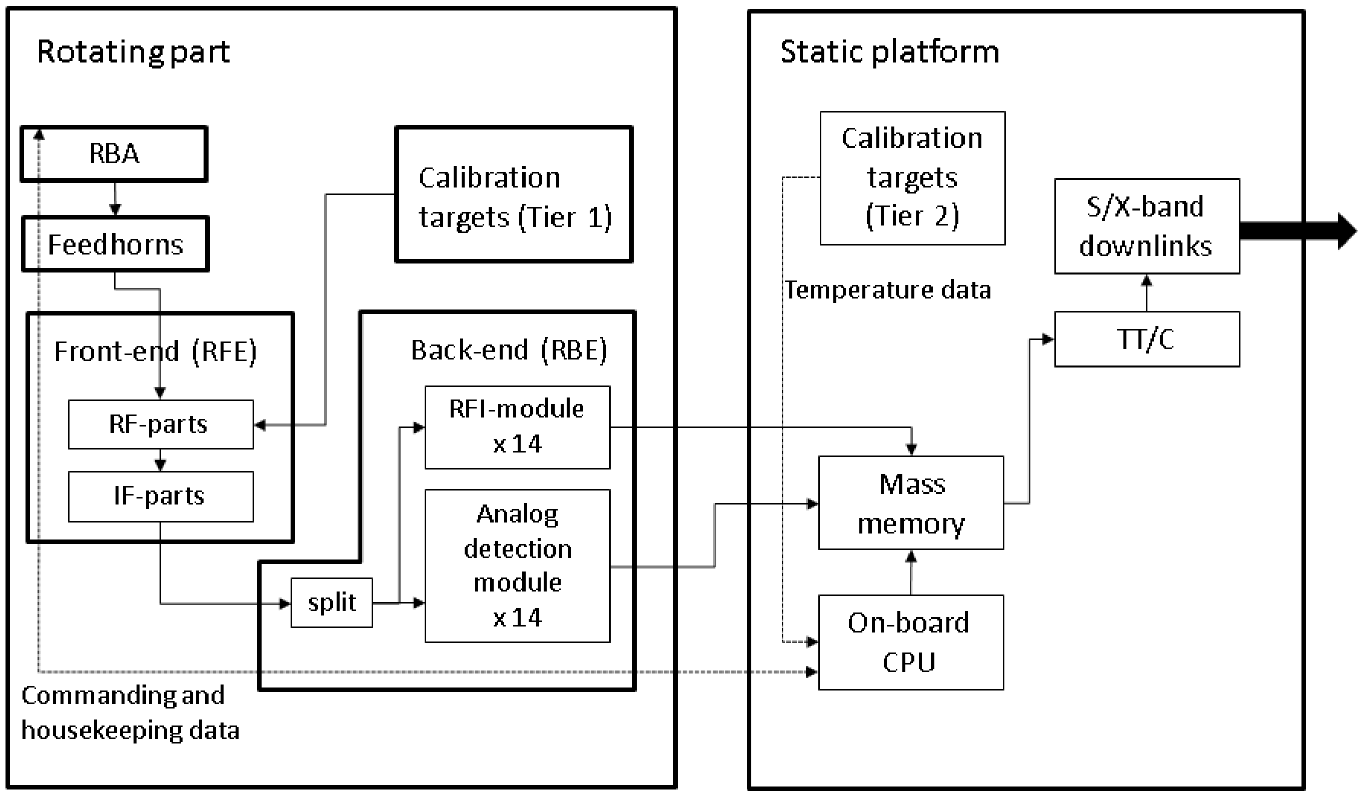


Image: Terma A/S

Scanner architecture and subsystems

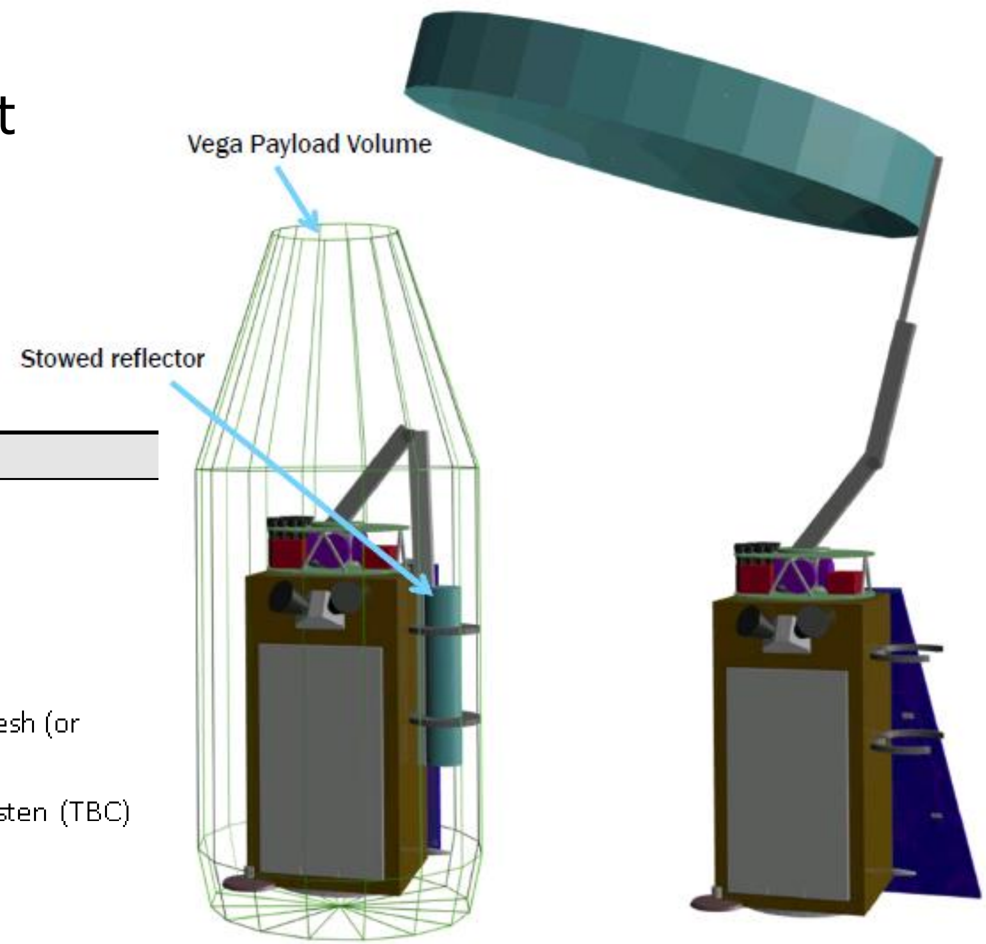




Scanner key aspects Reflector-Boom Assembly

- Highly-stowability
- Boom and reflector deployment
- Dense (40+ opi) knitted metal mesh

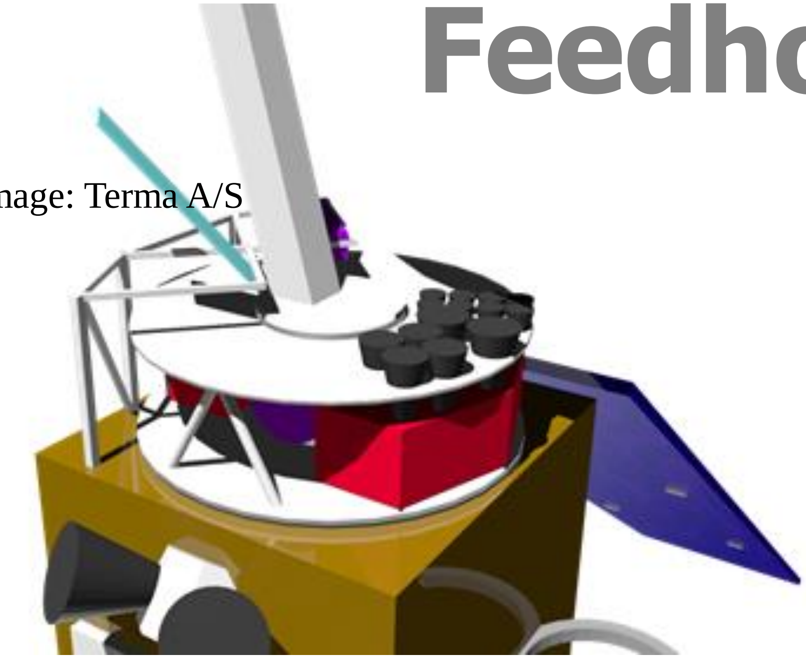
Parameter	*Value*
Reflector dimensions (unfolded)	4.9 m x 4.6 m
Reflector dimensions (stowed)	1.45 m x 0.30 m
Focal length	3.68 m
F/D ratio	0.8
Clearing	~0.7 m
Surface type	Knitted Metal Mesh (or possibly, CFRS)
Surface material	Gold plated tungsten (TBC)
Illuminated D (6.9/10.65/18.7 GHz)	4.6/2.14/2.13
Openings per Inch	40 opi
Mass (Reflector/boom)	85 kg
Ohmic losses	0.04 dB at 18.7 GHz
Temperature uncertainty (required)	8 K (1σ)

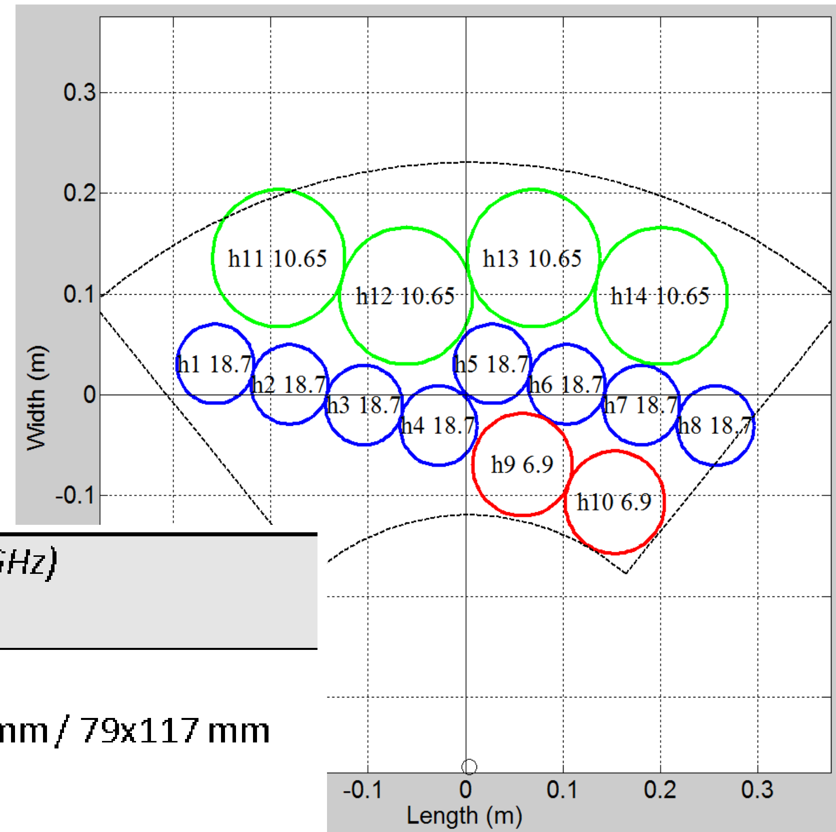


Images: Terma A/S

Scanner key aspects Feedhorn cluster

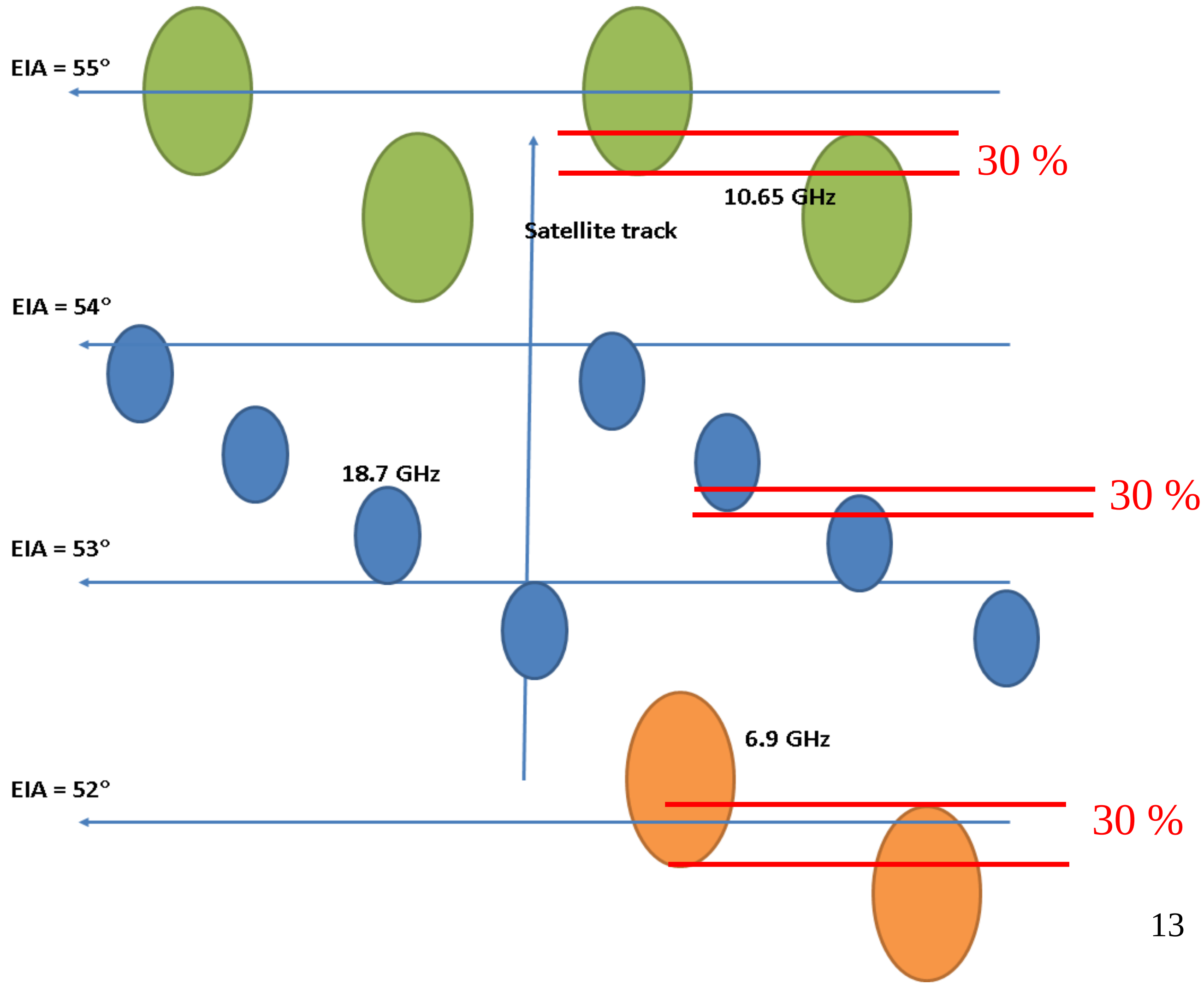
Image: Terma A/S





Parameter	***Value** (6.9/10.65/18.7 GHz)*
Number of horns per frequency	2/4/8
Horn dimensions (dia. x length*)	102x86 mm / 136x205 mm / 79x117 mm
Mass (including OMTs)	3.4 kg
Horn type	Conical, smooth walled
3 dB HPBW	0.7° / 0.7° / 0.35°

Scanner key aspects
Footprints



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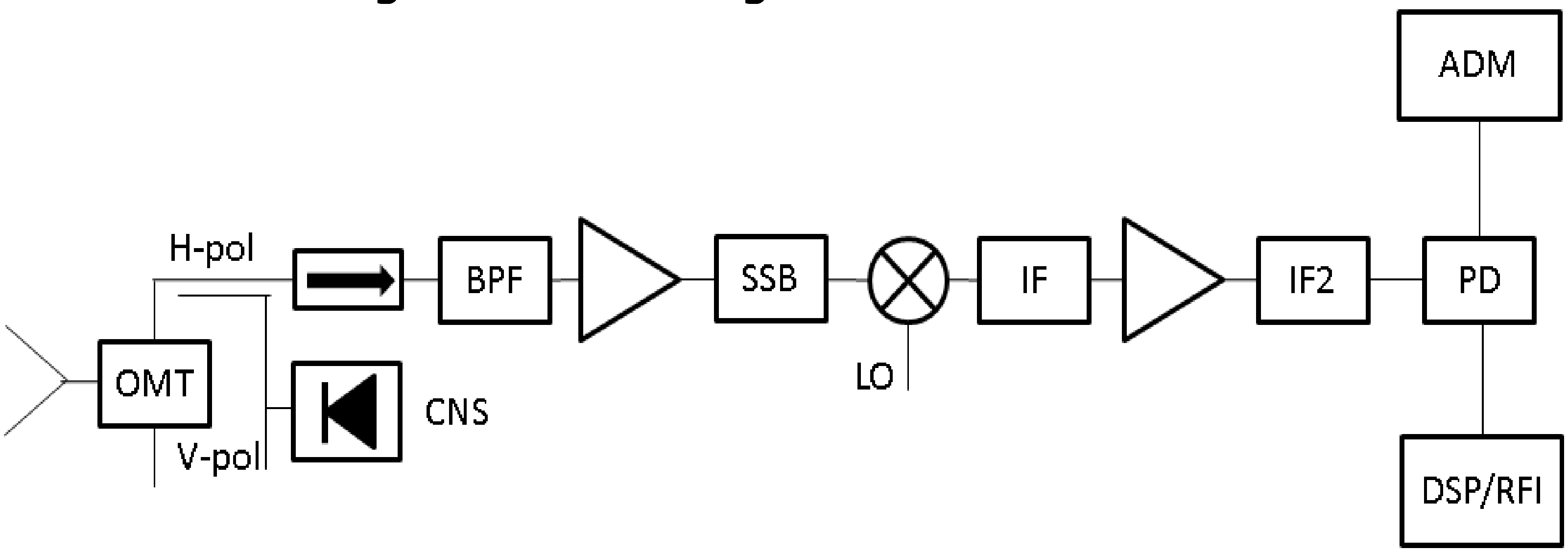
Scanner key aspects Receiver architecture

- Super-heterodyne architecture in order to implement ADC (currently available to < 2 Ghz).
- ADC followed by FPGA-based DSP for efficient RFI mitigation
- Noise adding-front end design for calibration

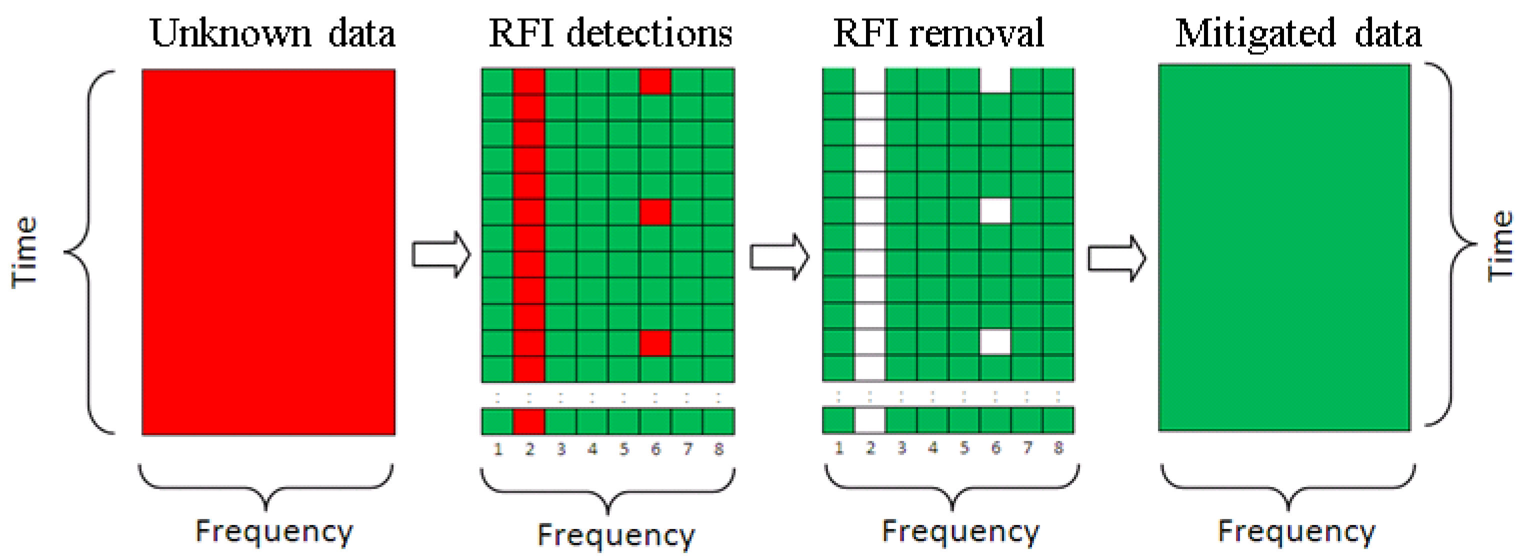


Scanner key aspects DSP/RFI module

- Developed at Harp with DTU Space in ESAs Tech. Dev. P. for MWI.
- Functions needed for SST/OVW RM implemented.
- Breadboard design:
  - BW 200 MHz
  - 10 sub-bands
  - VIRTEX-4 FPGA for RFI mitigation
  - Design already updated for VIRTEX-5 baseline (most powerful space-q FPGA)
  - Can be further modified to match SST/OVW requirements

Scanner key aspects
Advanced RFI methods

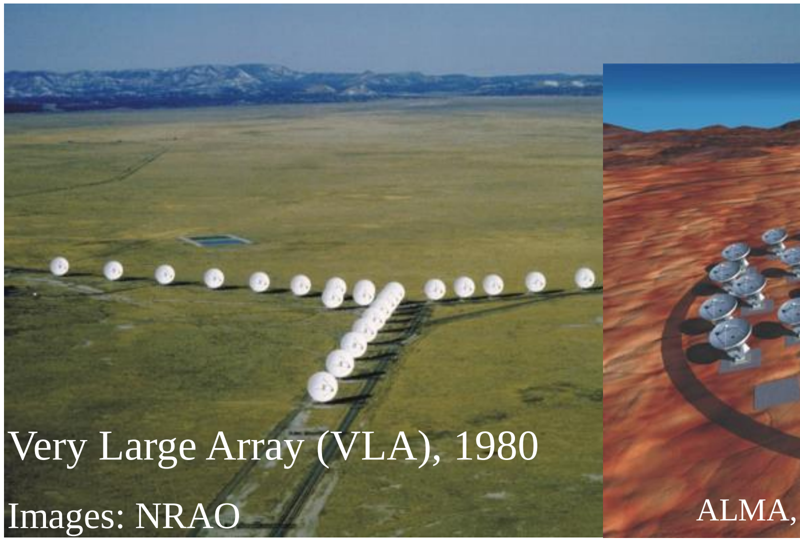
- For each sub-band, independently:
  - Anomalous amplitude (”glitch”) detection (Aquarius)
  - Sub-band-specific kurtosis (SMAP+MWI)
  - New algorithm: spectral kurtosis?
  - Polarimetric method for fully polarimetric frequencies



Scanner key aspects Performance

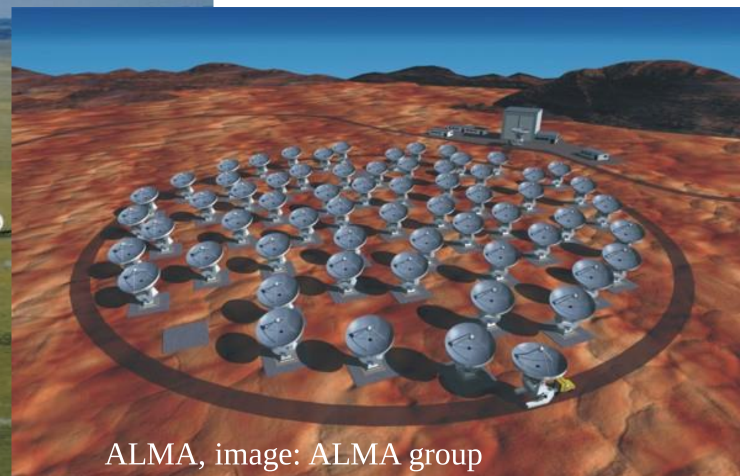
- Frequent and robust calibration by means of consolidated external load technology (absorption load and cold sky mirror). However, reflector is excluded.
- Large foldable reflector at Ku-band.
  - → Undemonstrated surface finess requirement
  - → Undemonstrated loss requirement
  - → Thermal uncertainty yields significant emission uncertainty
  - → Difficulty of Antenna pattern characterization in 1-G.
  - → No high TRL European development
- Enhanced antenna side-lobe correction required

Interferometric radiometer concept

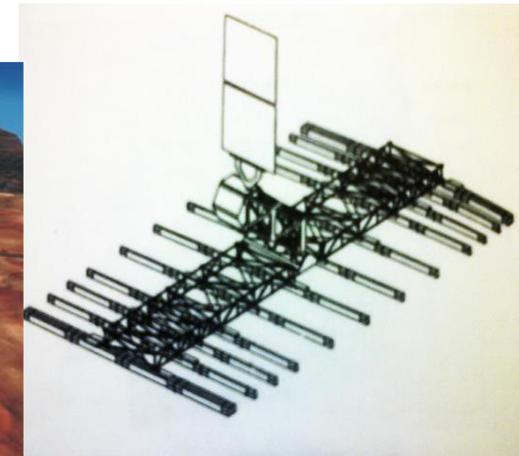


Very Large Array (VLA), 1980

Images: NRAO



ALMA, image: ALMA group



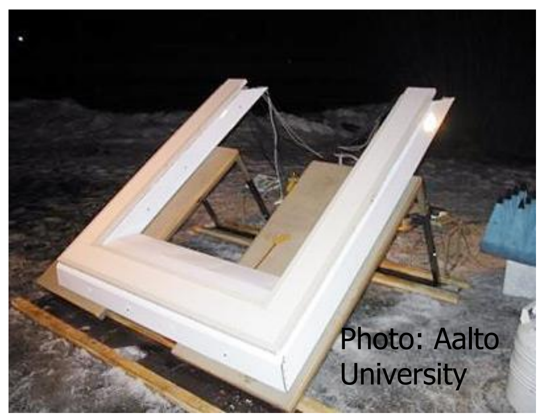


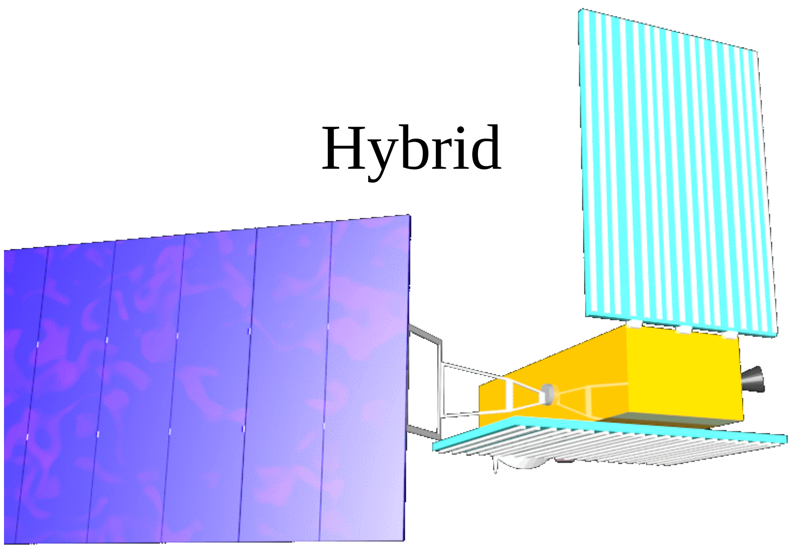
Photo: Aalto University

Image: ESA

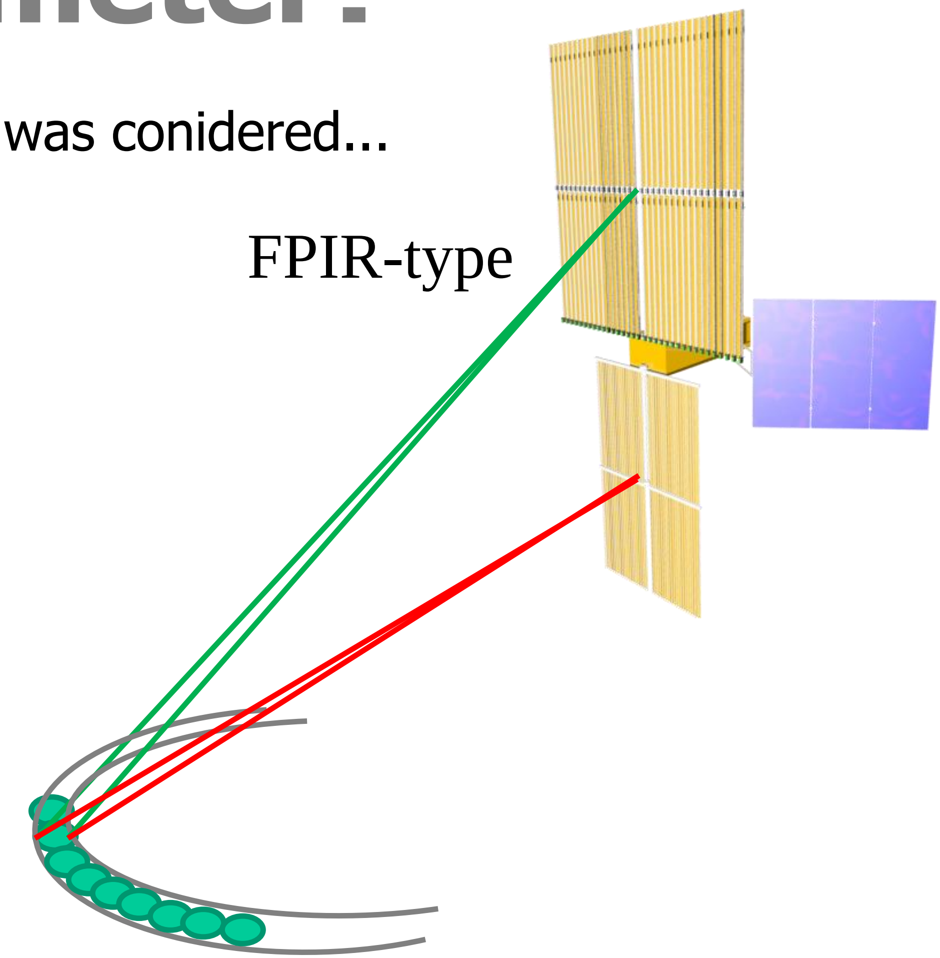
Interferometric SST/OVW radiometer?

- First, different configurations was conidered...

Hybrid



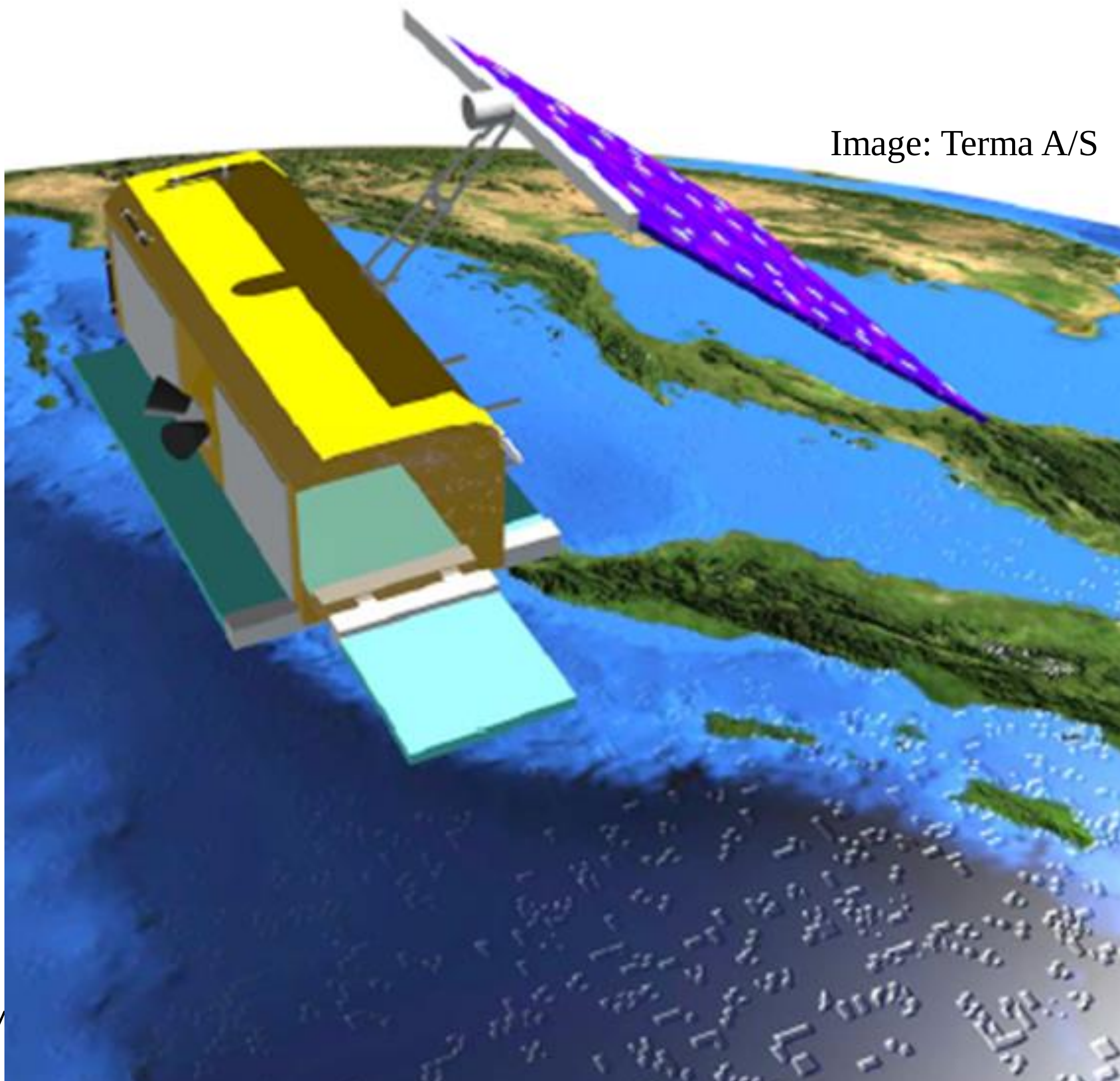
FPIR-type



Images: Terma A/S

Interferometric SST/OVW radiometer

- 1-dimensional waveguide arrays pointing nadir.
- 6.9 GHz: 3.2 x 2.1 m array
  18.7 GHz: 1.0 x 1.0 m array
- H- and V-pol arrays interleaved
- 23 / 46 antennas per polarization
- Ground res 20/15 km



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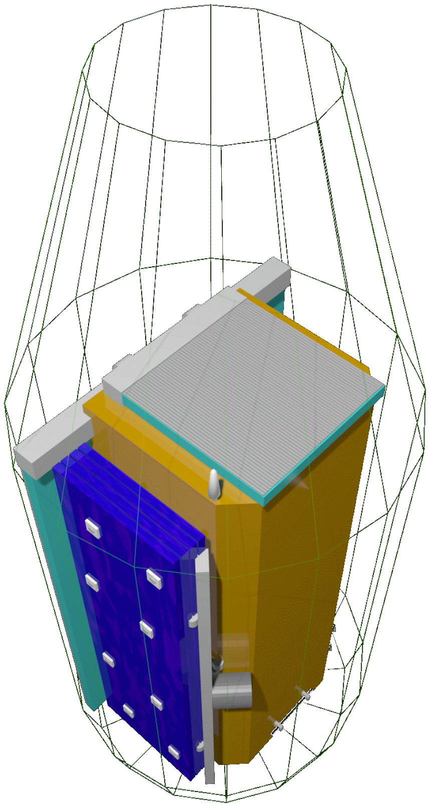
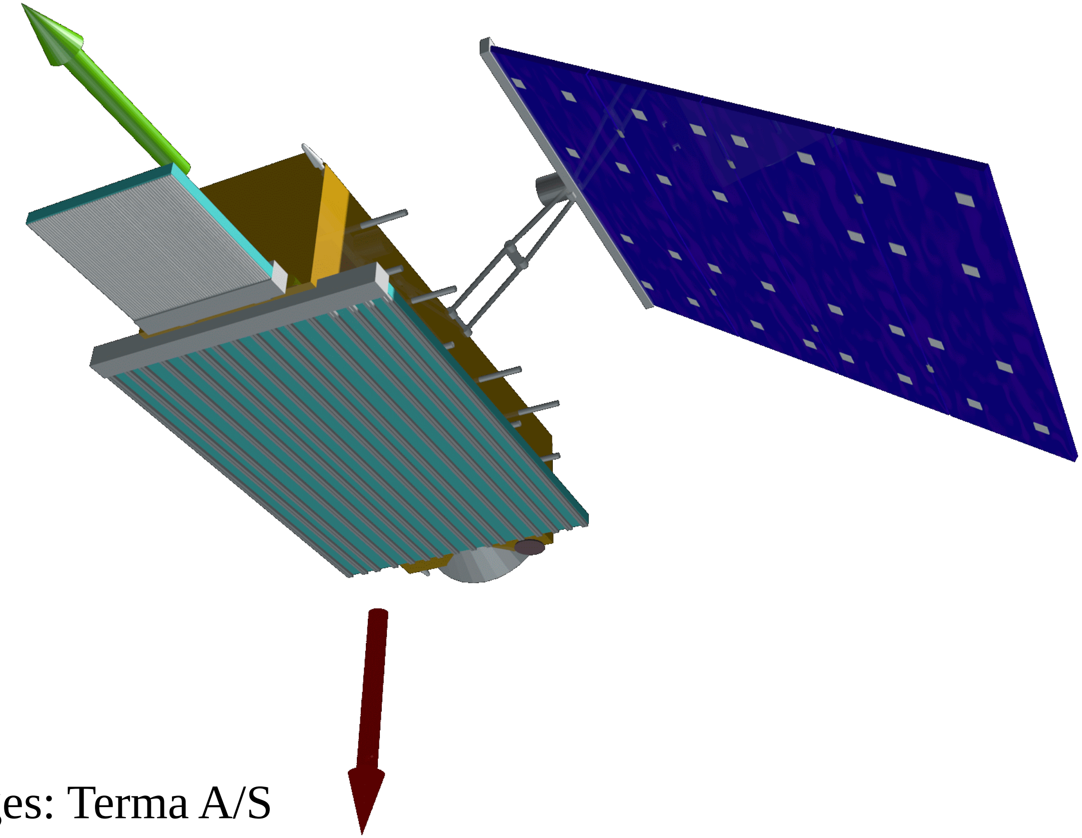
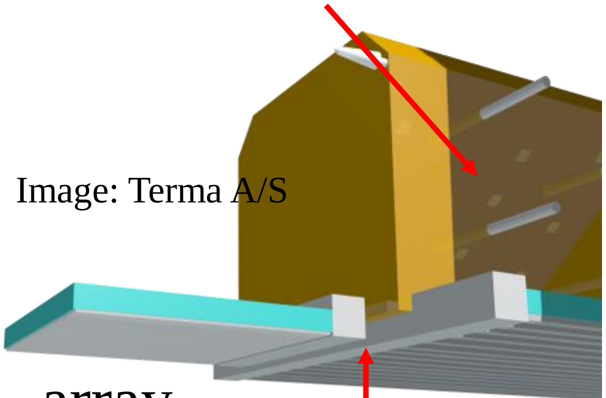
Interferometric SST/OVW radiometer

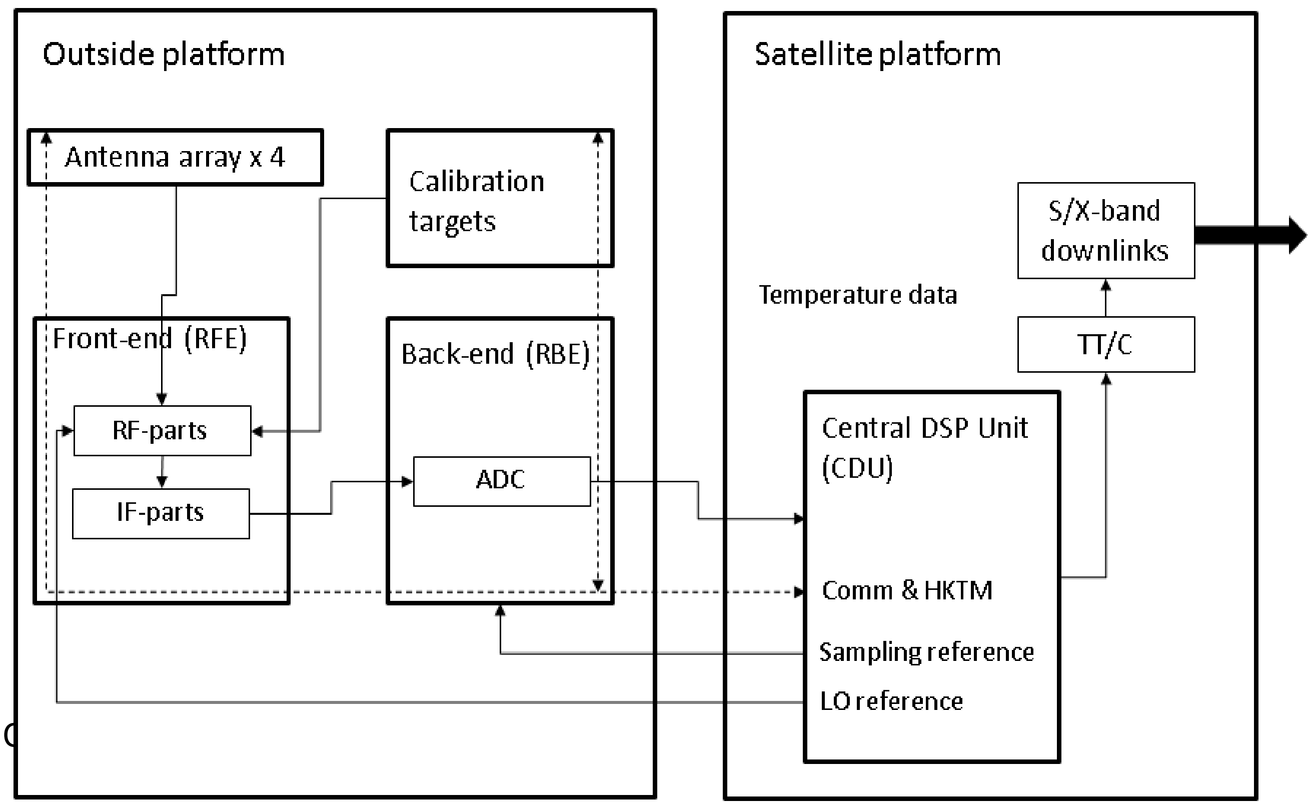




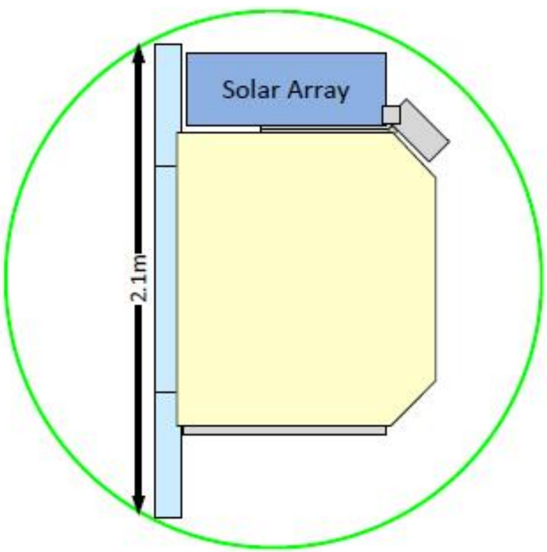
Images: Terma A/S

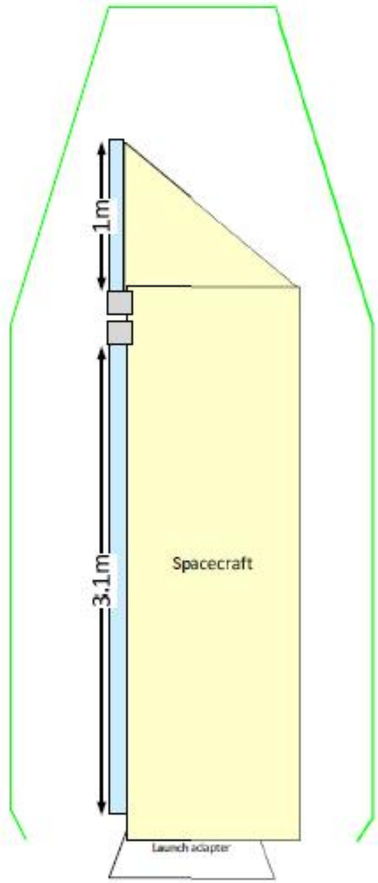
Interferometer architecture and subsystems

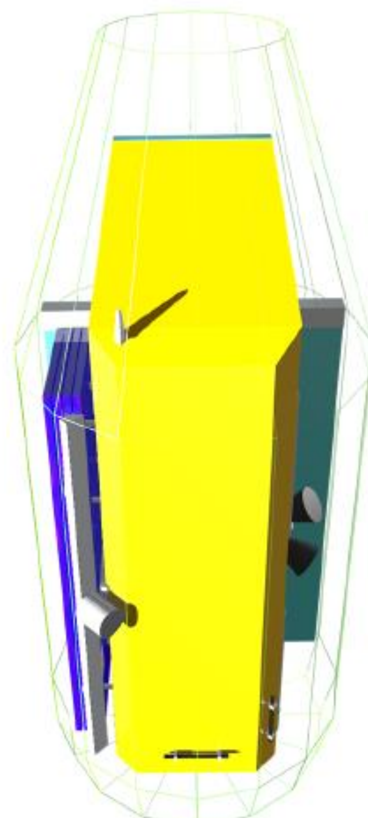




Interferometer key aspects Mechanical accommodation

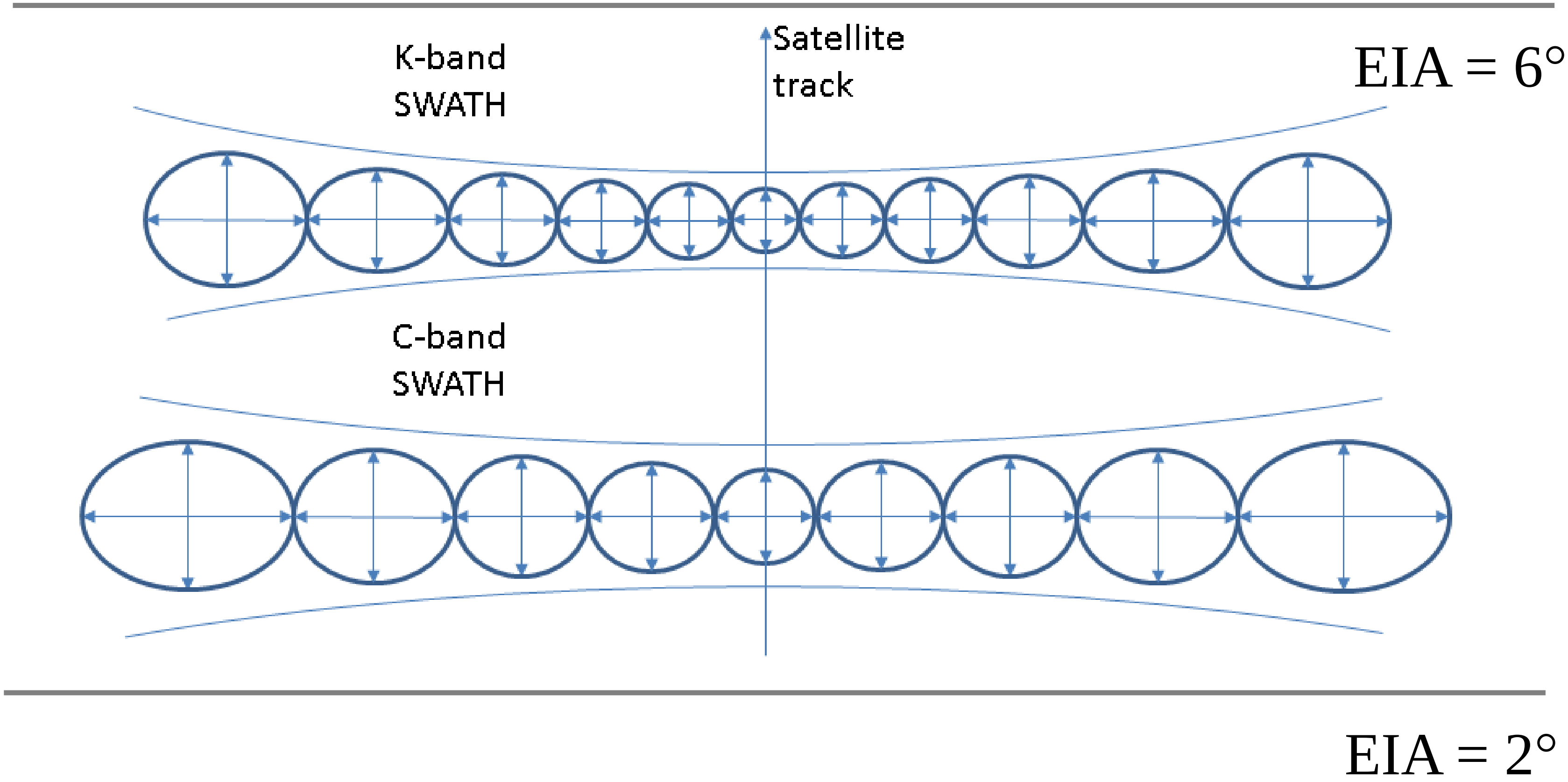






Images: Terma A/S

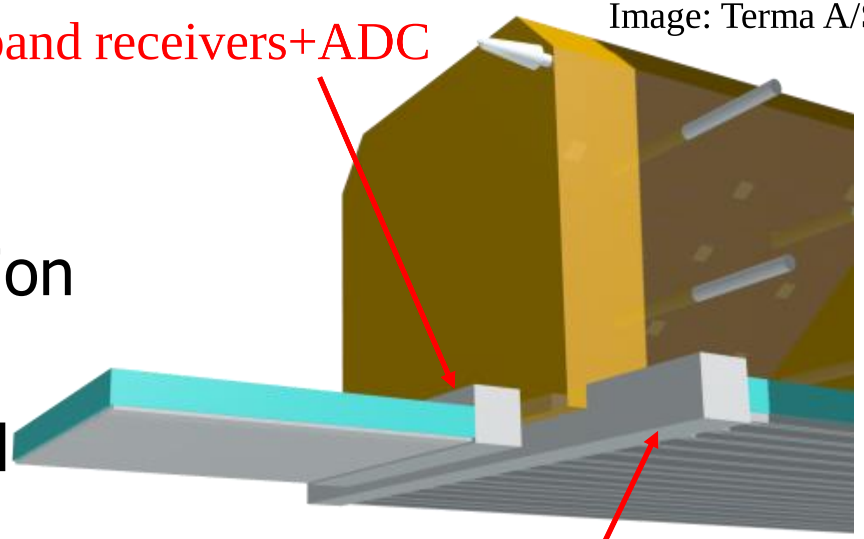
Interferometer key aspects Footprint

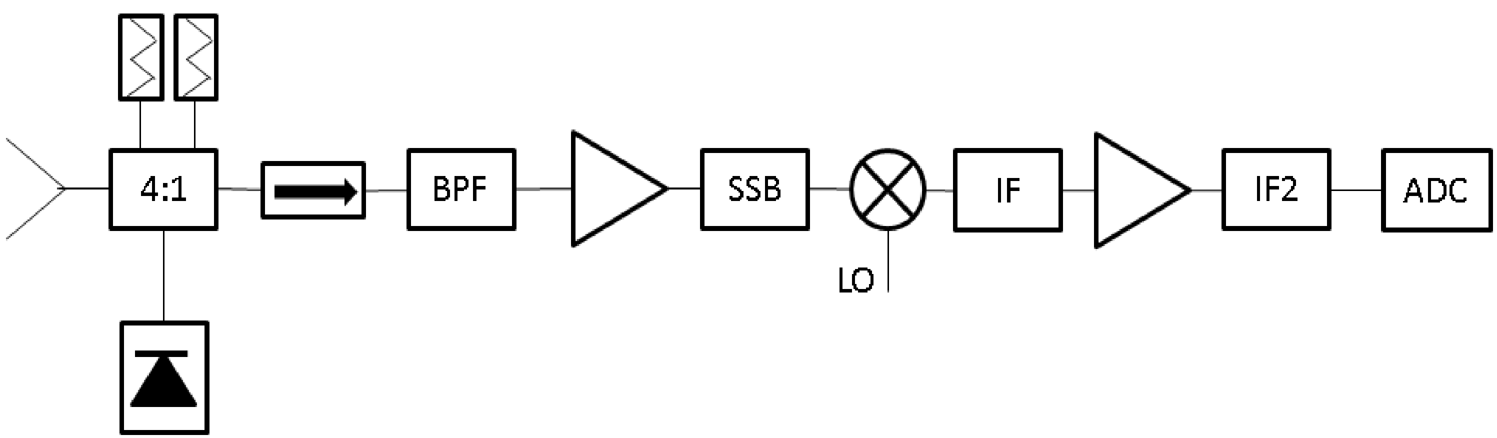


Interferometer key aspects Miniature digital radiometers

- Superheterodyne architecture
- 46/92 receivers at C/K-band
- ADC included → Power consumtion (500W using current ADC tech)?
- Calibration loads in the front-end
- Low-loss switch tech. required

Image: Terma A/S





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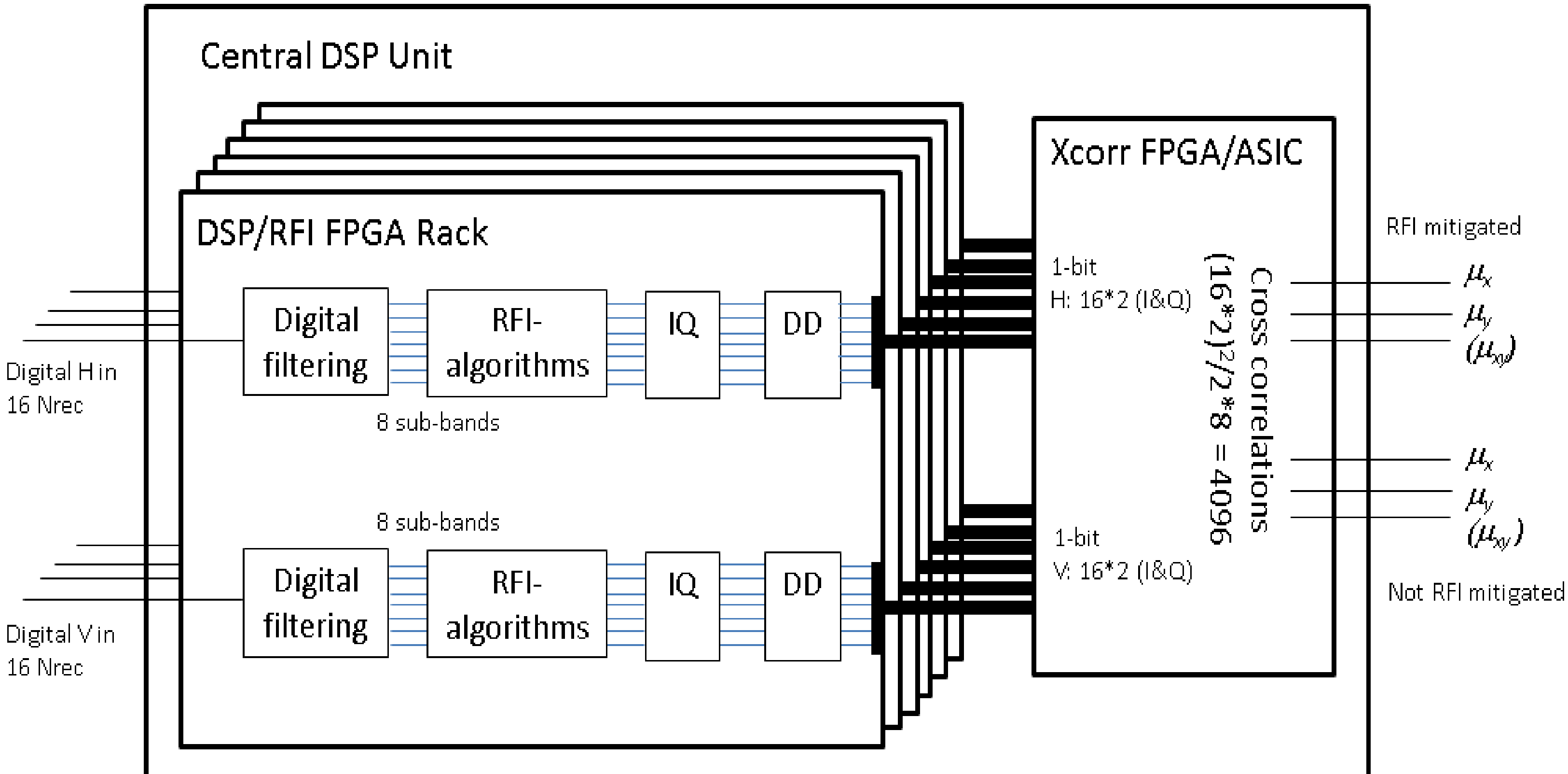
Interferometer key aspects Central DSP Unit



Interferometer key aspects Central DSP Unit

Parameter	6.9 GHz	18.7 GHz
Input central frequency	1.375 GHz	1.375 MHz
IF bandwidth	300 MHz	200 MHz
Input sampling frequency	650 Ms/s	450 Ms/s
Sub-bands	8	8
DSP/RFI Cards	6	10
Sub-band bandwidth	37.5 MHz	25 MHz
Sub-band sampling frequency	100 Ms/s	75 Ms/s
Number of input signals	16*2	30*2
Number of 1 bit signals	256	480
Number of correlations	4736	22 800
Number of Xcorr FPGA units	2	5
Power consumption per DSP/RFI card	9 W	9 W
Power consumption per Xcorr FPGA	9 W	9 W
Total power consumption	72 W	135 W
Dimensions of Central DSP Unit	20 x 30 x 15 cm	30 x 30 x 15 cm
Mass of Central DSP Unit	3.7 kg (comp.) 3 kg (housing)	7.3 kg (comp.) 3.5 kg (housing)
Output data rate	17.87 kB/s	114.7 kB/s

Interferometer key aspects Performance

- Immaturity of interferometric data processing algorithms.
  → Image reconstruction algorithms developed along with the SMOS mission (European knowhow)
  → Enhanced side-lobe correction needed (or minimization by means of antenna pattern design!)
- Inavailability of external calibration targets
  → Internal calibration needed
  → Low loss switch technology development needed
- Robust antenna solution: non-foldable mechanics, possibility to characterize in 1-G.
- Well-behaving thermal operation environment.

Main trade-off aspects

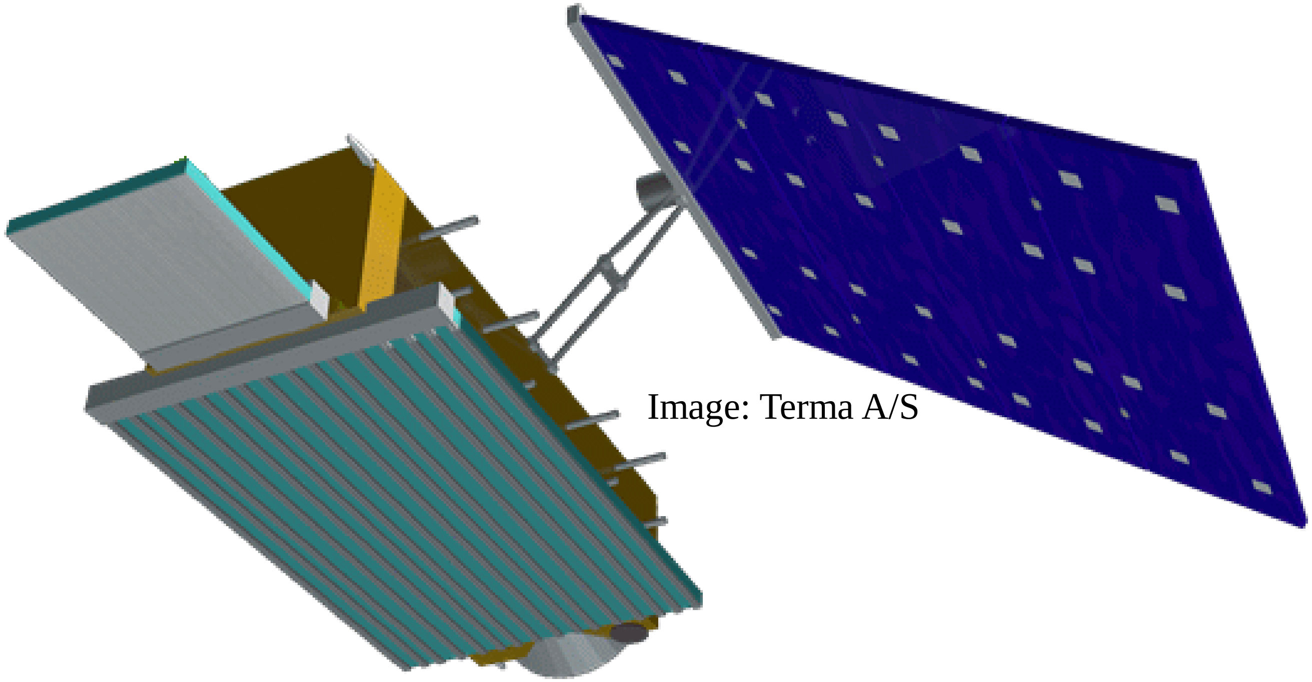
Scanner

- ☺ Established concept, data processing and cal methods
- ☺ External (Tier 2) calibration
- ☺ Switchless design
- ☹ Antenna structure extremely challenging: rotation, losses, surface accuracy
- ☹ Antenna pattern charact.
- ☹ Influence of the Sun (thermal and direct)

1D interferometer

- ☺ Solid and robust antenna structure
- ☺ No rotation nor unfolding
- ☺ AP characterization possible
- ☺ Thermal stability of antennas
- ☹ Immature calibration & IR
- ☹ Non-compliant with ground resolution requirement

Candidate instrument for SST/OVW mission:



- Deepen the preliminary design
- Further performance analysis
- Subsystem requirements etc.
- TRL assessment and development roadmap.....

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THANK YOU! COMMENTS/QUESTIONS?

Image: Terma A/S