Technology Developments towards a SMOS Follow-on Mission

Manuel Martìn-Neira[1], Martin Suess[1], Nikos Karafolas[1], Petri Piironen[1], François Deborgies[1], Berthyl Duesmann[1], Erio Gandini[1], Albert Catalán[2], Roger Vilaseca[2], José Montero[2], Montserrat Puertolas[2], Diego Outumuro[2], Ignasi Corbella[3], Nuria Duffo[3], Roberto Materni[4], Francesco Piazza[4], Steve Crivelli[4], Teresa Mengual[5], Miguel Angel Piqueras[5], Pablo Villalba[5], Juan Ignacio Ramírez[6], Albert Zurita[6], Josep Closa[6], Roger Oliva[7], Raúl Onrubia[7], Adriano Camps[3], Jorge Querol[8,9], Adrián Pérez-Portero[3,8], Steen Savstrup Kristensen[10], Niels Skou[10], Uwe Liebstüeckel[11], Benedikt Rink[11], Nicolas Jeannin[12], Quiterio García[6], David Spinosa[6], Jeppe Majlund Bjørstorp[10], Miguel Piera[6], Francesca Scala[13], Camilla Colombo[13]

[1] European Space Agency, ESTEC, Noordwijk, The Netherlands
[2] SENER Aeroespacial, Spain
[3] Universitat Politècnica de Catalunya, Barcelona, Spain
[4] Saphyrion Sagl, Bioggio, Switzerland
[5] DAS Photonics, Valencia, Spain
[6] Airbus Defence and Space, Madrid, Spain
[7] Zenithal Blue Technologies, Barcelona, Spain
[8] MITIC Solutions, Barcelona, Spain
[9] University of Luxembourg, Luxembourg
[10] Technical Universtity of Denmark, Copenhague, Denmark
[11] Airbus Defense and Space, Ottobrun, Germany
[12] Airbus Defense and Space, Toulouse, France
[13] Politecnico di Milano, Italy

An Overview of Passive L-band Observation Missions

- ESA's Soil Moisture and Ocean Salinity (**SMOS**) mission:
  - launched 2-Nov-2009 (still operational after **12 years** and **6 months**)
  - **40 km** spatial resolution
- NASA's Aquarius radiometer aboard the SAC-D mission:
  - launched 10-Jun-2011, ended 8-Jun-2015
  - 85, 100 and 122 km spatial resolution
- NASA's Soil Moisture Active Passive (**SMAP**) mission:
  - launched 31-Jan-2015 (still operational after **7 years** and **3 months**)
  - **40 km** spatial resolution

Gap of passive L-band observations likely to happen

- ESA's Copernicus Imaging Microwave Radiometer (**CIMR**) mission:
  - expected launch **≥ 2028**
  - **60 km** spatial resolution

LESSONS LEARNT

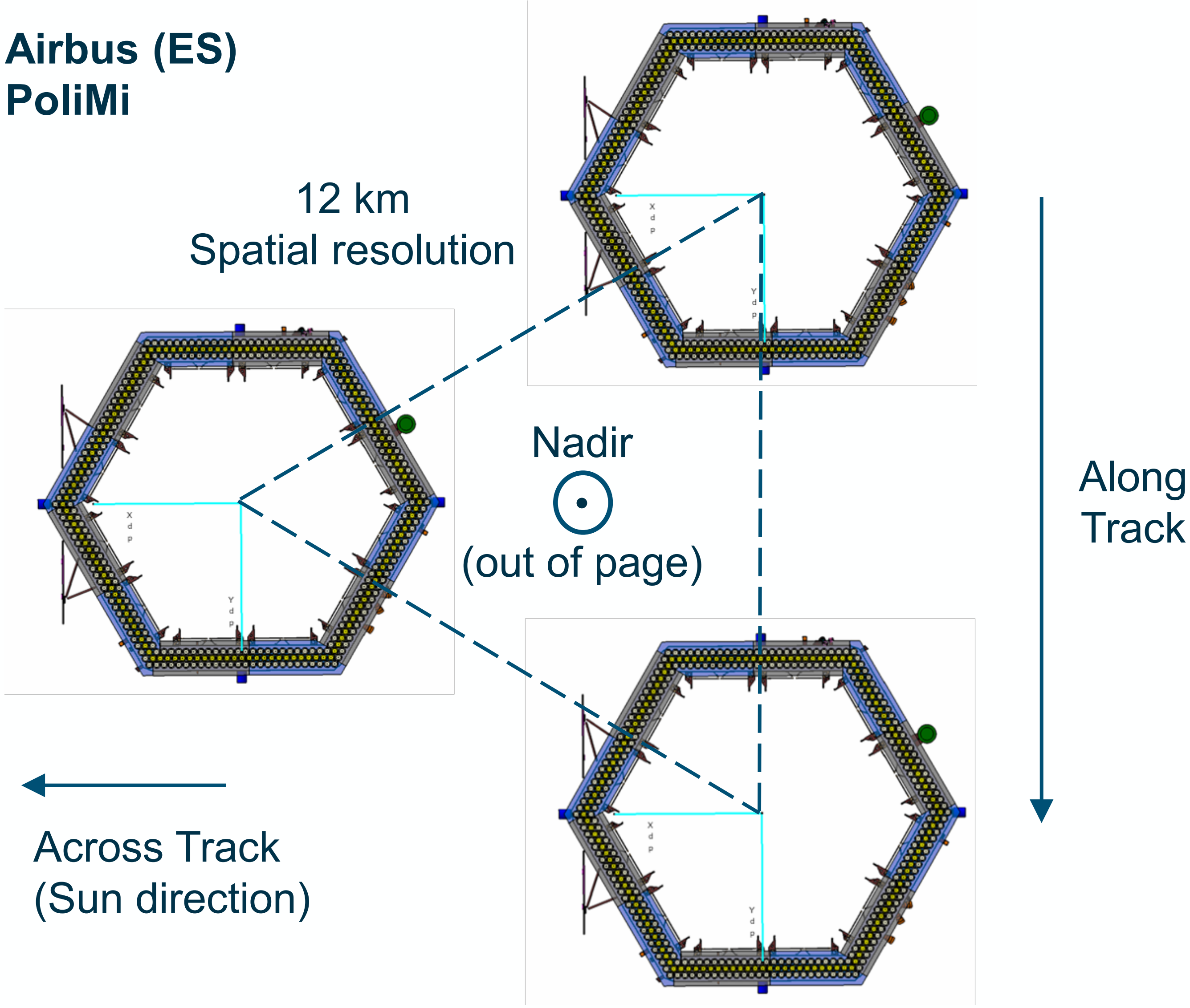
TECHNOLOGY PREPARATION FOR < 3 km RESOLUTION L-BAND RADIOMETER

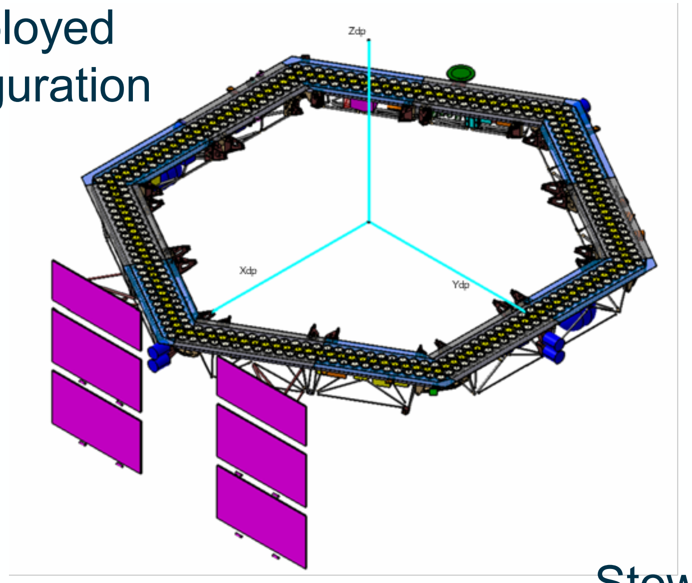
TECHNOLOGY DEVELOPMENTS FOR SMOS FOLLOW-ON

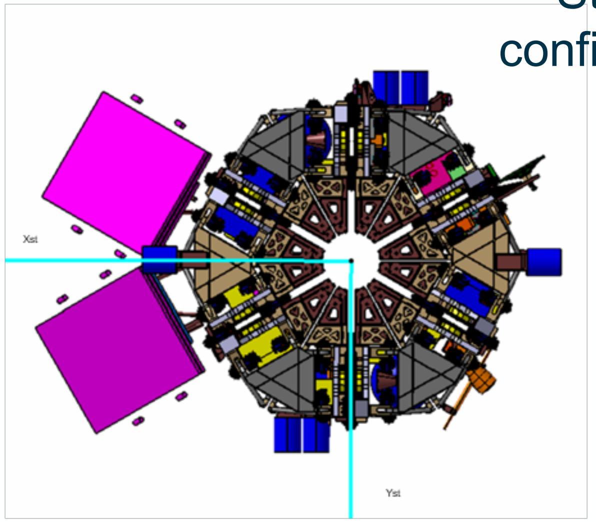
- the study of **formation-flying L-band aperture synthesis** arrays **(FFLAS)**
- an **antenna** of a size compatible with an inter-element spacing enabling **alias-free imaging**
- **two advanced L-band receivers** with parallel dual polarisation, **high sensitivity**, high out-of-band interference rejection and digital in-phase quadrature demodulation
- development of an **RF ASICs** with **digital functionality** for radiometer applications
- a **multi-wavelength optical harness** connecting the receivers and the correlator supporting the centralised distribution of the local oscillator, sampling clock and calibration signal as well as the acquisition of raw data
- the development of an **advanced correlator with built-in radio frequency interference (RFI) filtering** for aperture synthesis application

Formation Flying L-band Aperture Synthesis (FFLAS) 1/2

- **Airbus (ES)**
- **PoliMi**





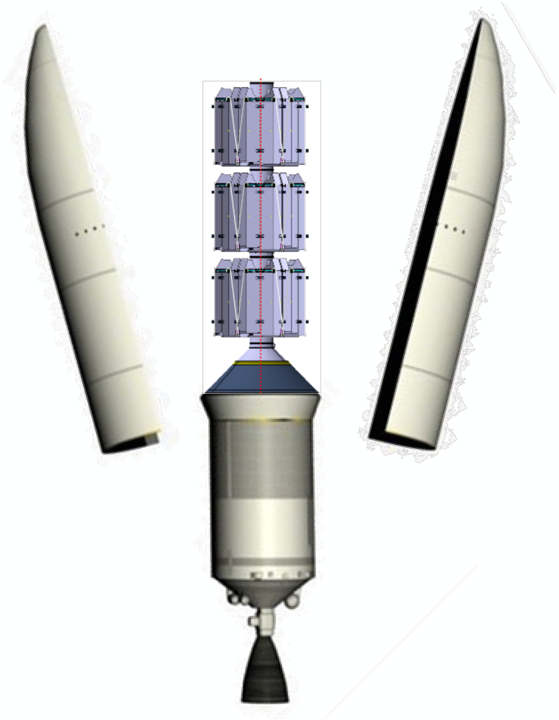


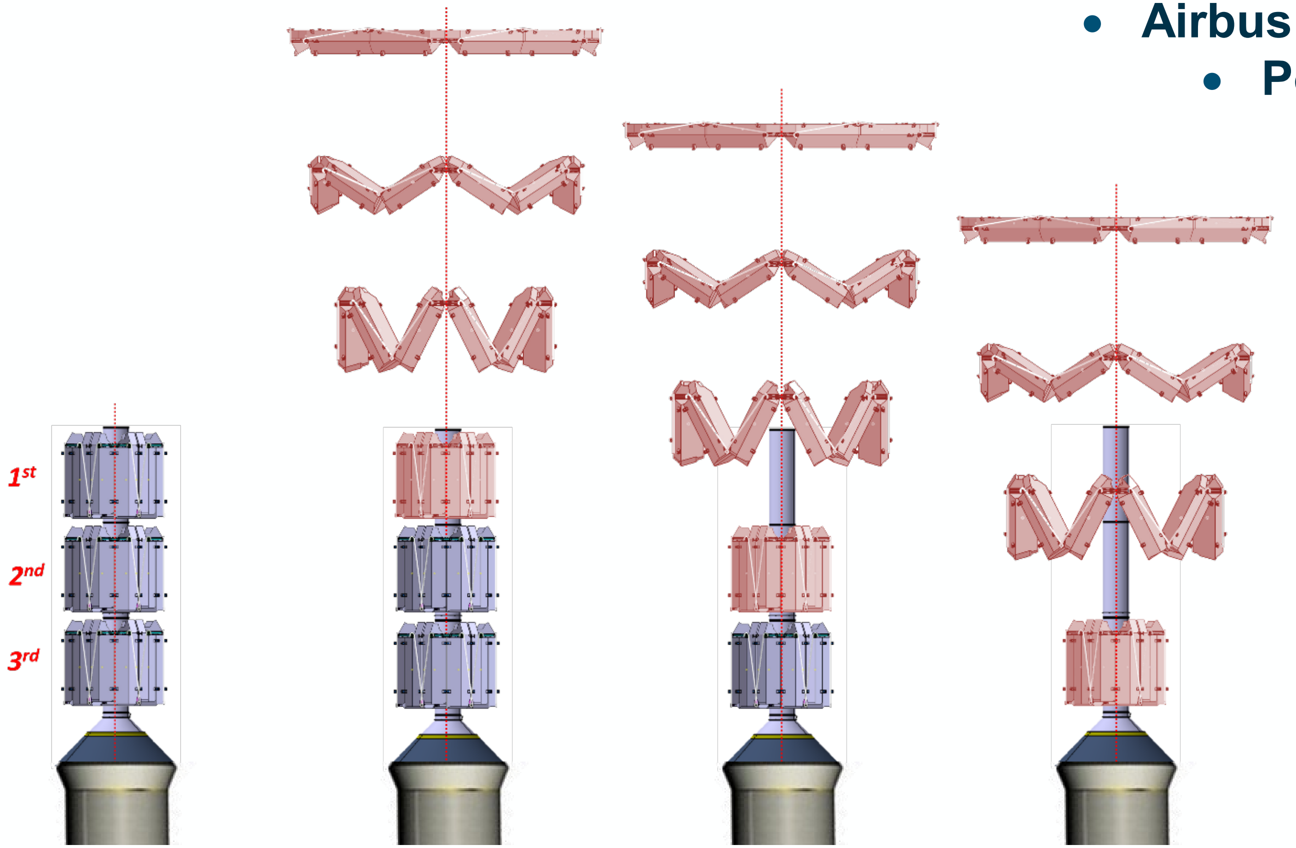
Formation Flying L-band Aperture Synthesis (FFLAS) 2/2

Tuesday: 24.05.2022, 18:15 | Poster 65677 – Miguel Piera (Airbus) on:
Performance assessment for the Formation Flying L-band Aperture Synthesis mission concept

Tuesday: 24.05.2022, 18:16 | Poster 64567 – Francesca Scala (PoliMi) on:
Satellite Design for a Formation Flying L-band Aperture Synthesis mission concept

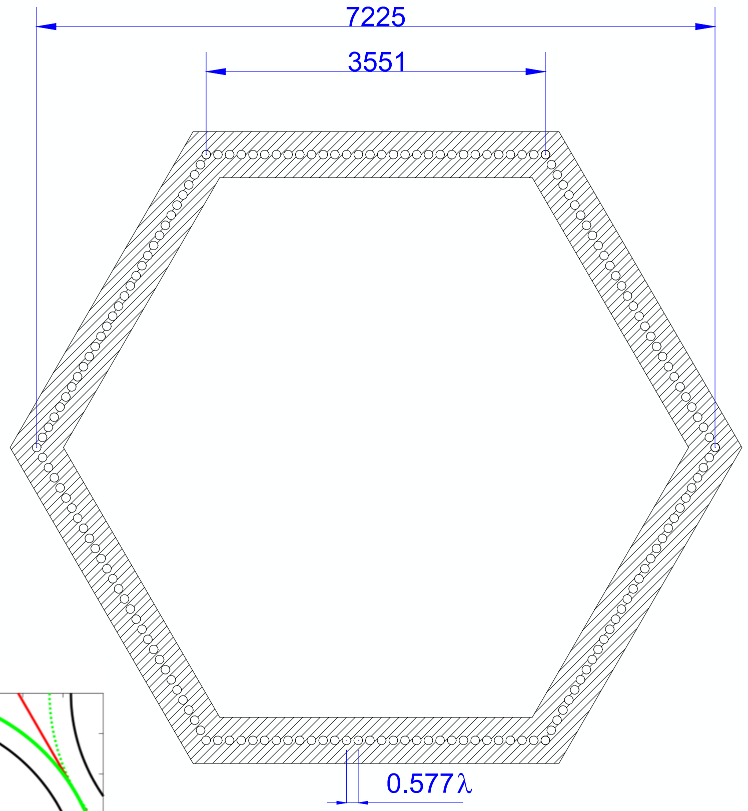
- Airbus (ES)
- PoliMi

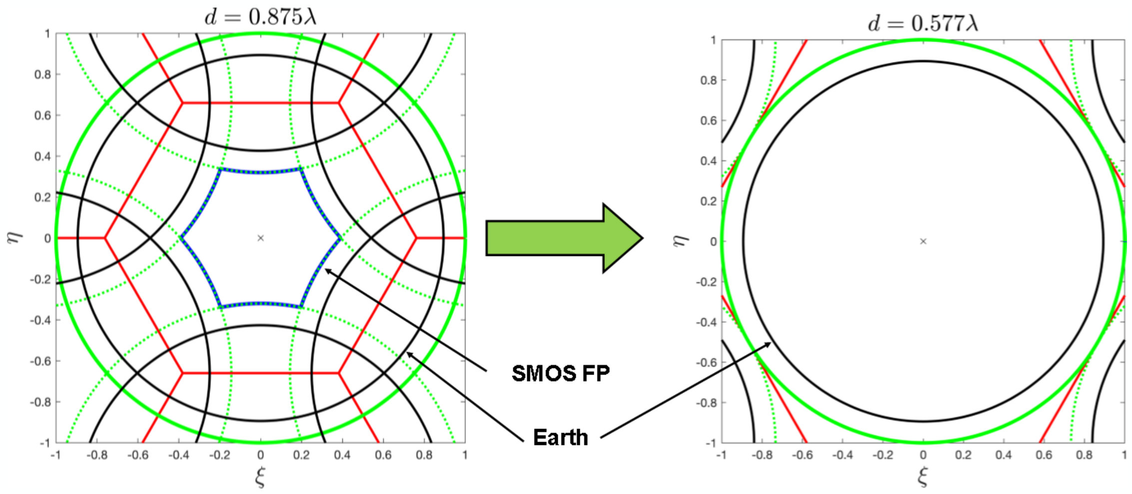




Antenna Element for Alias-Free Imaging (1/2)

- Objective 1: **increase resolution**. In the future SMOS Instrument the antenna configuration is based on a hexagonal array. The antenna diameter provides a 20% improvement of spatial resolution
- Objective 2: **alias-free imaging**. This is achieved by a reduction of the inter-element distance to **0.577λ**
- 0.577λ element spacing is **challenging** as it implies larger mutual coupling which affects the shape, similarity and symmetry of the embedded element pattern
- The reduced spacing broadens the alias-free field of view achieving **1 day revisit time** and **full polar coverage**
- Main objective: **to develop and test** antenna elements compliant with this tight requirement

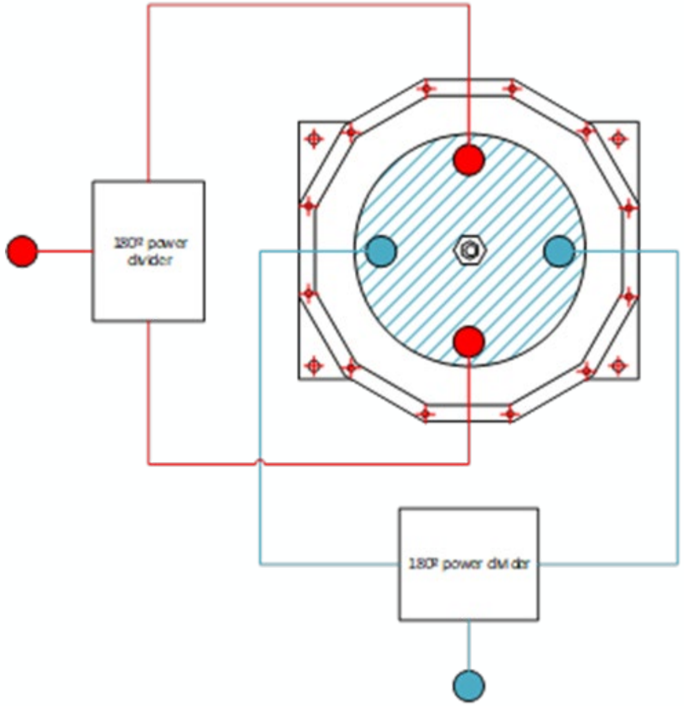


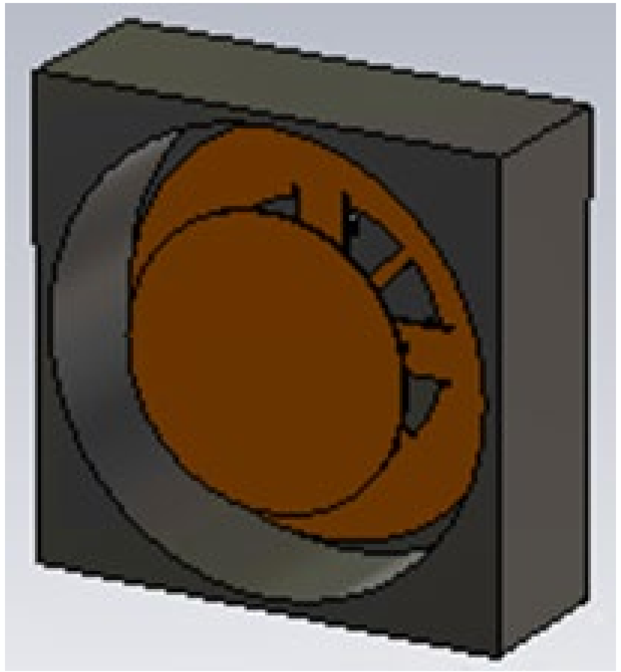


- **Airbus (ES)**

Antenna Element for Alias-Free Imaging (2/2)

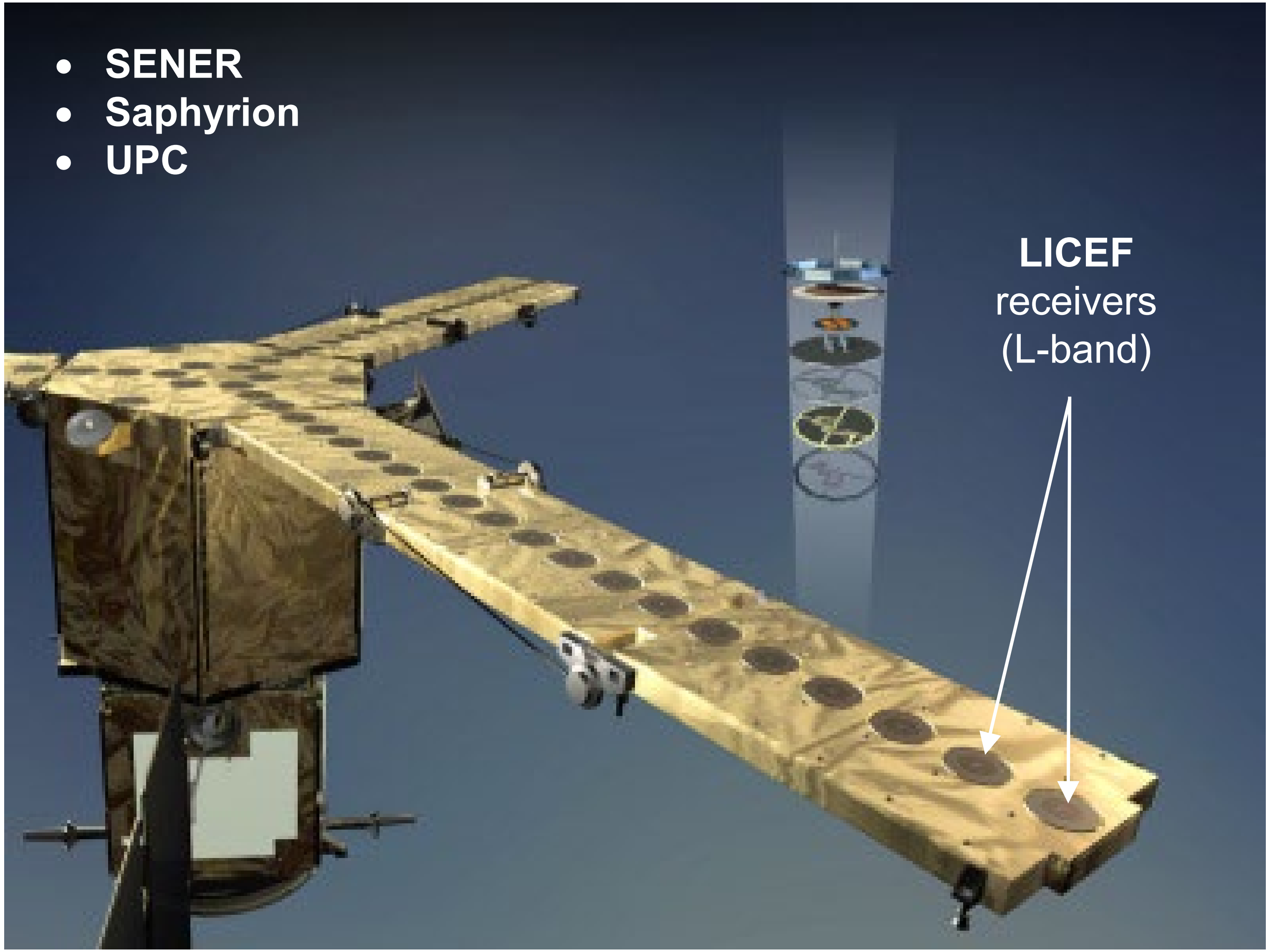
- A trade off between several dual-pol antenna candidates has been performed considering the requirements (gain, loss, beamwidth, crosspol, matching, pattern symmetry, mass…)
- Heritage from Airbus in the earlier SMOS antenna design has been used to select candidate antenna configurations fitting in the available space and compliant to requirements. Work is ongoing using 3D EM full-wave simulation
- The most promising candidate is a stacked annular ring patch antenna with balanced feed network
- The antenna study is yet in process with EM analysis of the impact of mutual couplings in antenna pattern mask (H-V symmetry, similarity between elements along the full antenna...)





- **Airbus (ES)**

Advanced L-band Receiver (1/2)



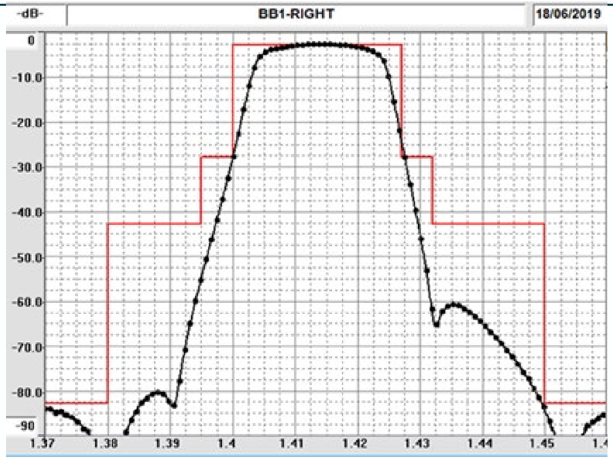
SMOS LICEF	SMOS follow-on ALR
NF = 1.86 dB (155 K)	NF = 1.35 dB (114 K)
Single Channel H or V	Dual Channel H and V
Analog I/Q demodulation	Digital I/Q demodulation
1-bit sampling	Same (N-bit ADC discarded)
Analog Power Detector	Same (N-bit ADC discarded)
Sharp Analog Bandpass Filtering against RFI	Same (additional RFI filtering implemented in correlator)

Advanced L-band Receiver (2/2)

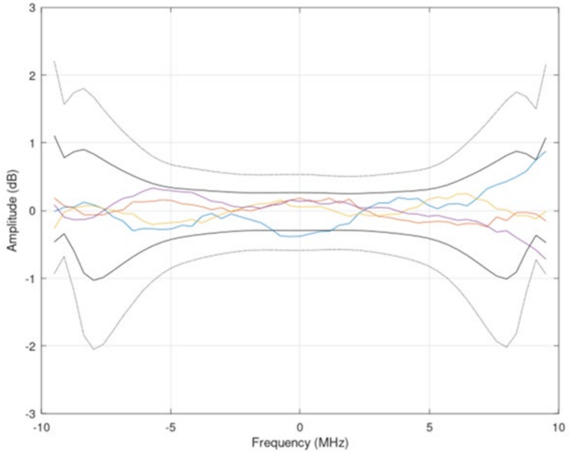
- SENER
- Saphyrion
- UPC

SMOS BPF = 75 g

ALR BPF = 55 g



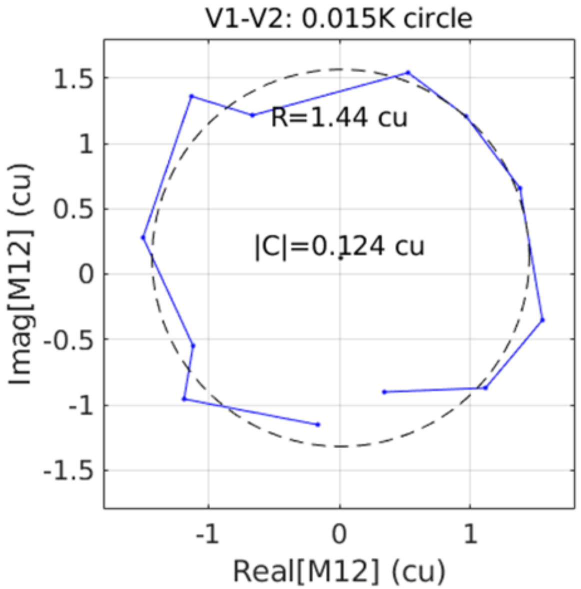
Frequency Response



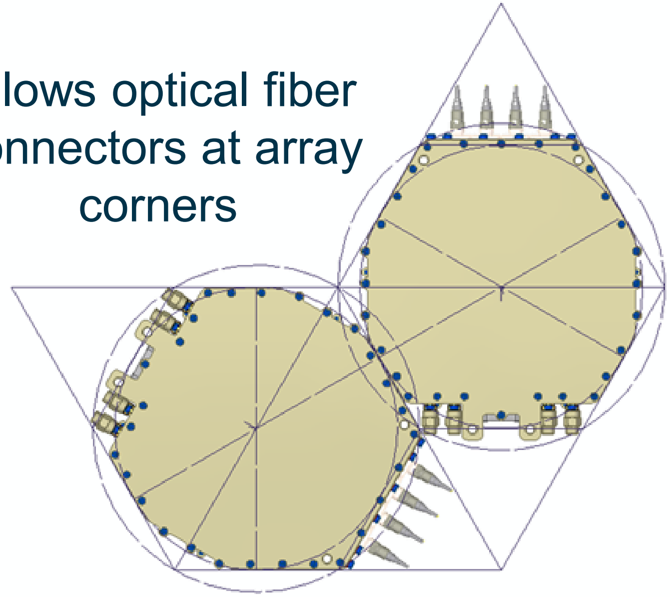
Response Similarity

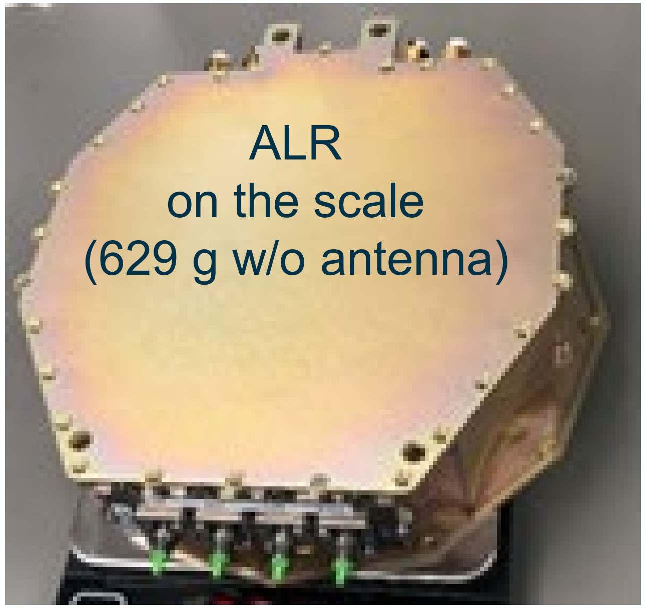
Systematic Correlation Offsets:

<< 15 mK



Allows optical fiber connectors at array corners





DiReRa-2 Digital Receiver for Radiometer (1/2)

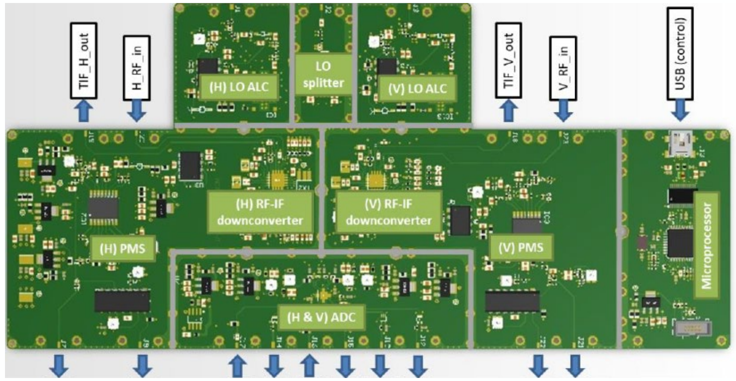
- Saphyrion
- SENER
- UPC

Background and motivation:

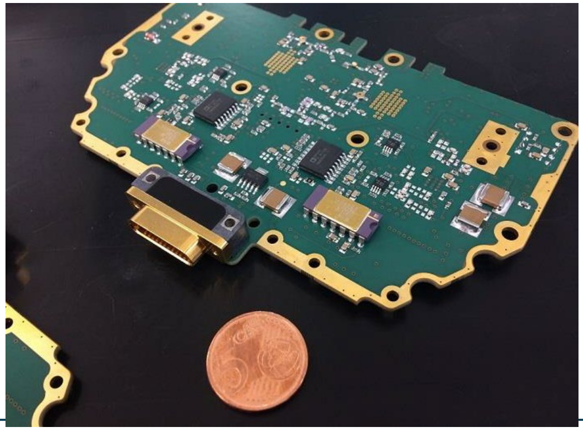
- SMOS is carrying 72 elementary receivers (LICEF-3) with excellent performance.
- SMOS follow-on is expected to contain a substantially bigger number of dual-pol receivers which highlights the importance to further reduce the mass and power consumption of the receivers
- DiReRa-1 chip from previous R&D project (2018) has been successfully demonstrated and then applied in the Advanced Receiver for Future L-Band Radiometer (ALR) project (2020)

Objective:

- DiReRa-2 De-Risk activity will implement modifications as identified in DiReRa-1 and ALR projects: foundry process change due to obsolescence, Rx gain/linearity, IF filtering implementation, on-chip V/F converter



RF/IF test board w/ DiReRa-1 chip 2018



ALR RF/IF test board w/ DiReRa-1 chip 2020

2022/23 DiReRa-2

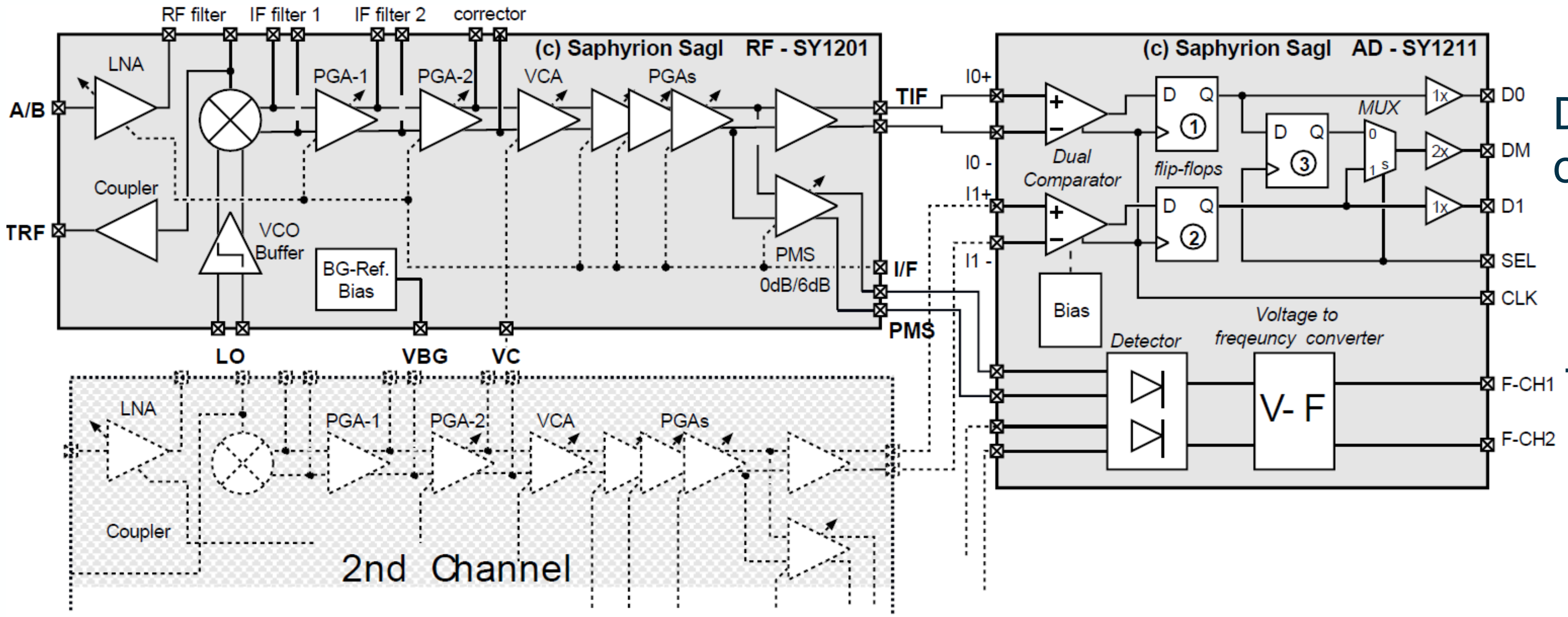
DiReRa-2 Digital Receiver for Radiometer (2/2)

- Saphyrion
- SENER
- UPC

Baseline block diagram

RF input H

RF input V



Digital I/Q outputs H&V

Total power H&V

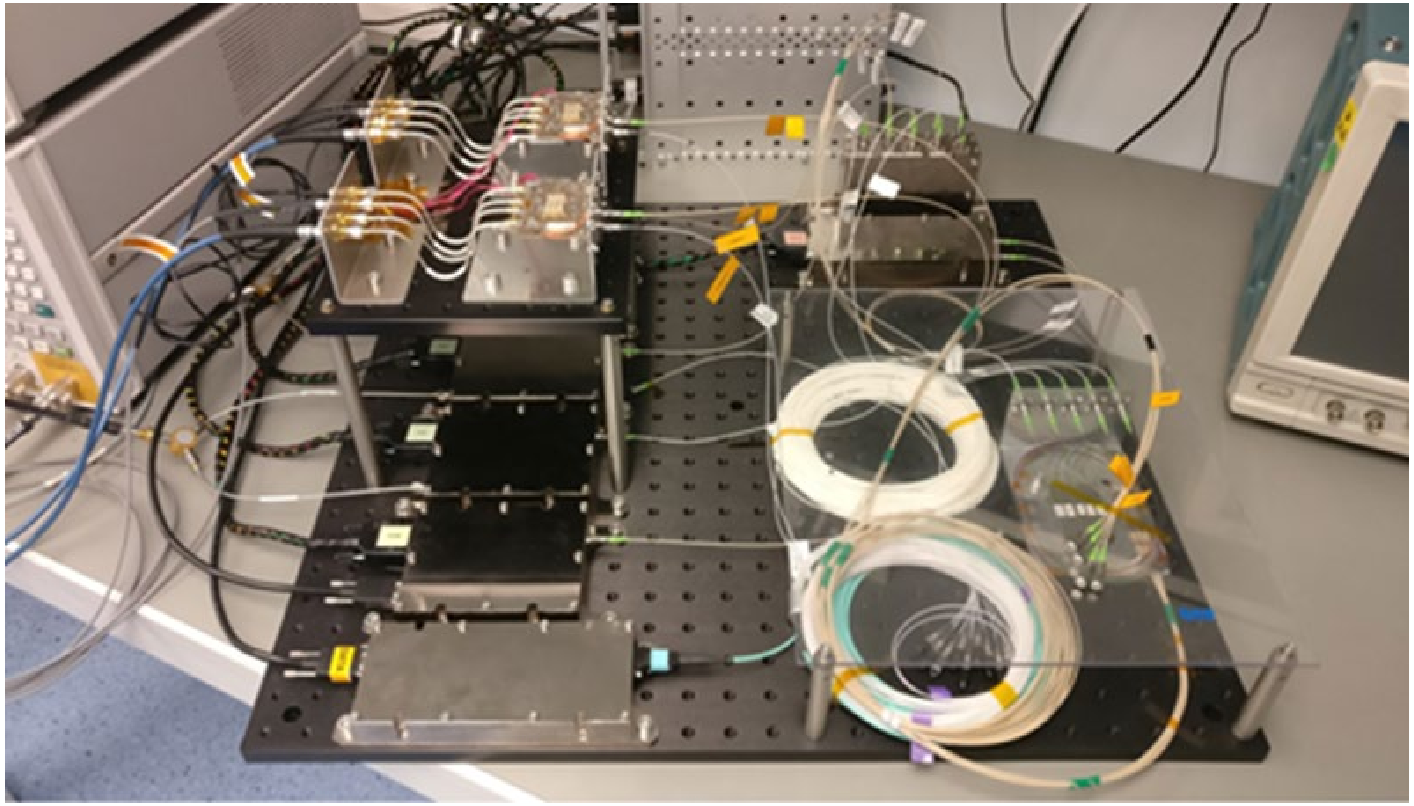
- Most of the LICEF RF/IF functions fully integrated
- Small consumption thanks to SiGe BiCMOS technology

- External components still needed for the best performance: LNA, RF filter and optical LO and CAL interfaces & harness
- Work started in 2022, expected completion 2023

Multi-Wavelength Optical Harness

- DAS Photonics

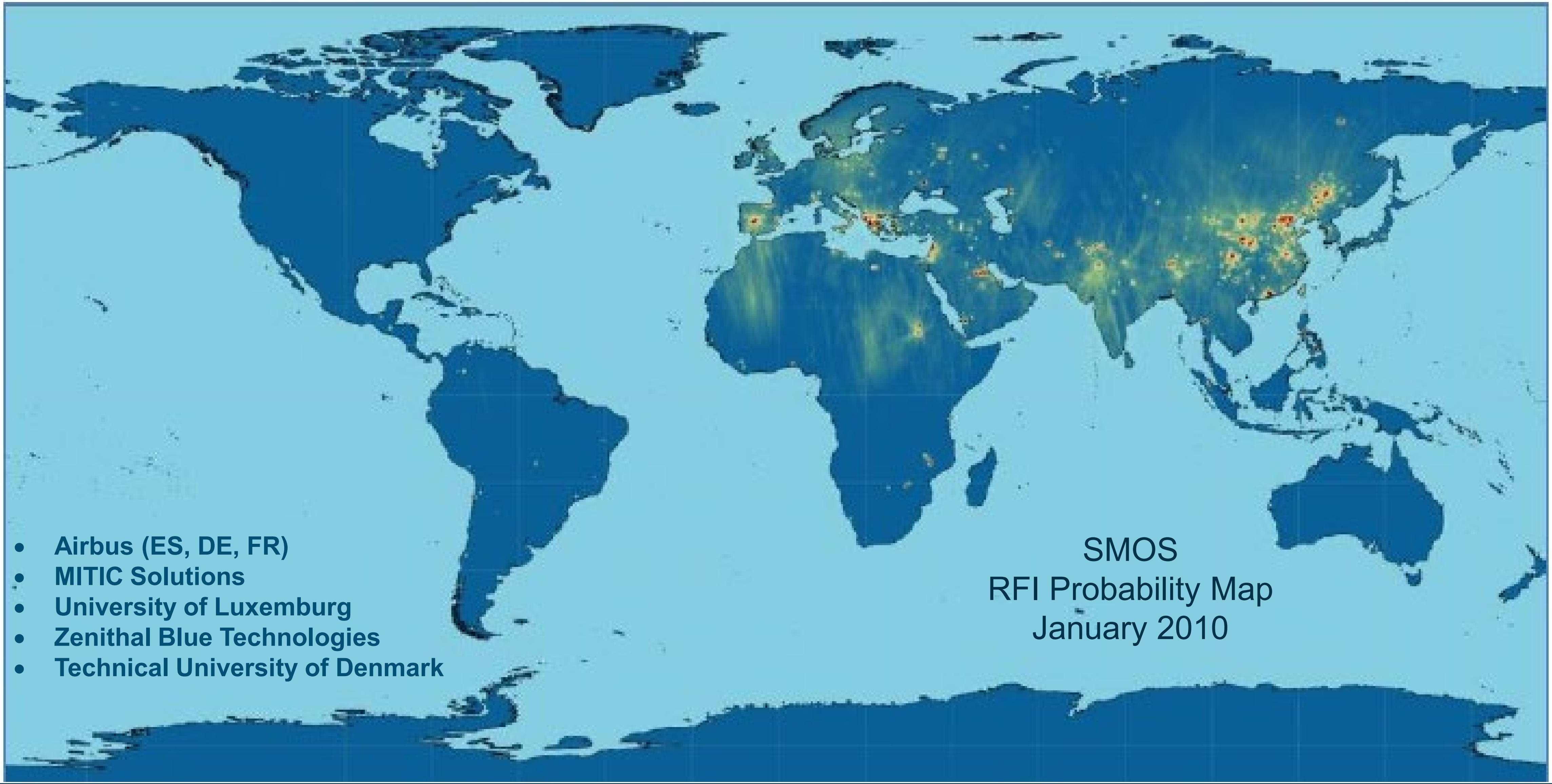
- Centralised Up-link (correlator to receivers) of Local Oscillator, Calibration Signal and Sampling Clock
- Up-link performance demonstrated through multi-wavelength Mux-Demux
- Down-link of high-rate (230 Mbps) 1-bit raw data (receivers to correlator)



The Optical Harness brings:

- Mass saving at system level
- Simpler instrument architecture
- Simpler calibration
- Ensures EMC cleanliness
- Up-link performance

Advanced Correlator with Built-in RFI Filtering (1/3)

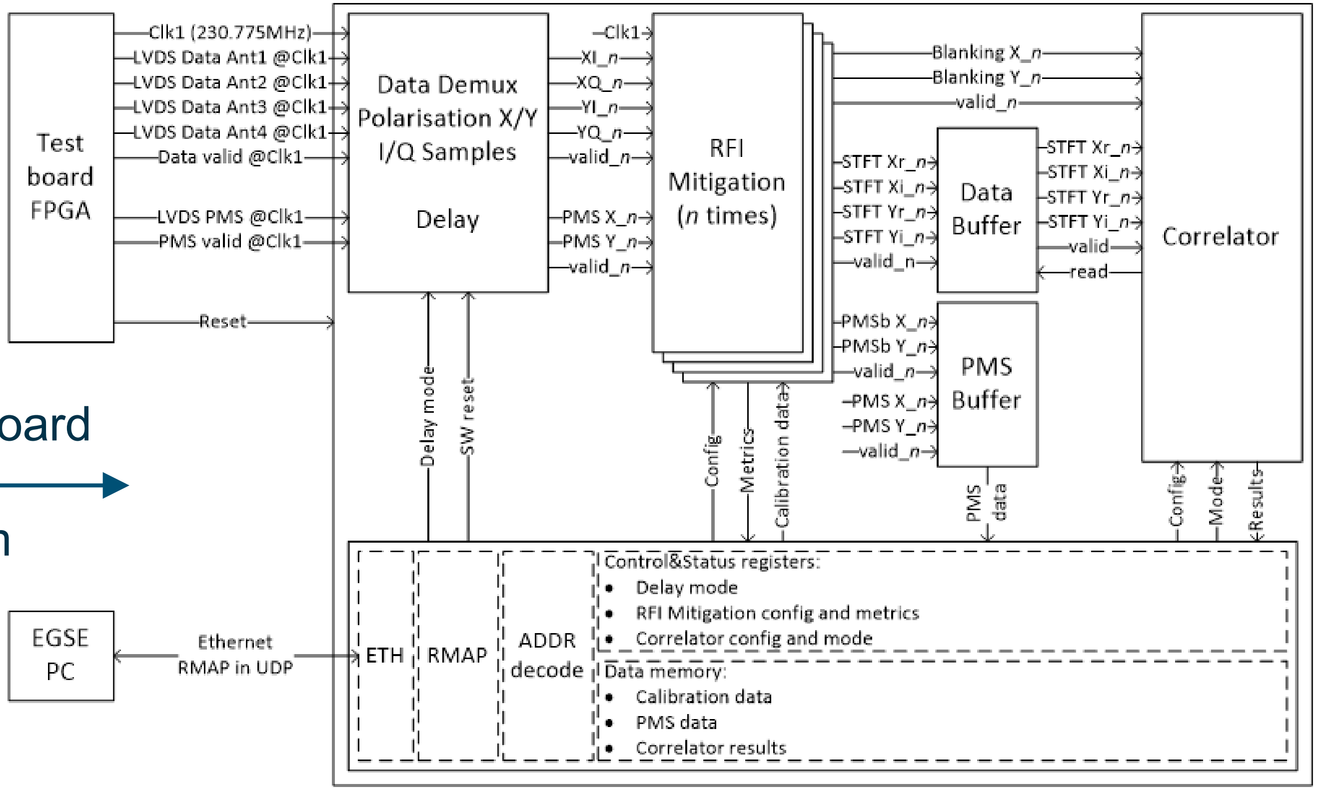


- **Airbus (ES, DE, FR)**
- **MITIC Solutions**
- **University of Luxemburg**
- **Zenithal Blue Technologies**
- **Technical University of Denmark**

Advanced Correlator with Built-in RFI Filtering (2/3)

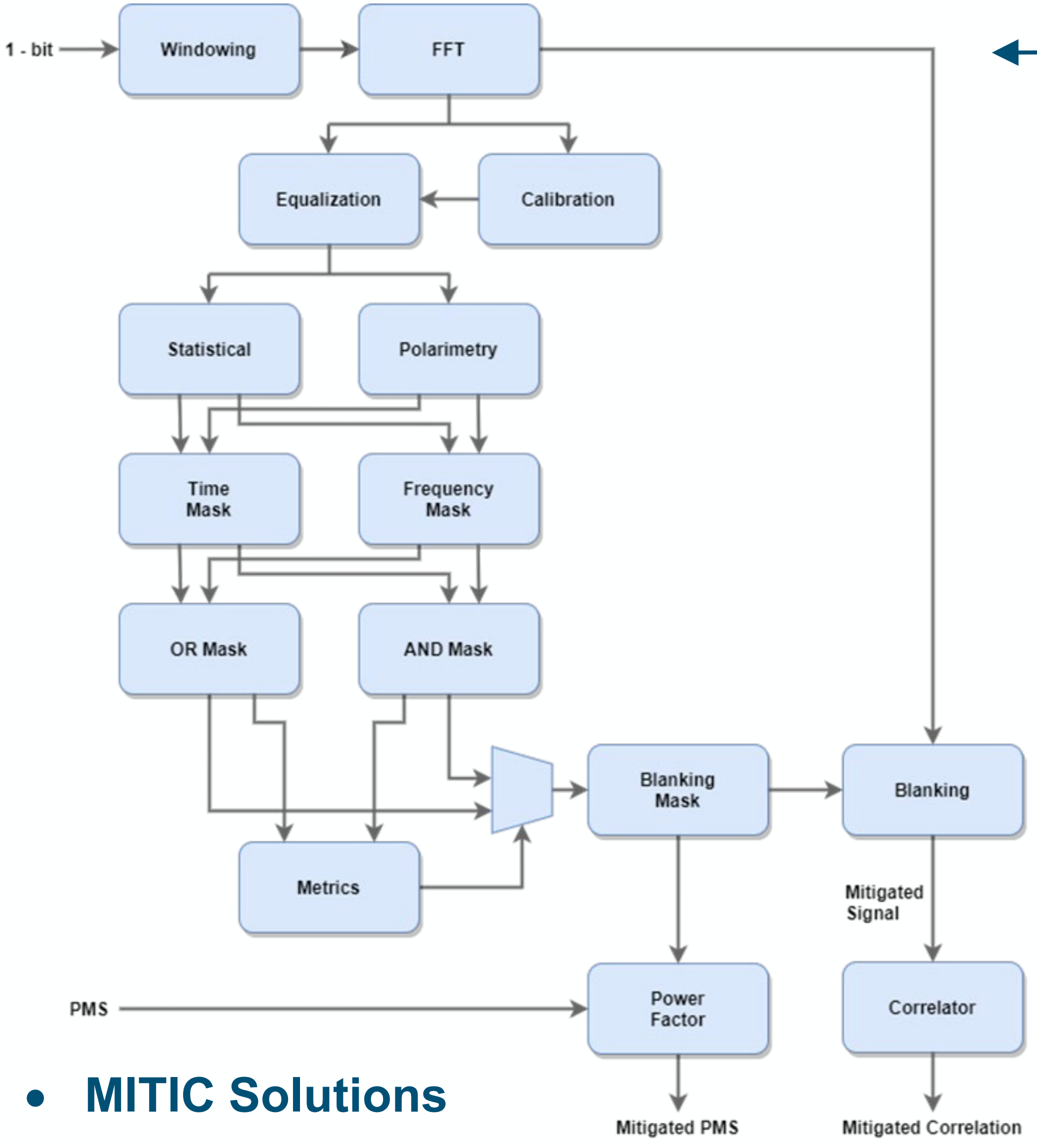
- Study the state of the art of algorithms to detect and filter RFI, with the constraints of L-Band radiometers with an architecture as that of SMOS
- Implement this algorithm in the radiometer correlator (FPGA), and probe its feasibility and performance
- Study the potential implementation in an ASIC
- Status: a breadboard implementation (FPGA) is about to start; it will be tested to validate the selected algorithm

FPGA Breadboard Test Set-up Block Diagram



- **Airbus (ES, DE, FR)**
- **MITIC Solutions**
- **University of Luxemburg**
- **Zenithal Blue Technologies**
- **Technical University of Denmark**

Advanced Correlator with Built-in RFI Filtering (3/3)



RFI Filtering Algorithm Block Diagram

STEPS:

- Windowed truncation of data stream to reduce Gibbs effect
- FFT: spectrum computation of the 1-bit raw signals
- RFI-free acquisition used to equalize frequency response
- Measurement equalization performed during normal operation
- Statistical or polarimetric tests applied in time and frequency domains to detect RFI
- Blanking mask is computed if RFI is detected in any of these domains by any technique
- Removal of corrupted spectrogram samples in any domain

- **MITIC Solutions**

CONCLUSIONS

- POTENTIAL GAP AFTER SMOS / SMAP MISSIONS IN PASSIVE L-BAND OBSERVATIONS

- ESA’s CIMR IS PLANNED TO PROVIDE THESE OBSERVATIONS (60 km RESOLUTION, ≥ 2028)

- TECHNOLOGY BEING PREPARED FOR A HIGH-RESOLUTION (<10 km) SMOS FOLLOW-ON MISSION