Multi Frequency Feeds for Millimetre-Wave Earth Observation Applications

Richard Wylde

Thanks to my co-authors:

Janet Charlton | JCR Systems Ltd Kingdom

Dr. Adam Woodcraft | Thomas Keating Ltd

Dr Soe Min Tun | S M T Consultancy Ltd

And to AIRBUS (MWS), ESA (MWS, Triband Study) and MIT/NASA (TROPICS)

Microwave / mm-wave earth observation satellites - both passive radiometer and active radars - if they have beams at multiple frequencies - often need their beams to be co-aligned, and in particular, very well co-aligned

This talk will discuss the amalgam of quasi-optical design and precision manufacturing techniques used in a number of currently working and future missions which use our quasi-optics approach to multiplex beams. Multiplexing can be obtained through the use of polarization – as in the case of NASA/MIT's TROPICS mission and our recent Triband ESA study - but also using dichroics as in the soon-to-be-launched MetOP-SG MWS instrument

Starting with MetOP-SG MicroWave Sounder

EumetSAT MetOP-SG Micro Wave Sounder

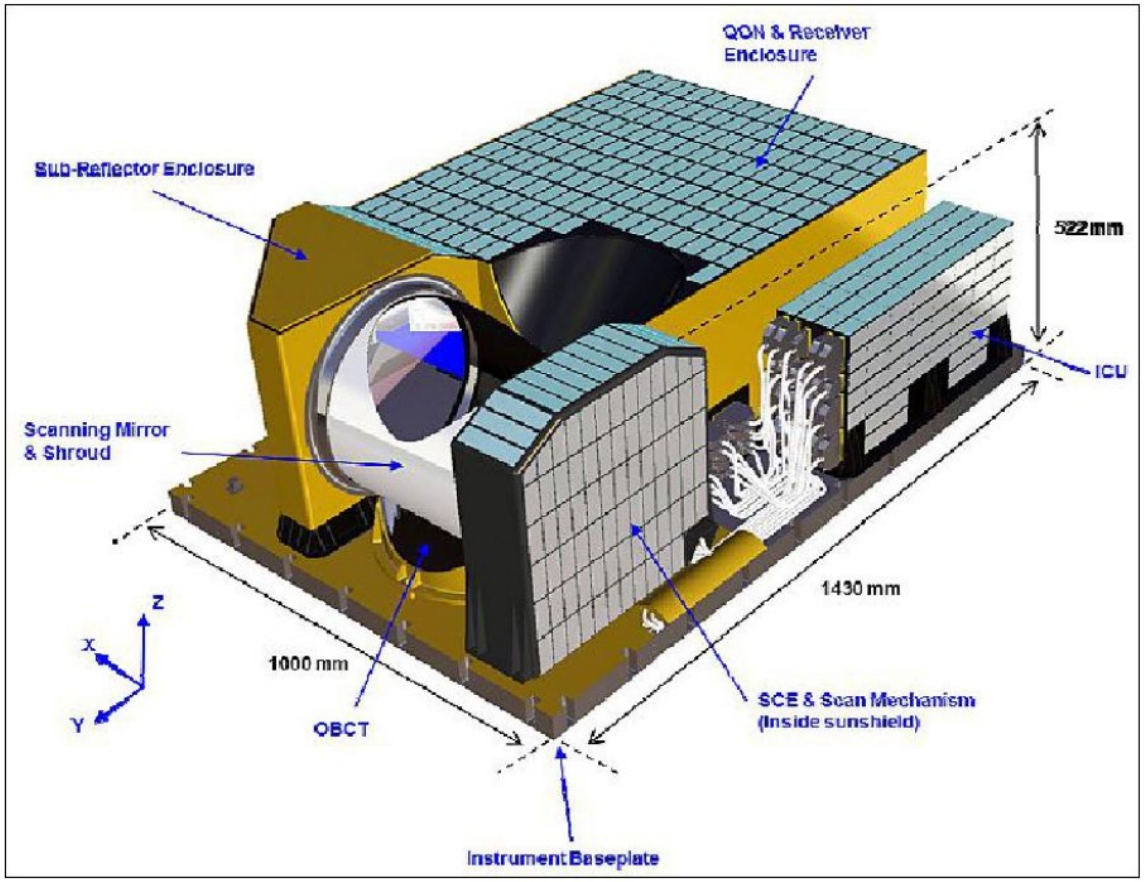
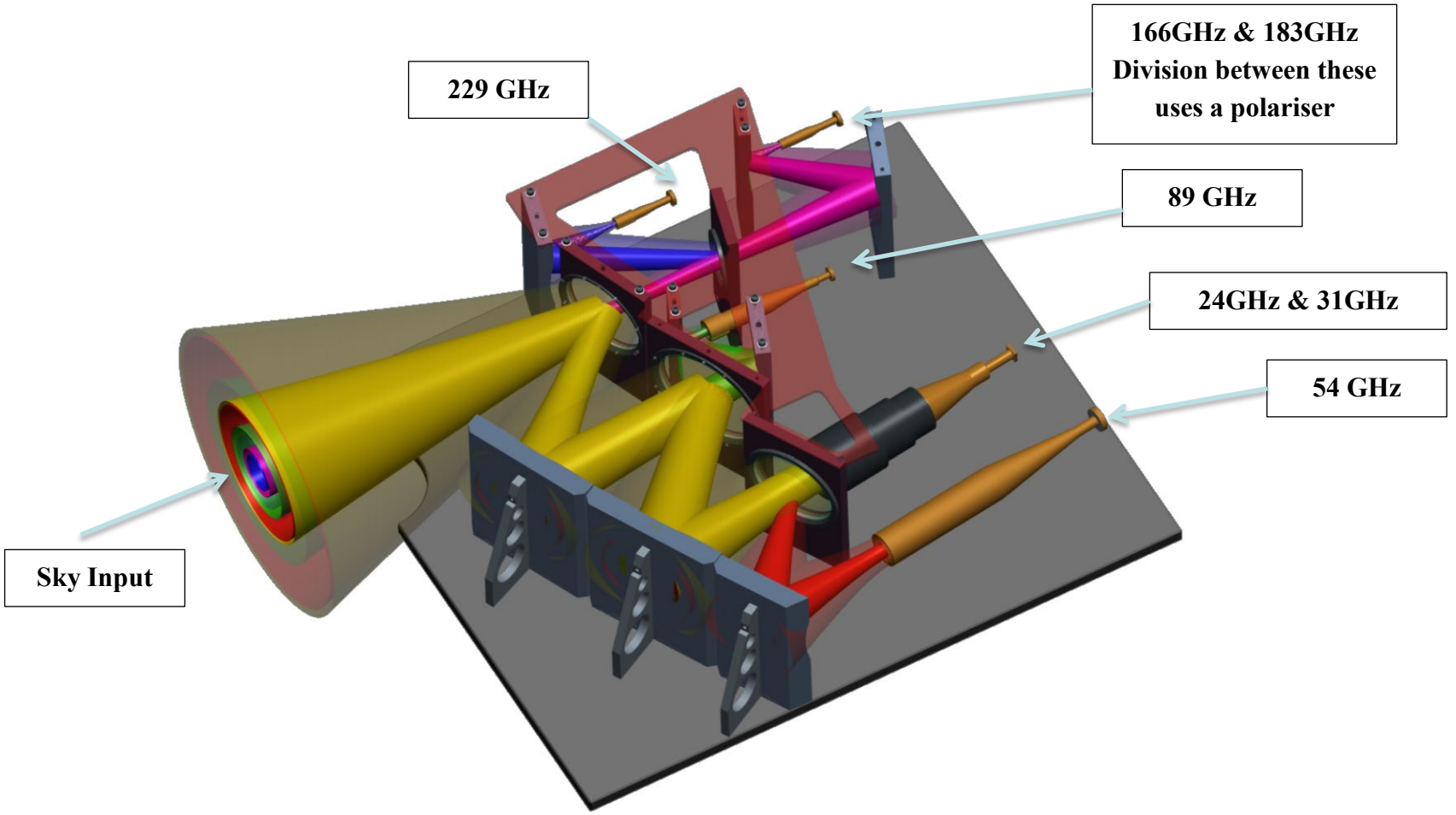


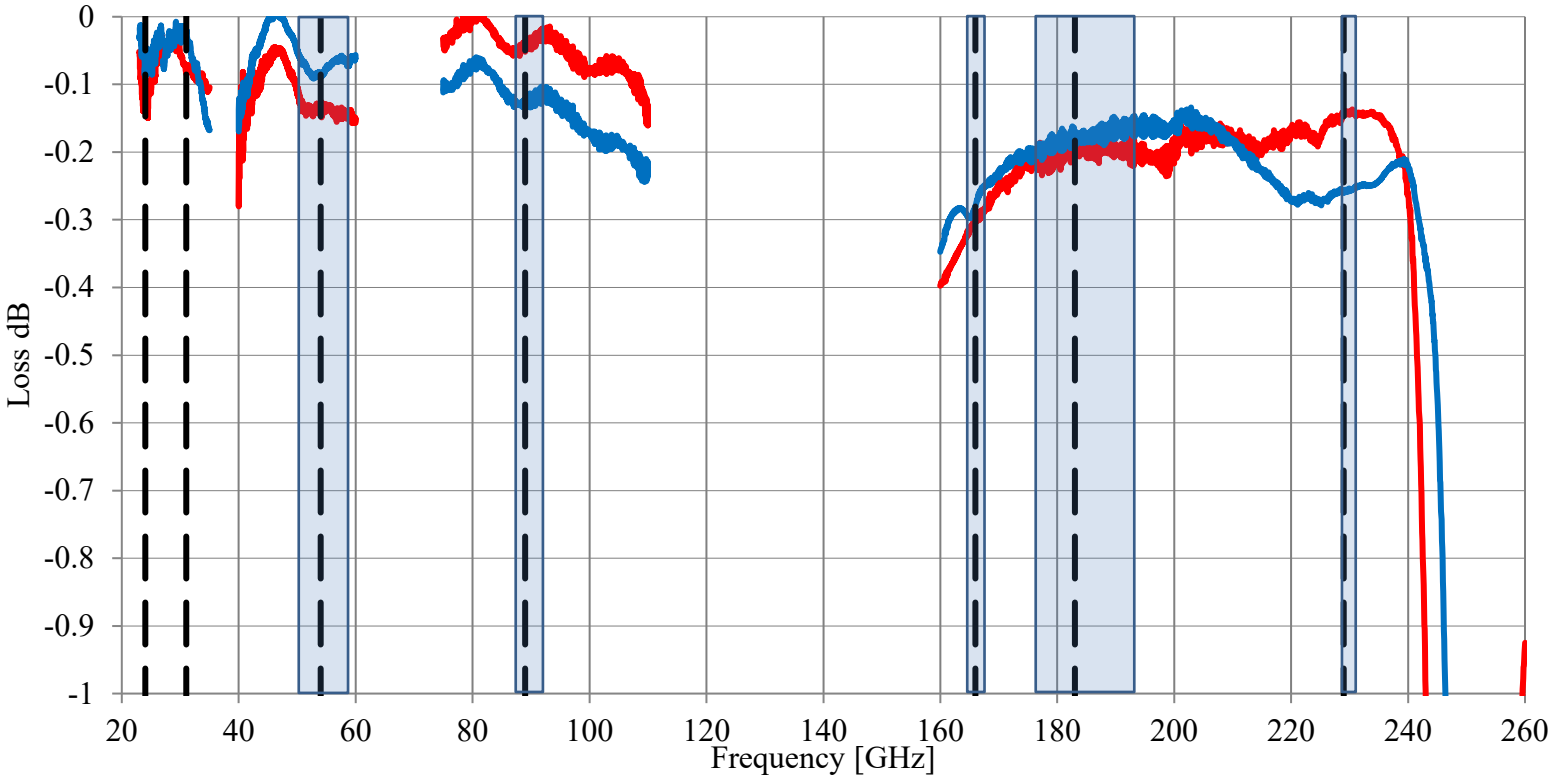
Figure 15: Configuration of the MWS instrument (image credit: Airbus Defence and Space)

The MWS is an cross-track scanning microwave radiometer, measuring the total power, atmospheric brightness temperature in 24 channels over the frequency range from 23.8 GHz up to 229 GHz. The instrument provides measurements of temperature and humidity (water vapor) profiles and total liquid water columns.

Quasi-Optical Concept



Dichroic D1 – High Pass at 128GHz

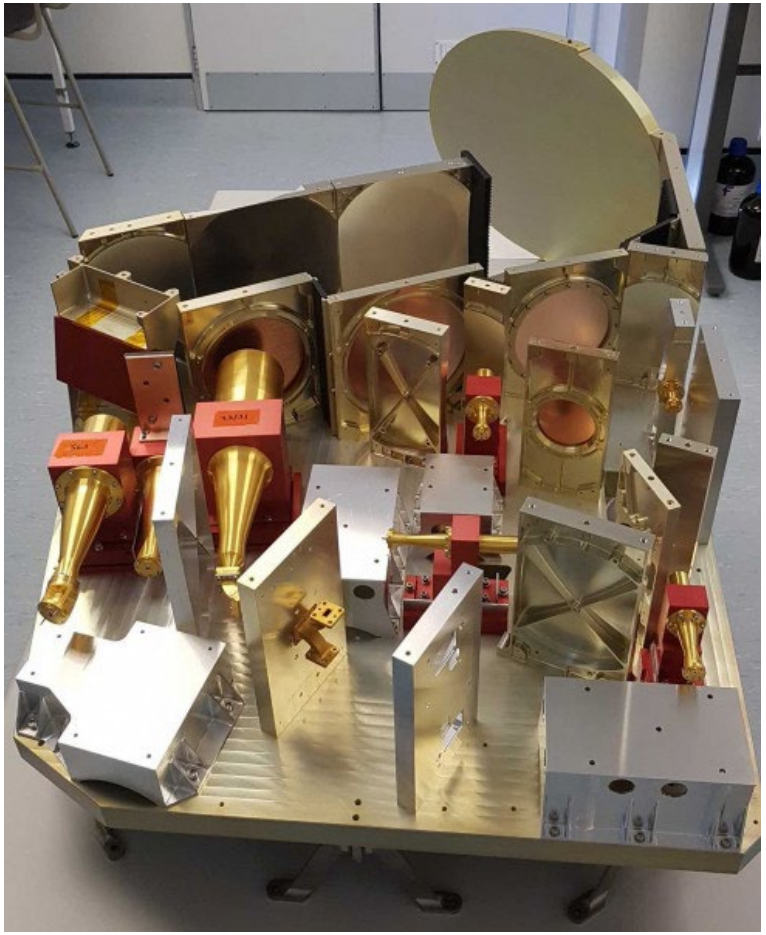


P state polarisation - **red lines**, **S** state polarisation - **blue lines**

Summary – Dichroic Performance within requirements

Dichroic	ID	24GHz	31GHz	54GHz	89GHz	166GHz	183GHz	229GHz
D1	W2236	0.13	0.07	0.13	0.13	0.30	0.20	0.26
D2	W2234	0.08	0.05	0.07	0.25	0	0	0
D3	W2238	0.01	0.09	0.09	0	0	0	0
D4	W2222	0	0	0	0	0.10	0.15	0.20
Total dichroic Loss		**0.22**	**0.21**	**0.29**	**0.38**	**0.40**	**0.35**	**0.46**
QON Loss		0.35	0.335	0.2	0.18	0.16	0.16	0.40
Total QON + Dichroic Loss		0.57	0.545	0.49	0.56	0.56	0.51	0.86
Specification		**< 0.87**	**< 0.87**	**< 0.94**	**< 1.2**	**< 1.5**	**< 1.5**	**< 1.2**

MetOP-SG MWS EQM



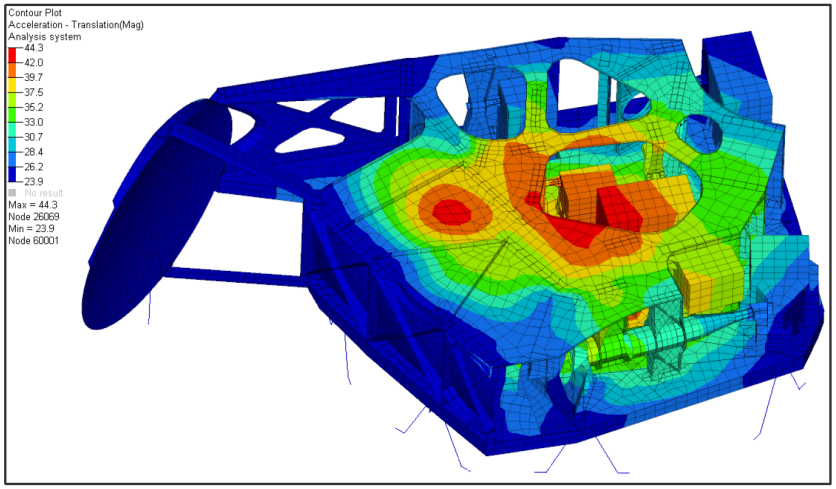
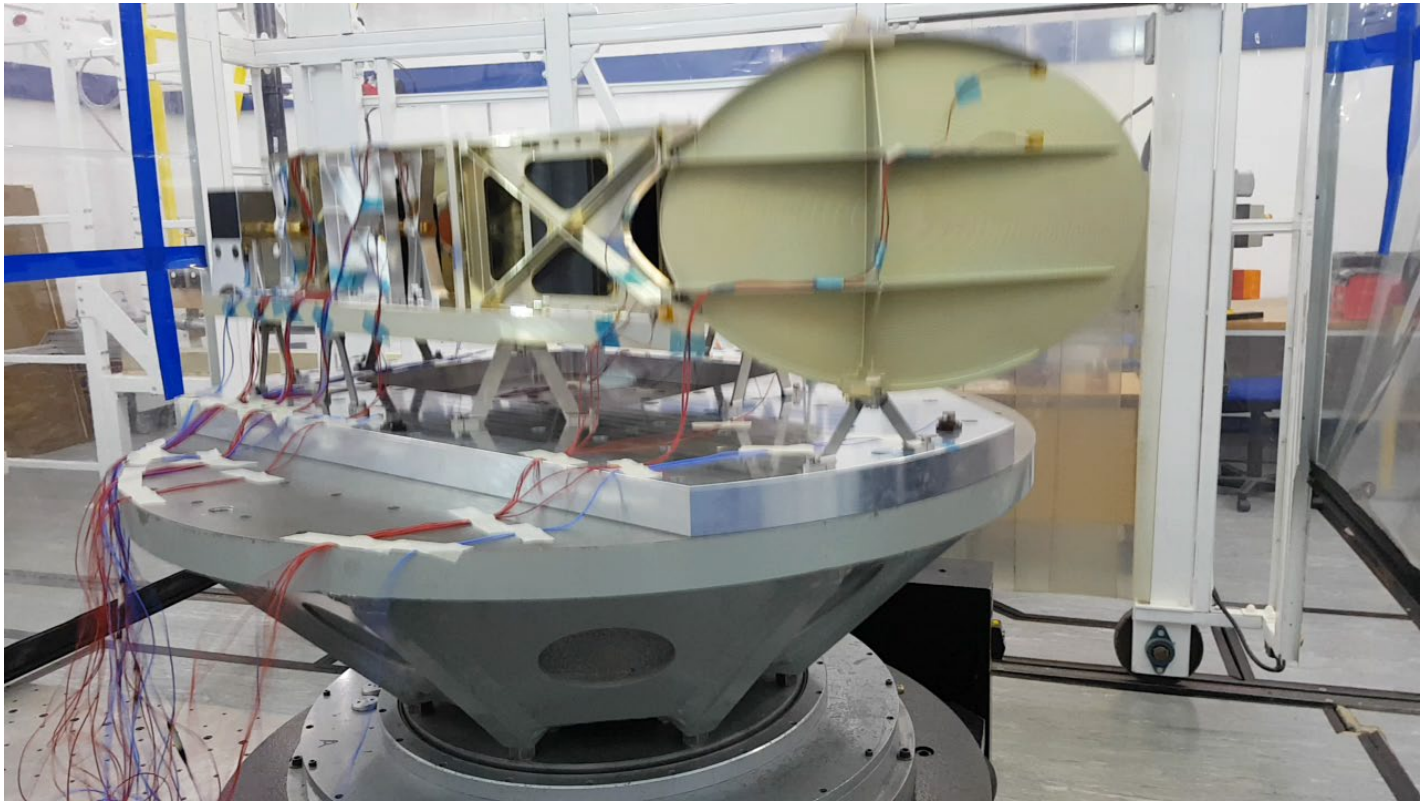
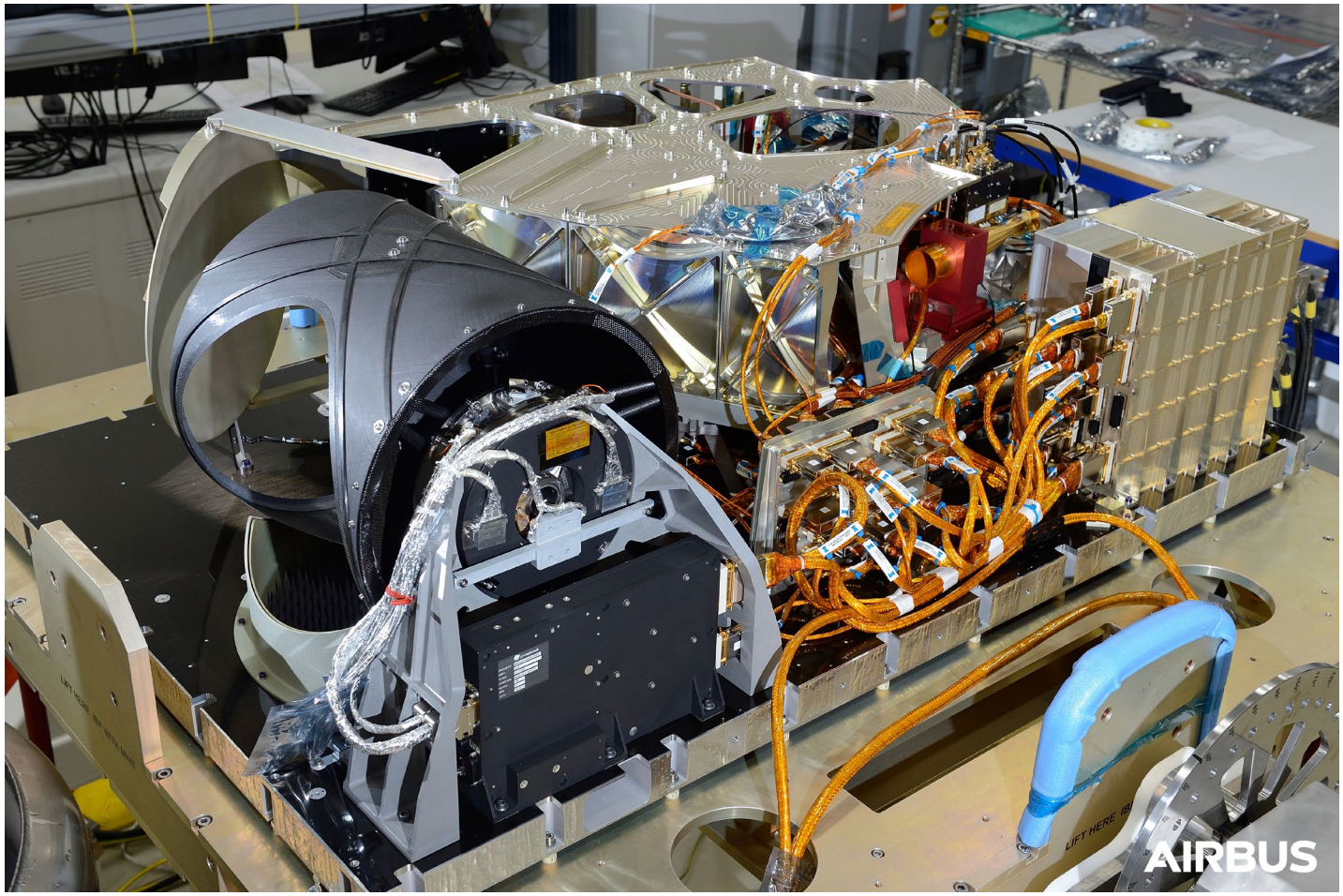


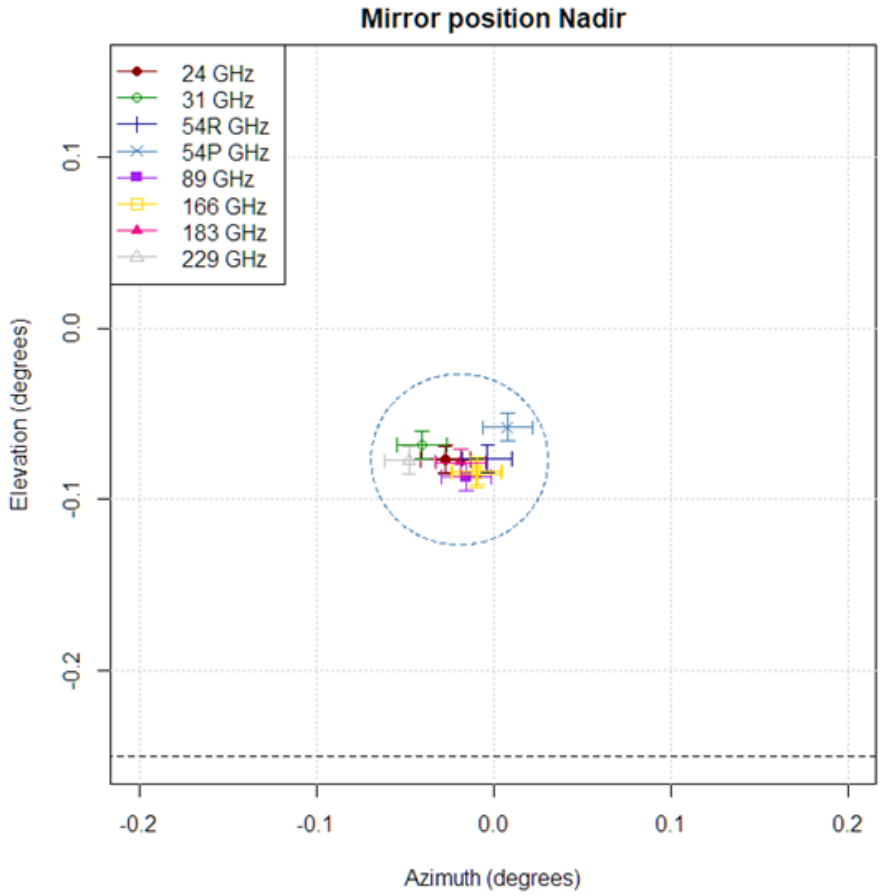
Figure 6-15: Sine Vibration, Acceleration Response (in g) to Z-Direction Excitation

MetOP-SG MWS EQM – 24g RMS



MetOP-SG MWS EQM



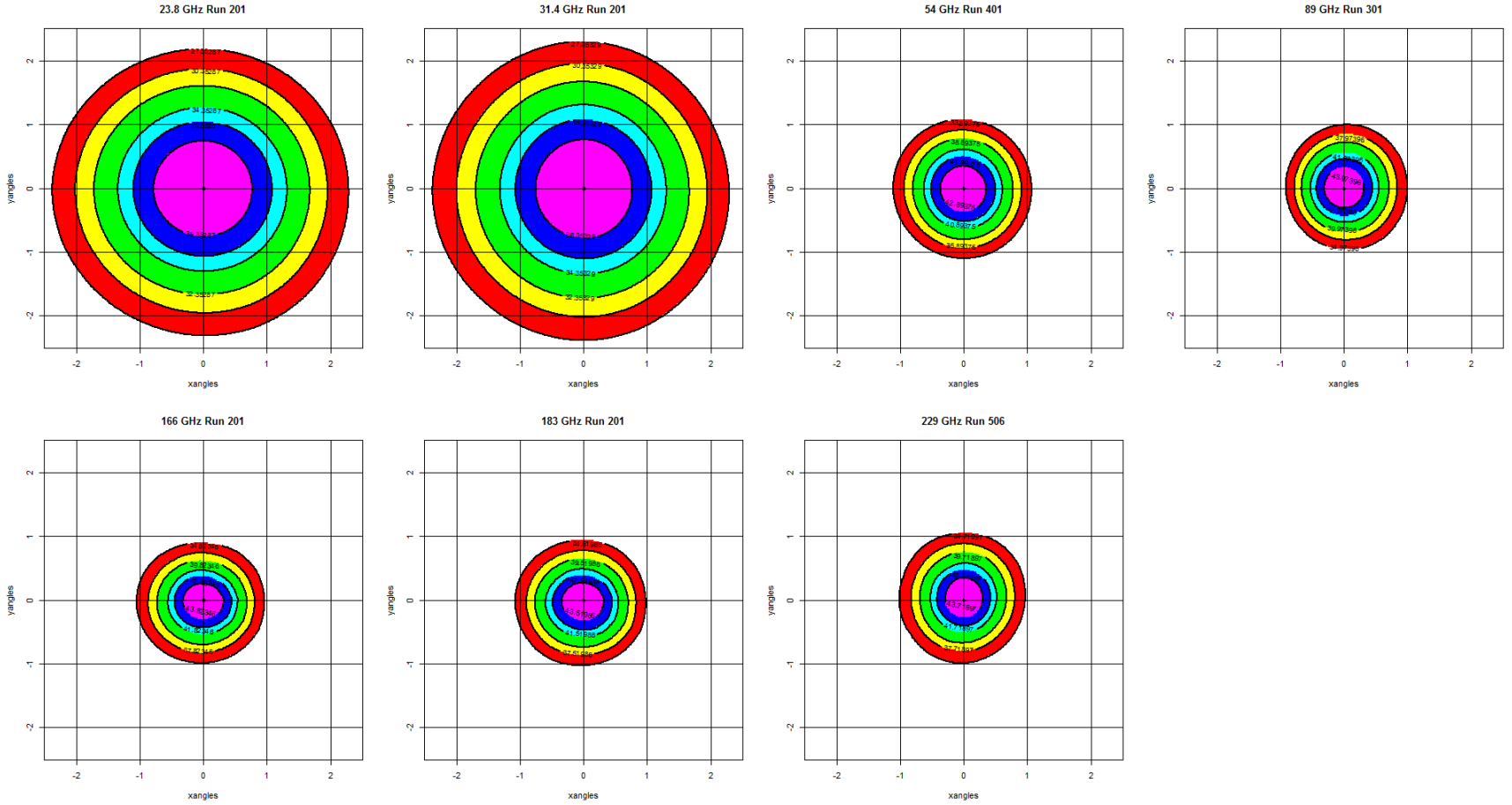


Pointing: MWS FM3

The requirement (blue circle) is +/- 0.05 degrees for relative pointing.

The diameter of the circle (0.1 degrees) is from ~4% to 10% of the HPBW depending on band.

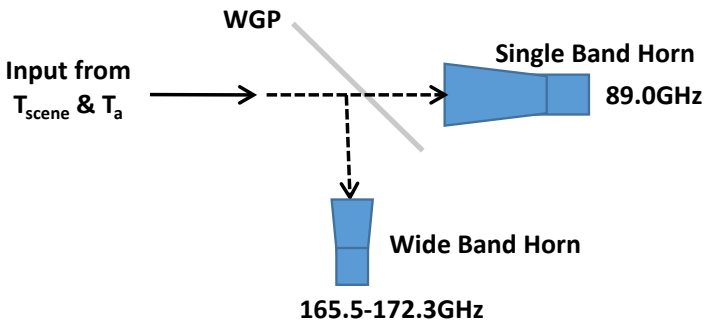
And – Beam Performance within requirements



Contours are at (approximately) -1, -2, -3, -5, -7 and -10 dB.

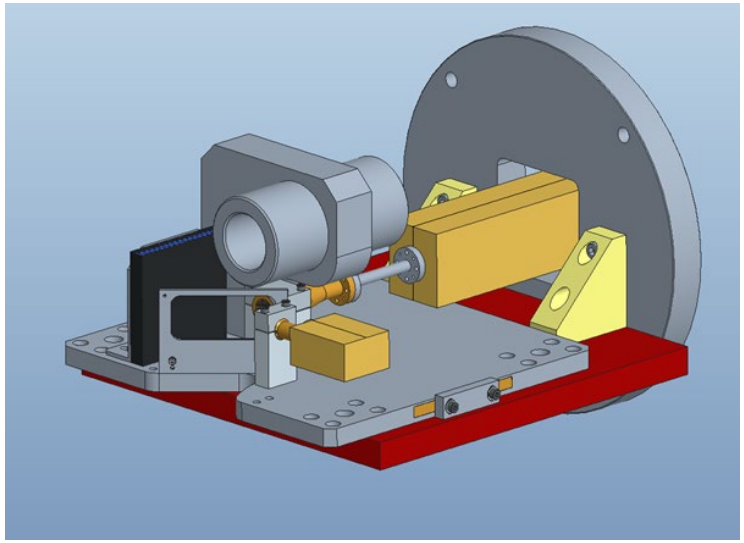
ESA Triband Study

The main objective of this activity was to design, manufacture and test a Multi-Frequency Feed, operating at frequencies from 89 up to 183 GHz, to be combined with an offset reflector. The testing was performed in a laboratory environment to demonstrate the performance and provide input to future ESA activities on the potential performance that can be expected from such a multi-frequency horn.



Parameter	Range/Value
Spectral Range (GHz)	89-229
• Priority 1	89,165.5,183-11
• Priority 2	183.3+LSB, 229
• Priority 3	118GHz,183.3+USB
Polarisation	Linear H or V
Insertion Loss (dB)	0.2dB (goal) 0.25dB (baseline) 89GHz
	>0.3dB 165.5GHz
Return Loss	>20dB (Baseline) >25dB (Goal)
Port to Port Isolation	>40dB

ESA Triband Study



Direction	WR8 89 GHz	WR5 165.5 GHz	WR5 172.311 GHz
Vertical /degrees	-0.022	-0.017	-0.0164
Horizontal /degrees	0.003	0.0034	0.0034

Absolute Beam Alignment
Relative – good to 0.006 degrees.

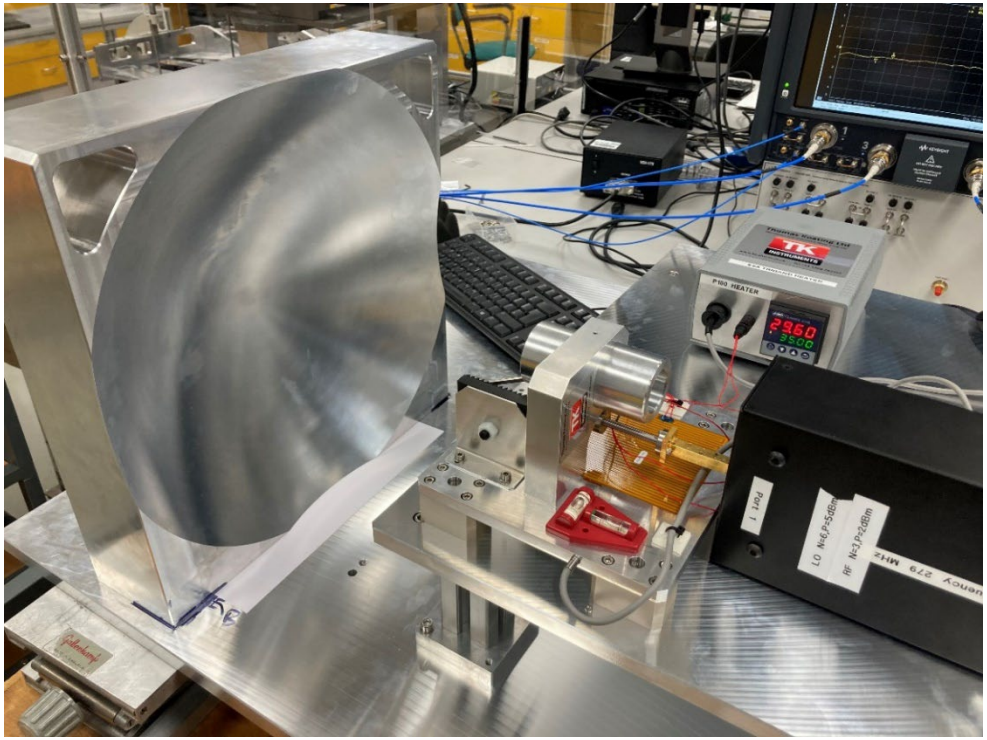
GRASP predicts pattern performance and Beam Efficiency with great accuracy

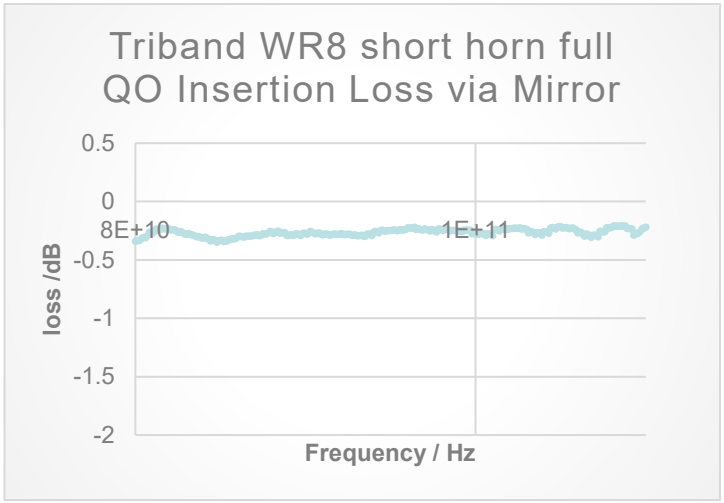
	BW min (deg)	BW max (deg)	BW mean (deg)	BE (%)	BE_Xp (%)	FBE (%)
HFSS predicted at 164.15 GHz	0.191	0.192	0.192	96.9	0.3	97.4
Measured at 164.15Hz	0.185	0.186	0.186	97.4	0.3	97.4

Measuring Triband

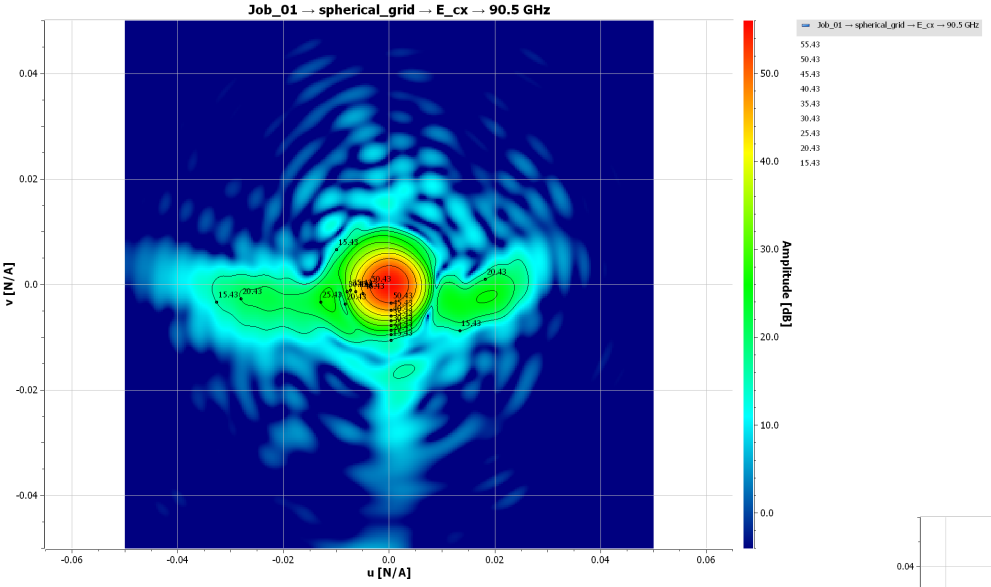
Measuring Triband

Insertion loss – via S11 refection from a matched mirror



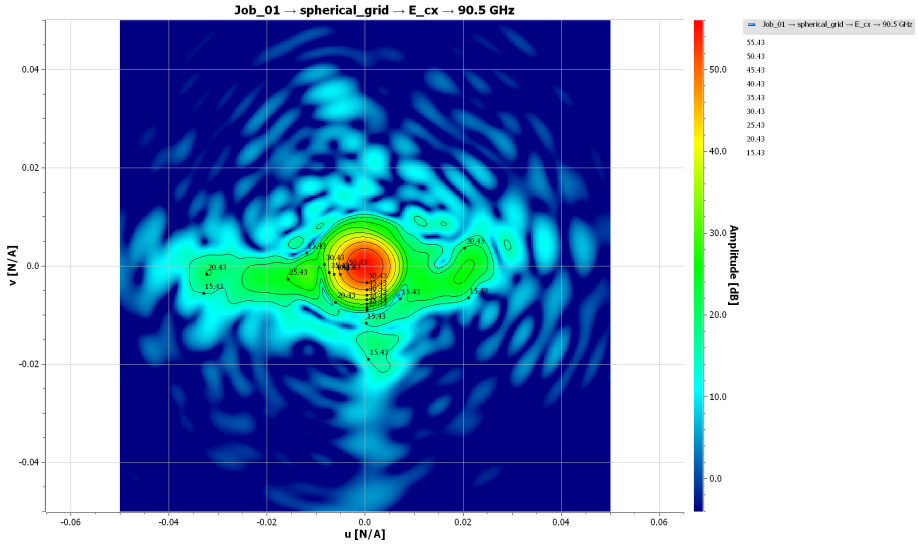


ESA Triband Study



Measured – Right

Predicted - Below



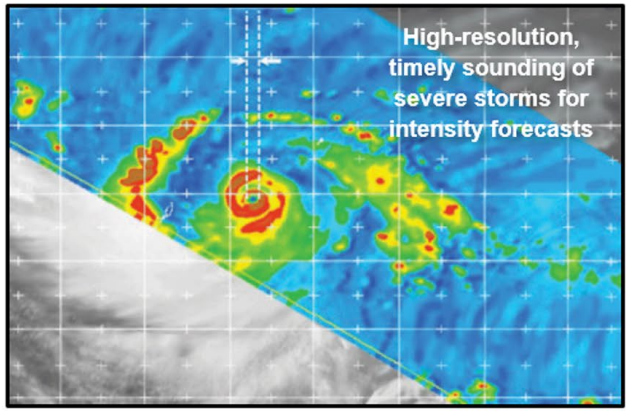
90.5 GHz (Upper Band Edge)Antenna Performance with Main Reflector

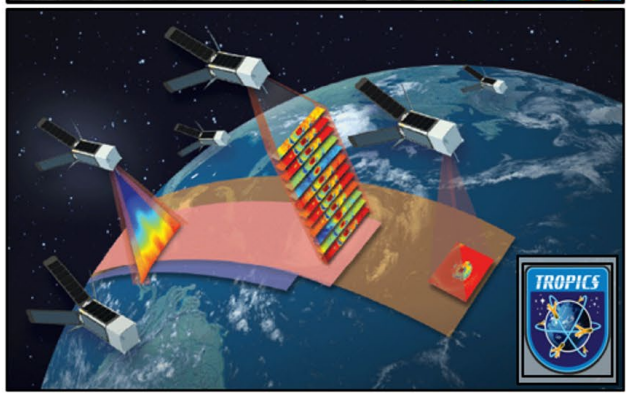
TROPICS

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

TROPICS – a NASA Earth Venture Instrument program – awarded March 2016

- **Innovative solution to provide data for severe storm intensity forecasts**
  - **Timely: 30 minute data update**
  - **Cost-effective: $30M + launch**
  - **Improved performance: all-weather retrievals of temperature, water vapor, precipitation, and cloud properties**
- **CubeSat constellation**
  - **4.5 kg, 10 Watts, 34cm x 10cm x 10 cm (each cubesat)**
  - **MIT LL 12-channel passive compact microwave radiometer**
- **Three 2020 launches provided by NASA to populate the constellation**

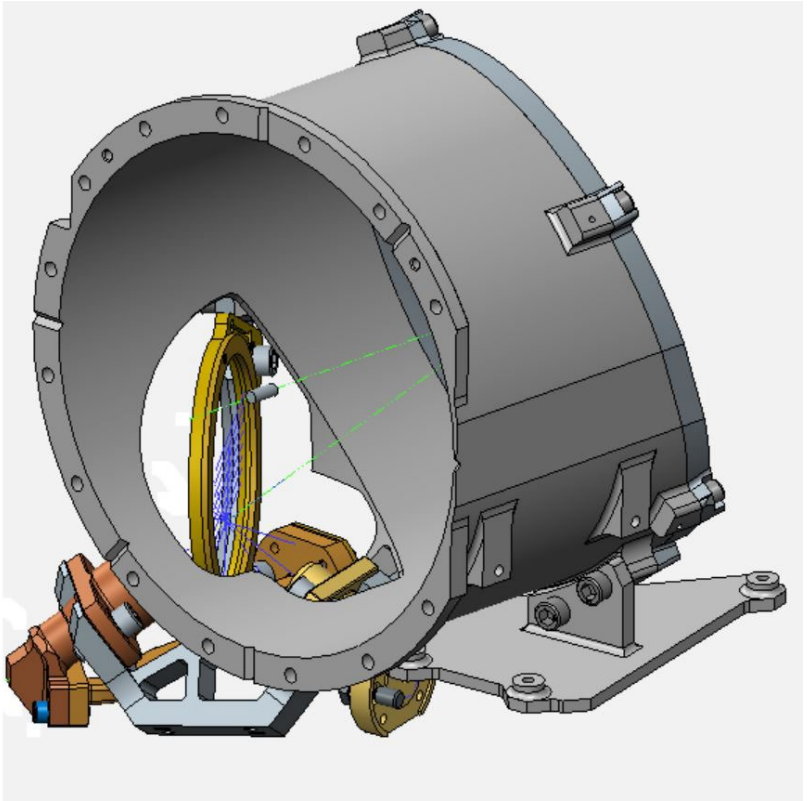




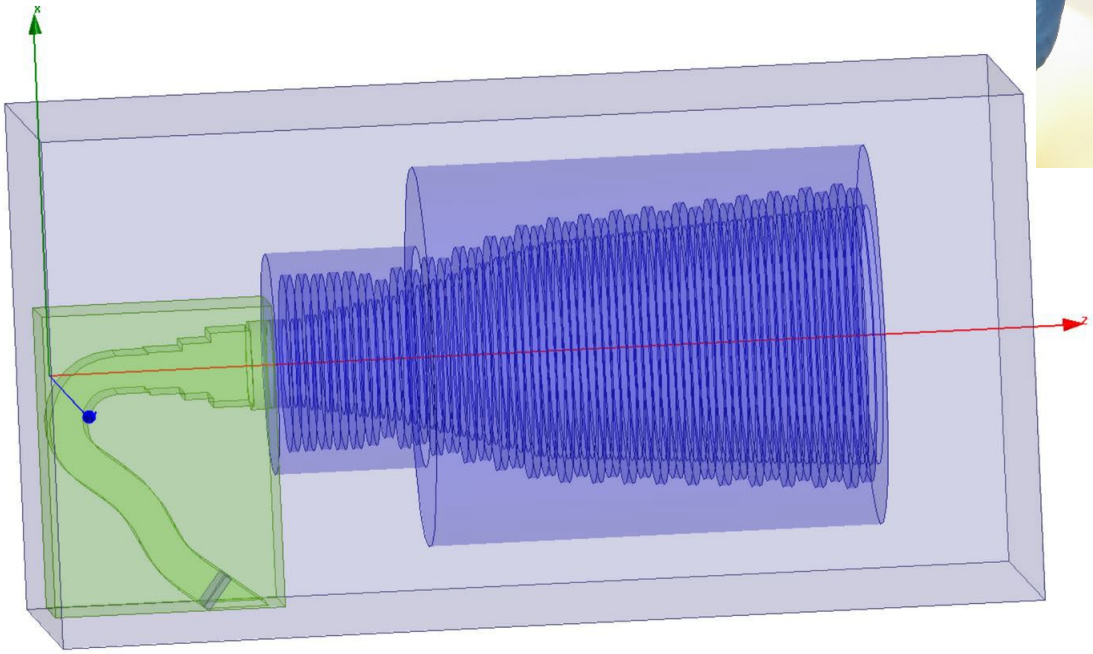
TROPICS

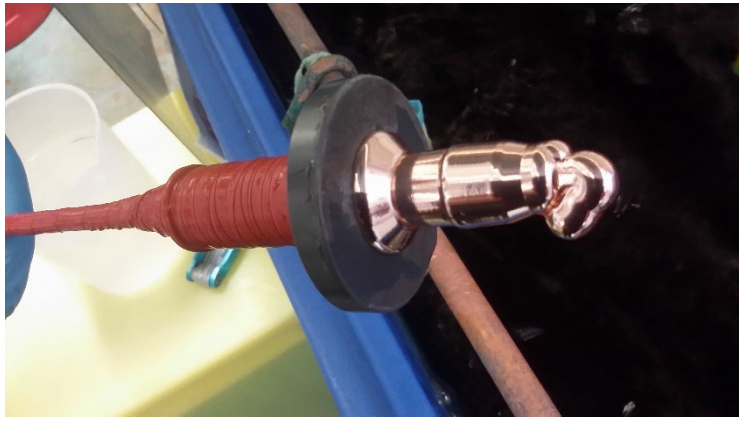
3U box --- with the radiometer housed in 100 by 100 by a little more tan 100mm spinning cube…

TK contracted to provide the Antenna



TROPICS





Grid based circuit to multiplex 89/115 and 183 channels using two very strange corrugated horn designs

Dual depth horn with good operational Return loss – though terrible where it is not need

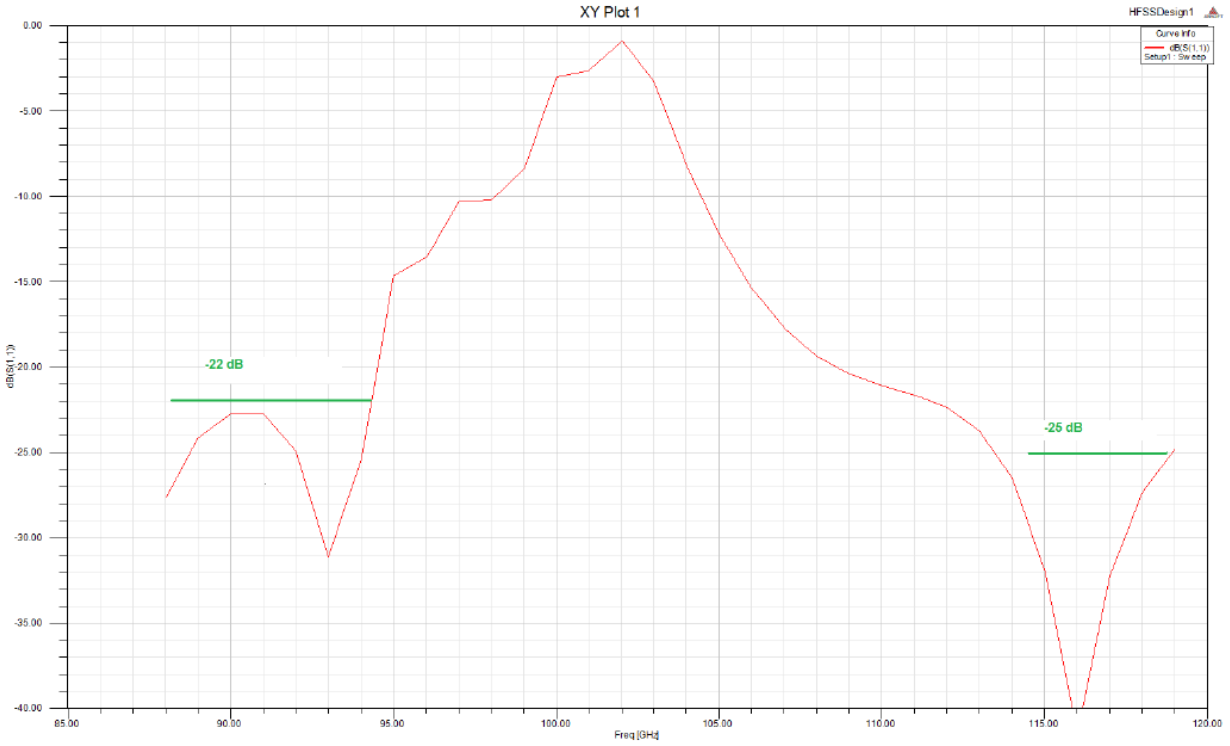
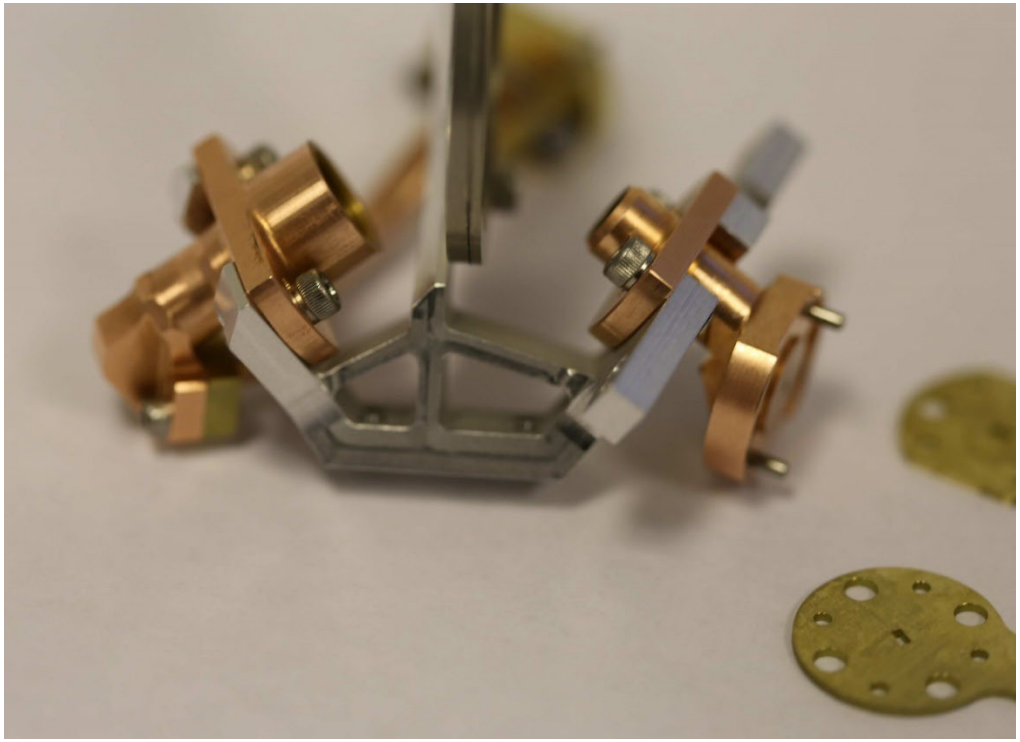
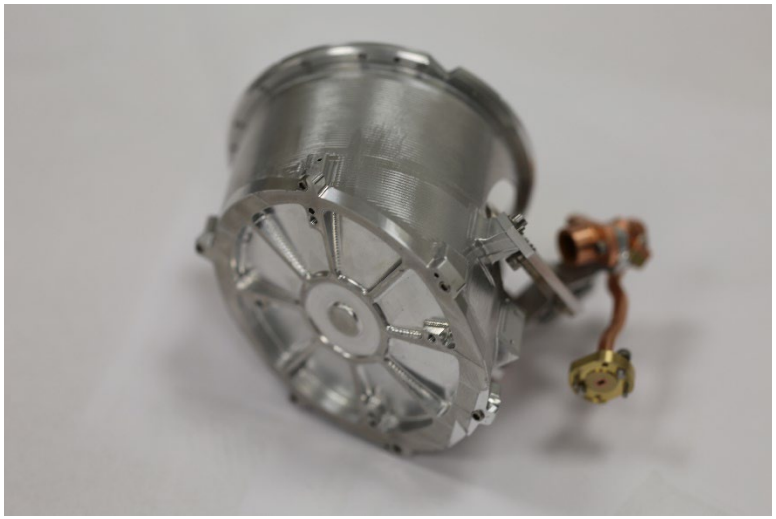


Figure 4-6: S11 over both bands.

Beam-co-alignment comes from reflection/transmission though an (almost electromagnetically perfect – 0.05dB losses/>40 dB rejection) free standing wire grid.

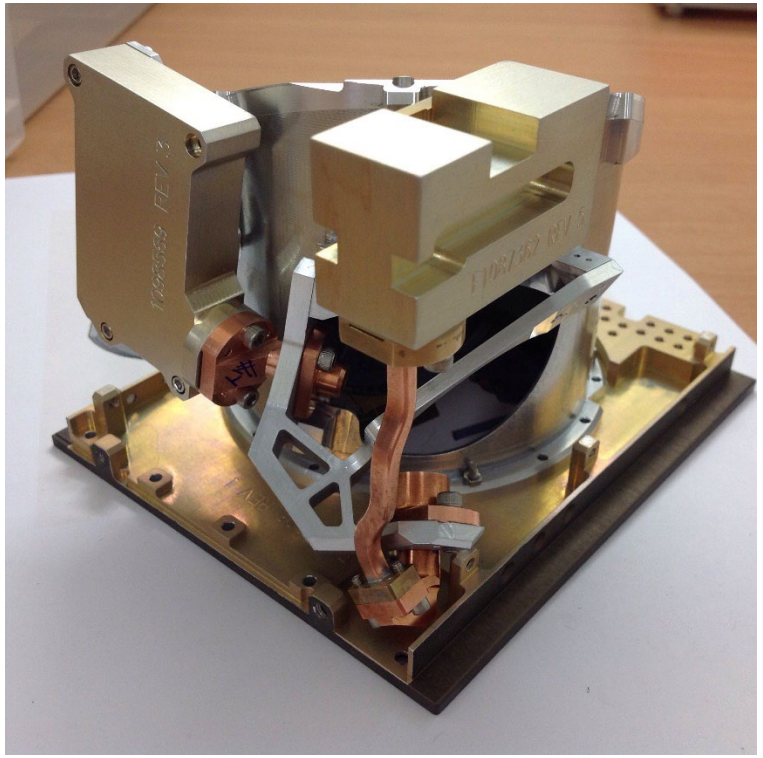




TROPICS

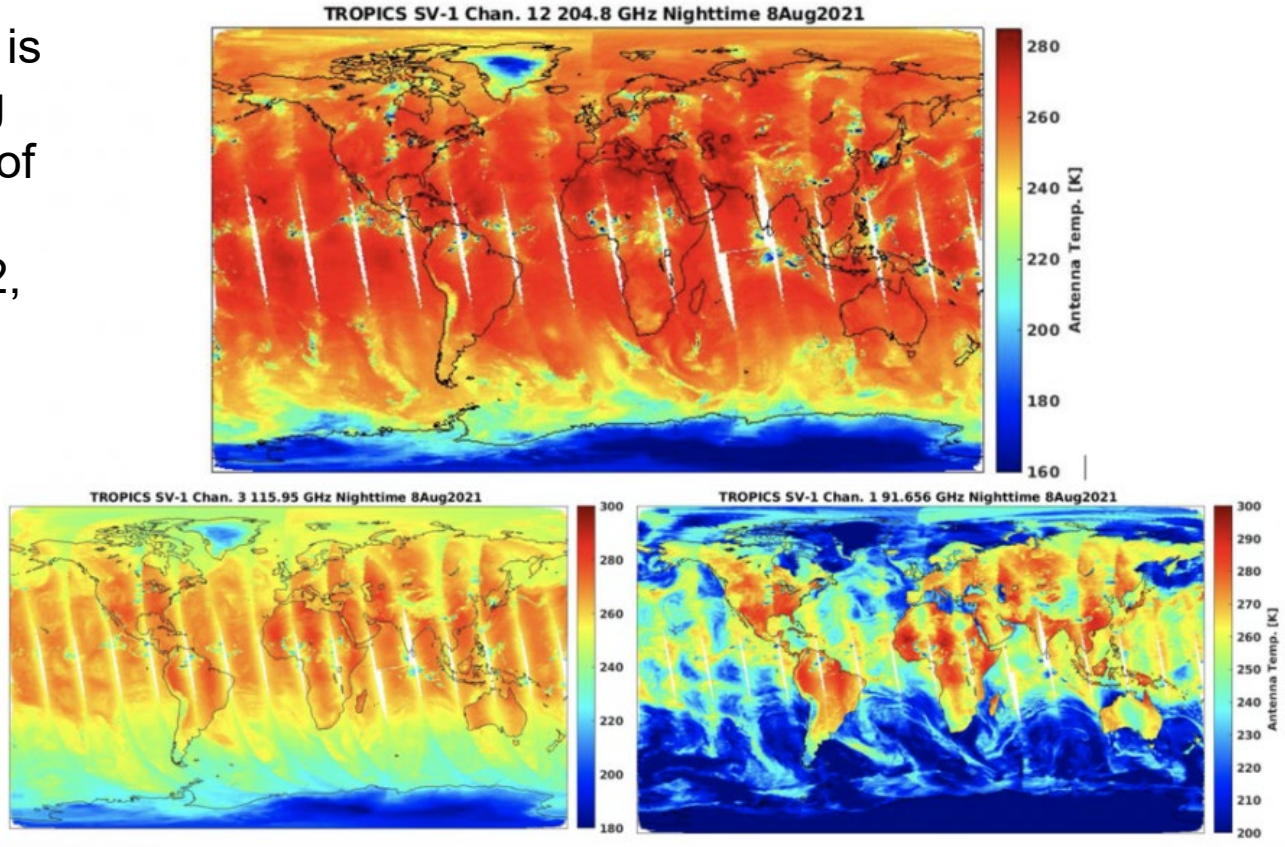
3U box --- with the radiometer housed in 100 by 100 by a little more tan 100mm spinning cube…

Every mm counts!

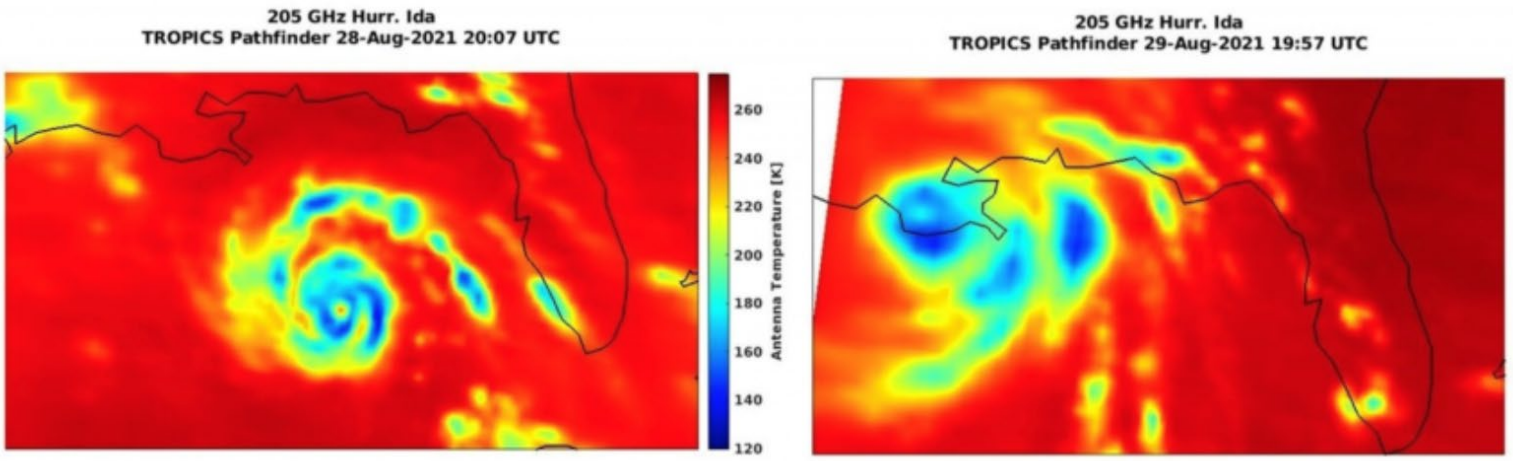


TROPICS

Launched on the 30th June 2022 into a polar orbit by SpaceX's Transporter 2 - is operating well, and giving useful mm-wave images of the whole globe - three examples of which (at 92, 116 and 205 GHz) are below



TROPICS


205 GHz Hurr. Ida
TROPICS Pathfinder 28-Aug-2021 20:07 UTC
260
240
220
200
180
160
140
120
Antenna Temperature [K]
205 GHz Hurr. Ida
TROPICS Pathfinder 29-Aug-2021 19:57 UTC

Take home message:

Very well co-aligned, high beam-efficiency, low loss space-qualifiable multiplexed antennas

……are available