May 4th
2017

Microwave Radiometry for Accurate Coastal Altimetry

Background

- Microwave radiometers have a long heritage of providing a dedicated wet tropospheric correction to the path delay of radar altimeter pulses due to water vapour content within the troposphere. In general, the water vapour measurement is performed for which the radar altimeter footprint lies within the radiometer beam in order to obtain time-coincident data.
- With the introduction of synthetic aperture processing in radar altimetry, more accurate altimetry data is available for coastal and inland waters. However, the quality of radiometer data in these areas is degraded with respect to those of the open oceans due to the rather wide field of view of the MWR (~20 km) and contamination by land brightness temperatures which fall within the MWR foot-prints.
- Hence a long standing recommendation on potential improvement of the Jason-CS mission, made by the radar altimetry community during the Ocean Surface Topography Science Team Meeting in 2012, [RD-1]: “The most significant benefit from the embarkation of a second radiometer would be for the second radiometer to operate at high frequencies to resolve km-scale water vapour to improve coastal altimetry and inland hydrology applications”.
- JCR Systems is leading the third in a succession of ESA studies into enhanced microwave radiometers with the objective of improving the wet tropospheric correction : particularly in coastal regions. (The commonly agreed requirement on WTC for current missions is to retrieve WTC with an error better than 1cm rms.)

Background

- **Objective of current studies is to address MWR instrument design for future operational radar altimetry missions such as next Generation Sentinel-3 and Jason-CS+.**
- **Such a design was to be compact and to include the classical, current MWR channels for ensuring observation continuity, augmented by a set of high frequency channels for enabling accurate altimetry over coastal and inland waters.**
- **Design goals are three fold:**
  - **Improved spatial resolution**
  - **Improved spatial discrimination**
  - **For non sun synchronous missions : improved radiometric accuracy.**

Mission Requirements

- Working with CLS at present (responsible for Sentinel 3 MWR & Altika WTC) to identify preferred frequency suite.
- Still under development, but sufficient to identify new technology requirements
- However preliminary instrument specification appears to look very similar to MWS &MWI:

Channel No.	Centre Frequency (GHz)	Bandwidth (MHz)	Antenna Loss (dB)	Trec (K)	NeΔT (K)		Spatial Resolution (Alt 817km / 1336km)
					Prediction	Req'mt	
2	23.8	400	0.9	264	0.07	0.15	<15 km / < 25 km
3	36.5	200	0.9	335	0.09	0.15	<15 km / < 25 km
4	53.596	400	0.5	351	0.09	0.2	<10 km / < 15 km
5	89.00	3000	0.6	450	0.11	0.2	<5 km / < 10 km
8	165.0	1350	0.9	1048	0.23	0.30	<5 km / < 10 km
9	183.311-11.00	2000	0.9	957	0.21	0.30	<5 km / < 10 km

- Beams to be co-aligned
- Beam Efficiencies to be ~98-99% for "full" beam efficiency (3x HPBW)

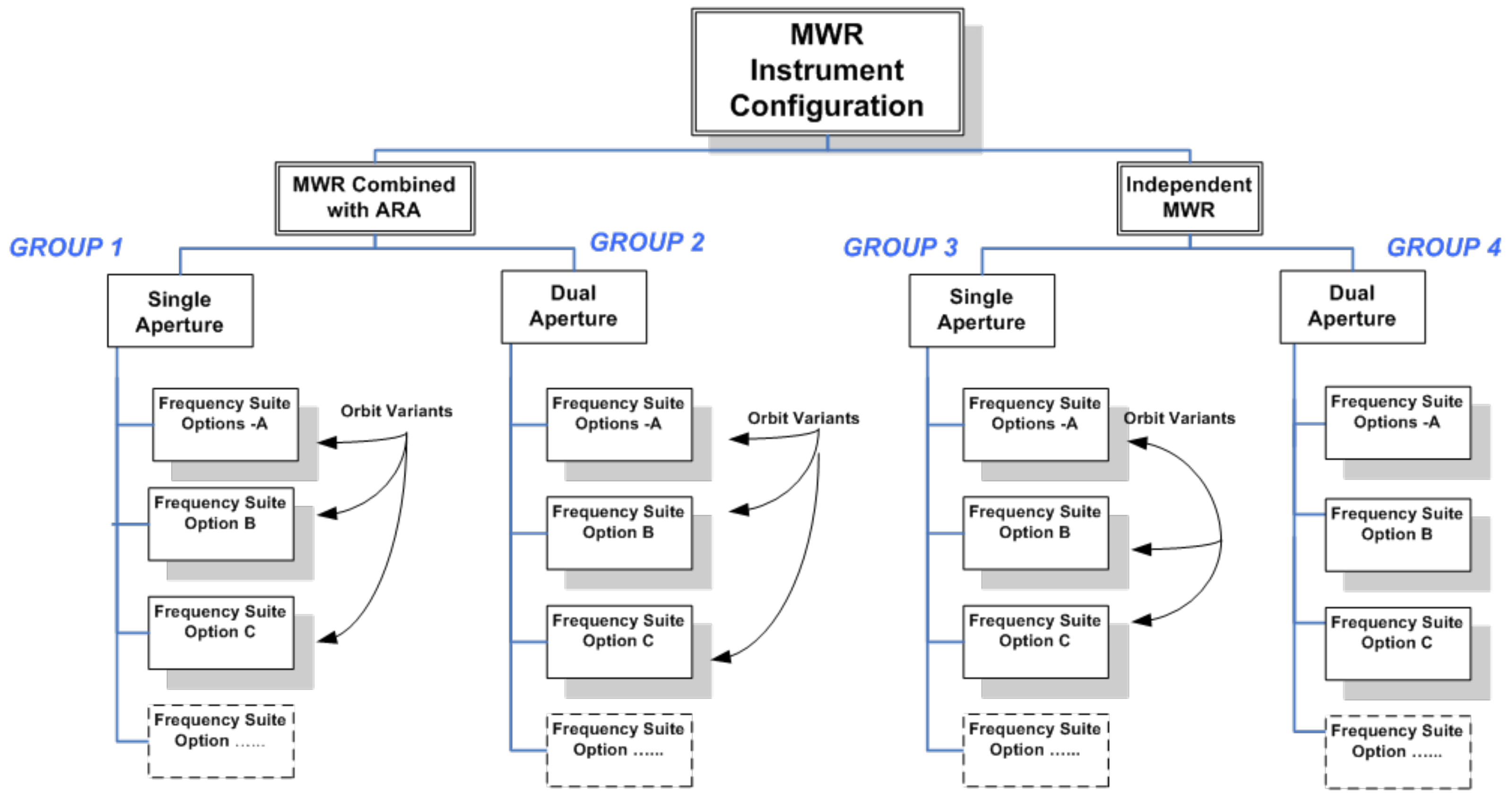
Mission Requirements

Frequency Band (GHz)	Spatial Resolution		Comparison with Current Missions
	817km SS Orbit	1336km Non SS Orbit	
18.7	<15km	<25km	JASON-2 & 3 33.5km,
23.8	<15km	<25km	Altika 12km, Sentinel 3 23.5km JASON 26.8km
36.5	<15km	<25km	Altika 8km, Sentinel 3 18.5km JASON (34GHz) 19.8km
53.596	<10km	<15km	MWS 20km. MWI 30km
89	<5km	<10km	MWI 10km, MWS 17km
110/118	<5km	<10km	
165	<5km	<10km	
183	<5km	<10km	

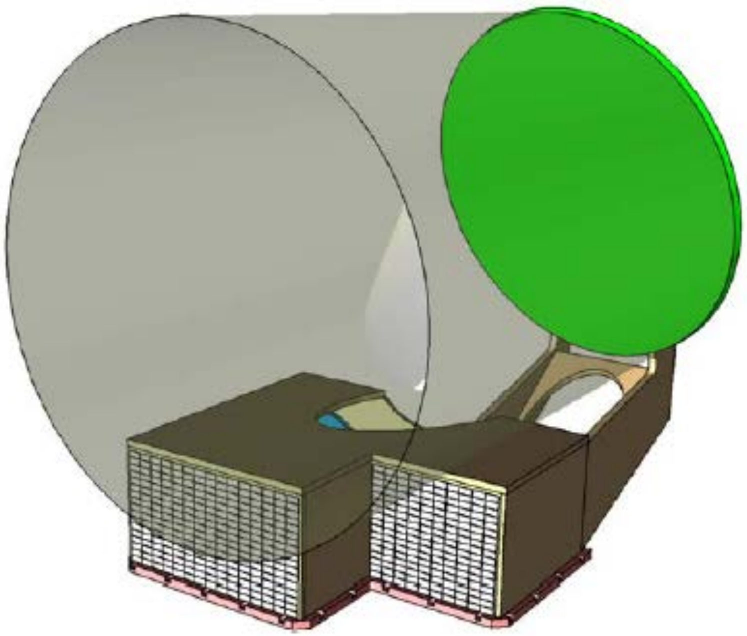
- **Implying that apertures are of the order of ~1.1m**

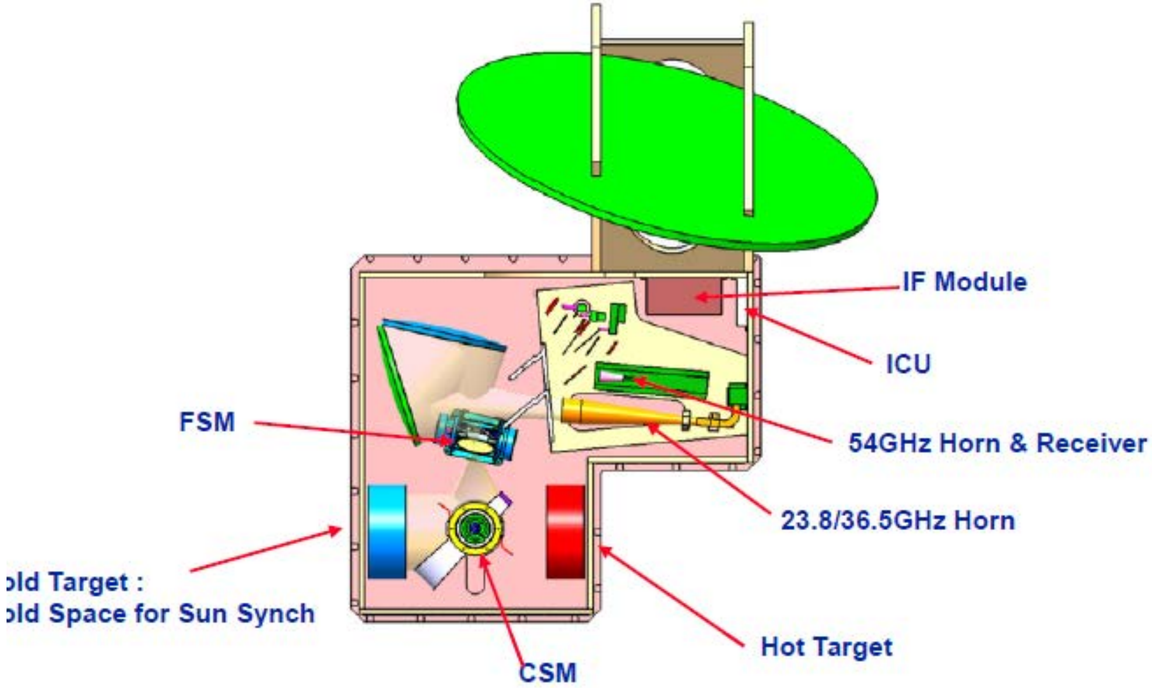
May 4th
2017

Instrument Options



Initial Antenna Configuration from RD1

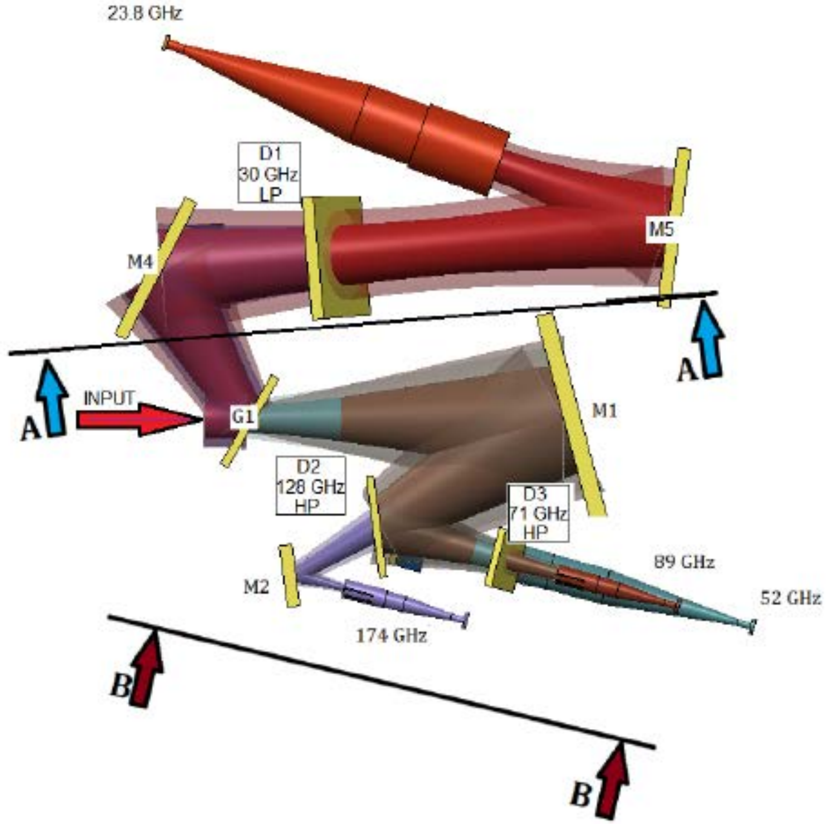


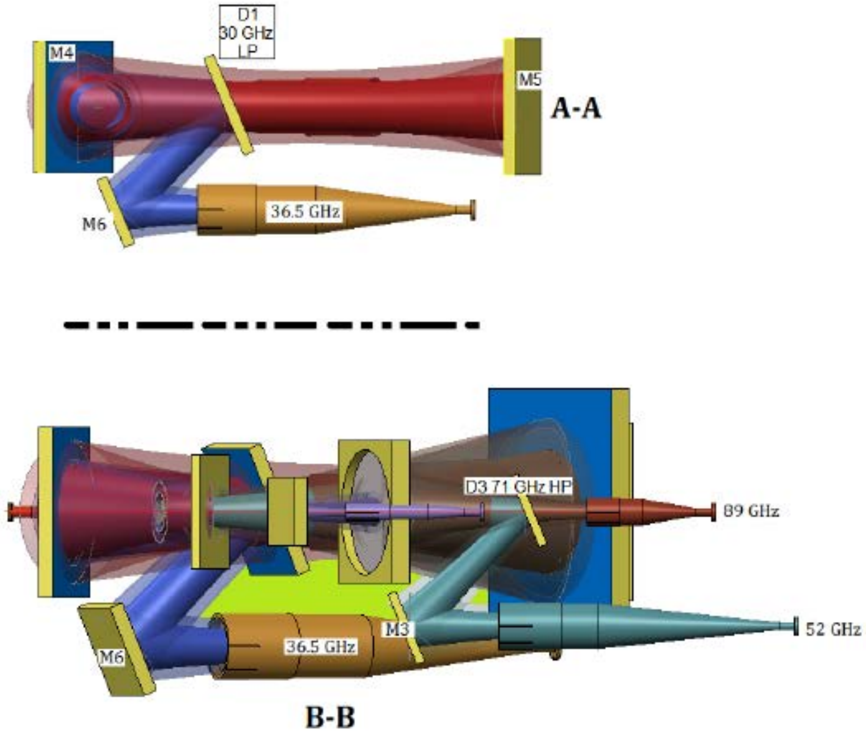


- **Illustrating strong similarities with MWS using UK QON technology from Cardiff & Thomas Keating**

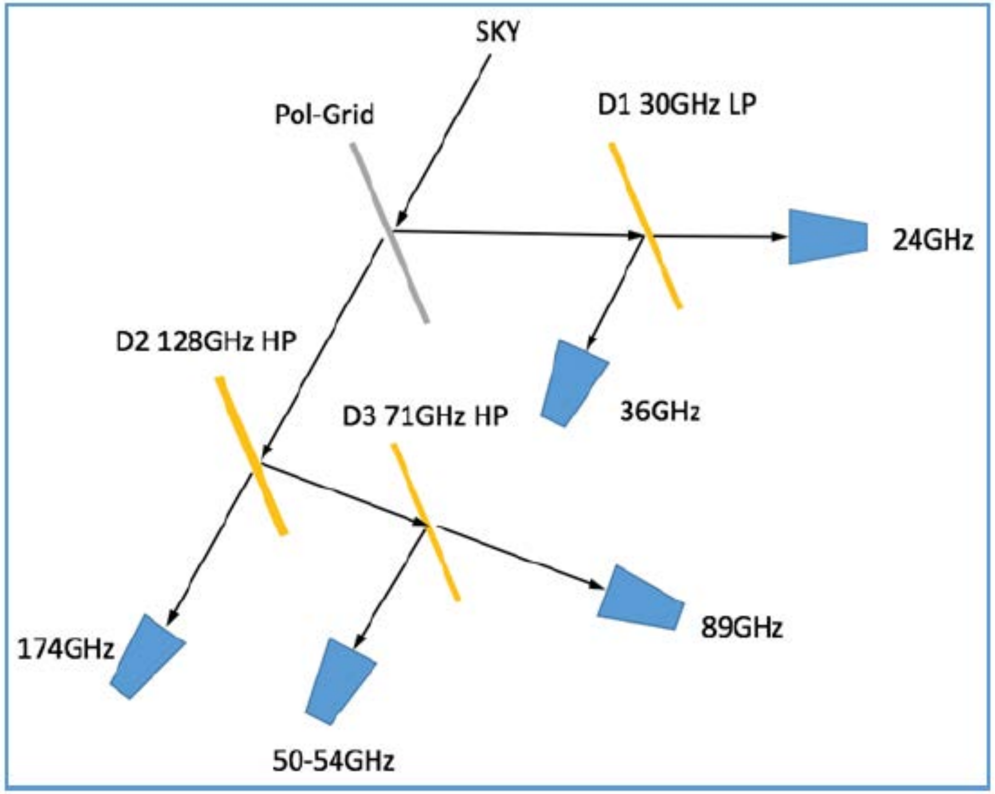
QON Topology

- Establishing initial topology dictated by length of horns.
- More efficient w.r.t. volume to use WGP operating at 32.5°, instead of D4 at 22.5°,.
- Folding mirrors driven by illumination constraints to minimise spillover, control cross polarisation and retain circularity.





Diplexing Configuration



Diplexer-	Type Function	Frequency
G1	High Pass	WGP -
D1	Low Pass	30GHz
D2	High Pass	128GHz
D3	High Pass	71GHz

- **Proposed network employs a polarising grid, and three dichroic plates (DCPs).**
- **The design driver is to reduce the requirements on the DCPs, such that no single DCP has to cover the entire frequency range of the instrument.**
- **Dichroics are based on the dielectric embedded metal mesh designs described in TN1a, and as currently used for MWS**
- **Each of these dichroics operate at an angle of 22.5 degrees to the incident beam.**
- **Additionally, the choice of a high-pass (HP) or low pass (LP) DCP is set by the transmitted bandwidth of the DCP.**
- **Predicted performance of each DCP:**

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DCP Performance

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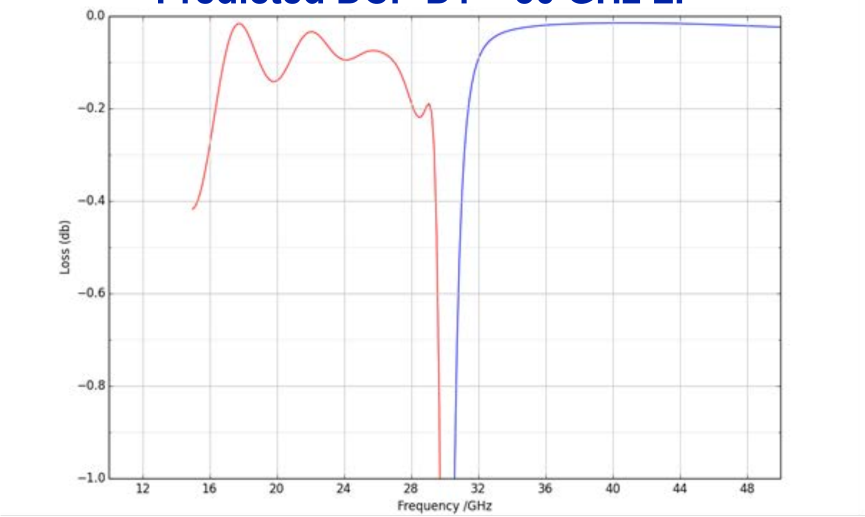
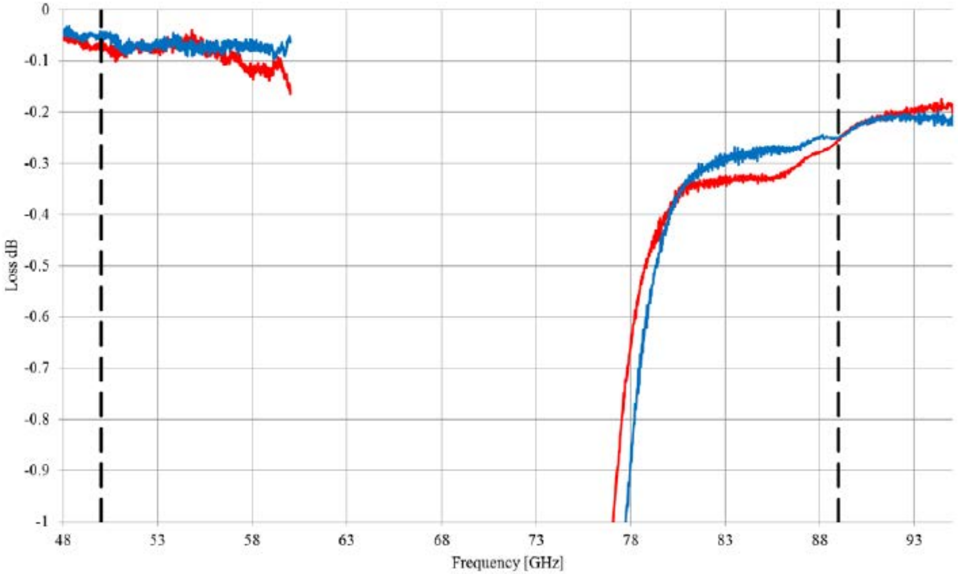
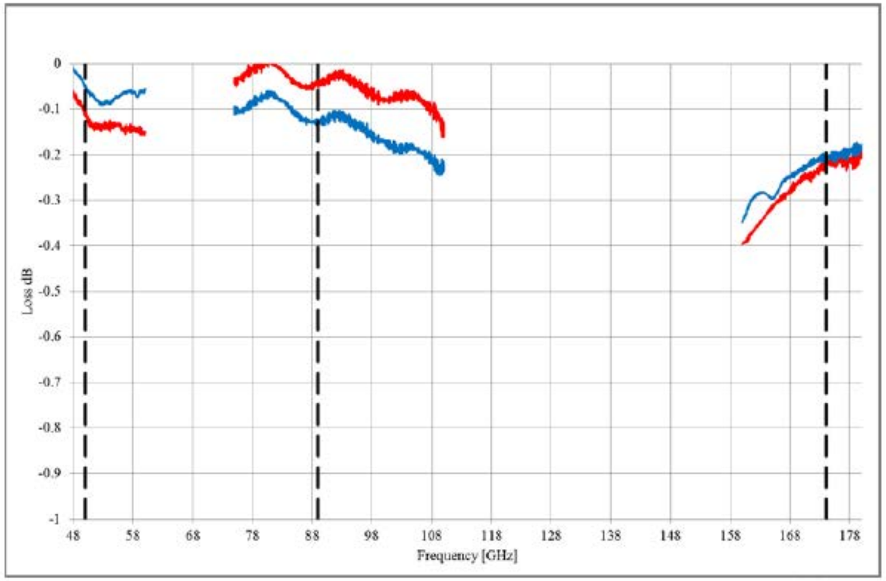
Predicted DCP D1 – 30 GHz LP



Measured DCP D3 – 71 GHz HP



Measured DCP D2 – 128 GHz HP



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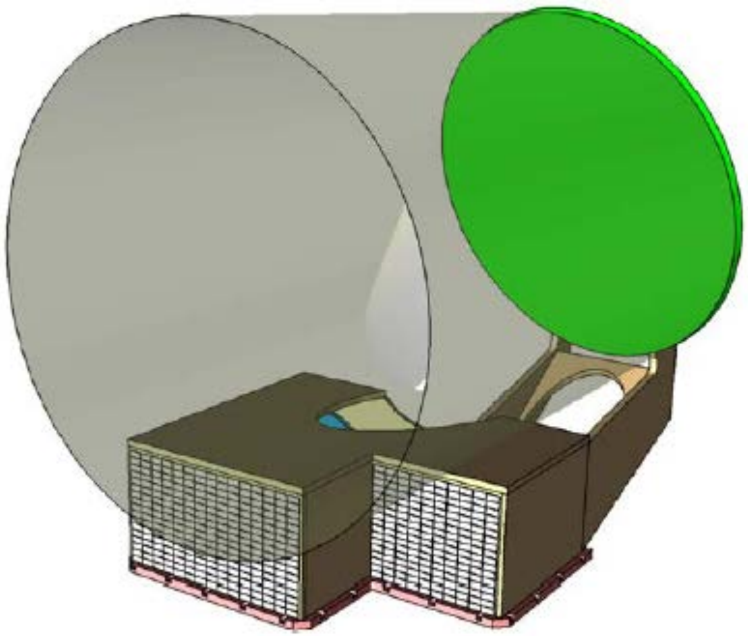
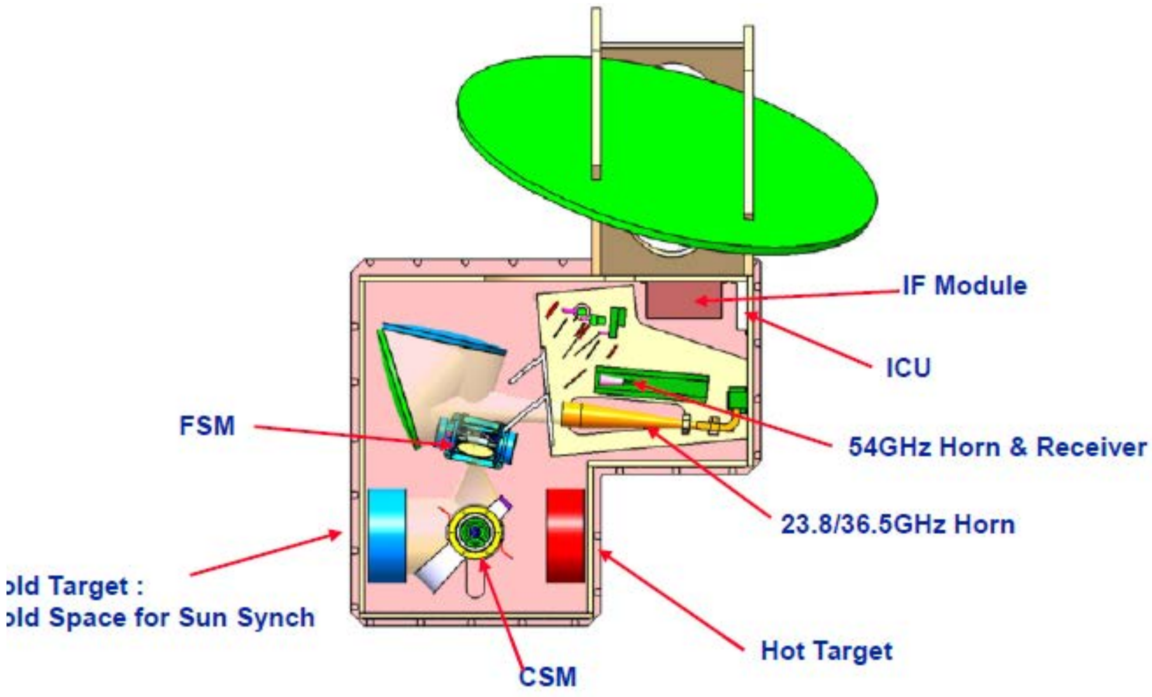
CARDIFF UNIVERSITY
S.M.T. Consultancies Ltd.
TK INSTRUMENTS

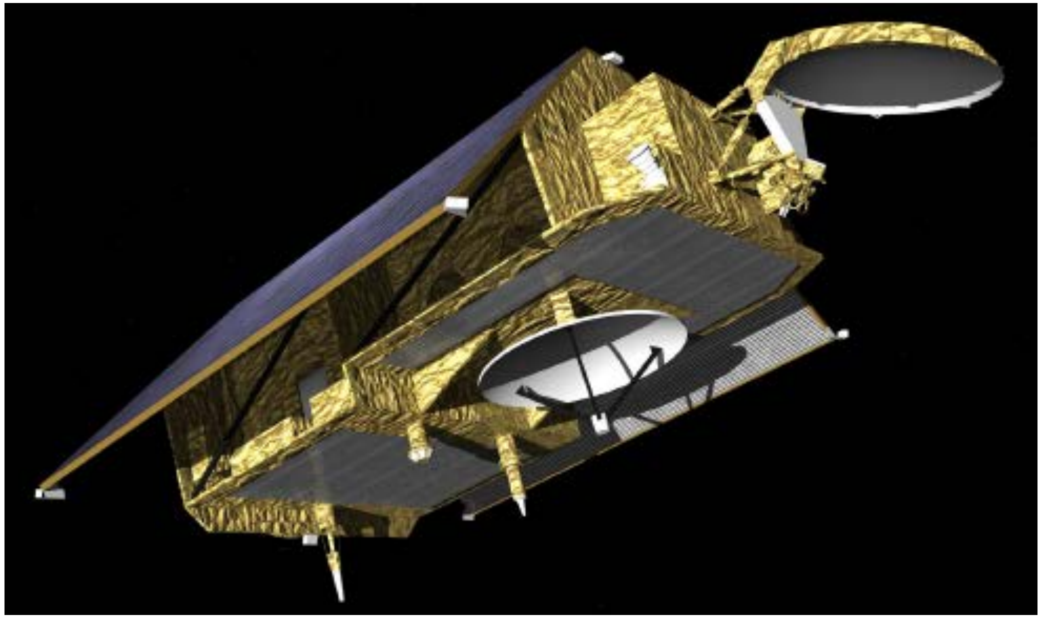
Initial Antenna Configuration from RD1





- **Illustrating strong similarities with MWS but with significant pressure to make more compact as above is**
  - **1.6m (Height) x 1.4m (Width) x 1.6m (Depth)**

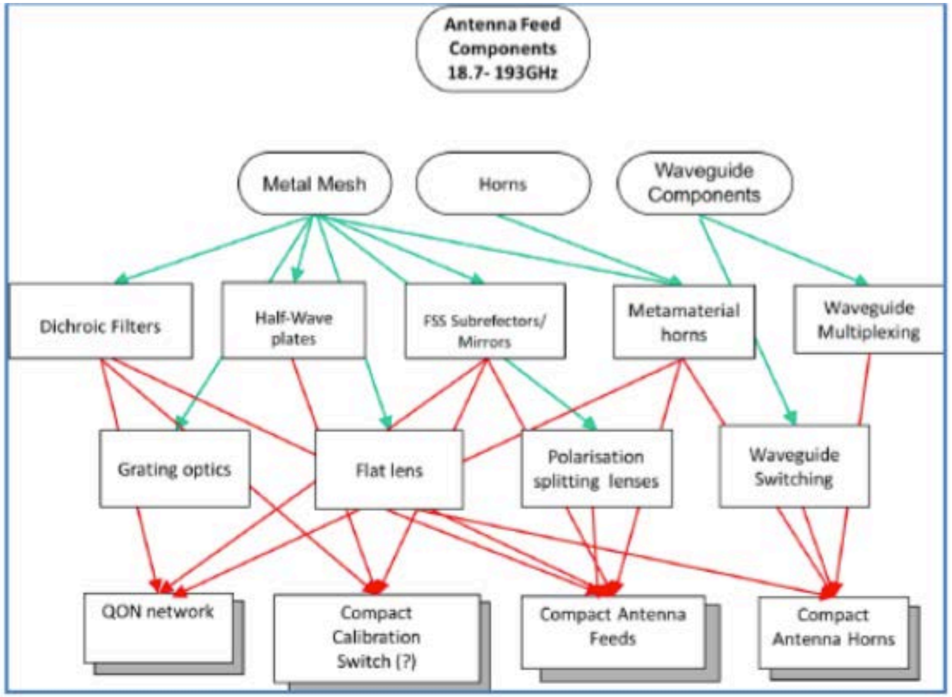
Volumetric Issues



- Dedicated Radar Altimeter missions tend to provide balcony face to larger MWR.
- Multi functional mission platforms have not YET flown large MWR
- Pressure to share to launch for dedicated RA missions
- Illustration shows AMR-C (JPL provision)
- Must be more compact – yet retain radiometric performance

State of the art technology review

- **Overview of components that can be created using mesh technology**
- **Highlight current state of the art as well as new concepts.**



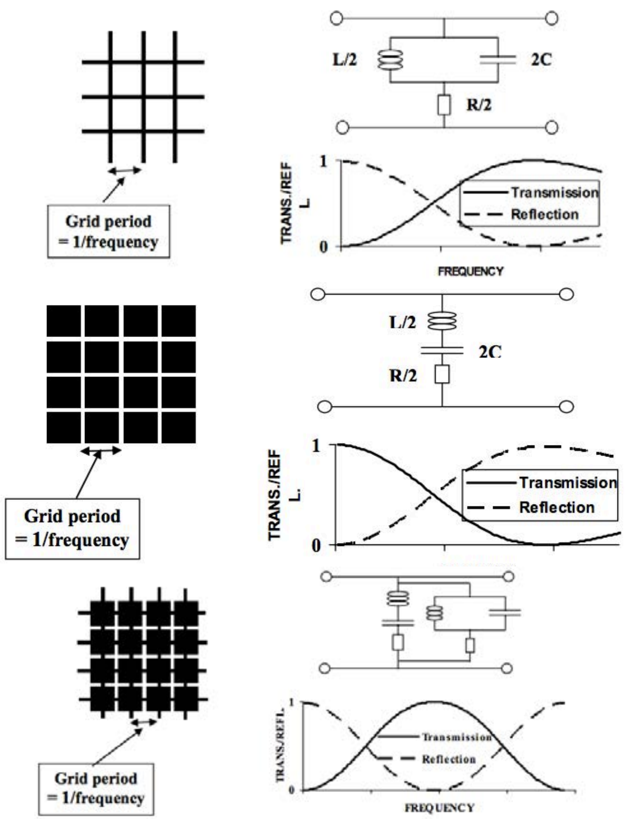
State of the Art Technology Review

- Filtering devices
  - Cardiff Filters
  - Cardiff Dichroics
  - QUB Dichroics
- Focusing devices
  - GRIN Lens
  - Polarisation Splitting Lens
  - Phase Modulation Lens
  - Lens array
- Polarisation devices
  - Transmitting HWP
  - Reflecting HWP
  - Polarisation rotators
- Mesh Horns
- Waveguide Components

- As well calibration switching technologies such as super flex pivots
- Ultra gain stability within receivers due to longer calibration cycles

Metal Mesh Filters

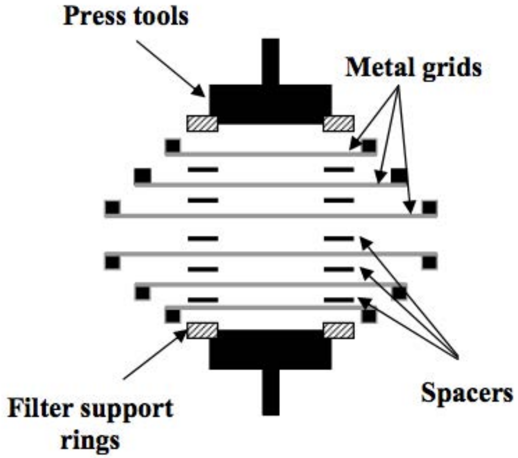
- Metal Mesh filters are the oldest Metamaterial based devices.

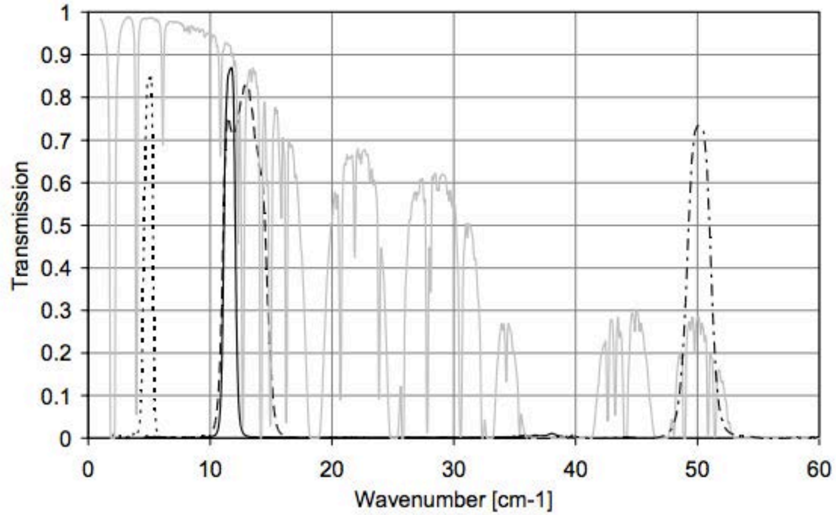


- Periodic structure, smaller then wavelength of interest.
- A single grid consists of copper on polypropylene.
- Made using photolithographic etching.
- Depending on the chosen geometry, the grid will have a certain filter response.
- Can be modeled using transmission line approach.

Metal Mesh Filters

- Filtering properties of grids can be improved by combing multiple grids together.





Band pass filters for atmospheric window selection.

- Filters can be made with an air-gap or 'Hot Pressed'.
- The latter forms a solid device which is very robust.

Metal Mesh Filters

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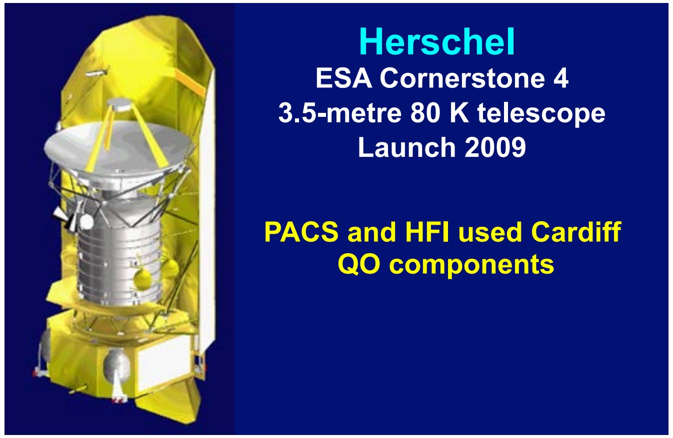
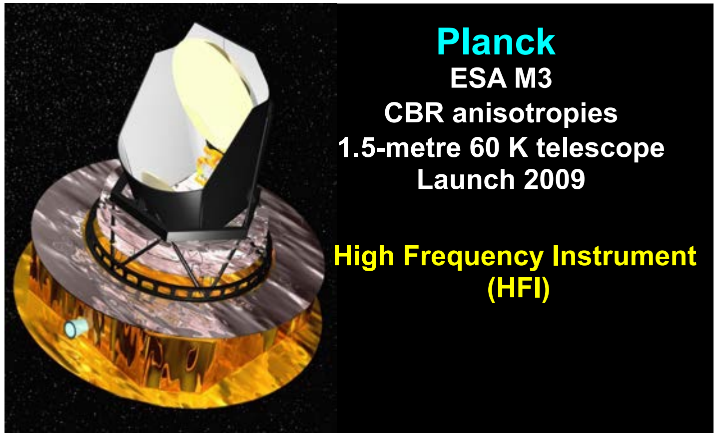
- **Filters based on these components have be used in many telescopes and satellites.**





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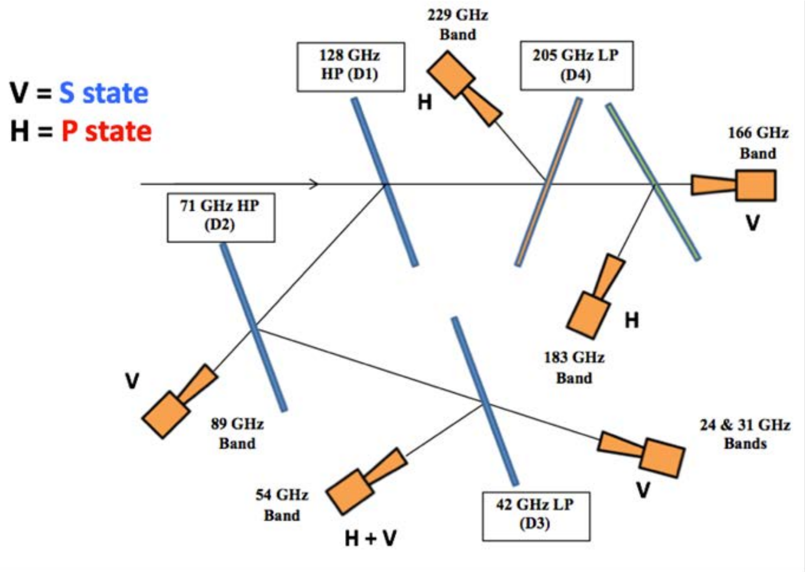
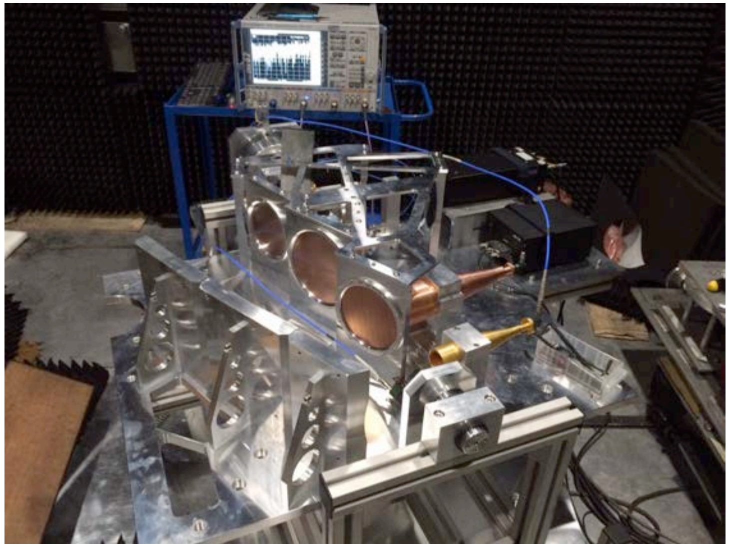
TK INSTRUMENTS

Metal Mesh Dichroics

- Cardiff have produced Dichroics for MWS – MetOp-SG





- Covered 24-229GHz – Combination of Low and High pass Dichroics
- Devices fabricated with a 300mm diameter and then cut down.
- Designed to operate at 22.5 degrees. Can operate at 45 degrees.
- All dichroics are polarisation insensitive.

State of the Art Technology Review

- Filtering devices
  - Cardiff Filters
  - Cardiff Dichroics
  - QUB Dichroics
- Focusing devices
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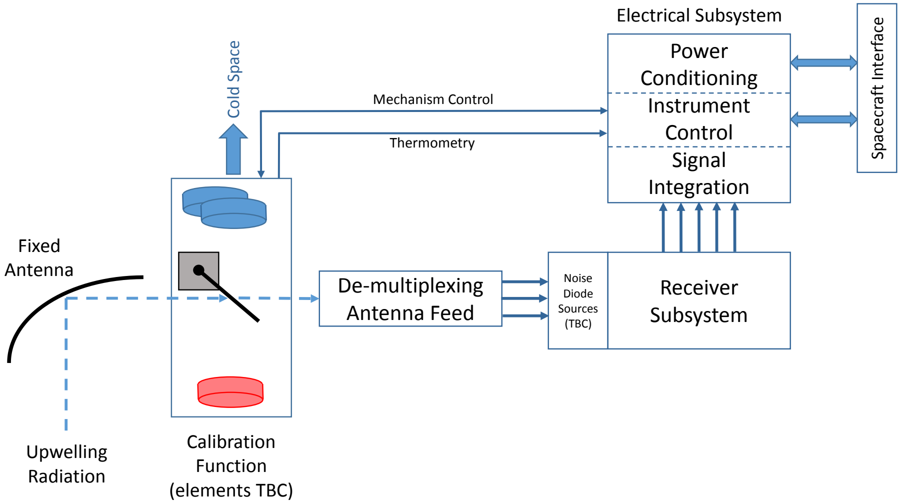
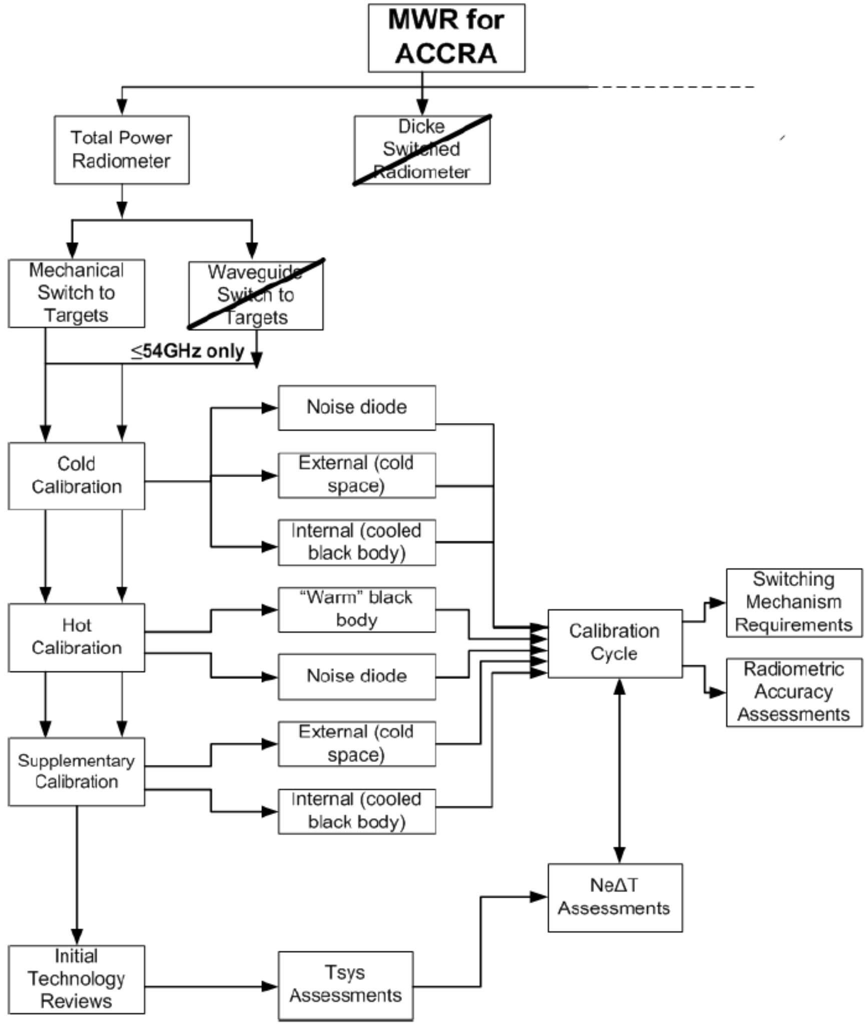
  - Polarisation Splitting Lens
  - Phase Modulation Lens
  - Lens array
- Polarisation devices
  - Transmitting HWP
  - Reflecting HWP
  - Polarisation rotators
- Mesh Horns
- Waveguide Components : compact feedhorns

- As well calibration switching technologies such as super flex pivots

Calibration Technologies & Configurations

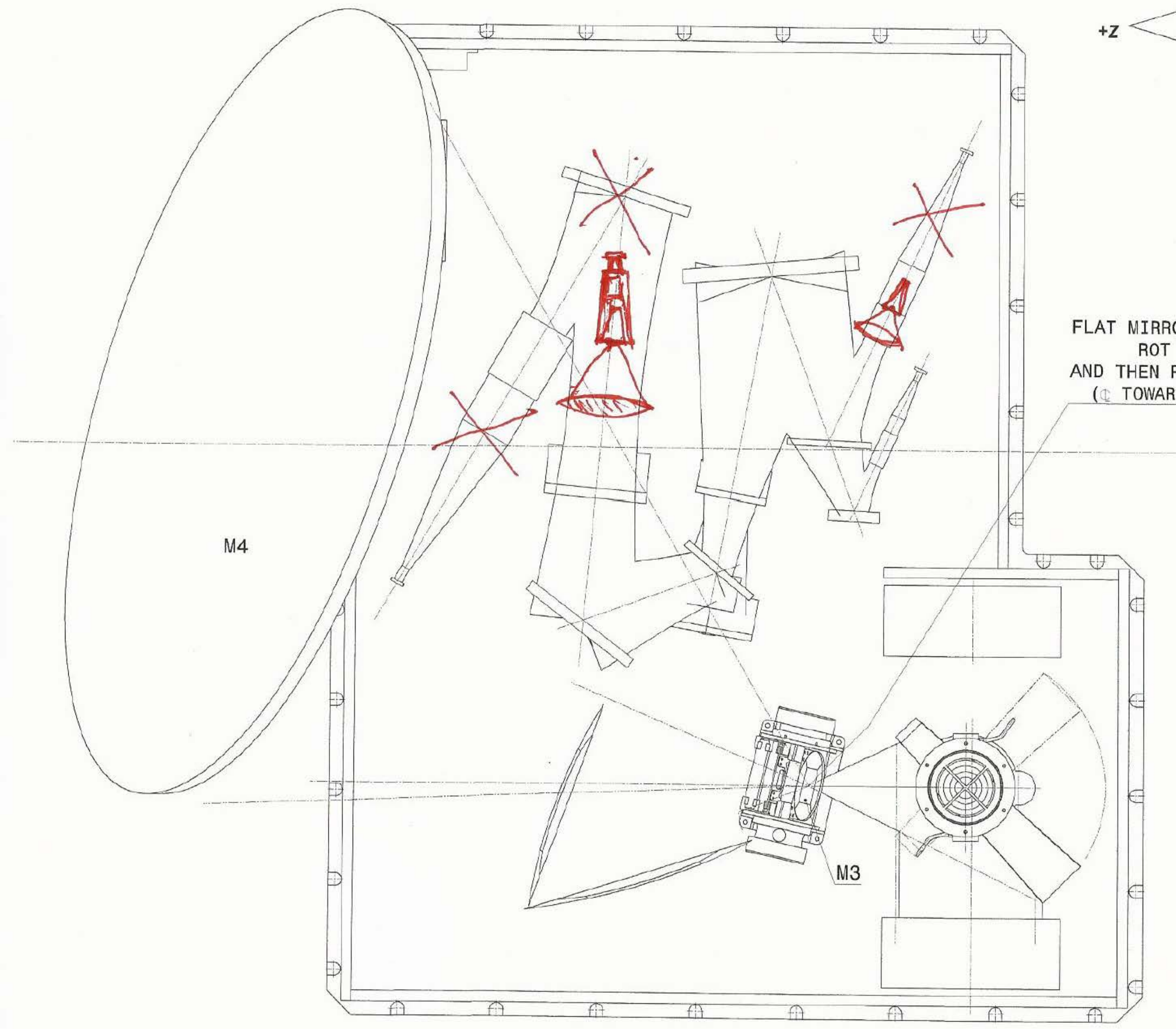
- **Summary of calibration options which has included assessment of mechanical switching too.**





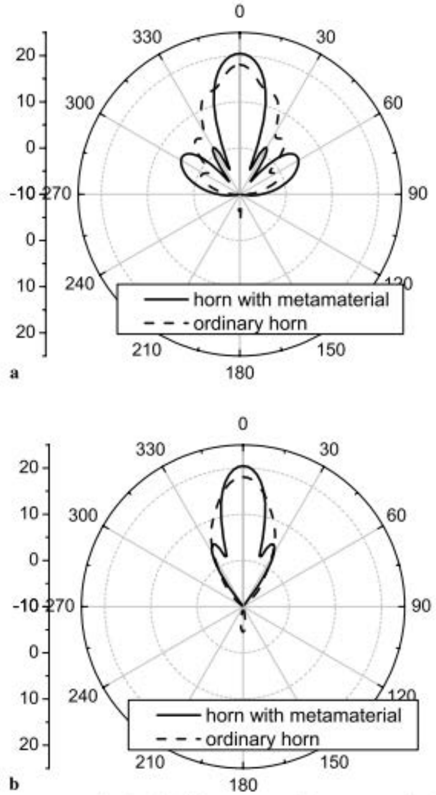
Strawman Lessons Learned

- **Example of potential configuration improvements**

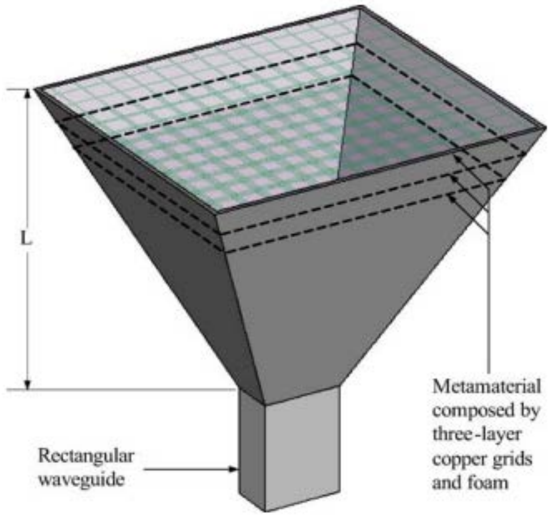


Metamaterial/Hybrid Horns

- It has been shown that it is possible that mesh grids combined with horn antennas can lead to an increase in the performance of the horn.
- Shapes the phase front at the horn aperture.
- WU et al. shows the performance of horn can be increased by 2db over 16-17GHz

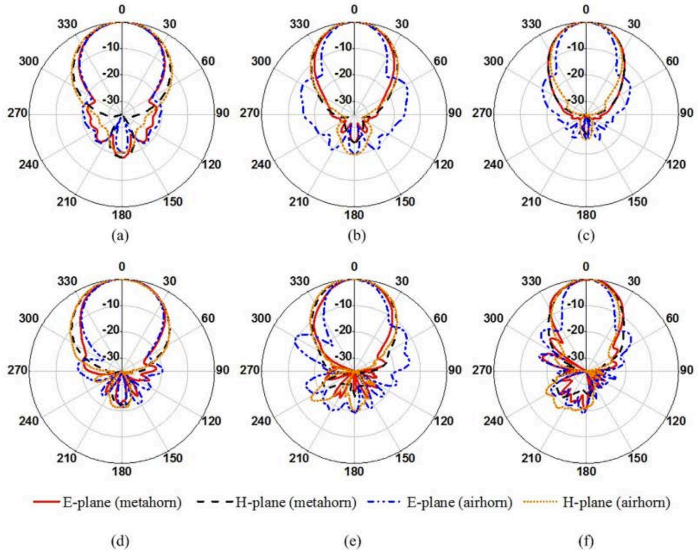


Chosen mesh structure is narrow band.



Metamaterial/Hybrid Horns

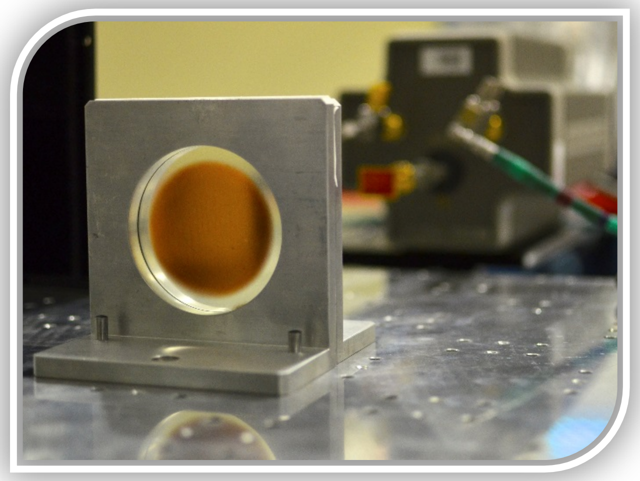
- Qing Qi et al. Included a graded index lens inside a horn antenna. A prototype of this horn was built.

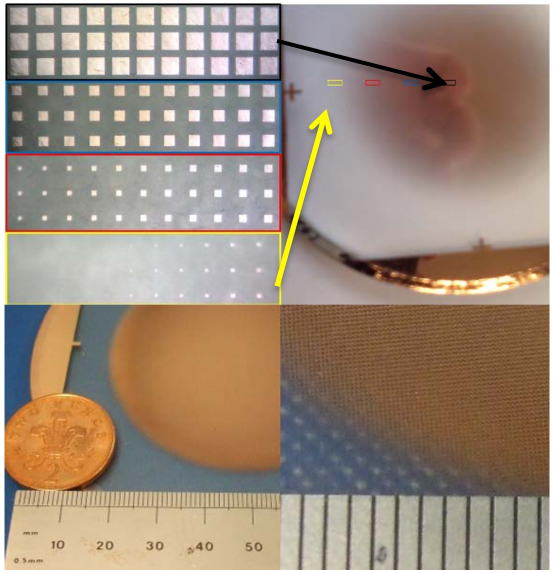


- With Cardiff and TK expertise, there is considerable potential that a similar device could be realized with metal mesh technology
- Additionally worthwhile investigating reduction of ultra Gaussian feedhorns.

Metal Mesh Lens – Graded index

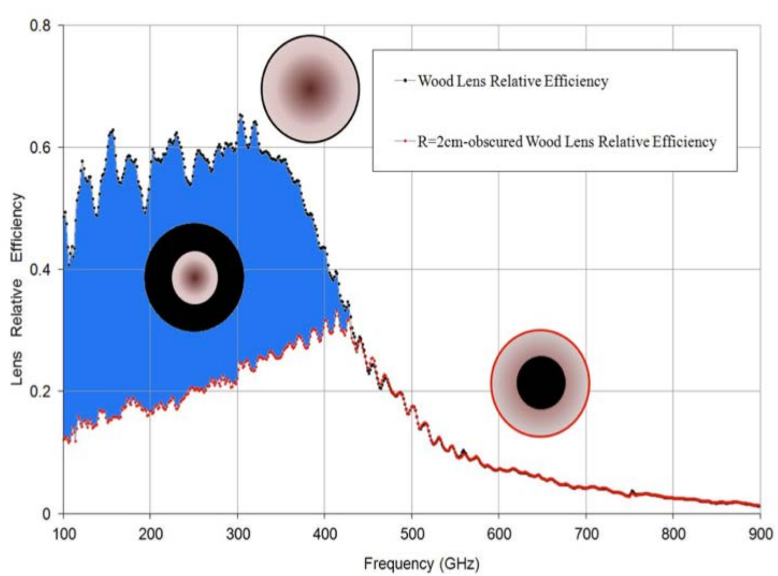
- Using metal mesh technology, a artificial dielectric can be created – Free choice of refractive index (n=1.5 - ~4.5)
- Flat lens was designed to have focal length of 250mm with a diameter of 80mm.
- Final lens consisted of 20 grid layers with a combined thickness of 2mm.

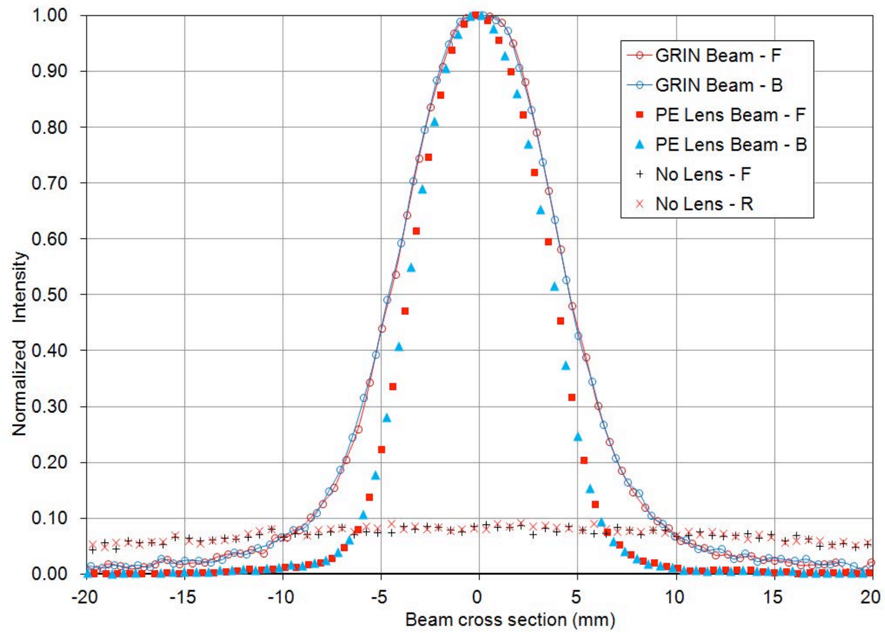




Metal Mesh Lens – Graded index

- Measured performance shows good broadband operation. 100-400Ghz
- Beam profile matches that of polyethylene lens of same f-number.





- This can be scaled to work at lower frequencies.

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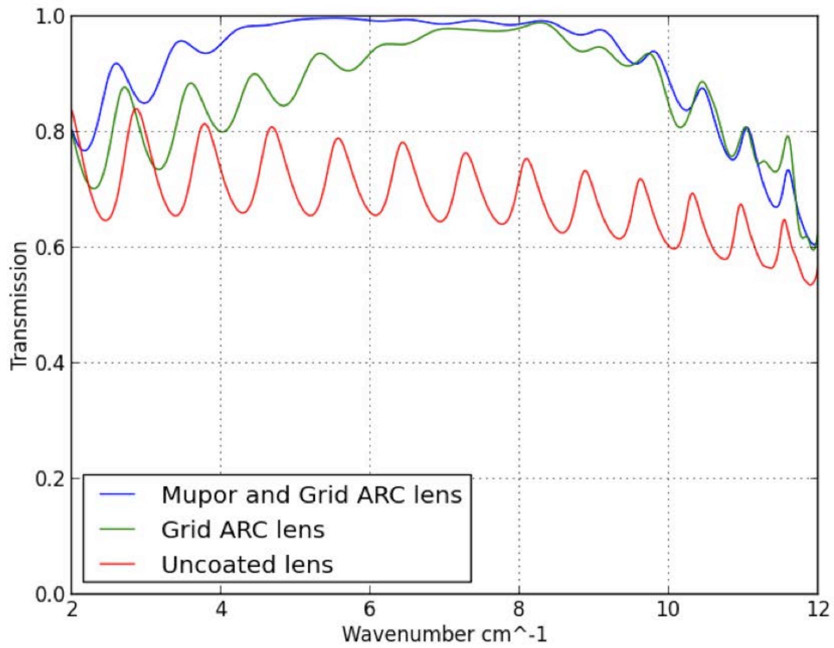
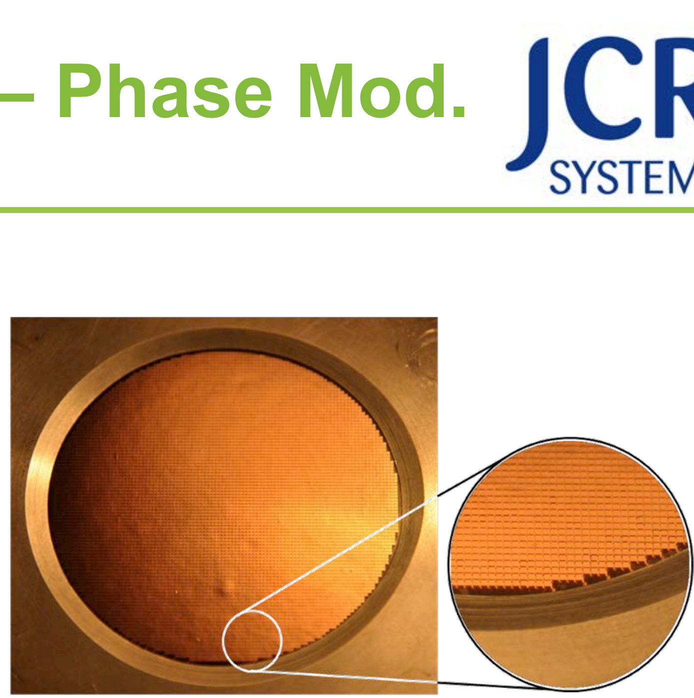
Metal Mesh Lens – Graded index

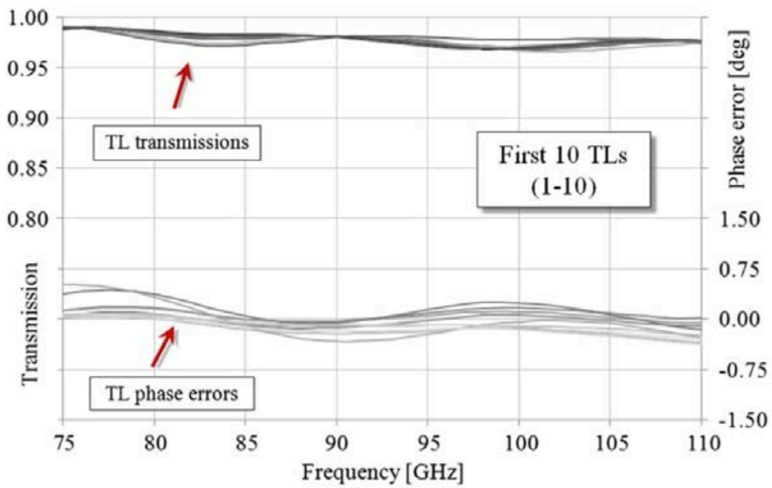
- **Lens transmission limited by impedance miss match. So anti-reflection coating (ARC) can be used.**
- **Designs exist which greatly improve performance of the lens.**
- **Further study into different graded index profiles is needed. – Larger lens with shorter focal length.**



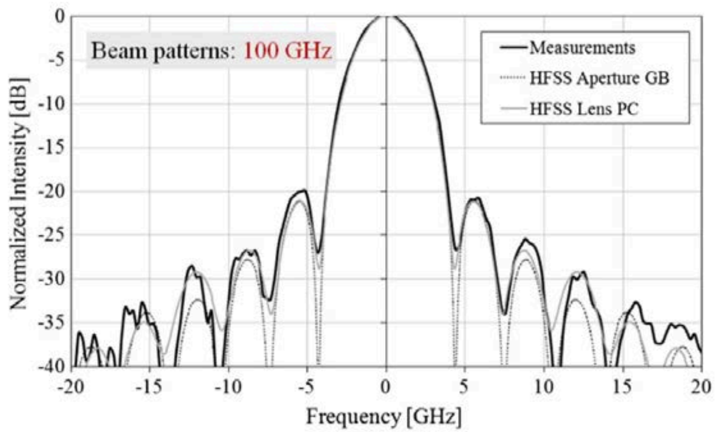
Metal Mesh Lens – Phase Mod.

- Using same mesh technology another lens was produced.
- Creating by modeling each point on the lens to get the required phase modulation.
- Lens had a diameter of 54mm with a focal length of 162mm. Required 10 Grids –Total thickness 2.33mm
- Computationally more intensive but can be designed to match free space.





Lens shown to have very good transmission over W-band



Beam pattern measurements were compared to simulation

Initial Conclusions

- At present concluding trade-off studies to select preferred lens technology & design approach for remaining phase of study.
- Demonstrates that despite the fact that this application is operational, next generation demands for improved performance yet efficient designs, are still driving new technology challenges.
- THANK YOU FOR LISTENING