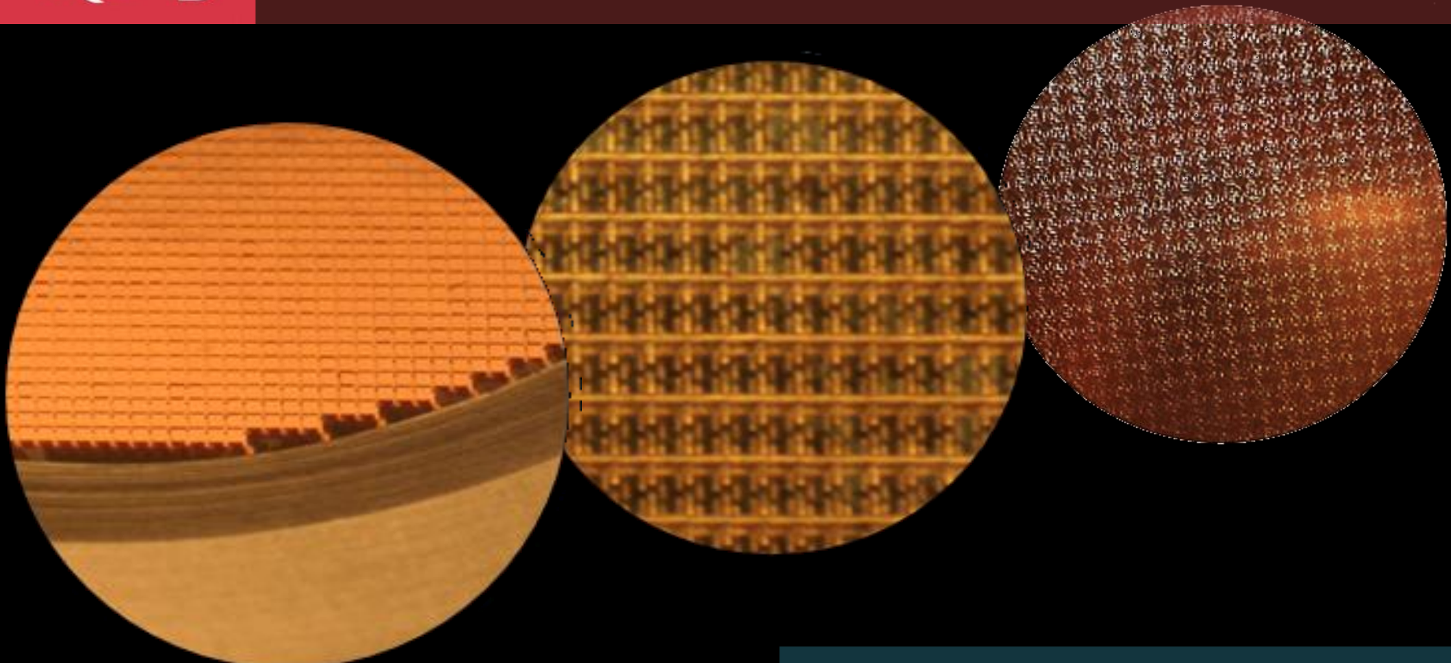
Metal Mesh Quasi-Optical Component Developments

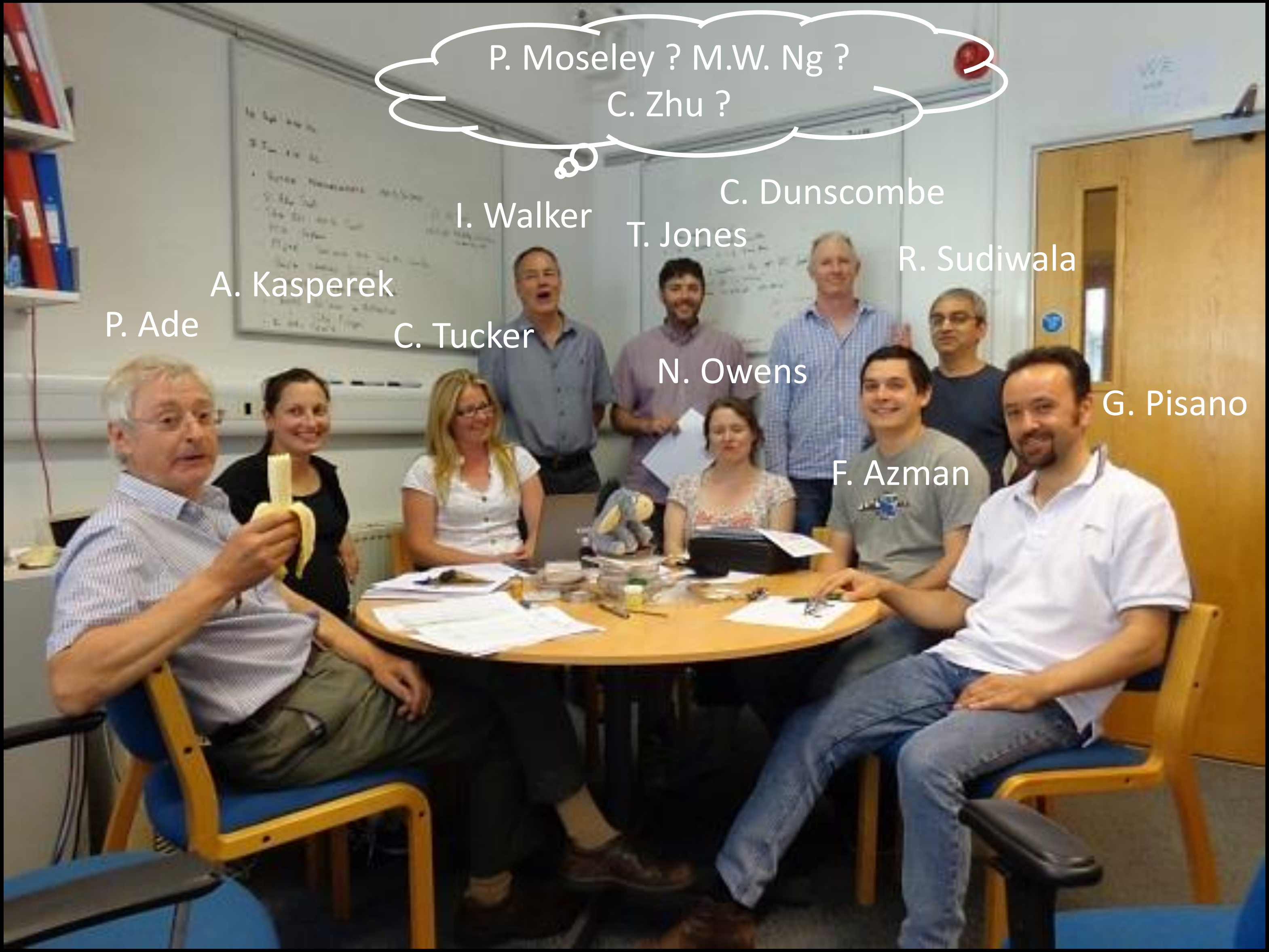


G. Pisano, C. Tucker and P. Ade

Astronomy Instrumentation Group - Cardiff University

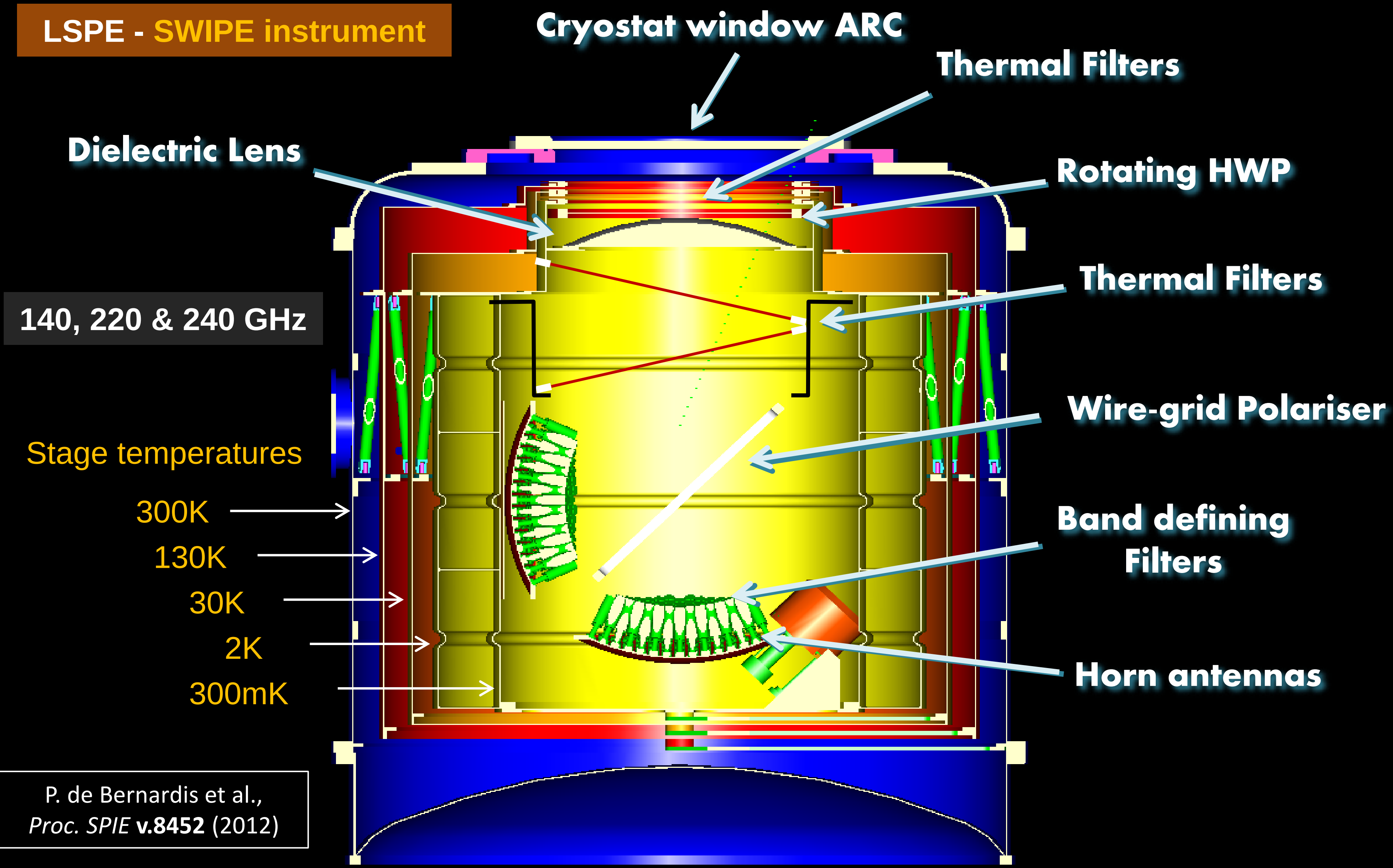
Towards the European Coordination of the CMB programme, Villa Finaly, Firenze, 9/9/2016

Metamaterial and QO production team



Astronomical instrumentation: CMB instrument example

LSPE - SWIPE instrument



P. de Bernardis et al., *Proc. SPIE* **v.8452** (2012)

→ All the highlighted devices can be realised using the Mesh Technology

Summary

- Mesh Filters Technology
- Mesh Lenses
- Mesh Lens Arrays

Mesh Technology: Modelling

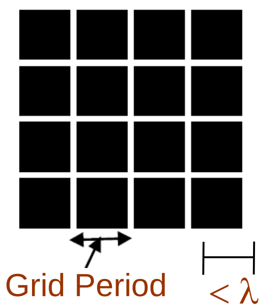
FSSs subgroup

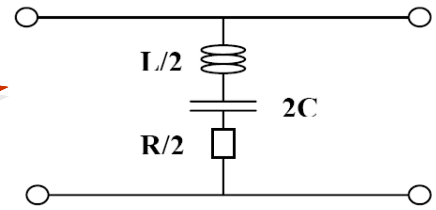
Markuvitz (1951)
Ulrich (1967)

Capacitive Low-Pass Filter

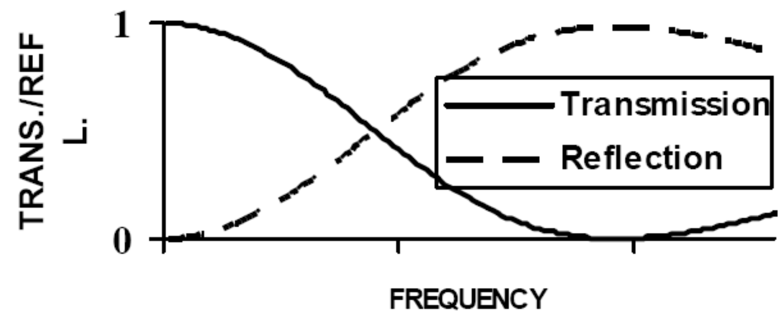
Sub-wavelength periodic structures

Spectral response

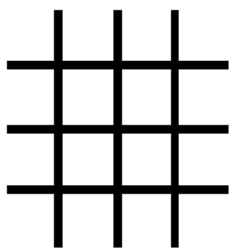


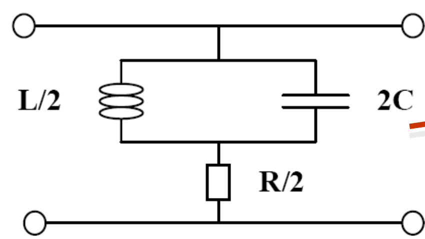


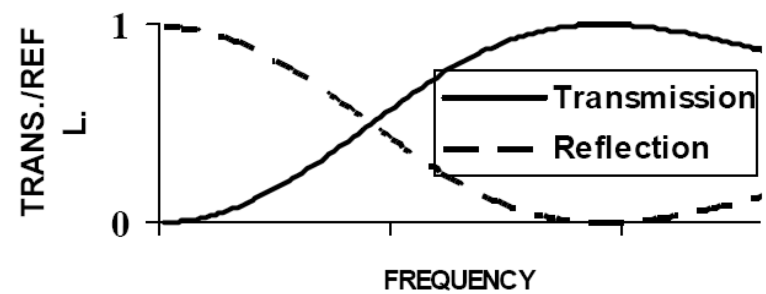
Equivalent Circuit



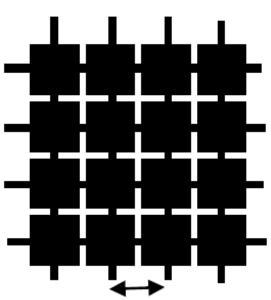
Inductive High-Pass Filter

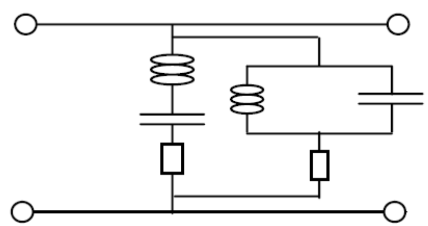


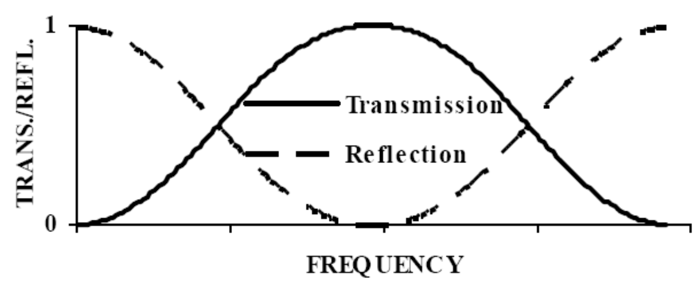




Resonant Band-Pass Filter

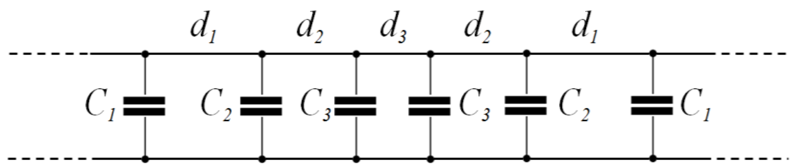


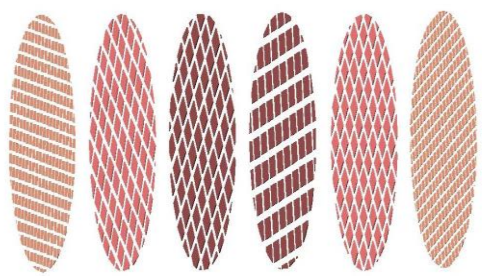


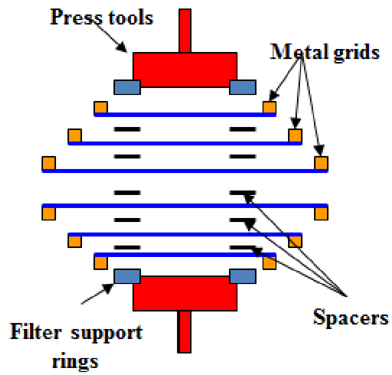


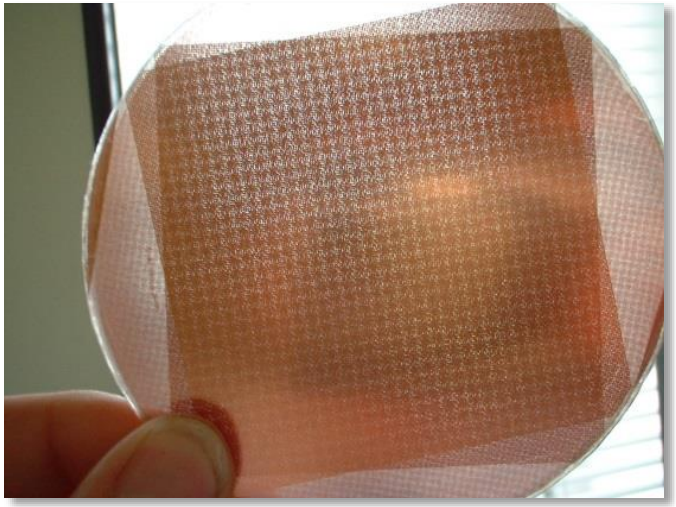
Mesh Technology: Manufacture

Free standing (air-gap) multiple-mesh devices

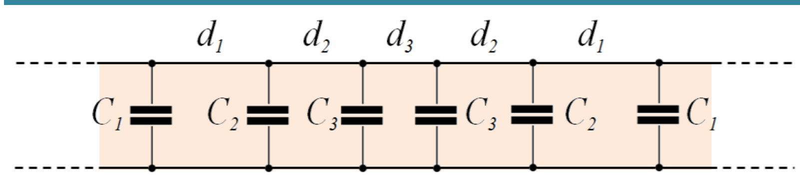


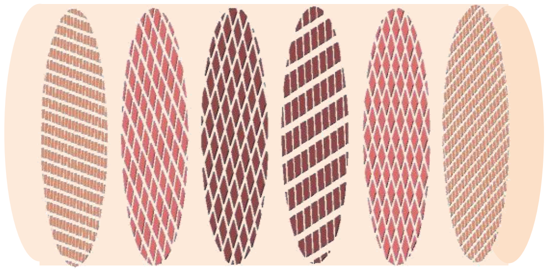


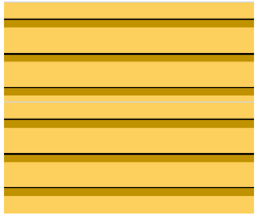


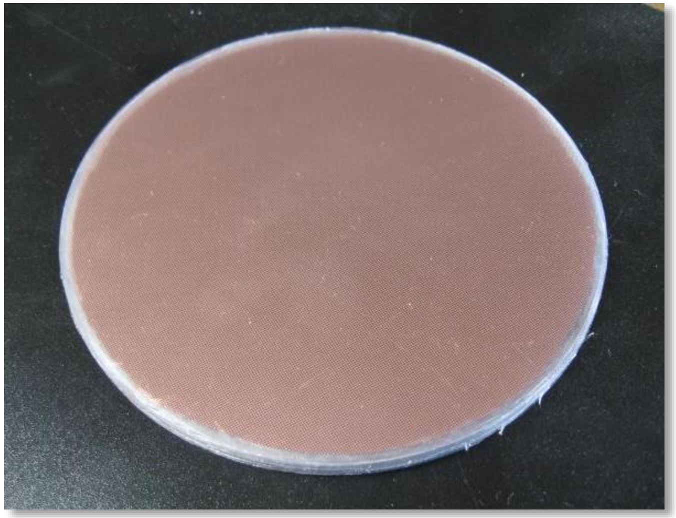


Dielectrically embedded multi-mesh devices



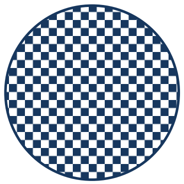




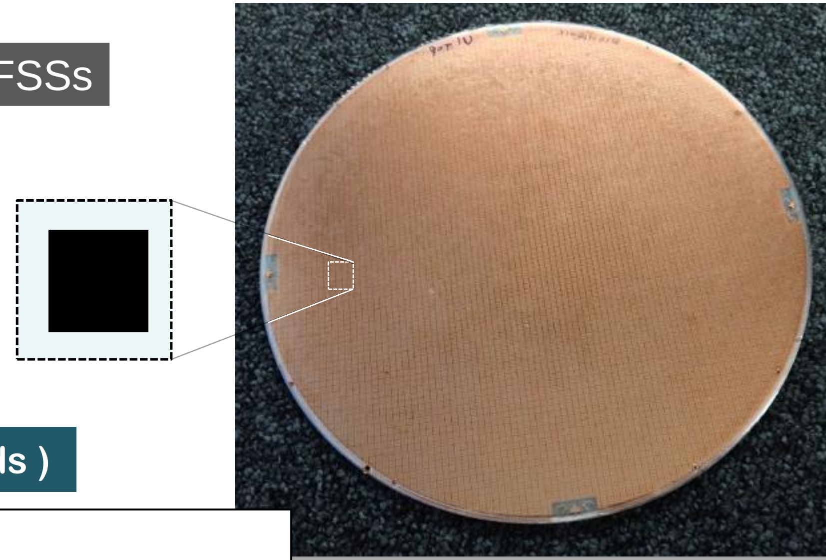


Mesh Filters: Band defining 1/2

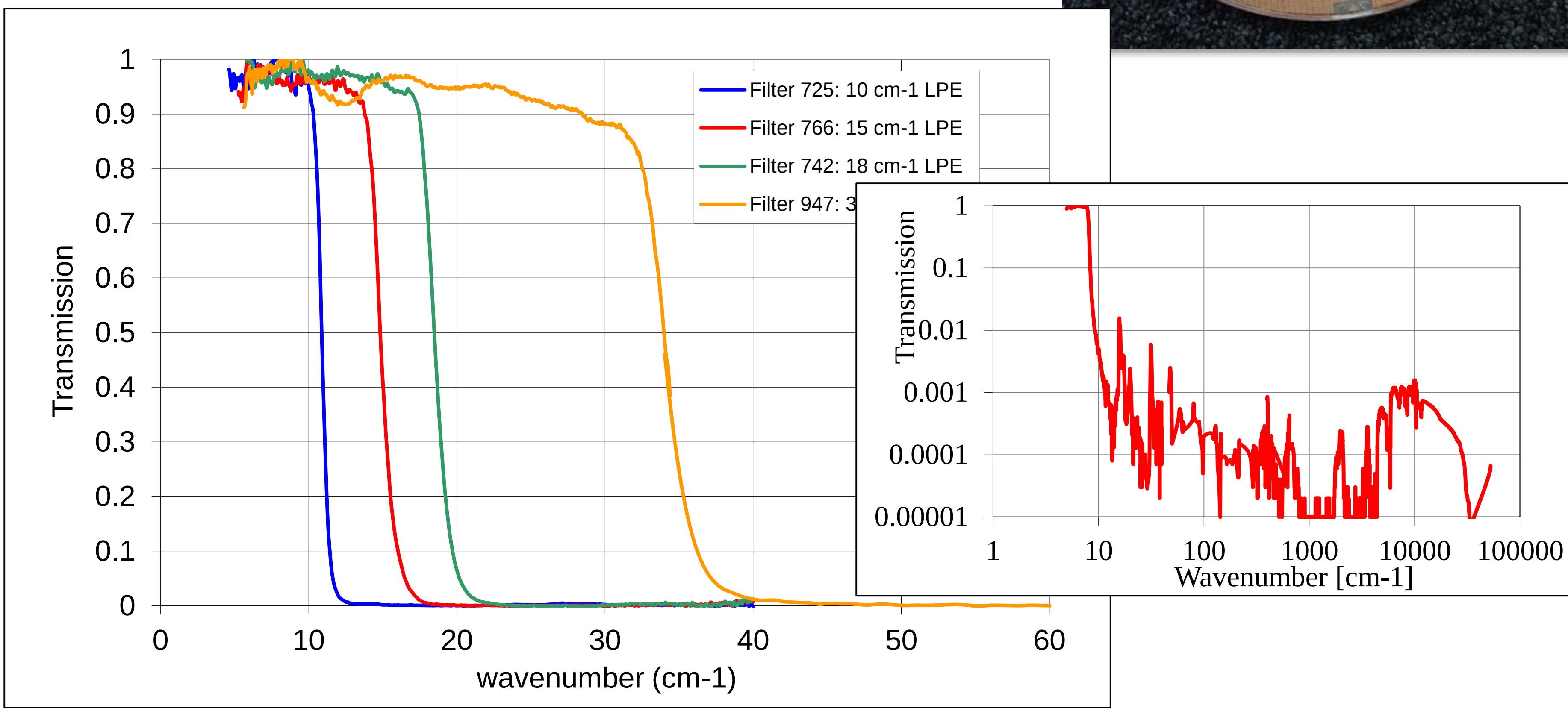
FSSs



Homogeneous grids



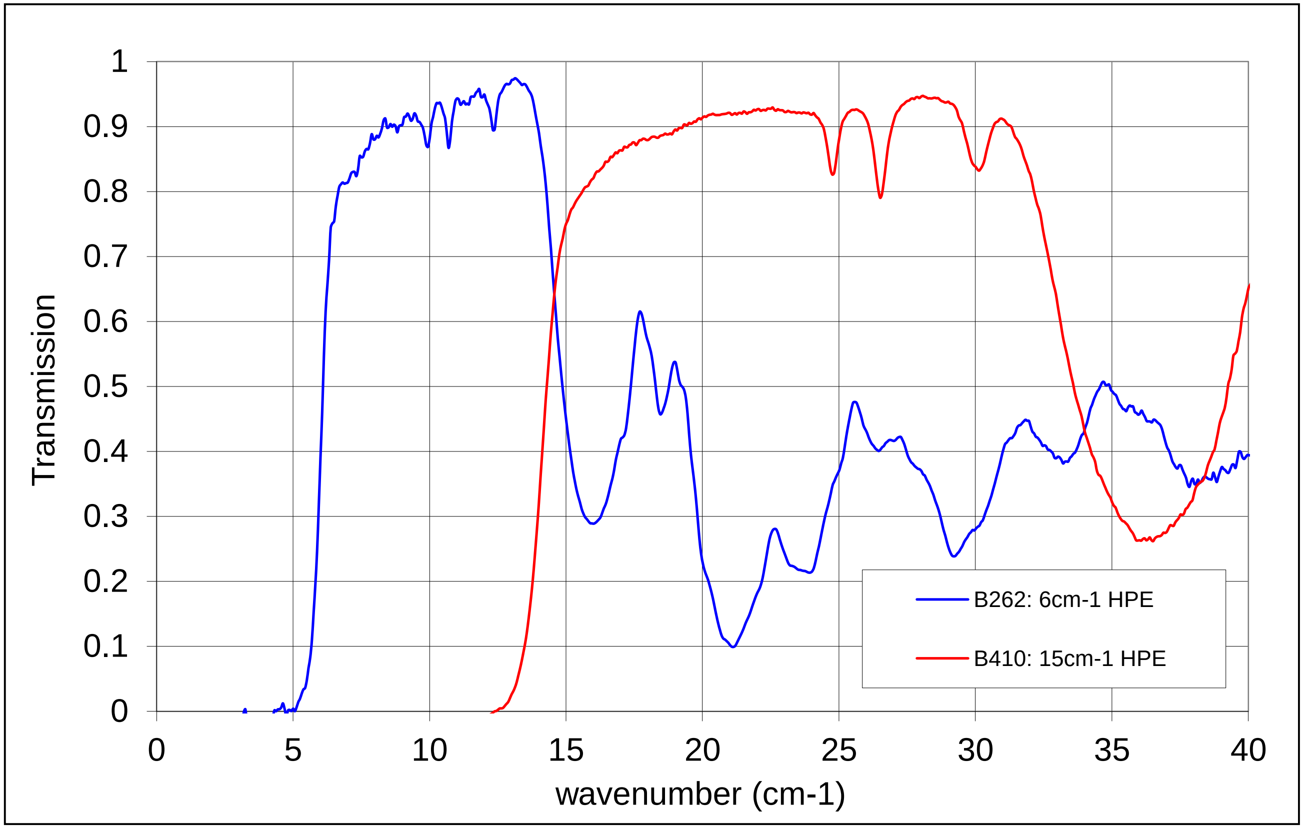
Low Pass Capacitive Hot Pressed Mesh Filters (10 grids)



- Hot pressed high frequency rejection continues through diffraction region

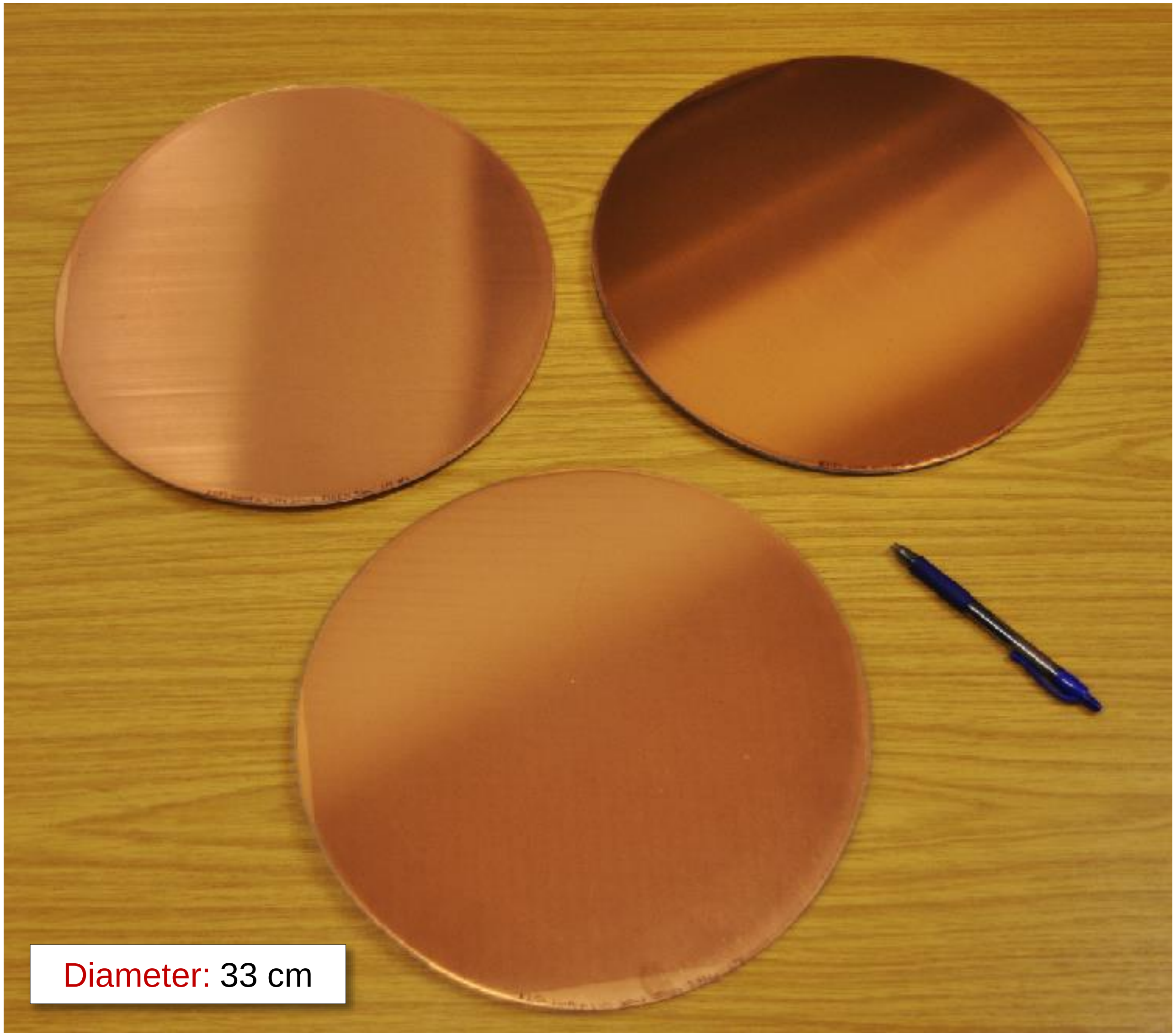
Mesh Filters: Band defining 2/2

High Pass Inductive Hot Pressed Mesh Filters (8 grids)



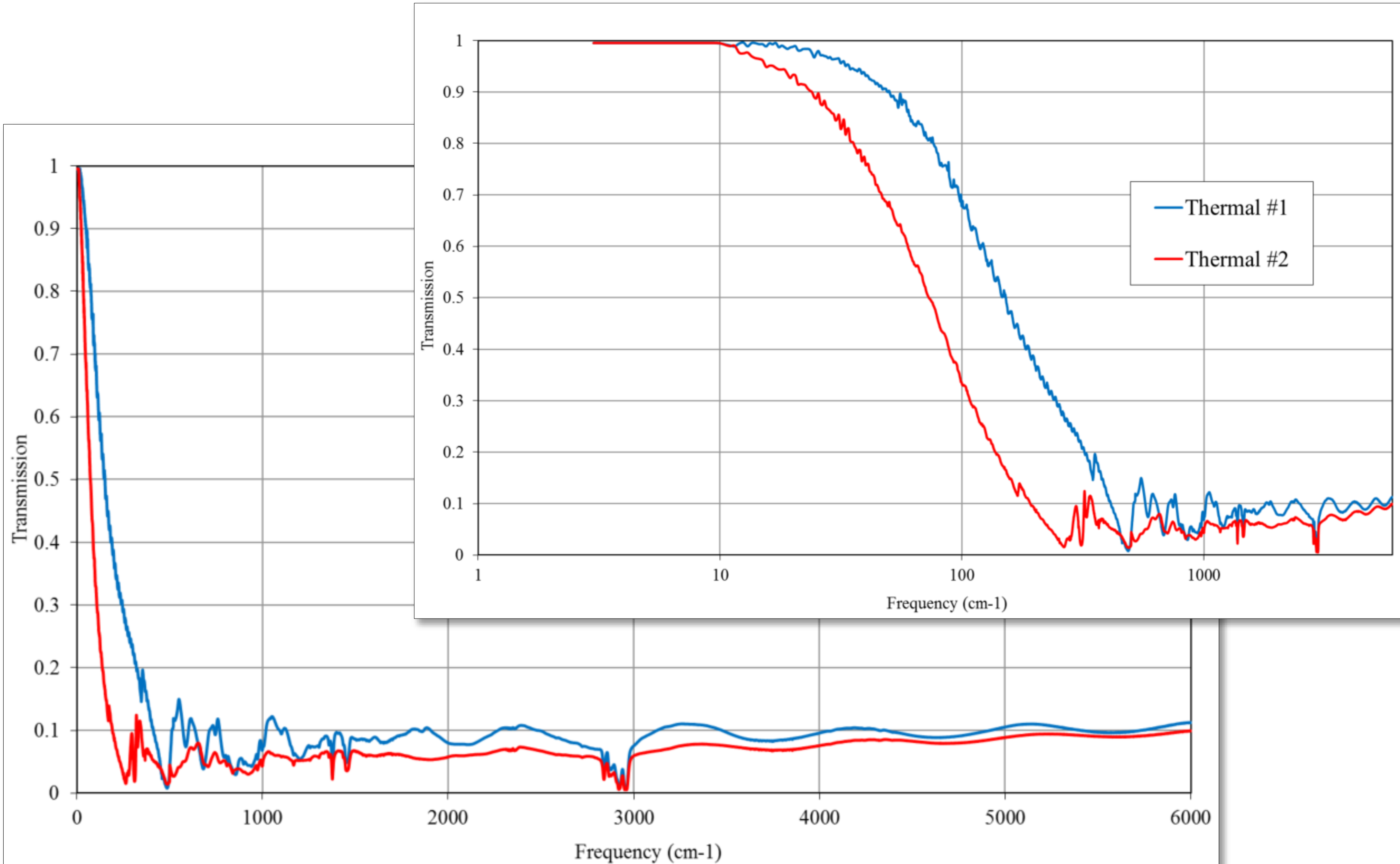
- The diffraction region limits the achievable bandwidth

Mesh Filters: Band defining LPE examples



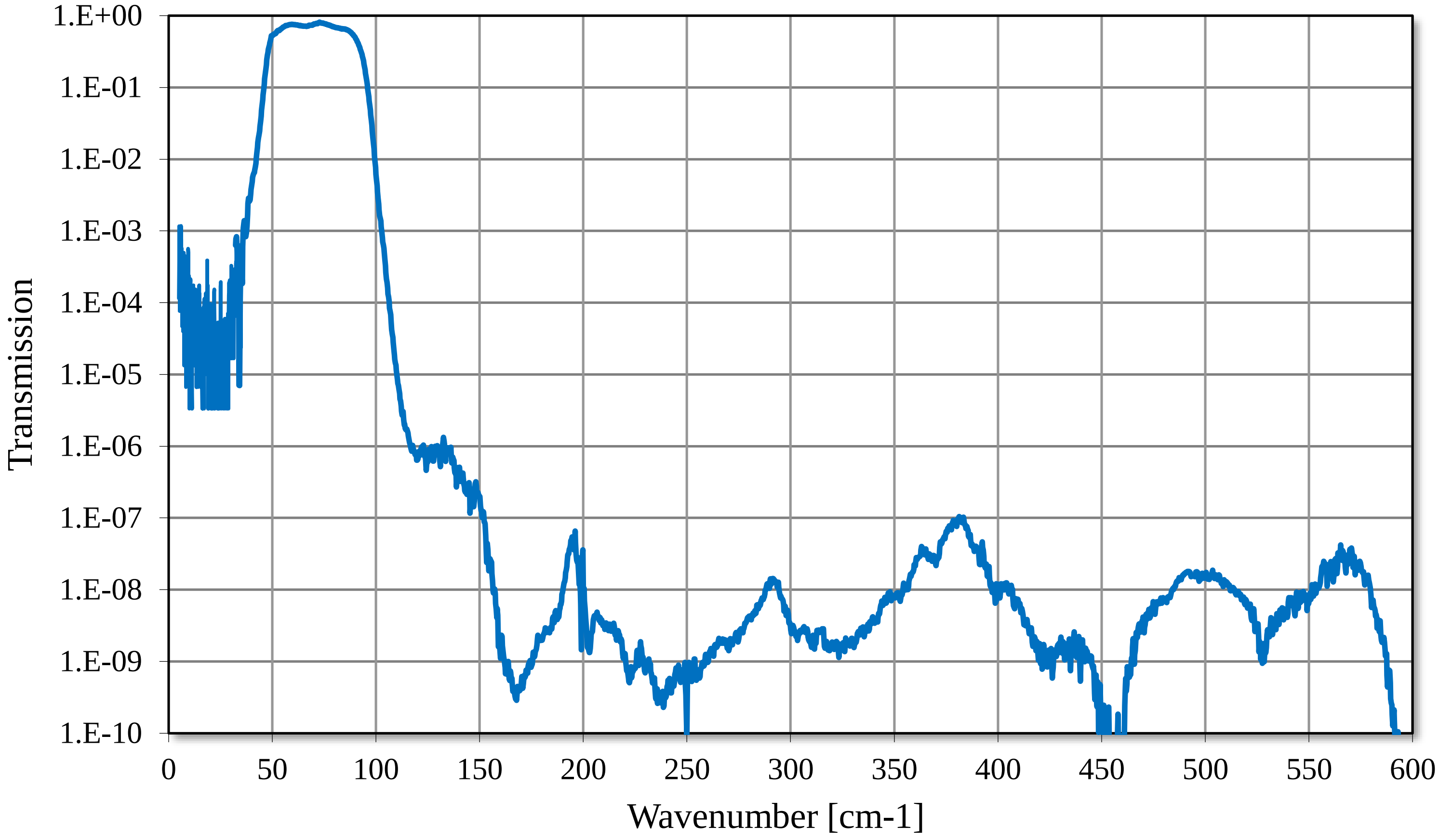
- These filters can be cut to any shape

Blocking Filters: Thermal filters



- Used in cryogenic systems to reject optical and near infrared radiation

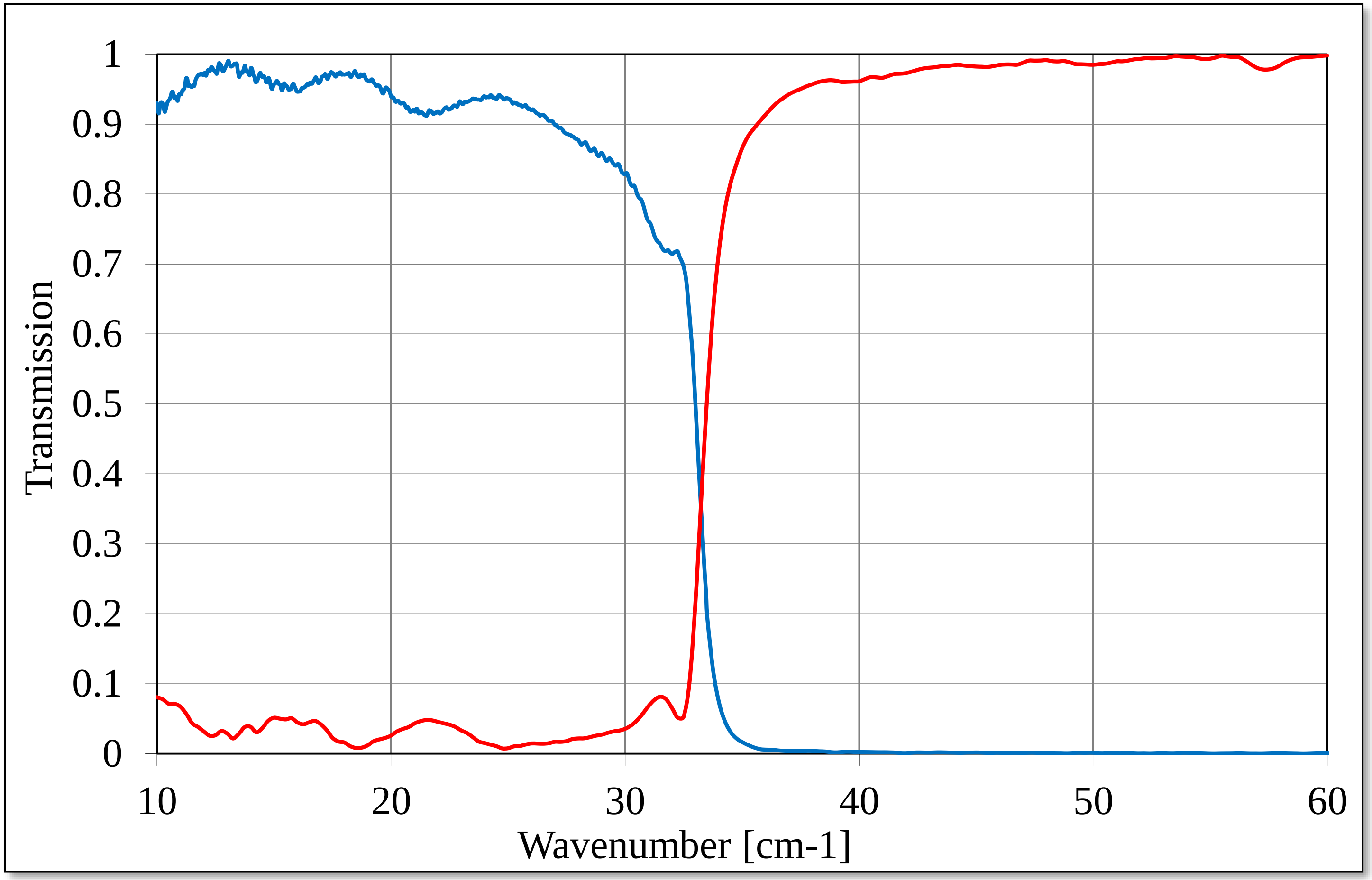
Mesh Filters Stacks: Blockers + band defining filters



- Multiple filters can be cascaded to achieve rejection of NIR radiation down to ~1:10^9

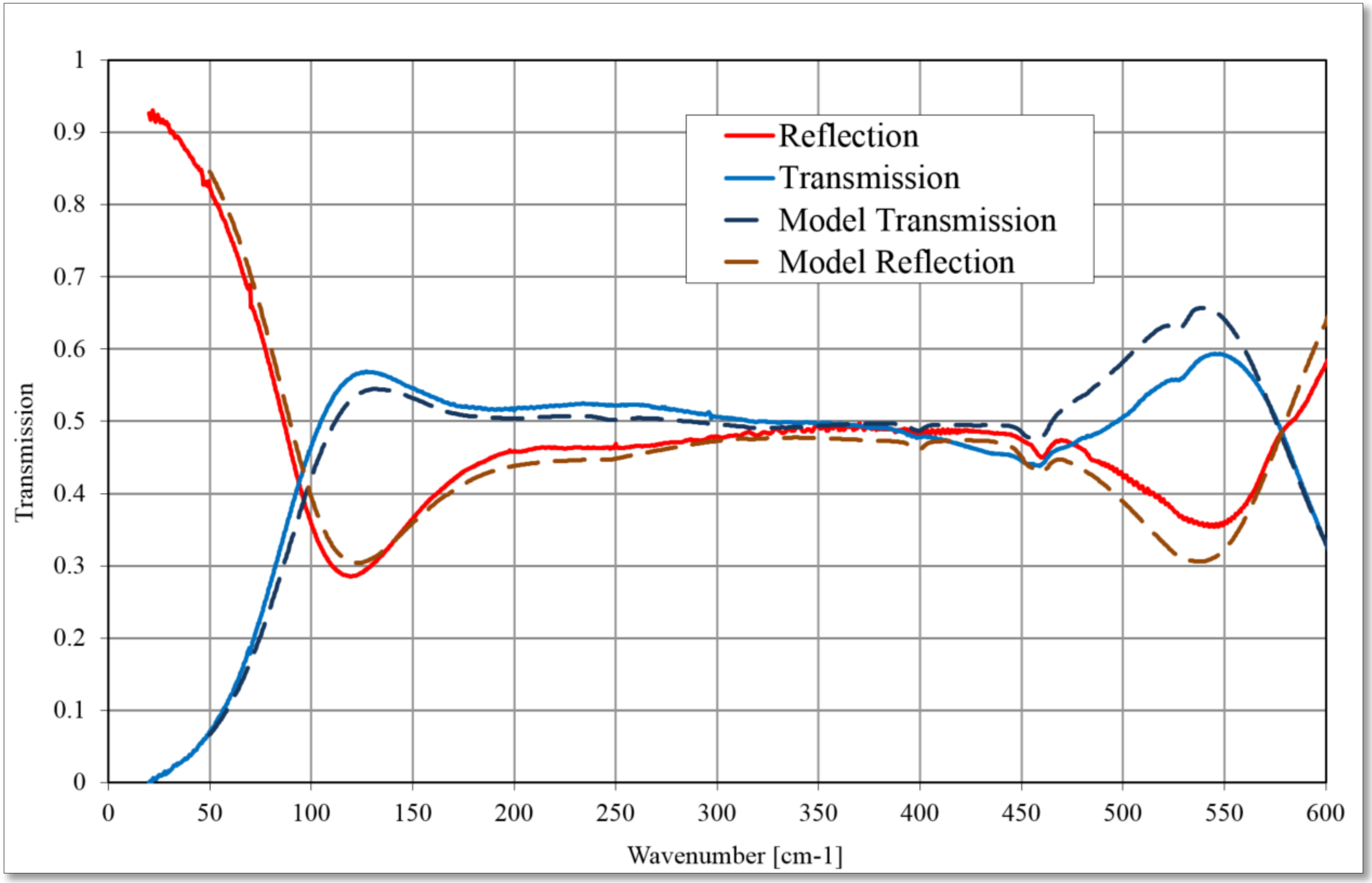
Dichroics: Frequency Splitters

Capacitive grid air-gap with f/4 beam at 30deg incidence angle



- Essential components for multi-frequency photometers
- Allow simultaneous imaging of the source in several wavebands
- Wood's anomalies increase with off-axis incidence angle and beam convergence

Beam dividers: Intensity splitters

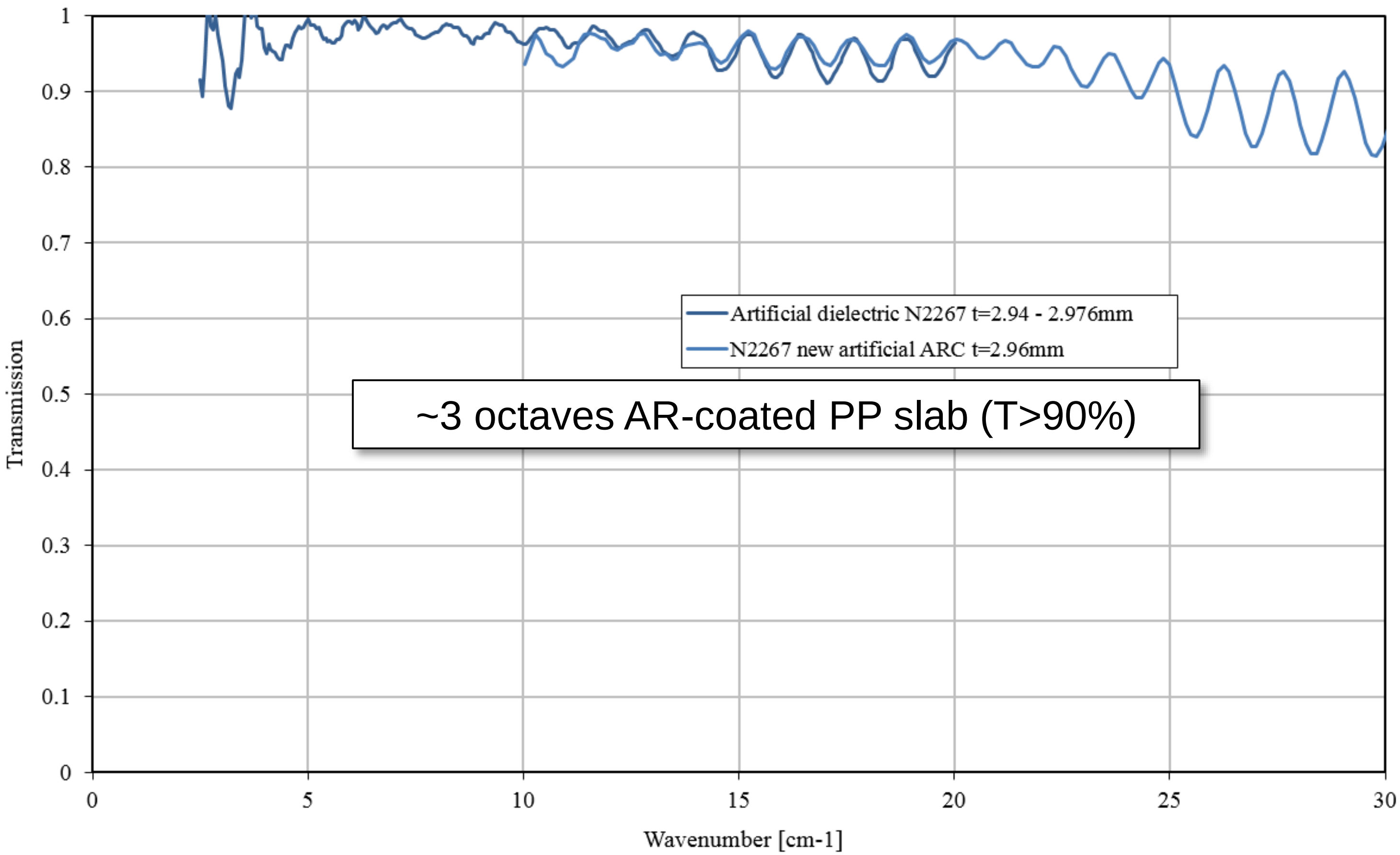


- Intensity beam dividers used in Fourier Transform spectrometers
- Combinations of capacitive and inductive meshes provide uniform R and T

Photolithographic Polariser: Example

Period: 20µm , Diameter: 42 cm

Anti-Reflection Coatings: Artificial dielectrics

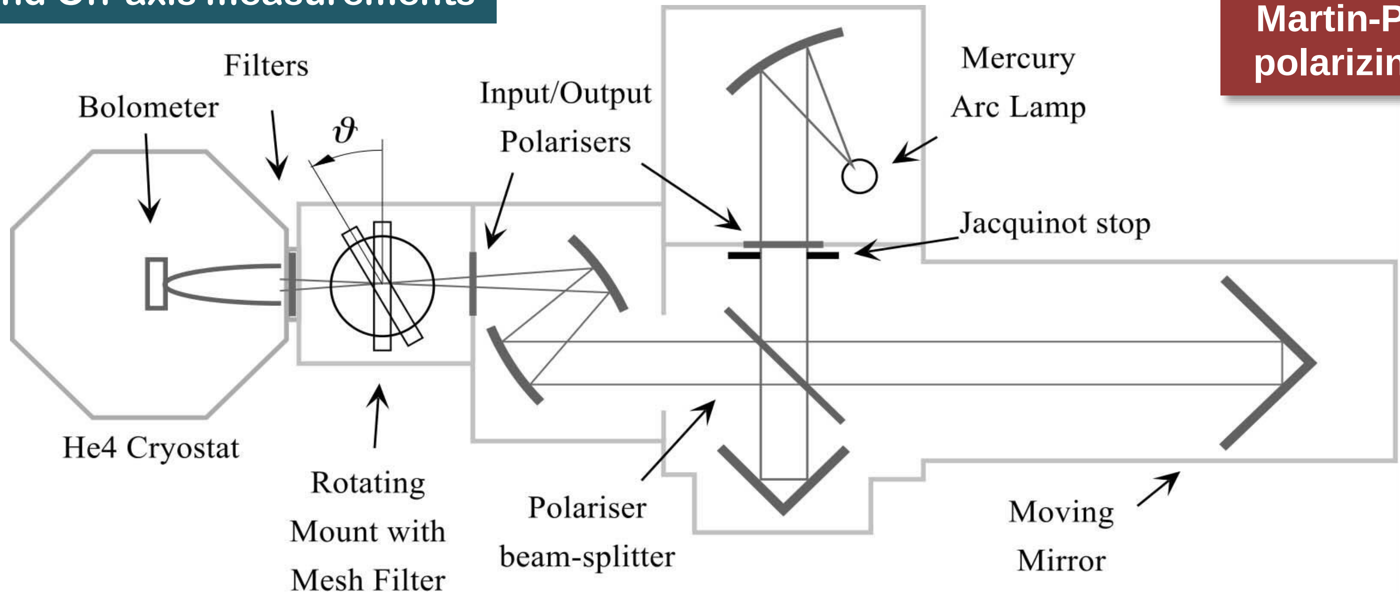


- ARCs based on existing material or **artificial dielectrics** (metamaterials)

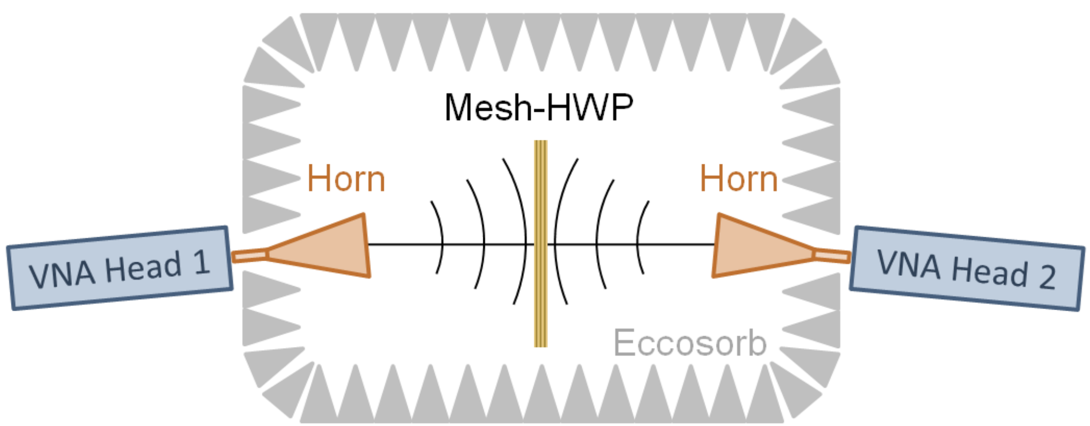
Mesh Technology: Testing

FTS On-axis and Off-axis measurements

Martin-Puplett polarizing FTS



VNA On-axis waveplate measurements



Summary

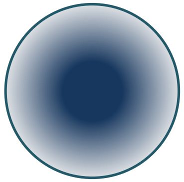
Mesh Filters Technology

Mesh Lenses

Mesh Lens Arrays

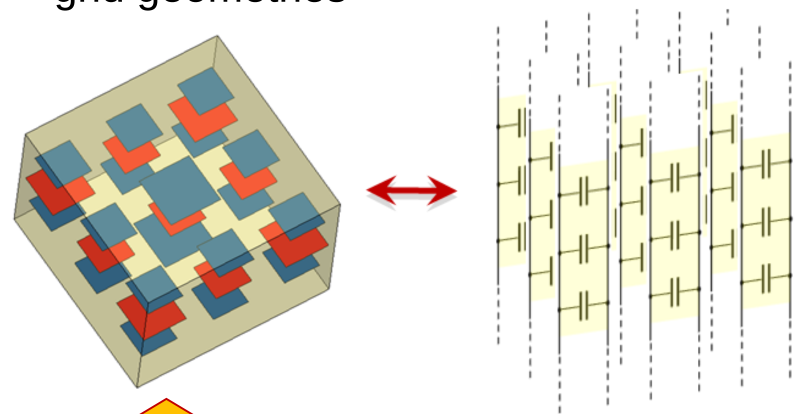
Flat Mesh Lens: Inhomogeneous Phase Delays

G. Pisano et al.
Applied Optics **52**,n.11, (2013)

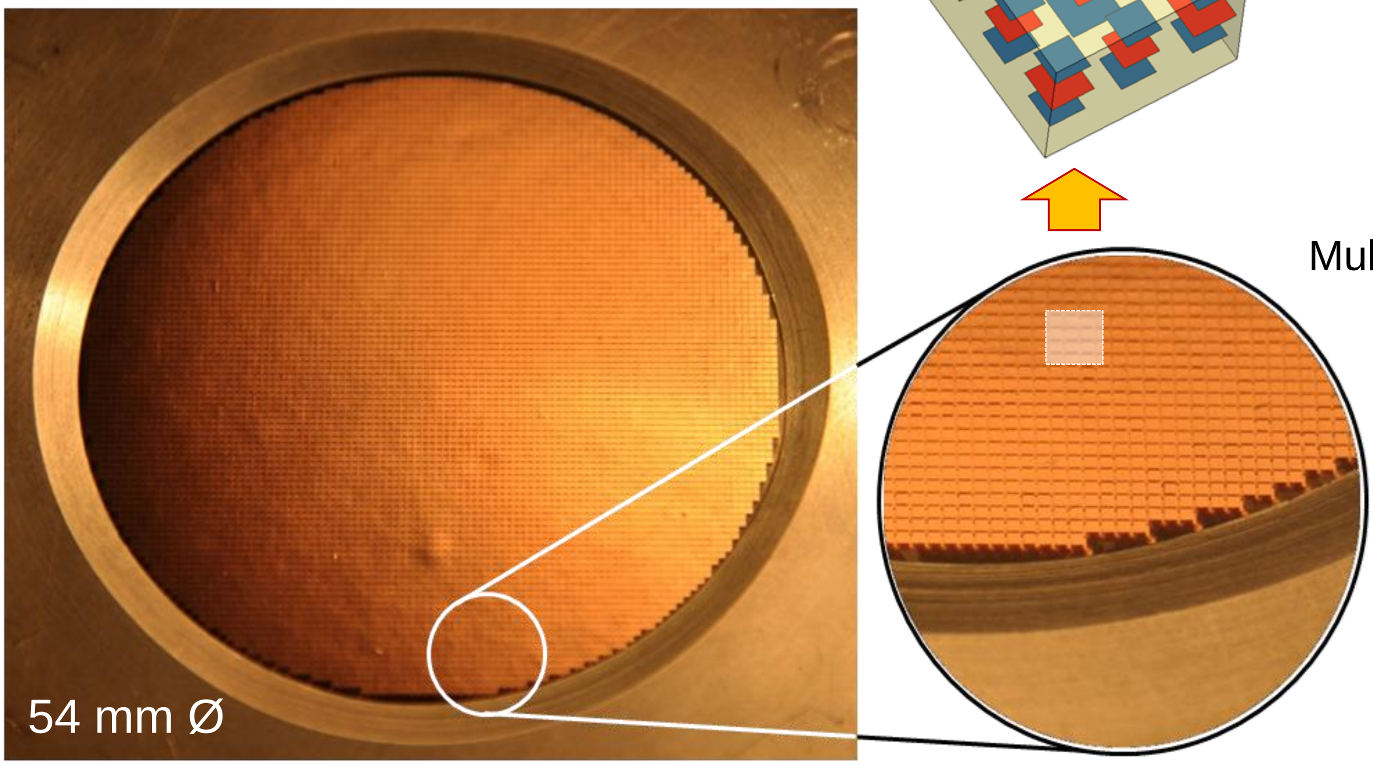


Inhomogeneous grids

Locally variable grid geometries



Multiple transmission lines

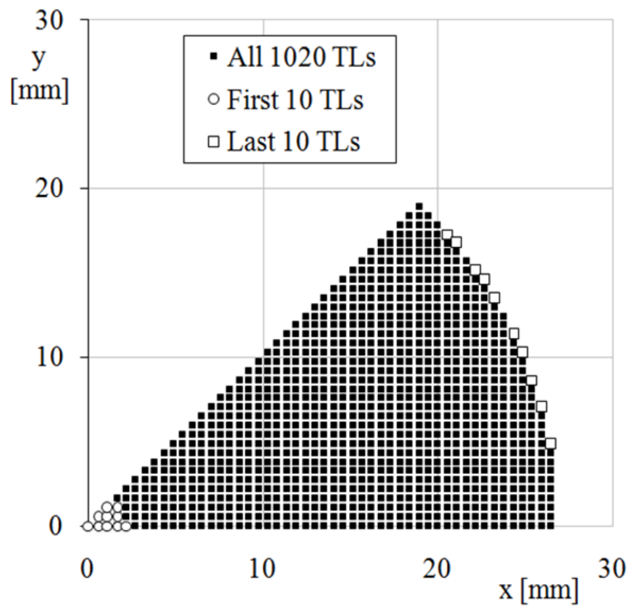


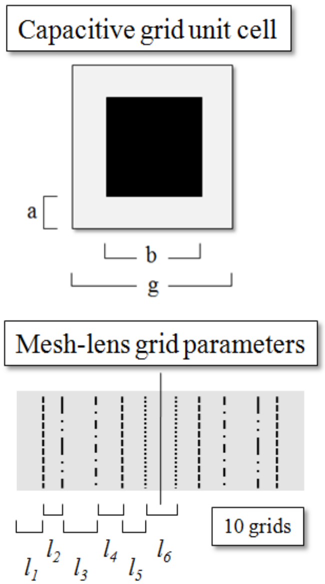
W-Band f/3 lens prototype (1.4mm thick)

- Very thin and robust
- Very light and low loss
- No Anti Reflection Coatings required

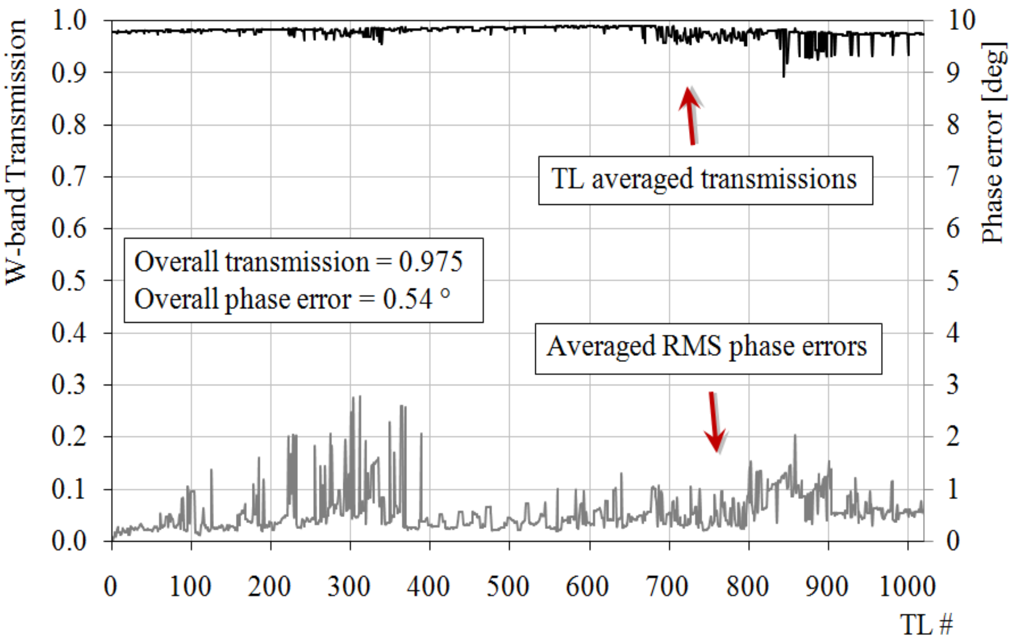
Flat Mesh Lens: Transmission line design

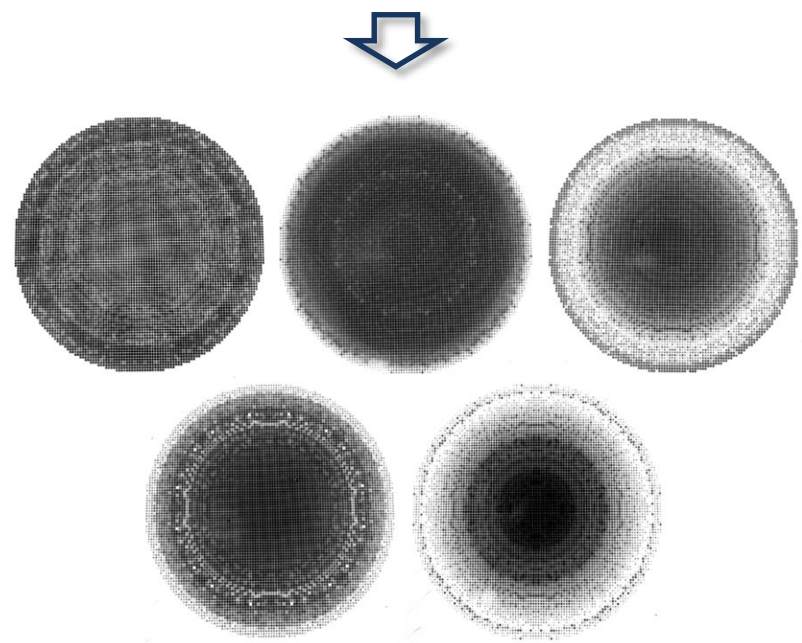
G. Pisano et al.
Applied Optics **52**,n.11, (2013)





- Lens consisting of ~ 8000 TLs
- Solution of just 1/8 of the surface
- Optimisation for max transmission & appropriate differential phase shift





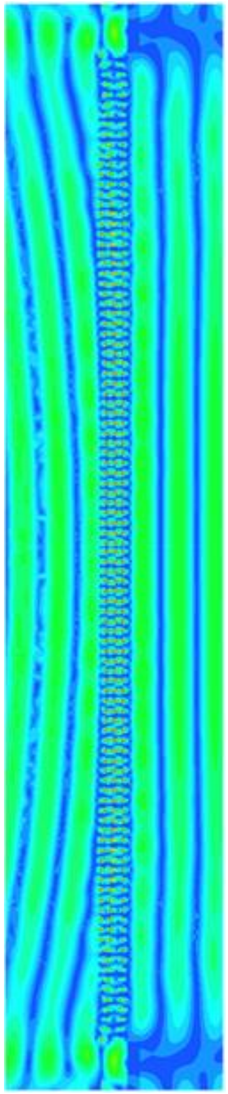
Flat lens made with 10 grids (5+5)

Flat Mesh Lens: Finite-element modelling

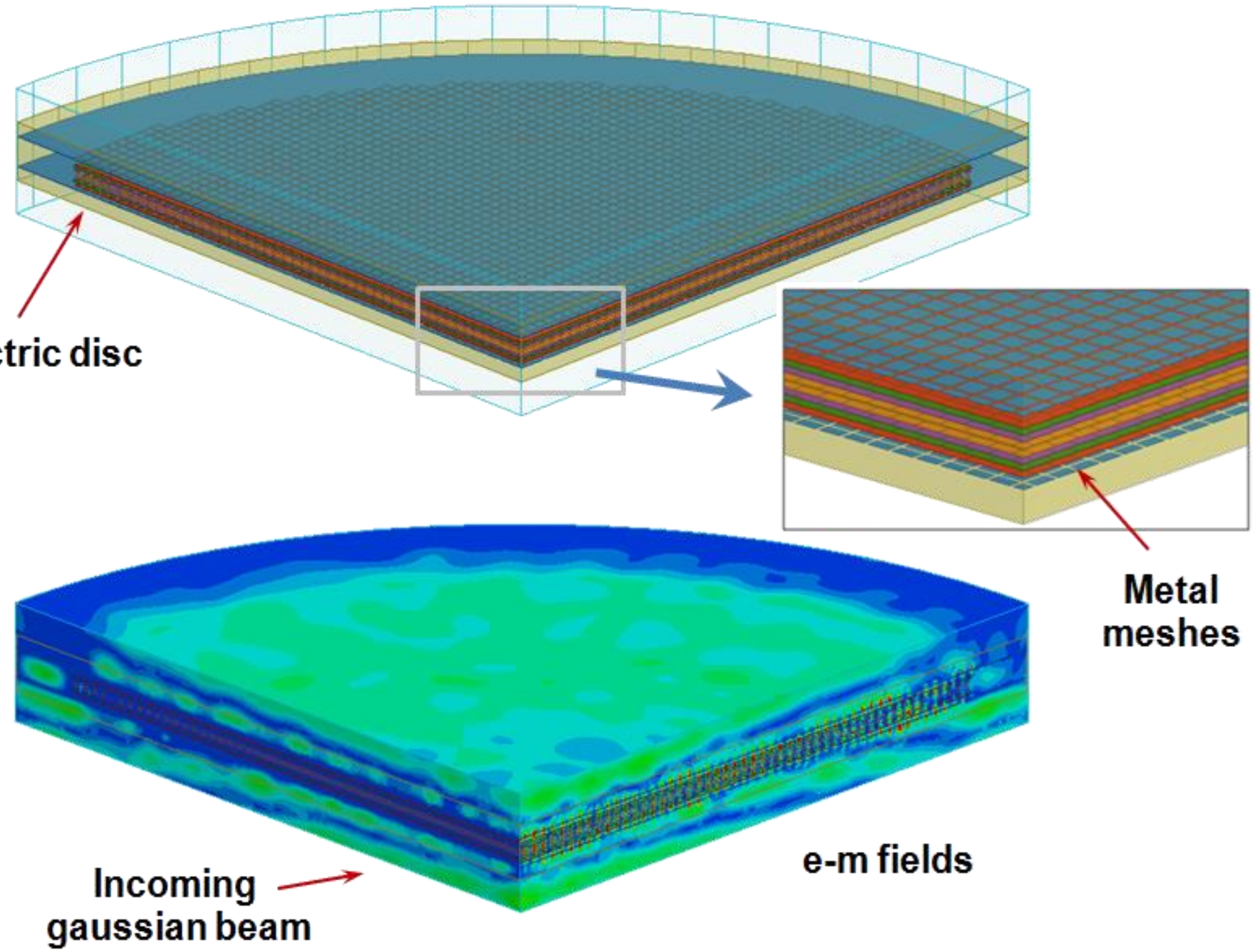
G. Pisano et al.
Applied Optics **52**,n.11, (2013)

2D model (cylindrical)

Central TL array

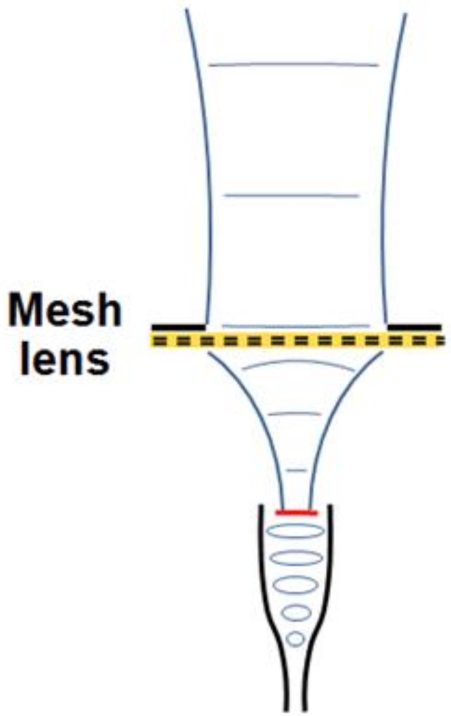


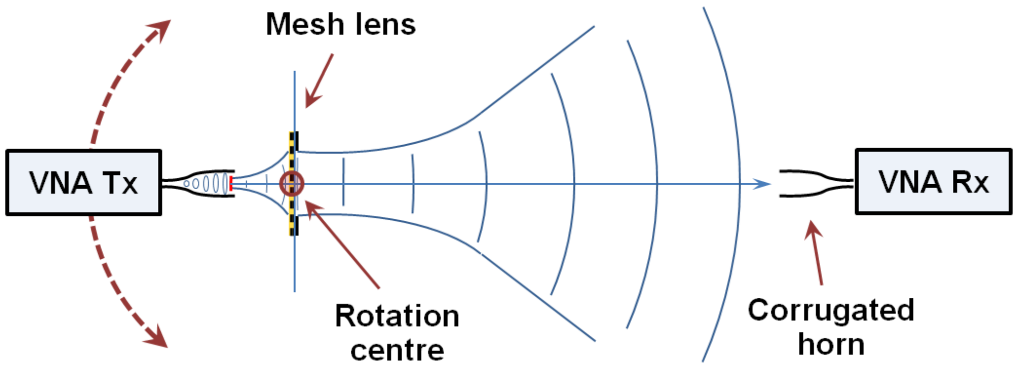
3D full model

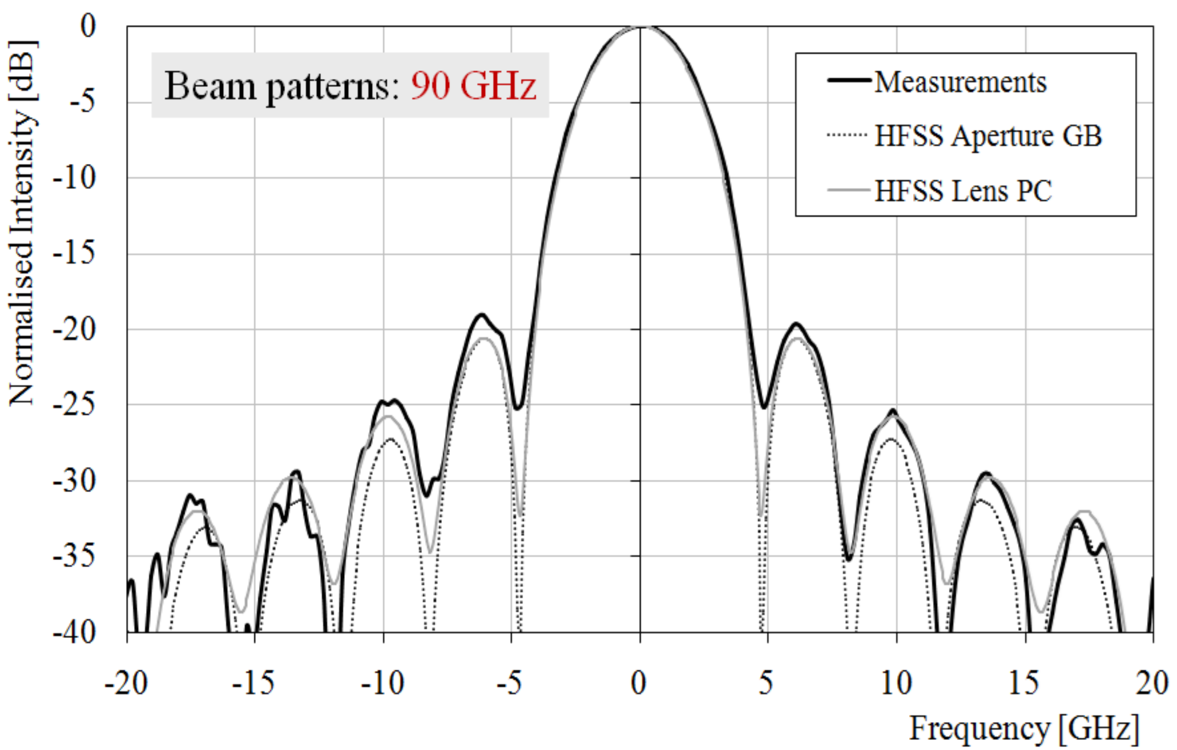


Flat Mesh Lens: VNA beam tests

G. Pisano et al.
Applied Optics **52**,n.11, (2013)







→ Experimental agreement down to the 4th side lobes

Summary

Mesh Filters Technology

Mesh Lenses

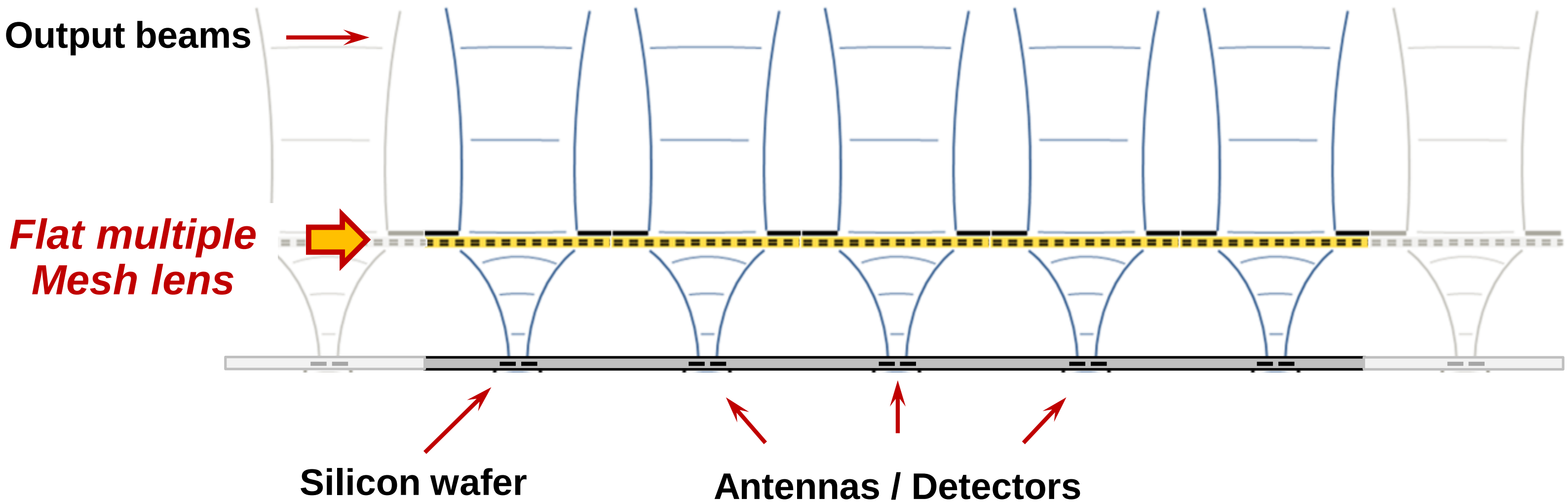
Mesh Lens Arrays

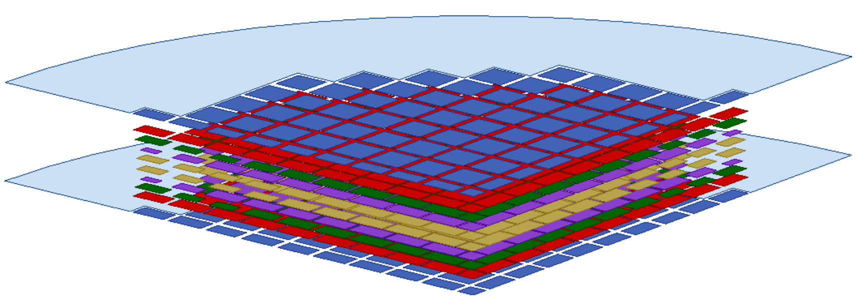
Mesh Lens Array: Concept

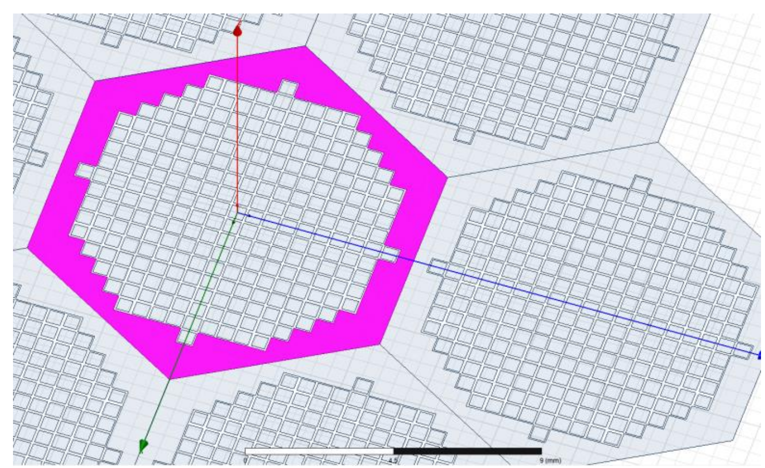
ESA project collaboration:

"Next Generation Sub-Millimetre Wave Focal Plane Array Coupling Concepts"

Maynooth (PI), Manchester, Cardiff, Rome, Paris APC & Chalmers

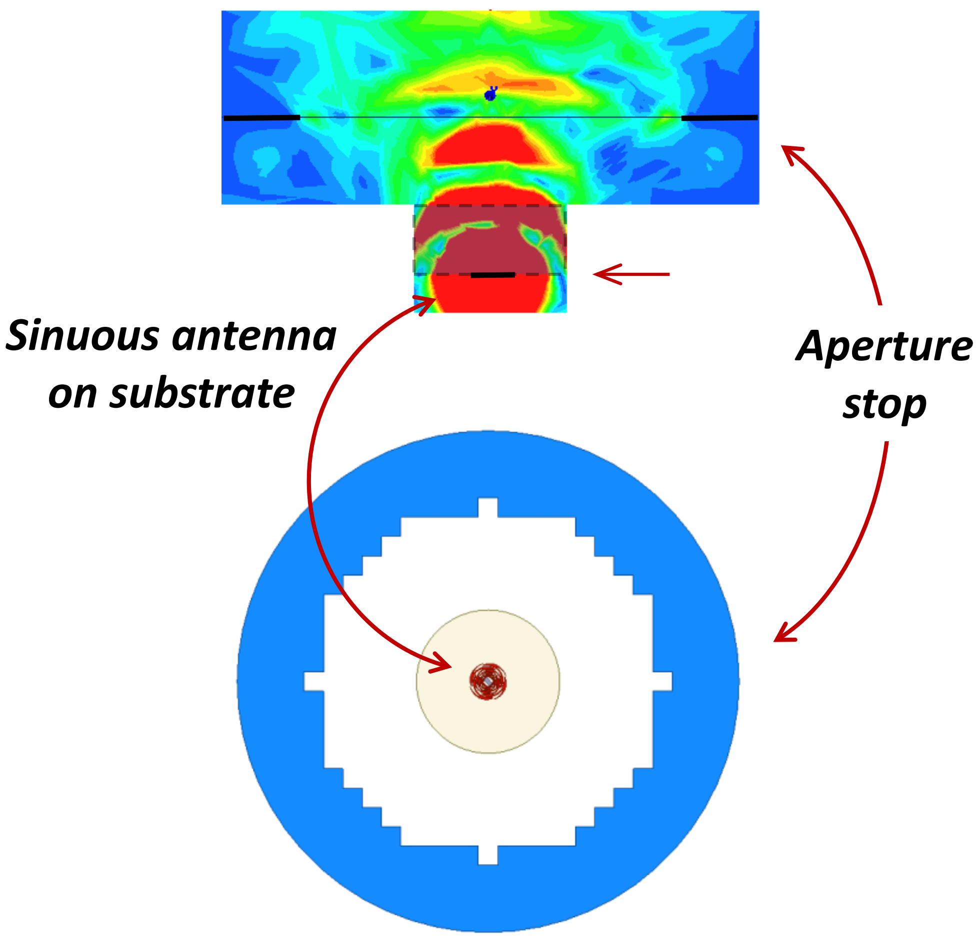




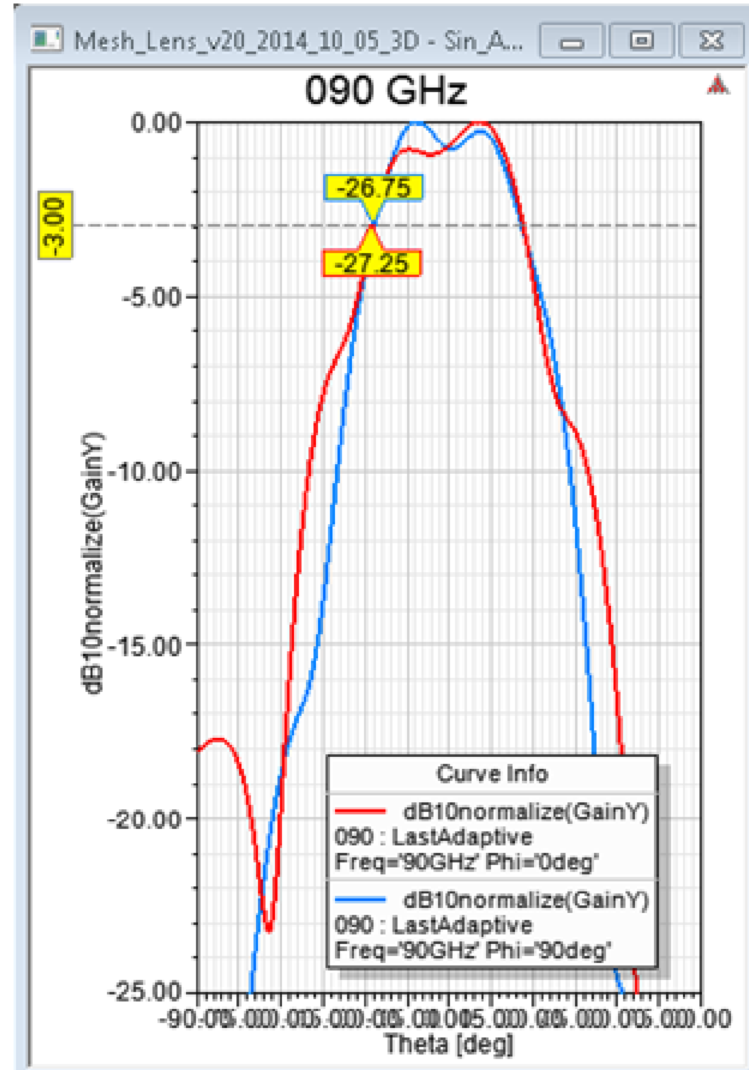


Mesh Lens Array: Coupling to a Sinuous Antenna

Aperture stop

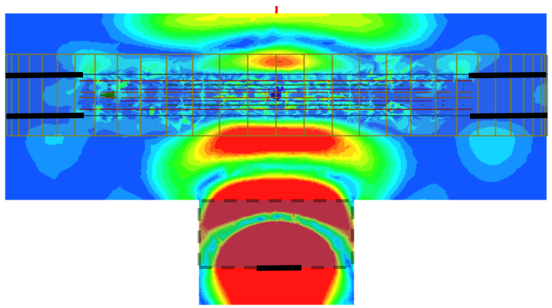


FEA simulation



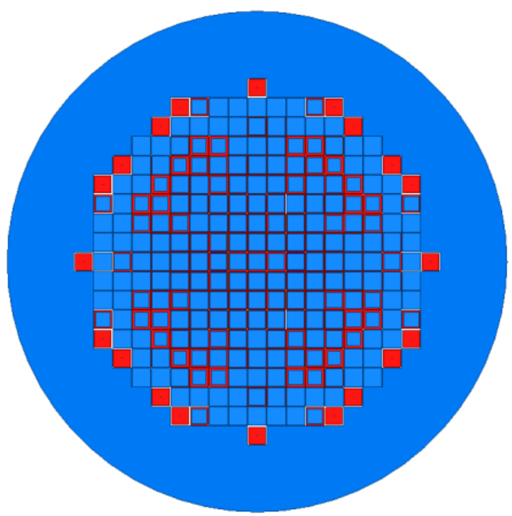
Mesh Lens Array: Coupling to a Sinuous Antenna

Mesh Lens

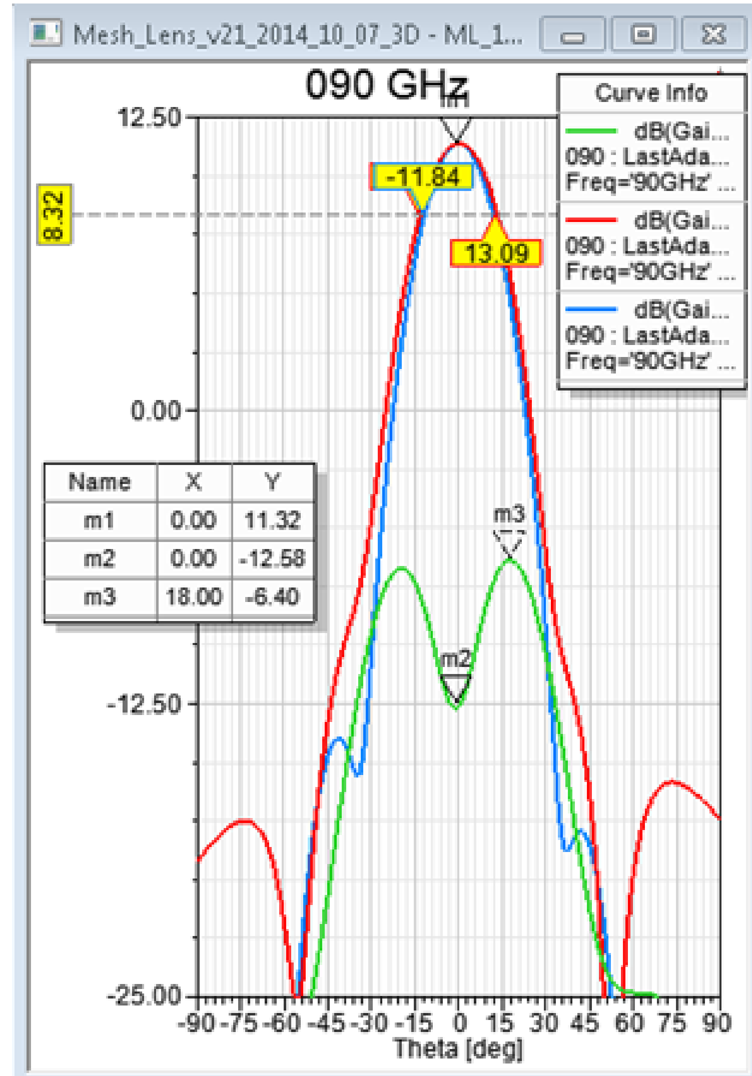


Sinuous antenna on substrate

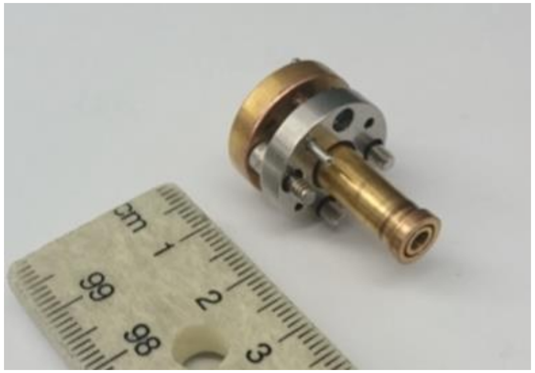
Mesh Lens

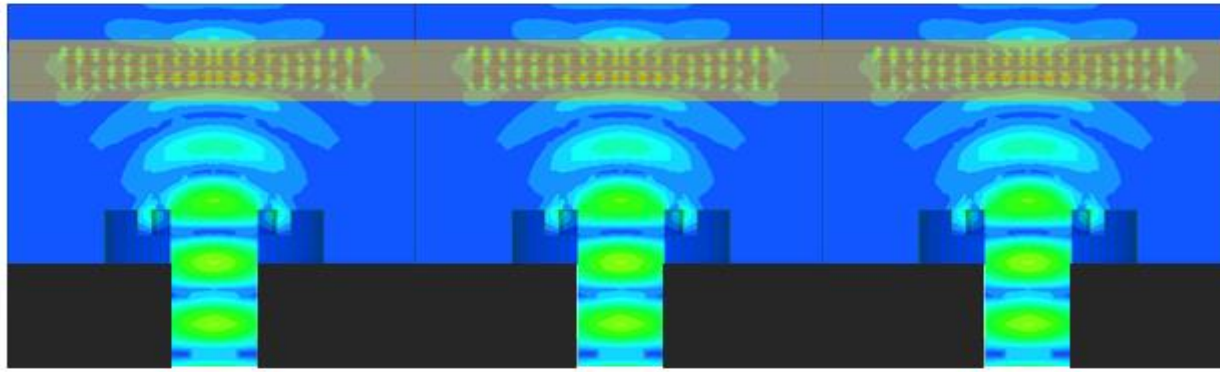


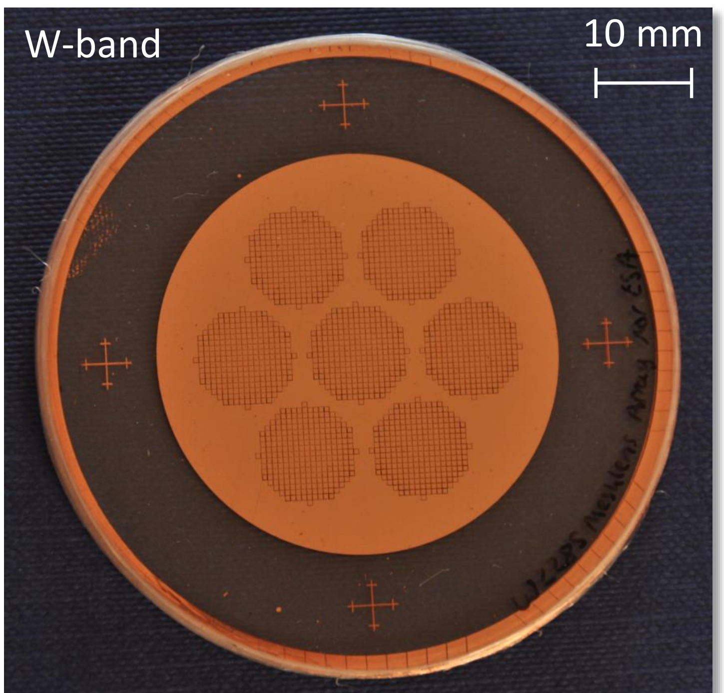
FEA simulation

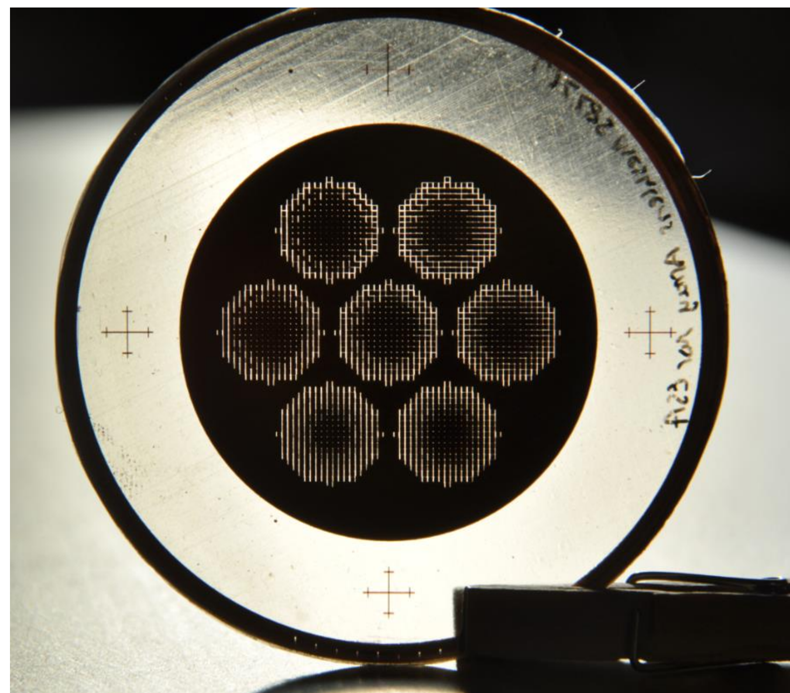


Mesh Lens Array: Coupling to a Waveguide Probe Antenna

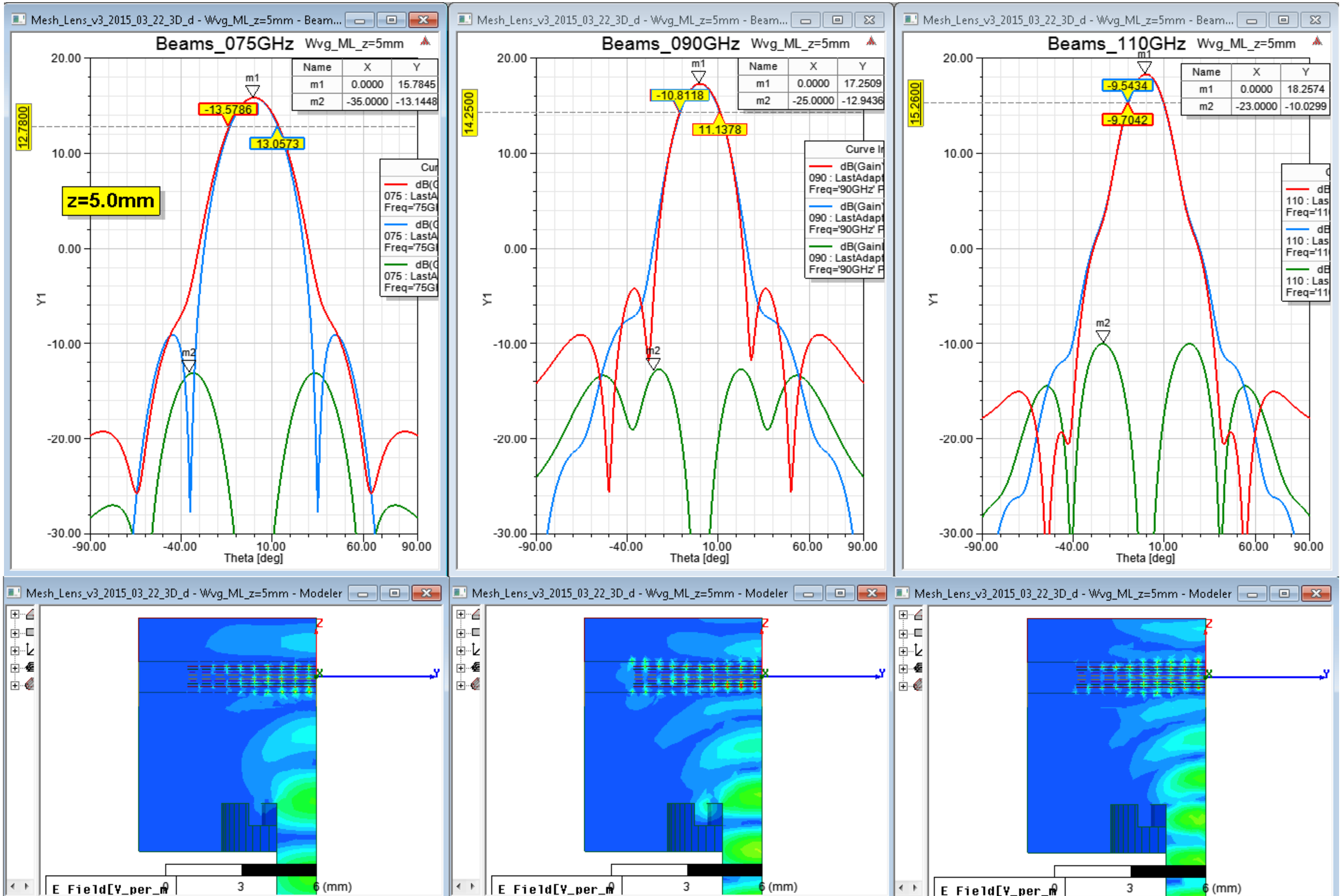






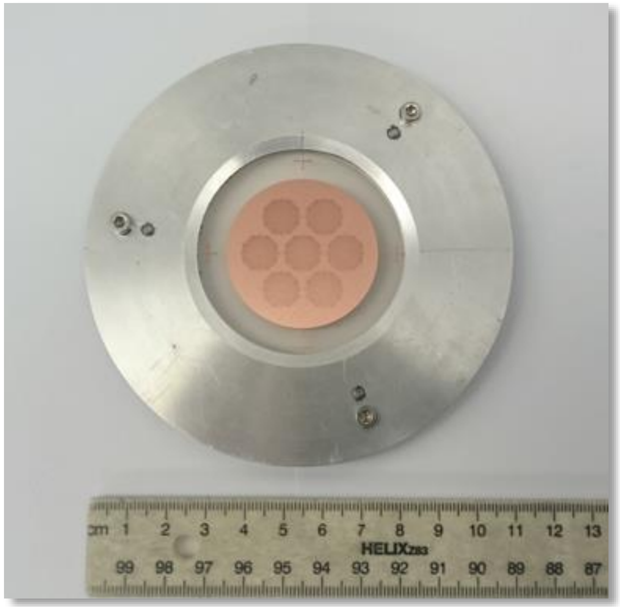


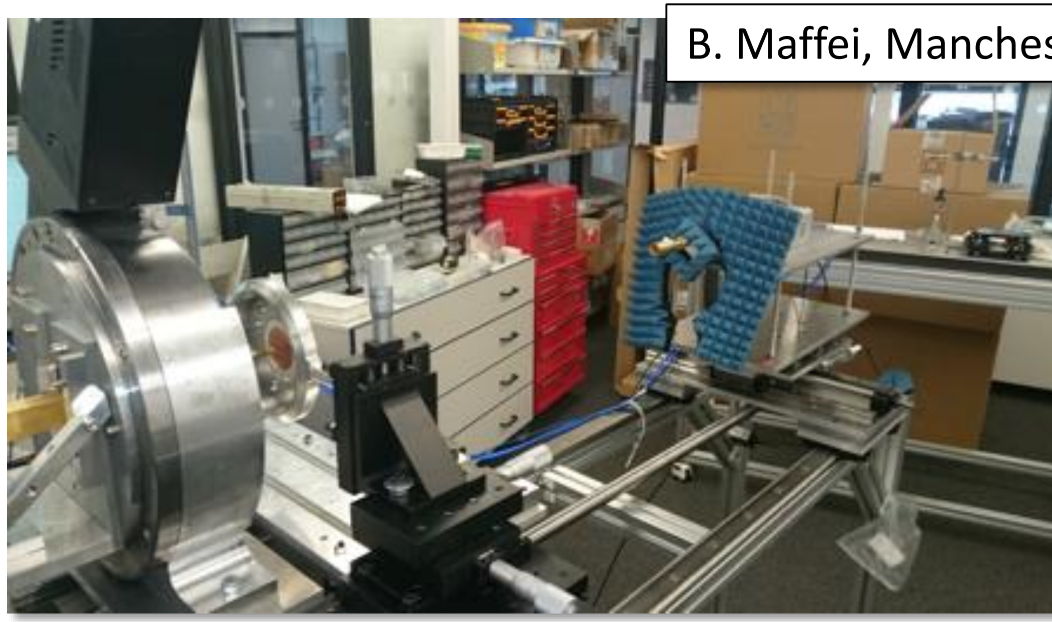
Mesh Lens Array: Waveguide Probe Antenna Simulations

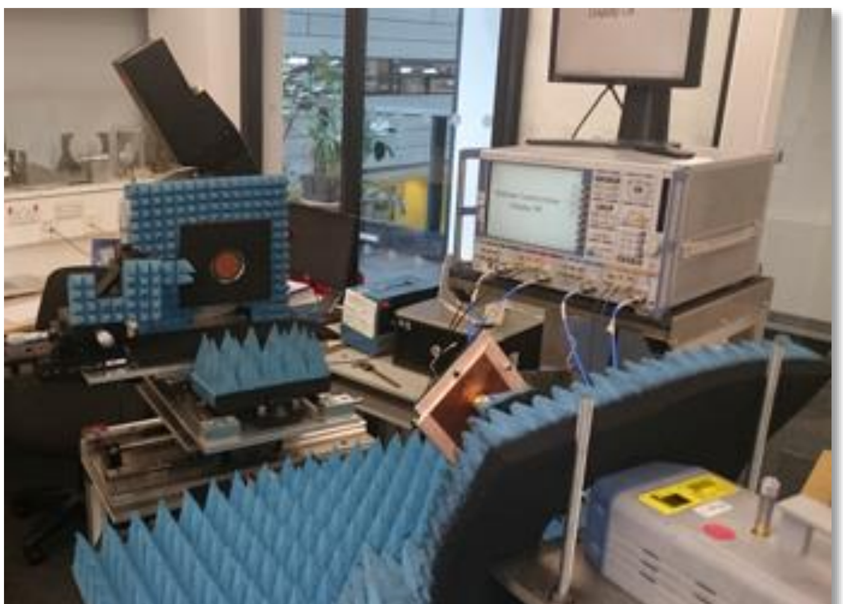


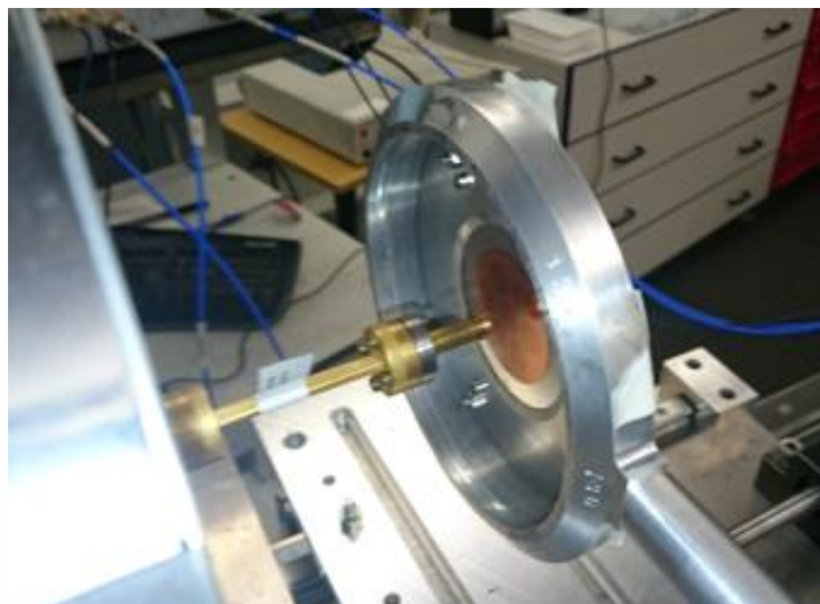
Mesh Lens Array: Waveguide Probe Antenna - VNA tests setup

B. Maffei, Manchester

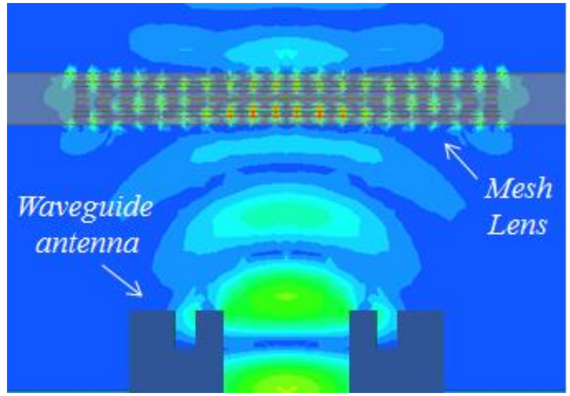


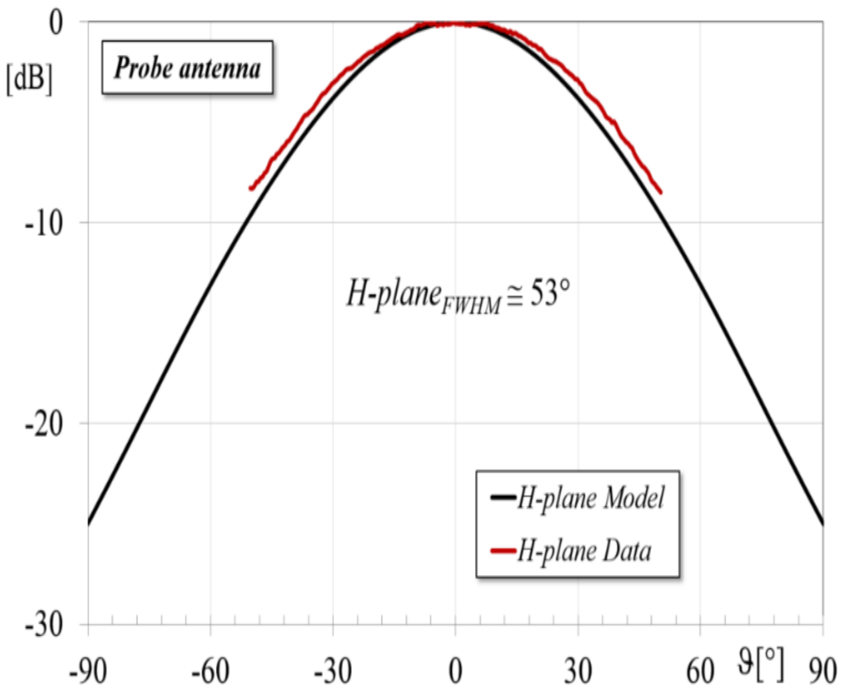


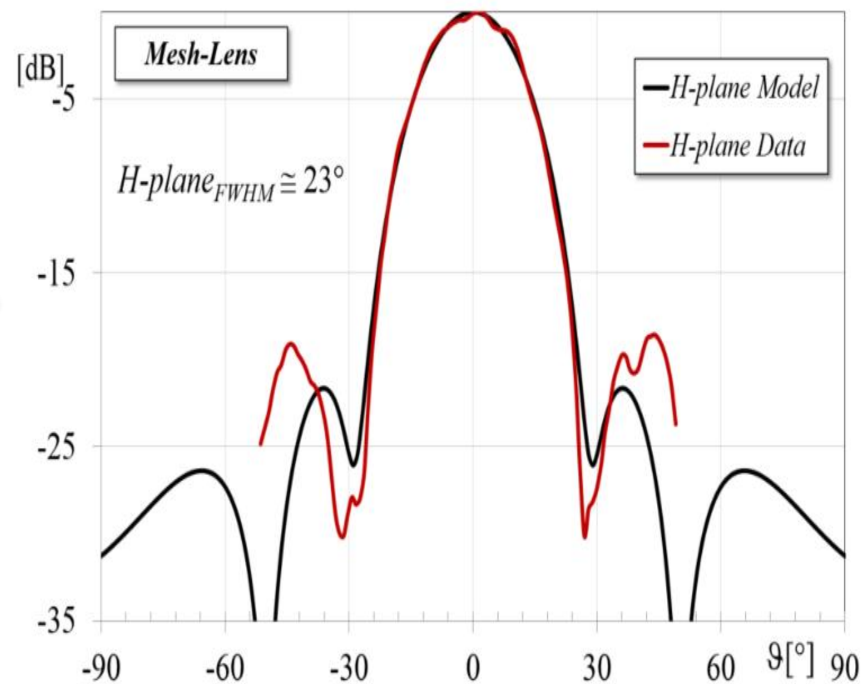




Mesh Lens Array: Waveguide Probe Antenna - Preliminary results

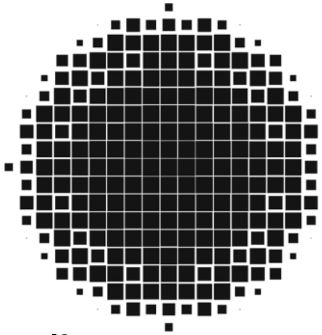




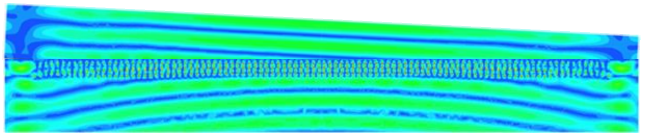


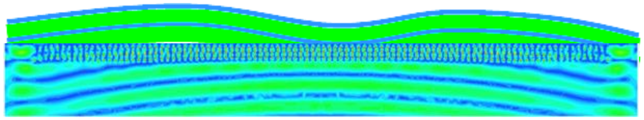
→ First prototype results in good agreement with the models

Phase Manipulation: Arbitrary surfaces



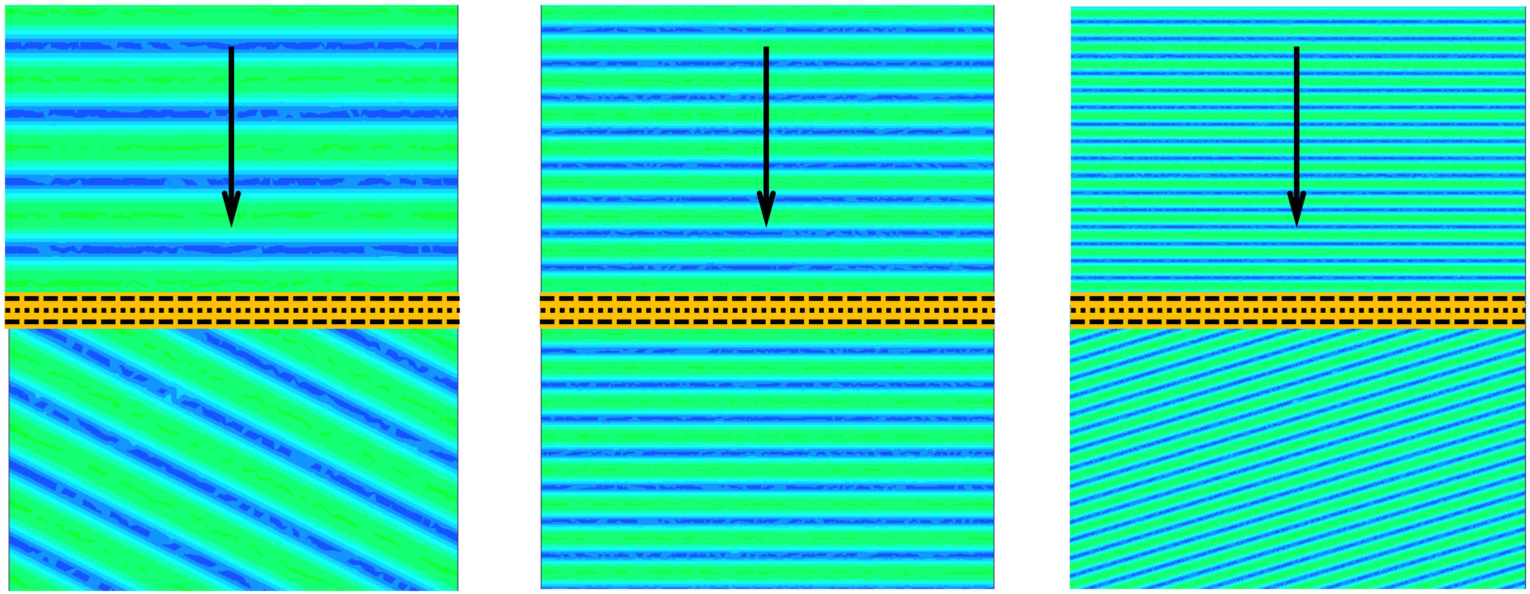
- **Advantages**:





- Phase fronts can be manipulated with hundreds/thousands delay lines
- Beam steering for non-normal incidence
- Arbitrary beam corrections/optimisations
- No complex ARC required
- ARC for larger bandwidths are just flat additional layers
- Independent from source (only original beam phase front required)
- Large arrays produced with the same # of processes for a mesh filter
- Arrays can be cut to arbitrary shapes
- Mesh filters and polarisers can be added within the same structures

Phase Manipulating surfaces: Dichroics / Trichroics



$\nu_1 \pm \Delta\nu_1$ $\nu_2 \pm \Delta\nu_2$ $\nu_3 \pm \Delta\nu_3$

- The frequency-dependent differential phase-shift, respect to a fixed point (ex: centre), would create the required off-axis <u>phase-fronts</u> at the output

Conclusions: Mesh-device summary

Filters

- Low pass & high pass
- Band pass
- Blocking filters
- Neutral density

Retarders

- Mesh HWP
- Mesh QWP (circ.polariser)
- Reflective HWP
- Spiral Phase Plate

Flat lenses

- Graded index lens
- Mesh lens
- Mesh lens array
- Negative index lens

Dividers

- Beam divider
- Dichroic
- Polariser
- Polarisation splitter
- Mesh Prism

Metamaterials

- Artificial dielectrics
- Artificial birefringent materials
- Anti-Reflection Coatings (ARCs)
- Negative Index metamaterials
- Artificial Magnetic Conductors
- Mesh Absorbers & …. more 'exotic' devices

Dimensions

- 33 cm ∅ hot-pressed devices available
- 45 cm ∅ single-grid devices available
- 50 cm ∅ hot-pressed devices planned within 6 months
- 120 cm ∅ hot-pressed devices planned within 12 months