FIR-to-Radio quasi-optical component design and development at JBCA

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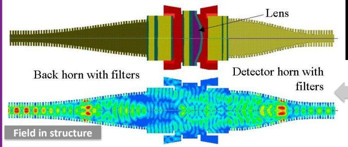
One of the major research topics of the Radio Astronomy Technology Group at JBCA (Jodrell Bank Centre for Astrophysics) Technology is dedicated to the development of Quasi-Optical and waveguide components for Far-Infrared, millimetric and Radio spectral domains. Our expertise ranges from tailored design (using finite element analysis, Gaussian optics and Physical optics software as well as own codes) to manufacture, optical/RF tests of components and optical sub-systems. We present some examples of our developments in QO components based on embedded metallic meshes as well as our research in lens based systems.

Modelling

In order to optimise instrument optical/RF designs, large efforts are dedicated to modelling using complementary methods depending on the system (from component to full system) and the goals.

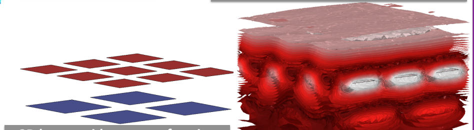


Here are examples of quasi-optical and waveguide component modelling using finite element analysis simulations performed by G. Pisano using HFSS (www.Ansoft.com)

Planck 143GHz horn coupling study [1]

Simulated field inside the 3D periodic structure of 2D layers

Other software used for our optical simulations:
- Ray-tracing (Zemax) – Full system
- Physical Optics (GRASP) – Reflective optics
- Mode matching software – Horns
- Own codes - Filters and dichroics



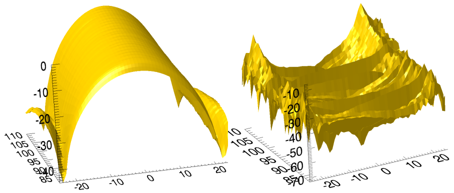
2D layers grid structure forming part of a mesh filter

[1] - B. Maffei et al A&A Planck special issue 2010

Characterisation

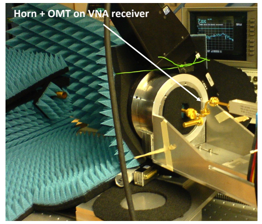
Great care is taken to analyse the performance of our QO components (to be compared with simulations) but also to study their systematic effects on the rest of the instrument [2]. Below is an example of beam characterisation with a filter in front of a horn aperture for a CMB experiment. Data were taken within the full band of our VNA (75-110GHz).

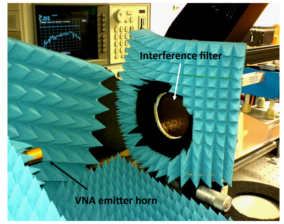
[2] - B. Maffei et al, SPIE, Volume 7020 (2008)



Co-polarisation beam — Cross-polarisation beam

Beam characterisation within the full spectral band of the VNA



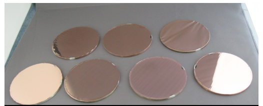


Beam measurement test set-up using a Vector Network Analyser

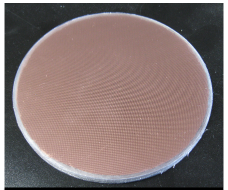
Filters

From modelling (for specific needs) to manufacture and testing we are developing dielectric-embedded mesh filters for a large spectral range (1 GHz to several THz typically).

Example: 100GHz low-pass mesh filter.
All the steps of the manufacture have been performed at JBCA



Individual grids making up the filter



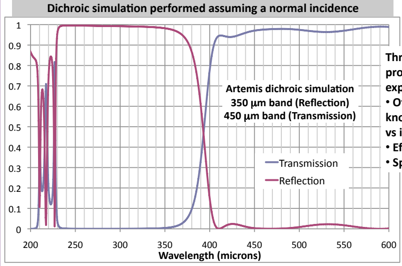
100 GHz low-pass mesh filter (no A/R coating)

Result:
In-band transmission > 90%
> 95% with Anti-reflection coating
Out of band transmission < 0.1%

Dichroics

The project ArTéMis [André Ph. et al, 2008] is an ESO PI project that aims to develop a large bolometer camera on the APEX telescope located on the Atacama plateau in Chile. JBCA is developing the filters and dichroics for this 3 band instrument (200, 350, 450 µm)

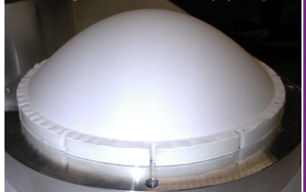
Dichroic simulation performed assuming a normal incidence



Through modelling and prototype development we are expecting to improve:
- Off axis performance knowledge (spectral transmission vs incident angle)
- Efficiency
- Spectral edge definition

Lenses

A/R coating made at Cardiff University by V. Haynes

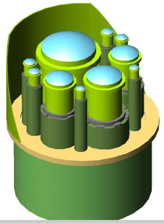


20cm diameter polyethylene lens for QUAD

Several projects (mainly dedicated to CMB studies) need very low systematic effects and large-format lenses.

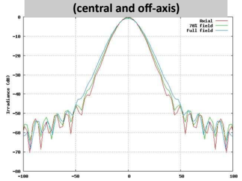
Starting from previous developments (such as lenses developed for QUAD), we are investigating the optical, mechanical and thermal properties of such devices.

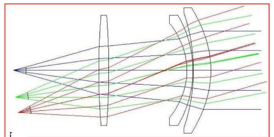
WHY?
So far, most of the CMB experiments are based on off-axis reflective telescopes. While their RF properties are very well understood (model/measurement agreement down to 80dB), the next generation of CMB space mission will require large focal plane arrays with several spectral channels for which reflective based optics become in-practical (dimensions and mass).
For that purpose, missions like the potential future B-Pol project (proposal at www.b-pol.org) are based on refractive telescopes, and for this instance, one on-axis refractive telescope for each spectral band. Our aim is to bring the required technology to the same level of maturity that has been achieved with mirrors.



B-Pol optical design with one refractive telescope system per spectral band

B-Pol beam simulation for 3 pixels (central and off-axis)



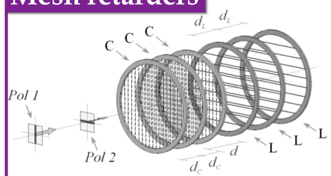


B-Pol refractive system based on 3 lenses

Goals:
The predictions for an ideal lens system (above figure) show the variation of the beam with the position of the pixel. We need a better understanding of a real system.

Low aberrations for each pixel	Low emissivity	Extension of bandwidth (several bands/system)
Low cross-polarisation	Low weight	Use of single and multi-moded optics
Large diameter (50cm diameter)	Very high efficiency	Cryogenic operation

Mesh retarders

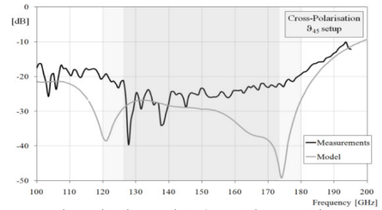


Sketch of an achromatic mesh-HWP

The best mm and sub-mm QO retarders are based on birefringent materials [3],[4]. The required phase-shifts between the orthogonal axes are achieved using the refractive index difference between the ordinary and extraordinary axes. The phase shift depends on the plate thickness and thus is inherently only effective over a narrow frequency band leading to Half or Quarter Wave Plates (HWP/QWP) devices.
Broader bandwidth can be achieved with the Pancharatnam recipes (heavy and expensive)

An alternative solution can be based on the photolithographic technology used to build mesh-filters. These devices comprise several metal grid sheets in a plane parallel stack with either air or dielectric filled spacers [5].

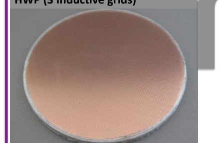
150 GHz air-gap mesh HWP prototype

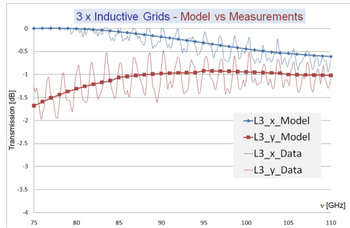


Results: predicted cross polarisation is -35dB. Measured one is about -25dB, comparable to that of birefringent devices [3].

The next step is to develop dielectrically-embedded Mesh-HWPs.
- Mechanically robust
- Can be cooled easily
- Cheaper than birefingent HWPs
- Large diameter possible

Part of dielectrically embedded HWP (3 Inductive grids)





[3] G. Pisano et al., Appl.Opt., v.45, n.27, pp.6982-6989 (2006).
[4] G.Savini et al, Appl. Opt., v.45, n.35, pp.8907-8915 (2006).
[5] G.Pisano et al., Appl.Opt., vol.47, n.33, pp.6251-6256 (2008).