A Metal Mesh Achromatic Half-Wave Plate

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Metal Mesh Filters Modelling

Capacitive Low-Pass

Inductive High-Pass

Resonant Band-Pass

Equivalent Circuit

Spectral response

Grid Period
Shatrow retarders design

Pol 1

Pol 2

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12-grids Mesh HWP Prototype @ 150 GHz

\[ \begin{array}{cccccccc}
\varepsilon_0 & \varepsilon & \varepsilon_0 & \varepsilon & \varepsilon_0 & \varepsilon_0 & \varepsilon_0 & \varepsilon_0 \\
C_1 & C_2 & \ldots & C_6 & L_1 & L_2 & \ldots & L_6
\end{array} \]

\[ \begin{array}{cccccccc}
\varepsilon_0 & \varepsilon & \varepsilon_0 & \varepsilon & \varepsilon_0 & \varepsilon_0 & \varepsilon_0 & \varepsilon_0 \\
C_1 & C_2 & \ldots & C_6 & L_1 & L_2 & \ldots & L_6
\end{array} \]
Experimental setup

- Detector
- Lens
- Polariser
- Incidence angle rotating mount
- Half Wave Plate
- Modulation angle rotating mount
- FTS
Mesh HWP Prototype: Experimental Results

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Fast Axis Transmission

- Single grids and stacks of 3 grids measured previously

Slow Axis Transmission
Mesh HWP Prototype: Experimental Results

Differential Phase-Shift (Retardance)

Cross-Polarisation
# Mesh HWP Performance

## Bands

<table>
<thead>
<tr>
<th></th>
<th>127-173 GHz (30%)</th>
<th>120-180 GHz (40%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured / Model</td>
<td>0.976 / 0.950</td>
<td>0.981 / 0.955</td>
</tr>
<tr>
<td>Fast axis transmission</td>
<td></td>
<td></td>
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<tr>
<td>Slow axis transmission</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast axis total reflection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow axis total reflection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast axis absorption</td>
<td>NA / 0.039</td>
<td>NA / 0.032</td>
</tr>
<tr>
<td>Slow axis absorption</td>
<td>NA / 0.016</td>
<td>NA / 0.024</td>
</tr>
<tr>
<td>Average Cross-polarisation (dB)</td>
<td>-25.5 / -29.8</td>
<td>-25.0 / -30.2</td>
</tr>
<tr>
<td>Phase shift (°)</td>
<td>NA / 183.2 ± 1.7</td>
<td>NA / 182.5 ± 2.2</td>
</tr>
<tr>
<td>Modulation efficiency</td>
<td>0.996 / 0.999</td>
<td>0.995 / 0.999</td>
</tr>
</tbody>
</table>

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(A sapphire 3 plates comparison is more appropriate)

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### Sapphire 5 plates (300K)

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<thead>
<tr>
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<th>127-173 GHz (30%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.922</td>
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<tr>
<td></td>
<td>0.924</td>
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<tr>
<td></td>
<td>0.033</td>
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<td></td>
<td>0.030</td>
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<tr>
<td></td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td>0.046</td>
</tr>
<tr>
<td>Average Cross-polarisation (dB)</td>
<td>-41dB to -30 dB</td>
</tr>
<tr>
<td>Phase shift (°)</td>
<td>177.9 ± 2.5</td>
</tr>
<tr>
<td>Modulation efficiency</td>
<td>0.999</td>
</tr>
</tbody>
</table>

Discussion

- Well known and proven technology
  (Air gap filters used in ISO, Mars Observer, etc. are space qualified)
- Mesh HWP less expensive than birefringent based HWPs
- Maximum diameters as large as mesh filters (birefringent limited to ~300mm)
- Design easy to scale at any frequency of CMB interest
- Different mesh geometries can be adopted to do the same job
- Bandwidths of 70% easily achievable
- Losses very low due to conductivity
- Weight due to polypropylene substrates << sapphire plates
- Symmetric as a single plate birefringent HWP
- Unambiguous definition of ‘Fast’ and ‘Slow’ axis (for calibration issues)
  - A laser can be used to find the axes orientation
Conclusions

• Highest frequency limited by diffraction region of the mesh with bigger period
  → Achievable bandwidths not as wide as the birefringent ones

• Impact on the beam to be modelled and experimentally investigated

• Present air-gap design fragile:
  → More robust hot pressed version (dielectrically filled) to be designed
    (Hot pressed technology is space qualified)

→ Next devices will differ from a normal filter only in the mesh geometries adopted and should be considered a mature technology
Sapphire Achromatic HWPs Studies (FTS)

**Setup**

- Modulation angle rotating mount
- Lens
- Half Wave Plate
- Polariser
- Incidence angle rotating mount

**Results**

- Fast axis Transmission
  - Measurements
  - Model
  - Graph showing transmission vs. frequency for $\phi_0$ setup

- Slow axis Transmission
  - Measurements
  - Model
  - Graph showing transmission vs. frequency for $\phi_{90}$ setup

- Measured Cross-Polarisation
  - Measurements
  - Model
  - Graph showing cross-polarisation vs. frequency for $\phi_{45}$ setup

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Sapphire Achromatic HWPs Studies (FTS)

Model

Results

Measured Cross-Polarisation

Extrapolated Minimum Cross Polarisation

5-plates Sapphire HWP Modulation and Cross-Polarisation 1/2

Incoming Pol on X direction

Parallel Detector (X)  Perpendicular Detector (Y)  Reflections (X&Y)

$\vartheta = 0^\circ$

$\vartheta = 45^\circ$

$\vartheta = 90^\circ$

$\vartheta = 135^\circ$

Fast Axis

Slow Axis

Incoming Pol on X direction
HWP modulation and Cross-Polarisation 1/2

- Fast
- Slow

Relative Intensity

- Aligned polarisers
- Orthogonal polarisers

Dilation angle [°]
Light splits in an **ordinary** and an **extraordinary ray** in different directions.

**Refractive index** not isotropic

- Ray-tracing
- No multiple reflections
- Single plate