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Instrumental systematic effects of quasi-optical components for astronomical instruments

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Introduction

Both the current and future astrophysical experiments dedicated to millimetre-wave polarimetry (e.g. COrE and QUBIC) are in need of well defined antenna beam shapes, in order to measure polarisation accurately. However, in order to have such well defined beam shapes, the instruments forming these beams not only have to be designed with care, but also have to be characterised properly by experimental characterisation and computer simulation.

The beam characterisation process is especially important for instrumentation with bolometers in operation, as many of the quasi-optical components (such as the thin film polypropylene window for the cryostat dewars, interference filters and waveplates) in such systems are required to be in the optical path, which in turn can modify the beam shape / radiation pattern of corrugated antenna horns (Fig 1) and potentially increase the cross-polarisation (X-pol).

Characterisation of quasi-optical components

The modifications of the co-polarisation and cross-polarisation radiation patterns due to the thin film polypropylene window (Fig 2) were studied using an experimental setup based on the vector network analyser (VNA), at the W-band frequency range (75 GHz to 110 GHz). The window was placed on a mount, in front of the emitter horn (Fig 3).

Fig 1: The type of corrugated antenna horns used as receiver and emitter horns in the experimental setup.

Fig 2: Thin film polypropylene window (thickness = 75 μm) on the sample mount in front of the emitter horn.

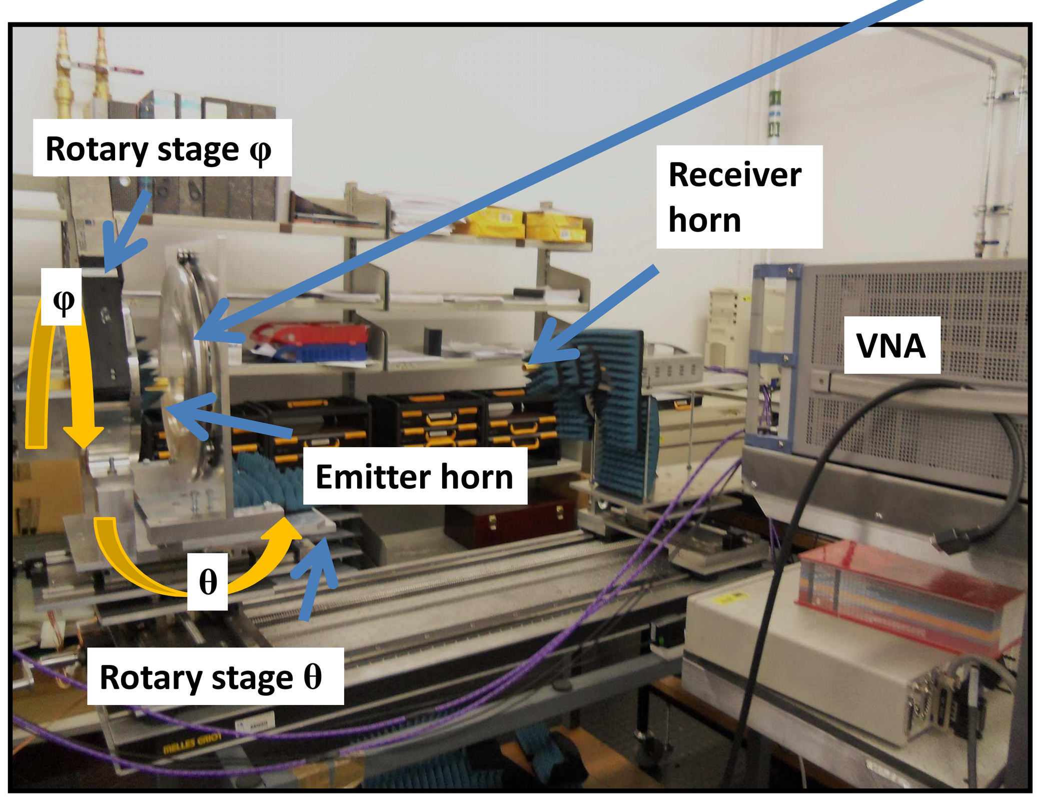
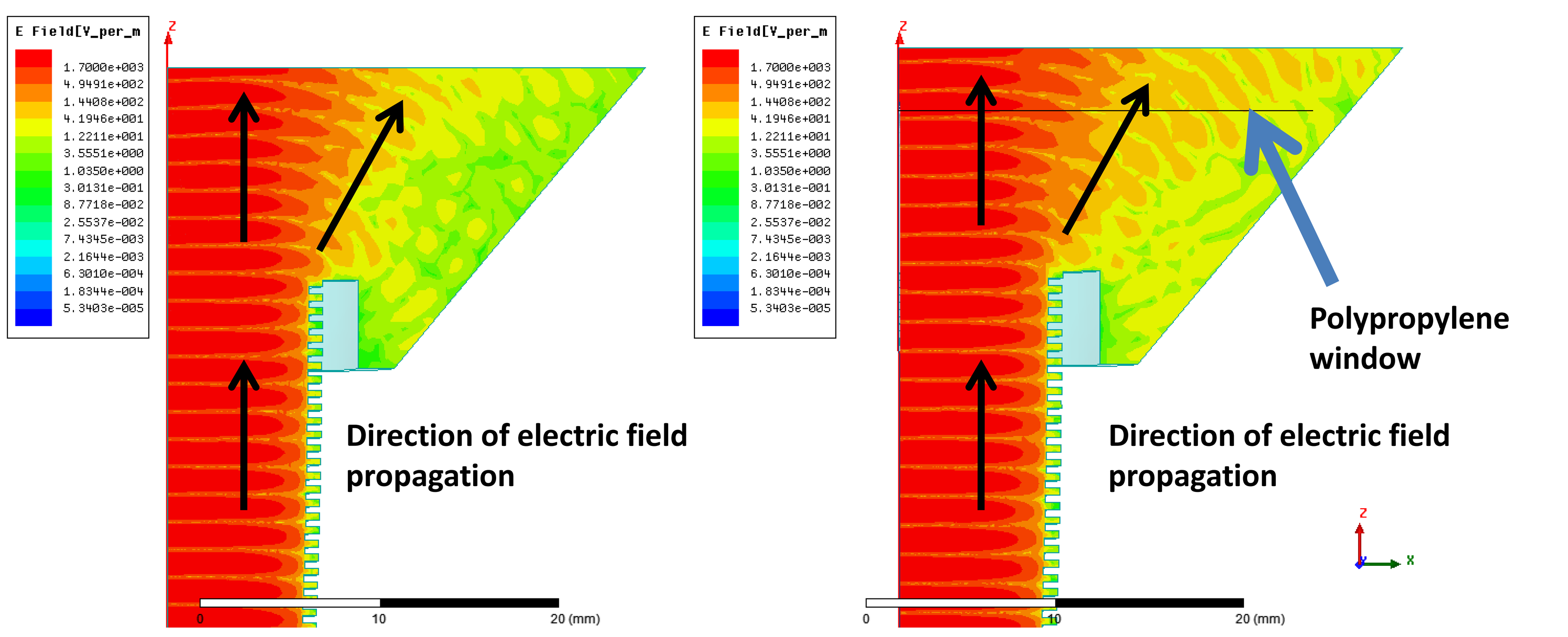


Fig 3: Experimental setup with the VNA that was used to extract the modified co-polarisation and cross-polarisation radiation patterns due to the window. Two rotary stages were used to vary the off-axis (θ) and azimuthal angle (φ).

The orientation of the receiver horn determines which cut of the emitter horn's radiation pattern is being extracted (E, H or diagonal cut). Two rotary stages were used (Fig 3) to vary the off-axis angle (θ) and azimuthal angle (φ), in order to extract the co-polarisation and cross-polarisation radiation pattern.

Computer simulations



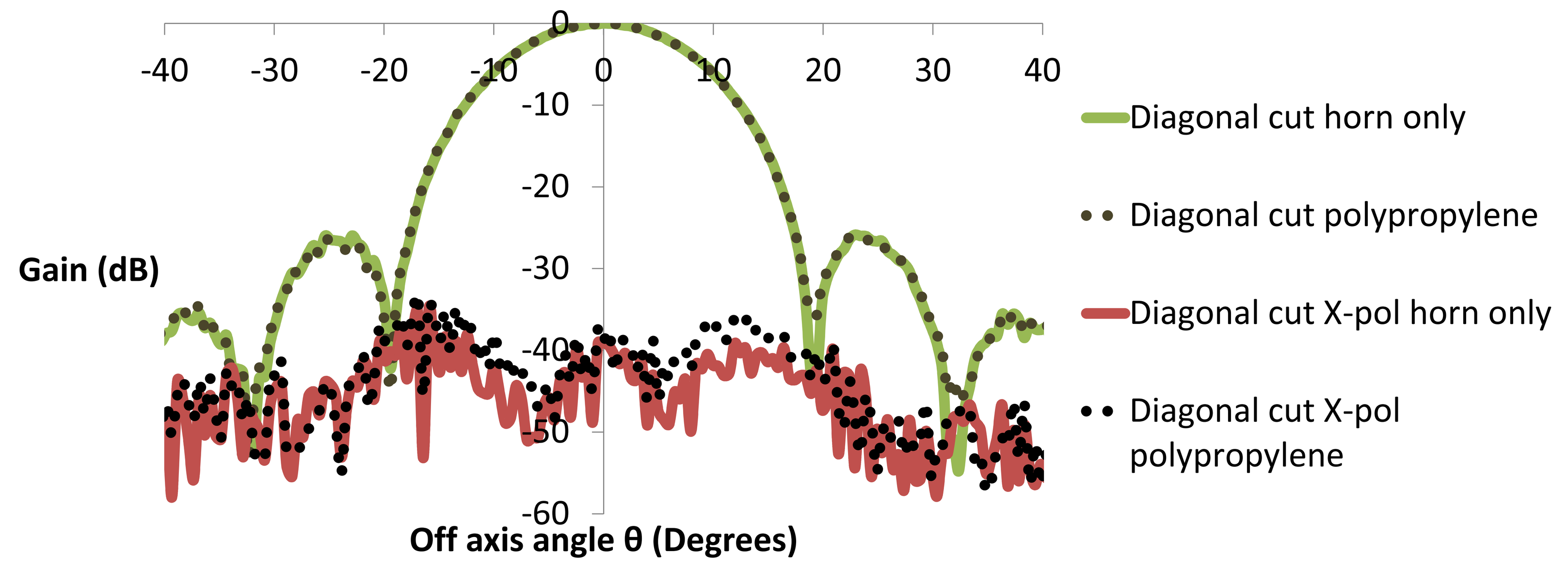
Horn only **Horn with window**

Fig 4: HFSS - an electromagnetic simulation package was used to predict the co-polarisation and cross-polarisation radiation pattern, with and without the thin film polypropylene window.

Computer simulation with HFSS (Fig 4) was conducted to see whether the simulated co-polarisation, cross-polarisation radiation pattern and the beam difference (Fig 5, Fig 6) all agree with the experimental measurements.

Results

Experiment 97 GHz



Simulation 97 GHz

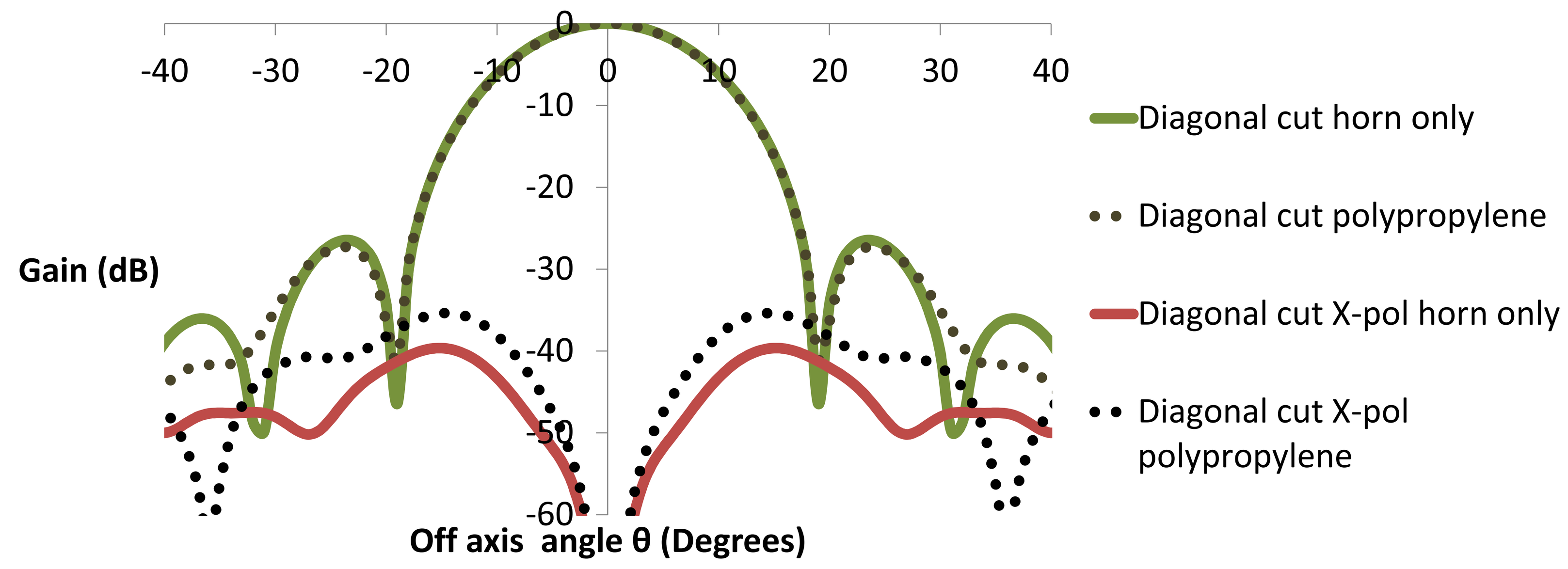


Fig 5: The diagonal co-polarisation and X-pol radiation pattern for the emitter horn at φ=45 degrees, with and without the thin film polypropylene window, using both the experimental setup (Fig 3) and the HFSS simulation package.

Beam difference 97 GHz

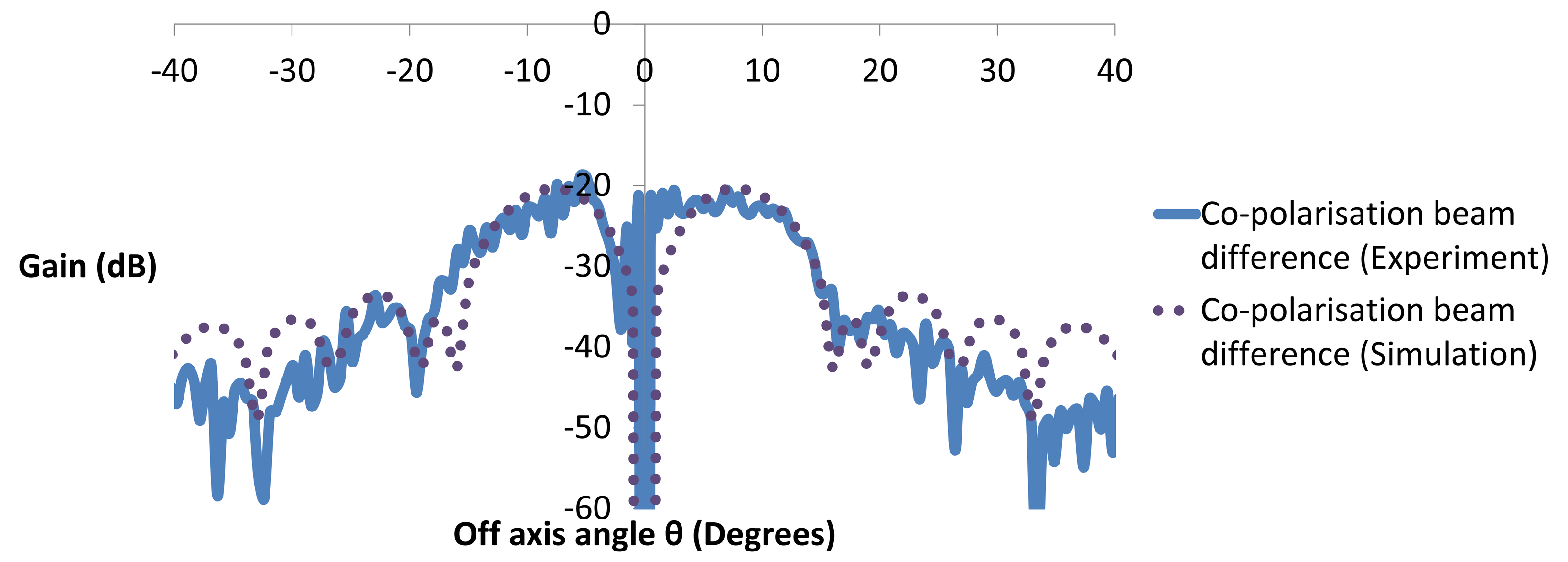


Fig 6: A comparison between the experimental and simulated diagonal co-polarisation beam difference for the emitter horn at φ=45 degrees (i.e. with and without the polypropylene window).

$$\text{Beam difference}(\theta) = 10 \times \log_{10}\left(\frac{|\text{Beam with window}(\theta) - \text{Horn Beam}(\theta)|}{\text{Horn beam}(\theta = 0)}\right)$$

Beam difference is a measure of the radiation pattern's modification, due to the presence of quasi-optical components.

Conclusions

- Both the experimental co-polarisation and cross-polarisation radiation pattern agree with the computer simulations, up to θ = 20 degrees.
- A difference in the main beam and side-lobe of ~ -20 dB and ~ -35 dB were observed respectively, due to the presence of the thin film polypropylene window.
- An increase of -37 dB in cross-polarisation was observed, due to the presence of the thin film polypropylene window.

References

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