Band 7 Xpol. Role of grid orientation. Modeling and experimental results

Prepared in compliance with an action item following the teleconference of 2008-01-23 with: T.Beasley, R.Hills, G.H.Tan, F.Patt, Ch.Haupt, B.Lazareff, S.Mahieu.

Date: 20-Feb 2008
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Abstract

We show that an ideal wire-grid diplexer induces cross-polarization when three conditions are met: i) the incident beam has a finite extent (in contrast with a plane wave); ii) the incidence is oblique; iii) the position angle of the grid wires within the grid plane deviates from an ideal value. This is illustrated in the case of the ALMA Band 7 optics. We analyze the cross-polarization performance of the grid diplexer as implemented in the pre-series, and show how it can be improved.

1 Introduction

1.1 Cross polarization specification

The Band 7 cartridge was designed to meet a number of specifications, among which a maximum level of cross-polarization (Xpol) of -20dB. Note that the precise meaning attached to that number was not always fully clear; it can be understood as: a) peak level of the Xpol beam relative to the peak level of the Copol beam; b) peak value of the ratio Xpol/Copol; c) ratio of integrated power coupling in the Xpol beam to the same integral for the Copol beam. The interpretation (b) is generally more stringent than (a), when the peak Xpol occurs off bore sight; on the other hand, prescriptions (a) and (c) are found in practice to be near equivalent.

1.2 Configuration adopted for the Band 7 cartridge

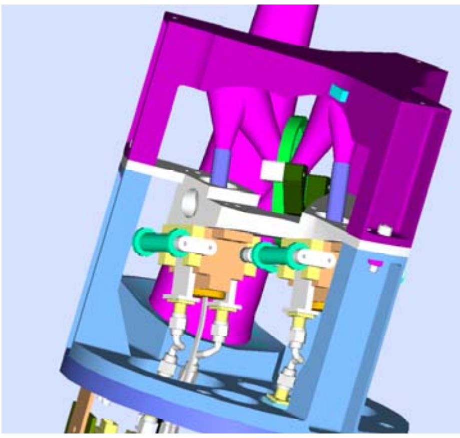


Figure 1. Optical configuration for the Band 7 optics.

As can be seen on Figure 1, and propagating from the mixer horn outwards, the beams from the mixers are reflected off one of two off-axis mirrors (top); they then meet a grid diplexer (green), such that (having appropriate polarizations) one of the beams is transmitted and the other reflected. From then on they follow a common path. It has been thought that after being recombined at the grid diplexer, each of the beams would have virtually perfect polarization purity, with any Xpol in the mixer horn beam being reduced by the grid Xpol rejection, of order –30dB at 300 GHz with the chosen wire grid parameters (25μm wire at 100μm pitch). Accordingly, it was thought that the final off-axis elliptical mirror (rear bottom on Figure 1) would dominate the Xpol performance of the optics, and that mirror was designed with a small reflection angle (~25°) and a relatively small curvature. Following the analysis of Murphy, J.A., 1987, Int. J. Ir mm Waves, 8, 9, 1165, the Xpol induced by this mirror should be –34.5dB (integrated power), and the *design* was considered compliant.

1.3 Xpol performance of pre-production cartridges

Measurements made on the pre-production cartridges showed Xpol levels in the range -22dB to -18dB (typical values, several measurement methods). Even though it was also found that a significant contribution comes from the molded IR filter, it was clear that the cartridge optics was not performing as expected. That was the starting point for the investigation reported here.

2 Copol and Xpol definition

Ludwig, A.C., 1973, IEEE Trans. Antennas and Propagation, and all that stuff.

Differences between various definitions of reference polarization Ludwig 1, 2, 3 are not significant at the levels discussed here.

To be written up later.

3 Modeling results

The Xpol in the B7 cartridge arises because:

- The beam going through the grid, having a finite spatial extent contains a spectrum of plane waves (in simpler language, that is just the far-field pattern).
- The projected (onto the local E-H wave plane) of the grid wires, that defines the Cpol or Xpol (depending on whether we are dealing with transmitted or reflected beam) has only a local definition;
- The surface of a sphere being intrinsically curved, there is no canonical way to relate directions in the tangent planes of two different points on the sphere, whence:
    a. The various definition of Xpol mentioned in the previous section;
    b. A local definition of the Co- and Xpol actually defined by the grid;
    c. If (a) and (b) are made to agree on boresight, they will not generally agree over the beam.

We have modeled this phenomenon with a suitable computer program. One parameter is varied: the position angle of the polarization diplexing grid within its plane. The rest of the cartridge geometry is unchanged, except for re-definition of position angles for the polarization vectors.

The PA of the grid is reckoned by angle ϕ_g , which has a value of $0°$ in the nominal configuration.

3.1 Nominal configuration

Results shown for polarization P1 (transmitted through grid)

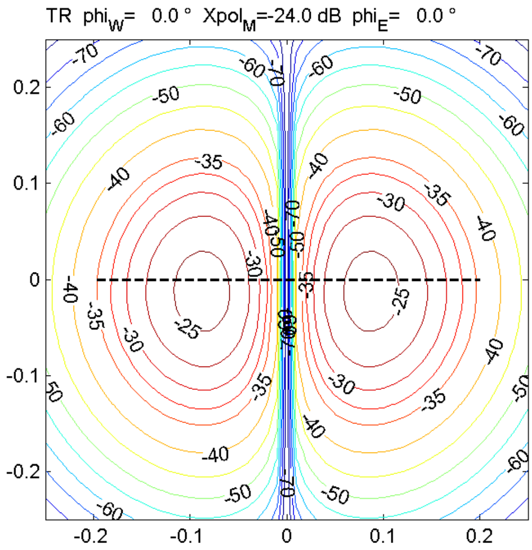


Figure 2. Xpol diagram (relative to Cpol on boresight). Nominal configuration. ϕg=0°.

3.2 Optimum configuration.

That is achieved when the grid wires are perpendicular to the projection of the beam' s chief ray onto the plane of the grid.

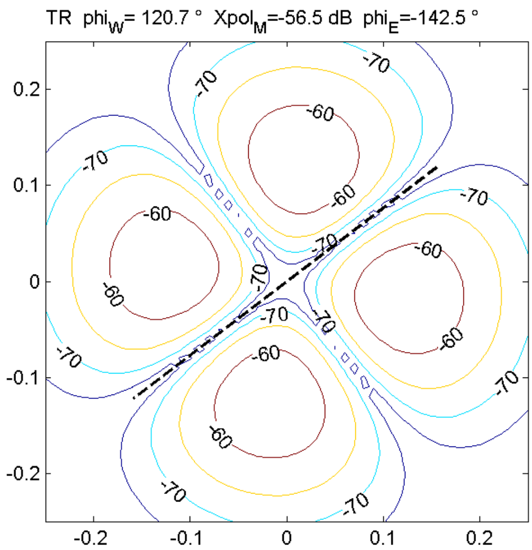


Figure 3. Xpol diagram in optimum configuration. Dotted line and ϕ_E refer to the Cpol electric field orientation at the exit of the cartridge

3.3 Is the optimum robust?

We show below the Xpol diagram for a PA of the grid 5° away from the optimum (quite pessimistic for the alignment tolerance).

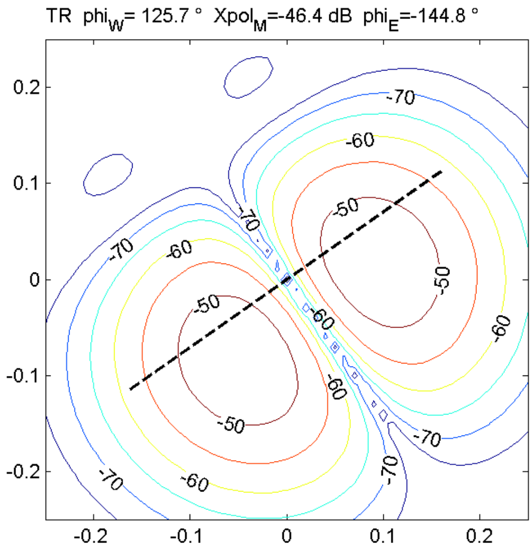


Figure 4. Xpol for grid PA 5° away from optimum. Xpol is still –46dB (formally at least).

3.4 Overall geometry.

We have produced a " wireframe" model of the geometry of the cartridge and polarization vectors in the optimum configuration.

Conventions:

- XYZ are basis vectors, drawn black, with various suffixes that are more or less self-explanatory and will be detailed in a final version of this memo.
- T, R are the E vectors for the polarization transmitted, reflected (resp.) off the grid.
- "o" and "n" suffixes refer to the "old" and "new" configurations.
- "h", "g", and "2" suffixes denote locations at the horn mouth, between the grid and M2, and at exit from the cartridge optics.

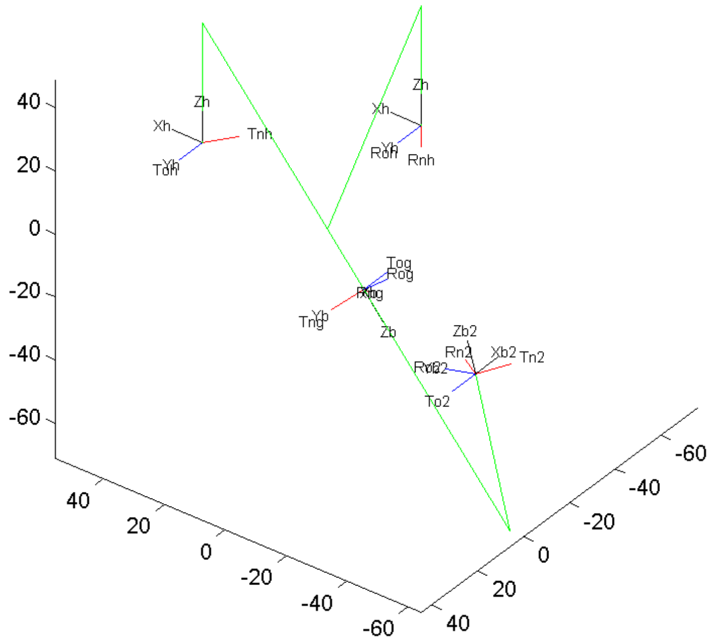


Figure 5. Perspective view of the wireframe model.

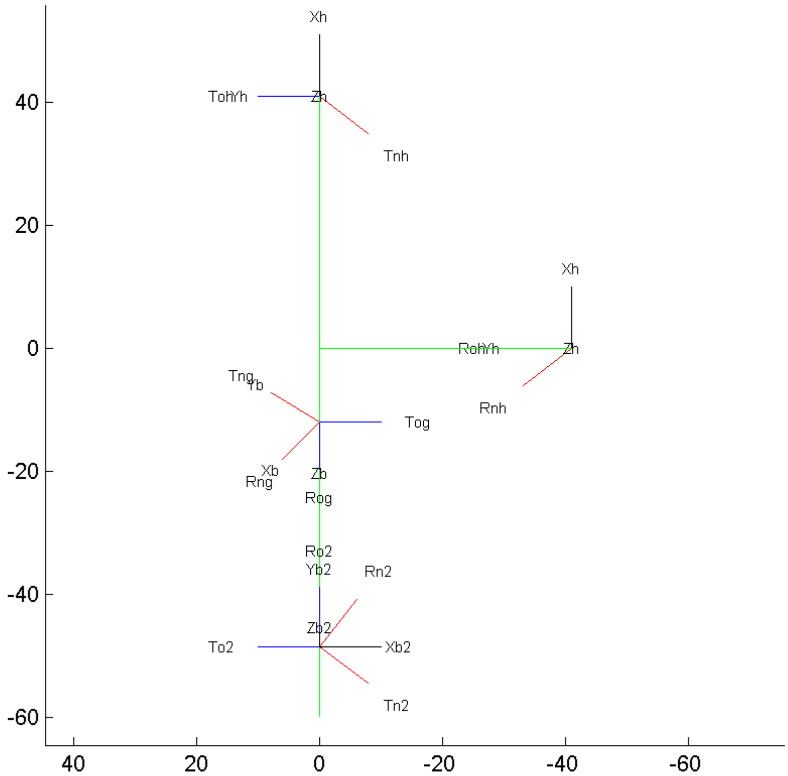
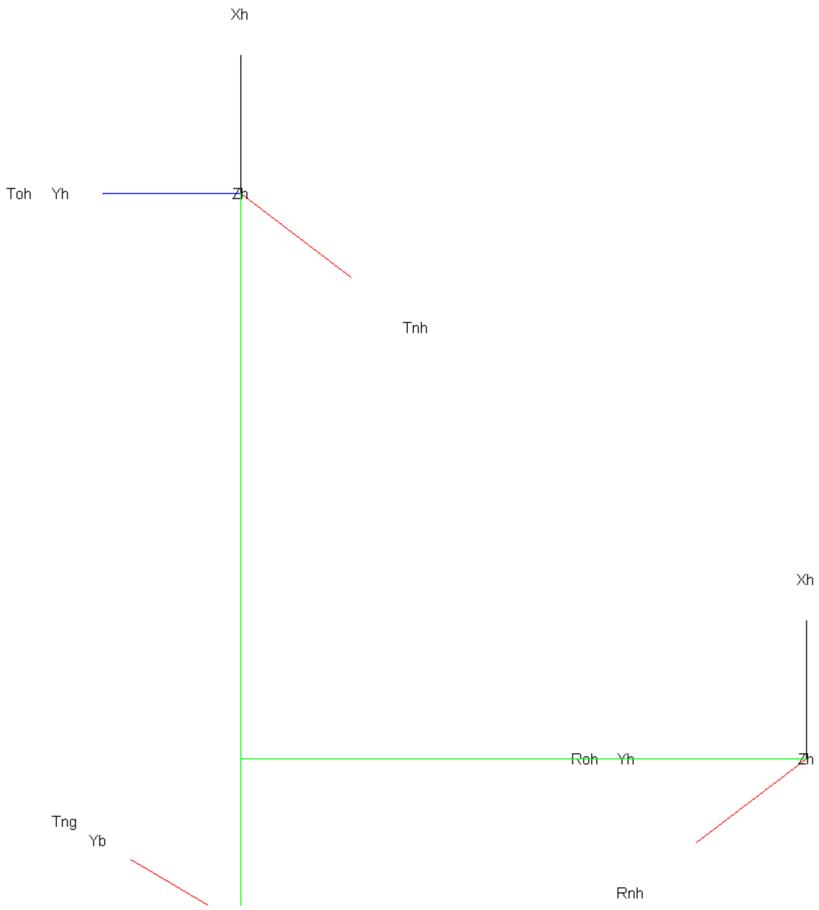


Figure 6. Looking down along the axis of the horns; the beam exiting from the cartridge is ~15° away from the line of sight.



The E vectors at the horns rotate in opposite direction, by $\pm 37.5°$ (from the present baseline position where they were parallel). Accordingly, two kinds of horns must be fabricated, whose twists are mirror images.

4 Experimental results

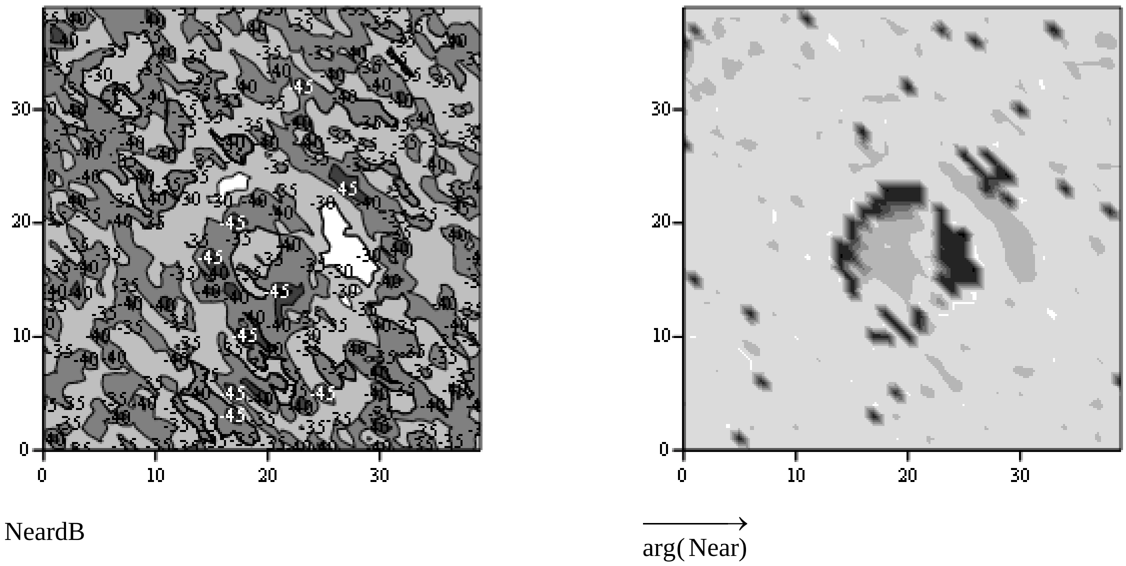


Figure 7. Sample Xpol Amplitude and Phase plots, for the worst case (P0. 342GHz)

RF Frequency	*Xpol P0*	*Xpol P1*
288	-30.3	-31.0
324	-29.7	-29.7
342	-25.6	-32.8

5 Estimates of impact

5.1 Manpower (extra from baseline)

Work so far: Gift to Project.

Verify that horn cone can be shortened without significant impact on optics performance, model verification of EM performance of horn+twist, translate to Cad file and drawings. 2 weeks.

Re-write CNC program for horn mandrel: 1 week.

Modify grid drawing 0.5 day.

Modify cartridge test to accommodate slant pol angle. 3-6 man-weeks tbc (various options).

5.2 Schedule

From decision date

- 3 weeks above for re-design
- 2 week for machining mandrels
- 8 weeks for electroforming (subcontract)
- 2 weeks post machining (outside shape, flange)
- 2 weeks RF testing (VNA).
- 1 week room temperature full optics validation

18 weeks from decision. Must complete before start of cartridge #9, i.e. In order to be ready by start of mixer AIV (2008-08-26) and not impact the overall schedule, the decision must be taken by 2008-04-22.

5.3 Budget impact

None beyond manpower.

5.4 Risk

IRAM has already on several occasions implemented successfully horns with integrated twists. We estimate that the main risk is a fabrication problem, i.e. no larger than in any batch of corrugated horns. To remain consistent with that assessment, we will refrain from implementing improvements in the horn that (as we learnt since the original design) should improve the return loss.