

Ideal Grid Generates Cross Polarization

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Abstract—The ALMA Band 7 cartridge dual-polarization cold optics has been designed to meet a number of specifications, among which the level of cross polarization (initially <-20 dB, now <-23 dB). The initial design was based on the assumption that the coupling diagram from each of the two horns would be free from cross polarization (Xpol) just beyond the polarization diplexing grid, with the only contribution to Xpol coming from the final refocusing mirror.

Initial measurements were showed levels of Xpol significantly worse than expected. This led (after some time) to the realization that an ideal grid can generate cross polarization, which can be brought down to a negligible level by a proper orientation of the grid.

The design has been modified accordingly, and the measurements indeed have shown a significant improvement, that allowed a tighter specification to be instated.

Optics, Polarization, Quasi-optics, Grid.

I. INTRODUCTION

THE ALMA Band 7 cartridge is a module of the ALMA front end, located in the Cassegrain focal plane of the telescope. It contains the tertiary optics and electronic components for a dual polarization and dual sideband receiver, covering the 275-373 GHz band, and delivering four 4-8 GHz IF bands. The transition between guided and open-space propagation is realized, for each of the two SIS mixers, by a corrugated horn.

The tertiary optics, that interface these two horns to the optics of the Cassegrain telescope, must meet a number of specifications, generally aimed at maximizing the efficiency of the system. It comprises, among other, a polarization diplexer consisting of a conducting grid.

One important specification is the level of cross polarization (Xpol), i.e; the coupling of one channel to the polarization orthogonal to its nominal state. In the present case, as is most frequent, the nominal polarization states are linear.

This contribution provides an account on how the Band 7 tertiary optics was initially designed, found to not meet the expected performance, how it was realized that the Xpol issue arose in the grid, and how that issue was resolved.

II. INITIAL DESIGN

As is customary when dealing with quasi-optical systems, we will describe the system from the horn outwards to the

telescope, as if we were dealing with a transmitter.

The beam from each horn is refocused by an offset elliptical mirror (respectively M1 and M1R), with a deviation angle of 40° ; that relatively large angle is not optimized for low Xpol.

In the next step, a wire grid recombines the two beams, respectively in transmission and reflection. With the chosen grid parameters ($25\mu\text{m}$ diameter, $100\mu\text{m}$ pitch), the unwanted couplings, intrinsic to the grid, should be below 1%. Furthermore, the Xpol rejection of the grid combines with the intrinsic polarization purity of the scalar horns (even degraded by the first offset elliptical mirror), so that we expected the polarization purity just after beam recombination to be better than -30 dB.

Accordingly, a driving consideration in the design of the Band 7 tertiary optics has been to minimize the Xpol induced by the final offset elliptical mirror (M2). This requires "slow" beams and a small angle of reflection. We designed for a $1/e$ beam width (at the central frequency) $w=13$ mm, an equivalent focal length $f=77$ mm, and a reflection angle of 25° ($i=12.5^\circ$). Accordingly, following equation 21 of [1], we expected an (integrated) cross polarization level of -34 dB.

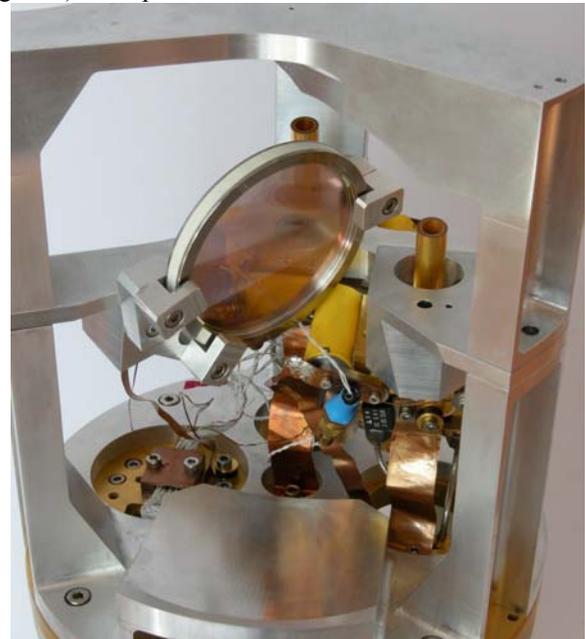


Figure 1. The Band 7 cold optics. Mirrors M1 and M1R are at the top, partly hidden; horns at the back, circular grid in middle, mirror M2R bottom foreground.

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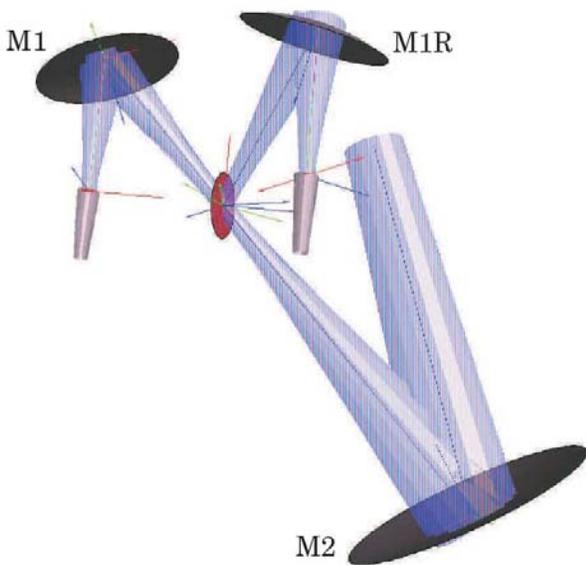


Figure 2. A schematic of the Band 7 tertiary optics. Reproduced from the design verification contracted by ESO to TICRA.

III. INITIAL MEASUREMENTS

Initial measurements were disappointing. Not only did we not come close to the design value of -34 dB, but, more often than not, we failed to meet the contractual specification of -20 dB !

IV. ANALYSIS

A. A matter of definitions

It is straightforward to show that a sheet that is a perfect conductor in one direction, and has zero conductivity in the orthogonal direction, acts a perfect polarization diplexer for a plane wave, under arbitrary oblique incidence, and for arbitrary orientation of the incident polarization with respect to the incidence plane. A wire grid is (with proper parameters) a close approximation to such an ideal diplexer.

However, in real-world systems, a quasi-optical beam has a finite transverse extent, typically in the range 5-50 wavelengths. As a result, its decomposition into plane waves (a straightforward Fourier transform) contains a spectrum of spatial directions, around the central direction, or chief ray, of the beam.

These directions can be thought of as spanning a region of the unit sphere. And the notions of co- and cross- polarization over a finite region of the sphere require a definition of "parallel" and perpendicular over that region. That question has no canonical answer.

That issue has been addressed in [2]. Ludwig proposes and analyzes three possible definitions of co- and cross-polarization over the sphere. Definition 3 has been generally adopted, because a) the two patterns (co- and cross-) transform into each other by a *global* rotation; b) it has a natural implementation in beam scanner hardware.

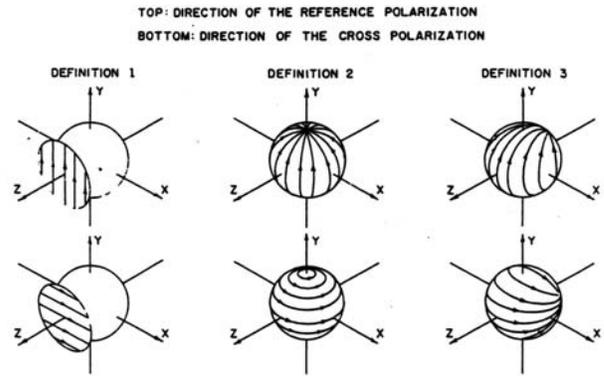


Fig. 1. Alternate polarization definition.

Figure 3. The three definitions of co- and cross-polarization according to Ludwig [2]. Picture worth thousand words.

But, if the definition of co- and cross-polarization over a finite angular extent is, to a degree, arbitrary, does it make sense to discuss the cross-polarization induced by an ideal grid? To help answer that question, we have evaluated the coupling between Cp and Xp belonging to different Ludwig definitions. This results in a 3x3 matrix of coupling maps. Along the diagonal, we have of course zero cross couplings between Cp and Xp belonging to the same definition; note that the matrix is *not* symmetrical. The strongest cross coupling is between Ludwig2 Cp and Ludwig1 Xp, shown on Figure 4. The $1/e$ angular extent of the intermediate beam (between M1 and M2) is ≈ 0.13 rd, and at that radius, the cross-coupling is below -40 dB. The Xpol level would be even lower if referred to the co-polarized beam on bore sight, rather than to its local value. The levels of Xpol that we will discuss in the next section are significantly higher, and therefore do not boil down to a matter of choice between Ludwig1/2/3.

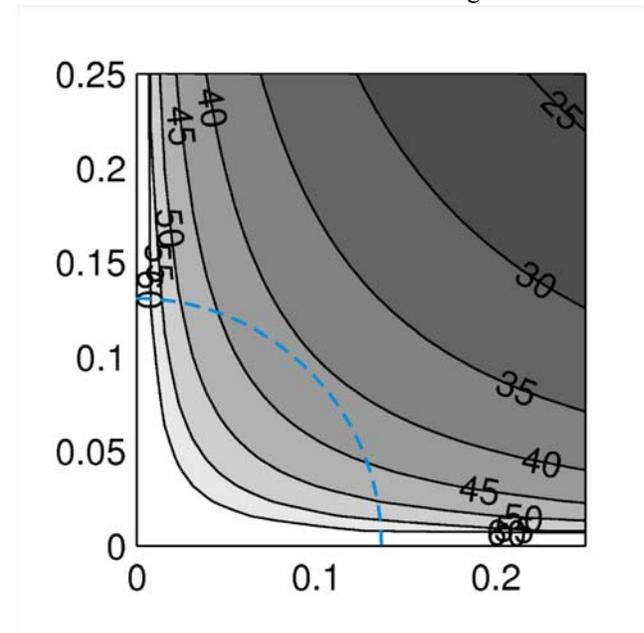


Figure 4. Isolation (dB) between Cp Ludwig2 and Xp Ludwig1. Coordinates are azimuth and elevation, in radians, with the origin at bore sight (chief ray). The $1/e$ angular radius of the Band 7 intermediate beam is shown (dotted blue). See text for discussion.

B. Cross polarization from an ideal grid

We have evaluated the cross polarization in the beam(s) emerging from the grid in the following way (transmitted beam):

- a) Define the beam's waist size, and therefore its angular spectrum;
- b) Along the direction of the chief ray, define Xpol as the projection of the grid wires onto the plane perpendicular to the chief ray, and Cpol perpendicular to the latter, in that same plane.
- c) Set up a spherical coordinate system with polar origin along the chief ray; this defines, according to the Ludwig3 definition, the Xp and Cp vectors over the whole sphere.
- d) Along any arbitrary direction, define the actual Xpol vector (as outlined above) and compute its coupling with the Ludwig3 definition of Cpol along the same direction.

With the grid in its original orientation, a maximum Xpol level of -23dB is obtained. See Figure 5. Note that Xp levels are referred to the *peak* Cp level. (We did not reach the -20dB specification, because of another, unrelated issue with birefringence in molded IR filters, that was addressed separately)

The dual-lobe pattern, provides evidence that the obtained Xp is unrelated to matters of definition (as discussed in the previous section), that are at a much lower level ($< -40\text{dB}$) and produce a four-lobe pattern.

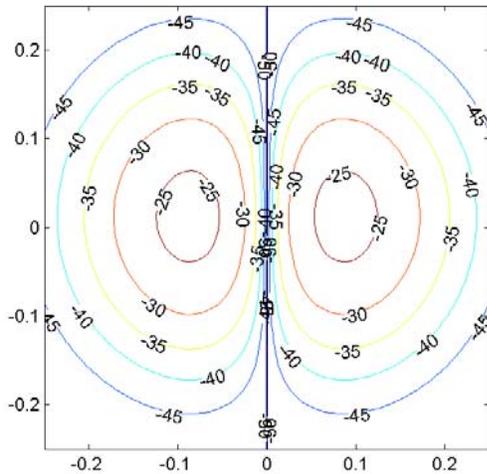


Figure 5. Xp levels in the intermediate beam after recombination by the grid, with grid in original orientation. Coordinates are radians

Following heuristic arguments, we determined that the Xp would be minimized with the grid oriented with its wires perpendicular to the beam's chief ray. This required turning the grid by 120.7° from its original position. Indeed, the same modeling calculation, for the new orientation, results in much lower Xp levels (and a 4-lobe pattern).

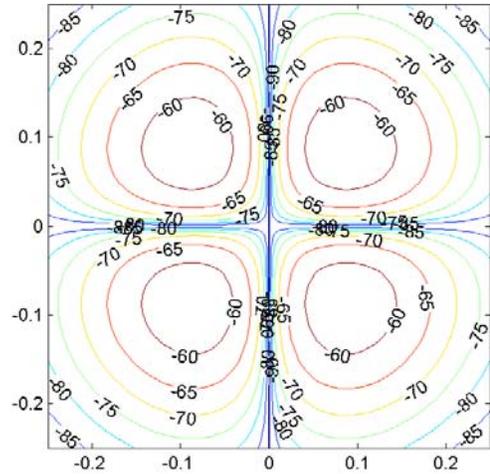


Figure 6. Same as previous, but with grid rotated 120.68° from its original position. The coordinate system is tied the Cp orientation, and therefore the figure does not reflect the change of Cp and Xp orientation.

V. EXPERIMENTAL VERIFICATION

We first show on Figure 7 the cross polarization measured for cartridge SN07, with the original grid orientation.

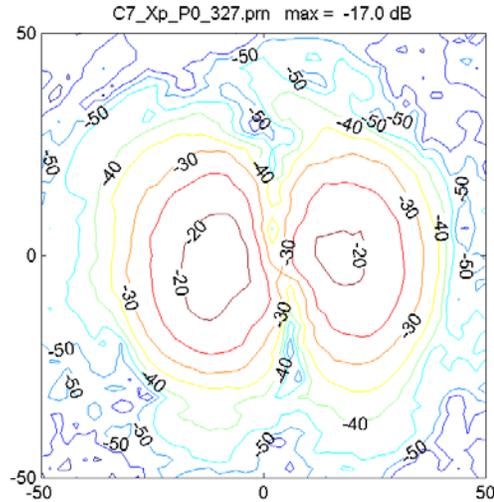


Figure 7. Level of Xp (relative to CP bore sight) measured for cartridge SN07, polarization channel 0, mid-band. Scan location is approximately 250mm past the Cassegrain plane. Coordinates are mm. Note similarity with Figure 5;

Implementing the modification required the following:

1. Changing the alignment pins to define the new grid orientation;
2. Adapting the mixers to the new polarization; this was achieved by integrating a 37° wave guide twist in the feed horns.
3. Adopting a new definition of the two polarization channels, as concerns the E-field orientation in the telescope frame; these were also rotated by 37° .

An example of the cross polarization performance of cartridge SN09 is shown on Figure 8. The Xp level is, in that particular instance, almost 7dB lower than previously.

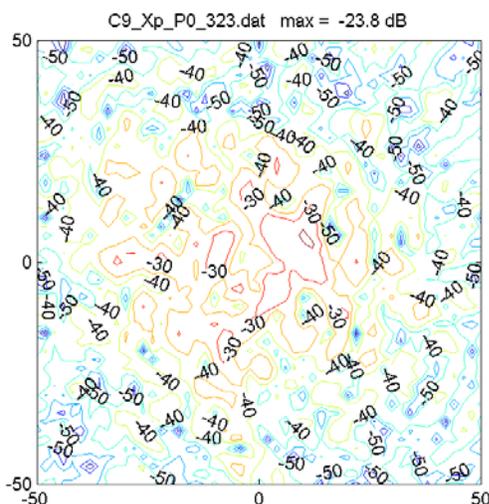


Figure 8. Same as previous, except Cartridge SN09, with modified grid orientation.

At present, a different metric is used by the ALMA project to characterize the cross-polarization: it is the integrated power over the telescope aperture. Because the Xp pattern (particularly after the modification) tends to have structure on smaller scale than the Cp pattern, that metric gives more favorable results. The nominal gain in the Xp performance, in that instance, is close to 8dB.

Table 1; Xp levels compared for cartridges SN07 (pre-modification) and SN09 (post-modification). The levels shown are based on the power integral over the pupil of the telescope.

	Xp level
C7 323 P0	-20.218
C7 323 P1	-20.155
C9 323 P0	-28.355
C9 323 P1	-28.814

VI. RE INVENTING THE WHEEL

As most of the work described here had been completed, we became aware through IRAM colleagues of previous work [3] analyzing the same issue, with the conclusion that the wire grids should be perpendicular to the plane of incidence.

ACKNOWLEDGMENT

B. Lazareff thanks his IRAM colleagues C. Thum and D. Morris for mentioning the reference [3].

REFERENCES

- [1] J. A. Murphy, "Distortion of a simple Gaussian beam on reflection from off-axis ellipsoidal mirrors" International Journal of Infrared and Millimeter Waves, vol. 8, Sept. 1987, p. 1165-1187.
- [2] A. C. Ludwig, "The definition of cross polarization" IEEE Transaction on Antennas and Propagation AP-21(1), 116-119, 1973..
- [3] T. S. Chu, M. J. Gans, and W. E. Legg; "Quasi optical polarization diplexing of microwaves", The Bell System Technical Journal, 54, 10, 1975, pp1665-1680.