Beam squint specification: elements for a proposal

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At the Optics Group meeting, held in IRAM, Grenoble 26-27 Oct 2005, it was noted that there was no specification for the co-alignment (squint) on the sky (i.e., in the focal plane) between the two linearly polarized beams of one frequency band. An action item was assigned to B.L. to prepare a proposal for a specification of the allowed beam squint between the two linear polarization channels of one cartridge. The issue of the squint between the two circularly polarized beams generated by quadrature combination of the linearly polarized beams was not raised; this more complex issue will not be discussed here.

I start from the pointing error antenna specification: 0.6" (relative to a reference source within 2°). That is 1/10 the FWHM at the maximum operating frequency of the instrument.

The loss of on-axis efficiency is probably negligible; the main consequence of the pointing error is linked with the restoration of the primary beam pattern. The instrumental gain is normally calibrated using an amplitude calibrator observed on-axis (at the centre of the primary beam). If the astronomical target is an extended object, the parts of the field located off-axis will suffer an attenuation according to "the" pattern of the antennas (assuming they are all identical); one step of the data processing is, accordingly, to divide the map by the pattern of the antenna (often a simple parameterised model, i.e. Gaussian).

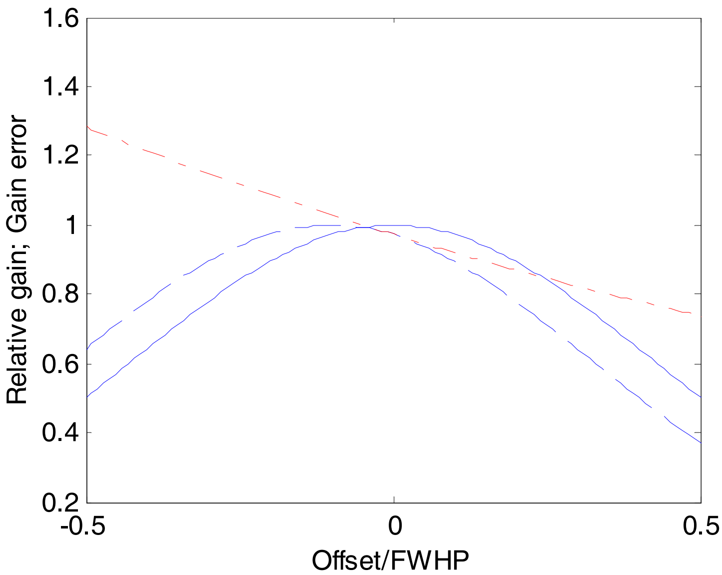

Figure 1. Nominal and offset (by 0.1×FWHM) Gaussian beams, and their ratio. For other small values of the offset, the error (deviation of the ratio from unity) scales linearly with the offset.

If "the" antenna was not actually pointing at the assumed position, that restoration is in error by the ratio of the displaced to the nominal beam pattern; see Figure 1 above. Such an amplitude error is especially disturbing when mapping in mosaic mode, introducing discrepancies between sub-fields.

Proposal.

To make the spec for beam squint (on-sky) between the polarization channels of one cartridge 1/10 the full width at half maximum of the beam.

Discussion.

Our old friends Astronomus and Ingenius meet for one of their controversial dialogues.

A. You reason as if there was a single pointing error applying globally to the map; actually each antenna has its own pointing error, and each amplitude in the UV plane is affected by the product of the voltage patterns of the two antennas.

I. Same for squint errors.

A. But pointing errors are random, while squint errors are systematic.

I. Possibly with 1000+ baselines, the squint errors can be treated as random. And, if you are serious about systematic errors, you can calibrate (once for all?) antenna-based squint errors.

A. You propose to add another source of pointing error equal (at band 10) to the contribution of antenna pointing, isn't this excessive?

I. Actually, the squint spec is the discrepancy between the two beams; each deviates from the mean position by half that amount, added to the pointing error in RSS, this causes an increase of only $\sqrt{1+(1/2)^2} = 1.118$ (at Band 10).

A. You base your criterion on the pointing error normalized to the smallest beam, at the highest operating frequency. At longer wavelengths, the antenna pointing error is a smaller fraction of the beamwidth, and the mechanical tolerances should also improve relative to the wavelength.

I. A tolerance analysis needs to be made to know what is technically possible. Tolerances involve both lengths and angles; so, longer wavelength may or may not help.

Revised proposal.

Baseline spec for squint 1/10 FWHM; perform tolerance analysis to know whether it is possible to achieve better at longer wavelengths.

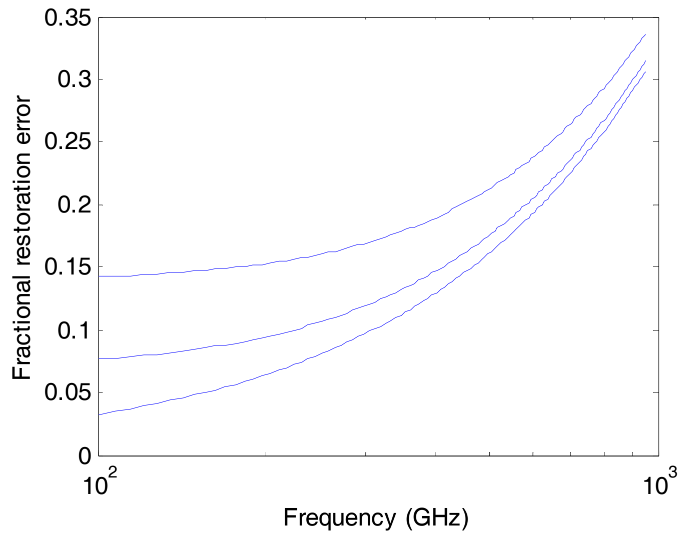

Figure 2. Fractional gain error in beam restoration at -3dB points under the hypotheses:
- Beam squint between linear polarizations is a fraction of the beam FWHP: top to bottom 1/10, 1/20, and zero.
- Beam restoration is based on the mean position of the two orthogonally polarized beams, i.e. the position error is half the beam squint
- Position errors arising from antenna pointing and beam squint are added RSS.

The following equations are used: $\delta\,\mathrm{Ln}(P) = \left.\frac{d\,\mathrm{Ln}(P)}{d\theta}\right|_{-3dB} \times \delta\theta = \frac{4\,\mathrm{Ln}(2)}{\theta_{-3dB}} \times \delta\theta$**, with**

$$\delta\theta = \sqrt{(\delta\theta_{point})^2 + (0.5\,\delta\theta_{squint})^2}$$