TITLE: **Integration of Photometer PFM BDAs: alignment issues**

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CHANGE RECORD

ISSUE	DATE	SECTION	REASON FOR CHANGE
0.1	16/02/2005	All	First issue as draft TN, PMW only
0.2	25/02/2005	All	Addition of PSW data assessment
1.0	15/03/2005	All	Addition of PLW data assessment

CONTENTS

APPLICABLE AND REFERENCE DOCUMENTS

RD1 Alignment Measurement Summary for PFM PMW BDA 10209800-2 SN012, Mark Weilert (JPL – 28 Jan 05), *as part of the delivered EIDP*

RD2 Alignment Measurement Summary for PFM PSW BDA 10209800-3 SN013, Mark Weilert (JPL – 17 Feb 05), *added in the delivered EIDP*

RD3 Alignment Requirements of detector arrays in SPIRE, SPIRE-RAL-NOT-000912 v0.3, Bruce Swinyard & Tony Richards (RAL, 17-Oct-2001)

RD4 Alignment Measurement Summary for PFM PLW BDA 10209800-1 SN014, Mark Weilert (JPL – 08 Mar 05), *added in the delivered EIDP*

This note briefly assesses the impact of the alignment measurements performed on PFM PSW, PMW and PLW BDAs (see RD1 & RD2 and RD4) wrt the integration of the respective BDAs into the SPIRE PFM FPU sub-assembly (Photometer detector box).

This note comes in parallel with a similar assessment performed for the Spectrometer PFM BDAs in SPIRE-RAL-NOT-002194 (issue 0.3, 03/11/04).

1. Defocus and lateral shift

From RD1, the local coordinates system is reproduced below (originally from ICD). The local z axis is out-of-the plane of the figure.

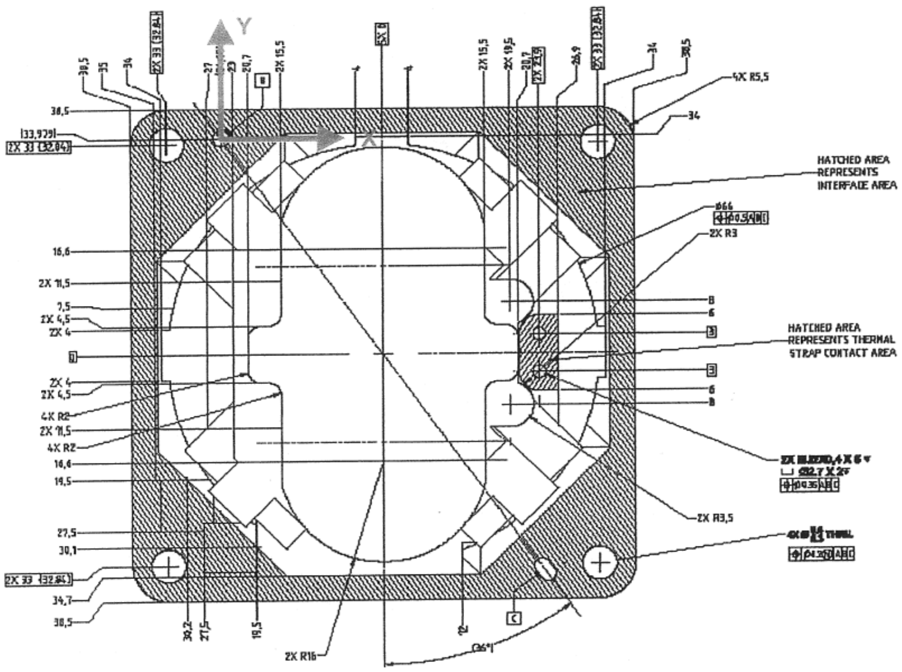


Figure 1 (excerpt from ICD dwg 10209721, with coordinate axes shown)

1.1 Case of PMW

The deviation found (total i.e. ambient and cold measurement from RD1) from the nominal plane along the local z axis is -0.088+/-0.05mm. This will translates into a very small defocus of the PMW BDA in operation wrt the nominal best focal plane, well within the +/-0.5mm allowed margin in RD3, even if uncertainty is included. This is therefore acceptable as it's a small value (about 2 orders of magnitude lower) when compared to the F/5 depth-of-focus at PMW wavelengths.

_NB:_ this is assumed to be the residual after the correction of the initial defocus issue discussed in the note "*Assessment of defocus tolerance and margin on SPIRE PMW BDA*", Marc Ferlet, 19/05/04.

The lateral in-plane shift of the BDA centre wrt to nominal centre is found to be (total i.e. ambient and cold measurement):

- along X: - 0.033+/-0.05mm
- along Y: +0.249+/-0.05mm

so that the max displacement from centre is sqrt(dx^2+dy^2)~0.251+/-0.100mm. This represents ~8% of the PMW pixel size and, at the entrance focal plane (CFIL1 location), is equivalent to 0.436+/-0.175mm displacement which is within the oversize (wrt FoV) of the shaped aperture at CFIL1. Nevertheless this means that the centre of the PMW FoV is shifted on sky by ~3.16+/-1.26arcsec wrt the nominal location in the Herschel coordinates system but this does not affect directly the performances of the PMW channel.

1.2 Case of PSW

The deviation found (total i.e. ambient and cold measurement from RD1) from the nominal plane along the local z axis is -0.025+/-0.05mm. This will translates into a very small defocus of the PMW BDA in operation wrt the nominal best focal plane, well within the +/-0.5mm allowed margin in RD3, even if uncertainty is included. This is therefore acceptable as it's a very small value when compared to the F/5 depth-of-focus at PSW wavelengths.

NB: this is assumed to be the residual after the correction of the initial defocus issue discussed in the note "*Assessment of defocus tolerance and margin on SPIRE PMW BDA*", Marc Ferlet, 19/05/04 (which applies to PSW as well).

The lateral in-plane shift of the BDA centre wrt to nominal centre is found to be (total i.e. ambient and cold measurement):

- along X: - 0.070+/-0.05mm
- along Y: +0.330+/-0.05mm

so that the max displacement from centre is sqrt(dx^2+dy^2)~0.337+/-0.100mm. This represents ~15% of the PSW pixel size and, at the entrance focal plane (CFIL1 location), is equivalent to 0.600+/-0.175mm displacement which is within the oversize (wrt FoV) of the shaped aperture at CFIL1. Nevertheless this means that the centre of the PSW FoV is shifted on sky by ~4.3+/-1.3arcsec wrt the nominal location in the Herschel coordinates system but this does not affect directly the performances of the PSW channel.

1.3 Case of PLW

The deviation found (total i.e. ambient and cold measurement from RD1) from the nominal plane along the local z axis is -0.117+/-0.05mm. This will translates into a very small defocus of the PMW BDA in operation wrt the nominal best focal plane, well within the +/-0.5mm allowed margin in RD3, even if uncertainty is included. This is therefore acceptable as it's a very small value when compared to the F/5 depth-of-focus at PLW wavelengths.

The lateral in-plane shift of the BDA centre wrt to nominal centre is found to be (total i.e. ambient and cold measurement):

- along X: - 0.037+/-0.05mm
- along Y: +0.439+/-0.05mm

so that the max displacement from centre is sqrt(dx^2+dy^2)~0.440+/-0.100mm. This represents ~9% of the PLW pixel size and, at the entrance focal plane (CFIL1 location), is equivalent to 0.765+/-0.175mm displacement which is within the oversize (wrt FoV) of the shaped aperture at CFIL1. Nevertheless this means that the centre of the PLW FoV is shifted on sky by ~5.5+/-1.3arcsec wrt the nominal location in the Herschel coordinates system but this does not affect directly the performances of the PSW channel.

1.4 Conclusion

The amount of cold to ambient induced defocus of the PSW and PMW BDAs wrt their respective structure is found sufficiently small (with margin) so no correction to be applied.

There is no direct requirement in RD3 wrt the in-plane lateral shift but a need to maintain co-alignment with PSW centre to within 120μm. Below is the illustrated summary of the BDAs centres lateral shift as-measured and reported in RD1 (axes orientation are as per). The separation (black arrows) between PSW and PMW centres and PSW and PLOW centres is 88±50µm and 114±50µm respectively which is then still OK (the circle approximately represent the reported uncertainty in the data). The centre of gravity or barycentre of the different BDAs measured central positions is shown (cross) and found to be within ~100µm max of the centre while still acting like the reference, as within the PSW uncertainty circle.

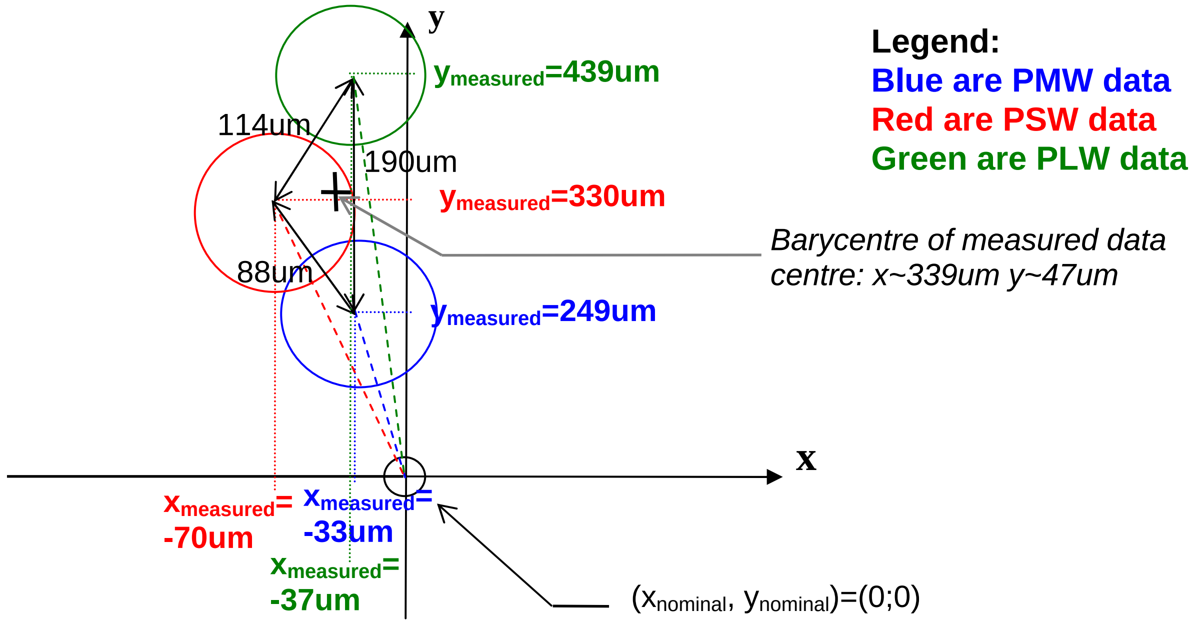


Figure 2: Distribution of the measured PFM BDAs centre positions in the focal plane wrt nominal

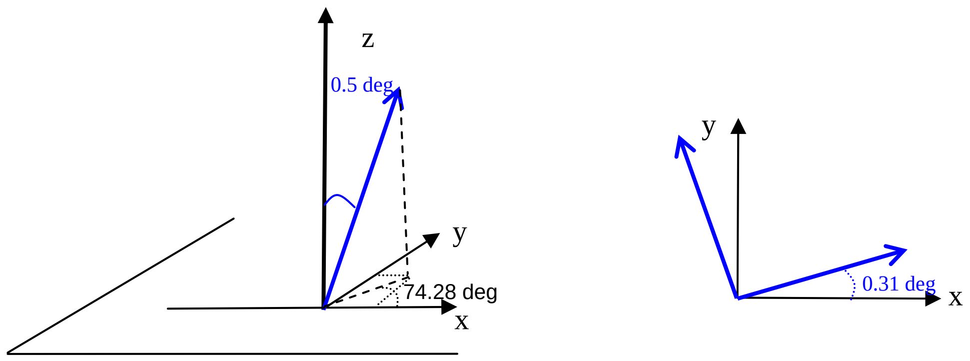
The barycentre above used as global central reference is then located 342±100µm radially from nominal central position which translates by a field radial displacement on-sky (wrt nominal) of 4.28±1.3arcsec, assuming everything else in the opto-mechanical chain of SPIRE + Herschel telescope is perfect and nominal.

Even if the centring is not perfect wrt the nominal (as-built BDAs centres measured at typically 250-350µm radially from nominal), they match well the Spectro BDAs which have been found with very similar deviation in the xy plane. This means that on-sky (assuming here no other source of separate misalignment) the angular distance between Spectro and Phot FoV can be expected as per design. This is another reason why the correction of the decentring is not found necessary.

2. Tilt and rotation

2.1 Case of PMW

The measured tilt of the as-built x-y plane compared to the nominal one is found at ambient to be 0.5deg wrt the local z axis. Although this measurement is at ambient only, this is at the limit of the +/-30arcmin=+/-0.5deg acceptable tolerance around the gut ray which nominally is aligned with the local z axis at the centre of the array. The cryo data indicates supplementary hysteretic effect (in rotation about x) which is equivalent to uncertainty in the range of +/-0.025deg on the above value.
This tilt wrt z axis will reduce the coupling from science beam into BDA PMW feedhorns. First-order estimate indicate that ~1% loss in coupling efficiency could be resulting from such a tilt.
A correction is still desirable and experience with SSW BDA shows the possibility of having a wedge shape interface plate to correct even smaller amount of tilt deg in the case of SSW).

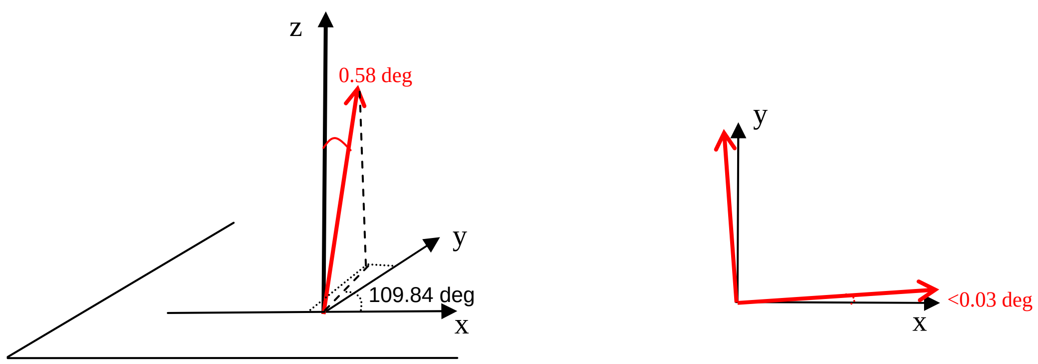


The in-plane rotation has been found (ambient + cold) to be 0.31deg which is larger than the allowed +/-0.233deg (=+/-14 arcmin stated in RD3) but the impact may (or not) be acceptable depending on the respective value for in-plane rotation for PLW and PSW as PSW chop axis being the main reference.

Because there seems to be no in-plane rotation of the PSW array (see next section), the above means that for the (secondary) outer chop pixels and (primary) chop pixels should be expected to be ~+53µm instead of the allowed +/-40µm. Remembering that at array focal plane 1arcsec on sky is about 80µm, this represents a supplementary (wrt max allocation in RD3) shift in the chop direction of 0.163arcsec (TBC if this is acceptable).

2.2 Case of PSW

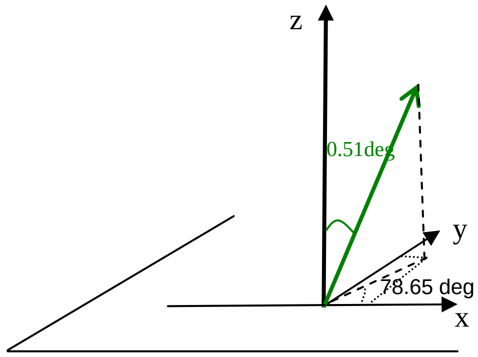
The measured tilt of the as-built x-y plane compared to the nominal one is found at ambient to be 0.58deg wrt the local z axis. Although this measurement is at ambient only, this is slightly larger than the limit of the +/-30arcmin=+/-0.5deg acceptable tolerance around the gut ray which nominally is aligned with the local z axis at the centre of the array. No info from the cryo data so possible larger than average uncertainty here.
This tilt wrt z axis will reduce the coupling from science beam into BDA PSW feedhorns. First-order estimate indicate that ~1.5% loss in coupling efficiency could be resulting from such a tilt.
A correction is still desirable and experience with SSW BDA shows the possibility of having a wedge shape interface plate to correct even smaller amount of tilt deg in the case of SSW).

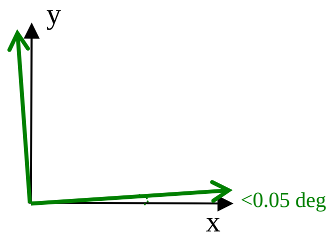


The in-plane rotation has been found (ambient + cold) to be smaller than 0.03deg which is almost 1 order of magnitude lower than the allowed +/-0.233deg (=+/-14 arcmin stated in RD3) so no problem for this DoF.

2.3 Case of PLW

The measured tilt of the as-built x-y plane compared to the nominal one is found at ambient to be 0.51deg wrt the local z axis. Although this measurement is at ambient only, this is slightly larger than the limit of the +/-30arcmin=+/-0.5deg acceptable tolerance around the gut ray which nominally is aligned with the local z axis at the centre of the array. No info from the cryo data so possible larger than average uncertainty here.
This tilt wrt z axis will reduce the coupling from science beam into BDA PSW feedhorns. First-order estimate indicate that <~1% loss in coupling efficiency could be resulting from such a tilt.
A correction is still desirable and experience with SSW BDA shows the possibility of having a wedge shape interface plate to correct even smaller amount of tilt deg in the case of SSW).





The in-plane rotation has been found (ambient + cold) to be smaller than 0.05deg which is almost 1 order of magnitude lower than the allowed +/-0.233deg (=+/-14 arcmin stated in RD3) so no problem for this DoF.

2.4 Conclusion

PSW is the reference array. The in-plane rotation seems to be quasi inexistent but the tilt from the z axis is larger than the spec. Although it may induced a reduction in coupling by only 1-2% (at centre of the array, typically a few more % for pixels at FoV worst case edge), it is suggested to correct and compensate for it at interface plate level to create a positive rotation of + 0.5deg about local +x (this should leave a final residual tilt of 0.05deg max, very acceptable as 1 order of magnitude below the requirement).

It is also suggested to apply the same correction to the interface of PMW BDA ie +0.5deg tilt correction about local +x. A correction for the in-plane rotation issue of PMW can be envisaged but will depend the acceptance of the above discrepancy as it can represent a displacement of the nominal interface hole pattern (mounting points + dowel pin) by less than 100um i.e. typically of the same order of eventual correction for decentring which is not suggested here for the reason discussed in the section 1.4.

The case of PLW is very similar to PSW and therefore only the tilt of the array plane from the z axis would need to be corrected.

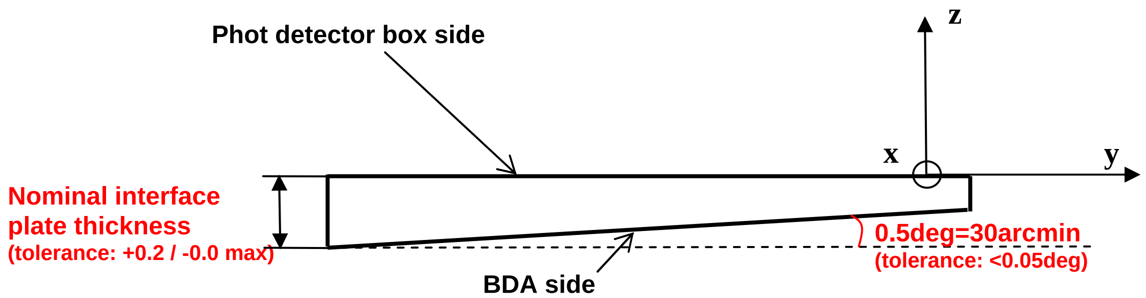
Remark: *all the BDAs seem to show relatively similar value in tilt wrt the local z axis. By design they share the same cold stop aperture at the entrance of Phot detector box and with same focal ratio (F~5) spatial co-registration on same FoV (with dichroics-based band splitting). For a cold stop aperture diameter D, the pupil shift induced by a tilt* α *is* $\Delta R/R \sim (FD/(D/2))*\tan(\alpha) \sim 2F*\tan(\alpha)$*. The associated* *geometric reduced throughput (diffraction-limited optical chain) is then 1-0.64*(ΔR/R)~1-6.4*tan(α) here. The angular dependence of the individual detector directivity due the presence of attached feedhorn design with edge-taper ~8dB induces for all bands, and therefore BDAs, an equivalent pupil amplitude apodisation which further reduced (by factor ~3-5 approximately) the geometric throughput loss above (estimated to 5.6% in case of α=0.5deg). This is slightly varying with wavelengths and therefore bands but one could consider it as acceptable as almost constant between the different bands. Actually the number of pixels in the array of the different bands varies a lot and although planar they are located at a focal plane of on optical chain not perfectly telecentric. This would mean that under a tilt α about the local x axis, for each BDA, there would be a quasi optimal coupling to optical beam coming from cold stop at one edge of the array (typically at the local –y zone of the array) while coupling would drops by factor ~2-3x the estimated value in the requirements for pixels at the +y end of the array. This will create a gradient (with magnitude up to 5-6% over the entire array) of coupling efficiency regardless of individual detector response performances in the y direction. This is another justification for the correction of the tilt for all detecting arrays.*

3. Conclusion and proposed corrective actions on respective interface plates

For all Phot BDAs, the defocus is ok[1]. Decentring of PMW and PLW wrt PSW is within the acceptable range to maintain initial co-alignment of the BDAs in the different bands wrt PSW. Corrective improvement will call for less than 100μm displacement of the interface plate mounting point and is not suggested here.

In-plane rotations (about local z axis) of the BDAs are well within the allowed range except for PMW, although this would require a correction a small correction (smaller than 100μm, reliability ?) which can induce a further decentring and therefore trigger a extra need for decentring correction on PLW and the reference PSW. The risk associated with this "cascade" of small corrections is not suggested as the potential improvement is relatively low compared to danger of further increasing the presently small errors.
But for the tilt of the feedhorn array plane wrt local z axis, all BDAs indicate a value (dominated by a rotation about the local x axis) which is at the edge of beyond the allowed requirement and therefore a correction for this measured tilt on the BDAs is strongly suggested.

- ⇨ ***Consequences for interface plates on the case of PSW, PMW and PLW:*** from the above considerations, it is suggested to machine the interface plates (for PMW and PSW) in a wedge shape for the schematic below. This is similar to what was proposed for SSW in SPIRE-RAL-NOT-002194 v0.3.



NB: the removal of material from the nominal constant thickness interface plate will produce an axial shift along +z which is estimated to be of the order of +200-250μm max (suggested tolerance above

[1] This is again assuming that the issue in the note "*Assessment of defocus tolerance and margin on SPIRE PMW BDA*", Marc Ferlet, 19/05/04 (which applies to PSW as well) has been dealt with separately.

tuned to minimise this). Added to the above nominal expected BDA internal defocus along z, the net result will still be well within the allocated +/-0.5mm.