

Identification and discussion of
Degrees of Freedom (DoF) for BAM
sensitivity analysis

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Rapporto nr.135

03/09/2010



Assumption

The BAM system consists of two sets of mirrors that pick a laser beam up and fold it through the M1 of each telescope. The single common source is split in four beams, two for each telescope, that combine to realize a fringe pattern on a dedicated CCD over the FPA (we neglect for the moment the redundant channel that focuses over a different CCD). Each set of BAM optics is mounted on a rigid bar linked to the torus of the payload in front of the M1 by means of isostatics struts. The bar mounting is such to avoid vignetting a part of the periscope upper mirror that folds the beams out of the bar plane through M1.

The two bars support a different number of mirrors [GAIA.ASF.TCN.PLM.00068 and GAIA.TNO.RP.BAM.00018]. With reference to the available documentation and to the “multi-configuration” designed using ZEMAX optical code and made available in '09 (JdB), we refer to the combination bar#1 + Telescope 1 with configuration 2 and 3 and to the combination bar#1 + bar#2 + Telescope2 with the configurations 1 and 4.

2. Identification of DoFs

In the following tables we summarize the degrees of freedom (DoF) we identified for all configurations. Red crosses represent DoF that have less important impact on sensitivity, but in principle might be considered. Generally they are related with the aperture of the mirror/beam splitter, so the only effect to be eventually taken in account is a vignetting of the beam.

TABLE 1: BAR#1 + Telescope 1 Degrees of Freedom

Location	Element	dx	dy	dz	d α	d β	dy		
Wavelength variation	SOURCE							0	1
Source	COLL2	x	x	x	x	x	x	0	6
Common Path	BS1				x	x		0	2
Configuration 2	BS2	x	x	x	x	x		2	3
Configuration 2 – Periscope	FM9	x	x	x	x	x		2	3
Configuration 2 – Periscope	FM10	x	x	x	x	x		2	3
Common Path	BS1	x	x	x	x	x		2	3
Configuration 3	FM1	x	x	x	x	x		2	3
Configuration 3	FM2	x	x	x	x	x		2	3
Configuration 3	BS3				x	x		0	2
Configuration 3 – Periscope	FM11	x	x	x	x	x		2	3
Configuration 3 – Periscope	FM12	x	x	x	x	x		2	3
Gaia T1	M1	x	x	x	x	x	x	0	6
Gaia T1	M2	x	x	x	x	x	x	0	6
Gaia T1	M3	x	x	x	x	x	x	0	6
Gaia T1	M4	x	x	x	x	x		2	3
Gaia T1	M5	x	x	x	x	x		2	3
Gaia T1	M6	x	x	x	x	x		2	3
Gaia T1	FP	x	x	x	x	x	x	0	6
TOTAL								22	68

TABLE 2: BAR #1 + BAR#2 + Telescope 2 Degrees of Freedom

Location	Element	dx	dy	dz	d α	d β	dy		
Wavelength variation	SOURCE							0	1
Source	COLL2	x	x	x	x	x	x	0	6
Common Path	BS1				x	x		0	2
Configuration 1	BS2				x	x		0	2
Configuration 1	FM4	x	x	x	x	x		2	3
Configuration 1	FM5	x	x	x	x	x		2	3
Configuration 1	FM6	x	x	x	x	x		2	3
Configuration 1	FM7	x	x	x	x	x		2	3
Configuration 1	FM8	x	x	x	x	x		2	3
Configuration 1	FM13	x	x	x	x	x		2	3
Configuration 1	FM14	x	x	x	x	x		2	3



Configuration 1	FM15	x	x	x	x	x		2	3
Configuration 1	FM16	x	x	x	x	x		2	3
Configuration 1 – Periscope	FM21	x	x	x	x	x		2	3
Configuration 1 – Periscope	FM22	x	x	x	x	x		2	3
Common Path	BS1	x	x	x	x	x		2	3
Configuration 4	FM1	x	x	x	x	x		2	3
Configuration 4	FM2	x	x	x	x	x		2	3
Configuration 4	BS3	x	x	x	x	x		2	3
Configuration 4	FM3	x	x	x	x	x		2	3
Configuration 4	FM19	x	x	x	x	x		2	3
Configuration 4	FM20	x	x	x	x	x		2	3
Configuration 4 – Periscope	FM17	x	x	x	x	x		2	3
Configuration 4 – Periscope	FM18	x	x	x	x	x		2	3
Gaia T2	M1	x	x	x	x	x	x	0	6
Gaia T2	M2	x	x	x	x	x	x	0	6
Gaia T2	M3	x	x	x	x	x	x	0	6
Gaia T2	M4	x	x	x	x	x		2	3
Gaia T2	M5	x	x	x	x	x		2	3
Gaia T2	M6	x	x	x	x	x		2	3
Gaia T2	FP	x	x	x	x	x	x	0	6
TOTAL								46	104

2.1 Composite DoFs

The laser beams exit the bar planes and are launched through the telescope by mean of a couple of mirrors mounted in a periscope. We can consider each periscope as a whole and associate 5 DoF to each one (IBV). This analysis shall need more information on the mechanical assembly of this element.

3 DoF variation distribution and values

We can consider two different distributions for the values of each DoF:

- Gaussian: to simulate DoF random variation due to uncertainties in mounting, settling;
- Uniform: to simulate effects of unexpected perturbations as launch stresses, micro-meteorites, attitude perturbation.

3.1 Values of variation

In following tables we show the values of variation around the nominal position.

Values of these table are derived from available documentation (“GAIA PLM Optical Design and Performances”, Gaia Livelink, 2007; “The Basic Angle Monitoring system: picometer stability with Silicon Carbide optics”, van Veggel AA, PhD Thesis, 2007).

We consider the number listed in the tables as the limit values for a uniform distribution (see previous paragraph).

TABLE 3: BAR#1 + Telescope 1 Ranges of Variation


Location	Element	dx pm	dy pm	dz pm	d α prad	d β prad	d γ prad
Wavelength variation	SOURCE						
Source	COLL2	±29.2	±29.2	±29.2	±3.77	±3.77	±3.77
Common Path	BS1				±3.26	±3.26	
Configuration 2	BS2			±21.5	±2.85	±2.85	
Conf. 2 – Periscope	FM9			±46.0	±4.35	±4.35	
Conf. 2 – Periscope	FM10			±46.0	±4.35	±4.35	
Common Path	BS1			±30.9	±3.26	±3.26	
Configuration 3	FM1			±19.2	±13.8	±13.8	
Configuration 3	FM2			±3.4	±2.17	±2.17	
Configuration 3	BS3				±3.82	±3.82	
Conf. 3 – Periscope	FM11			±46.0	±4.35	±4.35	



Conf. 3 – Periscope	FM12			±46.0	±4.35	±4.35	
Gaia T1	M1	±6.5E6	±29.5 E6	±14.0 E6	±5.4 E6	±5.6 E6	±3.4 E6
Gaia T1	M2	±9.4 E6	±16.1 E6	±4.7 E6	±34.6 E6	±2.6 E6	±15.9 E6
Gaia T1	M3	±10.2 E6	±30.3 E6	±9.1 E6	±5.7 E6	±5.7 E6	±3.8 E6
Gaia T1	M4			±8.3 E6	±7.8 E6	±0.3 E6	
Gaia T1	M5			±13.7 E6	±6.3 E6	±4.3 E6	
Gaia T1	M6			±27.1 E6	±6.3 E6	±3.4 E6	
Gaia T1	FP	±1.1 E6	±7.1 E6	±3.7 E6	±17.5 E6	±0.2 E6	±0.2 E6

TABLE 4: BAR #1 + BAR#2 + Telescope 2 Ranges of Variation

Location	Element	dx pm	dy pm	dz pm	dα prad	dβ prad	dγ prad
Wavelength variation	SOURCE						
Source	COLL2	±29.2	±29.2	±29.2	±3.77	±3.77	±3.77
Common Path	BS1				±3.26	±3.26	
Configuration 1	BS2				±2.85	±2.85	
Configuration 1	FM4			±17.1	±2.37	±2.37	
Configuration 1	FM5			±32.6	±3.38	±3.38	
Configuration 1	FM6			±6.2	±2.23	±2.23	
Configuration 1	FM7			±42.3	±4.35	±4.35	
Configuration 1	FM8			±46.0	±3.71	±3.71	
Configuration 1	FM13			±46.0	±4.35	±4.35	
Configuration 1	FM14			±46.0	±4.35	±4.35	
Configuration 1	FM15			±46.0	±4.35	±4.35	
Configuration 1	FM16			±46.0	±4.35	±4.35	
Conf. 1 – Periscope	FM21			±46.0	±4.35	±4.35	
Conf. 1 – Periscope	FM22			±46.0	±4.35	±4.35	
Common Path	BS1			±30.9	±3.26	±3.26	
Configuration 4	FM1			±19.2	±2.85	±2.85	
Configuration 4	FM2			±3.4	±2.17	±2.17	
Configuration 4	BS3			±43.6	±3.82	±3.82	
Configuration 4	FM3			±21.5	±2.85	±2.85	
Configuration 4	FM19			±46.0	±4.35	±4.35	
Configuration 4	FM20			±46.0	±4.35	±4.35	
Conf. 4 – Periscope	FM17			±46.0	±4.35	±4.35	
Conf. 4 – Periscope	FM18			±46.0	±4.35	±4.35	
Gaia T2	M1	±6.9E6	±29.1 E6	±12.5 E6	±3.6 E6	±6.0 E6	±3.8 E6
Gaia T2	M2	±11.6 E6	±16.7 E6	±4.9 E6	±44.5 E6	±2.5 E6	±16.1 E6
Gaia T2	M3	±11.1 E6	±29.8 E6	±9.3 E6	±4.0 E6	±5.2 E6	±4.0 E6
Gaia T2	M4			±8.0 E6	±1.7 E6	±0.3 E6	
Gaia T2	M5			±13.7 E6	±6.3 E6	±4.3 E6	
Gaia T2	M6			±27.1 E6	±6.3 E6	±3.4 E6	
Gaia T2	FP	±1.1 E6	±7.1 E6	±3.7 E6	±17.5 E6	±0.2 E6	±0.2 E6

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4 Merit Function

The identification of the MF is a critical issue. The scope of BAM is the monitoring of any fringe pattern variation, being it position, shape and fringe spacing. These assumptions suggest to consider some merit functions that refers to the image on the CCD and not to the WFE as done in other studies.

After discussion it has been decided that the MF evaluation over fringes will not be applied at “optical” level. It is necessary to process the optical images with the CCD dedicated algorithms, in order to have an “effective” image. The MF evaluation will be performed over these effective images.

However the study can be performed even at intermediate stage, using some Zemax features.

We propose to consider an user defined MF, being the standard ones, typically used by optical ray tracers i.e. spot diagram, WFE RMS, OPD, inadequate or incomplete. The study will be carried on using ZEMAX that allow to set “user defined” MF.

As example of possible implementation, in past studies (GAIA-1) it was decided to built a user MF as a linear combination of typical markers, i.e.:

$$MF = \Sigma [(\Delta OPD)^2 + (\Delta x^2 + \Delta y^2)] \quad \rightarrow \quad OPD + \text{spot diagram variations}$$

Other possible combinations are under study. For instance, ZEMAX gives the value of the location of the fringe envelope centre (the chief ray location of the image or the centroid of the envelope that is the Airy image of a single aperture) that can be used as reference value for fringes shift monitoring (the use of this parameter is strongly faster than other figures of merit, so it can be considered for preliminary assessment on the variations tendencies).

The spacing of the fringes can be used too. The fringes are generated by beams that hit non-planar mirrors (M1, M2, M3) at different positions, not symmetric with respect mirrors axes. This means a different aberration contribution to each beam wavefront (to be verified with a proper study that can involve the WFE maps analysis by e.g. cross-correlation). It follows that the fringe spacing could vary within the Airy envelope showing some loss of correlation. We can plan to consider a section of the fringes along the HR direction for a reference (nominal) configuration and use it as correlation term to check the changes during sensitivity analysis. This correlation check can be run using 1D image of a fitting curve opportunely defined, too. Furthermore, this term can be used in combination with other markers (centroid of Airy envelope) to build up a more robust MF.

After the discussion it has been outlined the need of a deeper discussion about MF definition and usage.

4.1 Merit Function variation

How much must the MF vary to fix acceptable or unacceptable values?

The discussion about this topic didn’t reach a definitive resolution. The initial set of DoF values and the results of the MF evaluation over perturbed configuration will require a detailed discussion, that can give an answer to the question.


5 Library format

We propose to deliver a library of optical images to be transformed in effective ones (CCD effects). One of the open points is the image resolution of each image.

The image generation will require a time and CPU allocation that will vary with the resolution and with the MF we will decide to use for analysis. Smaller resolution, faster calculations. We propose an output image with a sampling of 2048x2048 and a step sample of 2 microns.

Each image should contain in its header information about:

- pupil sampling
- image sampling
- sampling step
- DoF values used
- Line of Sight variation / BAV value

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As a reference we may consider that the generation of each image with ZEMAX, employing a 2Gb RAM unit, requires:

- 40 min of calculation;
- 5 min transformation and save in TXT;
- About 55 MB of disk space.

We propose to split the sensitivity analysis in two steps: a first run using a simple merit function, e.g. the centre of the Airy envelope in order to have a fast feedback about the most critical DoF and their variation regions; a second time and CPU consuming run, using a more sophisticated MF. The discussion underlined the necessity of processing images directly with the dedicated MF (see 4.2).