LISA-AEI-IDS-TN-007

PAAM Static Offset Check

Issue1 - Revision 1

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1 INTRODUCTION

The purpose of this technical note and the supporting material is to address lingering concerns regarding the correctness of the specification of the sign and orientation of the static offset angle of the TX beam point ahead and subsequently the point ahead mechanism on the optical bench assembly of the LISA IDS.

For this purpose, a minimalistic ray-tracer has been implemented that is simple enough for everyone to check easily for correctness, but still captures quantitatively the effect of 3D coordinate transformations and surface angles.

The analysis notebook can be accessed via the following link:

https://mybinder.org/v2/gh/eliasbreunig/PAA_analysis/main?urlpath=tree/paa_angles.ipynb

2 INPUTS

2.1 Orbit and Constellation

All assessments made in this document are valid for the point ahead requirement associated with a “clockwise” orbit. That is a constellation that appears to be rotating clockwise about its barycentre when viewed from the heliocentric origin (aka the sun).

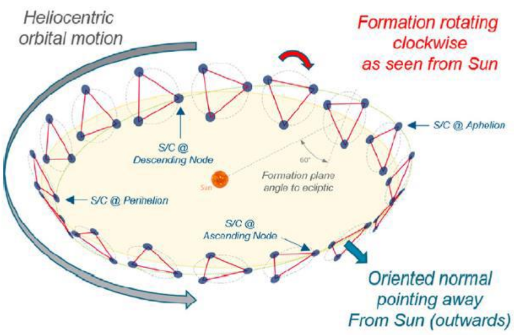

Figure 1: Overview of constellation motion for clockwise rotation (baseline) – from [RD2]

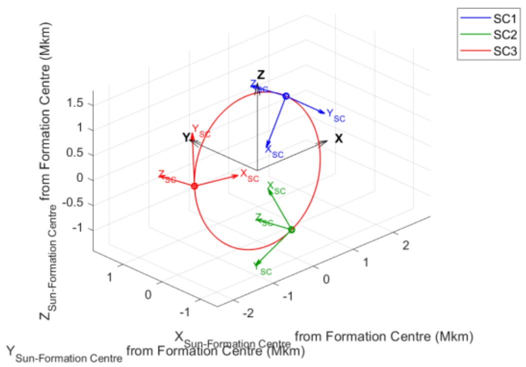

Figure 2: Spacecraft coordinate frames within the constellation – from [RD2]

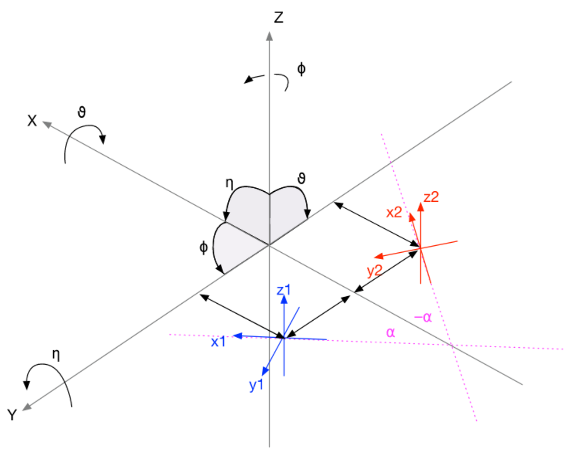

Figure 3: Nominal TM and SC reference frames - from [RD1]

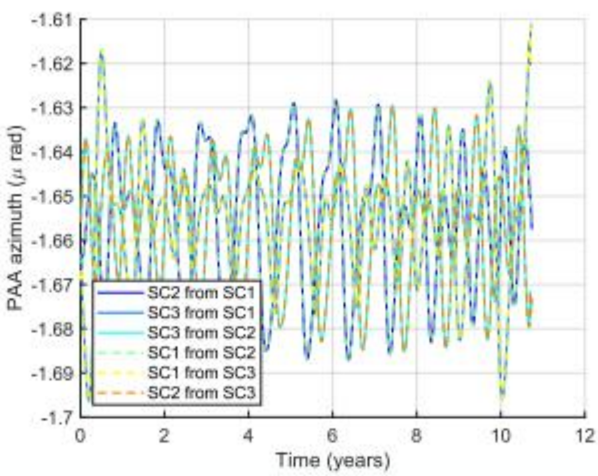

Figure 4: Point Ahead Azimuth in SC Frame, CW Orbits – from [RD2]

Figure 4 shows the resulting point ahead azimuth which is per definition [RD2]:

Point Ahead azimuth (angle in XY_{SC} plane, measured from RX direction, positive around $+Z_{SC}$)

These definitions and statements form the basis of the subsequent analysis.

2.2 Coordinate frames

Going from the point ahead angle in the SC frame down to the individual PAAM on the OB involves the following chain of elements which each can in principle introduce a change in the angle either from physics or convention that can ultimately lead to a wrong derived requirement.

- SC FRAME
- MOSA FRAME (=TM Frame???)
- OB Frame
- OB elements in TX path
- PAAM OIRF
- PAAM Mirror

The important part here is to assert the co-alignment of all frames with the spacecraft Z axis which is the important reference for the initial specification of the point ahead angle [RD2] through to the IRD requirement on the IDS. This ensures that in the OB frame e.g. a negative RZ point ahead angle is still a negative RZ point ahead angle.

This assertion of this condition(s) can be made according to the following table:

IDS.DEF_SYS_140: requires the OB_MRF to be matched to the MOSA MRF

This needs to go with a requirement to have the Z axis of the MOSA and SC frames coaligned.

This is assumed to be put in place in the SC-PL-IRD???? … i.e. if the MOSA (or one of the MOSAs would be put into the SC upside down with respect to the other, the point ahead scheme would not work as intended.

However, the requirement to the IDS is now already specified in terms of the OB MRF [RD3]

The IDS shall provide a static point-ahead angle offset between the TX and RX beams in the Phi degree of freedom of the OB MRF.

This means that effectively the responsibility for the correct SC->MOSA->OB flow down of the transformations is ultimately not IDS responsibility.

In the end, what really matters is the transformation that is applied to redirect the TX beam flying parallel to the optical bench away from the optical bench and towards the telescope interface, in combination with said coalignment of frames about the z axis.

For the analysis presented, the translation component in the transformations between reference frames is only for illustration purposes. It is not considered by the ray tracing algorithm.

3 ANALYSIS

It follows a brief discussion of some of the definitions and conventions used in the analysis. Please always refer to the actual analysis notebook for full and up-to-date details. The analysis itself is not reproduced in this document!

3.1 Definition of Reflection Matrix

The following Reflection Matrix definition is used to calculate the reflections in the optical path that is being studied:

$$R_I^K = \begin{bmatrix}1 & 0 & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix} - 2 \cdot \begin{bmatrix}n_x\\n_y\\n_z\end{bmatrix} \cdot [n_x \quad n_y \quad n_z]$$

With K denoting the Frame of Reference in which the reflection is being defined (e.g OB), and I being a unique identifier (e.g. PBS1).

3.2 Definition of Transformation Matrix

Transformations between Reference frames a modelled as a translation followed by a SINGLE rotation, both with respect to the parent frame in which they are defined.

Complex rotations must be modelled as an explicit sequence of rotations, which avoids any ambiguity due to hidden sequence conventions.

3.3 Definition of PAAM Rotation

The static offset rotation of the paam is considered as the transformation between the OB fixed PAAM OIRF frame and the PAAM fixed paam mirror frame around the Y axis of the PAAM OIRF.

3.4 Definition of Surface Normal and Trace Path

The surface normal of the optical elements on the OB and the trace path from the Paam to the telescope have been inferred from the OB layout- drawing v2.2.2 [RD4].

The important part of this drawing is reproduced hereafter to allow verification of the derived definitions.

The Tracing Path and surface normals are therefore given as:

Element	**OB_X**	**OB_Y**	**OB_Z**	**Comment**
Beam	0.0	1.0	0.0	TX Pre Paam
PAAM	0	-0.707	0.707	Nominal (no offset)
PBS1	0	-0.707	-0.707	
TelecopeIF	0.707	0.707	0	

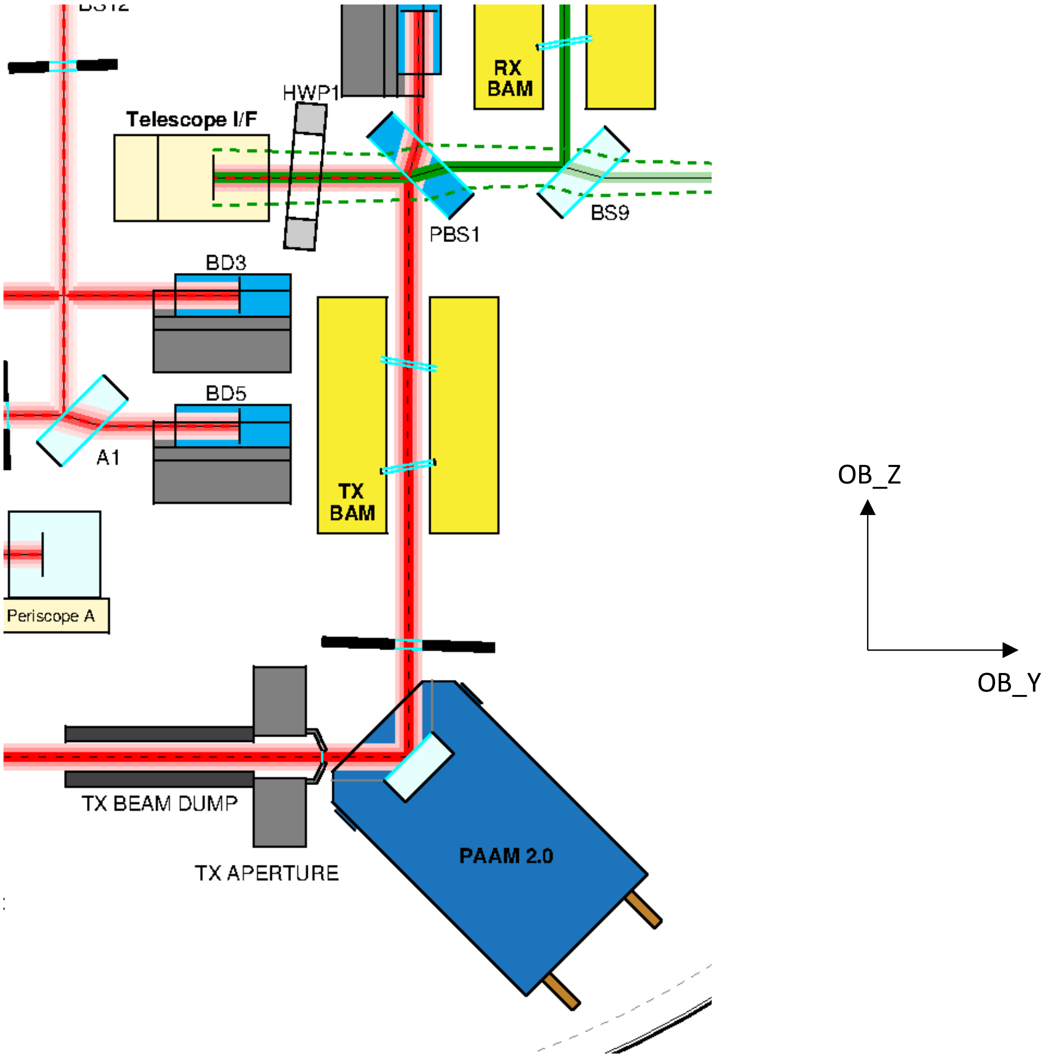

Figure 5: Excerpt from Telescope Layout v2.2.2 [RD4]

3.5 Postprocessing

For the assessment of compliance, a trace without any added offset is compared to a trace with offset. The rotation angle between the two resulting beams in OB frame and SC frame is calculated and compared to the requirment. The requirment is met when the difference is smaller than 1µrad (TBC). The effect on secondary angles is considered separately.

4 DISCUSSION

The analysis confirms that for the case of a clockwise rotating constellation a static offset requirement for the PAAM mirror that is consistent with a rotation of the PAAM of -156µrad around the y axis of the PAAM OIRF is correct. This is equivalent to lowering the back side of the PAAM towards the optical bench.

5 DERIVED REQUIREMENTS

To guarantee the correctness of the analysis presented so far, the following requirements need to be placed on the respective systems / subsystems:

➔ Coalignment of SC, MOSA and OB frames with respect to their Z axis direction.

BIBLIOGRAPHY

[RD1] LISA-LCST-MIS-ST-001_Top-Level Nomenclature and Conventions in LISA_1.0

[RD2] ESA-LISA-EST-MIS-HO-034_ LISA Point Ahead Angle Corrections for Clockwise and Counterclockwise Formations_1.0

[RD3] ESA-LISA-EST-PL-RS-004 IDS-IRD i1r0

[RD4] LISA-UKOB-INST-RP-0005 Optical Bench Design Report_3.0