POLITECNICO DI TORINO

Corso di Laurea in Ingegneria Aerospaziale

Tesi di Laurea Magistrale

Modeling and optimization of an integration process of an antenna on new satellite generation Neosat

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Abstract

Antenna reflector is designed to be located and oriented respect to the feed according to the Alignment Specifications in order to satisfy the customer's requirements. It might be possible that, due to defaults and uncertainty, the desired antenna configuration is not achieved and a correction must be performed in order to satisfy the specifications. These defaults have different sources, like manufacturing uncertainties or assembly errors, and their tolerances are defined by the Subsystem Assembly Specifications.

The goal of this thesis is to verify if the defaults are always offset by using the adjustment capabilities designed to perform the correction. For this study, a statistical approach is performed with the Montecarlo method in order to check if the adjustments are able to satisfy the Alignment Specifications for every defaults configuration. Since that approach requires to define in input a defaults distribution, a uniform one is chosen because the solver must not be influenced to find a solution.

Once verified that the adjustment capabilities are sufficient to offset the defaults, an optimization process is performed. Optimizing in that case means to find many ways to correct the antenna configuration and to point out the best ones. The best solution for this study is the one that requires the shortest time possible to carry out the correction or the easiest one to perform. These results are useful to give to the alignment team good work practices regarding the antenna alignment process.

Finally a cross-check of these results is performed with the Alignment software results.

Sommario

Il riflettore dell'antenna è progettato per essere posizionato e orientato rispetto al feed secondo le specifiche di allineamento in modo da soddisfare le richieste del cliente. Può accadere che, a causa di errori ed incertezze, la configurazione desiderata dell'antenna non venga raggiunta e una correzione deve essere eseguita al fine di soddisfare le specifiche. Diverse cause sono responsabili di questi errori, tra cui incertezze di produzione e assemblaggio, e le loro tolleranze sono definite dalle Subsystem Assemby Specifications.
Lo scopo di questa tesi è di verificare che tali errori siano sempre compensati usando le capacità di aggiustamento progettate per eseguire la correzione. Per questo studio, un approccio statistico è svolto usando il Metodo di Montecarlo in modo da valutare se tali aggiustamenti sono in grado di soddisfare le specifiche di allineamento. Poiché tale approccio richiede di definire in input una distribuzione dell'errore, quella uniforme è stata scelta al fine di non dare alcun tipo di influenza al solver nel trovare la migliore soluzione al problema.
Una volta verificato che le capacità di aggiustamento sono sufficienti a compensare gli errori, un processo di ottimizzazione viene eseguito. Ottimizzare in questo caso significa trovare diversi modi per correggere la configurazione dell'antenna e individuare le migliori soluzioni. In particolare, tali soluzioni sono quelle più facili da eseguire e che richiedono il minor tempo possibile. Questi risultati sono utili per dare al team di allineamento buone pratiche di lavoro per eseguire l'allineamento dell'antenna.
Infine un controllo incrociato dei risultati è fatto con quelli derivanti dal software tutt'ora utilizzato dal team di allineamento.

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Chapter 1

Presentation of the enterprise

1.1 Thales Group

Thales Group is an international leader in the field of the high technology thanks to its unique diversity of expertise, talents and cultures. Its five keys factors are: Aerospace, Space, Ground Transportation, Defence and Security. The entire group can count 64,000 employees and operations in 56 countries making Thales a key player in keeping the public safe and secure.

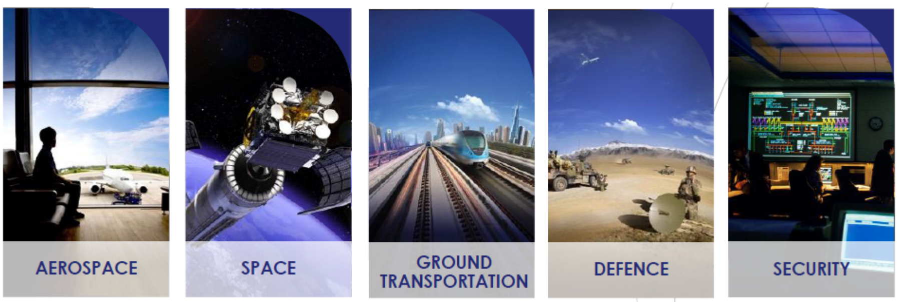

Figure 1.1. Thales group's sectors

Its role is to assist costumers helping them providing the tools and technologies they need to gather, process and distribute information and giving them an help to understand complex situations so they can decide and act in timely fashion and obtain the best outcomes.

1.2 Thales Alenia Space

Thales Alenia Space is an enterprise born in 2007 by the acquisition of Alcatel Alenia Space by the group Thales. It is the result of a joint-venture between the Thales and Leonardo in collaboration with Telespazio (in a Space Alliance).

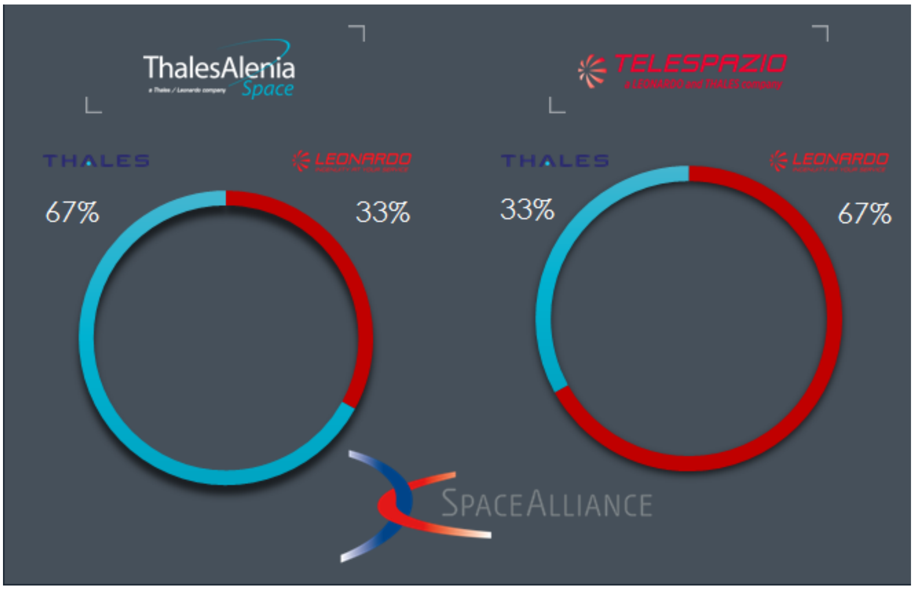

Figure 1.2. Thales Alenia Space alliance

Thanks to its 40 years of experience in space field, it is at the top in delivering high technology solutions for telecommunications, navigation, Earth observation, environmental management, exploration, science and orbital infrastructures. States, governments and companies rely on Thales Alenia Space to design, operate and deliver satellite-based system in order to optimize the use of our planet's resources, to help Earth observation and to discover our Solar System.
Employees' number in Thales Alenia Space is 7,980, which work in 15 sites in Europe.

As visible in the Figure 1.4, Thales Alenia Space represent a world player in each space sector.

Concerning telecommunications, the enterprise provides high performance, reliable and flexible spacebus satellite for broadcast, broadband and dual-use mission. It plays an important role also for the navigation systems in Europe (EGNOS, GALILEO). Moreover it deals with climate change monitoring. In fact, Thales is the prime contractor for all European Meteosat Meteorological satellite and it gives a contribution to almost every

Figure 1.3. Map of Thales Alenia Space enterprises

Figure 1.4. Thales Alenia Space sectors

European climate-related mission. At last it plays a prime role in all major European exploration mission (EXOMARS, HUYGENS, ROSETTA, MARS and VENUS EXPRESS) and it represents the largest industrial provider after Boeing for the International Space Station.

1.3 Site of Cannes

Cannes enterprise is born in 1929 as aeronautic industry and specialized for seaplane construction. Only in 1957 it moved towards astronautic field and year by year it focused increasingly the attention towards space activities. It is actually the first enterprise for employments in Cote d'Azur, in fact more than 2000 people work there.

Figure 1.5. Site of Cannes

Thanks to its different test and integration equipment, the site of Cannes is unique in Europe; The enterprise in Cannes is provided by 75 hectare, of which 13,000 sqm for the integration of six to eight satellites per year. About the activities performed in Cannes, there are:

- Assembly, integration and testes of satellites;
- Production and integration of satellite platforms;
- Production and integration of scientific payloads and optical instruments Image processing;
- On board and ground segment software;
- Design, Production and integration of satellite subsystems and units.

1.4 AIT Alignment

Alignment group is part of the service Assemblage Propulsion Alignment, which in turn is under the department of AIT Platform and Satellite test centre. This group has an important role since it performs a set of measures on assembled components in order to achieve the best integration between these sub-systems of the satellite. Indeed the antenna location and orientation are the main work objects of the Alignment team.
Moreover the team tests the correct deployment of the reflectors and of the solar arrays through an instrument (balloon or counterweight) to simulate the absence of gravity.
Furthermore the Alignment work is focused on the measurements and integration of several satellite's components.

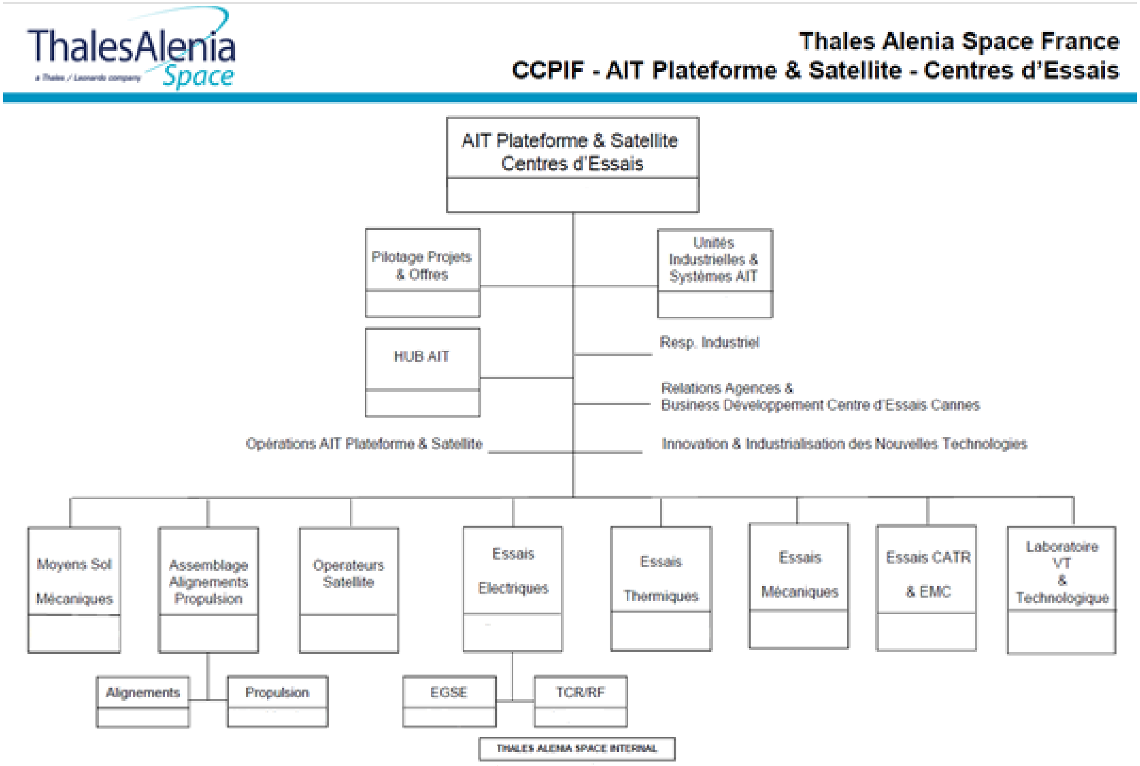

Figure 1.6. AIT scheme

Chapter 2

Introduction to the study

2.1 Spacebus NEO satellite generation

This study is performed for a specific generation of satellite, called Spacebus NEO generation.
Spacebus NEO is the new family of platforms from Thales Alenia Space for geostationary telecommunications satellites. All Spacebus NEO platforms now feature all-electric propulsion, and combine higher performance, greater robustness, modular design and higher power. Electric propulsion means a drastic reduction in satellite launch weight. And of course, the lower the weight of the platform, the bigger the payload it can carry.
Four Spacebus Neo-based satellites have already been ordered by commercial and government customers, with a first launch planned in 2019 [4].
These platforms include a number of innovations, not only all-electric propulsion, but also:

- Highly innovative thermal control and a high-performance power subsystem, enabling an effective 3D organization of the powerful payload.
- Flexible and modular design, in order to both reduce manufacturing cycles and also enhance the satellite's capability for its Telecommunication mission.
- Payloads tailored to each customer's requirements, including flexible digital solutions and very high data throughput.

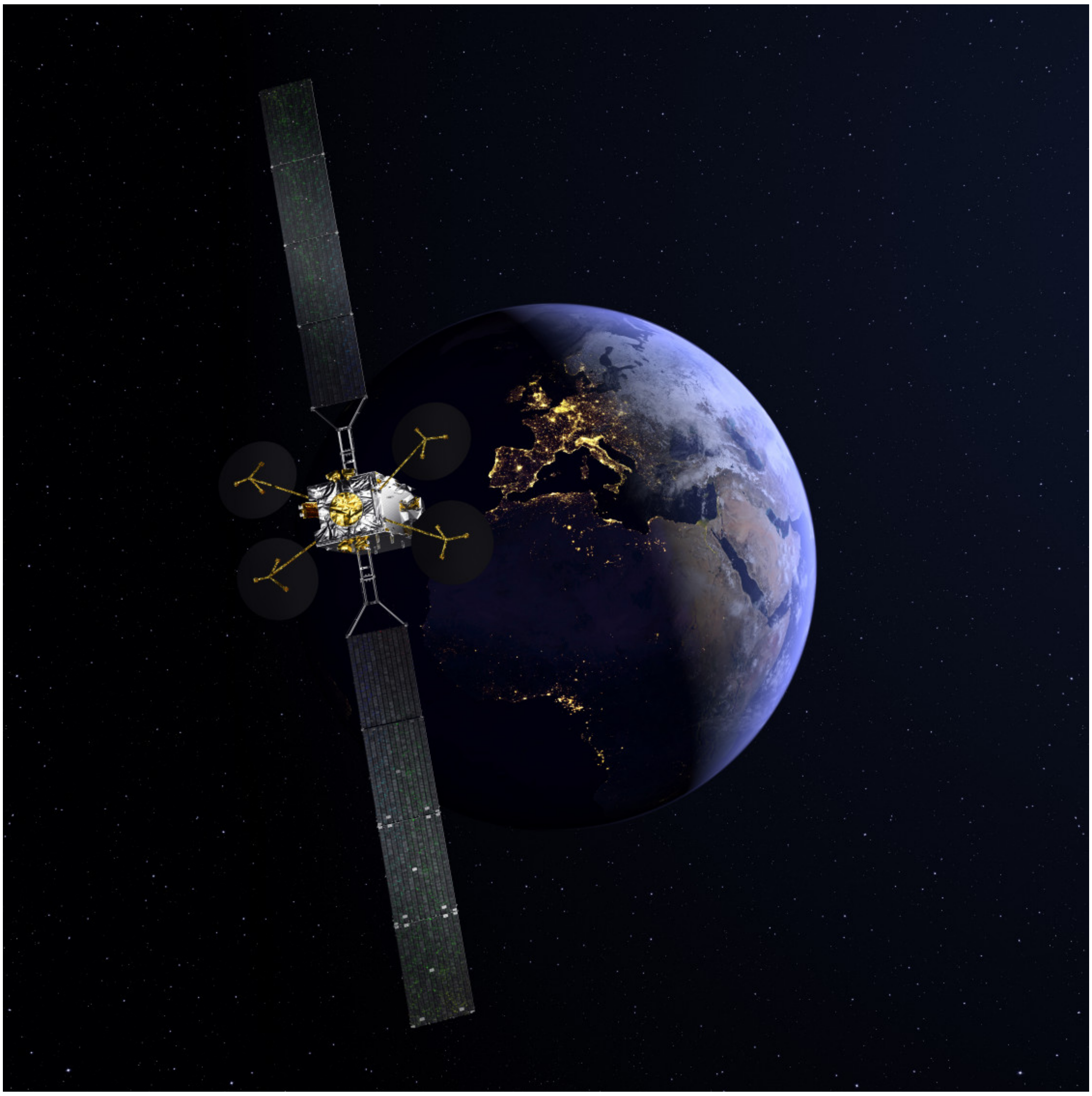

Figure 2.1.

In particular, between the Spacebus NEO generation, this study is focused on INTERNAL. That satellite, as the other of the same generation, is an ell-electric satellite, provided by Thales Alenia Space. With 75 Gbps of capacity across a network of 65 spotbeams, the project will achieve quasi-complete broadband coverage for Sub-Saharan Africa. In the following table the main data of are listed:

Family	Telecommunication
Customers	INTERNAL
Mission	Europe and Africa Broadband Services
Payload power	7.6 kW (EOL)
Platform	INTERNAL
Orbital position	14°E
Launcher	Ariane 5
Launch mass	3689 kg
Lifetime	15,25 years

Table 2.1.

2.2 Antenna subsystem for Spacebus Neo satellites

The goal of the study is to find an optimization process to verify and to correct the location and the orientation of the antennas on the new generation of NEOsat Satellites in deployed and stowed configuration.
Firstly, the antennas taken into account are lateral ones, which are composed by:

- A **feed** at the focal point;
- A **parabolic reflector** with its summit at the vertex point.

It is really important that the orientation and the location of the reflector reference system, that is the vertex one, called in this study RV reference system, are very close to the design values compared to the feed reference system, here called RCFA reference system. However, due to defaults from various sources (machining, assembly, motor uncertainties, etc.), the tolerances, fixed for a correct pointing of the reflector, are not respected. Thus adjustment capabilities need to offset these defaults leading the antenna to be in the tolerances.
On the new generation of Neosat satellites there will be four lateral antenna and, in particular, two for each side (west and east side) of the satellite. Its entire architecture is composed by various components, that are showed in Figure 2.3:

- Feeds module;
- A starlight reflector;
- ADPM2+, whose function is the deployment of the reflector;
- HRM2X are four per each side of the satellite and they are useful for the stocking of the reflector during the launch;

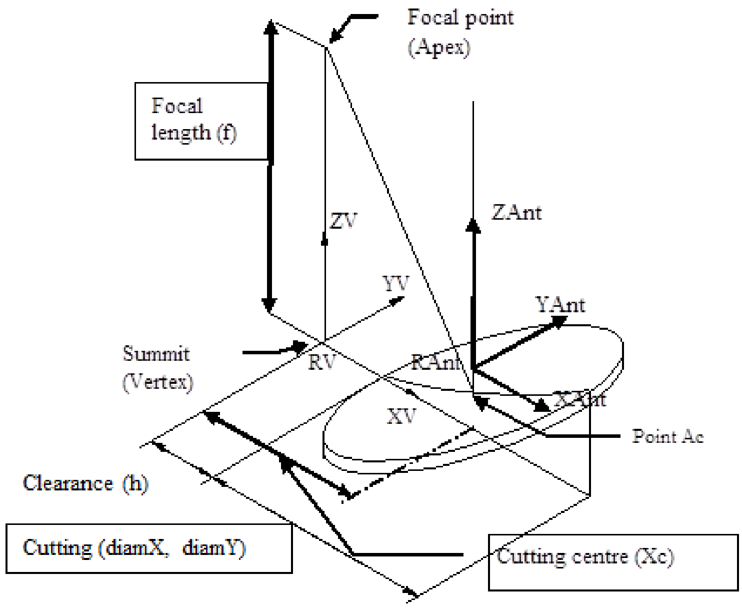

Figure 2.2. Reflector scheme compared with the feed

- LLD is another support of the reflector for the stowed configuration. There is one LLD dedicated for each antenna.

Concerning the innovation on this type of architecture respect to the previous one is the adding of a motor permitting new adjustment capabilities of the reflector and the use of HRM2X, which supports both antenna together.
Moreover, regarding the geometry of ADPM2+, it is possible to see that the two motor axis are not perpendicular. Consequently, the rotation of the first motor affects the orientation of the second motor axis. For this reason, motor adjustment capabilities are often used concurrently with other adjustment capabilities available for the ADPM2+.

Due to this non perpendicularity, it is not feasible performing corrections in orbit, so a new geometry, called ADPM3+ is designed to add a motor in order to make the axis perpendicular and crossing in the RV point.
HRM2X is the development of the HRM, which allows the fixation of one reflector to the Satellite for the launch. While HRM2X is a specific HRM allowing the fixation of 2 reflectors on the same side.

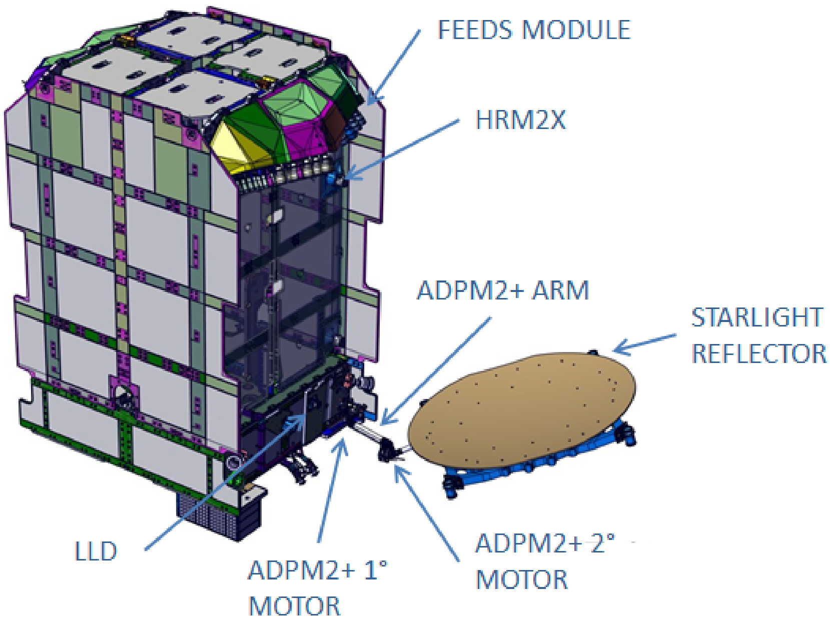

Figure 2.3. Antenna architecture

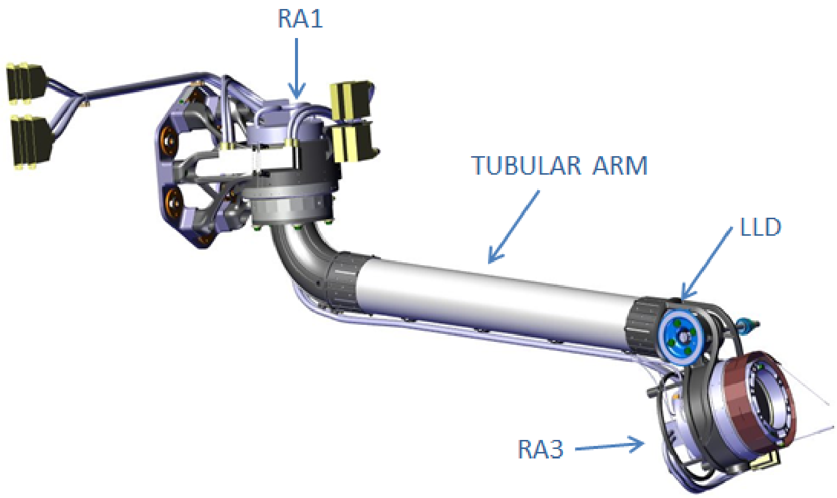

Figure 2.4. ADPM2+ architecture

In stacked configuration the two reflectors are linked through the HRM2X as shown in Figure 2.6.

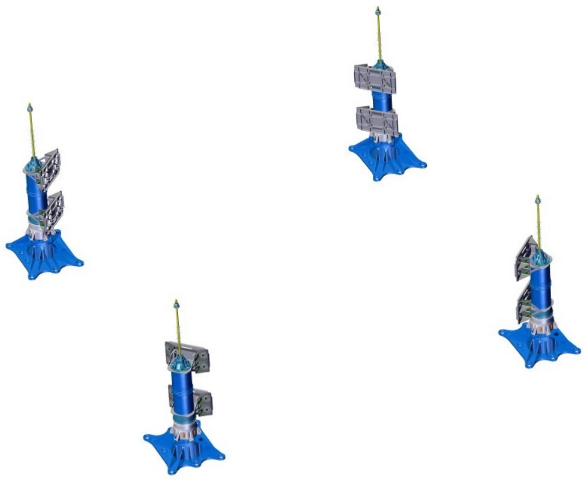

Figure 2.5. HRM2X disposition

Figure 2.6. HRM2X in stacked configuration

The HRM2X has two interface planes, one for each reflector deployment, as well as two separation planes “USP” and “LSP”. The distance between them is adaptable to the mission , but no closer than 80 mm.

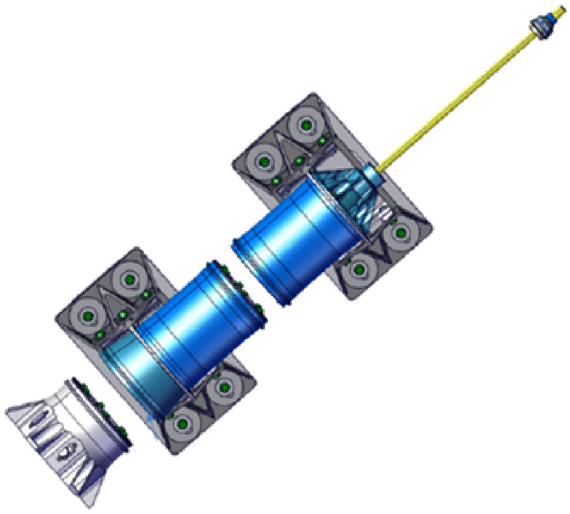

Figure 2.7. HRM2X in released configuration

Moreover the whole mechanism is fixed to the spacecraft thanks to the LLD, that is the Launch Locking Device.

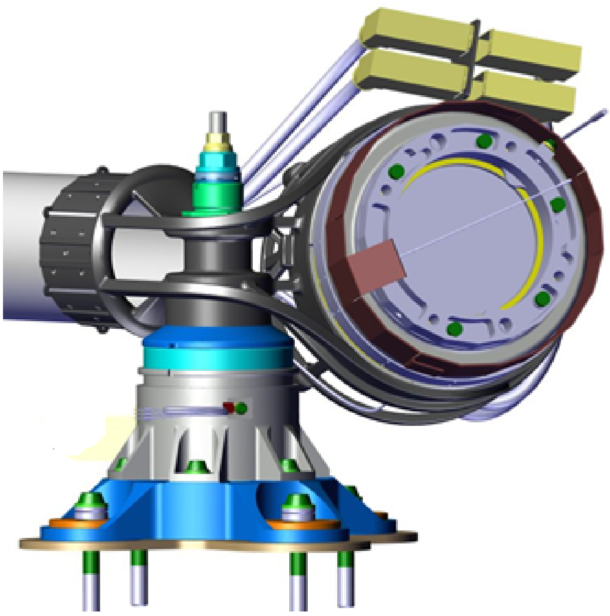

Figure 2.8. LLD in stacked configuration

The LLD is fixed to the spacecraft through a bracket in interface with the S/C as showed in Figure 2.9.

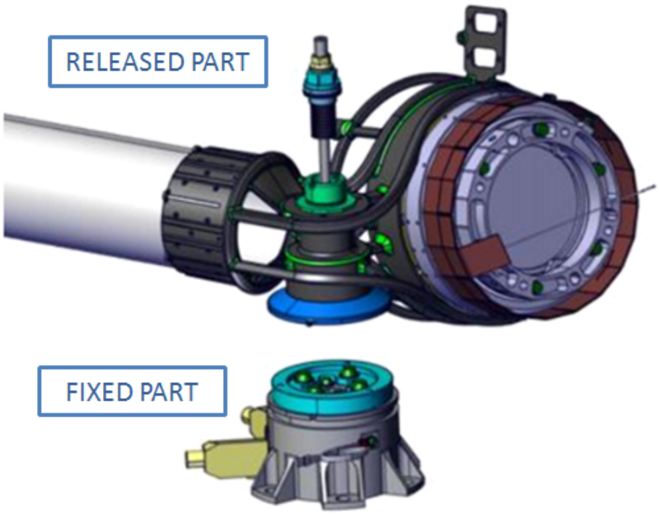

Figure 2.9. LLD in released configuration

2.3 Scheme of the work

Following a brief schematic presentation of this study. In order to perform the computation different steps are necessary and they are summed in Figure 2.10.
The first step is the construction of the mathematical model for the entire architecture of the antenna. That means creating various models for each its component: ADPM2+, HMR2X and LLD.
Following the study is focused on the defaults, which affect the antenna configuration. In that part a statistical approach is performed in order to evaluate many default configurations. Thus, a Montecarlo method is used to approach the problem and an uniform distribution is used to characterize the default distribution. Each default distribution is limited by two boundaries, which are defined by the Subsystem assembly specifications. At the end a focus is given to the effect of the specifications to the output default distributions.
The third step is solving the problem and that means to find the adjustment capabilities which lead the antenna to be in the AIT specifications. Therefore, the solver has to find a solution in terms of adjustment capabilities. As previously defined, the AIT specifications recommend the maximum values acceptable in order to declare the antenna correctly oriented and located.

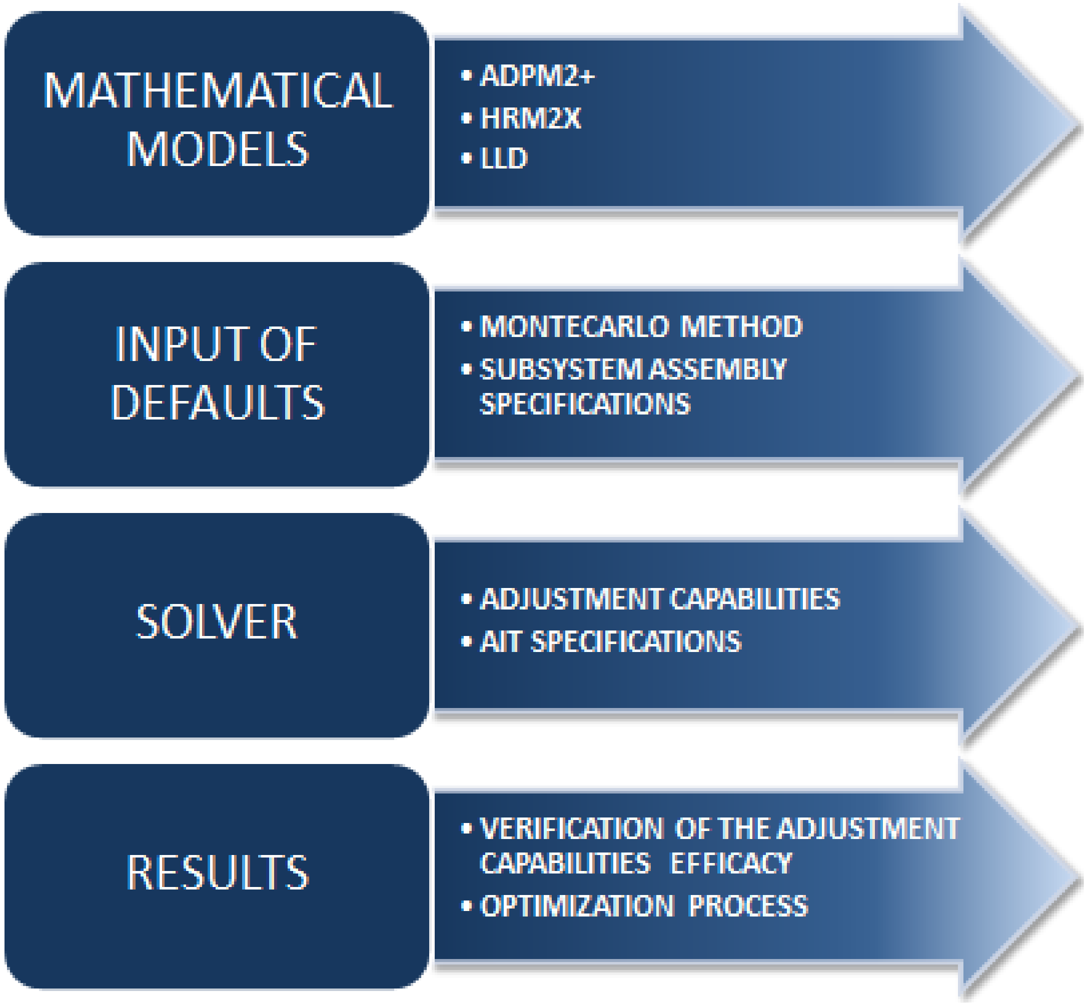

Figure 2.10. Scheme of the computation

The last step is to analyse the results. Firstly, a verification of the efficacy of the adjustment capabilities is performed. Then, an optimization process is developed to find simplest ways to offset the defaults on the reflector. Moreover good practises addressed to the alignment team are searched through the optimization.

Chapter 3

Mathematical models

3.1 Math Model for ADPM2+ in deployed configuration

Orthonormal matrices are used in this program in order to build the mathematical model. Example data are given for Antenna MS2 SE of Satellite B4A.

GLOSSARY USED FOR THE MATH MODEL:

R_z= rotation around z axis
R_y= rotation around y axis
R_x= rotation around x axis
'inv' = matrix without adjustments or defaults
'adj' = matrix with adjustments
'int' = intermediate matrix for machining computation
'mach' = final matrix for machining adjustment
'disp' = matrix with adjustments and defaults

SCHEME COLOR LEGEND:
Reference systems in RED are the final one, achieved by rotating the previous reference system in GREEN. While the reference systems in BROWN stand for the reference systems got by the adjustment capabilities.

3.1.1 Satellite axis

The reference axis system for the satellite is defined as follows:

- **Origin O** is situated in the centre of the launch ring at the base of the satellite;
- **Z axis** is pointing the Earth from O and it is perpendicular to the separation plane;
- **Y axis** is included in the separation plane and it is pointing, from O, a slot labeled +Y (in South direction)
- **X axis** forms a direct orthogonal axis system and it points towards East.

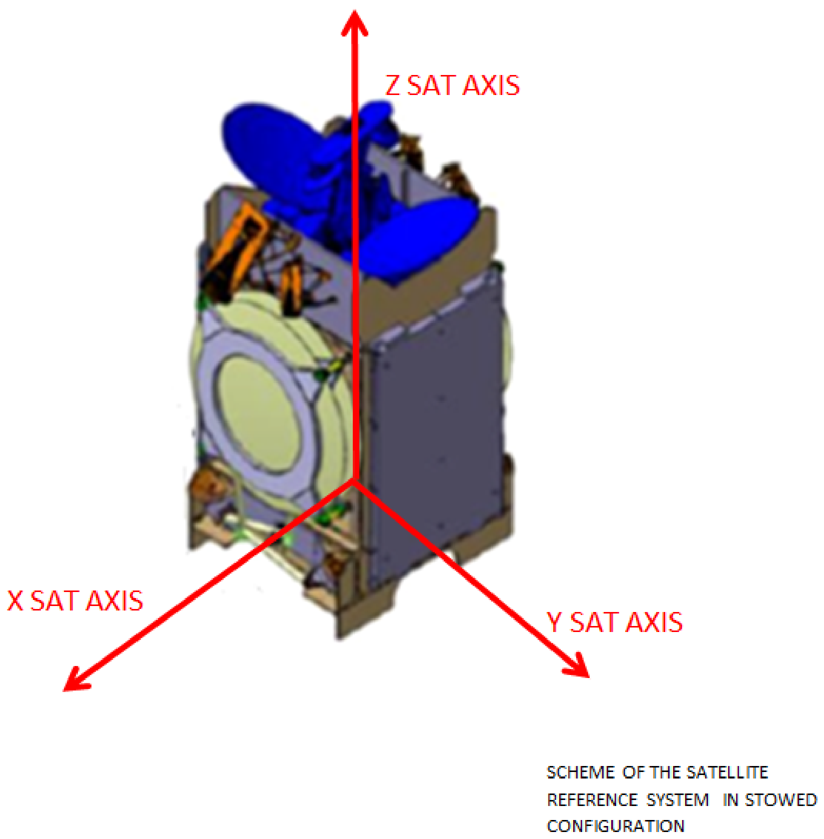

Figure 3.1. Satelite axis

3.1.2 Peliable shims

This reference axis system is created in order to point out the variation of the layers' thickness. In fact, it is possible to displace the origin of the system through the peliable shims of maximum +/- 10 mm in z SHIM M1 direction.

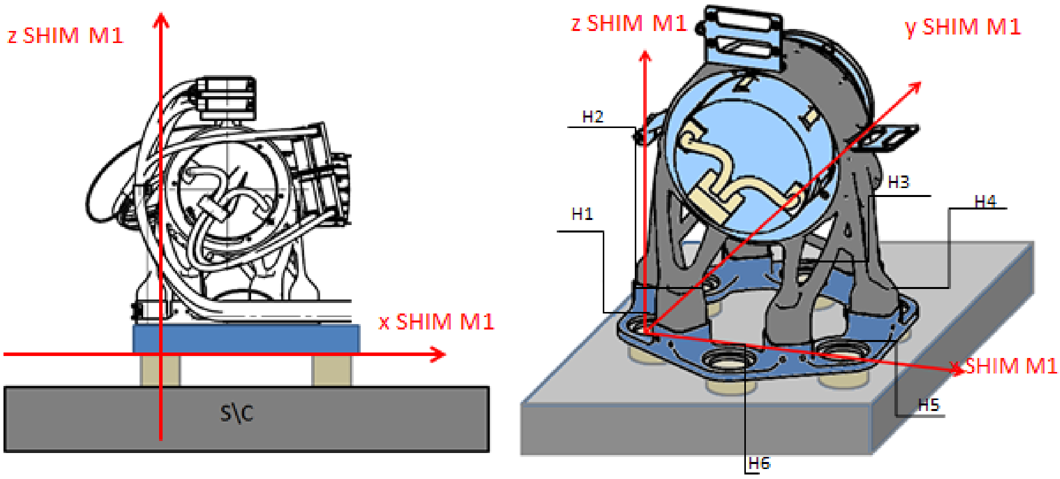

Figure 3.2. SHIM M1 reference system

$$_{shimM1_{inv}}()^{SAT} = R_z(\theta_z)*R_y(\theta_y) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\theta_y) & 0 & -sin(\theta_y) \\ 0 & 1 & 0 \\ sin(\theta_y) & cos(\theta_y) & 0 \end{pmatrix} \tag{3.1}$$

$$_{shimM1_{inv}}()^{SAT} = R_z(\theta_z) * R_y(\theta_y) = \tag{3.2}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{shimM1}	0.0000000	-0.5426870	-0.8399350
y_{shimM1}	0.0000000	0.8399350	-0.5426870
z_{shimM1}	1.0000000	0.0000000	0.0000000

Table 3.1. Theoretical rotation matrix of shim M1 respect to satellite reference system

$$_{shimM1_{disp}}()^{SAT} =_{shimM1_{disp}} ()^{shimM1_{inv}} *_{shimM1_{inv}} ()^{SAT} \tag{3.3}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{shimM1}	0.0000000	-0.5426870	-0.8399350
y_{shimM1}	0.0000000	0.8399350	-0.5426870
z_{shimM1}	1.0000000	0.0000000	0.0000000

Table 3.2. Rotation matrix of shim M1 for antenna MS2 with dispersion refers to satellite ref.

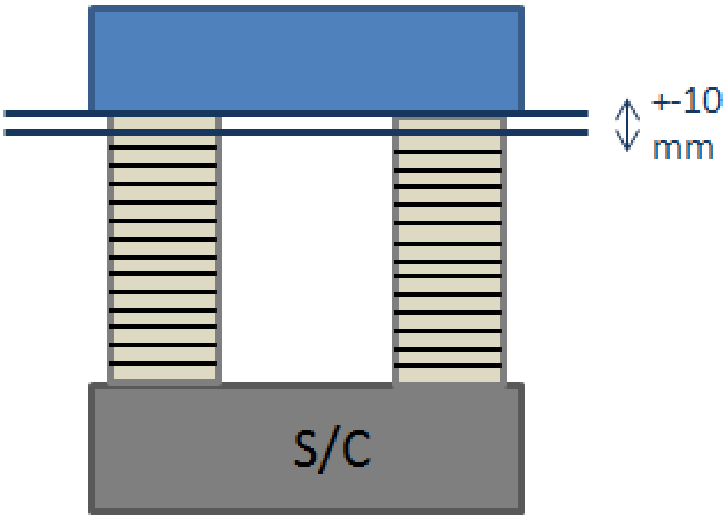

Figure 3.3. Peliable shims capabilities for ADPM2+

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

$$\begin{Bmatrix} x_{SHIMM1} \\ y_{SHIMM1} \\ z_{SHIMM1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta_{PELIABLESHIM} \\ 0 \\ 0 \end{Bmatrix} \tag{3.4}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN shimM1 REF	1251.000	-970.999	414.043

Table 3.3. Origin displacement for antenna MS2

3.1.3 USI1 reference system

The second reference system has the goal to define the rotation due to the machining of the shim. Firstly, the reference system is shifted in the centre of the shim and rotated by 180° around x-axis. While the final rotation, which reproduces the machining, consists of a product of different rotations. The first rotation is performed around the z-axis of an α angle (included between 0° and 360°), which is the direction of the machining. Subsequently, the reference system is rotated of β angle, which is the angle of machining and it assumes a value no higher than 0.5°. At last the reference system is rotated in order to bring x-axis in the initial x-z plane.

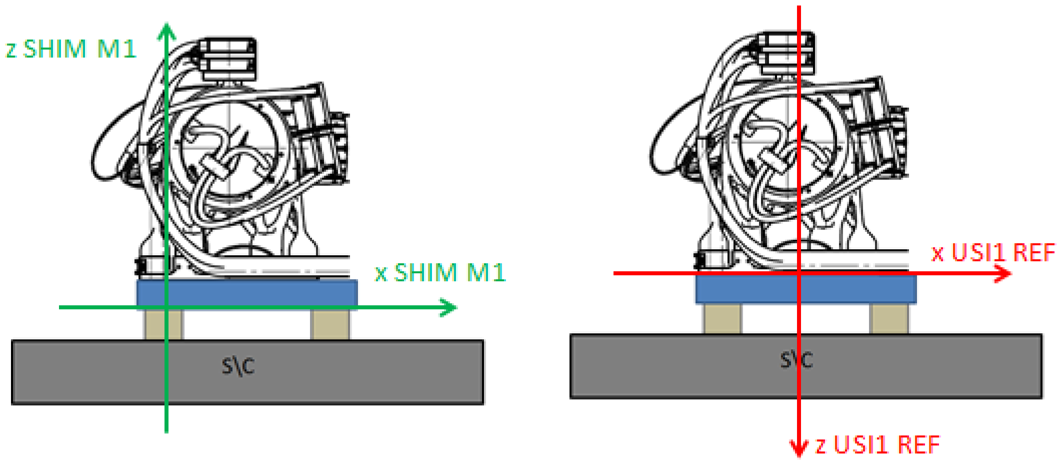

Figure 3.4. USI1 reference system

$$_{USI1_{inv}}()^{shimM1_{disp}} = R_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\theta_x) & sin(\theta_x) \\ 0 & -sin(\theta_x) & cos(\theta_x) \end{pmatrix} \tag{3.5}$$

$$_{USI1_{inv}}()^{shimM1_{disp}} = R_x(-180^(\circ)) \tag{3.6}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{shimM1}	0.0000000	-0.5426870	-0.8399350
y_{shimM1}	0.0000000	0.8399350	-0.5426870
z_{shimM1}	1.0000000	0.0000000	0.0000000

Table 3.4. Rotation matrix of USI1 respect to shim M1 reference system

MODEL FOR THE MACHINING

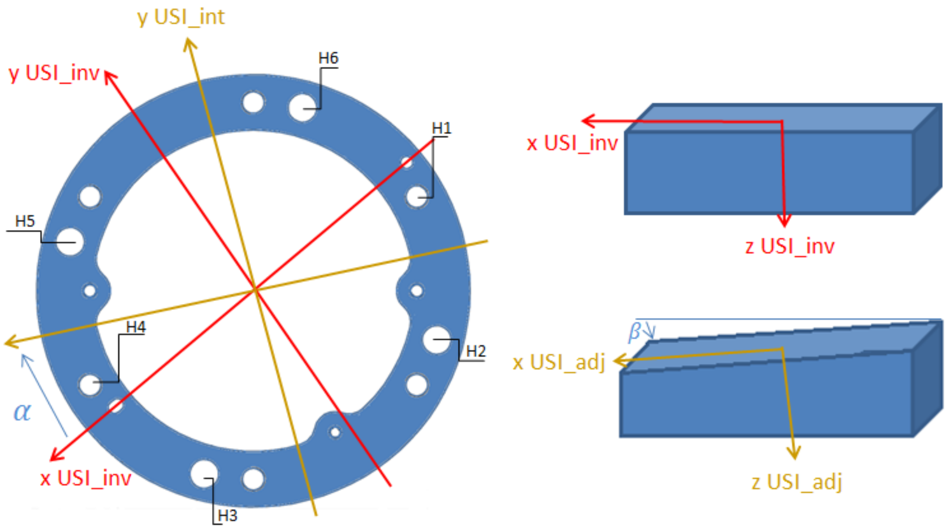

Figure 3.5. Geometry explanation for the machining shim 1

α and β angles must be entered positive by the user. In order to get USI$_{int}$ Reference system a clock wise β rotation is performed [7].

$$_{USI1_{mach}}()^{USI1_{inv}} = Rz_{adj}(\gamma) * Ry_{int}(\beta) * Rx_{inv}(\alpha) = \tag{3.7}$$

$$\begin{pmatrix} cos(\gamma) & sin(\gamma) & 0 \\ -sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\beta) & 0 & -sin(\beta) \\ 0 & 1 & 0 \\ sin(\beta) & cos(\beta) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\alpha) & sin(\alpha) \\ 0 & -sin(\alpha) & cos(\alpha) \end{pmatrix} \tag{3.8}$$

	$x_{USI1inv}$	$y_{USI1inv}$	$z_{USI1inv}$
$x_{USI1mach}$	$cos\beta\ cos\alpha\ cos\gamma - sin\alpha\ sin\gamma$	$cos\beta\ cos\gamma\ sin\alpha + cos\alpha\ sin\gamma$	$-sin\beta\ cos\gamma$
$y_{USI1mach}$	-$cos\gamma\ sin\alpha - cos\beta\ cos\alpha\ sin\gamma$	$cos\alpha\ cos\gamma - cos\beta\ sin\alpha\ sin\gamma$	$sin\beta\ sin\gamma$
$z_{USI1mach}$	$sin\beta\ cos\alpha$	$sin\beta\ sin\alpha$	$cos\beta$

Table 3.5. Rotation matrix for machining shim 1

γ angle represents the rotation angle necessary to perform the rotation of x USI adj in order to bring it in the initial x USI1 – z USI1 plane. This condition leads to compute the γ angle by imposing null the component of x USI1 MACH along y USI1 INV.

$$cos\beta\ \ cos\gamma\ \ sin\alpha + cos\alpha\ \ sin\gamma = 0 \tag{3.9}$$

$$\gamma = -tan^{-1}\Big(\frac{cos\beta * sin\alpha}{cos\alpha}\Big) \tag{3.10}$$

$$_{USI1_{disp}}()^{SAT} = USI1_{disp}()^{USI1_{mach}} *_{USI1_{mach}}()^{USI1_{inv}} *_{USI1_{inv}}()^{shimM1_{disp}} *_{shimM1_{disp}}()^{SAT} \tag{3.11}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{USI1}	0.0000000	-0.5426870	-0.8399350
y_{USI1}	0.0000000	0.8399350	-0.5426870
z_{USI1}	1.0000000	0.0000000	0.0000000

Table 3.6. Rotation matrix of USI1 respect to SAT reference system for antenna MS2

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

The machining leads not only to a reference system rotation, but also to a displacement of the reference origin. Considering the width of the layer equal to 150 mm, the displacement along z USI is:

$$\Delta z \quad MACHINING = \frac{widthcale}{2} * sin\beta \tag{3.12}$$

$$\begin{Bmatrix} x_{USI1} \\ y_{USI1} \\ z_{USI1} \end{Bmatrix} = \begin{Bmatrix} x_{SHIM1} \\ y_{SHIM1} \\ z_{SHIM1} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} 0 \\ 0 \\ \Delta z \quad MACHINING \end{Bmatrix} *_{shimM1_{disp}} ()^{SAT} \tag{3.13}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI1 REF	1251.000	-974.999	334.1448
	x_{SHIMM1}	y_{SHIMM1}	z_{SHIMM1}
ORIGIN USI1 REF	69.28	40	4.5

Table 3.7. Origin displacement for antenna MS2

3.1.4 CALEP1 reference system

CaleP1 reference system is related to the bracket (in yellow) over the shim. The origin of the reference system is displaced in the x-y axis of CALEP reference.

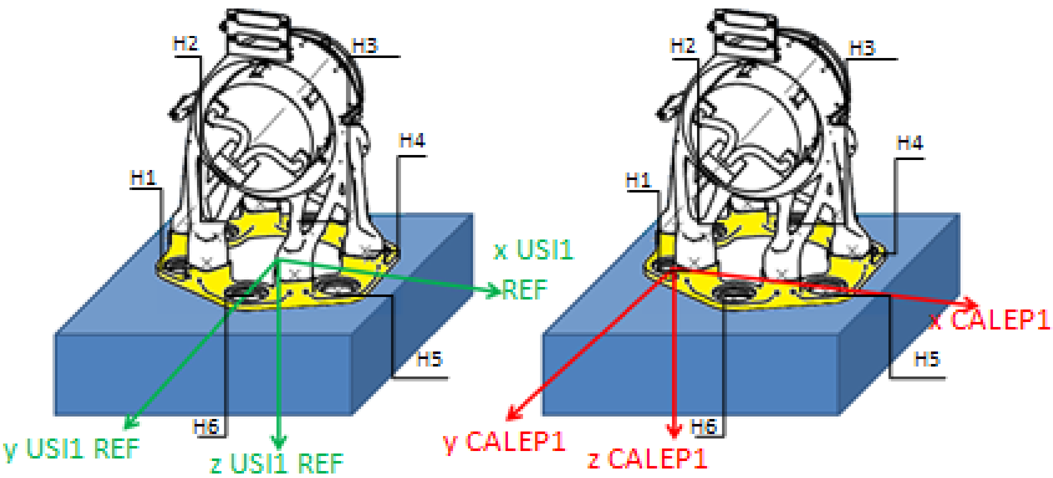

Figure 3.6. CALEP1 reference geometry

$$ {}_{CALEP1_{inv}}()^{USI1_{disp}} = \tag{3.14}$$

	x_{USI1}	y_{USI1}	z_{USI1}
x_{CALEP1}	1.0000000	0.0000000	0.0000000
y_{CALEP1}	0.0000000	1.0000000	0.0000000
z_{CALEP1}	0.0000000	0.0000000	1.0000000

Table 3.8. Rotation matrix of CALEP1 respect to USI1 reference system

$$ {}_{CALEP1_{disp}}()^{SAT} = {}_{CALEP1_{disp}}()^{CALEP1_{inv}} * {}_{CALEP1_{inv}}()^{USI1_{disp}} * {}_{USI1_{disp}}()^{SAT} \tag{3.15}$$

	SAT	SAT	SAT
x_{CALEP1}	0.0000000	-0.5426870	-0.8399350
y_{CALEP1}	0.0000000	0.8399350	-0.5426870
z_{CALEP1}	1.0000000	0.0000000	0.0000000

Table 3.9. Rotation matrix of CALEP1 respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN CALEP1 REF	1251.000	-970.999	414.043
	x_{USI1}	y_{USI1}	z_{USI1}
ORIGIN CALEP1 REF	-69.28	40	0

Table 3.10. CALEP1 origin displacement for antenna MS2

3.1.5 MEC reference system

This reference system is related to the bracket (in yellow) and it stands for Mechanical reference system. It is obtained by rotating CALEP1 reference system by 180° around CALEP1 x-axis. The origin coincides with the previous one without defaults or adjustments. However, this reference system is also the result of the adjustment capability performed on the bracket. In particular, they have effect on the origin position making a displacement maximum equal to a radius of 10 mm from the hole centre in the x – y MEC plane.

$$ {}_{MEC_{inv}}()^{SAT} = R_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\theta_x) & sin(\theta_x) \\ 0 & -sin(\theta_x) & cos(\theta_x) \end{pmatrix} = \tag{3.16} $$

$$ {}_{MEC_{disp}}()^{SAT} = {}_{MEC_{disp}}()^{MEC_{inv}} * {}_{MEC_{inv}}()^{CALEP1_{disp}} * {}_{CALEP1_{disp}}()^{SAT} \tag{3.17} $$

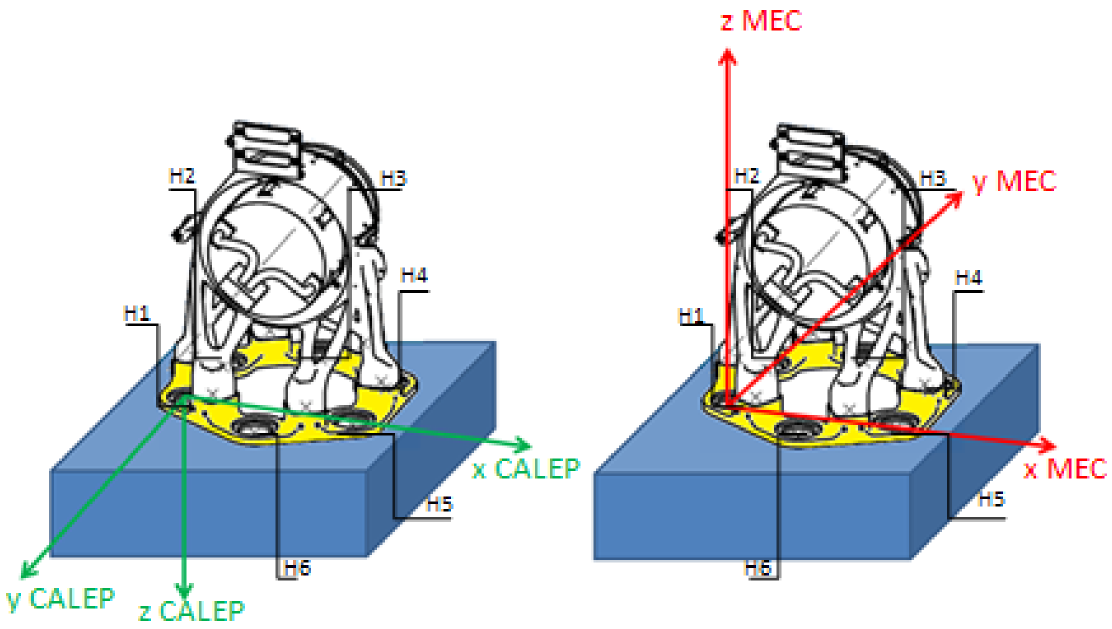

Figure 3.7. Mechanical reference system geometry

	x_{CALEP1}	y_{CALEP1}	z_{CALEP1}
x_{USI1}	1.0000000	0.0000000	0.0000000
y_{USI1}	0.0000000	-1.0000000	0.0000000
z_{USI1}	0.0000000	0.0000000	-1.0000000

Table 3.11. Rotation matrix of MEC respect to CALEP1 reference system for antenna MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{MEC}	0.0000000	-0.5426870	-0.8399350
y_{MEC}	0.0000000	0.8399350	-0.5426870
z_{MEC}	1.0000000	0.0000000	0.0000000

Table 3.12. Rotation matrix of MEC respect to SAT reference system

ADJUSTMENT CAPABILITIES IN POLAR COORDINATES

$$\Delta x_{adj} = radius_{MEC} * cos(\theta) \tag{3.18}$$

$$\Delta y_{adj} = radius_{MEC} * sin(\theta) \tag{3.19}$$

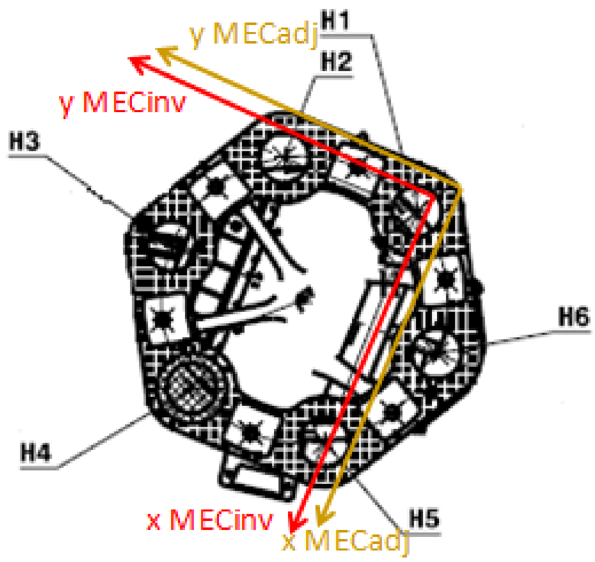

Figure 3.8. Mechanical capbailities at the base of motor 1 bracket

$$\begin{Bmatrix} x_{MEC} \\ y_{MEC} \\ z_{MEC} \end{Bmatrix} = \begin{Bmatrix} x_{MECinv} \\ y_{MECinv} \\ z_{MECinv} \end{Bmatrix} + \begin{Bmatrix} \Delta x_{adj} \\ \Delta y_{adj} \\ \Delta z_{adj} \end{Bmatrix} *_{CALEP1_{disp}} ()^{SAT} \tag{3.20}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN MEC REF	1251.000	-970.999	414.043
	x_{CALEP1}	y_{CALEP1}	z_{CALEP1}
ORIGIN MEC REF	0	0	0

Table 3.13. MEC origin displacement for antenna MS2

3.1.6 FERRURE reference system

Ferrure reference system refers to ADPM bracket 1 (in orange). Its axis result to be parallel in nominal position to MEC axis. However, ADPM bracket 1 has the capability to rotate of maximum 0.3° around the reference hole, here called PTSB-1 in order to get a perfect centering of the ADPM bracket1.

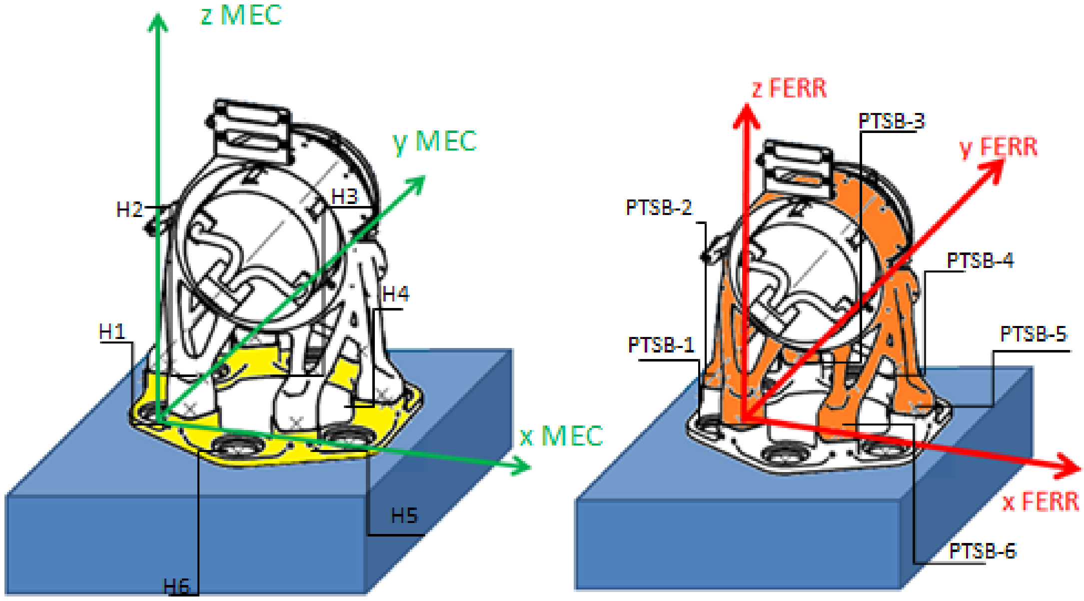

Figure 3.9. FERRURE reference system geometry

$$_{FERR_{inv}}()^{MEC_{disp}} = \tag{3.21}$$

	x_{MEC}	y_{MEC}	z_{MEC}
$x_{FERRURE}$	1.0000000	0.0000000	0.0000000
$y_{FERRURE}$	0.0000000	1.0000000	0.0000000
$z_{FERRURE}$	0.0000000	0.0000000	1.0000000

Table 3.14. Rotation matrix of FERRURE respect to MEC reference system for antenna MS2

ROTATION MATRIX FOR CLOCKING CAPABILITY

$$_{FERR_{Clock}}()^{FERR_{inv}} = R_z(\delta) = \begin{pmatrix} cos(\delta) & sin(\delta) & 0 \\ -sin(\delta) & cos(\delta) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3.22}$$

$$_{FERR_{disp}}()^{SAT} = _{FERR_{disp}}()^{FERR_{Clock}} * _{FERR_{Clock}}()^{FERR_{inv}} * _{FERR_{inv}}()^{MEC_{disp}} * _{MEC_{disp}}()^{SAT} \tag{3.23}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{FERR}	0.0000000	-0.5426870	-0.8399350
y_{FERR}	0.0000000	0.8399350	-0.5426870
z_{FERR}	1.0000000	0.0000000	0.0000000

Table 3.15. Rotation matrix of FERR respect to SAT reference system

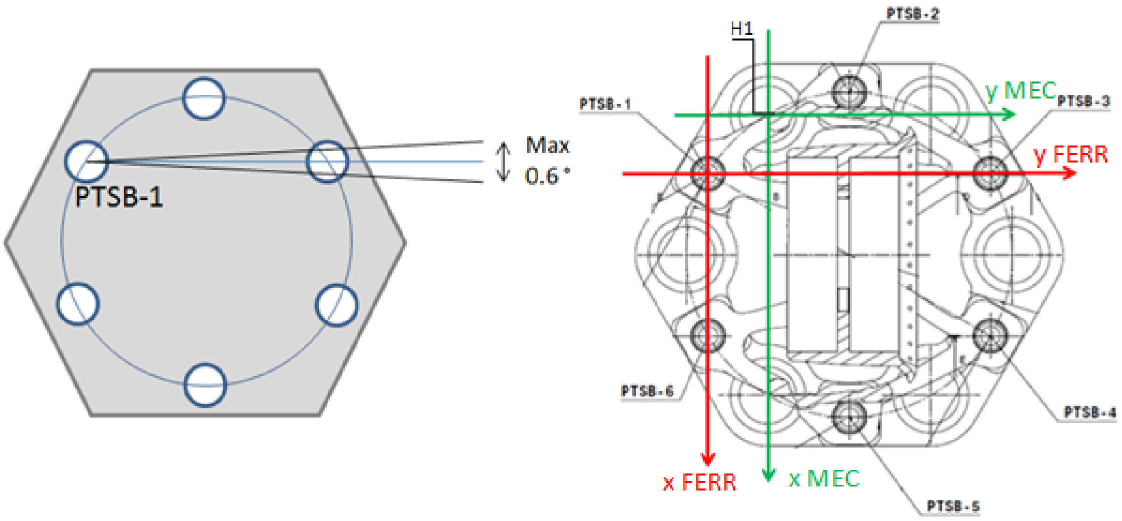

Figure 3.10. Clocking capability

$$\begin{Bmatrix} x_{FERR} \\ y_{FERR} \\ z_{FERR} \end{Bmatrix} = \begin{Bmatrix} x_{MEC} \\ y_{MEC} \\ z_{MEC} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} \tag{3.24}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN FERRURE REF	1275.000	-1011.4849	405.33898
	x_{MEC}	y_{MEC}	z_{MEC}
ORIGIN FERRURE REF	29.282	-29.282	24

Table 3.16. FERRURE origin displacement for antenna MS2

3.1.7 MOTOR1 reference system

In order to define the initial position of the motor 1 before the rotation a reference system, called RIF. 1, is used. It is useful to compare the reference system in rotated position in order to verify the motor operation.

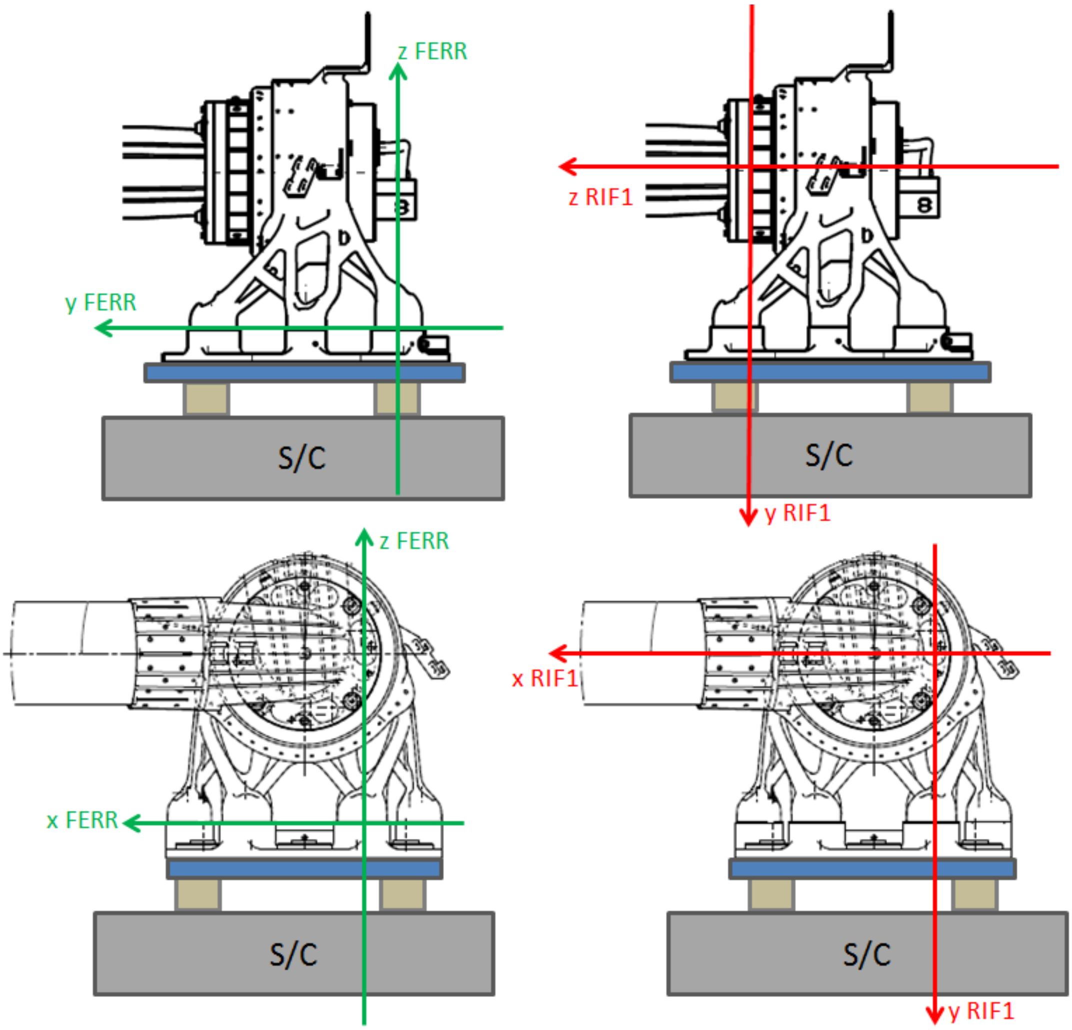

Figure 3.11. RIF1 reference system geometry

$$_{RIF1_{inv}}()^{FERR_{disp}} = R_z(\phi_z) * R_y(\phi_y) * R_x(\phi_x) = \tag{3.25}$$

$$\begin{pmatrix} cos(\phi_z) & sin(\phi_z) & 0 \\ -sin(\phi_z) & cos(\phi_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\phi_y) & 0 & -sin(\phi_y) \\ 0 & 1 & 0 \\ sin(\phi_y) & cos(\phi_y) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\phi_x) & sin(\phi_x) \\ 0 & -sin(\phi_x) & cos(\phi_x) = \end{pmatrix} \tag{3.26}$$

$$_{RIF1_{disp}}()^{SAT} = _{RIF1_{disp}}()^{RIF1_{inv}} * _{RIF1_{inv}}()^{FERR_{disp}} * _{FERR_{disp}}()^{SAT} \tag{3.27}$$

	$x_{FERRURE}$	$y_{FERRURE}$	$z_{FERRURE}$
x_{RIF1}	0.9876469	-0.0293135	-0.1539296
y_{RIF1}	-0.1566959	-0.1847616	-0.9702111
z_{RIF1}	0.0000000	0.9823461	-0.1870725

Table 3.17. Rotation matrix of RIF1 respect to FERRURE reference system for antenna MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{RIF1}	-0.1539296	-0.5606046	-0.8136511
y_{RIF1}	-0.9702111	-0.0701509	0.2318821
z_{RIF1}	-0.1870725	0.8251069	-0.5331065

Table 3.18. Rotation matrix of RIF1 respect to SAT reference system for antenna MS2

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

$$\begin{Bmatrix} x_{RIF1} \\ y_{RIF1} \\ z_{RIF1} \end{Bmatrix} = \begin{Bmatrix} x_{FERR} \\ y_{FERR} \\ z_{FERR} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} \tag{3.28}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RIF1 REF	1471.787	-901.604	340.811
	x_{FERR}	y_{FERR}	z_{FERR}
ORIGIN RIF1 REF	-5.43165	127.3113	196.787

Table 3.19. RIF1 origin displacement for antenna MS2

3.1.8 MOTOR1 rotation

The following reference system is ROT1 reference system, which defines the rotation of motor 1 around its axis. For each antenna the rotation angle is different. However, the step angle is equal for everyone and it is 0.009375 deg. Consequently, for each antenna there is a different number of motor steps to achieve the final deployed configuration. At last for the antennas MS1 and MS4 the rotation is clock wise, while for MS2 and MS3 the direction is counter clock wise.
In order to get ROT1 reference system, a rotation of θ angle around motor 1 axis is performed [7]. Moreover, adjustment capability for motor 1 are performed in order to offset the defaults effects on the reflector's deployed configuration.

At last an origin displacement is taken into account, since the origin is not placed along the motor axis.

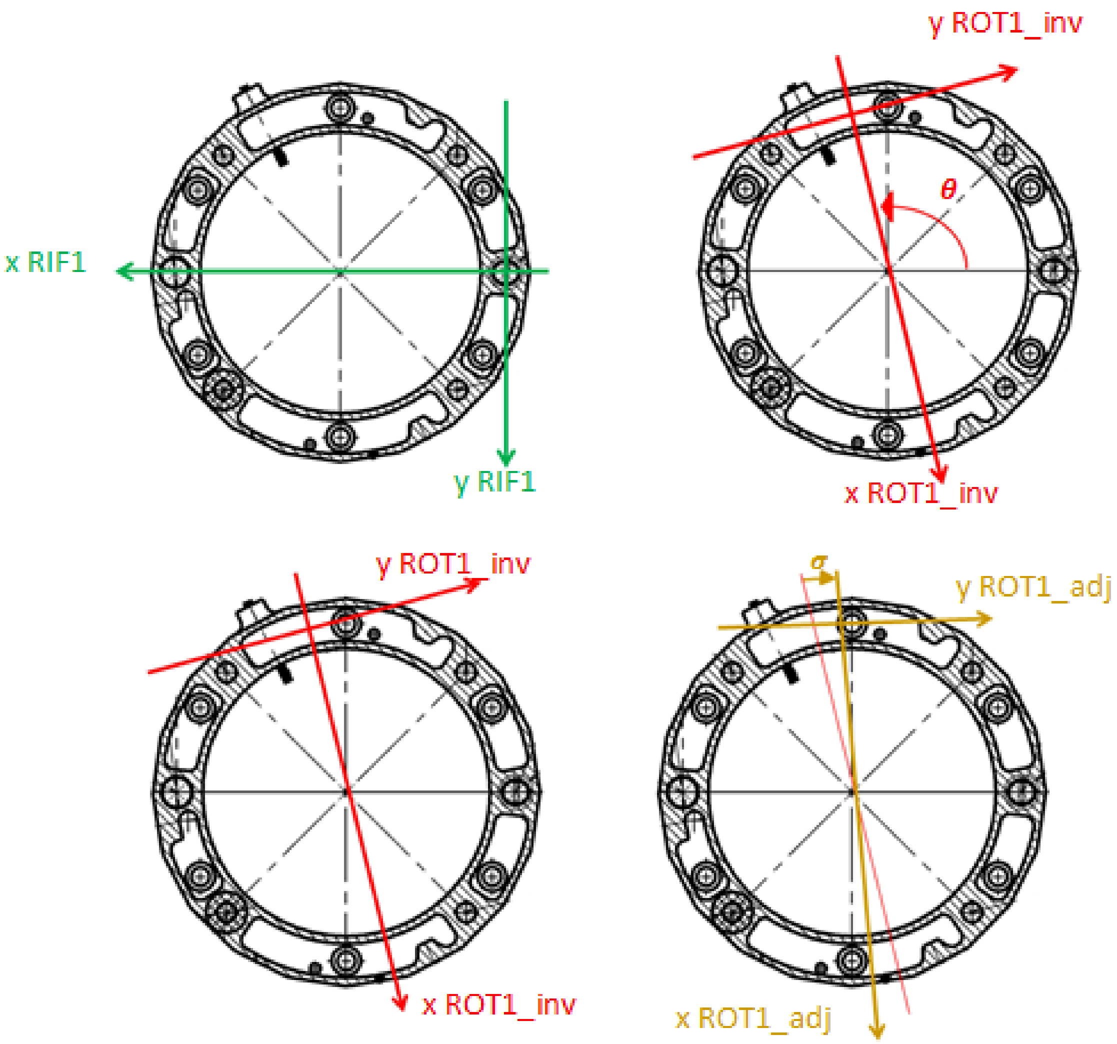

Figure 3.12. MOTOR 1 rotation geometry

$$_{ROT1_{inv}}()^{RIF1_{disp}} = R_z(\theta_z) = R_z(107.92309615°) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} = \quad (3.29)$$

	x_{RIF1}	y_{RIF1}	z_{RIF1}
x_{ROT1}	-0.3077402	0.9514704	0.0000000
y_{ROT1}	-0.9514704	-0.3077402	0.0000000
z_{ROT1}	0.0000000	0.0000000	1.0000000

Table 3.20. Rotation matrix of ROT1 respect to RIF1 reference system for antenna MS2

ROTATION MATRIX FOR MOTOR 1 CAPABILITY: σ is the adjustment angle

$$_{ROT1_{adj}}()^{ROT1_{inv}} = R_z(\sigma) = \begin{pmatrix} cos(\sigma_z) & sin(\sigma_z) & 0 \\ -sin(\sigma_z) & cos(\sigma_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3.30}$$

$$_{ROT1_{disp}}()^{SAT} =_{ROT1_{disp}} ()^{ROT1_{adj}} *_{ROT1_{adj}} ()^{ROT1_{inv}} *_{ROT1_{inv}} ()^{RIF1_{disp}} *_{RIF1_{disp}} ()^{SAT} \tag{3.31}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{ROT1}	-0.8757568	0.1057741	0.4710221
y_{ROT1}	0.4450324	0.5549870	0.7028055
z_{ROT1}	-0.1870725	0.8251069	-0.5331065

Table 3.21. Rotation matrix of ROT1 respect to SAT reference system for antenna MS2

ORIGIN DISPLACEMENT

The computation of the displacement is based on trigonometric demonstration. Following the geometric scheme for a generic rotation and the math formulas used for the computation, in which R1 stands for the motor 1 reference system origin and equal to 46 mm :

$$\begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} = \begin{Bmatrix} R1 - R1 * cos(\theta_z) \\ -R1 * sin(\theta_z) \\ 0 \end{Bmatrix} + \begin{Bmatrix} R1 - R1 * cos(\sigma_z) \\ -R1 * sin(\sigma_z) \\ 0 \end{Bmatrix} \tag{3.32}$$

$$\begin{Bmatrix} x_{ROT1} \\ y_{ROT1} \\ z_{ROT1} \end{Bmatrix} = \begin{Bmatrix} x_{RIF1} \\ y_{RIF1} \\ z_{RIF1} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} *_{RIF1_{disp}} ()^{SAT} \tag{3.33}$$

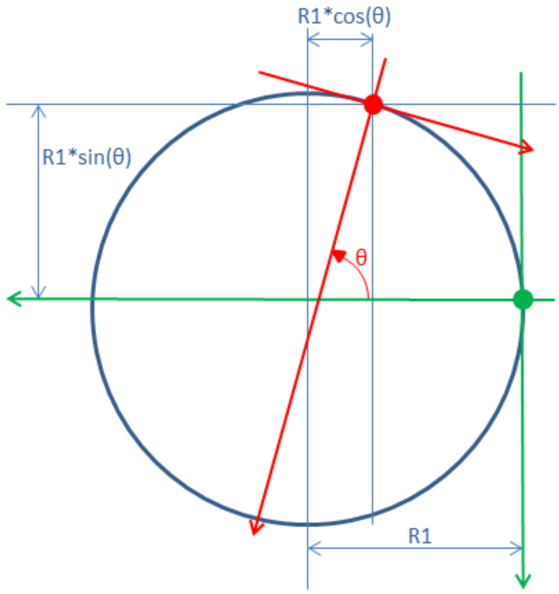

Figure 3.13. MOTOR 1 displacement due to the rotation

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN ROT1 REF	1504.991	-932.257	281.716
	x_{RIF1}	y_{RIF1}	z_{RIF1}
ORIGIN ROT1 REF	60.1560	-43.7676	0

Table 3.22. ROT1 origin displacement for antenna MS2

3.1.9 USI3 reference system

This reference system has the goal to define the rotation due to the machining of the shim. Firstly, the reference system is shifted in the centre of the shim. While the rotation, which reproduces the machining, consists of a product of different rotations. The first rotation is performed around the z-axis of an α angle (included between 0° and 360°), which is the direction of the machining. Subsequently, the reference system is rotated of β angle, which is the angle of machining and it assumes a value no higher than 1.1°. At last the reference system is rotated in order to bring x-axis in the initial x-z plane.

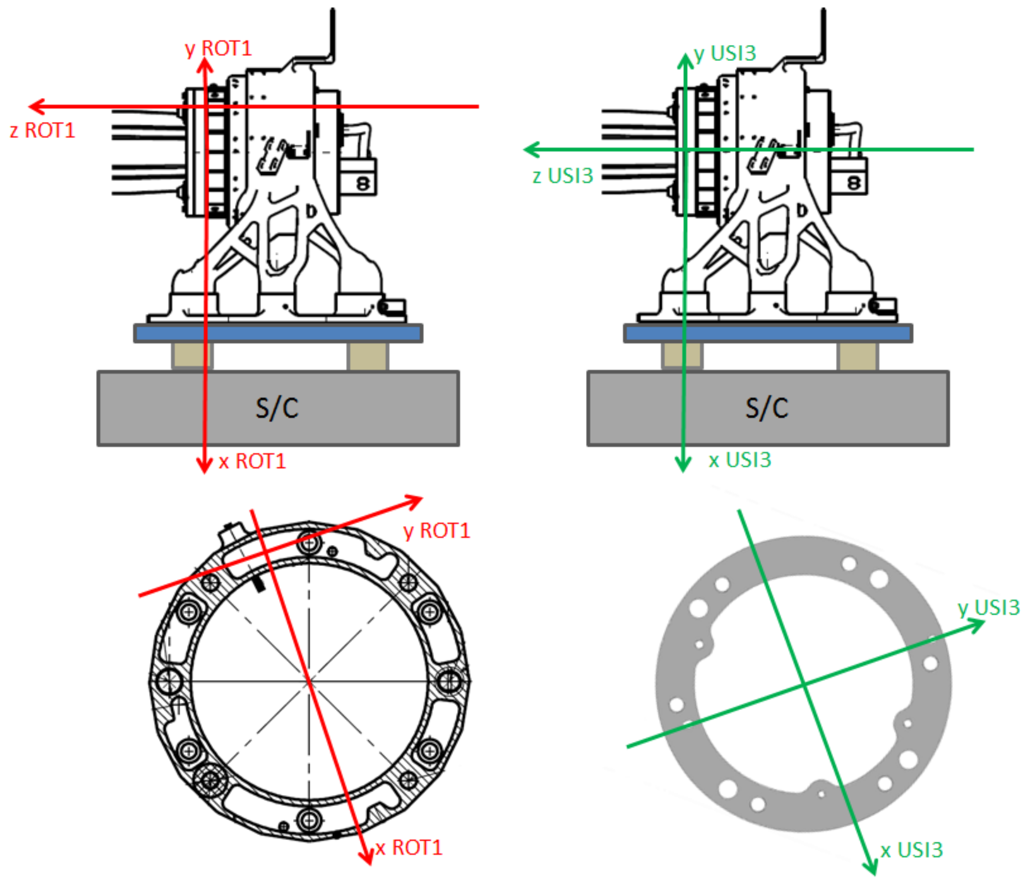

Figure 3.14. USI3 reference system geometry

$$
{}_{USI3_{inv}}()^{ROT1_{disp}} = R_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\theta_x) & sin(\theta_x) \\ 0 & -sin(\theta_x) & cos(\theta_x) \end{pmatrix} = \tag{3.34}
$$

	x_{ROT1}	y_{ROT1}	z_{ROT1}
x_{USI3}	1.0000000	0.0000000	0.0000000
y_{USI3}	0.0000000	1.0000000	0.0000000
z_{USI3}	0.0000000	0.0000000	1.0000000

Table 3.23. Rotation matrix of USI3 respect to ROT1 reference system for antenna MS2

MODEL FOR THE MACHINING

α and β angles must be entered positive by the user. In order to get USI$_{int}$ Reference system a clock wise β rotation is performed.

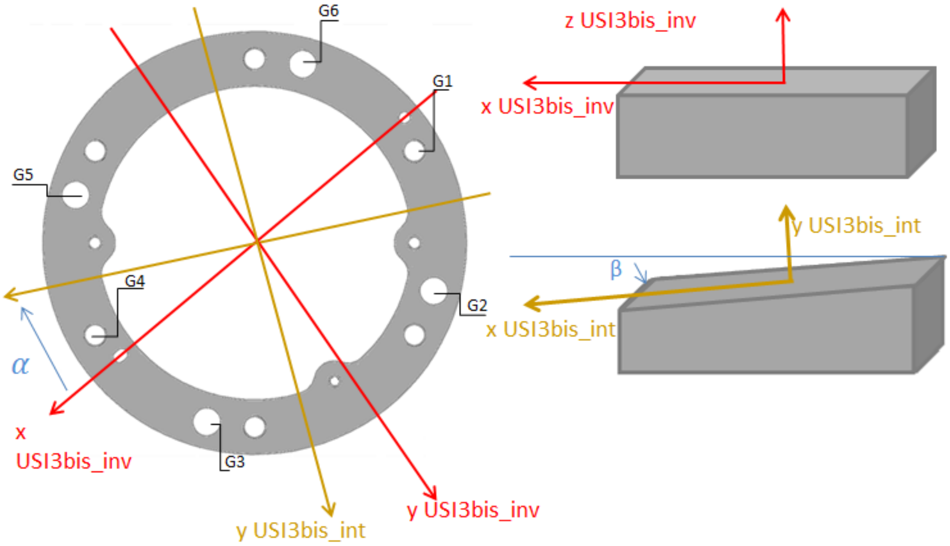

Figure 3.15. Geometry explanation for the machining shim 3

$$_{USI3_{mach}}()^{USI3_{inv}} = Rz_{adj}(\gamma) * Ry_{int}(\beta) * Rx_{inv}(\alpha) = \tag{3.35}$$

$$\begin{pmatrix} cos(\gamma) & sin(\gamma) & 0 \\ -sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\beta) & 0 & -sin(\beta) \\ 0 & 1 & 0 \\ sin(\beta) & cos(\beta) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\alpha) & sin(\alpha) \\ 0 & -sin(\alpha) & cos(\alpha) \end{pmatrix} \tag{3.36}$$

	$x_{USI3inv}$	$y_{USI3inv}$	$z_{USI3inv}$
$x_{USI3mach}$	$cos\beta\ cos\alpha\ cos\gamma - sin\alpha\ sin\gamma$	$cos\beta\ cos\gamma\ sin\alpha + cos\alpha\ sin\gamma$	$-sin\beta\ cos\gamma$
$y_{USI3mach}$	-$cos\gamma\ sin\alpha - cos\beta\ cos\alpha\ sin\gamma$	$cos\alpha\ cos\gamma - cos\beta\ sin\alpha\ sin\gamma$	$sin\beta\ sin\gamma$
$z_{USI3mach}$	$sin\beta\ cos\alpha$	$sin\beta\ sin\alpha$	$cos\beta$

Table 3.24. Rotation matrix for machining shim 3

γ angle represents the rotation angle necessary to perform the rotation of x USI3 adj in order to bring it in the initial x USI3 – z USI3 plane. This condition leads to compute the γ angle by imposing null the component of x USI3 MACH along y USI3 INV.

$$cos\beta\ \ cos\gamma\ \ sin\alpha + cos\alpha\ \ sin\gamma = 0 \tag{3.37}$$

$$\gamma = -tan^{-1}\Big(\frac{cos\beta * sin\alpha}{cos\alpha}\Big) \tag{3.38}$$

$$_{USI3_{disp}}()^{SAT} = _{USI3_{disp}}()^{USI3_{mach}} *_{USI3_{mach}}()^{USI3_{inv}} *_{USI3_{inv}}()^{ROT1_{disp}} *_{ROT1_{disp}}()^{SAT} = \tag{3.39}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{USI3}	-0.8757568	0.1057741	0.4710221
y_{USI3}	0.4450324	0.5549870	0.7028055
z_{USI3}	-0.1870725	0.8251069	-0.5331065

Table 3.25. Rotation matrix of USI3 respect to SAT reference system for antenna MS2

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

The machining leads not only to a reference system rotation, but also to a displacement of the reference origin. Considering the width of the layer equal to 104 mm and the thickness equal to 12 mm, the displacement along z USI is equal to:

$$\Delta x \quad MACHINING = thickness * sin(\beta) * cos(\alpha) \tag{3.40}$$

$$\Delta y \quad MACHINING = thickness * sin(\beta) * sin(\alpha) \tag{3.41}$$

$$\Delta z \quad MACHINING = \frac{widthcale}{2} * sin\beta \tag{3.42}$$

$$\begin{Bmatrix} x_{USI3} \\ y_{USI3} \\ z_{USI3} \end{Bmatrix} = \begin{Bmatrix} x_{ROT1} \\ y_{ROT1} \\ z_{ROT1} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta x \quad MACHINING \\ \Delta y \quad MACHINING \\ \Delta z \quad MACHINING \end{Bmatrix} *_{ROT1_{disp}}()^{SAT} \tag{3.43}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI3 REF	1470.046627	-920.7319686	311.816715
	x_{ROT1}	y_{ROT1}	z_{ROT1}
ORIGIN USI3 REF	46	0	12

Table 3.26. USI3 origin displacement for antenna MS2

3.1.10 USI3BIS reference system

The origin of the reference system is displaced in the x-z plane of USI3 reference system.

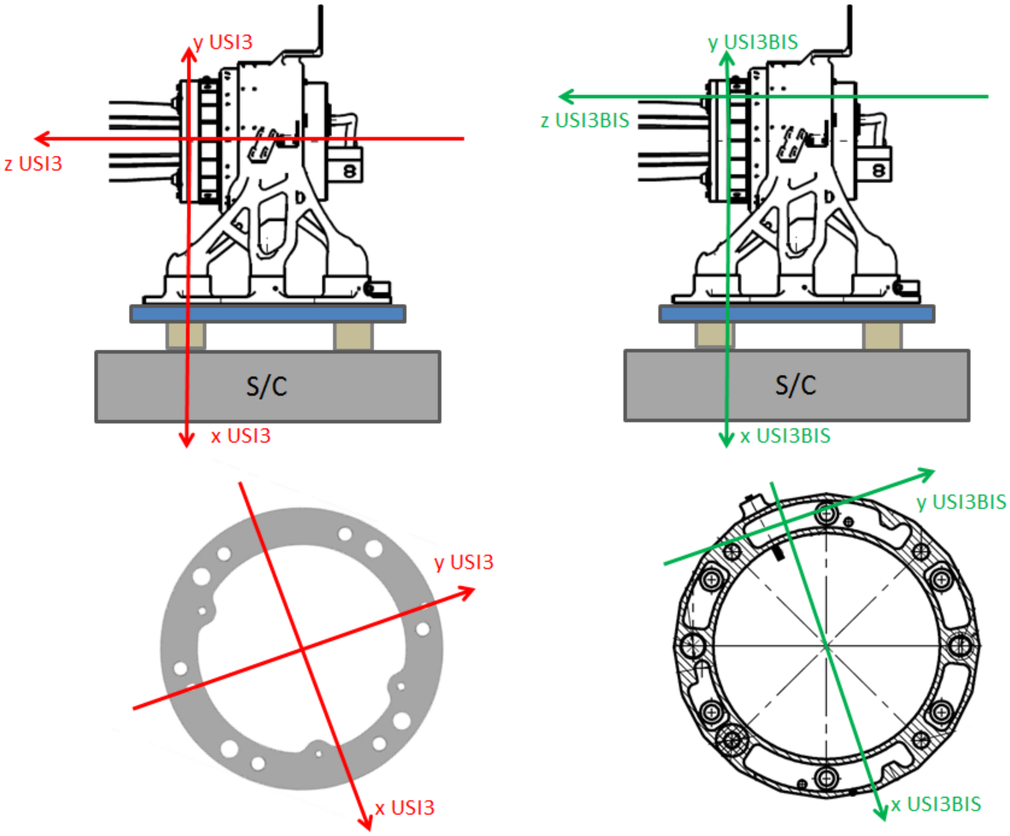

Figure 3.16. USI3BIS reference system geometry

$$_{USI3BIS_{inv}}()^{USI3_{disp}} = \tag{3.44}$$

	x_{USI3}	y_{USI3}	z_{USI3}
$x_{USI3BIS}$	1.0000000	0.0000000	0.0000000
$y_{USI3BIS}$	0.0000000	1.0000000	0.0000000
$z_{USI3BIS}$	0.0000000	0.0000000	1.0000000

Table 3.27. Rotation matrix of USI3BIS respect to USI3 reference system for antenna MS2

$$_{USI3BIS_{disp}}()^{SAT} = _{USI3BIS_{disp}}()^{USI3BIS_{inv}} * _{USI3BIS_{inv}}()^{USI3_{disp}} * _{USI3_{disp}}()^{SAT} = \tag{3.45}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{USI3BIS}$	-0.8757568	0.1057741	0.4710221
$y_{USI3BIS}$	0.4450324	0.5549870	0.7028055
$z_{USI3BIS}$	-0.1870725	0.8251069	-0.5331065

Table 3.28. Rotation matrix of USI3BIS respect to SAT reference system for antenna MS2

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI3BIS REF	1504.991	-932.257	281.716
	x_{USI3}	y_{USI3}	z_{USI3}
ORIGIN USI3BIS REF	-46	0	-12

Table 3.29. USI3BIS origin displacement for antenna MS2

3.1.11 MOTOR 2 reference system

The configuration of motor 2 before its rotation is defined by Motor 2 reference system, here identified with the abbreviation RM2. As RIF1, it is used to verify the correct working of the motor.

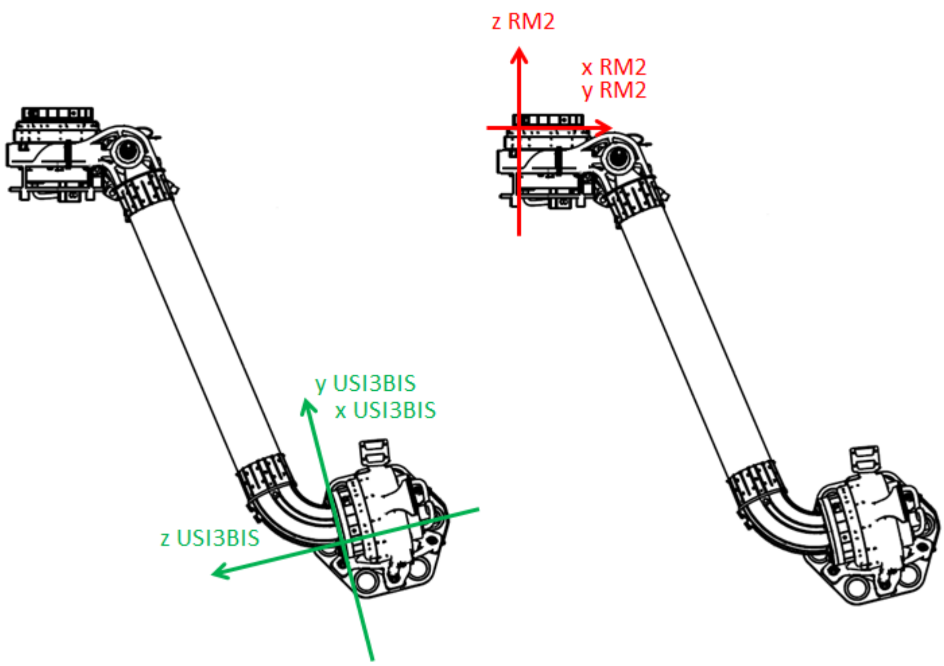

Figure 3.17. MOTOR 2 reference system geometry - view 1

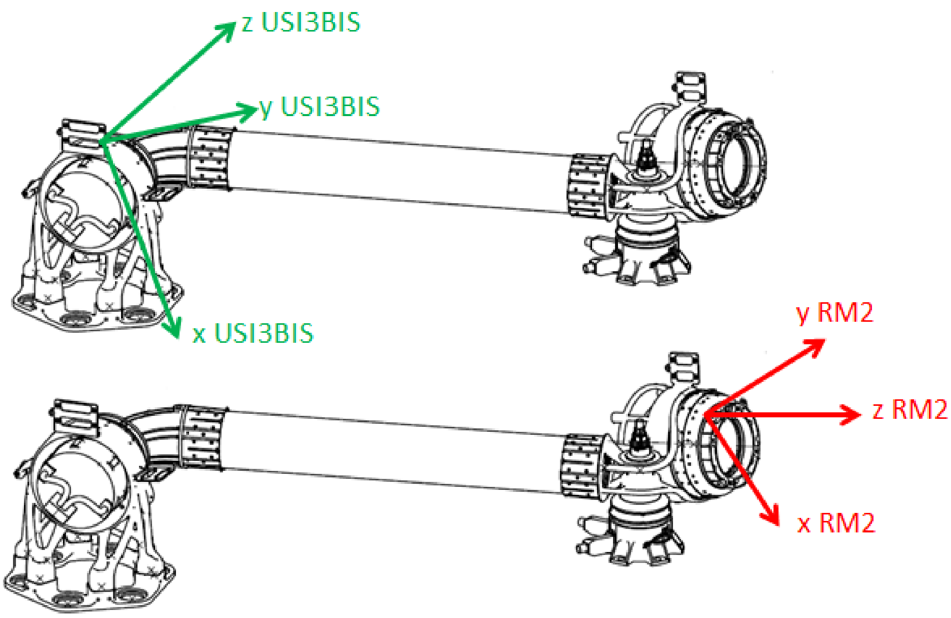

Figure 3.18. MOTOR 2 reference system geometry - view 2

$$_{RM2_{inv}}()^{USI3BIS_{disp}} = R_z(\phi_z) * R_y(\phi_y) * R_x(\phi_x) = \tag{3.46}$$

$$\begin{pmatrix} cos(\phi_z) & sin(\phi_z) & 0 \\ -sin(\phi_z) & cos(\phi_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\phi_y) & 0 & -sin(\phi_y) \\ 0 & 1 & 0 \\ sin(\phi_y) & cos(\phi_y) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\phi_x) & sin(\phi_x) \\ 0 & -sin(\phi_x) & cos(\phi_x) = \end{pmatrix} = \tag{3.47}$$

	$x_{USI3BIS}$	$y_{USI3BIS}$	$z_{USI3BIS}$
x_{RM2}	-0.6631515	-0.4405785	0.6050791
y_{RM2}	-0.2054552	0.8845016	0.4188617
z_{RM2}	-0.7197349	0.1534521	-0.6770777

Table 3.30. Rotation matrix of RM2 respect to USI3BIS reference system for antenna MS2

$$_{RM2_{disp}}()^{SAT} = _{RM2_{disp}}()^{RM2_{inv}} * _{RM2_{inv}}()^{RM2_{disp}} * _{USI3BIS_{disp}}()^{SAT} = \tag{3.48}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{RM2}	0.2714941	0.1845954	-0.9445716
y_{RM2}	0.4952031	0.8147607	0.3015608
z_{RM2}	0.8252665	-0.5496268	0.1297905

Table 3.31. Rotation matrix of RM2 respect to SAT reference system for antenna MS2

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RM2 REF	2048.691	-528.097	-354.375
	$x_{USI3BIS}$	$y_{USI3BIS}$	$z_{USI3BIS}$
ORIGIN RM2 REF	-733.012	19.220	570.868

Table 3.32. RM2 origin displacement for antenna MS2

3.1.12 MOTOR 2 rotation

The following reference system is USI2 reference system, which defines the rotation of motor 2 around its axis. For each antenna the rotation angle is different. However, the step angle is equal for everyone and it is 0.009375 deg. Consequently, for each antenna there is a different number of motor steps to achieve the final deployed configuration. At last for the antennas MS1 and MS4 the rotation is clock wise, while for MS2 and MS3 the direction is counter clock wise.

In order to get USI2 reference system, a rotation of θ angle around motor 2 axis is performed [7]. Moreover, adjustment capability for motor 2 are performed in order to offset the defaults effects on the reflector's deployed configuration.

At last an origin displacement is taken into account, since the origin is not placed along the motor axis.

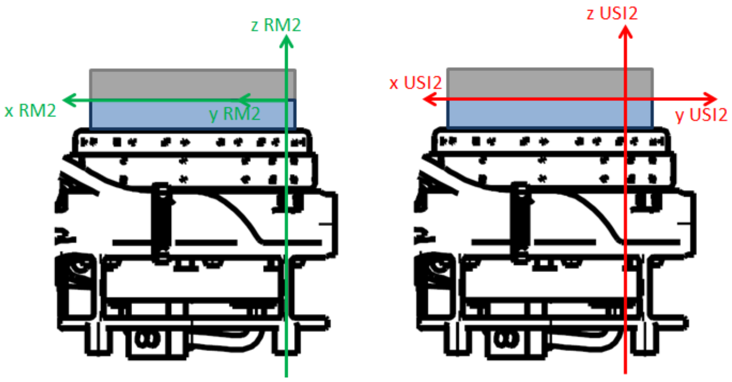

Figure 3.19. MOTOR 2 rotation - view 1

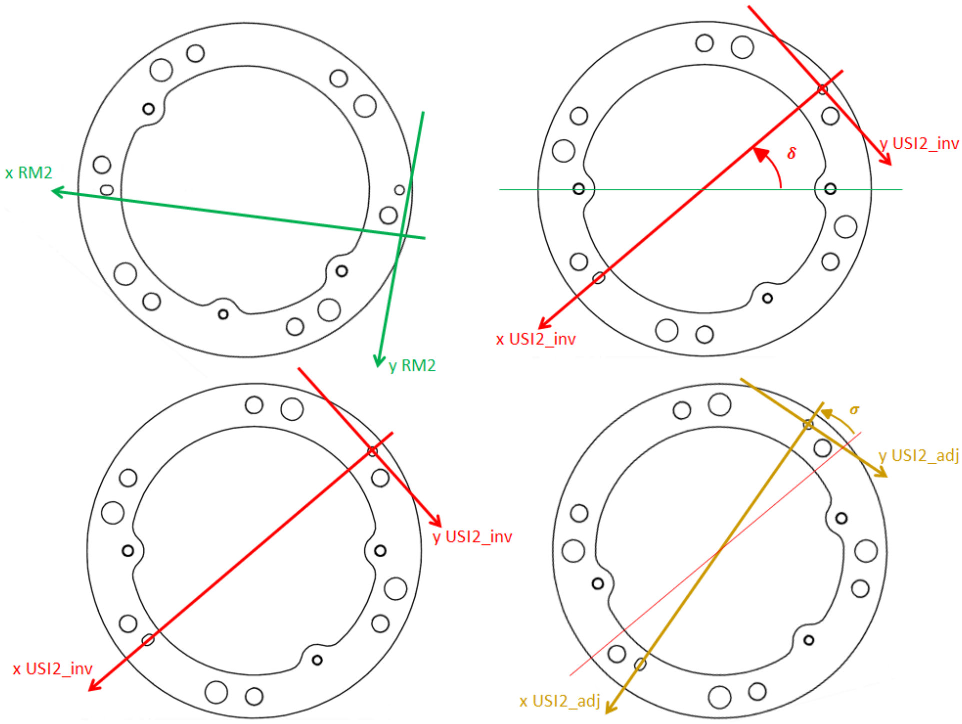

Figure 3.20. MOTOR 2 rotation - view 2

$$_{USI2_{inv}}()^{RM2_{disp}} = R_z(\theta_z) = R_z(51.2663368°) \tag{3.49}$$

$$\begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} = \tag{3.50}$$

	x_{RM2}	y_{RM2}	z_{RM2}
x_{USI2}	0.6257011	0.7800629	0.0000000
y_{USI2}	-0.7800629	0.6257011	0.0000000
z_{USI2}	0.0000000	0.0000000	1.0000000

Table 3.33. Rotation matrix of USI2 respect to RM2 reference system for antenna MS2

ROTATION MATRIX FOR MOTOR 2 CAPABILITY: σ is the adjustment angle

$$_{USI2_{adj}}()^{USI2_{inv}} = R_z(\sigma) = \begin{pmatrix} cos(\sigma_z) & sin(\sigma_z) & 0 \\ -sin(\sigma_z) & cos(\sigma_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3.51}$$

$$_{USI2_{disp}}()^{SAT} =_{USI2_{disp}} ()^{USI2_{adj}} *_{USI2_{adj}} ()^{USI2_{inv}} *_{USI2_{inv}} ()^{RM2_{disp}} *_{RM2_{disp}} ()^{SAT} \quad (3.52)$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{USI2}	0.5561637	0.7510661	-0.3557831
y_{USI2}	0.0980667	0.3658006	0.9255122
z_{USI2}	0.8252665	-0.5496268	0.1297905

Table 3.34. Rotation matrix of USI2 respect to SAT reference system for antenna MS2

ORIGIN DISPLACEMENT

The computation of the displacement is based on trigonometric demonstration. Following the geometric scheme for a generic rotation and the math formulas used for the computation, in which R2 stands for the motor2 reference system origin and equal to 48.5 mm :

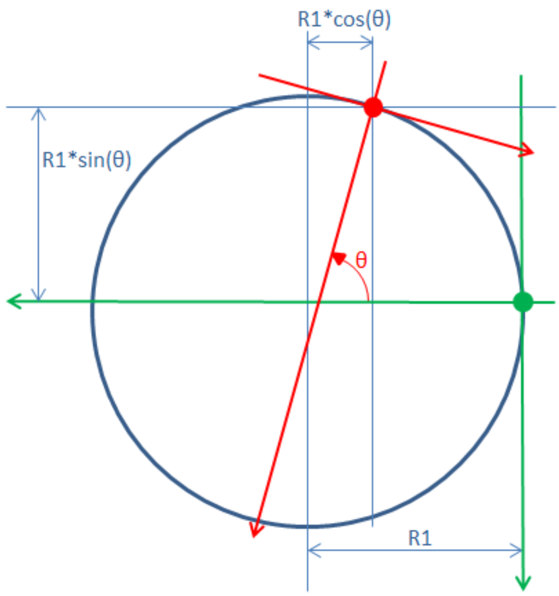

Figure 3.21. MOTOR 2 displacement due to the rotation

$$\begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} = \begin{Bmatrix} R2 - R2 * cos(\theta_z) \\ -R2 * sin(\theta_z) \\ 0 \end{Bmatrix} + \begin{Bmatrix} R2 - R2 * cos(\sigma_z) \\ -R2 * sin(\sigma_z) \\ 0 \end{Bmatrix} \quad (3.53)$$

$$\begin{Bmatrix} x_{USI2} \\ y_{USI2} \\ z_{USI2} \end{Bmatrix} = \begin{Bmatrix} x_{RM2} \\ y_{RM2} \\ z_{RM2} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} *_{RM2_{disp}} ()^{SAT} \tag{3.54}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI2 REF	2034.884	-555.571	-382.931
	x_{RM2}	y_{RM2}	z_{RM2}
ORIGIN USI2 REF	18.153	-37.833	0

Table 3.35. USI2 origin displacement for antenna MS2

3.1.13 USI2bis reference system

This reference system has the goal to define the rotation due to the machining of the shim. Firstly, the reference system is shifted in the centre of the shim. While the rotation, which reproduces the machining, consists of a product of different rotations. The first rotation is performed around the z-axis of an α angle (included between 0° and 360°), which is the direction of the machining. Subsequently, the reference system is rotated of β angle, which is the angle of machining and it assumes a value no higher than 1.1°. At last the reference system is rotated in order to bring x-axis in the initial x-z plane.

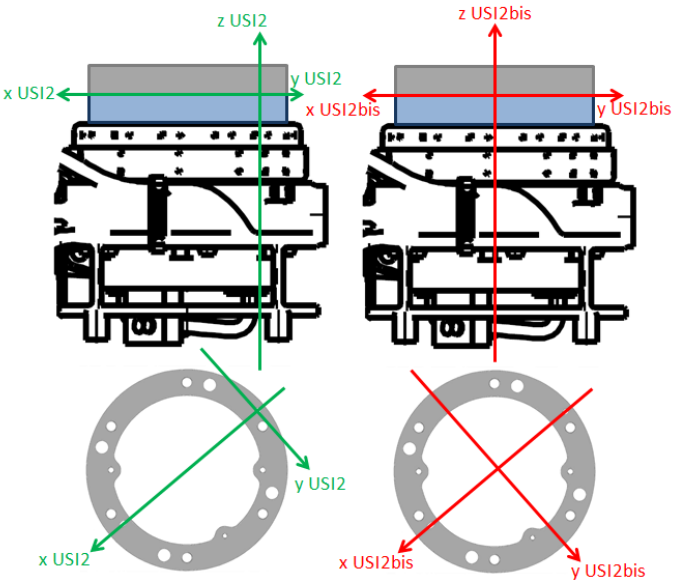

Figure 3.22. USI2bis reference system geometry

$$_{USI2bis_{inv}}()^{USI2_{disp}} = R_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\theta_x) & sin(\theta_x) \\ 0 & -sin(\theta_x) & cos(\theta_x) \end{pmatrix} = \tag{3.55}$$

	x_{USI2}	y_{USI2}	z_{USI2}
$x_{USI2bis}$	1.0000000	0.0000000	0.0000000
$y_{USI2bis}$	0.0000000	1.0000000	0.0000000
$z_{USI2bis}$	0.0000000	0.0000000	1.0000000

Table 3.36. Rotation matrix of USI2bis respect to USI2 reference system for antenna MS2

MODEL FOR THE MACHINING

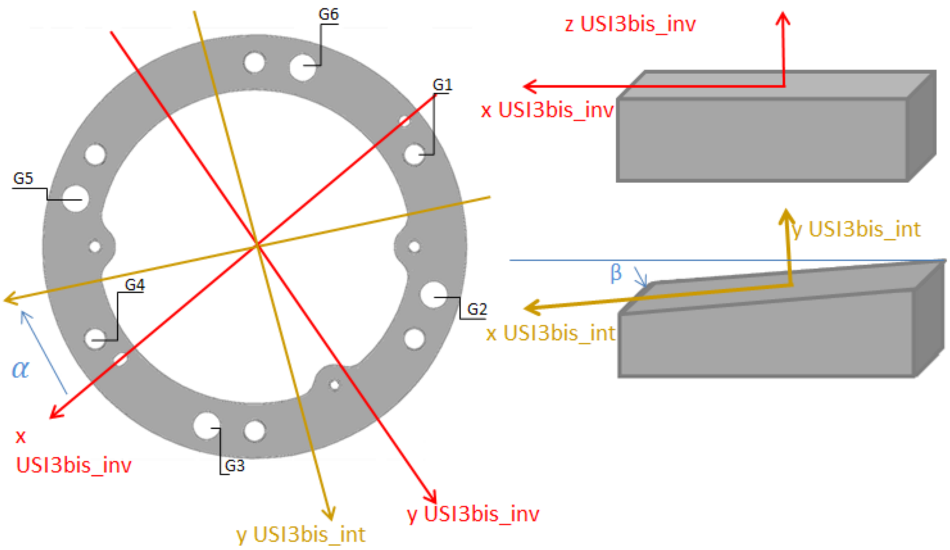

Figure 3.23. Geometry explanation for the machining shim 2

α and β angles must be entered positive by the user. In order to get USI_{int} Reference system a clock wise β rotation is performed.

$$_{USI2bis_{mach}}()^{USI2bis_{inv}} = Rz_{adj}(\gamma) * Ry_{int}(\beta) * Rx_{inv}(\alpha) = \tag{3.56}$$

$$\begin{pmatrix} cos(\gamma) & sin(\gamma) & 0 \\ -sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\beta) & 0 & -sin(\beta) \\ 0 & 1 & 0 \\ sin(\beta) & cos(\beta) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\alpha) & sin(\alpha) \\ 0 & -sin(\alpha) & cos(\alpha) \end{pmatrix} \tag{3.57}$$

	$x_{USI2bisinv}$	$y_{USI2bisinv}$	$z_{USI2bisinv}$
$x_{USI2bismach}$	$cos\beta\ cos\alpha\ cos\gamma - sin\alpha\ sin\gamma$	$cos\beta\ cos\gamma\ sin\alpha + cos\alpha\ sin\gamma$	$-sin\beta\ cos\gamma$
$y_{USI2bismach}$	-$cos\gamma\ sin\alpha - cos\beta\ cos\alpha\ sin\gamma$	$cos\alpha\ cos\gamma - cos\beta\ sin\alpha\ sin\gamma$	$sin\beta\ sin\gamma$
$z_{USI2bismach}$	$sin\beta\ cos\alpha$	$sin\beta\ sin\alpha$	$cos\beta$

Table 3.37. Rotation matrix for machining shim 2

γ angle represents the rotation angle necessary to perform the rotation of x USI2bis adj in order to bring it in the initial x USI2bis – z USI2bis plane. This condition leads to compute the γ angle by imposing null the component of x USI2bis MACH along y USI2bis INV.

$$cos\beta\ \ cos\gamma\ \ sin\alpha + cos\alpha\ \ sin\gamma = 0 \tag{3.58}$$

$$\gamma = -tan^{-1}\Big(\frac{cos\beta * sin\alpha}{cos\alpha}\Big) \tag{3.59}$$

$$\begin{aligned} {}_{USI2bis_{disp}}()^{SAT} =& {}_{USI2bis_{disp}}()^{USI2bis_{mach}} * \\ & {}_{USI2bis_{mach}}()^{USI2bis_{inv}} * {}_{USI2bis_{inv}}()^{USI2_{disp}} * {}_{USI2_{disp}}()^{SAT} = \end{aligned} \tag{3.60}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{USI2bis}$	0.5561637	0.7510661	-0.3557831
$y_{USI2bis}$	0.0980667	0.3658006	0.9255122
$z_{USI2bis}$	0.8252665	-0.5496268	0.1297905

Table 3.38. Rotation matrix of USI2bis respect to SAT reference system for antenna MS2

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

The machining leads not only to a reference system rotation, but also to a displacement of the reference origin. Considering the width of the layer equal to 105 mm and the thickness equal to 4 mm, the displacement along z USI is equal to:

$$\Delta x\quad MACHINING = thickness * sin(\beta) * cos(\alpha) \tag{3.61}$$

$$\Delta y\quad MACHINING = thickness * sin(\beta) * sin(\alpha) \tag{3.62}$$

$$\Delta z\quad MACHINING = \frac{widthcale}{2} * sin\beta \tag{3.63}$$

$$\begin{Bmatrix} x_{USI2bis} \\ y_{USI2bis} \\ z_{USI2bis} \end{Bmatrix} = \begin{Bmatrix} x_{USI2} \\ y_{USI2} \\ z_{USI2} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta x \quad MACHINING \\ \Delta y \quad MACHINING \\ \Delta z \quad MACHINING \end{Bmatrix} *_{USI2_{disp}} ()^{SAT} \tag{3.64}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI2bis REF	2061.8581	-519.1439	-400.1863
	x_{USI2}	y_{USI2}	z_{USI2}
ORIGIN USI2bis REF	48.5	0	0

Table 3.39. USI2bis origin displacement for antenna MS2

3.1.14 CALEP2 reference system

The origin of the reference system is displaced in the x-y axis of CALEP reference.

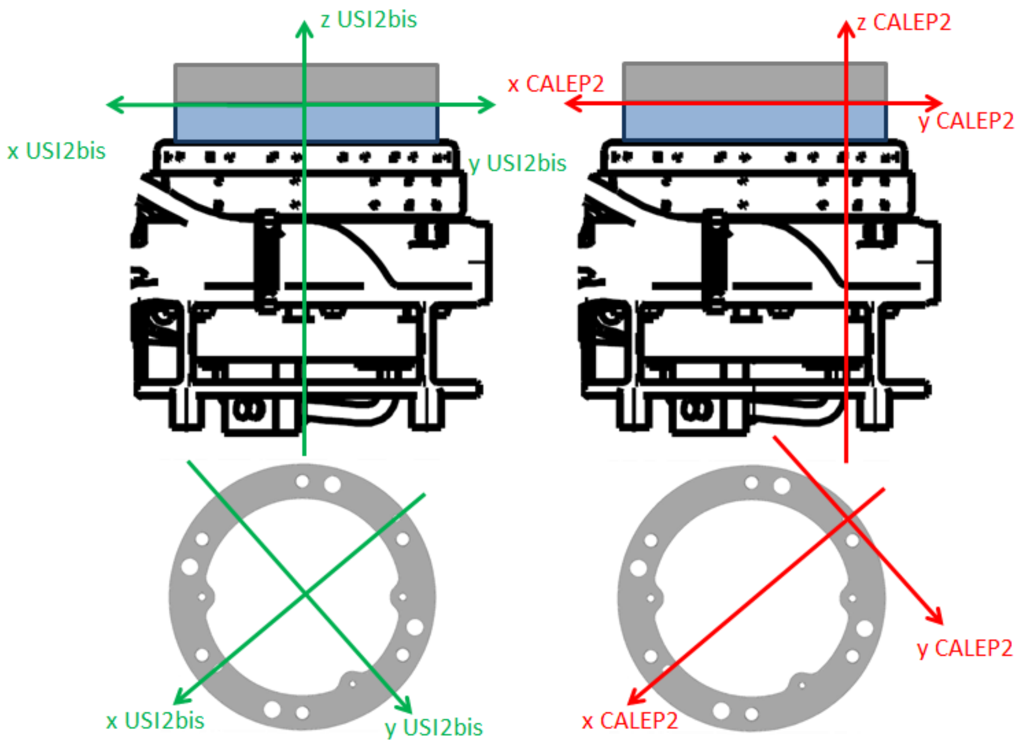

Figure 3.24. CALEP2 reference geometry

$$_{CALEP2_{inv}}()^{USI2bis_{disp}} = \tag{3.65}$$

	$x_{USI2bis}$	$y_{USI2bis}$	$z_{USI2bis}$
x_{CALEP2}	1.0000000	0.0000000	0.0000000
y_{CALEP2}	0.0000000	1.0000000	0.0000000
z_{CALEP2}	0.0000000	0.0000000	1.0000000

Table 3.40. Rotation matrix of CALEP2 respect to USI2bis reference system

$$_{CALEP2_{disp}}()^{SAT} = _{CALEP2_{disp}}()^{CALEP2_{inv}} * _{CALEP2_{inv}}()^{USI2bis_{disp}} * _{USI2bis_{disp}}()^{SAT} \tag{3.66}$$

	SAT	SAT	SAT
x_{CALEP2}	0.5561637	0.7510661	-0.3557831
y_{CALEP2}	0.0980667	0.3658006	0.9255122
z_{CALEP2}	0.8252665	-0.5496268	0.1297905

Table 3.41. Rotation matrix of CALEP2 respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN CALEP2 REF	2034.8844	-555.5706	-382.9308
	$x_{USI2bis}$	$y_{USI2bis}$	$z_{USI2bis}$
ORIGIN CALEP2 REF	-48.5	0	0

Table 3.42. CALEP2 origin displacement for antenna MS2

3.1.15 Reference system 2

At the end of the chain of rotation matrices for the ADPM2+, there is the reference system 2, here called shortly RIF2. It has the function to refer the ADPM to the vertex reference system of the antenna considering all the rotations and adjustment capabilities before.

$$_{RIF2_{inv}}()^{CALEP2_{disp}} = R_z(\theta_z) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} = \tag{3.67}$$

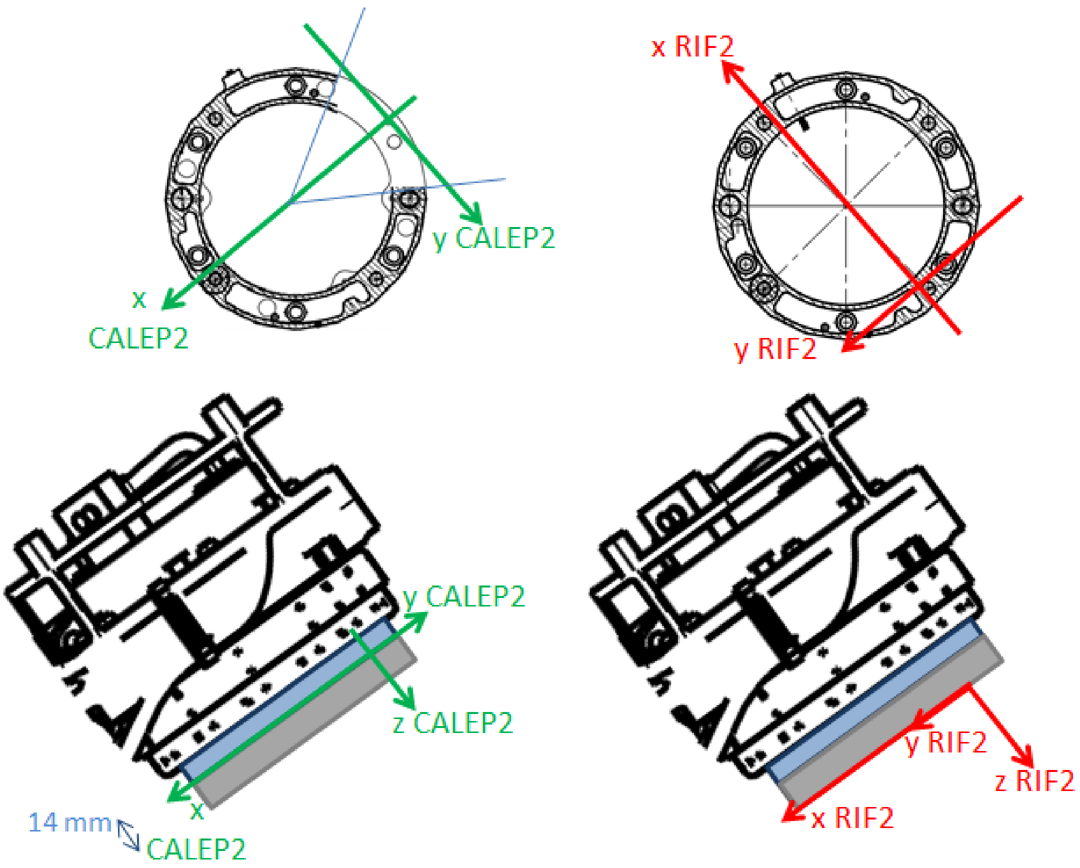

Figure 3.25. RIF2 reference system geometry

	x_{CALEP2}	y_{CALEP2}	z_{CALEP2}
x_{RIF2}	0.1736482	-0.9848078	0.0000000
y_{RIF2}	0.9848078	0.1736482	0.0000000
z_{RIF2}	0.0000000	0.0000000	1.0000000

Table 3.43. Rotation matrix of RIF2 respect to CALEP2 reference system

$$ {}_{RIF2_{disp}}()^{SAT} = {}_{RIF2_{disp}}()^{RIF2_{inv}} * {}_{RIF2_{inv}}()^{CALEP2_{disp}} * {}_{CALEP2_{disp}}()^{SAT} \qquad (3.68)$$

IRD data	SAT	SAT	SAT
x_{RIF2}	0.0000000	-0.2298220	-0.9732327
y_{RIF2}	0.5647434	0.8031764	-0.1896644
z_{RIF2}	0.8252665	-0.5496268	0.1297905

Table 3.44. Rotation matrix of RIF2 respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RIF2 REF	2073.4124	-516.2666	-353.6008
	x_{CALEP2}	y_{CALEP2}	z_{CALEP2}
ORIGIN RIF2 REF	40.5127	45.301	14

Table 3.45. RIF2 origin displacement for antenna MS2

3.1.16 Deployed antenna vertex reference system

In order to verify the correct antenna orientation and location, RVD reference system is introduced. It is compared to the ideal RVD reference system, so that the difference, in rotation and in displacement, is computable. If that difference is higher than the maximum acceptable value, corrective actions must be performed through upstream adjustment capabilities.

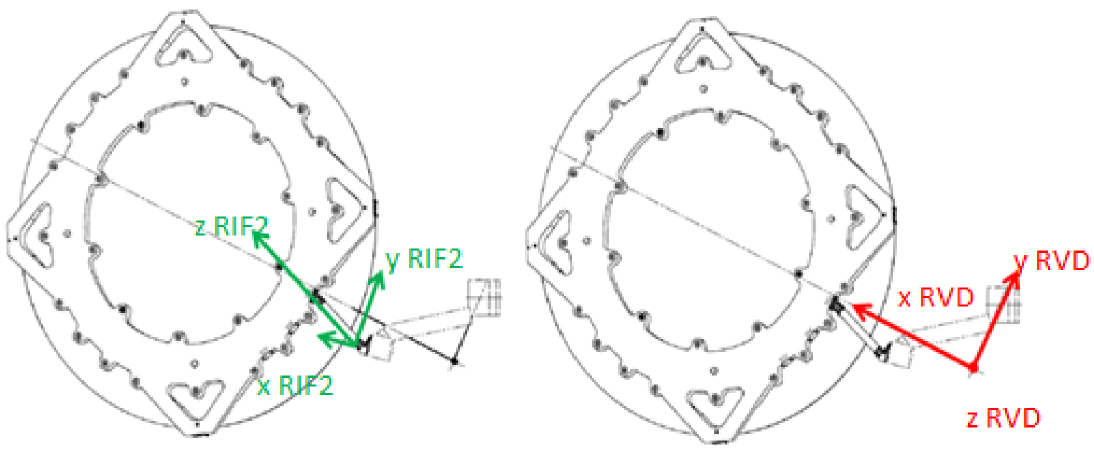

Figure 3.26. RVD reference system geometry

$$ {}_{RVD_{inv}}()^{RIF2_{disp}} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) = \tag{3.69}$$

	x_{RIF2}	y_{RIF2}	z_{RIF2}
x_{RVD}	0.1033403	0.2261328	0.9685994
y_{RVD}	-0.2318350	0.9524674	-0.1976320
z_{RVD}	-0.9672504	-0.2041319	0.1508538

Table 3.46. Rotation matrix of RVD respect to RIF2 reference system

$$ {}_{RVD_{disp}}()^{SAT} = {}_{RVD_{disp}}()^{RVD_{inv}} * {}_{RVD_{inv}}()^{RIF2_{disp}} * {}_{RIF2_{disp}}()^{SAT} \tag{3.70}$$

IRD data	SAT	SAT	SAT
x_{RVD}	0.9270597	-0.3744935	-0.0177485
y_{RVD}	0.3748006	0.9269039	0.0193295
z_{RVD}	0.0092124	-0.0245718	0.9996556

Table 3.47. Rotation matrix of RVD respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RVD REF	1483.1507	-361.7128	-343.6226
	x_{RIF2}	y_{RIF2}	z_{RIF2}
ORIGIN RVD REF	-45.231	-211.105	-570.775

Table 3.48. RVD origin displacement for antenna MS2

3.1.17 FEED reference system

The computation of the ideal RVD reference system is achievable by RCFA reference system, which stands for the feed reference system.

$$ {}_{RCFA_{inv}}()^{SAT} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) \tag{3.71}$$

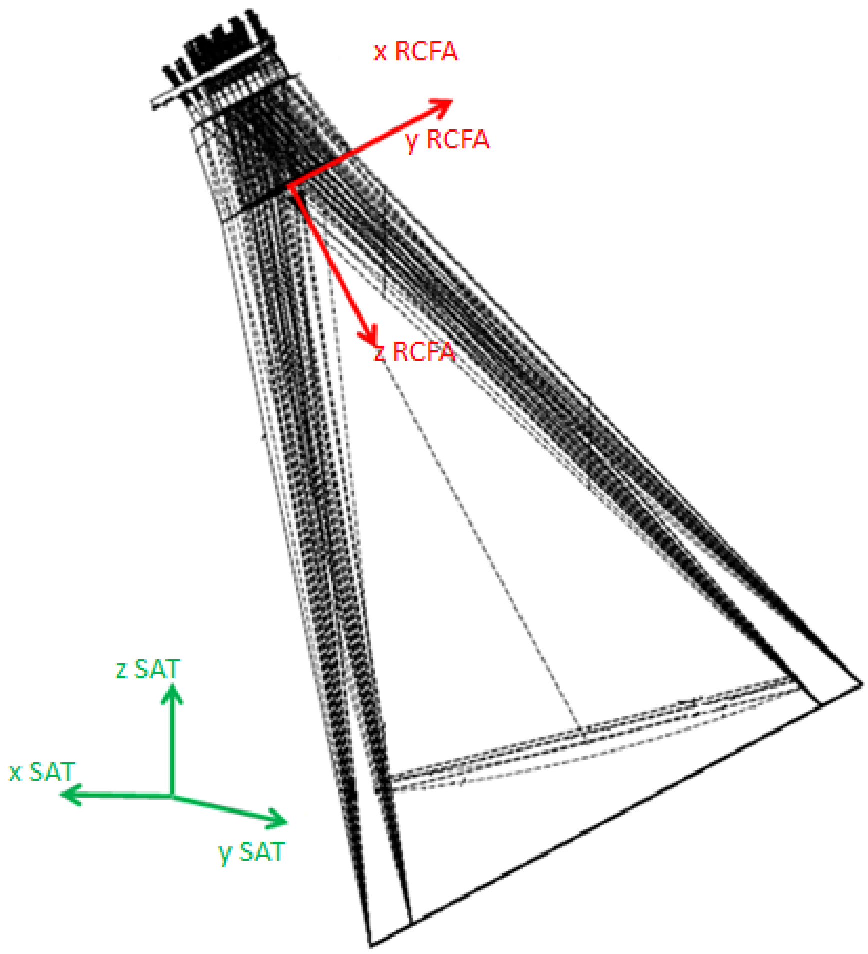

Figure 3.27. FEED reference system geometry

$$_{RCFA_{disp}}()^{SAT} =_{RCFA_{disp}} ()^{RCFA_{inv}} *_{RCFA_{inv}} ()^{SAT} = \tag{3.72}$$

IRD data	SAT	SAT	SAT
x_{RCFA}	-0.9028530	-0.0301287	-0.4288924
y_{RCFA}	0.0394592	0.9875253	-0.1524362
z_{RCFA}	0.4281348	-0.1545513	-0.8904013

Table 3.49. Rotation matrix of RCFA respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RCFA REF	1520	-460	3655

Table 3.50. RCFA origin displacement for antenna MS2

3.1.18 Deployed antenna vertex reference system (from RCFA)

The RVD reference system computed by rotating the RCFA reference system should match the RVD calculated by the ADPM2+ chain. In case of defaults, there would be a difference between the final matrices or the final displacements. If these defaults result to be unacceptable since they exceed the tolerance, then it would be necessary performing adjustments in order to achieve the correct configuration.

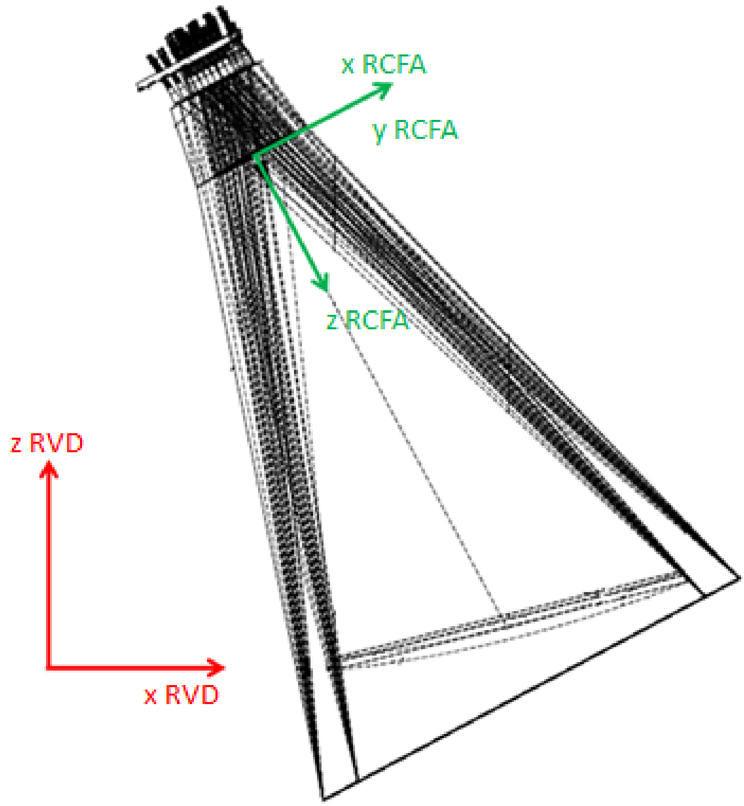

Figure 3.28. RVD reference system geometry from RCFA ref. system

$$_{RVD_{inv}}()^{RCFA_{disp}} = \tag{3.73}$$

	x_{RCFA}	y_{RCFA}	z_{RCFA}
x_{RVD}	-0.8181034	-0.3305352	0.4705882
y_{RVD}	-0.3746066	0.9271839	0.0000000
z_{RVD}	-0.4363218	-0.1762855	-0.8823529

Table 3.51. Rotation matrix of RVD respect to RCFA reference system

$$_{RVD_{disp}}()^{SAT} = _{RVD_{disp}}()^{RVD_{inv}} * _{RVD_{inv}}()^{RCFA_{disp}} * _{RCFA_{disp}}()^{SAT} \tag{3.74}$$

IRD data	SAT	SAT	SAT
x_{RVD}	0.9270597	-0.3744935	-0.0177485
y_{RVD}	0.3748006	0.9269039	0.0193295
z_{RVD}	0.0092124	-0.0245718	0.9996556

Table 3.52. Rotation matrix of RVD respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RVD REF	1483.15	-361.713	-343.622
	x_{RCFA}	y_{RCFA}	z_{RCFA}
ORIGIN RVD REF	1745.2873	705.1417	3529.4112

Table 3.53. RVD origin displacement for antenna MS2

3.2 Math Model for ADPM2+ in stowed configuration

Orthonormal matrices are used in this program in order to build the mathematical model. Example data are given for Antenna MS2 SE of Satellite B4A.

GLOSSARY USED FOR THE MATH MODEL:

R_z= rotation around z axis
R_y= rotation around y axis
R_x= rotation around x axis
'inv' = matrix without adjustments or defaults
'adj' = matrix with adjustments
'int' = intermediate matrix for machining computation
'mach' = final matrix for machining adjustment
'disp' = matrix with adjustments and defaults

SCHEME COLOR LEGEND:
Reference systems in RED are the final one, achieved by rotating the previous reference system in GREEN. While the reference systems in BROWN stand for the reference systems got by the adjustment capabilities.

3.2.1 Satellite axis

The reference axis system for the satellite is defined as follows:

- **Origin O** is situated in the centre of the launch ring at the base of the satellite;
- **Z axis** is pointing the Earth from O and it is perpendicular to the separation plane;
- **Y axis** is included in the separation plane and it is pointing, from O, a slot labeled +Y (in South direction)
- **X axis** forms a direct orthogonal axis system and it points towards East.

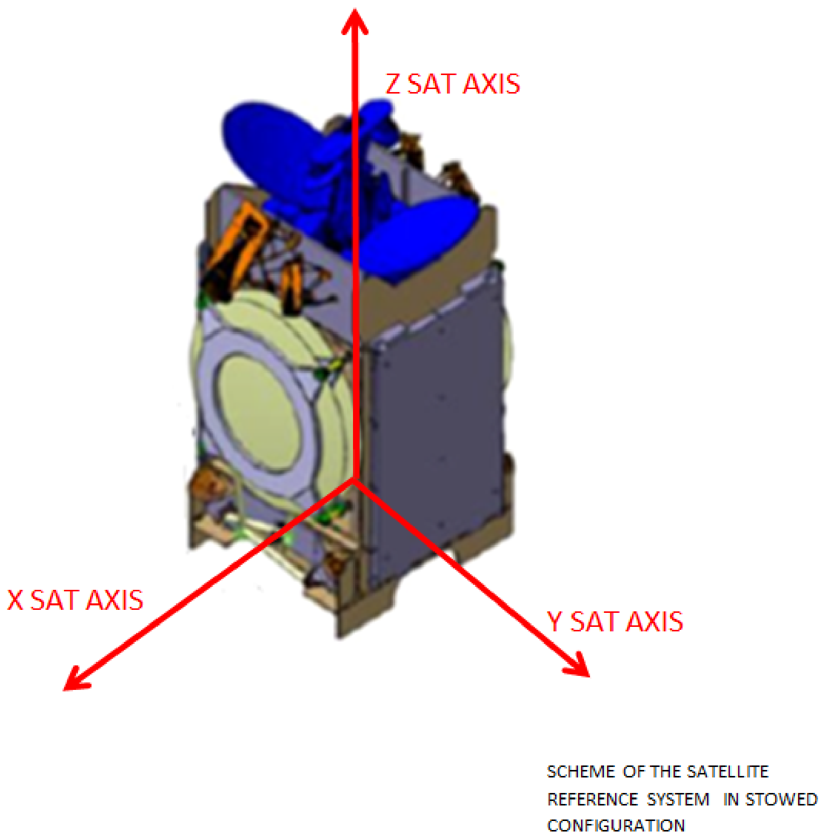

Figure 3.29. Satelite axis in stowed configuration

Since the rotation matrix chain until motor 1 reference system is the same for deployed and stowed configuration, it is not repeated for the math model in stowed configuration.

However, even if it is not repeated, it is necessary for the computation of the stowed configuration. For any reference to this part, it is visible in the paragraph which deals with the deployed configuration.

3.2.2 MOTOR 1 reference system

In order to define the initial position of the motor 1 before the rotation a reference system, called RIF. 1, is used. It is useful to compare the reference system in rotated position in order to verify the motor operation.

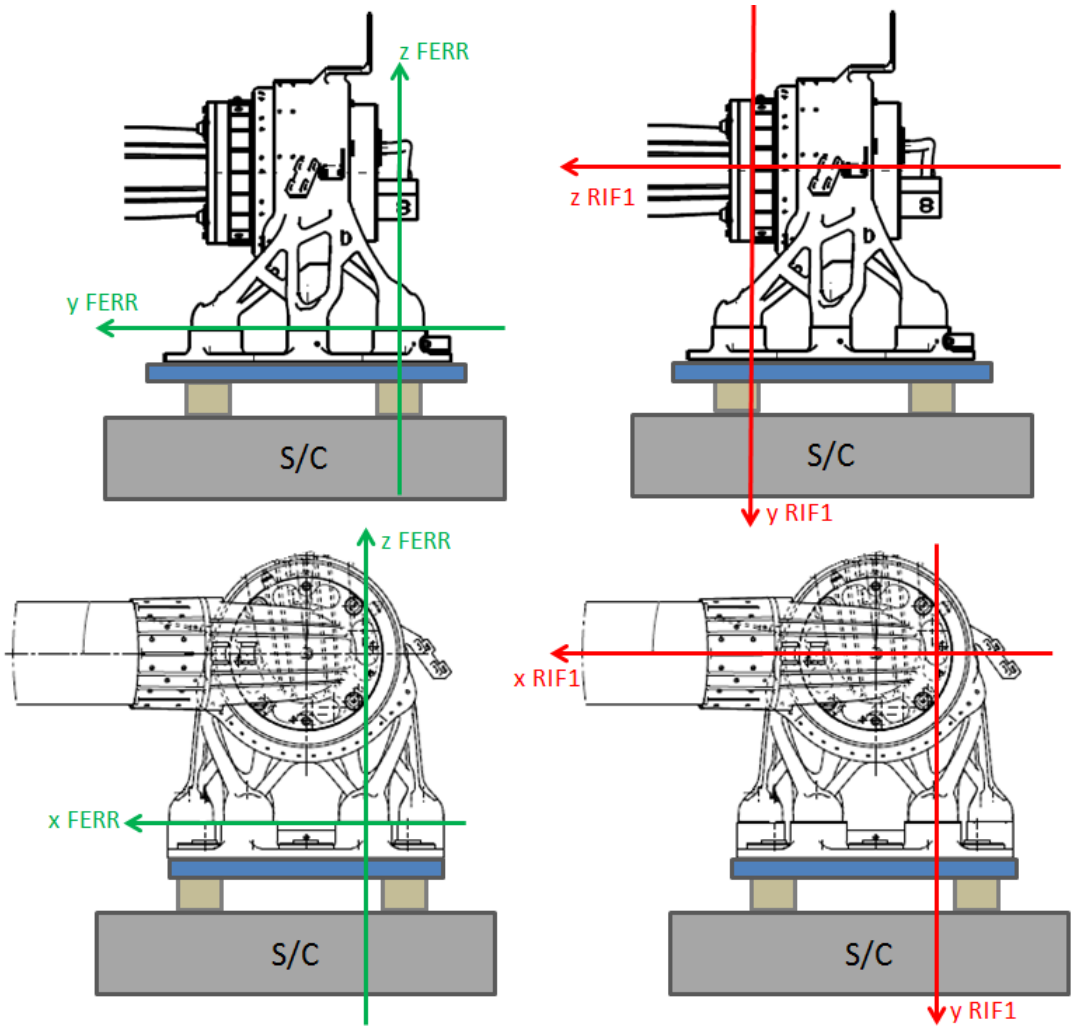

Figure 3.30. RIF1 reference system geometry for stowed position

$$_{RIF1_{inv}}()^{FERR_{disp}} = R_z(\phi_z) * R_y(\phi_y) * R_x(\phi_x) = \tag{3.75}$$

$$\begin{pmatrix} cos(\phi_z) & sin(\phi_z) & 0 \\ -sin(\phi_z) & cos(\phi_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\phi_y) & 0 & -sin(\phi_y) \\ 0 & 1 & 0 \\ sin(\phi_y) & cos(\phi_y) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\phi_x) & sin(\phi_x) \\ 0 & -sin(\phi_x) & cos(\phi_x) = \end{pmatrix} \tag{3.76}$$

	$x_{FERRURE}$	$y_{FERRURE}$	$z_{FERRURE}$
x_{RIF1}	0.9876469	-0.0293135	-0.1539296
y_{RIF1}	-0.1566959	-0.1847616	-0.9702111
z_{RIF1}	0.0000000	0.9823461	-0.1870725

Table 3.54. Rotation matrix of RIF1 respect to FERRURE reference system for antenna MS2

$$_{RIF1_{disp}}()^{SAT} =_{RIF1_{disp}} ()^{RIF1_{inv}} *_{RIF1_{inv}} ()^{FERR_{disp}} *_{FERR_{disp}} ()^{SAT} \tag{3.77}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{RIF1}	-0.1539296	-0.5606046	-0.8136511
y_{RIF1}	-0.9702111	-0.0701509	0.2318821
z_{RIF1}	-0.1870725	0.8251069	-0.5331065

Table 3.55. Rotation matrix of RIF1 respect to SAT reference system for antenna MS2 in stowed configuration

ORIGIN DISPLACEMENT FOR ANTENNA MS2 IN SAT. REFERENCE

$$\begin{Bmatrix} x_{RIF1} \\ y_{RIF1} \\ z_{RIF1} \end{Bmatrix} = \begin{Bmatrix} x_{FERR} \\ y_{FERR} \\ z_{FERR} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} \tag{3.78}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RIF1 REF	1471.787	-901.604	340.811
	x_{FERR}	y_{FERR}	z_{FERR}
ORIGIN RIF1 REF	-5.43165	127.3113	196.787

Table 3.56. RIF1 origin displacement for antenna MS2 in stowed configuration

3.2.3 MOTOR1 rotation

The following reference system is ROT1 reference system, which defines the rotation of motor 1 around its axis. For stowed configuration the motor has the function to perform rotation in order to offset the defaults effects on the reflector's stowed configuration.
At last an origin displacement is taken into account, since the origin is not placed along the motor axis.

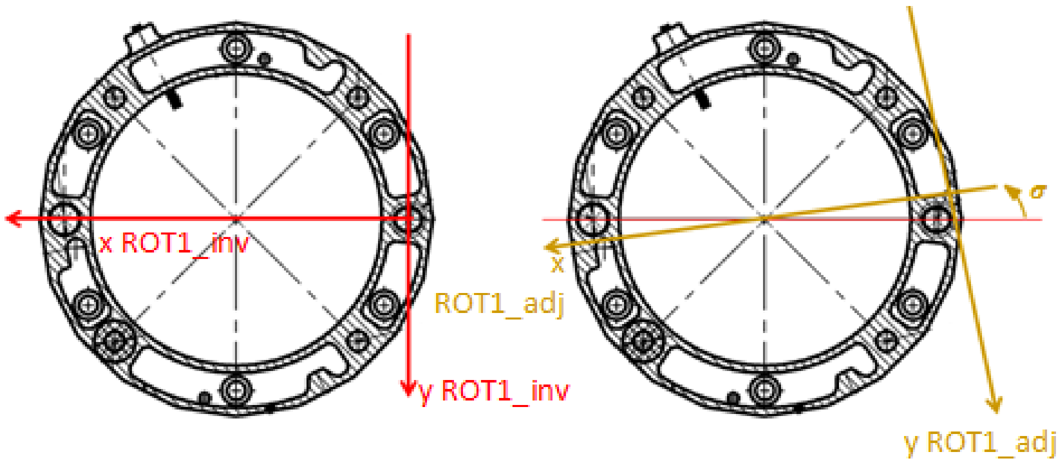

Figure 3.31. MOTOR 2 rotation geometry

$$
{}_{ROT1_{inv}}()^{RIF1_{disp}} = R_z(\theta_z) = R_z(0°) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} = \tag{3.79}
$$

	x_{RIF1}	y_{RIF1}	z_{RIF1}
x_{ROT1}	1.0000000	0.0000000	0.0000000
y_{ROT1}	0.0000000	1.0000000	0.0000000
z_{ROT1}	0.0000000	0.0000000	1.0000000

Table 3.57. Rotation matrix of ROT1 respect to RIF1 reference system for antenna MS2 in stowed configuration

ROTATION MATRIX FOR MOTOR 1 CAPABILITY: σ is the adjustment angle

$$_{ROT1_{adj}}()^{ROT1_{inv}} = R_z(\sigma) = \begin{pmatrix} cos(\sigma_z) & sin(\sigma_z) & 0 \\ -sin(\sigma_z) & cos(\sigma_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3.80}$$

$$_{ROT1_{disp}}()^{SAT} = _{ROT1_{disp}}()^{ROT1_{adj}} * _{ROT1_{adj}}()^{ROT1_{inv}} * _{ROT1_{inv}}()^{RIF1_{disp}} * _{RIF1_{disp}}()^{SAT} \tag{3.81}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{ROT1}	-0.1539296	-0.5606046	-0.8136511
y_{ROT1}	-0.9702111	-0.0701509	0.2318821
z_{ROT1}	-0.1870725	0.8251069	-0.5331065

Table 3.58. Rotation matrix of ROT1 respect to SAT reference system for antenna MS2 in stowed configuration

ORIGIN DISPLACEMENT

The computation of the displacement is based on trigonometric demonstration. Following the geometric scheme for a generic rotation and the math formulas used for the computation, in which R1 stands for the motor 1 reference system origin and equal to 46 mm:

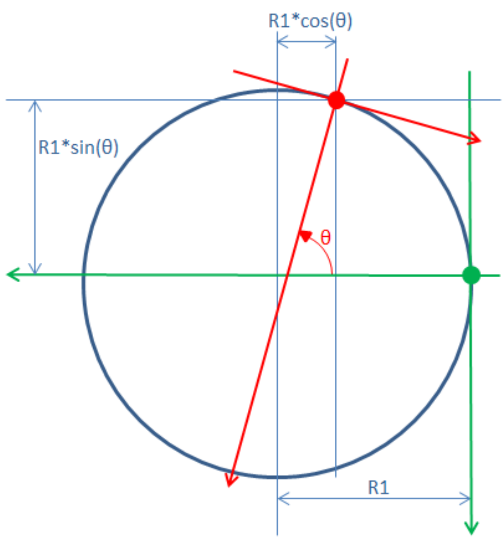

Figure 3.32. MOTOR 1 displacement due to the rotation

$$\begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} = \begin{Bmatrix} R1 - R1 * cos(\theta_z) \\ -R1 * sin(\theta_z) \\ 0 \end{Bmatrix} + \begin{Bmatrix} R1 - R1 * cos(\sigma_z) \\ -R1 * sin(\sigma_z) \\ 0 \end{Bmatrix} \tag{3.82}$$

$$\begin{Bmatrix} x_{ROT1} \\ y_{ROT1} \\ z_{ROT1} \end{Bmatrix} = \begin{Bmatrix} x_{RIF1} \\ y_{RIF1} \\ z_{RIF1} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} *_{RIF1_{disp}} ()^{SAT} \tag{3.83}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN ROT1 REF	1471.787	-901.604	340.811
	x_{RIF1}	y_{RIF1}	z_{RIF1}
ORIGIN ROT1 REF	0	0	0

Table 3.59. ROT1 origin displacement for antenna MS2 in stowed configuration

3.2.4 USI3 reference system

This reference system has the goal to define the rotation due to the machining of the shim. Firstly, the reference system is shifted in the centre of the shim. While the rotation, which reproduces the machining, consists of a product of different rotations. The first rotation is performed around the z-axis of an α angle (included between 0° and 360°), which is the direction of the machining. Subsequently, the reference system is rotated of β angle, which is the angle of machining and it assumes a value no higher than 1.1°. At last the reference system is rotated in order to bring x-axis in the initial x-z plane.

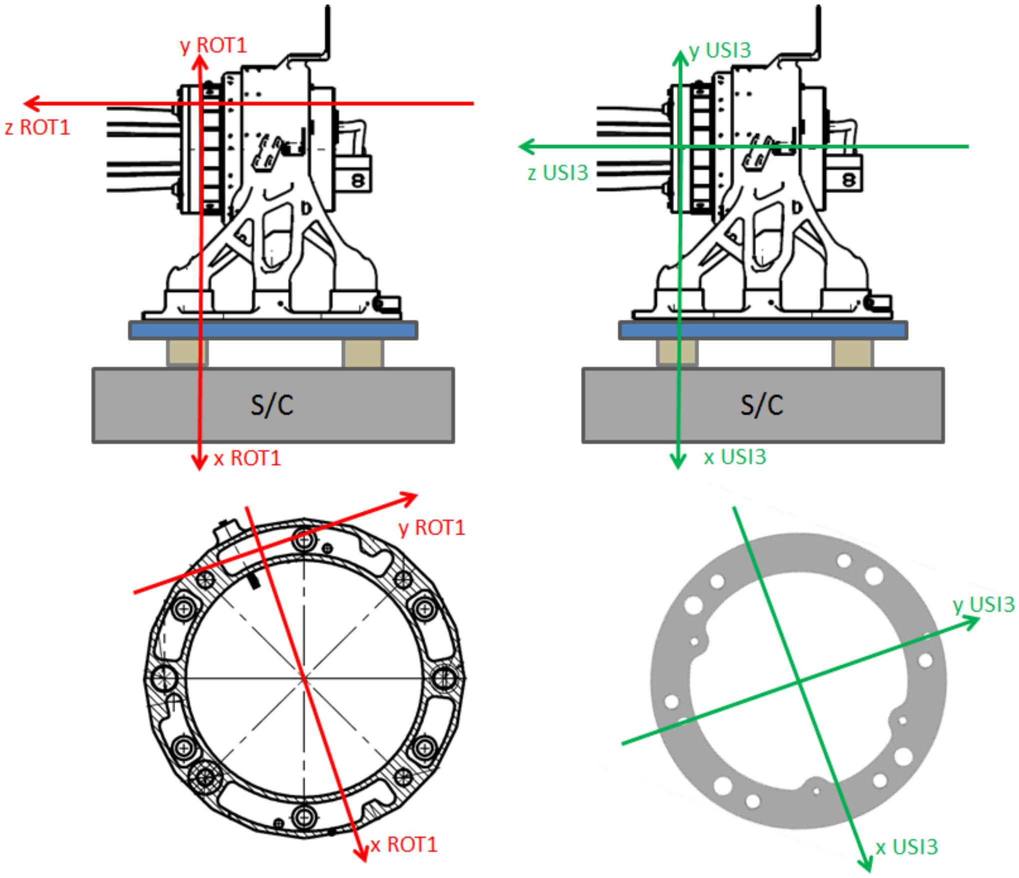

Figure 3.33. USI3 reference system geometry

$$
{}_{USI3_{inv}}()^{ROT1_{disp}} = R_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\theta_x) & sin(\theta_x) \\ 0 & -sin(\theta_x) & cos(\theta_x) \end{pmatrix} = \tag{3.84}
$$

	x_{ROT1}	y_{ROT1}	z_{ROT1}
x_{USI3}	1.0000000	0.0000000	0.0000000
y_{USI3}	0.0000000	1.0000000	0.0000000
z_{USI3}	0.0000000	0.0000000	1.0000000

Table 3.60. Rotation matrix of USI3 respect to ROT1 reference system for antenna MS2

MODEL FOR THE MACHINING

α and β angles must be entered positive by the user. In order to get USI$_{int}$ Reference system a clock wise β rotation is performed.

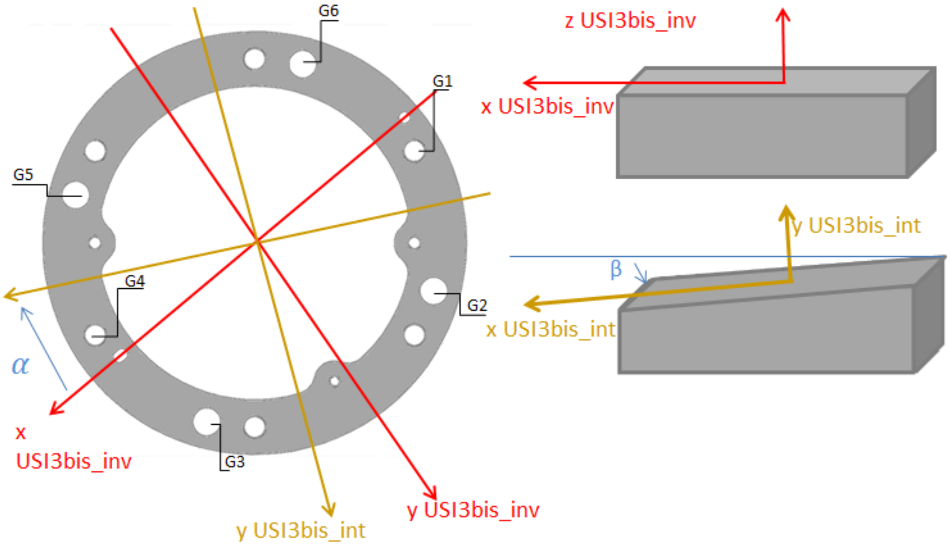

Figure 3.34. Geometry explanation for the machining shim 3

$$ {}_{USI3_{mach}}()^{USI3_{inv}} = Rz_{adj}(\gamma) * Ry_{int}(\beta) * Rx_{inv}(\alpha) = \tag{3.85} $$

$$ \begin{pmatrix} cos(\gamma) & sin(\gamma) & 0 \\ -sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\beta) & 0 & -sin(\beta) \\ 0 & 1 & 0 \\ sin(\beta) & cos(\beta) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\alpha) & sin(\alpha) \\ 0 & -sin(\alpha) & cos(\alpha) \end{pmatrix} \tag{3.86} $$

	$x_{USI3inv}$	$y_{USI3inv}$	$z_{USI3inv}$
$x_{USI3mach}$	$cos\beta\ cos\alpha\ cos\gamma - sin\alpha\ sin\gamma$	$cos\beta\ cos\gamma\ sin\alpha + cos\alpha\ sin\gamma$	$-sin\beta\ cos\gamma$
$y_{USI3mach}$	-$cos\gamma\ sin\alpha - cos\beta\ cos\alpha\ sin\gamma$	$cos\alpha\ cos\gamma - cos\beta\ sin\alpha\ sin\gamma$	$sin\beta\ sin\gamma$
$z_{USI3mach}$	$sin\beta\ cos\alpha$	$sin\beta\ sin\alpha$	$cos\beta$

Table 3.61. Rotation matrix for machining shim 3

γ angle represents the rotation angle necessary to perform the rotation of x USI3 adj in order to bring it in the initial x USI3 – z USI3 plane. This condition leads to compute the γ angle by imposing null the component of x USI3 MACH along y USI3 INV.

$$ cos\beta\ \ cos\gamma\ \ sin\alpha + cos\alpha\ \ sin\gamma = 0 \tag{3.87} $$

$$ \gamma = -tan^{-1}\Big(\frac{cos\beta * sin\alpha}{cos\alpha}\Big) \tag{3.88} $$

$$_{USI3_{disp}}()^{SAT} =_{USI3_{disp}} ()^{USI3_{mach}} *_{USI3_{mach}} ()^{USI3_{inv}} *_{USI3_{inv}} ()^{ROT1_{disp}} *_{ROT1_{disp}} ()^{SAT} = \tag{3.89}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{USI3}	-0.1539296	-0.5606046	-0.8136511
y_{USI3}	-0.9702111	-0.0701509	0.2318821
z_{USI3}	-0.1870725	0.8251069	-0.5331065

Table 3.62. Rotation matrix of USI3 respect to SAT reference system for antenna MS2 in stowed configuration

ORIGIN DISPLACEMENT FOR ANTENNA MS2

The machining leads not only to a reference system rotation, but also to a displacement of the reference origin. Considering the width of the layer equal to 104 mm and the thickness equal to 12 mm, the displacement along z USI is equal to:

$$\Delta x \quad MACHINING = thickness * sin(\beta) * cos(\alpha) \tag{3.90}$$

$$\Delta y \quad MACHINING = thickness * sin(\beta) * sin(\alpha) \tag{3.91}$$

$$\Delta z \quad MACHINING = \frac{widthcale}{2} * sin\beta \tag{3.92}$$

$$\begin{Bmatrix} x_{USI3} \\ y_{USI3} \\ z_{USI3} \end{Bmatrix} = \begin{Bmatrix} x_{ROT1} \\ y_{ROT1} \\ z_{ROT1} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta x \quad MACHINING \\ \Delta y \quad MACHINING \\ \Delta z \quad MACHINING \end{Bmatrix} *_{ROT1_{disp}} ()^{SAT} \tag{3.93}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI3 REF	1453.063643	-928.2338464	306.1653094
	x_{ROT1}	y_{ROT1}	z_{ROT1}
ORIGIN USI3 REF	46	0	12

Table 3.63. USI3 origin displacement for antenna MS2 in stowed configuration

3.2.5 USI3BIS reference system

The origin of the reference system is displaced in the x-z plane of USI3 reference system.

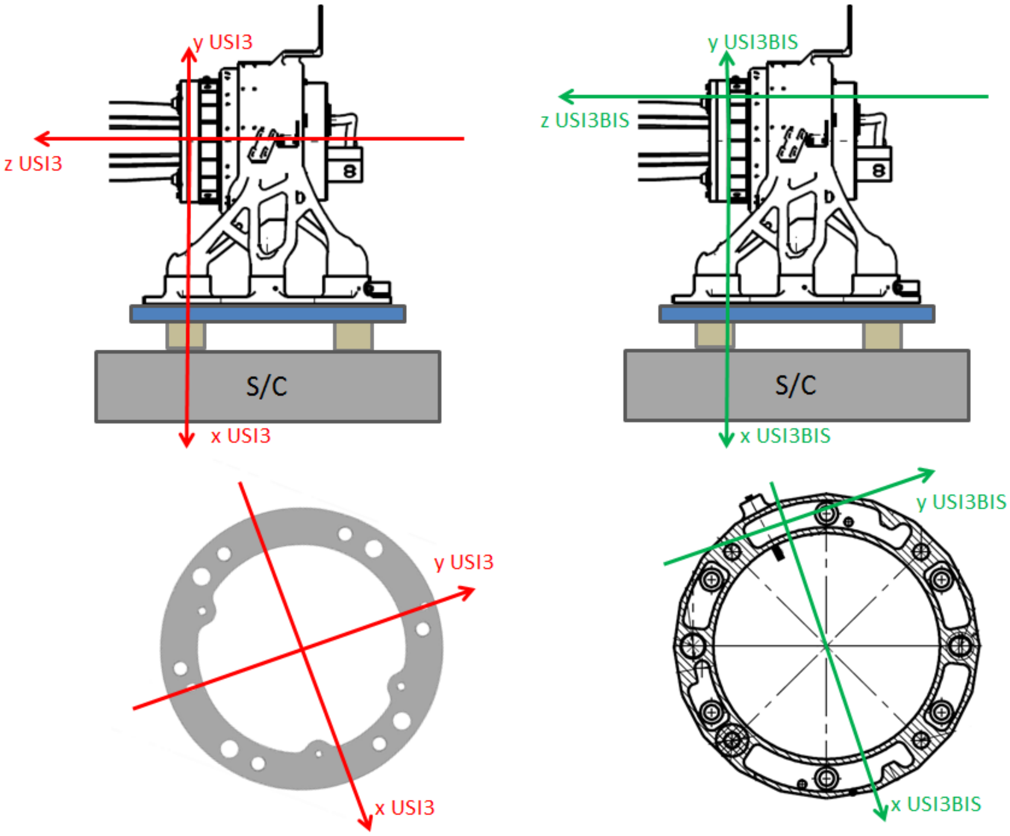

Figure 3.35. USI3BIS reference system geometry

$$_{USI3BIS_{inv}}()^{USI3_{disp}} = \tag{3.94}$$

	x_{USI3}	y_{USI3}	z_{USI3}
$x_{USI3BIS}$	1.0000000	0.0000000	0.0000000
$y_{USI3BIS}$	0.0000000	1.0000000	0.0000000
$z_{USI3BIS}$	0.0000000	0.0000000	1.0000000

Table 3.64. Rotation matrix of USI3BIS respect to USI3 reference system for antenna MS2

$$_{USI3BIS_{disp}}()^{SAT} = _{USI3BIS_{disp}}()^{USI3BIS_{inv}} * _{USI3BIS_{inv}}()^{USI3_{disp}} * _{USI3_{disp}}()^{SAT} = \tag{3.95}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{USI3BIS}$	-0.1539296	-0.5606046	-0.8136511
$y_{USI3BIS}$	-0.9702111	-0.0701509	0.2318821
$z_{USI3BIS}$	-0.1870725	0.8251069	-0.5331065

Table 3.65. Rotation matrix of USI3BIS respect to SAT reference system for antenna MS2 in stowed configuration

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI3BIS REF	1471.787	-901.604	340.811
	x_{USI3}	y_{USI3}	z_{USI3}
ORIGIN USI3BIS REF	-46	0	-12

Table 3.66. USI3BIS origin displacement for antenna MS2 in stowed configuration

3.2.6 LLD L1 reference system

LLD L1 reference system is achieved by comparing it with RIF1 reference system. It is useful in order to compute LLD CENTER reference system, that is the one used to verify the correct location of the ADPM2+.

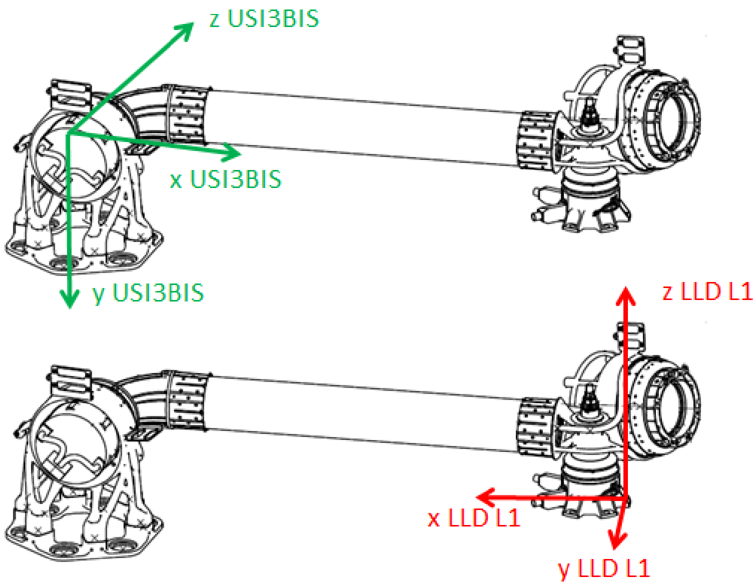

Figure 3.36. LLD L1 reference system geometry

$$_{LLDL1_{inv}}()^{USI3BIS_{disp}} = \tag{3.96}$$

	$x_{USI3BIS}$	$y_{USI3BIS}$	$z_{USI3BIS}$
x_{LLDL1}	-0.892323395	0.055188594	0.448010244
y_{LLDL1}	-0.424340233	0.235891242	-0.874237204
z_{LLDL1}	-0.153929614	-0.970211081	-0.187072533

Table 3.67. Rotation matrix of LLD L1 respect to USI3BIS reference system for antenna MS2

$$_{LLDL1_{disp}}()^{SAT} = _{LLDL1_{disp}}()^{LLDL1_{inv}} * _{LLDL1_{inv}}()^{USI3BIS_{disp}} * _{USI3BIS_{disp}}()^{SAT} = \tag{3.97}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{LLDL1}	-9.6037E-13	-0.866025404	0.5
y_{LLDL1}	4.39118E-13	-0.5	-0.866025404
z_{LLDL1}	1	-1.05125E-12	-9.99256E-14

Table 3.68. Rotation matrix of LLD L1 respect to SAT reference system for antenna MS2 in stowed configuration

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LLD L1 REF	1370.5	-33.65298661	548.6557882
	$x_{USI3BIS}$	$y_{USI3BIS}$	$z_{USI3BIS}$
ORIGIN LLD L1 REF	-640.0994164	85.57771457	624.2969373

Table 3.69. LLD L1 origin displacement for antenna MS2 in stowed configuration

3.2.7 LLD CENTER reference system

That reference system is used to compare the difference in location between LLD reference system computed from the ADPM2+ chain and the LLD reference system got by LLD chain. The difference between them shall be corrected by the adjustment capabilities of the LLD.

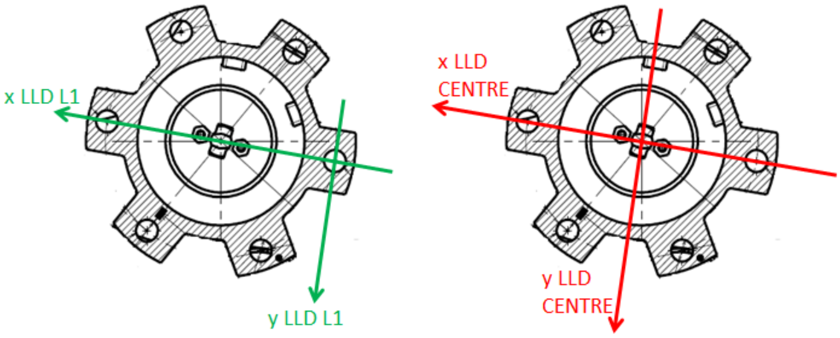

Figure 3.37. LLD CENTER reference system geometry - view 1

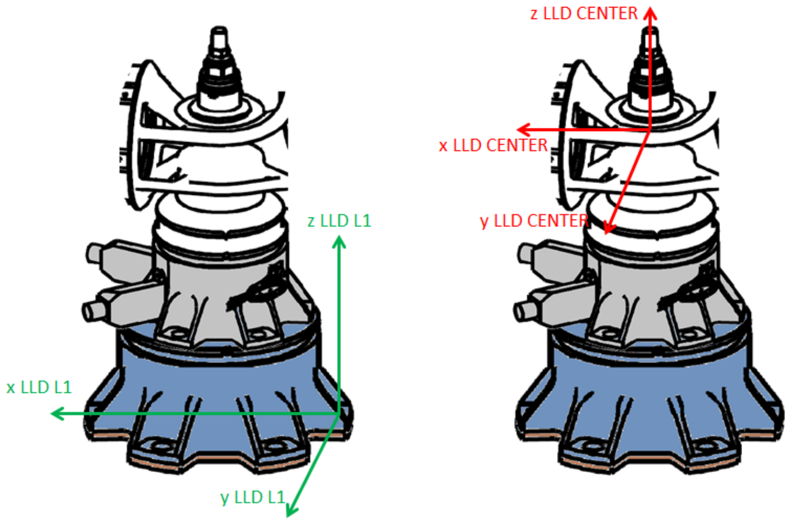

Figure 3.38. LLD CENTER reference system geometry - view 2

$$_{LLDCENTER_{inv}}()^{LLDL1_{disp}} = \tag{3.98}$$

	x_{LLDL1}	y_{LLDL1}	z_{LLDL1}
$x_{LLDCENTER}$	1.00000000	0.00000000	0.00000000
$y_{LLDCENTER}$	0.00000000	1.00000000	0.00000000
$z_{LLDCENTER}$	0.00000000	0.00000000	1.00000000

Table 3.70. Rotation matrix of LLD CENTER respect to LLD L1 reference system for antenna MS2

$$_{LLDCENTER_{disp}}()^{SAT} =_{LLDCENT_{disp}}()^{LLDCENT_{inv}} *_{LLDCENT_{inv}}()^{LLDL1_{disp}} *_{LLDL1_{disp}}()^{SAT} \tag{3.99}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{LLDL1}	-9.6037E-13	-0.866025404	0.5
y_{LLDL1}	4.39118E-13	-0.5	-0.866025404
z_{LLDL1}	1	-1.05125E-12	-9.99256E-14

Table 3.71. Rotation matrix of LLD CENTER respect to SAT reference system for antenna MS2 in stowed configuration

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LLD CENTER REF	1475.5	72.6241978	571.1557882
ICD data	x_{LLDL1}	y_{LLDL1}	z_{LLDL1}
ORIGIN LLD CENTER REF	45	0	105

Table 3.72. LLD CENTER origin displacement for antenna MS2 in stowed configuration

3.2.8 MOTOR 2 reference system

The configuration of motor 2 is defined by Motor 2 reference system, here identified with the abbreviation RM2.

$$_{RM2_{inv}}()^{USI3BIS_{disp}} = R_z(\phi_z) * R_y(\phi_y) * R_x(\phi_x) = \tag{3.100}$$

$$\begin{pmatrix} cos(\phi_z) & sin(\phi_z) & 0 \\ -sin(\phi_z) & cos(\phi_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\phi_y) & 0 & -sin(\phi_y) \\ 0 & 1 & 0 \\ sin(\phi_y) & cos(\phi_y) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\phi_x) & sin(\phi_x) \\ 0 & -sin(\phi_x) & cos(\phi_x) = \end{pmatrix} = \tag{3.101}$$

	$x_{USI3BIS}$	$y_{USI3BIS}$	$z_{USI3BIS}$
x_{RM2}	-0.6631515	-0.4405785	0.6050791
y_{RM2}	-0.2054552	0.8845016	0.4188617
z_{RM2}	-0.7197349	0.1534521	-0.6770777

Table 3.73. Rotation matrix of RM2 respect to USI3BIS reference system for antenna MS2

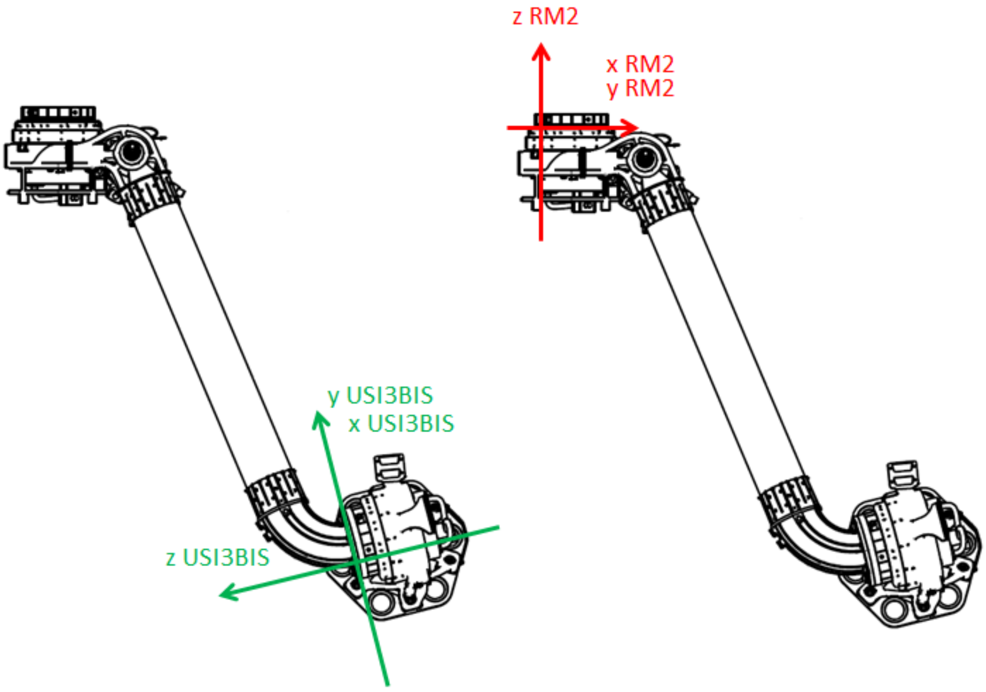

Figure 3.39. MOTOR 2 reference system geometry in stowed configuration - view 1

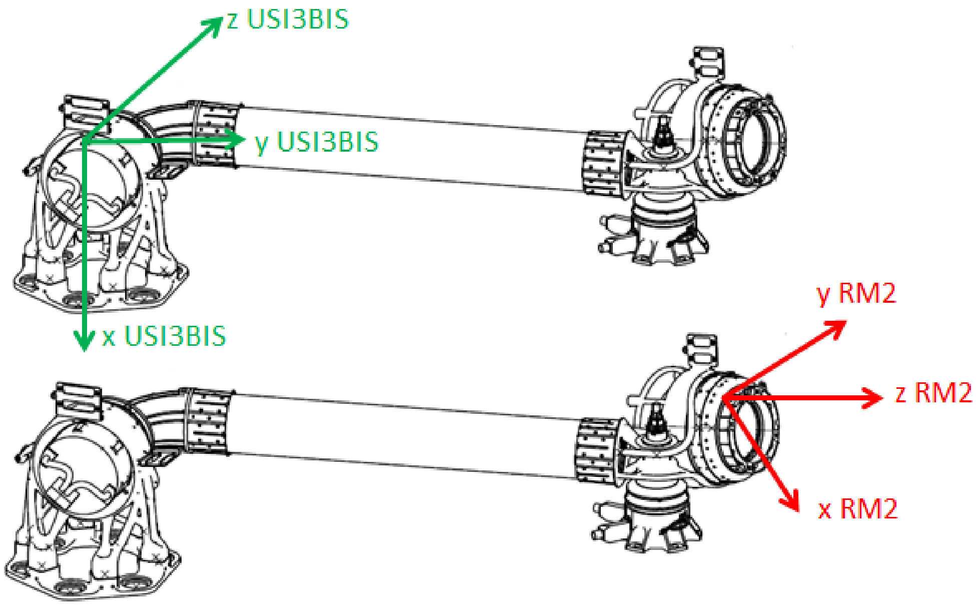

Figure 3.40. MOTOR 2 reference system geometry in stowed configuration - view 2

$$ {}_{RM2_{disp}}()^{SAT} = {}_{RM2_{disp}}()^{RM2_{inv}} * {}_{RM2_{inv}}()^{RM2_{disp}} * {}_{USI3BIS_{disp}}()^{SAT} = \tag{3.102} $$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
x_{RM2}	0.4163391	0.9019277	0.1148401
y_{RM2}	-0.9048851	0.3987362	0.1489710
z_{RM2}	0.0885702	-0.1659395	0.9821504

Table 3.74. Rotation matrix of RM2 respect to SAT reference system for antenna MS2 in stowed configuration

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RM2 REF	1459.178	-20.995	637.35
	$x_{USI3BIS}$	$y_{USI3BIS}$	$z_{USI3BIS}$
ORIGIN RM2 REF	-733.012	19.220	570.868

Table 3.75. RM2 origin displacement for antenna MS2 in stowed configuration

3.2.9 MOTOR 2 rotation

The following reference system is USI2 reference system, which defines the rotation of motor 2 around its axis. For stowed configuration the motor has the function to perform rotation in order to offset the defaults effects on the reflector's stowed configuration. At last an origin displacement is taken into account, since the origin is not placed along the motor axis.

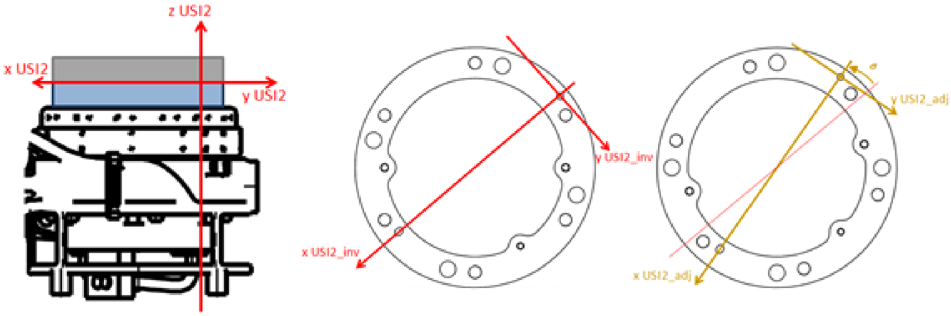

Figure 3.41. MOTOR 2 rotation in stowed configuration

$$_{USI2_{inv}}()^{RM2_{disp}} = R_z(\theta_z) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} = \tag{3.103}$$

	x_{RM2}	y_{RM2}	z_{RM2}
x_{USI2}	1.0000000	0.0000000	0.0000000
y_{USI2}	0.0000000	1.0000000	0.0000000
z_{USI2}	0.0000000	0.0000000	1.0000000

Table 3.76. Rotation matrix of USI2 respect to RM2 reference system for antenna MS2 in stowed configuration

ROTATION MATRIX FOR MOTOR 2 CAPABILITY: σ is the adjustment angle

$$_{USI2_{adj}}()^{USI2_{inv}} = R_z(\sigma) = \begin{pmatrix} cos(\sigma_z) & sin(\sigma_z) & 0 \\ -sin(\sigma_z) & cos(\sigma_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3.104}$$

$$_{USI2_{disp}}()^{SAT} =_{USI2_{disp}} ()^{USI2_{adj}} *_{USI2_{adj}} ()^{USI2_{inv}} *_{USI2_{inv}} ()^{RM2_{disp}} *_{RM2_{disp}} ()^{SAT} \tag{3.105}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{USI2}	0.4163391	0.9019277	0.1148401
y_{USI2}	-0.9048851	0.3987362	0.1489710
z_{USI2}	0.0885702	-0.1659395	0.9821504

Table 3.77. Rotation matrix of USI2 respect to SAT reference system for antenna MS2 in stowed configuration

ORIGIN DISPLACEMENT

The computation of the displacement is based on trigonometric demonstration. Following the geometric scheme for a generic rotation and the math formulas used for the computation, in which R2 stands for the motor2 reference system origin and equal to 48.5 mm :

$$\begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} = \begin{Bmatrix} R2 - R2 * cos(\theta_z) \\ -R2 * sin(\theta_z) \\ 0 \end{Bmatrix} + \begin{Bmatrix} R2 - R2 * cos(\sigma_z) \\ -R2 * sin(\sigma_z) \\ 0 \end{Bmatrix} \tag{3.106}$$

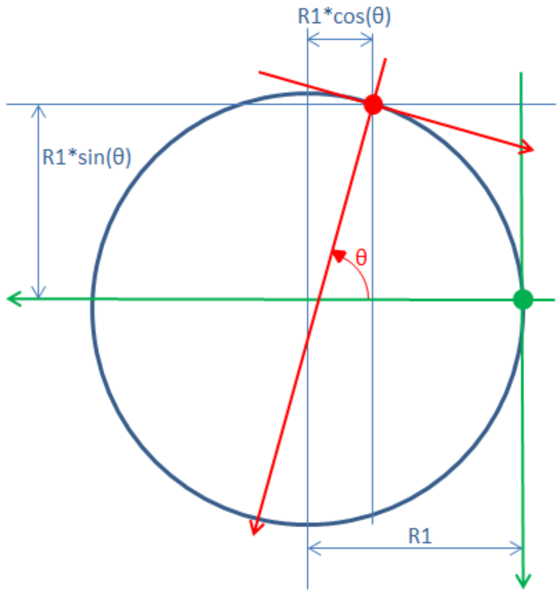

Figure 3.42. MOTOR 2 displacement due to the rotation

$$\begin{Bmatrix} x_{USI2} \\ y_{USI2} \\ z_{USI2} \end{Bmatrix} = \begin{Bmatrix} x_{RM2} \\ y_{RM2} \\ z_{RM2} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} *_{RM2_{disp}} ()^{SAT} \tag{3.107}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI2 REF	1459.178	-20.995	637.35
	x_{RM2}	y_{RM2}	z_{RM2}
ORIGIN USI2 REF	0	0	0

Table 3.78. USI2 origin displacement for antenna MS2 in stowed configuration

3.2.10 USI2bis reference system

This reference system has the goal to define the rotation due to the machining of the shim. Firstly, the reference system is shifted in the centre of the shim. While the rotation, which reproduces the machining, consists of a product of different rotations. The first rotation is performed around the z-axis of an α angle (included between 0° and 360°), which is the direction of the machining. Subsequently, the reference system is rotated of β angle, which is the angle of machining and it assumes a value no higher than 1.1°. At last the reference system is rotated in order to bring x-axis in the initial x-z plane.

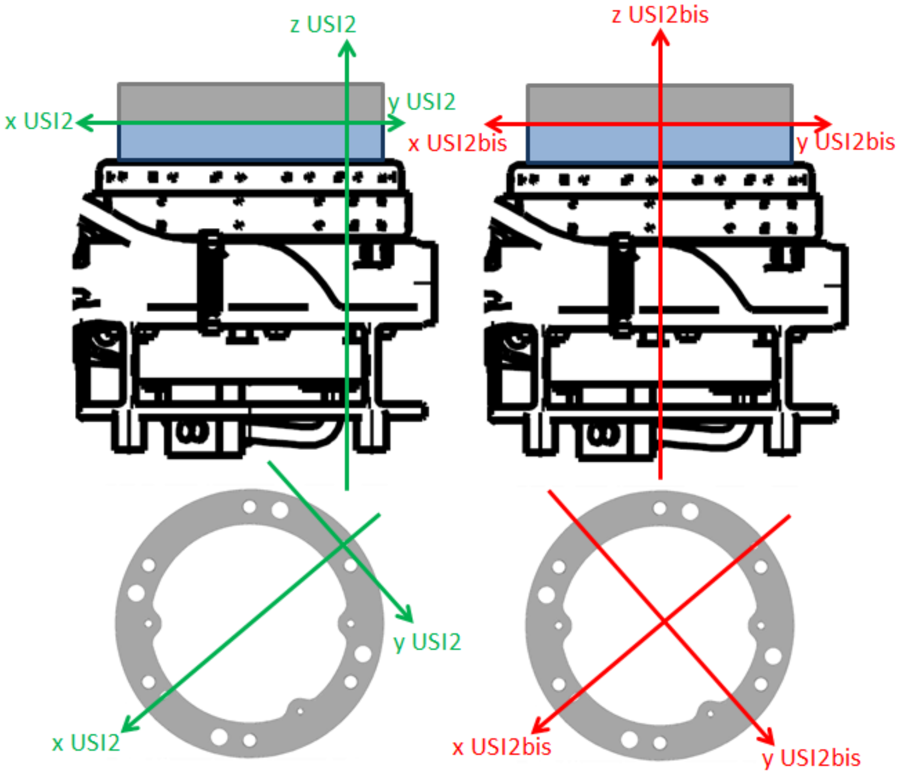

Figure 3.43. USI2bis reference system geometry in stowed configuration

$$_{USI2bis_{inv}}()^{USI2_{disp}} = R_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\theta_x) & sin(\theta_x) \\ 0 & -sin(\theta_x) & cos(\theta_x) \end{pmatrix} = \tag{3.108}$$

	x_{USI2}	y_{USI2}	z_{USI2}
$x_{USI2bis}$	1.0000000	0.0000000	0.0000000
$y_{USI2bis}$	0.0000000	1.0000000	0.0000000
$z_{USI2bis}$	0.0000000	0.0000000	1.0000000

Table 3.79. Rotation matrix of USI2bis respect to USI2 reference system for antenna MS2

MODEL FOR THE MACHINING

α and β angles must be entered positive by the user. In order to get USI$_{int}$ Reference system a clock wise β rotation is performed.

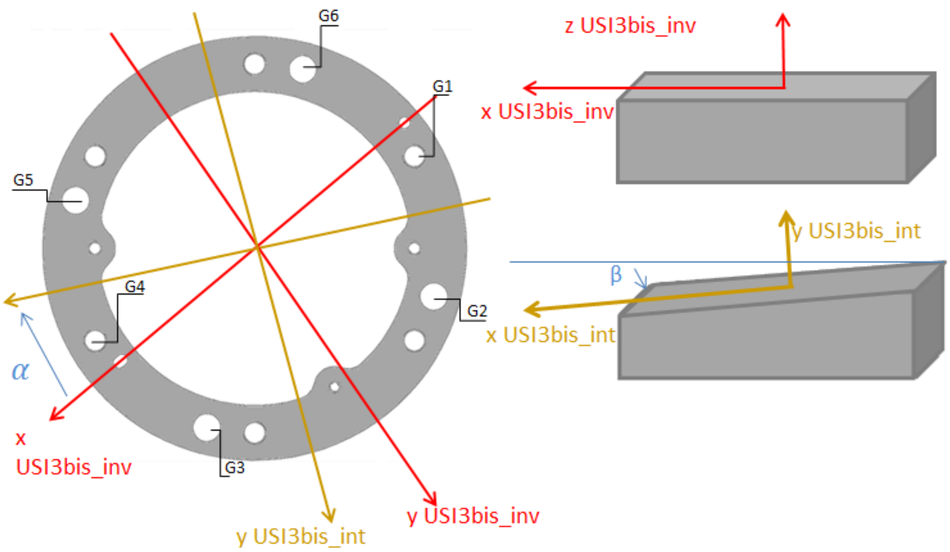

Figure 3.44. Geometry explanation for the machining shim 2

$$_{USI2bis_{mach}}()^{USI2bis_{inv}} = Rz_{adj}(\gamma) * Ry_{int}(\beta) * Rx_{inv}(\alpha) = \tag{3.109}$$

$$\begin{pmatrix} cos(\gamma) & sin(\gamma) & 0 \\ -sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\beta) & 0 & -sin(\beta) \\ 0 & 1 & 0 \\ sin(\beta) & cos(\beta) & 0 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\alpha) & sin(\alpha) \\ 0 & -sin(\alpha) & cos(\alpha) \end{pmatrix} \tag{3.110}$$

	$x_{USI2bisinv}$	$y_{USI2bisinv}$	$z_{USI2bisinv}$
$x_{USI2bismach}$	$cos\beta\ cos\alpha\ cos\gamma - sin\alpha\ sin\gamma$	$cos\beta\ cos\gamma\ sin\alpha + cos\alpha\ sin\gamma$	$-sin\beta\ cos\gamma$
$y_{USI2bismach}$	-$cos\gamma\ sin\alpha - cos\beta\ cos\alpha\ sin\gamma$	$cos\alpha\ cos\gamma - cos\beta\ sin\alpha\ sin\gamma$	$sin\beta\ sin\gamma$
$z_{USI2bismach}$	$sin\beta\ cos\alpha$	$sin\beta\ sin\alpha$	$cos\beta$

Table 3.80. Rotation matrix for machining shim 2

γ angle represents the rotation angle necessary to perform the rotation of x USI2bis adj in order to bring it in the initial x USI2bis – z USI2bis plane. This condition leads to compute the γ angle by imposing null the component of x USI2bis MACH along y USI2bis INV.

$$cos\beta\ \ cos\gamma\ \ sin\alpha + cos\alpha\ \ sin\gamma = 0 \tag{3.111}$$

$$\gamma = -tan^{-1}\Big(\frac{cos\beta * sin\alpha}{cos\alpha}\Big) \tag{3.112}$$

$$
\begin{aligned}
{}_{USI2bis_{disp}}()^{SAT} = & {}_{USI2bis_{disp}}()^{USI2bis_{mach}} * \\
& {}_{USI2bis_{mach}}()^{USI2bis_{inv}} * {}_{USI2bis_{inv}}()^{USI2_{disp}} * {}_{USI2_{disp}}()^{SAT} =
\end{aligned}
\tag{3.113}
$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{USI2bis}$	0.4163391	0.9019277	0.1148401
$y_{USI2bis}$	-0.9048851	0.3987362	0.1489710
$z_{USI2bis}$	0.0885702	-0.1659395	0.9821504

Table 3.81. Rotation matrix of USI2bis respect to SAT reference system for antenna MS2 in stowed configuration

ORIGIN DISPLACEMENT FOR ANTENNA MS2

The machining leads not only to a reference system rotation, but also to a displacement of the reference origin. Considering the width of the layer equal to 105 mm and the thickness equal to 4 mm, the displacement along z USI is equal to:

$$\Delta x \quad MACHINING = thickness * sin(\beta) * cos(\alpha) \tag{3.114}$$

$$\Delta y \quad MACHINING = thickness * sin(\beta) * sin(\alpha) \tag{3.115}$$

$$\Delta z \quad MACHINING = \frac{widthcale}{2} * sin\beta \tag{3.116}$$

$$
\begin{Bmatrix} x_{USI2bis} \\ y_{USI2bis} \\ z_{USI2bis} \end{Bmatrix} = \begin{Bmatrix} x_{USI2} \\ y_{USI2} \\ z_{USI2} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta x \quad MACHINING \\ \Delta y \quad MACHINING \\ \Delta z \quad MACHINING \end{Bmatrix} * {}_{USI2_{disp}}()^{SAT} \tag{3.117}
$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USI2bis REF	1479.3704	22.7485	642.9197
	x_{USI2}	y_{USI2}	z_{USI2}
ORIGIN USI2bis REF	48.5	0	0

Table 3.82. USI2bis origin displacement for antenna MS2 in stowed configuration

3.2.11 CALEP2 reference system

The origin of the reference system is displaced in the x-y axis of CALEP reference.

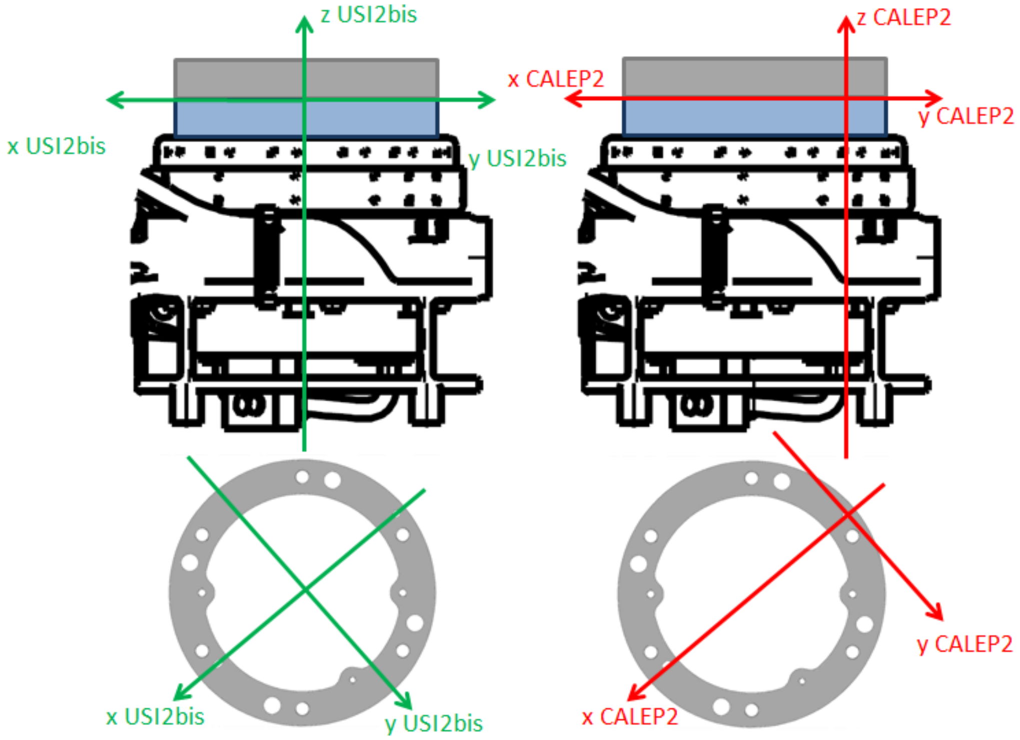

Figure 3.45. CALEP2 reference geometry in stowed configuration

$$CALEP2_{inv}()^{USI2bis_{disp}} = \tag{3.118}$$

	$x_{USI2bis}$	$y_{USI2bis}$	$z_{USI2bis}$
x_{CALEP2}	1.0000000	0.0000000	0.0000000
y_{CALEP2}	0.0000000	1.0000000	0.0000000
z_{CALEP2}	0.0000000	0.0000000	1.0000000

Table 3.83. Rotation matrix of CALEP2 respect to USI2bis reference system

$$_{CALEP2_{disp}}()^{SAT} = _{CALEP2_{disp}}()^{CALEP2_{inv}} * _{CALEP2_{inv}}()^{USI2bis_{disp}} * _{USI2bis_{disp}}()^{SAT} \tag{3.119}$$

	SAT	SAT	SAT
x_{CALEP2}	0.4163391	0.9019277	0.1148401
y_{CALEP2}	-0.9048851	0.3987362	0.1489710
z_{CALEP2}	0.0885702	-0.1659395	0.9821504

Table 3.84. Rotation matrix of CALEP2 respect to SAT reference system in stowed configuration

ORIGIN DISPLACEMENT FOR ANTENNA MS2

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN CALEP2 REF	1459.178	-20.995	637.35
	$x_{USI2bis}$	$y_{USI2bis}$	$z_{USI2bis}$
ORIGIN CALEP2 REF	-48.5	0	0

Table 3.85. CALEP2 origin displacement for antenna MS2 in stowed configuration

3.2.12 Reference system 2

At the end of the chain of rotation matrices for the ADPM2+, there is the reference system 2, here called shortly RIF2. It has the function to refer the ADPM2+ to the vertex reference system of the antenna considering all the rotations and adjustment capabilities before.

$$_{RIF2_{inv}}()^{CALEP2_{disp}} = R_z(\theta_z) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} = \tag{3.120}$$

	x_{CALEP2}	y_{CALEP2}	z_{CALEP2}
x_{RIF2}	0.1736482	-0.9848078	0.0000000
y_{RIF2}	0.9848078	0.1736482	0.0000000
z_{RIF2}	0.0000000	0.0000000	1.0000000

Table 3.86. Rotation matrix of RIF2 respect to CALEP2 reference system

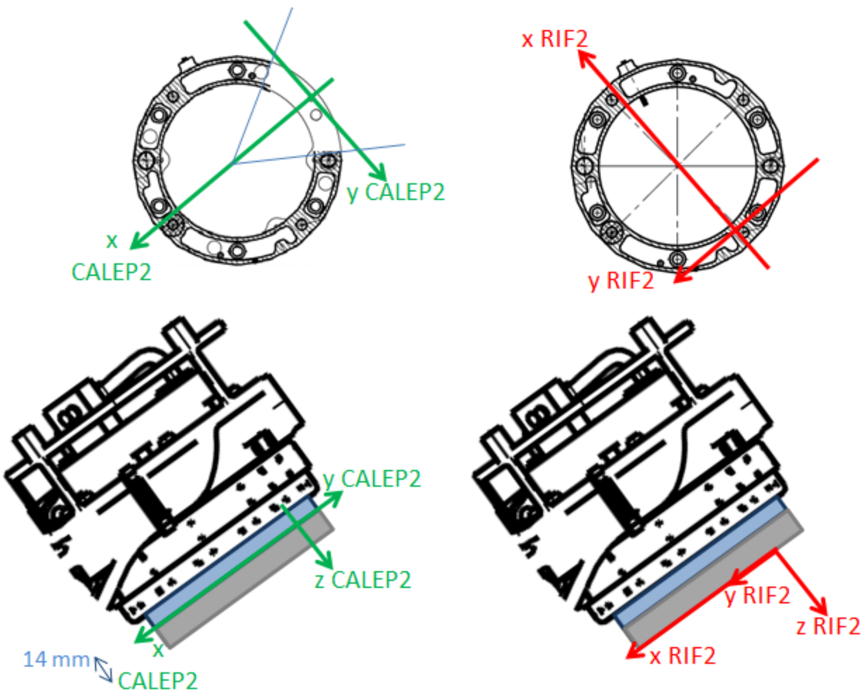

Figure 3.46. RIF2 reference system geometry in stowed configuration

$$_{RIF2_{disp}}()^{SAT} = _{RIF2_{disp}}()^{RIF2_{inv}} * _{RIF2_{inv}}()^{CALEP2_{disp}} * _{CALEP2_{disp}}()^{SAT} \tag{3.121}$$

IRD data	SAT	SAT	SAT
x_{RIF2}	0.9634344	-0.2360604	-0.1267660
y_{RIF2}	0.2528823	0.9574652	0.1389640
z_{RIF2}	0.0885702	-0.1659395	0.9821504

Table 3.87. Rotation matrix of RIF2 respect to SAT reference system in stowed configuration

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RIF2 REF	1436.293	31.284	662.501
	x_{CALEP2}	y_{CALEP2}	z_{CALEP2}
ORIGIN RIF2 REF	40.5127	45.301	14

Table 3.88. RIF2 origin displacement for antenna MS2 in stowed configuration

3.2.13 Stowed antenna vertex reference system

In order to verify the correct antenna orientation and location, RVS reference system is introduced.

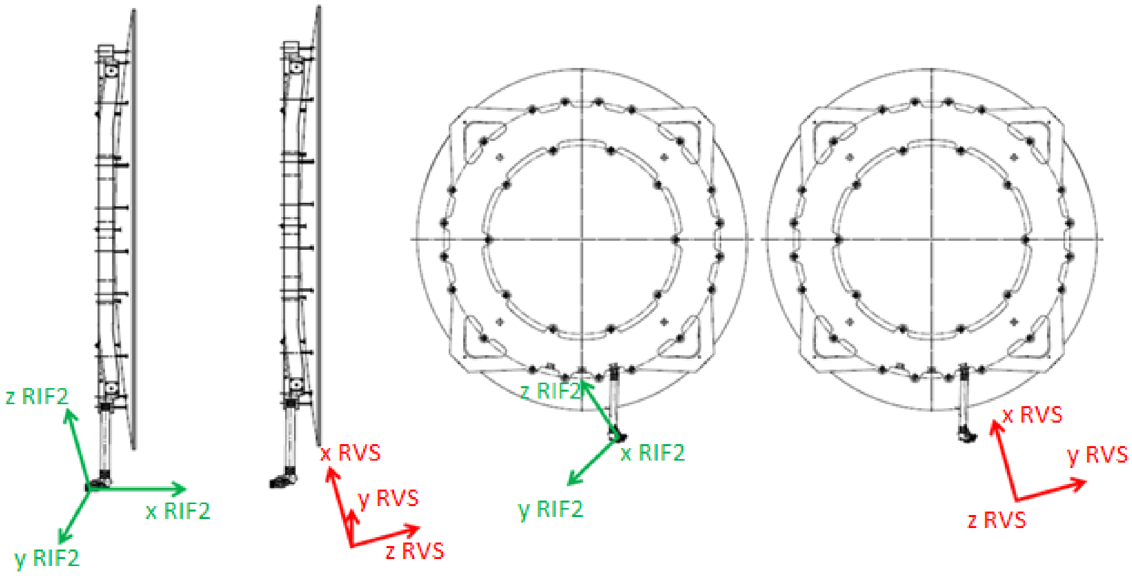

Figure 3.47. RVS reference system geometry

$$_{RVS_{inv}}()^{RIF2_{disp}} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) = \tag{3.122}$$

IRD data	x_{RIF2}	y_{RIF2}	z_{RIF2}
x_{RVS}	0.1033403	0.2261328	0.9685994
y_{RVS}	-0.2318350	0.9524674	-0.1976320
z_{RVS}	-0.9672504	-0.2041319	0.1508538

Table 3.89. Rotation matrix of RVS respect to RIF2 reference system

$$_{RVS_{disp}}()^{SAT} =_{RVS_{disp}} ()^{RVS_{inv}} *_{RVS_{inv}} ()^{RIF2_{disp}} *_{RIF2_{disp}} ()^{SAT} \quad (3.123)$$

IRD data	SAT	SAT	SAT
x_{RVS}	0.2425356	0.0313908	0.9696345
y_{RVS}	0.0000000	0.9994764	-0.0323569
z_{RVS}	-0.9701425	0.0078477	0.2424086

Table 3.90. Rotation matrix of RVS respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RVS REF	1288.7775	-65.4503	78.3119
IRD data	x_{RIF2}	y_{RIF2}	z_{RIF2}
ORIGIN RVS REF	-45.231	-211.105	-570.775

Table 3.91. RVS origin displacement for antenna MS2

3.2.14 RCP - HRM2X/reflector interface reference system

In stowed configuration, fixation devices are provided in order to perform the reflector stocking. The interface plane between reflector and the fixation device, that is HRM, is called LCP (Lower Centre Plane) for the lower antenna and UCP (Upper Centre Plane) for the upper Antenna. It is requested that the orientation and the location of RLCP are correct in order to match the HRM and reflector surfaces.

$$_{RCP1_{inv}}()^{RVS_{disp}} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) = \quad (3.124)$$

IRD data	x_{RVS}	y_{RVS}	z_{RVS}
x_{RCP1}	0.6634385	-0.7296163	0.1658596
y_{RCP1}	0.2425356	0.0000000	-0.9701425
z_{RCP1}	0.7078318	0.6838567	0.1769579

Table 3.92. Rotation matrix of RCP1 respect to RVS reference system

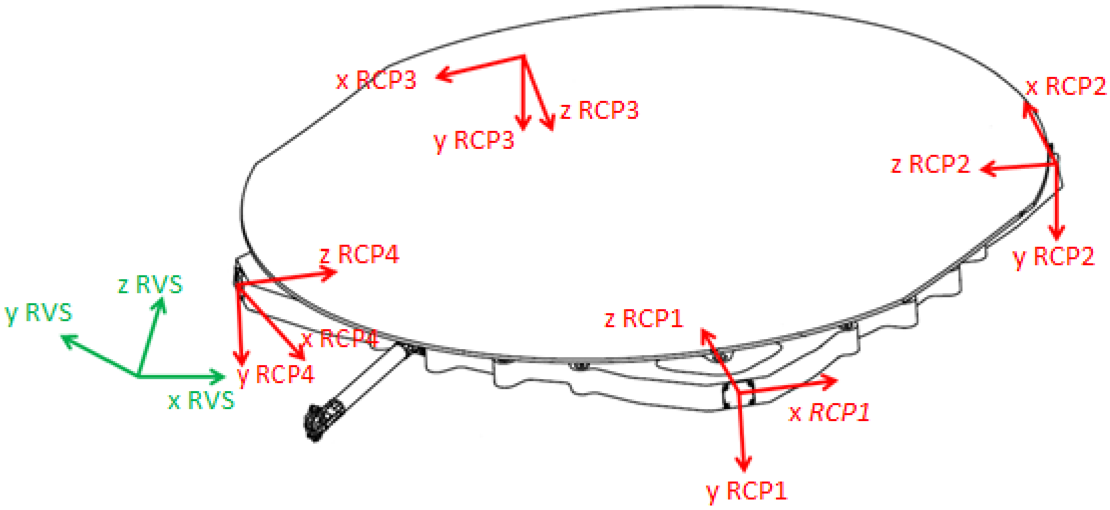

Figure 3.48. RCP reference system geometry

$$_{RCP2_{inv}}()^{RVS_{disp}} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) = \tag{3.125}$$

IRD data	x_{RVS}	y_{RVS}	z_{RVS}
x_{RCP2}	0.7078318	0.6838567	0.1769579
y_{RCP2}	0.2425356	0.0000000	-0.9701425
z_{RCP2}	-0.6634385	0.7296163	-0.1658596

Table 3.93. Rotation matrix of RCP2 respect to RVS reference system

$$_{RCP3_{inv}}()^{RVS_{disp}} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) = \tag{3.126}$$

IRD data	x_{RVS}	y_{RVS}	z_{RVS}
x_{RCP3}	-0.6634385	0.7296163	-0.1658596
y_{RCP3}	0.2425356	0.0000000	-0.9701425
z_{RCP3}	-0.7078318	-0.6838567	-0.1769579

Table 3.94. Rotation matrix of RCP3 respect to RVS reference system

$$_{RCP4_{inv}}()^{RVS_{disp}} = R_z(\theta_z) * R_y(\theta_y) * R_x(\theta_x) = \tag{3.127}$$

IRD data	x_{RVS}	y_{RVS}	z_{RVS}
x_{RCP4}	-0.7078318	-0.6838567	-0.1769579
y_{RCP4}	0.2425356	0.0000000	-0.9701425
z_{RCP4}	0.6634385	-0.7296163	0.1658596

Table 3.95. Rotation matrix of RCP4 respect to RVS reference system

ROTATION MATRIX IN SATELLITE REFERENCE SYSTEM

$$_{RCP1_{disp}}()^{SAT} =_{RCP1_{disp}} ()^{RCP1_{inv}} *_{RCP1_{inv}} ()^{RVS_{disp}} *_{RVS_{disp}} ()^{SAT} \tag{3.128}$$

	SAT	SAT	SAT
x_{RCP1}	0.0000000	-0.7071068	0.7071068
y_{RCP1}	1.0000000	0.0000000	0.0000000
z_{RCP1}	0.0000000	0.7071068	0.7071068

Table 3.96. Rotation matrix of RCP1 respect to SAT reference system

$$_{RCP2_{disp}}()^{SAT} =_{RCP2_{disp}} ()^{RCP2_{inv}} *_{RCP2_{inv}} ()^{RVS_{disp}} *_{RVS_{disp}} ()^{SAT} \tag{3.129}$$

	SAT	SAT	SAT
x_{RCP2}	0.0000000	0.7071068	0.7071068
y_{RCP2}	1.0000000	0.0000000	0.0000000
z_{RCP2}	0.0000000	0.7071068	-0.7071068

Table 3.97. Rotation matrix of RCP2 respect to SAT reference system

$$_{RCP3_{disp}}()^{SAT} = _{RCP3_{disp}}()^{RCP3_{inv}} * _{RCP3_{inv}}()^{RVS_{disp}} * _{RVS_{disp}}()^{SAT} \tag{3.130}$$

	SAT	SAT	SAT
x_{RCP3}	0.0000000	0.7071068	-0.7071068
y_{RCP3}	1.0000000	0.0000000	0.0000000
z_{RCP3}	0.0000000	-0.7071068	-0.7071068

Table 3.98. Rotation matrix of RCP3 respect to SAT reference system

$$_{RCP4_{disp}}()^{SAT} = _{RCP4_{disp}}()^{RCP4_{inv}} * _{RCP4_{inv}}()^{RVS_{disp}} * _{RVS_{disp}}()^{SAT} \tag{3.131}$$

	SAT	SAT	SAT
x_{RCP4}	0.0000000	-0.7071068	-0.7071068
y_{RCP4}	1.0000000	0.0000000	0.0000000
z_{RCP4}	0.0000000	-0.7071068	0.7071068

Table 3.99. Rotation matrix of RCP4 respect to SAT reference system

ORIGIN DISPLACEMENT FOR ANTENNA MS2

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RCP1 REF	1565.2503	-899.9467	1200.0537
ORIGIN RCP2 REF	1565.2503	-899.9467	2999.9460
ORIGIN RCP3 REF	1565.2503	899.9467	2999.9460
ORIGIN RCP4 REF	1565.2503	899.9467	1200.0537
IRD data	x_{RVS}	y_{RVS}	z_{RVS}
ORIGIN RCP1 REF	1128.5385	-870.3555	-2.8470
ORIGIN RCP2 REF	2873.7763	-928.5944	433.4624
ORIGIN RCP3 REF	2930.2763	870.3555	-447.5874
ORIGIN RCP4 REF	1185.0386	928.5944	11.2780

Table 3.100. RCPs origin displacement for antenna MS2

RCP1 FIXATION HOLES ORIGIN FOR ANTENNA MS2 IN SATELLITE REFERENCE SYSTEM

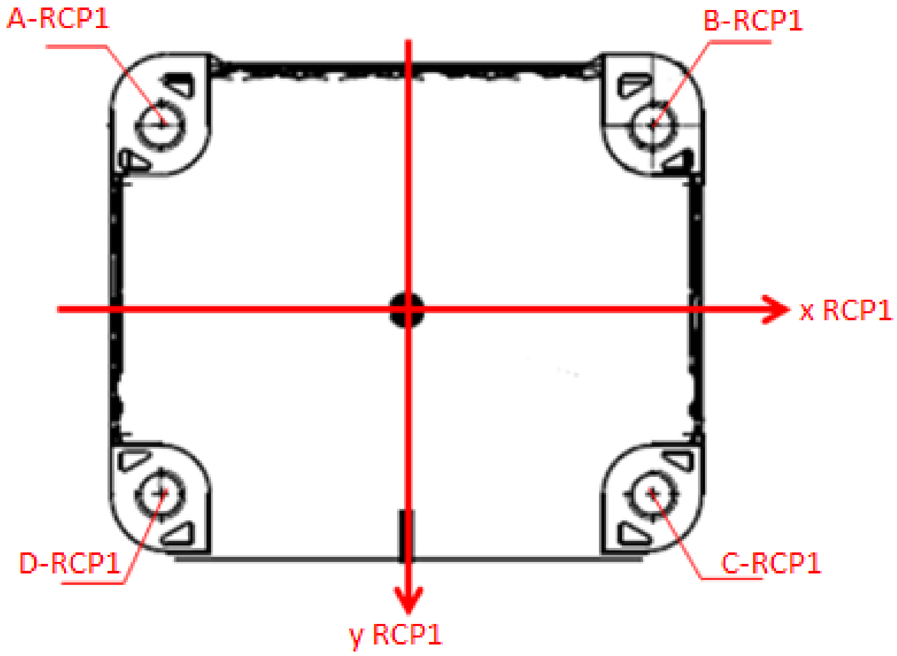

Figure 3.49. RCP1 fixation holes geometry

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN A-RCP1 REF	1595.2503	-871.6704	1171.7897
ORIGIN B-RCP1 REF	1595.2503	-928.2513	1228.3459
ORIGIN C-RCP1 REF	1535.2503	-928.2513	1228.3459
ORIGIN D-RCP1 REF	1535.2503	-871.6704	1171.7897
	x_{RVS}	y_{RVS}	z_{RVS}
ORIGIN A-RCP1 REF	1109.2965	-841.179	-38.5808
ORIGIN B-RCP1 REF	1162.3593	-899.5607	-25.3151
ORIGIN C-RCP1 REF	1147.8071	-899.5607	32.8934
ORIGIN D-RCP1 REF	1094.7444	-841.179	19.6278

Table 3.101. RCP1 fixation holes location for antenna MS2

3.2.15 RCHRM reference system

This reference system is that one used to compare the location of the reflector origin respect to HRM2X reference origin. For this reason RCHRM is computed both in RVS reference system (in order to take into account the defaults and adjustments of ADPM2+) both in satellite reference system (in order to take into account the defaults and adjustments capabilities of HRM2X).

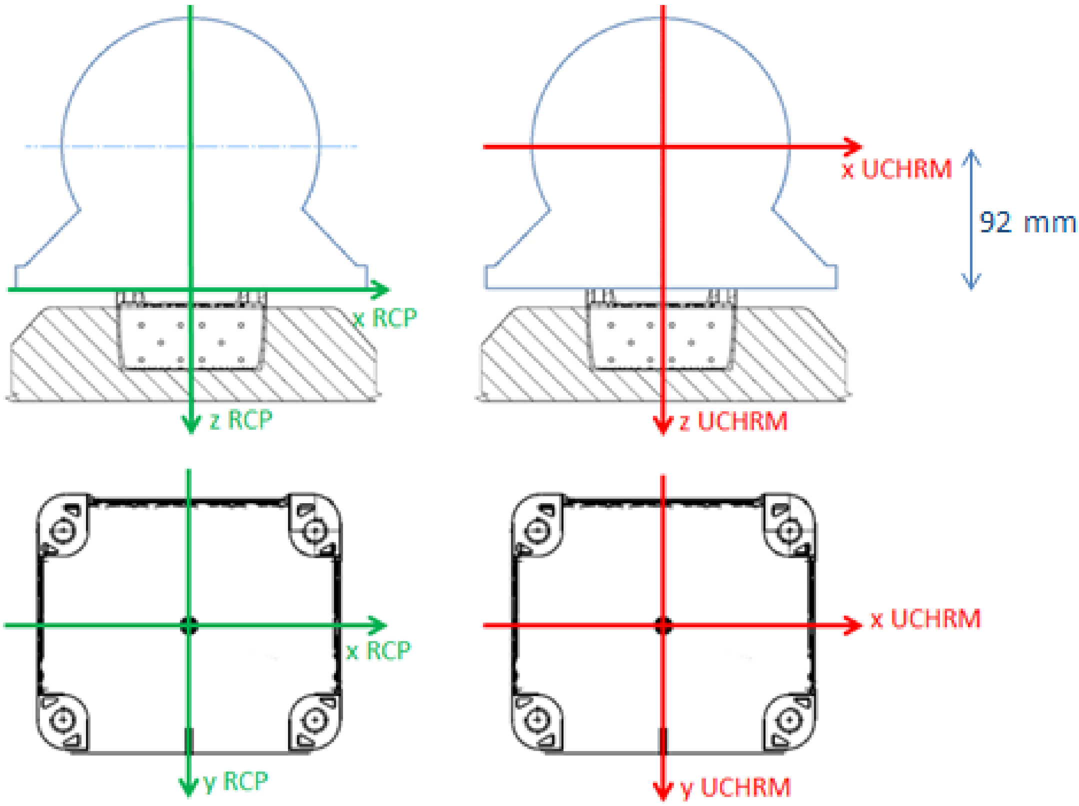

Figure 3.50. RCHRM reference system geometry

$$_{RCHRM_{inv}}()^{RCP_{disp}} = \tag{3.132}$$

	x_{RCP}	y_{RCP}	z_{RCP}
x_{RCHRM}	1.0000000	0.0000000	0.0000000
y_{RCHRM}	0.0000000	1.0000000	0.0000000
z_{RCHRM}	0.0000000	0.0000000	1.0000000

Table 3.102. Rotation matrix of RCHRM respect to RCP reference system

ROTATION MATRIX IN SATELLITE REFERENCE SYSTEM

$$_{RCHRM1_{disp}}()^{SAT} = _{RCHRM1_{disp}}()^{RCHRM1_{inv}} * _{RCHRM1_{inv}}()^{RCP1_{disp}} * _{RCP1_{disp}}()^{SAT} \tag{3.133}$$

	SAT	SAT	SAT
x_{RCHRM1}	0.0000000	-0.7071068	0.7071068
y_{RCHRM1}	1.0000000	0.0000000	0.0000000
z_{RCHRM1}	0.0000000	0.7071068	0.7071068

Table 3.103. Rotation matrix of RCHRM1 respect to SAT reference system

$$_{RCHRM2_{disp}}()^{SAT} = _{RCHRM2_{disp}}()^{RCHRM2_{inv}} * _{RCHRM2_{inv}}()^{RCP2_{disp}} * _{RCP2_{disp}}()^{SAT} \tag{3.134}$$

	SAT	SAT	SAT
x_{RCHRM2}	0.0000000	0.7071068	0.7071068
y_{RCHRM2}	1.0000000	0.0000000	0.0000000
z_{RCHRM2}	0.0000000	0.7071068	-0.7071068

Table 3.104. Rotation matrix of RCHRM2 respect to SAT reference system

$$_{RCHRM3_{disp}}()^{SAT} = _{RCHRM3_{disp}}()^{RCHRM3_{inv}} * _{RCHRM3_{inv}}()^{RCP3_{disp}} * _{RCP3_{disp}}()^{SAT} \tag{3.135}$$

	SAT	SAT	SAT
x_{RCHRM3}	0.0000000	0.7071068	-0.7071068
y_{RCHRM3}	1.0000000	0.0000000	0.0000000
z_{RCHRM3}	0.0000000	-0.7071068	-0.7071068

Table 3.105. Rotation matrix of RCHRM3 respect to SAT reference system

$$ {}_{RCHRM4_{disp}}()^{SAT} = {}_{RCHRM4_{disp}}()^{RCHRM4_{inv}} * {}_{RCHRM4_{inv}}()^{RCP4_{disp}} * {}_{RCP4_{disp}}()^{SAT} \tag{3.136} $$

	SAT	SAT	SAT
x_{RCHRM4}	0.0000000	-0.7071068	-0.7071068
y_{RCHRM4}	1.0000000	0.0000000	0.0000000
z_{RCHRM4}	0.0000000	-0.7071068	0.7071068

Table 3.106. Rotation matrix of RCHRM4 respect to SAT reference system

ORIGIN DISPLACEMENT

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN RCHRM1 REF	1565.2503	-965.0005	1134.9998
ORIGIN RCHRM2 REF	1565.2503	-965.0005	3064.9998
ORIGIN RCHRM3 REF	1565.2503	964.9995	3064.9998
ORIGIN RCHRM4 REF	1565.2503	964.9995	1134.9998
	x_{RCP}	y_{RCP}	z_{RCP}
ORIGIN RCHRM1 REF	0	0	-92
ORIGIN RCHRM2 REF	0	0	-92
ORIGIN RCHRM3 REF	0	0	-92
ORIGIN RCHRM4 REF	0	0	-92

Table 3.107. RCHRM origin displacement for antenna MS2

3.3 Math Model for HRM2X

Orthonormal matrices are used in this program in order to build the mathematical model. Example data are given for HRM1 of Satellite B4A.

GLOSSARY USED FOR THE MATH MODEL:

R_z= rotation around z axis
R_y= rotation around y axis
R_x= rotation around x axis
'inv' = matrix without adjustments or defaults
'adj' = matrix with adjustments
'int' = intermediate matrix for machining computation
'mach' = final matrix for machining adjustment
'disp' = matrix with adjustments and defaults

SCHEME COLOR LEGEND:
Reference systems in RED are the final one, achieved by rotating the previous reference system in GREEN. While the reference systems in BROWN stand for the reference systems got by the adjustment capabilities.

3.3.1 Satellite axis

The reference axis system for the satellite is defined as follows:

- **Origin O** is situated in the centre of the launch ring at the base of the satellite;
- **Z axis** is pointing the Earth from O and it is perpendicular to the separation plane;
- **Y axis** is included in the separation plane and it is pointing, from O, a slot labeled +Y (in South direction)
- **X axis** forms a direct orthogonal axis system and it points towards East.

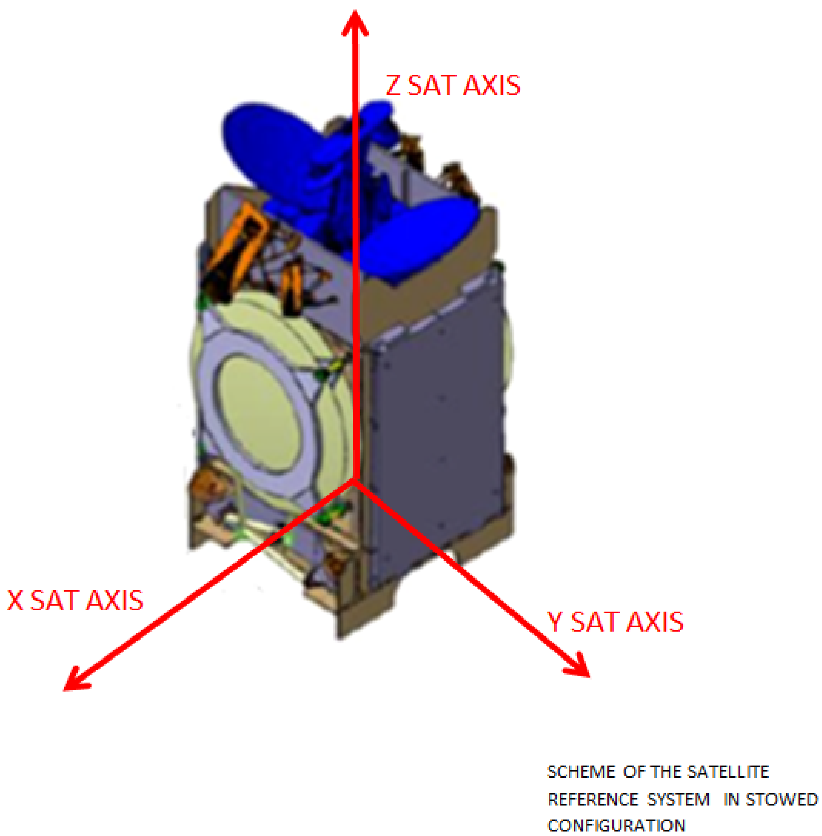

Figure 3.51. Satelite axis

3.3.2 Peliable shims

This reference axis system is created in order to point out the variation of the layers' thickness. In fact, it is possible to displace the origin of the system through the peliable shims of maximum +/- 7 mm in z SHIM M1 direction.

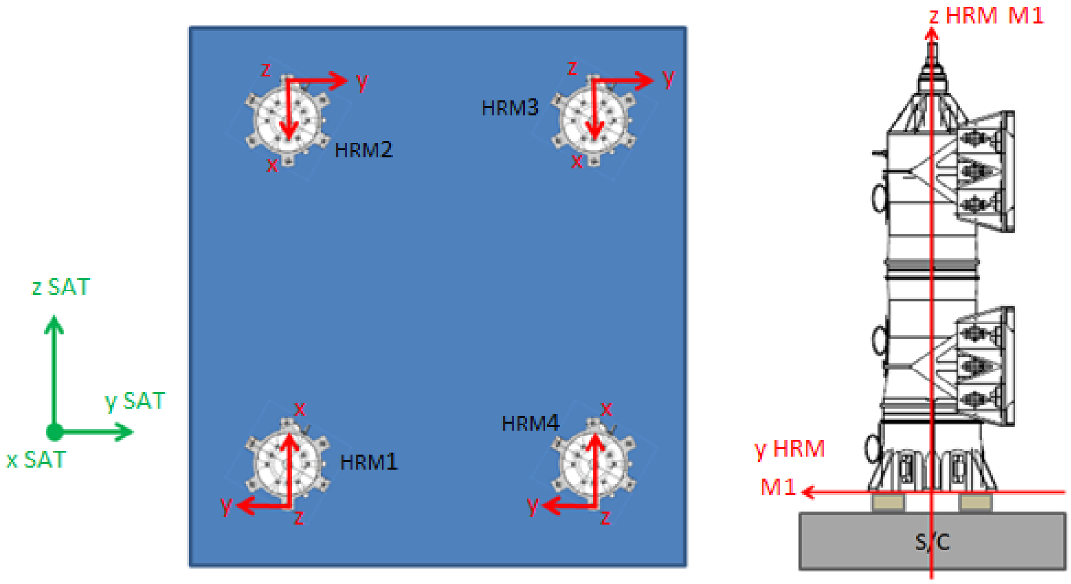

Figure 3.52. HRM2X peliable shim reference system geometry

$$_{hrmA1_{inv}}()^{SAT} = R_z(\theta_z)*R_y(\theta_y) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\theta_y) & 0 & -sin(\theta_y) \\ 0 & 1 & 0 \\ sin(\theta_y) & cos(\theta_y) & 0 \end{pmatrix} \tag{3.137}$$

$$_{hrmA1_{inv}}()^{SAT} = R_z(\theta_z) * R_y(\theta_y) = \tag{3.138}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{hrmA1}	0.0000000	0.0000000	1.0000000
y_{hrmA1}	0.0000000	-1.0000000	0.0000000
z_{hrmA1}	1.0000000	0.0000000	0.0000000

Table 3.108. Rotation matrix of HRM2X A1 peliable shim respect to satellite reference system

$$_{hrmA1_{disp}}()^{SAT} =_{hrmA1_{disp}} ()^{hrmA1_{inv}} *_{hrmA1_{inv}} ()^{SAT} \tag{3.139}$$

	x_{SAT}	y_{SAT}	z_{SAT}
x_{hrmA1}	0.0000000	0.0000000	1.0000000
y_{hrmA1}	0.0000000	-1.0000000	0.0000000
z_{hrmA1}	1.0000000	0.0000000	0.0000000

Table 3.109. Rotation matrix of hrm A1 for HRM1 refers to satellite reference system

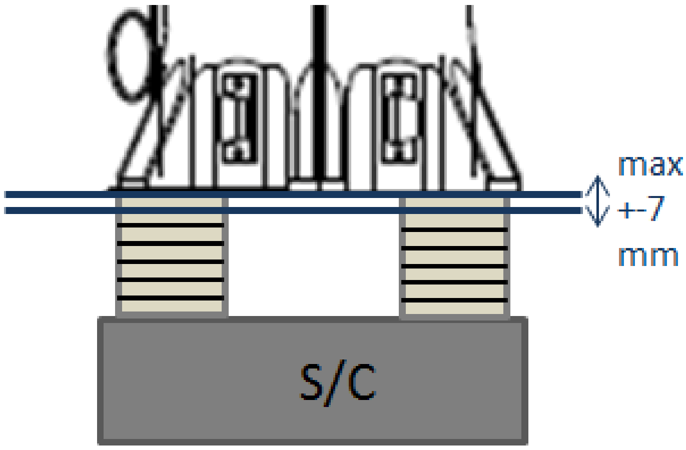

Figure 3.53. Peliable shims capabilities for HRM2X

ORIGIN DISPLACEMENT FOR HRM1

$$\begin{Bmatrix} x_{SHIMM1} \\ y_{SHIMM1} \\ z_{SHIMM1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta_{PELIABLESHIM} \\ 0 \\ 0 \end{Bmatrix} \tag{3.140}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN hrm A1 REF	1163.3	-965	1067

Table 3.110. Origin displacement for HRM1

3.3.3 HRM2X mechanical reference system

MEC reference system stands for Mechanical reference system of the HRM2X. Its axis are parallel to shim M1 reference system axis. The origin coincides with the previous one without defaults or adjustments. However, this reference system is also the result of the adjustment capability performed on the pod. In particular, they have effect on the origin position making a displacement of maximum +/- 6 mm along x MEC and y MEC.

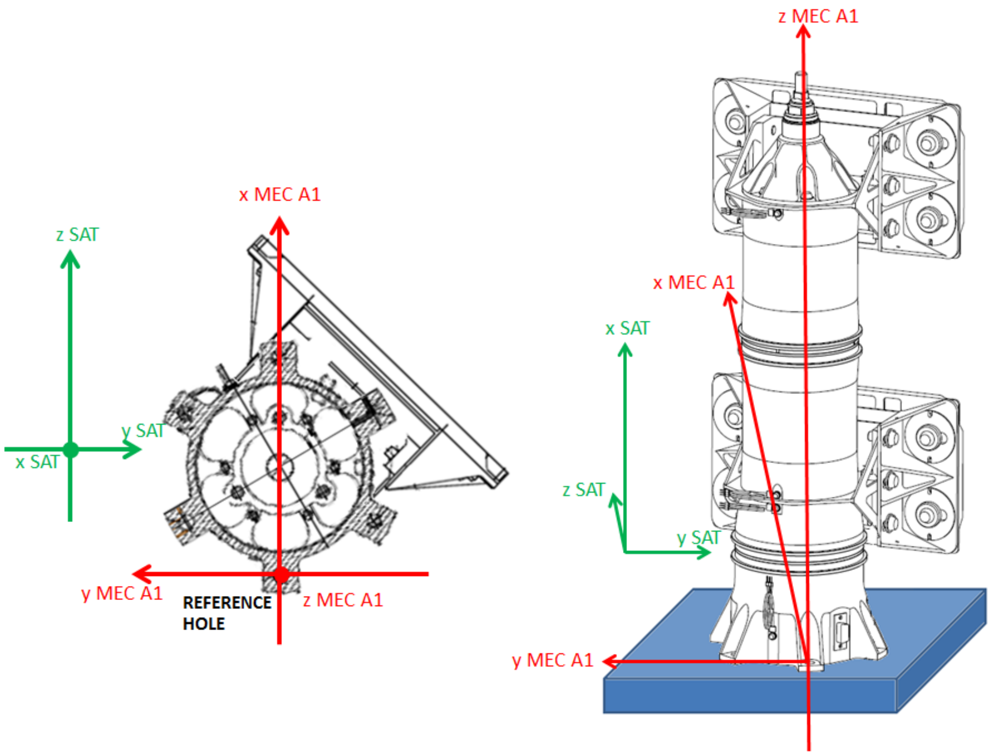

Figure 3.54. HRM2X Mechanical shim reference system geometry

$$_{hrmMEC_{inv}}()^{hrmA1_{disp}} = \tag{3.141}$$

	$x_{HRMshim}$	$y_{HRMshim}$	$z_{HRMshim}$
$x_{HRMMECA1}$	1.0000000	0.0000000	0.0000000
$y_{HRMMECA1}$	0.0000000	1.0000000	0.0000000
$z_{HRMMECA1}$	0.0000000	0.0000000	1.0000000

Table 3.111. Rotation matrix of HRM2X Mechanical shim A1 respect to hrm peliable shim A1 reference system

$$_{hrmMEC_{disp}}()^{SAT} =_{hrmMEC_{disp}} ()^{hrmMEC_{inv}} *_{hrmMEC_{inv}} ()^{hrmA1_{disp}} *_{hrmA1_{disp}} ()^{SAT} \tag{3.142}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{HRMMECA1}$	0.0000000	0.0000000	1.0000000
$y_{HRMMECA1}$	0.0000000	-1.0000000	0.0000000
$z_{HRMMECA1}$	1.0000000	0.0000000	0.0000000

Table 3.112. Rotation matrix of HRM2X Mechanical shim respect to satellite reference system

ADJUSTMENT CAPABILITIES IN POLAR COORDINATES

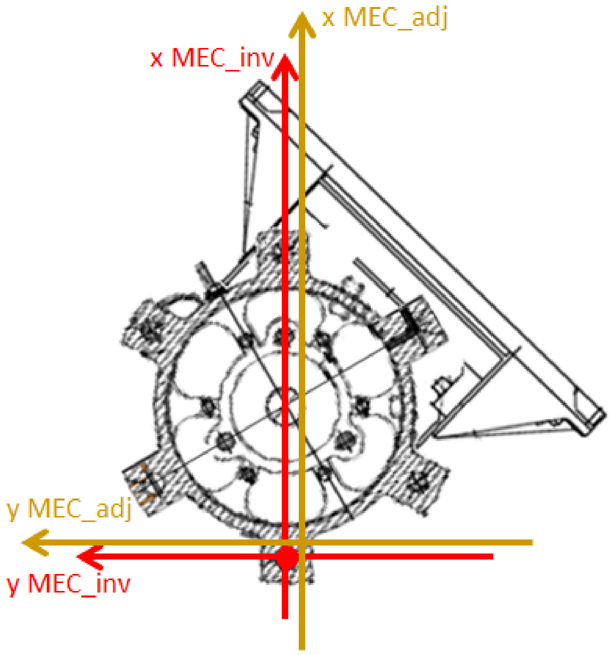

Figure 3.55. HRM2X Mechanical shim adjustment capability geometry

$$\Delta x_{adj} = radius_{hrmMEC} * cos(\theta) \tag{3.143}$$

$$\Delta y_{adj} = radius_{hrmMEC} * sin(\theta) \tag{3.144}$$

$$\begin{Bmatrix} x_{HRMMEC} \\ y_{HRMMEC} \\ z_{HRMMEC} \end{Bmatrix} = \begin{Bmatrix} x_{HRMSHIMA1} \\ y_{HRMSHIMA1} \\ z_{HRMSHIMA1} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} + \begin{Bmatrix} \Delta x_{adj} \\ \Delta y_{adj} \\ \Delta z_{adj} \end{Bmatrix} *_{hrmA1_{disp}} ()^{SAT} \tag{3.145}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN HRM MEC A1	1163.3	-965	1067
	$x_{HRMSHIM}$	$y_{HRMSHIM}$	$z_{HRMSHIM}$
ORIGIN HRM MEC A1	0	0	0

Table 3.113. HRM MEC A1 origin displacement for HRM1

ICD data	x_{MECA1}	y_{MECA1}	z_{MECA1}
ORIGIN HRM MEC B1	34	58.989	0
ORIGIN HRM MEC C1	102	58.989	0
ORIGIN HRM MEC D1	136	0	0
ORIGIN HRM MEC E1	102	-58.989	0
ORIGIN HRM MEC F1	34	-58.989	0

Table 3.114. HRM MEC holes origin respect to HRM A1 hole for HRM1

3.3.4 Lower separation plane

That reference system has the function to represent the rotation of the HRM2X around z HRM MEC axis. In deployed configuration LSP is the plane where the separation between the pod and the reflector interface is performed. In stowed position the HRM2X must be oriented correctly so that the two surfaces (HRM2X and reflector ones) could match without stress. In order to perform it, different rotation angles are provided for each HRM2X.

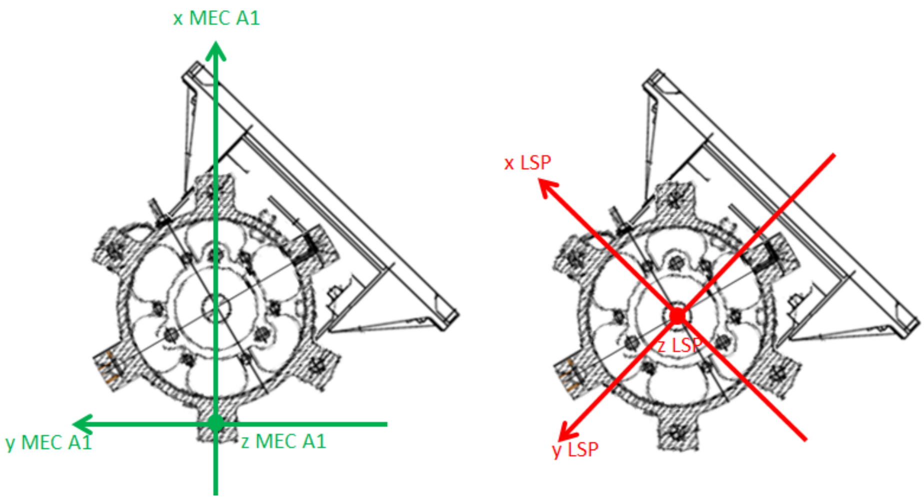

Figure 3.56. Lower separation plane - view 1

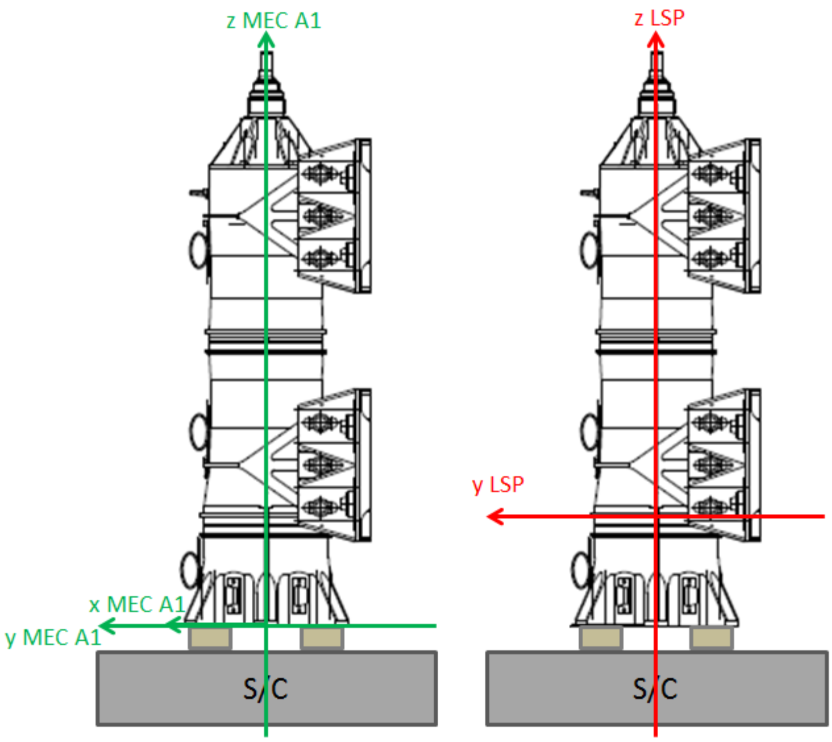

Figure 3.57. Lower separation plane - view 2

$$_{LSP_{inv}}()^{hrmMEC_{disp}} = \tag{3.146}$$

	x_{hrmMEC}	y_{hrmMEC}	z_{hrmMEC}
x_{LSP}	1.0000000	0.0000000	0.0000000
y_{LSP}	0.0000000	1.0000000	0.0000000
z_{LSP}	0.0000000	0.0000000	1.0000000

Table 3.115. Rotation matrix of LSP respect to hrm MEC reference system

ROTATION MATRIX FOR ADJUSTMENT CAPABILITY

$$_{LSP_{adj}}()^{LSP_{inv}} = R_z(\theta z) \tag{3.147}$$

	x_{LSPinv}	y_{LSPinv}	z_{LSPinv}
x_{LSPadj}	0.7071068	0.7071068	0.0000000
y_{LSPadj}	-0.7071068	0.7071068	0.0000000
z_{LSPadj}	0.0000000	0.0000000	1.0000000

Table 3.116. Rotation matrix of LSP adj respect to LSP inv reference system

$$_{LSP_{disp}}()^{SAT} =_{LSP_{disp}} ()^{LSP_{adj}} *_{LSP_{adj}} ()^{LSP_{inv}} *_{LSP_{inv}} ()^{hrmMEC_{disp}} *_{hrmMEC_{disp}} ()^{SAT} \tag{3.148}$$

	SAT	SAT	SAT
x_{LSP}	0.0000000	-0.7071068	0.7071068
y_{LSP}	0.0000000	-0.7071068	-0.7071068
z_{LSP}	1.0000000	0.0000000	0.0000000

Table 3.117. Rotation matrix of LSP respect to SAT reference system

ORIGIN DISPLACEMENT FOR HRM1

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LSP REF	1253.3	-965	1135
ICD data	$x_{HRMMECA1}$	$y_{HRMMECA1}$	$z_{HRMMECA1}$
ORIGIN LSP REF	68	0	90

Table 3.118. LSP origin displacement for HRM1

3.3.5 Lower centre HRM

That reference is used to compare the correct location and orientation of HRM2X refer to the reflector. Lower Centre HRM is here shortly called LCHRM. In order to match the LCHRM got by the HRM2X computation to the one computed by the ADPM2+ chain some adjustments are performed.

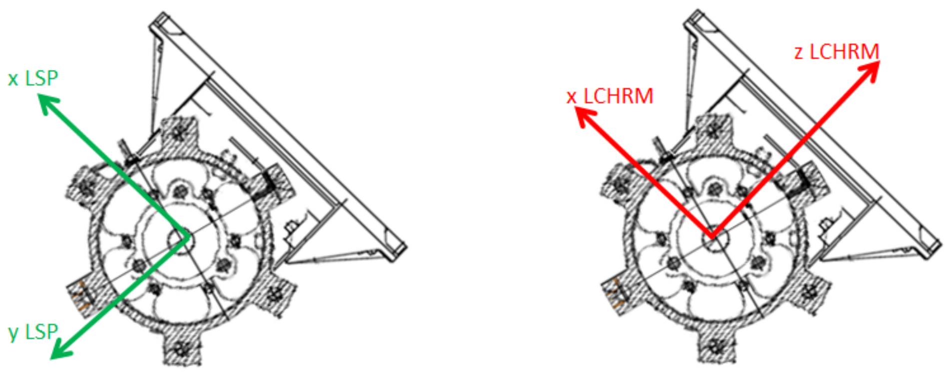

Figure 3.58. Lower CENTRE HRM reference system geometry - view 1

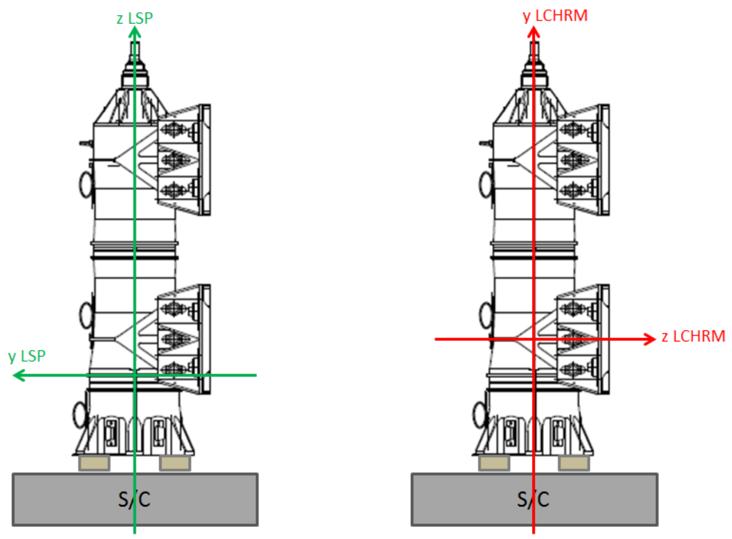

Figure 3.59. Lower CENTRE HRM reference system geometry - view 2

$$_{LCHRM_{inv}}()^{LSP_{disp}} = \tag{3.149}$$

	x_{LSP}	y_{LSP}	z_{LSP}
x_{LCHRM}	1.0000000	0.0000000	0.0000000
y_{LCHRM}	0.0000000	0.0000000	1.0000000
z_{LCHRM}	0.0000000	-1.0000000	0.0000000

Table 3.119. Rotation matrix of LCHRM respect to LSP reference system

ROTATION MATRICES FOR THE ADJUSTMENT CAPABILITIES

$$_{LCHRM_{adj1}}()^{LCHRM_{inv}} = R_x(\theta x) \tag{3.150}$$

$$_{LCHRM_{adj2}}()^{LCHRM_{adj1}} = R_z(\theta z) \tag{3.151}$$

$$\begin{aligned} _{LCHRM_{disp}}()^{SAT} = & _{LCHRM_{disp}}()^{LCHRM_{adj2}} * _{LCHRM_{adj2}}()^{LCHRM_{adj1}} \\ & * _{LCHRM_{adj1}}()^{LCHRM_{inv}} * _{LCHRM_{inv}}()^{LSP_{disp}} * _{LSP_{disp}}()^{SAT} \end{aligned} \tag{3.152}$$

	SAT	SAT	SAT
x_{LCHRM}	0.0000000	-0.7071068	0.7071068
y_{LCHRM}	1.0000000	0.0000000	0.0000000
z_{LCHRM}	0.0000000	0.7071068	0.7071068

Table 3.120. Rotation matrix of LCHRM respect to SAT reference system

ORIGIN DISPLACEMENT FOR HRM1

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LCHRM REF	1305.25	-965	1135
	x_{LSP}	y_{LSP}	z_{LSP}
ORIGIN LCHRM REF	0	0	51.95

Table 3.121. LCHRM origin displacement for HRM1

ADJSUTMENT CAPABILITIES IN LOCATION FOR LCHRM REFERENCE SYSTEM

These adjustment capabilities are defined in LCP reference system. They are performed in order to modify the single RCHRM origin location. For this reason the same adjustments are performed both for LCHRM reference system and both for UCHRM reference system. Here the explanation of these capabilities for LCHRM reference system.

Slotted holes

These slotted holes let an origin displacement along z LCP of maximum +/- 10 mm.

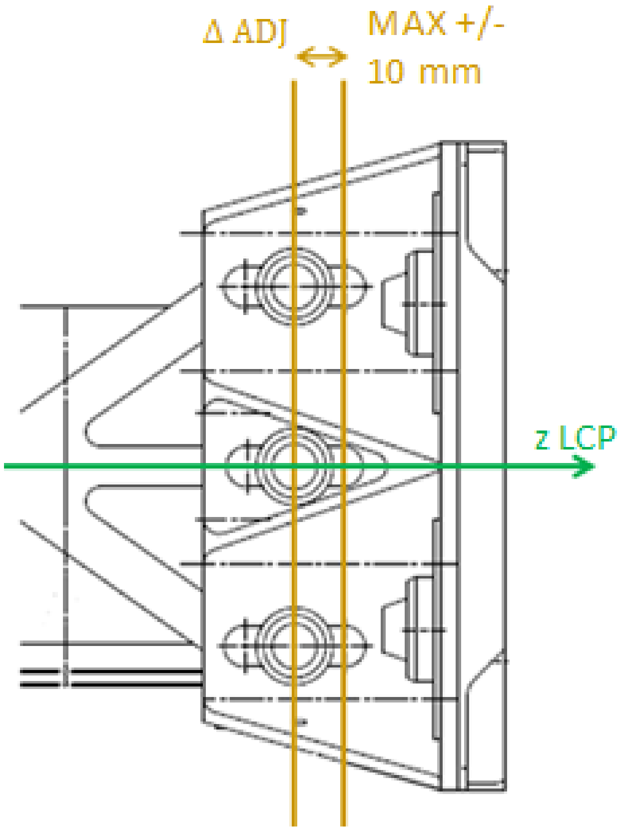

Figure 3.60. Slotted holes geometry for LCHRM adjustments

$$\begin{Bmatrix} x'_{LCHRM} \\ y'_{LCHRM} \\ z'_{LCHRM} \end{Bmatrix} = \begin{Bmatrix} x_{LCHRM} \\ y_{LCHRM} \\ z_{LCHRM} \end{Bmatrix} + \begin{Bmatrix} 0 \\ 0 \\ \Delta z_{adj} \end{Bmatrix} *_{LCP_{disp}} ()^{SAT} \tag{3.153}$$

Slotted washers

The adjustments are performed along x LCP and y LCP making a displacement maximum equal to a radius of 10 mm from the hole centre. These adjustments are computed in polar coordinates.

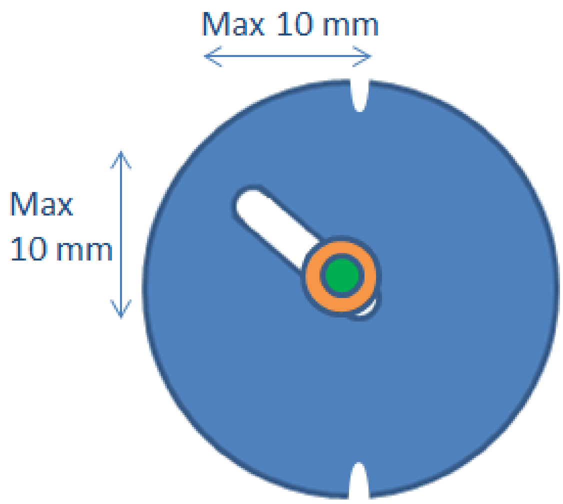

Figure 3.61. Slotted washers capabilities

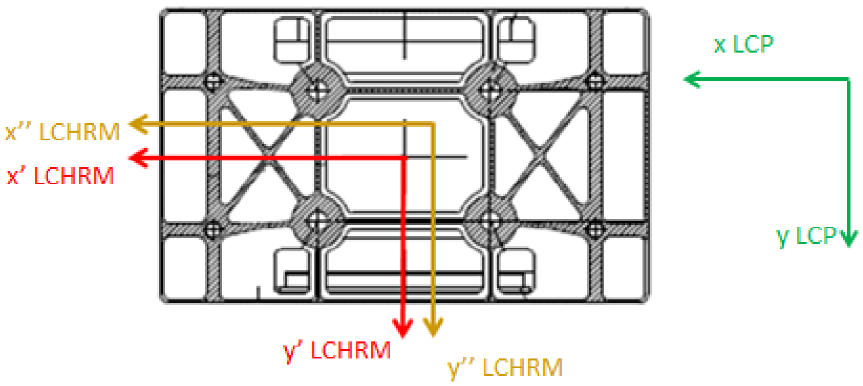

Figure 3.62. Slotted washers geometry for LCHRM adjustments

$$\Delta x_{adj} = radius_{LCHRM} * cos(\theta) \tag{3.154}$$

$$\Delta y_{adj} = radius_{LCHRM} * sin(\theta) \tag{3.155}$$

$$\begin{Bmatrix} x''_{LCHRM} \\ y''_{LCHRM} \\ z''_{LCHRM} \end{Bmatrix} = \begin{Bmatrix} x'_{LCHRM} \\ y'_{LCHRM} \\ z'_{LCHRM} \end{Bmatrix} + \begin{Bmatrix} \Delta x_{adj} \\ \Delta y_{adj} \\ 0 \end{Bmatrix} *_{LCP_{disp}} ()^{SAT} \tag{3.156}$$

3.3.6 Upper separation plane

In deployed configuration USP is the plane where the separation between the lower part of the HRM2X and the upper one is performed. USP axis result to be parallel to LSP axis. In stowed position the HRM2X must be oriented correctly so that the two surfaces (HRM2X and reflector ones) could match without stress. In order to perform it, different rotation angles are provided for each HRM2X.

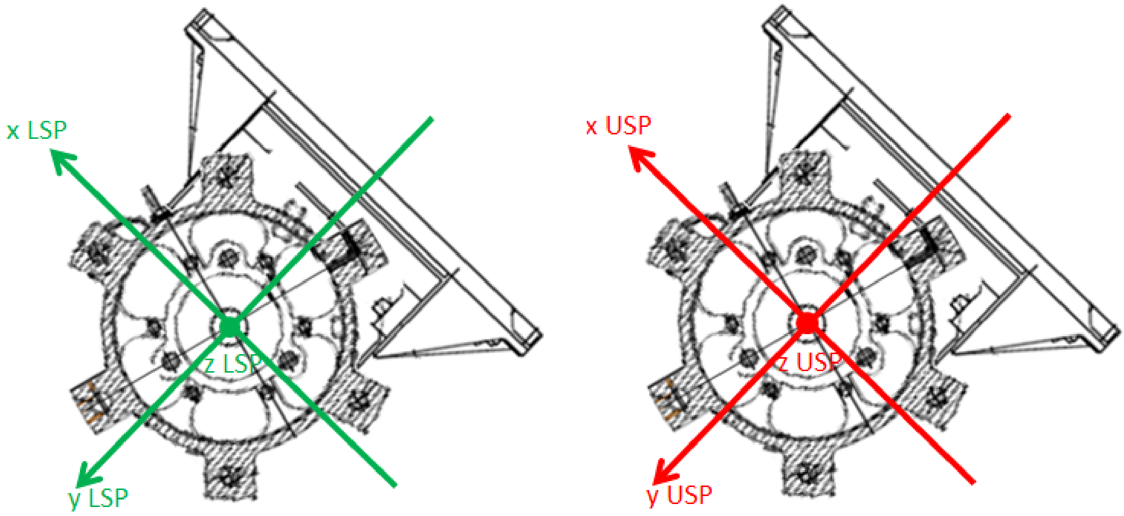

Figure 3.63. Upper separation plane - view 1

$$_{USP_{inv}}()^{LSP_{disp}} = \tag{3.157}$$

	x_{LSP}	y_{LSP}	z_{LSP}
x_{USP}	1.0000000	0.0000000	0.0000000
y_{USP}	0.0000000	1.0000000	0.0000000
z_{USP}	0.0000000	0.0000000	1.0000000

Table 3.122. Rotation matrix of USP respect to LSP reference system

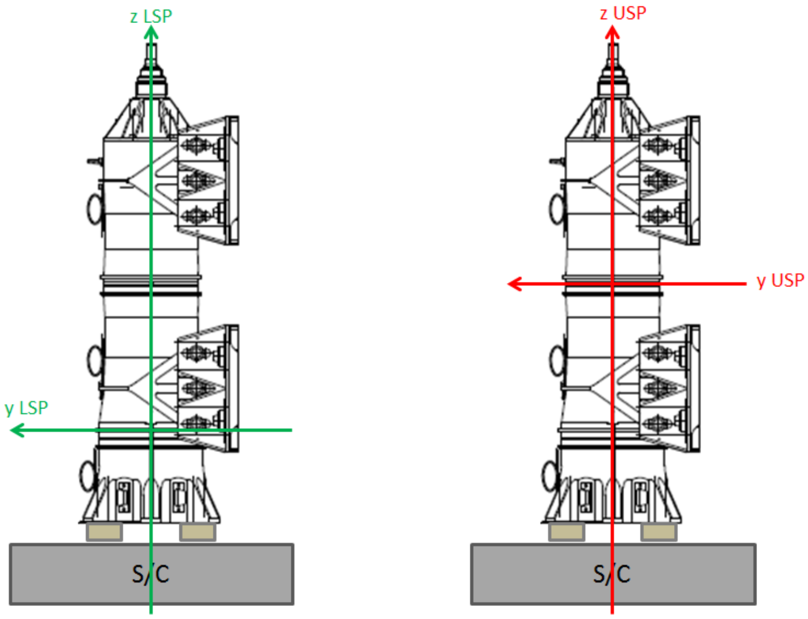

Figure 3.64. Upper separation plane - view 2

$$ {}_{USP_{disp}}()^{SAT} = {}_{USP_{disp}}()^{USP_{inv}} * {}_{USP_{inv}}()^{LSP_{disp}} * {}_{LSP_{disp}}()^{SAT} \tag{3.158} $$

	SAT	SAT	SAT
x_{USP}	0.0000000	-0.7071068	0.7071068
y_{USP}	0.0000000	-0.7071068	-0.7071068
z_{USP}	1.0000000	0.0000000	0.0000000

Table 3.123. Rotation matrix of USP respect to SAT reference system

ORIGIN DISPLACEMENT FOR HRM1

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN USP REF	1435.25	-965	1135
ICD data	x_{LSP}	y_{LSP}	z_{LSP}
ORIGIN USP REF	0	0	181.95

Table 3.124. USP origin displacement for HRM1

3.3.7 Upper centre HRM

That reference is used to compare the correct location and orientation of HRM2X refer to the reflector. UPPER Centre HRM is here shortly called UCHRM. In order to match the UCHRM got by the HRM2X computation to the one computed by the ADPM2+ chain some adjustments are performed.

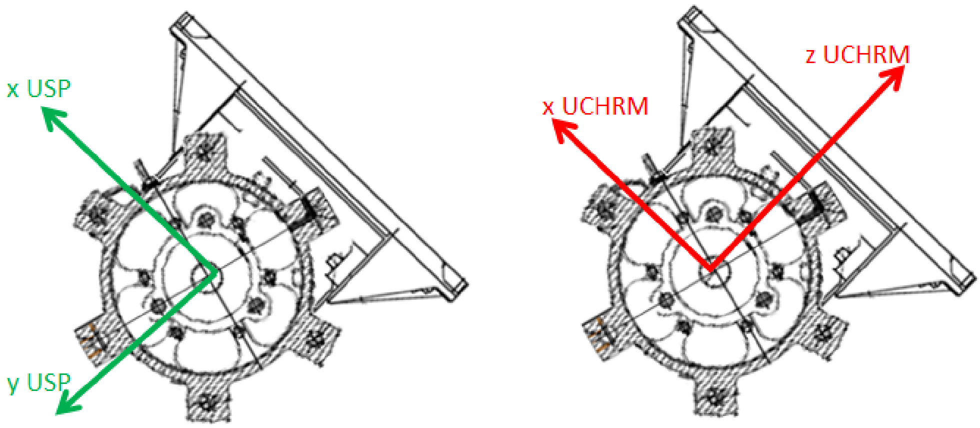

Figure 3.65. Upper CENTRE HRM reference system geometry - view 1

$$_{UCHRM_{inv}}()^{USP_{disp}} = \tag{3.159}$$

	x_{USP}	y_{USP}	z_{USP}
x_{UCHRM}	1.0000000	0.0000000	0.0000000
y_{UCHRM}	0.0000000	0.0000000	1.0000000
z_{UCHRM}	0.0000000	-1.0000000	0.0000000

Table 3.125. Rotation matrix of LCHRM respect to USP reference system

ROTATION MATRICES FOR THE ADJUSTMENT CAPABILITIES

$$_{UCHRM_{adj1}}()^{UCHRM_{inv}} = R_x(\theta x) \tag{3.160}$$

$$_{UCHRM_{adj2}}()^{UCHRM_{adj1}} = R_z(\theta z) \tag{3.161}$$

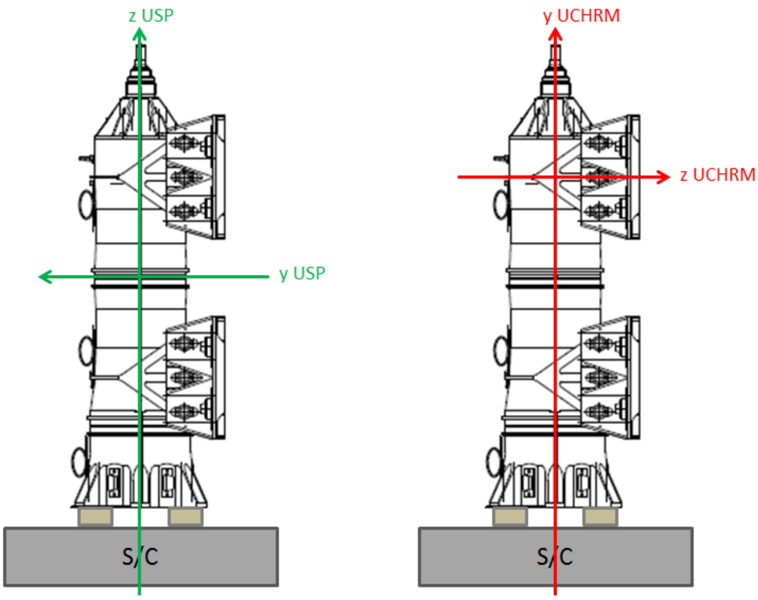

Figure 3.66. Upper CENTRE HRM reference system geometry - view 2

$$
\begin{aligned}
{}_{UCHRM_{disp}}()^{SAT} = & {}_{UCHRM_{disp}}()^{UCHRM_{adj2}} * {}_{UCHRM_{adj2}}()^{UCHRM_{adj1}} \\
& * {}_{UCHRM_{adj1}}()^{UCHRM_{inv}} * {}_{UCHRM_{inv}}()^{USP_{disp}} * {}_{USP_{disp}}()^{SAT}
\end{aligned} \tag{3.162}
$$

	SAT	SAT	SAT
x_{UCHRM}	0.0000000	-0.7071068	0.7071068
y_{UCHRM}	1.0000000	0.0000000	0.0000000
z_{UCHRM}	0.0000000	0.7071068	0.7071068

Table 3.126. Rotation matrix of UCHRM respect to SAT reference system

ORIGIN DISPLACEMENT FOR HRM1

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN UCHRM REF	1565.25	-965	1135
	x_{USP}	y_{USP}	z_{USP}
ORIGIN UCHRM REF	0	0	130

Table 3.127. UCHRM origin displacement for HRM1

ADJSUTMENT CAPABILITIES IN LOCATION FOR UCHRM REFERENCE SYSTEM

These adjustment capabilities are defined in UCP reference system. They are performed in order to modify the single RCHRM origin location. For this reason the same adjustments are performed both for LCHRM reference system and both for UCHRM reference system. Here the explanation of these capabilities for UCHRM reference system.

Slotted holes
These slotted holes let an origin displacement along z UCP of maximum +/- 10 mm.

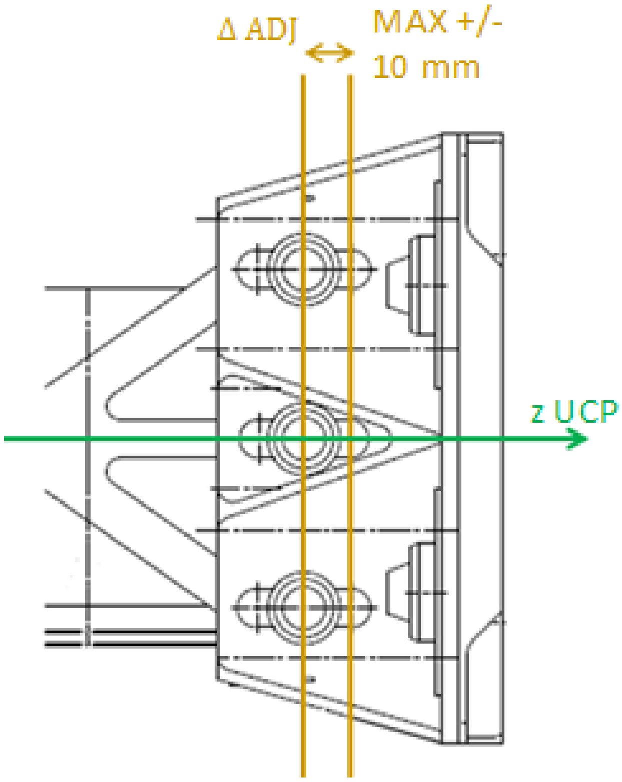

Figure 3.67. Slotted holes geometry for UCHRM adjustments

$$\begin{Bmatrix} x'_{UCHRM} \\ y'_{UCHRM} \\ z'_{UCHRM} \end{Bmatrix} = \begin{Bmatrix} x_{UCHRM} \\ y_{UCHRM} \\ z_{UCHRM} \end{Bmatrix} + \begin{Bmatrix} 0 \\ 0 \\ \Delta z_{adj} \end{Bmatrix} * UCP_{disp}\,()^{SAT} \tag{3.163}$$

Slotted washers

The adjustments are performed along x UCP and y UCP making a displacement maximum equal to a radius of 10 mm from the hole centre. These adjustments are computed in polar coordinates.

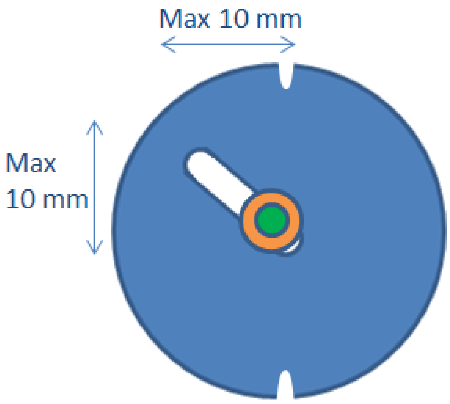

Figure 3.68. Slotted washers capabilities for UCHRM

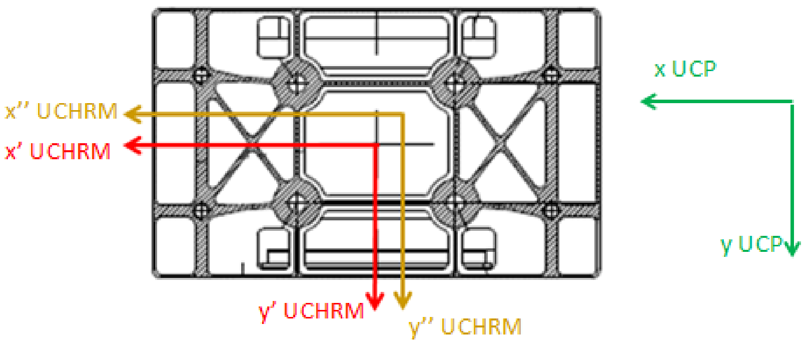

Figure 3.69. Slotted washers geometry for UCHRM adjustments

$$\Delta x_{adj} = radius_{UCHRM} * cos(\theta) \tag{3.164}$$

$$\Delta y_{adj} = radius_{UCHRM} * sin(\theta) \tag{3.165}$$

$$\begin{Bmatrix} x''_{UCHRM} \\ y''_{UCHRM} \\ z''_{UCHRM} \end{Bmatrix} = \begin{Bmatrix} x'_{UCHRM} \\ y'_{UCHRM} \\ z'_{UCHRM} \end{Bmatrix} + \begin{Bmatrix} \Delta x_{adj} \\ \Delta y_{adj} \\ 0 \end{Bmatrix} *_{UCP_{disp}} ()^{SAT} \tag{3.166}$$

3.4 Math Model for LLD

Orthonormal matrices are used in this program in order to build the mathematical model. Example data are given for LLD of Satellite B4A.

GLOSSARY USED FOR THE MATH MODEL:

R_z= rotation around z axis
R_y= rotation around y axis
R_x= rotation around x axis
'inv' = matrix without adjustments or defaults
'adj' = matrix with adjustments
'int' = intermediate matrix for machining computation
'mach' = final matrix for machining adjustment
'disp' = matrix with adjustments and defaults

SCHEME COLOR LEGEND:
Reference systems in RED are the final one, achieved by rotating the previous reference system in GREEN. While the reference systems in BROWN stand for the reference systems got by the adjustment capabilities.

3.4.1 Satellite axis

The reference axis system for the satellite is defined as follows:

- **Origin O** is situated in the centre of the launch ring at the base of the satellite;
- **Z axis** is pointing the Earth from O and it is perpendicular to the separation plane;
- **Y axis** is included in the separation plane and it is pointing, from O, a slot labeled +Y (in South direction)
- **X axis** forms a direct orthogonal axis system and it points towards East.

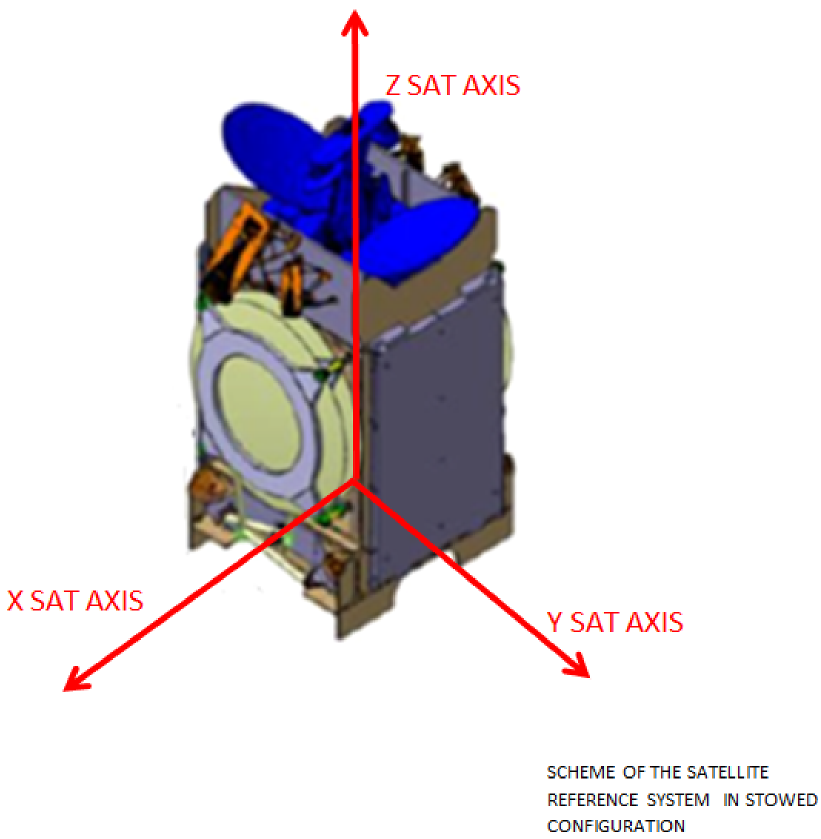

Figure 3.70. Satelite axis

3.4.2 LLD Peliable shims

This reference axis system is created in order to point out the variation of the layers' thickness. In fact, it is possible to displace the origin of the system through the peliable shims of maximum +/- 5 mm in z LLD SHIM L1 direction.

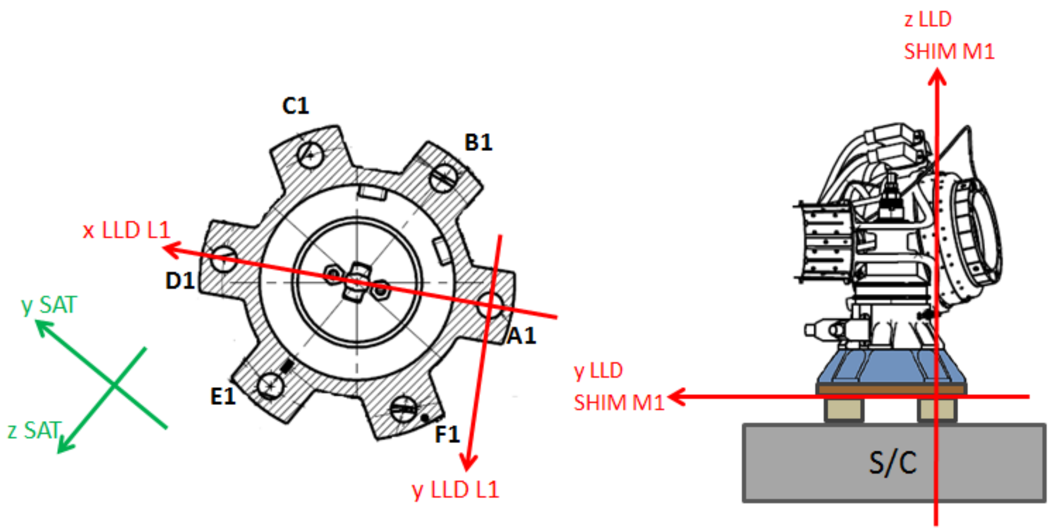

Figure 3.71. LLD peliable shim reference system geometry

$$_{lldshimL1_{inv}}()^{SAT} = R_z(\theta_z)*R_y(\theta_y) = \begin{pmatrix} cos(\theta_z) & sin(\theta_z) & 0 \\ -sin(\theta_z) & cos(\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} cos(\theta_y) & 0 & -sin(\theta_y) \\ 0 & 1 & 0 \\ sin(\theta_y) & cos(\theta_y) & 0 \end{pmatrix} \tag{3.167}$$

$$_{lldshimL1_{inv}}()^{SAT} = \tag{3.168}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{LLDSHIML1}$	0.0000000	0.8660254	0.5000000
$y_{LLDSHIML1}$	0.0000000	-0.5000000	0.8660254
$z_{LLDSHIML1}$	1.0000000	0.0000000	0.0000000

Table 3.128. Rotation matrix of LLD SHIM L1 peliable shim respect to satellite reference system

$$_{lldshimL1_{disp}}()^{SAT} =_{lldshimL1_{disp}} ()^{lldshimL1_{inv}} *_{lldshimL1_{inv}} ()^{SAT} \tag{3.169}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{LLDSHIML1}$	0.0000000	-0.8660254	0.5000000
$y_{LLDSHIML1}$	0.0000000	-0.5000000	-0.8660254
$z_{LLDSHIML1}$	1.0000000	0.0000000	0.0000000

Table 3.129. Rotation matrix of LLD shim L1 refers to satellite reference system

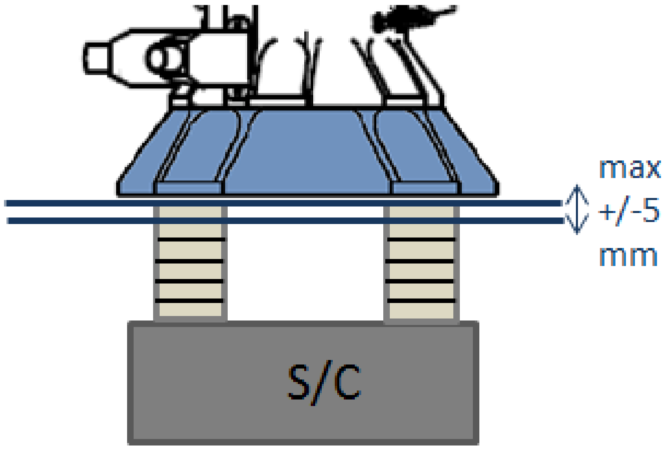

Figure 3.72. Peliable shims capabilities for LLD

ORIGIN DISPLACEMENT

$$\begin{Bmatrix} x_{LLDSHIML1} \\ y_{LLDSHIML1} \\ z_{LLDSHIML1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{Bmatrix} + \begin{Bmatrix} \Delta_{PELIABLESHIM} \\ 0 \\ 0 \end{Bmatrix} \tag{3.170}$$

IRD data	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LLD SHIM L1 REF	1370.5	-33.6529	548.6557

Table 3.130. Origin displacement for LLD

3.4.3 LLD Mechanical reference system

LLD MEC reference system stands for Mechanical reference system of the LLD. Its axis are parallel to LLD shim M1 reference system axis. The origin coincides with the previous one without defaults or adjustments. However, this reference system is also the result of the adjustment capability performed on the pod. In particular, they have effect on the origin position making a displacement maximum equal to a radius of 7 mm from the hole centre in the x − y MEC plane.

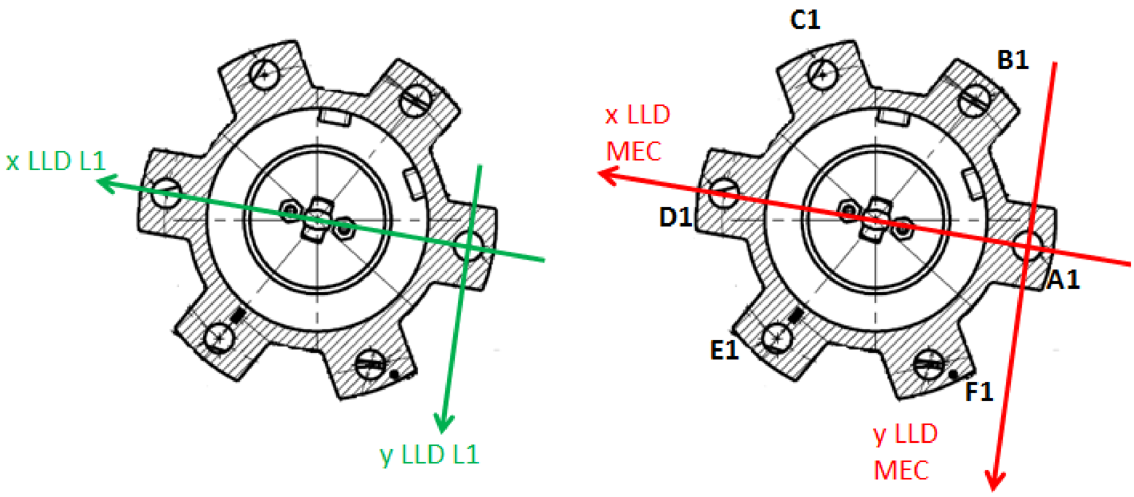

Figure 3.73. Mechanical shim geometry of LLD

$$
{}_{lldMEC_{inv}}()^{lldshimL1_{disp}} = \tag{3.171}
$$

	$x_{LLDshimL1}$	$y_{LLDshimL1}$	$z_{LLDshimL1}$
$x_{LLDMECL1}$	1.0000000	0.0000000	0.0000000
$y_{LLDMECL1}$	0.0000000	1.0000000	0.0000000
$z_{LLDMECL1}$	0.0000000	0.0000000	1.0000000

Table 3.131. Rotation matrix of LLD Mechanical shim L1 respect to LLD peliable shim L1 reference system

$$_{lldMEC_{disp}}()^{SAT} = _{lldMEC_{disp}}()^{lldMEC_{inv}} * _{lldMEC_{inv}}()^{lldshimL1_{disp}} * _{lldshimL1_{disp}}()^{SAT} \tag{3.172}$$

	x_{SAT}	y_{SAT}	z_{SAT}
$x_{LLDMECL1}$	0.0000000	-0.8660254	0.5000000
$y_{LLDMECL1}$	0.0000000	-0.5000000	-0.8660254
$z_{LLDMECL1}$	1.0000000	0.0000000	0.0000000

Table 3.132. Rotation matrix of LLD Mechanical shim respect to satellite reference system

ADJUSTMENT CAPABILITIES IN POLAR COORDINATES

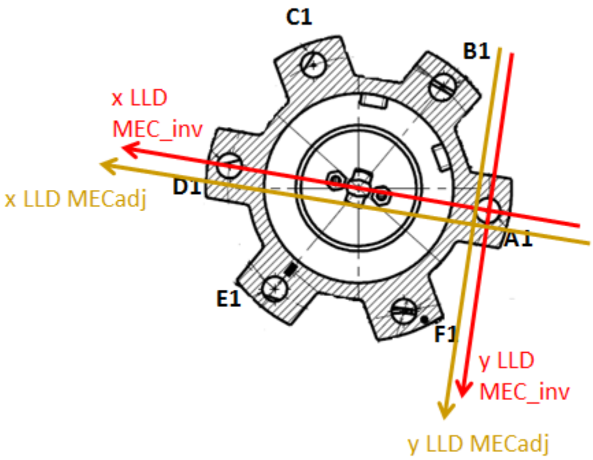

Figure 3.74. LLD Mechanical shim adjustment capability geometry

$$\Delta x_{adj} = radius_{LLDMEC} * cos(\theta) \tag{3.173}$$

$$\Delta y_{adj} = radius_{LLDMEC} * sin(\theta) \tag{3.174}$$

$$\begin{Bmatrix} x_{LLDMEC} \\ y_{LLDMEC} \\ z_{LLDMEC} \end{Bmatrix} = \begin{Bmatrix} x_{LLDSHIML1} \\ y_{LLDSHIML1} \\ z_{LLDSHIML1} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix} + \begin{Bmatrix} \Delta x_{adj} \\ \Delta y_{adj} \\ \Delta z_{adj} \end{Bmatrix} * _{LLDshimL1_{disp}}()^{SAT} \tag{3.175}$$

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LLD MEC A1	1370.5	-33.6529	548.6557
	$x_{LLDSHIML1}$	$y_{LLDSHIML1}$	$z_{LLDSHIML1}$
ORIGIN LLD MEC A1	0	0	0

Table 3.133. LLD MEC A1 origin displacement

	$x_{LLDMECL1}$	$y_{LLDMECL1}$	$z_{LLDMECL1}$
ORIGIN LLD MEC L2	22.500	38.971	0
ORIGIN LLD MEC L3	67.500	38.971	0
ORIGIN LLD MEC L4	90.000	0	0
ORIGIN LLD MEC L5	67.500	-38.971	0
ORIGIN LLD MEC L6	22.500	-38.971	0

Table 3.134. LLD MEC holes origin respect to LLD L1 hole

3.4.4 LLD CENTER reference system

That reference system is used to compare the difference in location between LLD reference system computed from the ADPM2+ chain and the LLD reference system got by LLD chain. The difference between them shall be corrected by the adjustment capabilities of the LLD.

$$_{lldCENTER_{inv}}()^{lldMEC_{disp}} = \tag{3.176}$$

	x_{LLDMEC}	y_{LLDMEC}	z_{LLDMEC}
$x_{LLDCENTER}$	1.0000000	0.0000000	0.0000000
$y_{LLDCENTER}$	0.0000000	1.0000000	0.0000000
$z_{LLDCENTER}$	0.0000000	0.0000000	1.0000000

Table 3.135. Rotation matrix of LLD CENTER respect to LLD MEC reference system

$$
\begin{aligned}
{}_{lldCENTER_{disp}}()^{SAT} = {}_{lldCENTER_{disp}}()^{lldCENTER_{inv}} \\
{}_{lldCENTER_{inv}}()^{lldMEC_{disp}} * {}_{lldMEC_{disp}}()^{SAT}
\end{aligned}
\tag{3.177}
$$

	SAT	SAT	SAT
$x_{LLDCENTER}$	0.0000000	-0.8660254	0.5000000
$y_{LLDCENTER}$	0.0000000	-0.5000000	-0.8660254
$z_{LLDCENTER}$	1.0000000	0.0000000	0.0000000

Table 3.136. Rotation matrix of LLD CENTER respect to SAT reference system

ORIGIN DISPLACEMENT

	x_{SAT}	y_{SAT}	z_{SAT}
ORIGIN LLD CENTER REF	1370.5	-72.624	548.6557
ICD data	x_{LLDMEC}	y_{LLDMEC}	z_{LLDMEC}
ORIGIN LLD CENTER REF	45	0	105

Table 3.137. LLD CENTER origin displacement

Chapter 4

Defaults input

This chapter deals with the insertion of the defaults in the ideal mathematical model of the entire system.

4.1 Statistical approach with Monte-Carlo method

In order to insert defaults in the model, a statistical approach is chosen, since their values are not fixed but defined in a range. A Monte-Carlo simulation [2] is performed for the need to evaluate several default matrices, that lead to reflector configurations displaced respect to the ideal one without defaults and uncertainties.
Firstly, the method requires to define the type of distributions for the input data. In particular, there are several types of distribution. Following the principal ones:

- **UNIFORM DISTRIBUTION** (or RECTANGULAR DISTRIBUTION):
  If the only available information regarding a quantity X is a lower limit a and an upper limit b with a < b, then, according to the principle of maximum entropy, a rectangular distribution R(a,b) over the interval [a,b] would be assigned to X. The probability density function (PDF), which is the derivative of the distribution function, for X is:

$$g_x(\xi) = \begin{Bmatrix} \frac{1}{b-a}, \, a \leq \xi \leq b \\ 0, \, otherwise \end{Bmatrix} \tag{4.1}$$

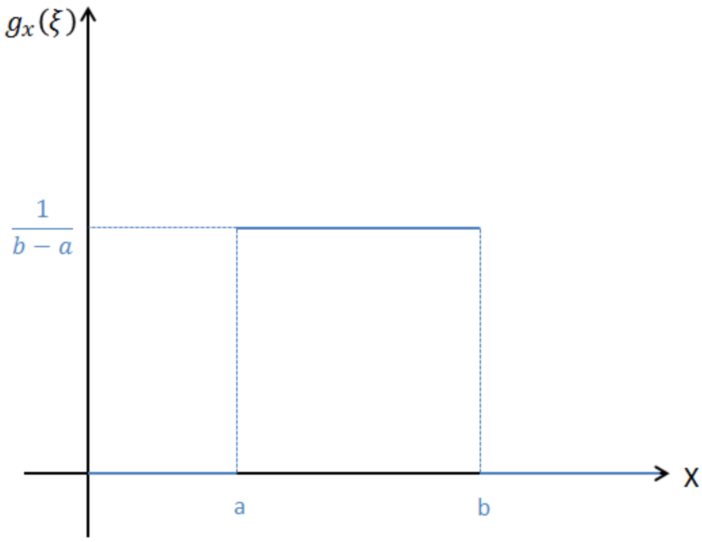

Figure 4.1. Uniform distribution

- **TRAPEZOIDAL DISTRIBUTION**
  Assigned when the available information is the sum of two quantities and, then, the lower limit a and the upper limit b are known;

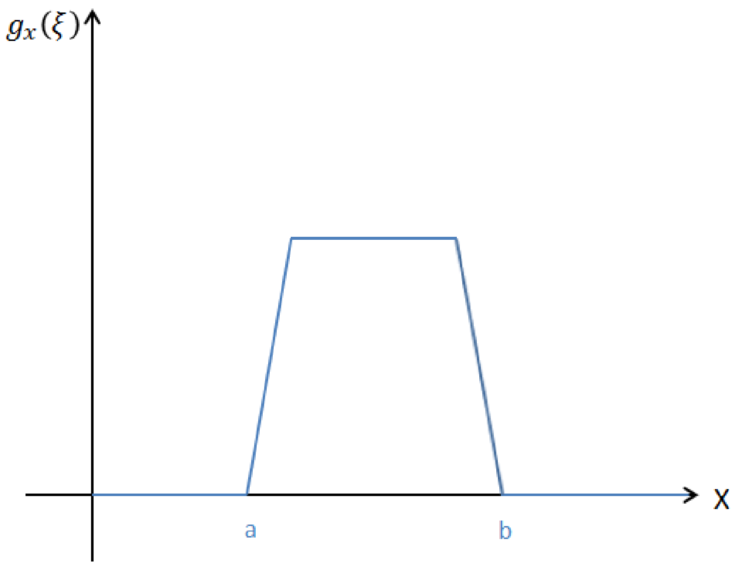

Figure 4.2. Trapezoidal distribution

- **GAUSSIAN DISTRIBUTION**
  The available information for that distribution is the best estimate x of the quantity X and its associated standard uncertainty u(x);

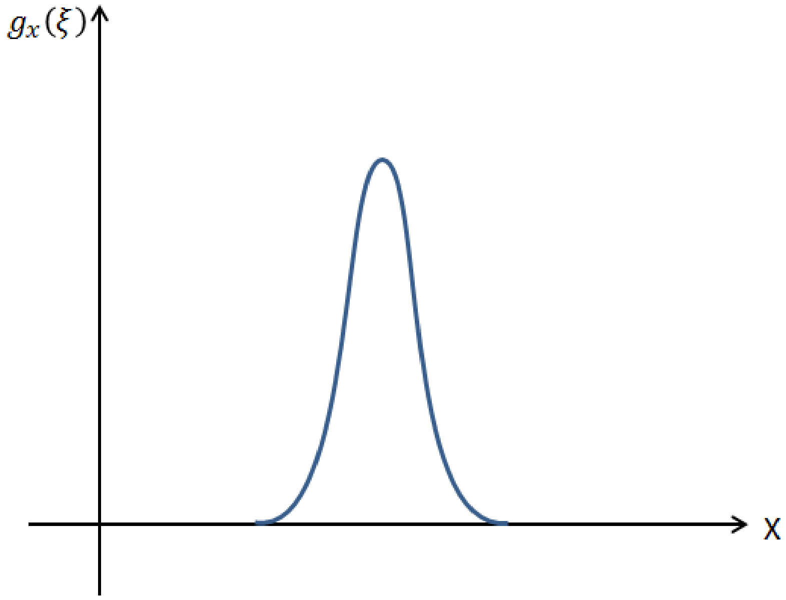

Figure 4.3. Gaussian distribution

Other distributions exists and each one should be chosen according to the case study.

In this study, an uniform distribution is chosen because for hypothesis there is no preference on the input data. That means the defaults values should cover all the ranges defined by the specifications without affecting the solver for the resolution of the problem. Moreover the uniform distribution is the simplest way to characterize the input and it does not require high computational power.
In the other hand, the Gaussian distribution has the advantage to not limit the defaults range. Moreover the Gaussian distribution is the most used since it represents physically the most of the phenomena.
The goal of the Monte-Carlo analysis is to reach the 95% coverage for the output quantity. However, that 5% remain could include the worst case.

4.2 Definition of the defaults values ranges

In order to verify the effect of the defaults on the final configuration, it is necessary to define a default in orientation and in location for each reference system[3]. The table 4.1 includes the defined specifications, called Subsystem Assembly Specifications. However, the information about all the specific reference systems is not defined. Regarding the intermediate reference systems the following hypothesis is supposed: all the intermediate reference systems are assumed to be equal to the subsystem assembly specifications.

TOLERANCES	**REFERENCE AXIS**	**MAX VALUE**	**REFERENCE SYSTEMS**
REFLECTOR MANUFACTURING TOLERANCES			
Reflector HRM fitting location error	X_V Y_V Z_V	S 3 mm	$[C_P/R_V]$
Reflector HRM fitting orientation error	X_V Y_V Z_V	0.5°	$[C_P/R_V]$
Reflector arm I/F error	X_V Y_V Z_V	S 2 mm	$[R_V/$RIF2]
Reflector arm I/F error	X_V Y_V Z_V	0.1°,0.1°,0.1°	$[R_V/$RIF2]
SATELLITE ASSEMBLY DEFAULTS AND IMPACTS			
ADPM2+ location error (integration on satellite)	X_{SAT}, Y_{SAT}, Z_{SAT}	1,1,1 mm	[MEC/SAT]
ADPM2+ orientation error (integration on satellite)	X_{SAT}, Y_{SAT}, Z_{SAT}	0.1°,0.1°,0.1°	[MEC/SAT]
HRM location error	X_{SAT}, Y_{SAT}, Z_{SAT}	1,1,1 mm	$[C_P/$SAT]

Table 4.1. SUBSYSTEM ASSEMBLY SPECIFICATIONS - PART 1

TOLERANCES	**REFERENCE AXIS**	**MAX VALUE**	**REFERENCE SYSTEMS**
ADPM2+ MANUFACTURING TOLERANCES			
Mechanism location error stowed and deployed configurations	X_{MEC}, Y_{MEC}, Z_{MEC}	S 3 mm	[RIF2/MEC]
Mechanism orientation error stowed and deployed configurations	X_{ROT1}, Y_{ROT1}, Z_{ROT1}	0.03°	[RUSI2/ROT1]
Mechanism orientation error stowed and deployed configurations	X_{MEC}, Y_{MEC}, Z_{MEC}	0.05°	[ROT1/FERR]
Mechanism parallelism error	X_{RIF2}, Y_{RIF2}, Z_{RIF2}	0.05°,0.05°	[RIF2/RUSI2]
LLD location error located at LLD pod interface	X_{MEC}, Y_{MEC}, Z_{MEC}	S 3 mm	[LLD/MEC]
LLD orientation error located at LLD pod interface	X_{LLD}, Y_{LLD}, Z_{LLD}	0.15°,0.15°	[LLD/LLD]
LLD MANUFACTURING TOLERANCES			
Mechanism location error*	X_{SAT}, Y_{SAT}, Z_{SAT}	1,1,1 mm	[LLD/SAT]
Mechanism orientation error*	X_{SAT}, Y_{SAT}, Z_{SAT}	0.1°,0.1°,0.1°	[LLD/SAT]

Table 4.2. SUBSYSTEM ASSEMBLY SPECIFICATIONS - PART 2

*ASSUMPTION DONE DUE TO INFORMATION LACK

Following the ADPM2+ scheme with all the default values.

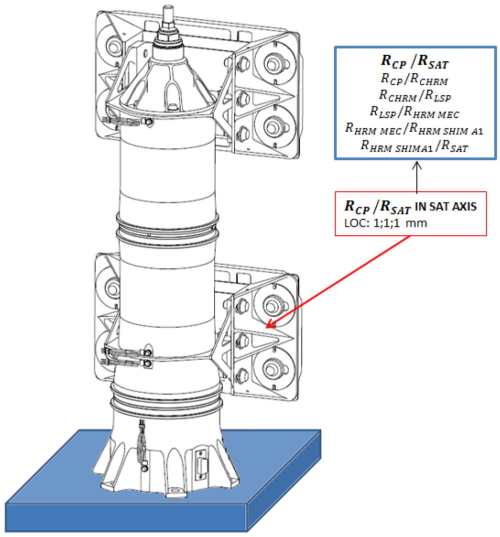

Figure 4.4. HRM2X Subsystem Assembly Specifications

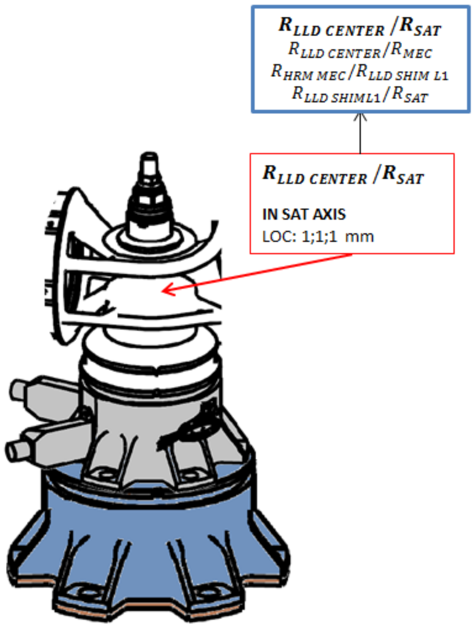

Figure 4.5. LLD Subsystem Assembly Specifications

As previously described, the table is not complete with all the defaults value. Watching to Figure 4.6, only the default specification in the red rectangles are given, while the

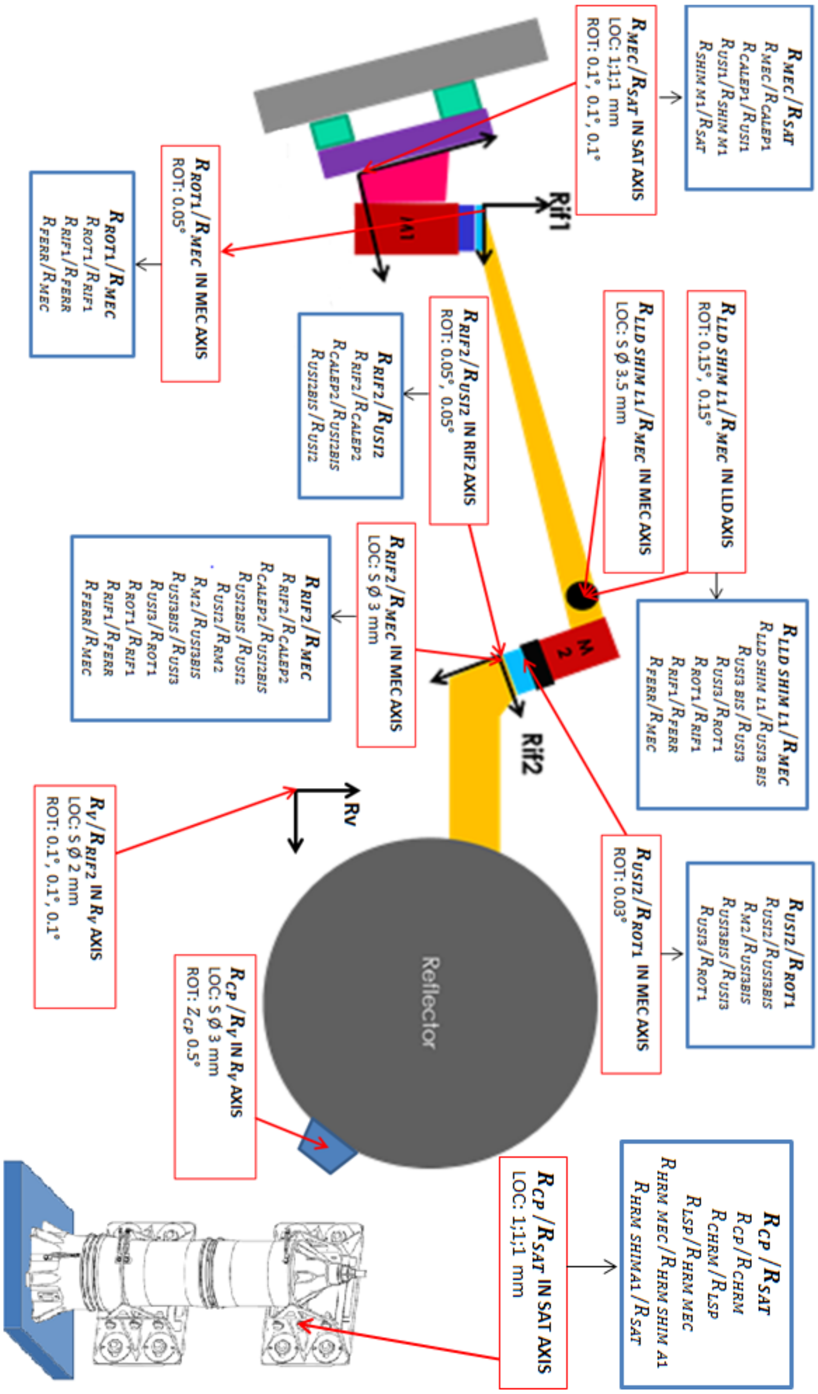

Figure 4.6. ADPM2+ Subsystem Assembly Specifications

defaults between the intermediate reference systems, listed in the blue rectangles, must be computed or supposed.

4.2.1 R_{MEC}/R_{SAT} default for ADPM2+

In location the maximum value is 1 mm along each Satellite axis. In orientation the maximum value is 0.1° around each Satellite axis. The default, which refers the Mechanical reference system to the Satellite one, has to be distributed along the intermediate reference systems.
Following the mathematical process used to introduce it.

DEFAULT FOR: R_{shimM1}/R_{SAT}
IN ORIENTATION:

$$_{shimM1_{disp}}()^{SAT} =_{shimM1_{disp}} ()^{shimM1_{inv}} *_{shimM1_{inv}} ()^{SAT} \tag{4.2}$$

Where $_{shimM1_{disp}}()^{shimM1_{inv}}$ is the default matrix computed by using three random angles around shimM1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \tag{4.3}$$

IN LOCATION

$$\begin{Bmatrix} x_{SHIMM1} \\ y_{SHIMM1} \\ z_{SHIMM1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{SATAXIS} \tag{4.4}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{SATAXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.5}$$

DEFAULT FOR: R_{USI1}/R_{SAT}
IN ORIENTATION:

$$_{USI1_{disp}}()^{SAT} =_{USI1_{disp}} ()^{USI1_{inv}} *_{USI1_{inv}} ()^{shimM1_{disp}} *_{shimM1_{disp}} ()^{SAT} \tag{4.6}$$

Where $_{USI1_{disp}}()^{USI1_{inv}}$ is the default matrix computed by using three random angles around USI1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \tag{4.7}$$

IN LOCATION

$$\begin{Bmatrix} x_{USI1} \\ y_{USI1} \\ z_{USI1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{shimM1} *_{shimM1_{disp}} ()^{SAT} \tag{4.8}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{shimM1AXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.9}$$

DEFAULT FOR: R_{CALEP1}/R_{SAT}
IN ORIENTATION:

$$_{CALEP1_{disp}}()^{SAT} =_{CALEP1_{disp}} ()^{CALEP1_{inv}} *_{CALEP1_{inv}} ()^{USI1_{disp}} *_{USI1_{disp}} ()^{SAT} \tag{4.10}$$

Where $_{CALEP1_{disp}}()^{CALEP1_{inv}}$ is the default matrix computed by using three random angles around CALEP1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \tag{4.11}$$

IN LOCATION

$$\begin{Bmatrix} x_{CALEP1} \\ y_{CALEP1} \\ z_{CALEP1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{USI1} *_{USI1_{disp}} ()^{SAT} \tag{4.12}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{USI1AXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.13}$$

DEFAULT FOR: R_{MEC}/R_{SAT}
IN ORIENTATION:

$$_{MEC_{disp}}()^{SAT} =_{MEC_{disp}} ()^{MEC_{inv}} *_{MEC_{inv}} ()^{CALEP1_{disp}} *_{CALEP1_{disp}} ()^{SAT} \tag{4.14}$$

Where $_{MEC_{disp}}()^{MEC_{inv}}$ is the default matrix computed by using three random angles around MEC axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \tag{4.15}$$

IN LOCATION

$$\begin{Bmatrix} x_{MEC} \\ y_{MEC} \\ z_{MEC} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{CALEP1} *_{CALEP1_{disp}} ()^{SAT} \tag{4.16}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{CALEP1AXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.17}$$

VERIFICATION OF THE SPECIFICATIONS
MEC0 reference system is now introduced in order to define the Mechanical reference system in case without defaults. The specifications require the displacement from the ideal configuration must be maximum 1 mm along each Satellite axis and maximum 0.1° around each Satellite axis.

$$_{SAT_{disp}}()^{SAT} =_{SAT_{disp}} ()^{MEC} *_{MEC} ()^{SAT} \tag{4.18}$$

Once achieved $_{SAT_{disp}}()^{SAT}$ it is possible computing the Euler angles from this matrix and

evaluate the displacement in orientation.
In location the difference between the ideal MEC reference and the MEC reference system including defaults leads to the displacement in location.

$$\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix} = \begin{Bmatrix} \Delta xMEC0 \\ \Delta yMEC0 \\ \Delta zMEC0 \end{Bmatrix}^{SATAXIS} - \begin{Bmatrix} \Delta xMEC \\ \Delta yMEC \\ \Delta zMEC \end{Bmatrix}^{SATAXIS} \tag{4.19}$$

4.2.2 R_{ROT1}/R_{MEC} orientation default for ADPM2+

In orientation a maximum angle of 0.05° between axis 1 of Motor 1 and R_{MEC} is permitted.
DEFAULT FOR: R_{FERR}/R_{SAT}
IN ORIENTATION:

$$_{FERR_{disp}}()^{SAT} =_{FERR_{disp}} ()^{FERR_{inv}} *_{FERR_{inv}} ()^{MEC_{disp}} *_{MEC_{disp}} ()^{SAT} \tag{4.20}$$

Where $_{CALEP1_{disp}}()^{CALEP1_{inv}}$ is the default matrix computed by using three random angles around FERR axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.05^\circ < \theta_x < 0.05^\circ, -0.05^\circ < \theta_y < 0.05^\circ, -0.05^\circ < \theta_z < 0.05^\circ \tag{4.21}$$

DEFAULT FOR: R_{IF1}/R_{SAT}
IN ORIENTATION:

$$_{RIF1_{disp}}()^{SAT} =_{RIF1_{disp}} ()^{RIF1_{inv}} *_{RIF1_{inv}} ()^{FERR_{disp}} *_{FERR_{disp}} ()^{SAT} \tag{4.22}$$

Where $_{RIF1_{disp}}()^{RIF1_{inv}}$ is the default matrix computed by using three random angles around RIF1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.05^\circ < \theta_x < 0.05^\circ, -0.05^\circ < \theta_y < 0.05^\circ, -0.05^\circ < \theta_z < 0.05^\circ \tag{4.23}$$

DEFAULT FOR: R_{ROT1}/R_{SAT}
IN ORIENTATION:

$$_{ROT1_{disp}}()^{SAT} =_{ROT1_{disp}} ()^{ROT1_{inv}} *_{ROT1_{inv}} ()^{RIF1_{disp}} *_{RIF1_{disp}} ()^{SAT} \tag{4.24}$$

Where $_{ROT1_{disp}}()^{ROT1_{inv}}$ is the default matrix computed by using three random angles around ROT1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.05° < \theta_x < 0.05°, -0.05° < \theta_y < 0.05°, -0.05° < \theta_z < 0.05° \tag{4.25}$$

VERIFICATION OF THE SPECIFICATIONS
In order to verify the tolerance on the angle between the two axis the following computation is performed:

$$_{ROT1_{disp}}()^{MEC_{disp}} =_{ROT1_{disp}} ()^{SAT} *_{SAT} ()^{MEC_{disp}} \tag{4.26}$$

$$\overrightarrow{z_{MEC}} * \overrightarrow{z_{ROT1}} = |z_{MEC}| * |z_{ROT1}| * cos\delta \tag{4.27}$$

Where δ is the angle between $\overrightarrow{z_{MEC}}$ and $\overrightarrow{z_{ROT1}}$, respectively z axis of MECHANICAL reference system and ROT 1 reference system.
Since the vectors are unit vectors, the angle is possible to compute as following:

$$\delta = cos^{-1}(\overrightarrow{z_{MEC}} * \overrightarrow{z_{ROT1}}) \tag{4.28}$$

The difference between δ in the ideal configuration and in that one with defaults, the displacement in orientation is achieved:

$$\Delta\delta = \delta_{ideal} - \delta_{defaults} \tag{4.29}$$

Where $\Delta\delta$ must respect the specification: $-0.05° < \Delta\delta < 0.05°$.

4.2.3 R_{USI2}/R_{ROT1} orientation default for ADPM2+

In orientation a maximum angle of 0.03° between axis 1 of Motor 1 and axis of Motor 2 is permitted.

DEFAULT FOR: R_{USI3}/R_{SAT}
IN ORIENTATION:

$$ {}_{USI3_{disp}}()^{SAT} = {}_{USI3_{disp}}()^{USI3_{inv}} * {}_{USI3_{inv}}()^{ROT1_{disp}} * {}_{ROT1_{disp}}()^{SAT} \tag{4.30} $$

Where ${}_{USI3_{disp}}()^{USI3_{inv}}$ is the default matrix computed by using three random angles around USI3 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$ -0.03^\circ < \theta_x < 0.03^\circ, -0.03^\circ < \theta_y < 0.03^\circ, -0.03^\circ < \theta_z < 0.03^\circ \tag{4.31} $$

DEFAULT FOR: $R_{USI3BIS}/R_{SAT}$
IN ORIENTATION:

$$ {}_{USI3BIS_{disp}}()^{SAT} = {}_{USI3BIS_{disp}}()^{USI3BIS_{inv}} * {}_{USI3BIS_{inv}}()^{USI3_{disp}} * {}_{USI3_{disp}}()^{SAT} \tag{4.32} $$

Where ${}_{USI3BIS_{disp}}()^{USI3BIS_{inv}}$ is the default matrix computed by using three random angles around USI3BIS axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$ -0.03^\circ < \theta_x < 0.03^\circ, -0.03^\circ < \theta_y < 0.03^\circ, -0.03^\circ < \theta_z < 0.03^\circ \tag{4.33} $$

DEFAULT FOR: R_{M2}/R_{SAT}
IN ORIENTATION:

$$ {}_{RM2_{disp}}()^{SAT} = {}_{RM2_{disp}}()^{RM2_{inv}} * {}_{RM2_{inv}}()^{USI3BIS_{disp}} * {}_{USI3BIS_{disp}}()^{SAT} \tag{4.34} $$

Where ${}_{RM2_{disp}}()^{RM2_{inv}}$ is the default matrix computed by using three random angles around RM2 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$ -0.03^\circ < \theta_x < 0.03^\circ, -0.03^\circ < \theta_y < 0.03^\circ, -0.03^\circ < \theta_z < 0.03^\circ \tag{4.35} $$

DEFAULT FOR: R_{USI2}/R_{SAT}
IN ORIENTATION:

$$_{USI2_{disp}}()^{SAT} =_{USI2_{disp}} ()^{USI2_{inv}} *_{USI2_{inv}} ()^{RM2_{disp}} *_{RM2_{disp}} ()^{SAT} \tag{4.36}$$

Where $_{USI2_{disp}}()^{USI2_{inv}}$ is the default matrix computed by using three random angles around USI2 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.03° < \theta_x < 0.03°, -0.03° < \theta_y < 0.03°, -0.03° < \theta_z < 0.03° \tag{4.37}$$

VERIFICATION OF THE SPECIFICATIONS
In order to verify the tolerance on the angle between the two axis the following computation is performed:

$$_{USI2_{disp}}()^{ROT1_{disp}} =_{USI2_{disp}} ()^{SAT} *_{SAT} ()^{ROT1_{disp}} \tag{4.38}$$

$$\overrightarrow{z_{ROT1}} * \overrightarrow{z_{USI2}} = |z_{ROT1}| * |z_{USI2}| * cos\delta \tag{4.39}$$

Where δ is the angle between $\overrightarrow{z_{ROT1}}$ and $\overrightarrow{z_{USI2}}$, respectively z axis of ROT1 reference system and USI2 reference system.
Since the vectors are unit vectors, the angle is possible to compute as following:

$$\delta = cos^{-1}(\overrightarrow{z_{ROT1}} * \overrightarrow{z_{USI2}}) \tag{4.40}$$

The difference between δ in the ideal configuration and in that one with defaults, the displacement in orientation is achieved:

$$\Delta\delta = \delta_{ideal} - \delta_{defaults} \tag{4.41}$$

Where $\Delta\delta$ must respect the specification: $-0.03° < \Delta\delta < 0.03°$.

4.2.4 R_{IF2}/R_{USI2} orientation default for ADPM2+

In orientation a maximum angle of 0.05° between axis 1 of Motor 1 and R_{MEC} is permitted.

DEFAULT FOR: $R_{USI2BIS}/R_{SAT}$
IN ORIENTATION:

$$_{USI2BIS_{disp}}()^{SAT} =_{USI2BIS_{disp}} ()^{USI2BIS_{inv}} *_{USI2BIS_{inv}} ()^{USI2_{disp}} *_{USI2_{disp}} ()^{SAT} \quad (4.42)$$

Where $_{USI2BIS_{disp}}()^{USI2BIS_{inv}}$ is the default matrix computed by using three random angles around USI2BIS axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.05^\circ < \theta_x < 0.05^\circ, -0.05^\circ < \theta_y < 0.05^\circ, -0.05^\circ < \theta_z < 0.05^\circ \quad (4.43)$$

DEFAULT FOR: R_{CALEP2}/R_{SAT}
IN ORIENTATION:

$$_{CALEP2_{disp}}()^{SAT} =_{CALEP2_{disp}} ()^{CALEP2_{inv}} *_{CALEP2_{inv}} ()^{USI2BIS_{disp}} *_{USI2BIS_{disp}} ()^{SAT} \quad (4.44)$$

Where $_{CALEP2_{disp}}()^{CALEP2_{inv}}$ is the default matrix computed by using three random angles around CALEP2 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.05^\circ < \theta_x < 0.05^\circ, -0.05^\circ < \theta_y < 0.05^\circ, -0.05^\circ < \theta_z < 0.05^\circ \quad (4.45)$$

DEFAULT FOR: R_{IF2}/R_{SAT}
IN ORIENTATION:

$$_{RIF2_{disp}}()^{SAT} =_{RIF2_{disp}} ()^{RIF2_{inv}} *_{RIF2_{inv}} ()^{CALEP2_{disp}} *_{CALEP2_{disp}} ()^{SAT} \quad (4.46)$$

Where $_{RIF2_{disp}}()^{RIF2_{inv}}$ is the default matrix computed by using three random angles around RIF2 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.05^\circ < \theta_x < 0.05^\circ, -0.05^\circ < \theta_y < 0.05^\circ, -0.05^\circ < \theta_z < 0.05^\circ \quad (4.47)$$

VERIFICATION OF THE SPECIFICATIONS
In order to verify the tolerance on the angle between the two axis the following computation is performed:

$$_{RIF2_{disp}}()^{USI2_{disp}} =_{RIF2_{disp}} ()^{SAT} *_{SAT} ()^{USI2_{disp}} \tag{4.48}$$

$$\overrightarrow{z_{USI2}} * \overrightarrow{x_{RIF2}} = |z_{USI2}| * |x_{RIF2}| * cos\delta \tag{4.49}$$

$$\overrightarrow{z_{USI2}} * \overrightarrow{y_{RIF2}} = |z_{USI2}| * |y_{RIF2}| * cos\gamma \tag{4.50}$$

Where δ is the angle between $\overrightarrow{z_{USI2}}$ and $\overrightarrow{x_{RIF2}}$, respectively z axis of USI2 reference system and x axis of RIF2reference system. While γ is the angle between $\overrightarrow{z_{USI2}}$ and $\overrightarrow{y_{RIF2}}$, respectively z axis of USI2 reference system and y axis of RIF2 reference system.
Since the vectors are unit vectors, the angle is possible to compute as following:

$$\delta = cos^{-1}(\overrightarrow{z_{USI2}} * \overrightarrow{x_{RIF2}}) \tag{4.51}$$

$$\gamma = cos^{-1}(\overrightarrow{z_{USI2}} * \overrightarrow{y_{RIF2}}) \tag{4.52}$$

The difference between δ and γ in the ideal configuration and in that one with defaults, the displacement in orientation is achieved:

$$\Delta\delta = \delta_{ideal} - \delta_{defaults} \tag{4.53}$$

$$\Delta\gamma = \gamma_{ideal} - \gamma_{defaults} \tag{4.54}$$

Where $\Delta\delta$ and $\Delta\gamma$ must respect the specification: $-0.05° < \Delta\delta < 0.05°$ and $-0.05° < \Delta\gamma < 0.05°$

4.2.5 R_{IF2}/R_{MEC} location default for ADPM2+

In location the maximum value is a spherical radius of 3 mm along each MECHANICAL reference axis.
IN LOCATION

$$\begin{Bmatrix} x_{FERR} \\ y_{FERR} \\ z_{FERR} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{MEC} *_{MEC_{disp}} ()^{SAT} \tag{4.55}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{MECAXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$\Delta x = RADIUS * sin(\alpha) * cos(\beta) \quad (4.56)$$

$$\Delta y = RADIUS * sin(\alpha) * sin(\beta) \quad (4.57)$$

$$\Delta z = RADIUS * cos(\alpha) \quad (4.58)$$

Where: $-3mm < RADIUS < 3mm, 0 < \alpha < 360°, 0 < \beta < 360°$.

This mathematical process is repeated for all the reference systems between MECHANICAL reference system and RIF2 reference system.

VERIFICATION OF THE SPECIFICATIONS

In order to verify the tolerance in location between the two axis the following computation is performed:

$$\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix} = \begin{Bmatrix} \Delta xRIF2_{ideal} \\ \Delta yRIF2_{ideal} \\ \Delta zRIF2_{ideal} \end{Bmatrix}^{MECAXIS} - \begin{Bmatrix} \Delta xRIF2 \\ \Delta yRIF2 \\ \Delta zRIF2 \end{Bmatrix}^{MECAXIS} \quad (4.59)$$

Where these defaults must respect the following specification:

$$\sqrt{(\Delta xDEFAULT)^2 + \Delta yDEFAULT)^2 + \Delta zDEFAULT)^2} < 3mm \quad (4.60)$$

4.2.6 R_{VD}/R_{IF2} default for ADPM2+

In location the maximum value is a spherical radius of 3 mm along each RVD reference axis. In orientation the maximum value is 0.1° around each RVD axis.
Following the mathematical process used to introduce it.

IN ORIENTATION:

$$_{RVD_{disp}}()^{SAT} =_{RVD_{disp}} ()^{RVD_{inv}} *_{RVD_{inv}} ()^{RIF2_{disp}} *_{RIF2_{disp}} ()^{SAT} \quad (4.61)$$

Where $_{RVD_{disp}}()^{RVD_{inv}}$ is the default matrix computed by using three random angles around RVD axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1° < \theta_x < 0.1°, -0.1° < \theta_y < 0.1°, -0.1° < \theta_z < 0.1° \quad (4.62)$$

IN LOCATION

$$\begin{Bmatrix} x_{RVD} \\ y_{RVD} \\ z_{RVD} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RIF2} *_{RIF2_{disp}}()^{SAT} \quad (4.63)$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RIF2AXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$\Delta x = RADIUS * sin(\alpha) * cos(\beta) \quad (4.64)$$

$$\Delta y = RADIUS * sin(\alpha) * sin(\beta) \quad (4.65)$$

$$\Delta z = RADIUS * cos(\alpha) \quad (4.66)$$

Where: $-2mm < RADIUS < 2mm, 0 < \alpha < 360°, 0 < \beta < 360°$.

4.2.7 R_{CP}/R_{VS} orientation default for ADPM2+

In location the maximum value is a spherical radius of 3 mm along each RVS reference axis. In orientation the maximum value is 0.5° around each RVS axis.
Following the mathematical process used to introduce it.

IN ORIENTATION:

$$_{RCP_{disp}}()^{SAT} = _{RCP_{disp}}()^{RCP_{inv}} *_{RCP_{inv}}()^{RVS_{disp}} *_{RVS_{disp}}()^{SAT} \quad (4.67)$$

Where $_{RCP_{disp}}()^{RCP_{inv}}$ is the default matrix computed by using three random angles around RCP axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.5° < \theta_x < 0.5°, -0.5° < \theta_y < 0.5°, -0.5° < \theta_z < 0.5° \quad (4.68)$$

IN LOCATION

$$\begin{Bmatrix} x_{RCP} \\ y_{RCP} \\ z_{RCP} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RVS} *_{RVS_{disp}}()^{SAT} \quad (4.69)$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RVSAXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$\Delta x = RADIUS * sin(\alpha) * cos(\beta) \quad (4.70)$$

$$\Delta y = RADIUS * sin(\alpha) * sin(\beta) \quad (4.71)$$

$$\Delta z = RADIUS * cos(\alpha) \quad (4.72)$$

Where: $-3mm < RADIUS < 3mm, 0 < \alpha < 360°, 0 < \beta < 360°$.

4.2.8 $R_{lldSHIML1}/R_{MEC}$ default for ADPM2+

In location the maximum value is a spherical radius of 3.5 mm along each MEC reference axis. In orientation the maximum value is 0.15° around each LLD L1 axis. The default, which refers the LLD L1 reference system to the MECHANICAL one, has to be distributed along the intermediate reference systems.
Following the mathematical process used to introduce it.

DEFAULT FOR: $R_{lldSHIML1}/R_{USI3BIS}$

IN ORIENTATION:

$$_{shimL1_{disp}}()^{SAT} =_{shimL1_{disp}} ()^{shimL1_{inv}} *_{shimL1_{inv}} ()^{USI3BIS_{disp}} *_{USI3BIS_{disp}} ()^{SAT} \quad (4.73)$$

Where $_{shimL1_{disp}}()^{shimL1_{inv}}$ is the default matrix computed by using three random angles around lld SHIM L1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.15° < \theta_x < 0.15°, -0.15° < \theta_y < 0.15°, -0.15° < \theta_z < 0.15° \quad (4.74)$$

IN LOCATION

$$\begin{Bmatrix} x_{lldSHIML1} \\ y_{lldSHIML1} \\ z_{lldSHIML1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{USI3BIS} *_{USI3BIS}()^{SAT} \quad (4.75)$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{USI3BIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$\Delta x = RADIUS * sin(\alpha) * cos(\beta) \quad (4.76)$$

$$\Delta y = RADIUS * sin(\alpha) * sin(\beta) \quad (4.77)$$

$$\Delta z = RADIUS * cos(\alpha) \quad (4.78)$$

Where: $-3.5mm < RADIUS < 3.5mm, 0 < \alpha < 360°, 0 < \beta < 360°$.

VERIFICATION OF THE SPECIFICATIONS

The specifications require the displacement from the ideal configuration must be maximum 0.15° around each LLD shim L1 axis.

$$_{shimL1_{disp}}()^{MEC_{disp}} =_{shimL1_{disp}} ()^{SAT} *_{SAT} ()^{MEC_{disp}} \quad (4.79)$$

$$_{shimL1_0}()^{MEC_0} =_{shimL1_0} ()^{SAT} *_{SAT} ()^{MEC_0} \quad (4.80)$$

$$_{shimL1_{disp}}()^{shimL1_0} =_{shimL1_{disp}} ()^{MEC_{disp}} *_{MEC_0} ()^{shimL1_0} \quad (4.81)$$

Once achieved $_{shimL1_{disp}}()^{shimL1_0}$ it is possible computing the Euler angles from this matrix and evaluate the displacement in orientation.
In order to verify the tolerance in location between the two reference systems the following computation is performed:

$$\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix} = \begin{Bmatrix} \Delta xLLDshimL1_{ideal} \\ \Delta yLLDshimL1_{ideal} \\ \Delta zLLDshimL1_{ideal} \end{Bmatrix}^{LLDshimL1} - \begin{Bmatrix} \Delta xLLDshimL1 \\ \Delta yLLDshimL1 \\ \Delta zLLDshimL1 \end{Bmatrix}^{LLDshimL1} \tag{4.82}$$

Where these defaults must respect the following specification:

$$\sqrt{(\Delta xDEFAULT)^2 + \Delta yDEFAULT)^2 + \Delta zDEFAULT)^2} < 3.5mm \tag{4.83}$$

4.2.9 R_{CP}/R_{SAT} default for HRM2X chain

This default defines HRM2X orientation and location error. RCP reference system is now referred to RCHRM passing by the HRM chain in order to verify the tolerance requested, but the default is inserted in the rotation matrix which refers RCP to RCHRM in the reflector chain.
The specifications require the displacement from the ideal configuration must be maximum 1 mm along each Satellite axis and maximum 0.1° around each Satellite axis. The default, which refers the RCP reference system to the Satellite one, has to be distributed along the intermediate reference systems.
Following the mathematical process used to introduce it.

DEFAULT FOR: $R_{HRMshimA1}/R_{SAT}$
IN ORIENTATION:

$$_{shimA1_{disp}}()^{SAT} =_{shimA1_{disp}} ()^{shimA1_{inv}} *_{shimA1_{inv}} ()^{SAT} \tag{4.84}$$

Where $_{shimA1_{disp}}()^{shimA1_{inv}}$ is the default matrix computed by using three random angles around shimA1 axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \tag{4.85}$$

IN LOCATION

$$\begin{Bmatrix} x_{SHIMA1} \\ y_{SHIMA1} \\ z_{SHIMA1} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{SATAXIS} \tag{4.86}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{SATAXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \qquad (4.87)$$

DEFAULT FOR: R_{HRMMEC}/R_{SAT}
IN ORIENTATION:

$$_{HRMMEC_{disp}}()^{SAT} = _{HRMMEC_{disp}}()^{HRMMEC_{inv}} * _{HRMMEC_{inv}}()^{shimA1_{disp}} * _{shimA1_{disp}}()^{SAT} \qquad (4.88)$$

Where $_{HRMMEC_{disp}}()^{HRMMEC_{inv}}$ is the default matrix computed by using three random angles around MEC axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \qquad (4.89)$$

IN LOCATION

$$\begin{Bmatrix} x_{HRMMEC} \\ y_{HRMMEC} \\ z_{HRMMEC} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{SHIMA1axis} * _{shimA1_{disp}}()^{SAT} \qquad (4.90)$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{SHIMA1axis}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \qquad (4.91)$$

DEFAULT FOR: R_{SP}/R_{SAT}
IN ORIENTATION:

$$_{RSP_{disp}}()^{SAT} = _{RSP_{disp}}()^{RSP_{inv}} * _{RSP_{inv}}()^{HRMMEC_{disp}} * _{HRMMEC_{disp}}()^{SAT} \qquad (4.92)$$

Where ${}_{RSP_{disp}}()^{RSP_{inv}}$ is the default matrix computed by using three random angles around RSP axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1° < \theta_x < 0.1°, -0.1° < \theta_y < 0.1°, -0.1° < \theta_z < 0.1° \tag{4.93}$$

IN LOCATION

$$\begin{Bmatrix} x_{RSP} \\ y_{RSP} \\ z_{RSP} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{HRMMECaxis} *_{HRMMEC_{disp}}()^{SAT} \tag{4.94}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{HRMMECaxis}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.95}$$

DEFAULT FOR: R_{RCHRM}/R_{SAT}
IN ORIENTATION:

$${}_{RCHRM_{disp}}()^{SAT} = {}_{RCHRM_{disp}}()^{RCHRM_{inv}} *_{RCHRM_{inv}}()^{RSP_{disp}} *_{RSP_{disp}}()^{SAT} \tag{4.96}$$

Where ${}_{RCHRM_{disp}}()^{RCHRM_{inv}}$ is the default matrix computed by using three random angles around RCHRM axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1° < \theta_x < 0.1°, -0.1° < \theta_y < 0.1°, -0.1° < \theta_z < 0.1° \tag{4.97}$$

IN LOCATION

$$\begin{Bmatrix} x_{RCHRM} \\ y_{RCHRM} \\ z_{RCHRM} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RSPAXIS} *_{RSP_{disp}}()^{SAT} \tag{4.98}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RSPAXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.99}$$

DEFAULT FOR: R_{CP}/R_{SAT}
IN ORIENTATION:

$$_{RCP_{disp}}()^{SAT} =_{RCP_{disp}} ()^{RCP_{inv}} *_{RCP_{inv}} ()^{RCHRM_{disp}} *_{RCHRM_{disp}} ()^{SAT} \tag{4.100}$$

Where $_{RCP_{disp}}()^{RCP_{inv}}$ is the default matrix computed by using three random angles around RCP axis $(\theta_x, \theta_y, \theta_z)$ in the following ranges:

$$-0.1^\circ < \theta_x < 0.1^\circ, -0.1^\circ < \theta_y < 0.1^\circ, -0.1^\circ < \theta_z < 0.1^\circ \tag{4.101}$$

IN LOCATION

$$\begin{Bmatrix} x_{RCP} \\ y_{RCP} \\ z_{RCP} \end{Bmatrix} = \begin{Bmatrix} x_{SAT} \\ y_{SAT} \\ z_{SAT} \end{Bmatrix} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}^{SATAXIS} + \begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RCHRMAXIS} *_{RCHRM_{disp}}()^{SAT} \tag{4.102}$$

Where $\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix}^{RCHRMAXIS}$ is the default vector computed by randomly choosing the three values in the following ranges:

$$-1mm < \Delta_x < 1mm, -1mm < \Delta_y < 1mm, -1mm < \Delta_z < 1mm \tag{4.103}$$

VERIFICATION OF THE SPECIFICATIONS
RCP0 reference system is now introduced in order to define the RCP reference system in case without defaults. The specifications require the displacement from the ideal configuration must be maximum 1 mm along each Satellite axis and maximum 0.1° around each

Satellite axis.

$$_{SAT_{disp}}()^{SAT} =_{SAT_{disp}} ()^{RCP} *_{RCP} ()^{SAT} \tag{4.104}$$

Once achieved $_{SAT_{disp}}()^{SAT}$ it is possible computing the Euler angles from this matrix and evaluate the displacement in orientation.
In location the difference between the ideal RCP reference and the RCP reference system including defaults leads to the displacement in location.

$$\begin{Bmatrix} \Delta xDEFAULT \\ \Delta yDEFAULT \\ \Delta zDEFAULT \end{Bmatrix} = \begin{Bmatrix} \Delta xRCP0 \\ \Delta yRCP0 \\ \Delta zRCP0 \end{Bmatrix}^{SATAXIS} - \begin{Bmatrix} \Delta xRCP \\ \Delta yRCP \\ \Delta zRCP \end{Bmatrix}^{SATAXIS} \tag{4.105}$$

4.3 Sensitivity analysis

Now the defaults are analysed by their effect on the final configuration. Various cases are presented in order to point out how the defaults affect ADPM2+ configuration. Moreover for each case the analysis is divided in two branches: the first one is linked to the orientation defaults, while the second one is linked to the location defaults.
In order to perform the analysis, a common default value is adopted. Furthermore this default value is chosen enough low, equal to 0.01° for orientation defaults and 0.01 mm for location defaults, to let the creation of a default gradient, useful for the following computations. Each orientation and location default is introduced in the mathematical model in the local reference system.
The analysis has the goal to detect the highest default values in order to identify the best locations to perform the measures [1].

4.3.1 Reflector sensitivity

In order to compute the reflector sensitivity, the following computation is performed:

$$_{SAT_{disp}}()^{SAT} =_{SAT_{disp}} ()^{RVD} *_{RVD} ()^{SAT} \tag{4.106}$$

Once got this matrix it is possible to obtain the Euler angles for RVD reference $(\theta_x, \theta_y, \theta_z)$, which correspond to the displacement in orientation of the reflector.

Following results regard the displacements of RVD and they refer to MS3 antenna.

	θ_x	θ_y	θ_z	Δ_x	Δ_y	Δ_z
SHIM M1	0,0021188	0,0060233	0,0076962	0,0964655	0,0110112	0,0090336
USI1	0,0021188	0,0060233	0,0076962	0,0894843	0,0104188	0,0085170
CALEP1	0,0021188	0,0060233	0,0076962	0,0964656	0,0104192	0,0085174
MEC	0,0021188	0,0060233	0,0076962	0,0964656	0,0104192	0,0085174
FERRURE	0,0021188	0,0060233	0,0076962	0,1015766	0,0072624	0,0057649
RIF1	0,0010989	0,0065125	0,0075087	0,1021872	0,0202199	0,0019497
ROT1	0,0089215	0,0019158	0,0040911	0,0322011	0,0954246	0,0390231
USI3	0,0089215	0,0019158	0,0040911	0,0318386	0,0969793	0,0376673
USI3BIS	0,0089215	0,0019158	0,0040911	0,0322011	0,0954246	0,0390231
RM2	0,0025938	0,0009106	0,0096148	0,0032582	0,1107832	0,0243464
USI2	0,0026469	0,0075568	0,0059906	0,0000558	0,0695764	0,0685660
USI2BIS	0,0026469	0,0075568	0,0059906	0,0000558	0,0695764	0,0685660
CALEP2	0,0026469	0,0075568	0,0059906	0,0000558	0,0695764	0,0685660
RIF2	0,0017481	0,0050263	0,0084665	0,0027612	0,0938192	0,0629100
RVD	0,0100000	0,0000000	0,0000000	0,0012800	0,0005481	0,0010453

Table 4.3. EFFECT OF A DEFAULT IN ORIENTATION AROUND X AXIS: $\gamma_X = 0.01°$

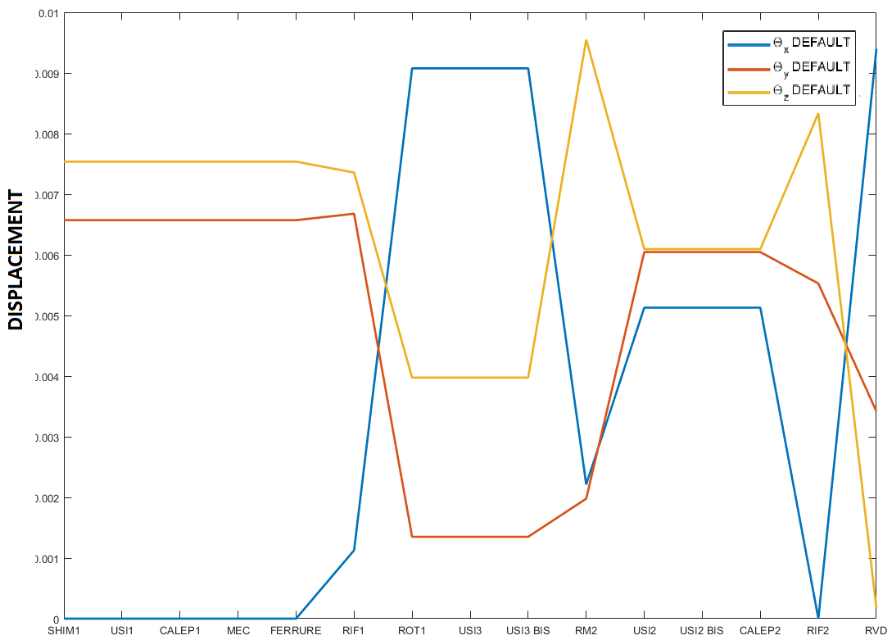

Figure 4.7. RVD orientation displacement due to the insertion of γ_X default along the reflector chain

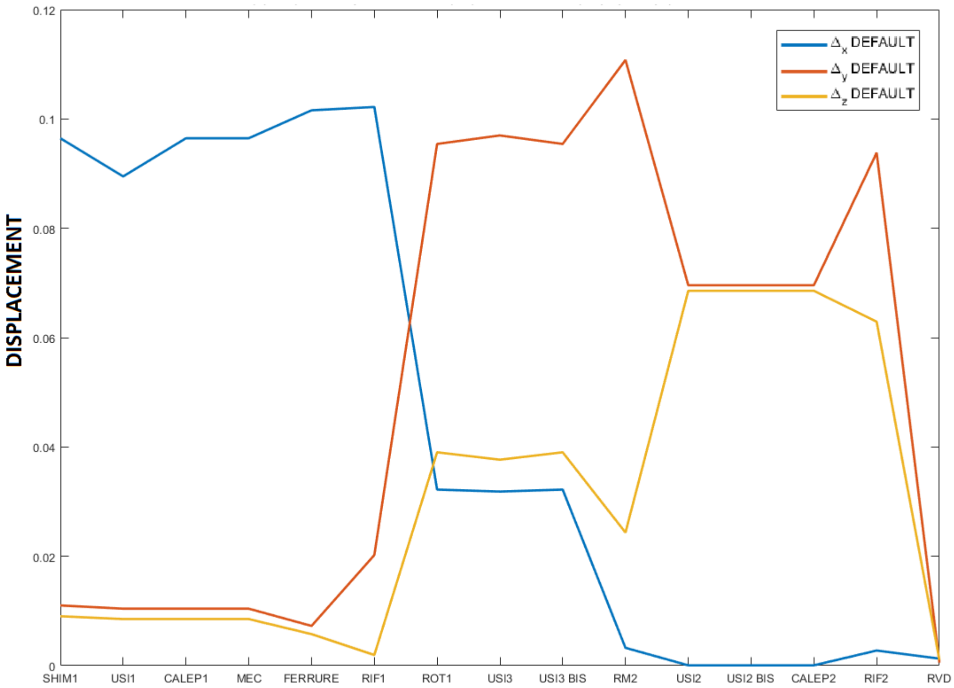

Figure 4.8. RVD location displacement due to the insertion of γ_X default along the reflector chain

	θ_x	θ_y	θ_z	Δ_x	Δ_y	Δ_z
SHIM M1	0,0026896	0,0072114	0,0063846	0,0713801	0,0095211	0,0125936
USI1	0,0026888	0,0072117	0,0063843	0,0567258	0,0101086	0,0099195
CALEP1	0,0026888	0,0072117	0,0063843	0,0688174	0,0101093	0,0099203
MEC	0,0026896	0,0072114	0,0063846	0,0713800	0,0090050	0,0120016
FERRURE	0,0026896	0,0072114	0,0063846	0,0662690	0,0062524	0,0088448
RIF1	0,0089735	0,0038984	0,0020689	0,0018807	0,1114586	0,0345392
ROT1	0,0014621	0,0073443	0,0066276	0,0986521	0,0442445	0,0121407
USI3	0,0014621	0,0073443	0,0066276	0,1000420	0,0502046	0,0069443
USI3BIS	0,0014621	0,0073443	0,0066276	0,0986521	0,0442445	0,0121407
RM2	0,0014112	0,0098843	0,0005555	0,0054738	0,0110122	0,0980724
USI2	0,0013075	0,0064364	0,0075407	0,0051298	0,0819908	0,0740474
USI2BIS	0,0013075	0,0064364	0,0075407	0,0020970	0,0856640	0,0764835
CALEP2	0,0013075	0,0064364	0,0075407	0,0051298	0,0819908	0,0740474
RIF2	0,0023796	0,0085596	0,0045901	0,0006346	0,0541945	0,0805477
RVD	0,0000000	0,0100000	0,0000000	0,0012800	0,0005481	0,0010453

Table 4.4. EFFECT OF A DEFAULT IN ORIENTATION AROUND Y AXIS: $\gamma_Y = 0.01°$

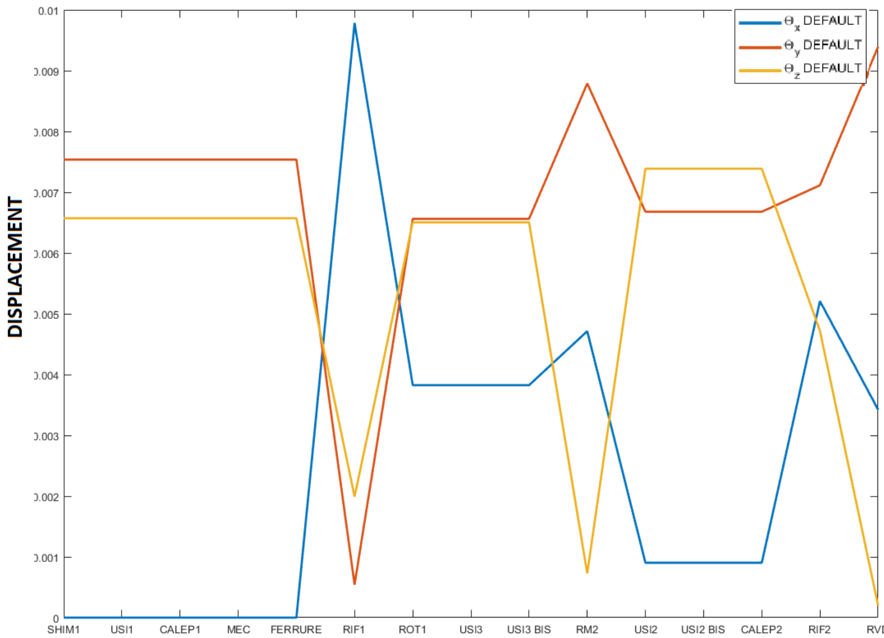

Figure 4.9. RVD orientation displacement due to the insertion of γ_Y default along the reflector chain

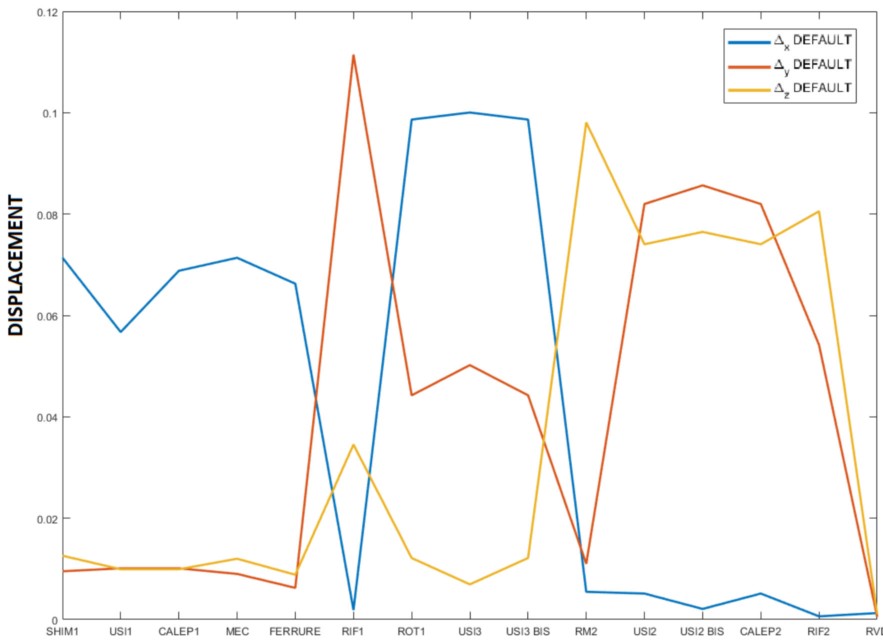

Figure 4.10. RVD location displacement due to the insertion of γ_Y default along the reflector chain

	θ_x	θ_y	θ_z	Δ_x	Δ_y	Δ_z
SHIM M1	0,0093958	0,0034222	0,00009181	0,0012800	0,1176192	0,0265708
USI1	0,0093958	0,0034222	0,0000924	0,0012800	0,1028262	0,0313267
CALEP1	0,0093958	0,0034222	0,0000924	0,0012800	0,1165278	0,0286410
MEC	0,0093958	0,0034222	0,0000918	0,0012800	0,1176192	0,0265708
FERRURE	0,0093958	0,0034222	0,0000918	0,0012800	0,1171252	0,0337815
RIF1	0,0042748	0,0065104	0,0062724	0,0652902	0,0263227	0,0147513
ROT1	0,0042748	0,0065104	0,0062724	0,0543627	0,0206184	0,0111303
USI3	0,0042748	0,0065104	0,0062724	0,0593356	0,0256039	0,0155188
USI3 BIS	0,0042748	0,0065104	0,0062724	0,0543627	0,0206184	0,0111303
RM2	0,0095541	0,0012129	0,0026921	0,0015579	0,0285080	0,0532690
USI2	0,0095541	0,0012129	0,0026921	0,0016668	0,0302950	0,0463992
USI2 BIS	0,0095541	0,0012129	0,0026921	0,0024319	0,0359481	0,0526530
CALEP2	0,0095541	0,0012129	0,0026921	0,0016668	0,0302950	0,0463992
RIF2	0,0095541	0,0012129	0,0026921	0,0016668	0,0302950	0,0463992
RVD	0,0000000	0,0000000	0,0100000	0,0012800	0,0005481	0,0010453

Table 4.5. EFFECT OF A DEFAULT IN ORIENTATION AROUND Z AXIS: $\gamma_Z = 0.01°$

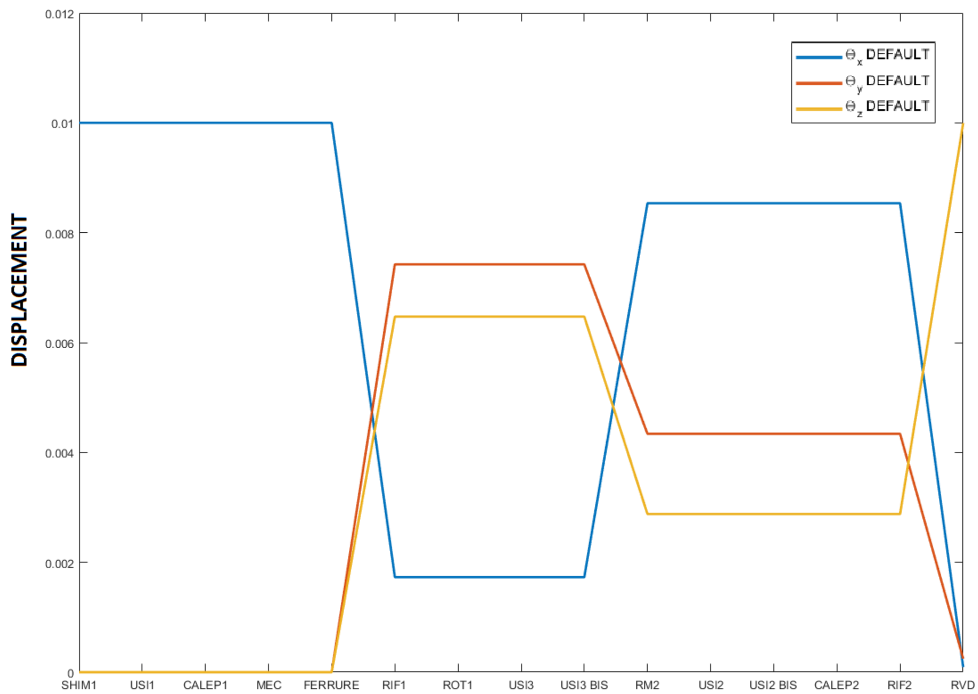

Figure 4.11. RVD orientation displacement due to the insertion of γ_Z default along the reflector chain

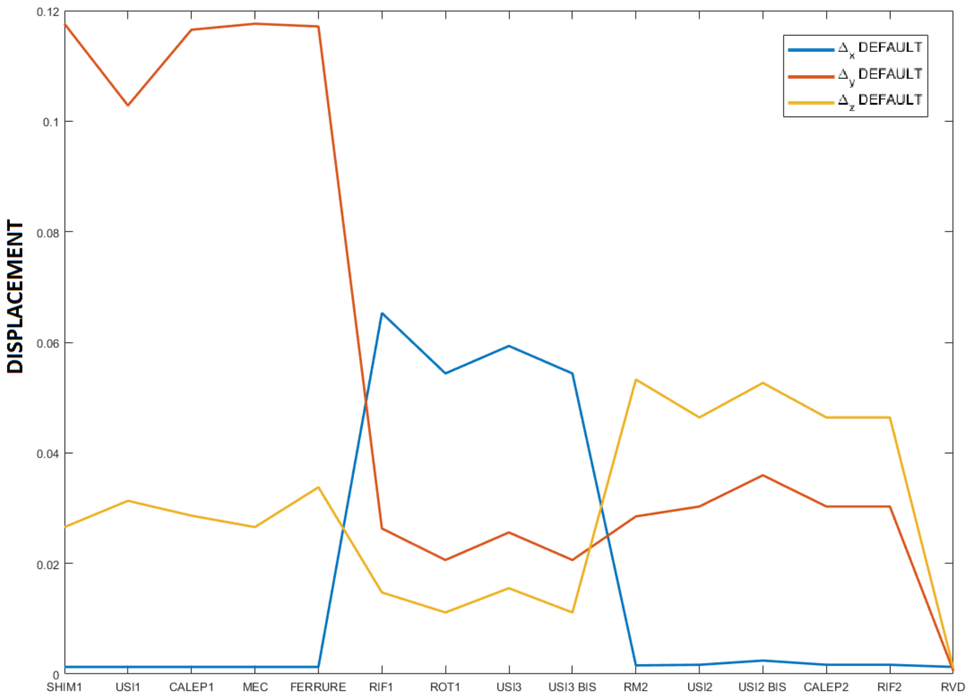

Figure 4.12. RVD location displacement due to the insertion of γ_Z default along the reflector chain

	θ_x	θ_y	θ_z	Δ_x	Δ_y	Δ_z
SHIM M1	0,0000000	0,0000000	0,0000000	0,0112800	0,0005481	0,0010453
USI1	0,0000000	0,0000000	0,0000000	0,0012800	0,0060238	0,0085825
CALEP1	0,0000000	0,0000000	0,0000000	0,0012800	0,0060238	0,0085825
MEC	0,0000000	0,0000000	0,0000000	0,0012800	0,0060238	0,0085825
FERRURE	0,0000000	0,0000000	0,0000000	0,0012800	0,0060238	0,0085825
RIF1	0,0000000	0,0000000	0,0000000	0,0012800	0,0060238	0,0085825
ROT1	0,0000000	0,0000000	0,0000000	0,0024075	0,0061299	0,0084028
USI3	0,0000000	0,0000000	0,0000000	0,0103558	0,0018990	0,0029303
USI3BIS	0,0000000	0,0000000	0,0000000	0,0103558	0,0018990	0,0029303
RM2	0,0000000	0,0000000	0,0000000	0,0103558	0,0018990	0,0029303
USI2	0,0000000	0,0000000	0,0000000	0,0009338	0,0014306	0,0105943
USI2BIS	0,0000000	0,0000000	0,0000000	0,0038485	0,0065945	0,0071395
CALEP2	0,0000000	0,0000000	0,0000000	0,0038485	0,0065945	0,0071395
RIF2	0,0000000	0,0000000	0,0000000	0,0038485	0,0065945	0,0071395
RVD	0,0000000	0,0000000	0,0000000	0,0012800	0,0049793	0,0093788

Table 4.6. EFFECT OF A DEFAULT IN LOCATION ALONG X AXIS: $\delta_X = 0.01mm$

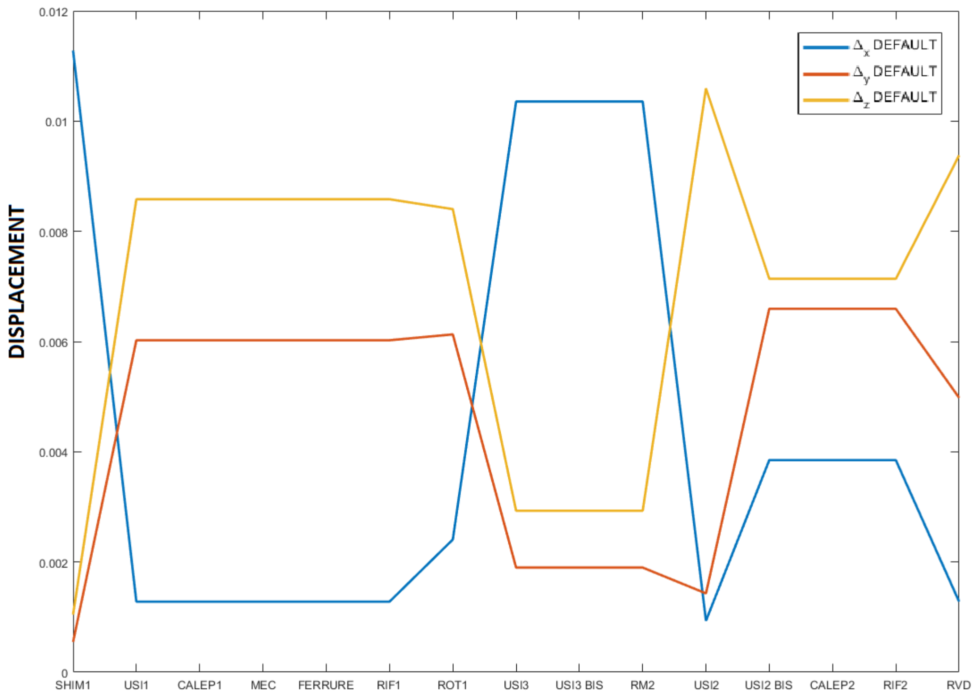

Figure 4.13. RVD location displacement due to the insertion of δ_X default along the reflector chain

	θ_x	θ_y	θ_z	Δ_x	Δ_y	Δ_z
SHIM M1	0,0000000	0,0000000	0,0000000	0,0012800	0,0094519	0,0010453
USI1	0,0000000	0,0000000	0,0000000	0,0012800	0,0080854	0,0076172
CALEP1	0,0000000	0,0000000	0,0000000	0,0012800	0,0069891	0,0055266
MEC	0,0000000	0,0000000	0,0000000	0,0012800	0,0069891	0,0055266
FERRURE	0,0000000	0,0000000	0,0000000	0,0012800	0,0080854	0,0076172
RIF1	0,0000000	0,0000000	0,0000000	0,0012800	0,0080854	0,0076172
ROT1	0,0000000	0,0000000	0,0000000	0,0110644	0,0000048	0,0009472
USI3	0,0000000	0,0000000	0,0000000	0,0025456	0,0071106	0,0054584
USI3BIS	0,0000000	0,0000000	0,0000000	0,0025456	0,0071106	0,0054584
RM2	0,0000000	0,0000000	0,0000000	0,0025456	0,0071106	0,0054584
USI2	0,0000000	0,0000000	0,0000000	0,0034336	0,0093374	0,0017738
USI2BIS	0,0000000	0,0000000	0,0000000	0,0003757	0,0072270	0,0063422
CALEP2	0,0000000	0,0000000	0,0000000	0,0003757	0,0072270	0,0063422
RIF2	0,0000000	0,0000000	0,0000000	0,0003757	0,0072270	0,0063422
RVD	0,0000000	0,0000000	0,0000000	0,0039276	0,0076624	0,0057641

Table 4.7. EFFECT OF A DEFAULT IN LOCATION ALONG Y AXIS: $\delta_Y = 0.01mm$

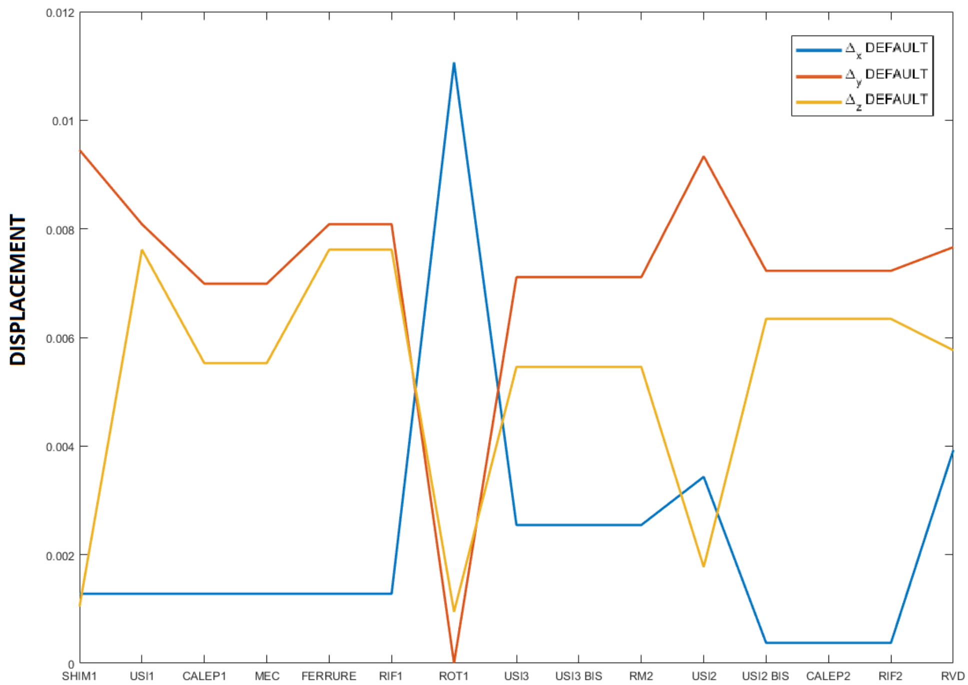

Figure 4.14. RVD location displacement due to the insertion of δ_Y default along the reflector chain

	θ_x	θ_y	θ_z	Δ_x	Δ_y	Δ_z
SHIM M1	0,0000000	0,0000000	0,0000000	0,0012800	0,0005481	0,0089547
USI1	0,0000000	0,0000000	0,0000000	0,0087200	0,0005481	0,0010453
CALEP1	0,0000000	0,0000000	0,0000000	0,0112800	0,0005481	0,0010453
MEC	0,0000000	0,0000000	0,0000000	0,0112800	0,0005481	0,0010453
FERRURE	0,0000000	0,0000000	0,0000000	0,0087200	0,0005481	0,0010453
RIF1	0,0000000	0,0000000	0,0000000	0,0087200	0,0005481	0,0010453
ROT1	0,0000000	0,0000000	0,0000000	0,0030104	0,0079717	0,0075181
USI3	0,0000000	0,0000000	0,0000000	0,0030104	0,0079717	0,0075181
USI3BIS	0,0000000	0,0000000	0,0000000	0,0030104	0,0079717	0,0075181
RM2	0,0000000	0,0000000	0,0000000	0,0030104	0,0079717	0,0075181
USI2	0,0000000	0,0000000	0,0000000	0,0072570	0,0037917	0,0018332
USI2BIS	0,0000000	0,0000000	0,0000000	0,0072570	0,0037917	0,0018332
CALEP2	0,0000000	0,0000000	0,0000000	0,0072570	0,0037917	0,0018332
RIF2	0,0000000	0,0000000	0,0000000	0,0072570	0,0037917	0,0018332
RVD	0,0000000	0,0000000	0,0000000	0,0072570	0,0037917	0,0018332

Table 4.8. EFFECT OF A DEFAULT IN LOCATION ALONG Z AXIS: $\delta_Z = 0.01mm$

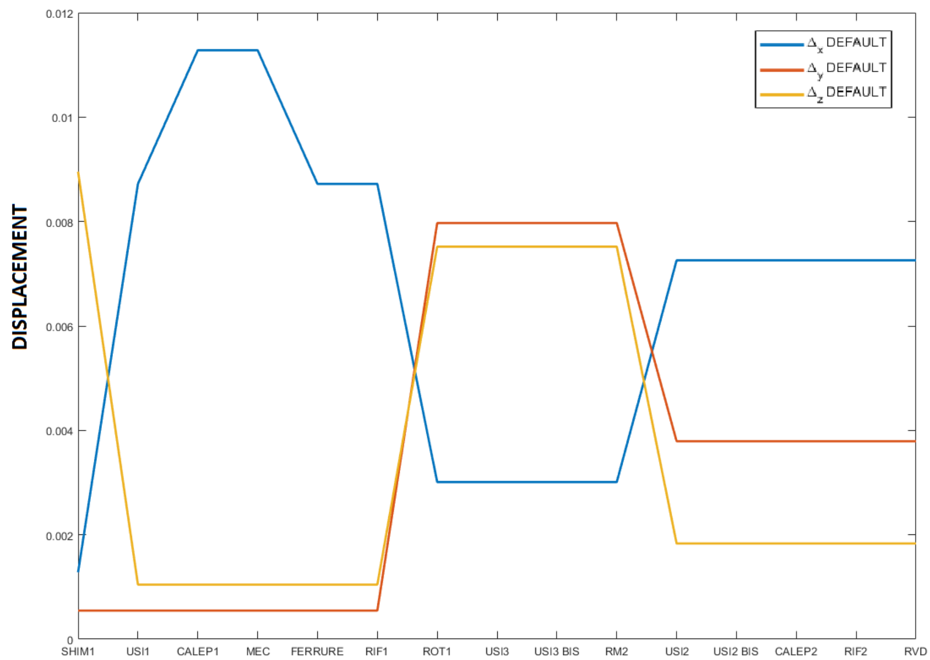

Figure 4.15. RVD location displacement due to the insertion of δ_Z default along the reflector chain

Some considerations about the previous results:

- The graphics represent the trends of the RVD displacements in orientation (Θ_X, Θ_Y, Θ_Z) and in location ($\Delta_X, \Delta_Y, \Delta_Z$) due to orientation defaults ($\gamma_X, \gamma_Y, \gamma_Z$) and location defaults ($\delta_X, \delta_Y, \delta_Z$). However, the location defaults δ affect only the location of the RVD reference system and so only the graphics regarding the location displacements are displayed;

- Some of the intermediate reference systems impact on the final configuration more than others;

- For the same intermediate reference system each default has a different effect on the RVD reference system;

- Considering the case of a default around the X axis of Figure 4.7 and Figure 4.8, RM2 has the highest RVD orientation and location displacements;

- For γ_Y defaults, RIF1 leads to the highest Δ_X and Δ_Y displacements, while RM2 leads to the highest Δ_Z;

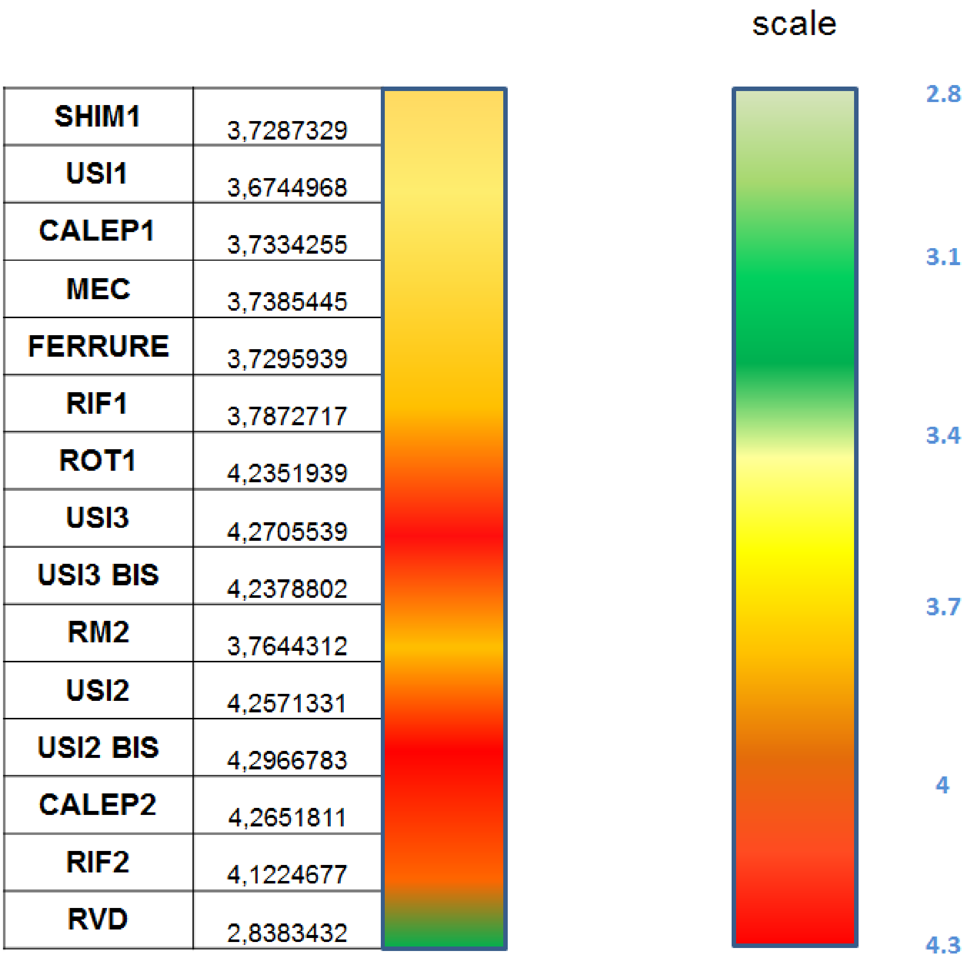

Figure 4.16. Sensitivity effect on RVD. Sum of the orientation and location displacements. Non dimensional values

- Inserting an error γ_Z in the intermediate reference systems between SAT and MEC reference systems, the displacement around RVD y axis is the highest.
- For location defaults, the most affected RVD axis is the X axis. The displacements regarding the RVD x axis are the highest and they are mainly due to a δ_X default on SHIM M1 reference, a δ_Y on ROT1 reference and a δ_Z on CALEP1 and MEC references;
- The colour bar of Figure 4.16 sums up the results about the sensitivity by displaying the sum of all the displacements due to orientation and location defaults;
- As displayed by the colour bar, the most influence reference systems are located after

motor 1 and motor 2.

- Regarding to these results, in order to point out the highest defaults the best locations to perform the measurements could be:
  1. In USI3 BIS reference system (after MOTOR 1);
  2. In RIF 2 reference system.
- RVD reference system results to be the location with the lowest values because orientation defaults, compared with the others reference systems, do not affect the location of the RVD origin.

4.4 Defaults distribution

As previously described, the defaults are randomly chosen according to an uniform distribution. That distribution is usually chosen when the only available information regarding a quantity X is a lower limit **a** and an upper limit **b** with a < b [2].

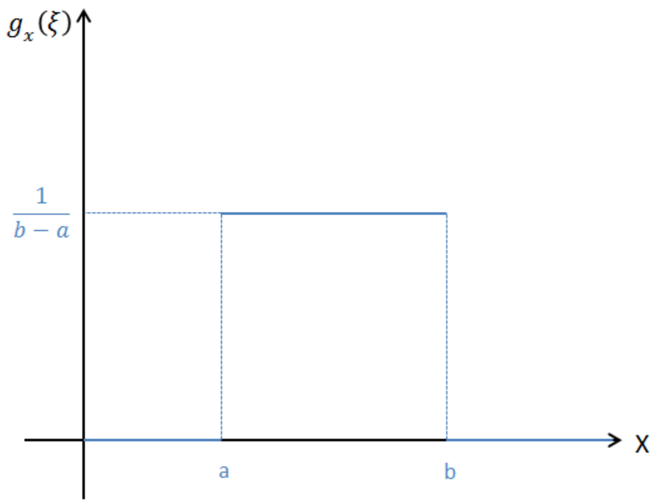

Figure 4.17. PDF for uniform distribution

The probability density function (PDF) assigned to this distribution is:

$$g_x(\xi) = \begin{Bmatrix} \frac{1}{b-a}, \, a \le \xi \le b \\ 0, \, otherwise \end{Bmatrix} \tag{4.107}$$

While the expectation for X would be:

$$E(X) = \frac{a+b}{2} \tag{4.108}$$

The final goal of performing a statistical approach is to reach the 95% of the coverage. This type of distribution has the advantage to not influence the solver for the resolution of the problem, but, in the other hand, it could not take into account the worst case.
This distribution is assigned to each default between two consecutive reference systems. However, since all these defaults must respect the specifications imposed by the manufactures, some of the default values drawn could be not acceptable since they lead to a configuration out of specification. For this reason it is necessary to study how the selection, made by the Subsystem Assembly specifications of Figure 4.18 and 4.19, modifies the uniform distribution.

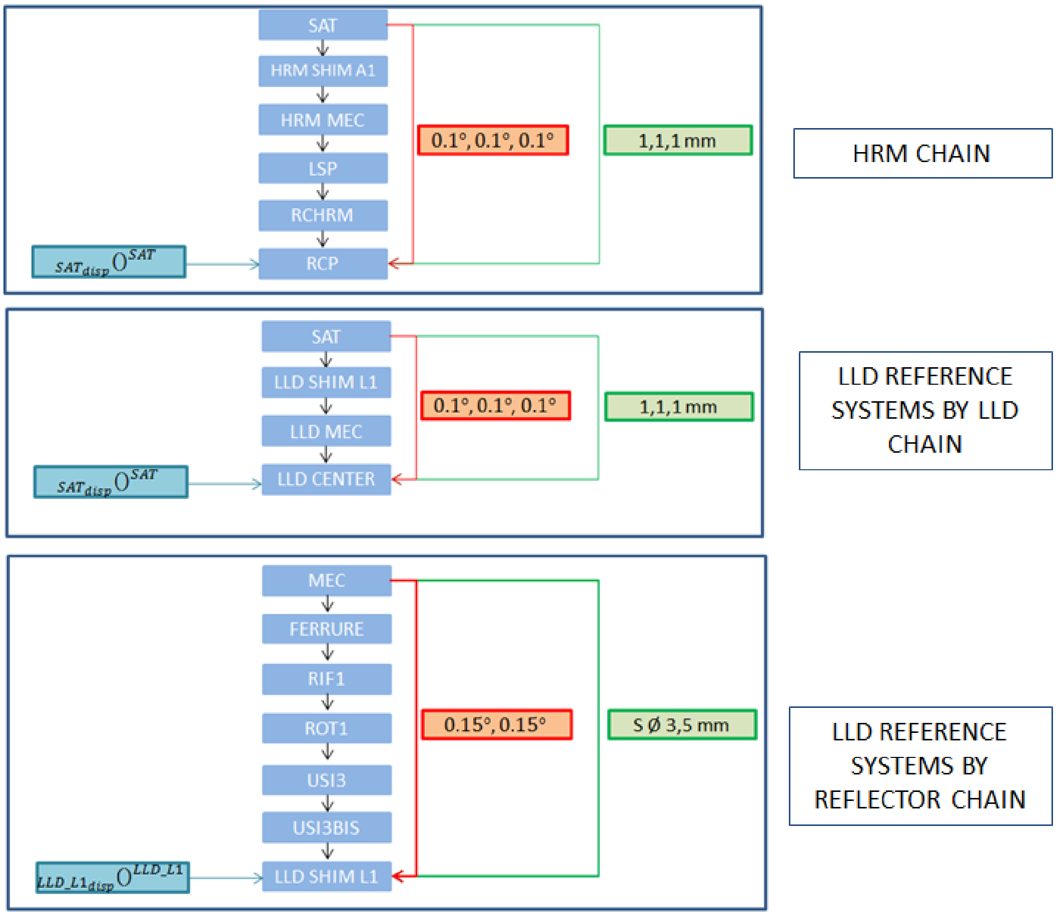

Figure 4.18. Subsystem assembly specifications for stowed configuration

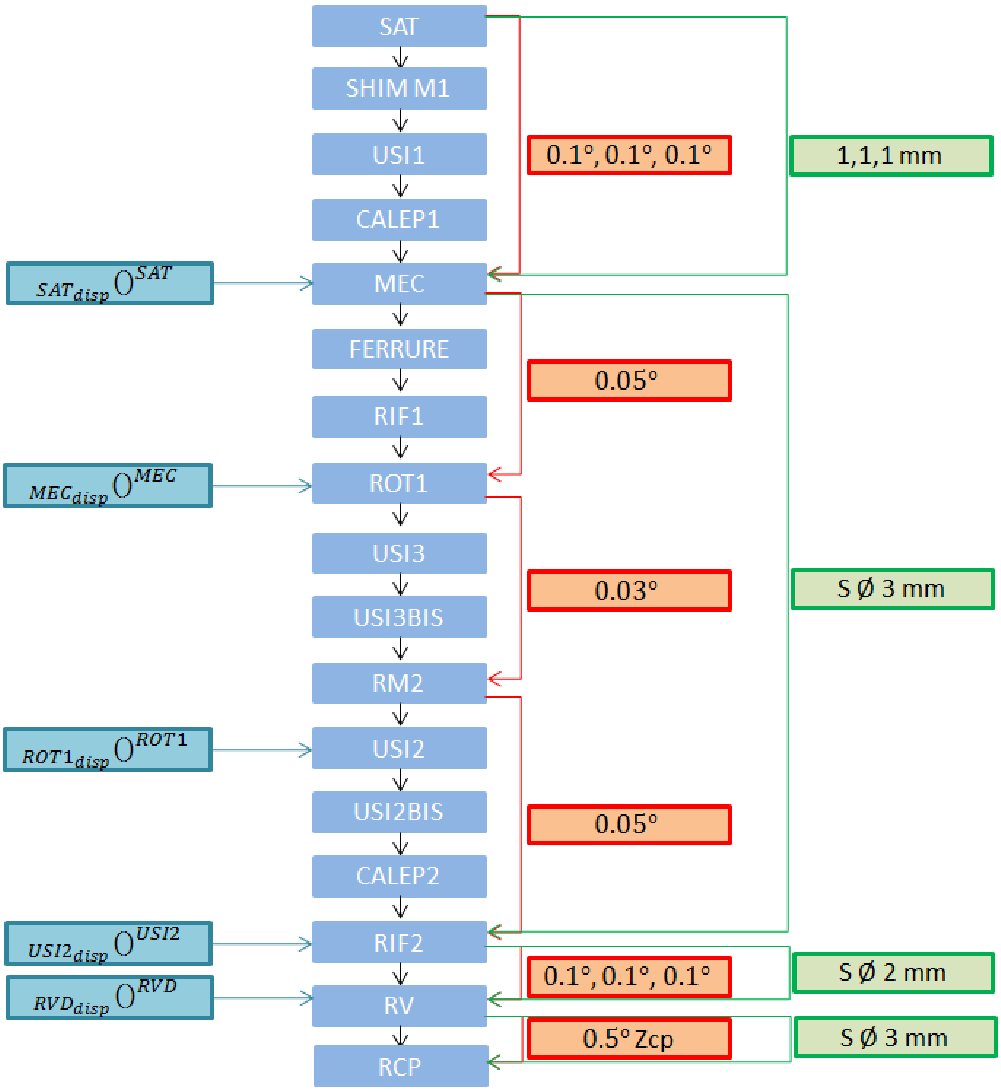

Figure 4.19. Subsystem assembly specifications for deployed configuration

Following some of the default distributions are displayed in the form of a histogram representation. In order to create the distribution, 2000 simulations are performed. Each simulation has in input 318 default values, which correspond to the three orientation defaults and three location defaults between the 53 reference systems of the model. Furthermore a function interpolation is performed in order to point out the trend of the distribution along the default range. The function degree chosen to interpolate the default values is the fourth since the corresponding polynomial is the one which describes the best the default trends.

4.4.1 R_{MEC}/R_{SAT} defaults for ADPM2+

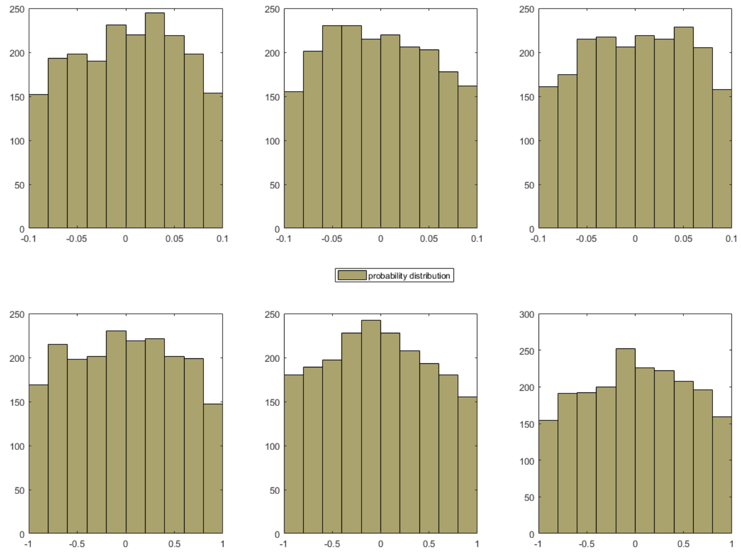

Figure 4.20. Default distribution for R_{SHIMM1}/R_{SAT}

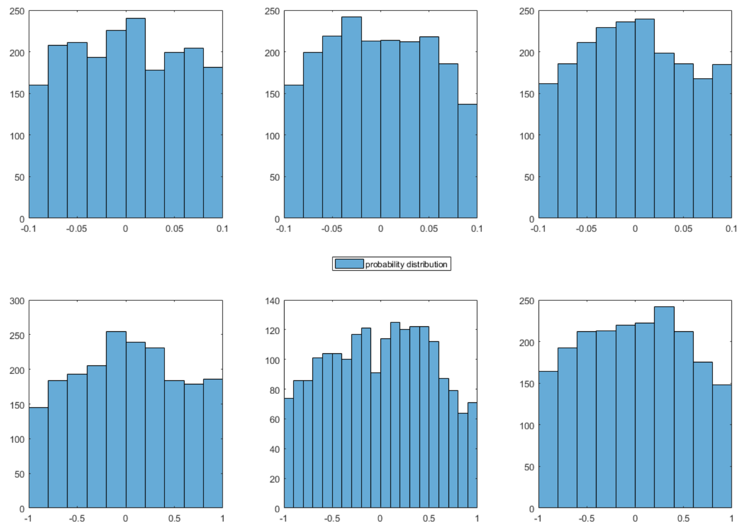

Figure 4.21. Default distribution for R_{USI1}/R_{SHIMM1}

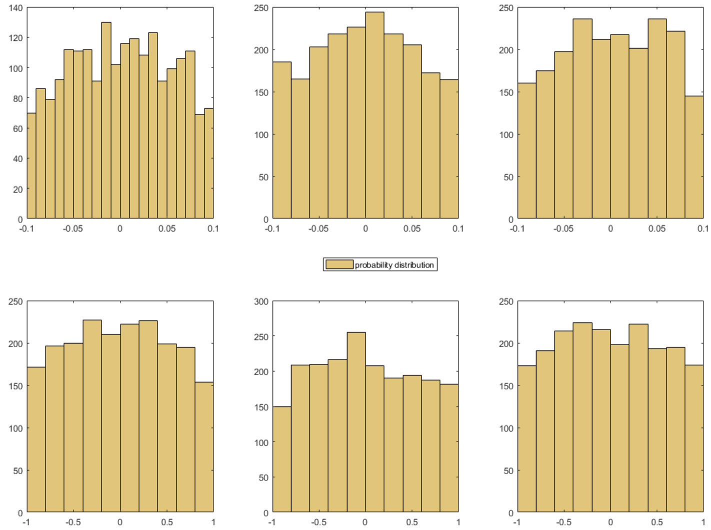

Figure 4.22. Default distribution for R_{CALEP1}/R_{USI1}

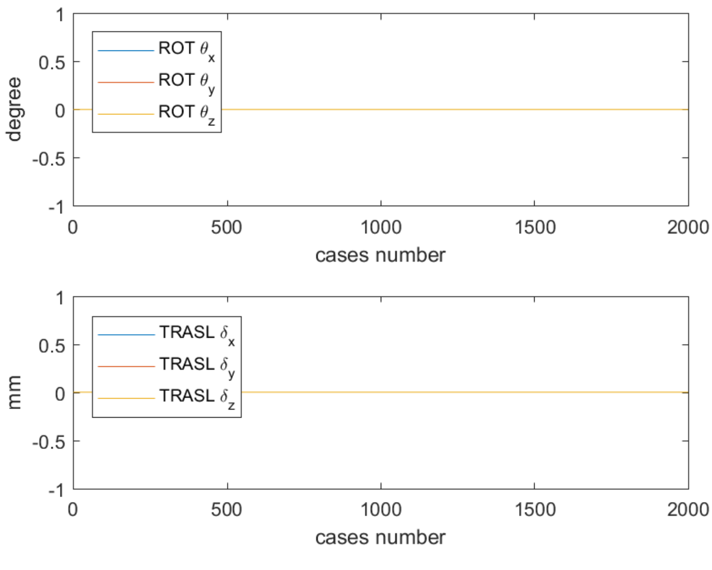

Figure 4.23. Default distribution for R_{MEC}/R_{CALEP1}

For hypothesis there are no defaults between CALEP1 reference system and MEC reference systems since the two origins coincide and the axis result to be parallel.

Typical distribution trend for each reference system of this block is in Figure 4.24. As visible, the distribution is almost linear and that means the defaults are uniformly distributed along the interval. Moreover a first derivative trend is proposed in Figure 4.24 in order to point out possible deviations from the uniform trend. The first derivative values do not vary in its range more than $4 * 10^{-4}$ confirming the previous results.

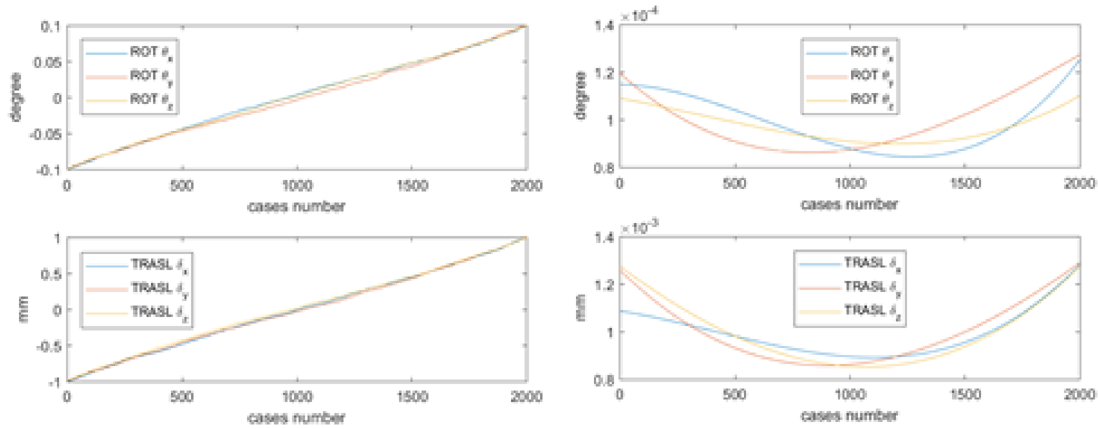

Figure 4.24. Default trend for R_{MEC}/R_{SAT}

As the histograms in Figure 4.20, 4.21 and 4.22 display, the defaults involving the MEC/SAT chain are almost uniformly distributed. The uniformity is lost for the values close to the borders since high values can lead easily the configuration out of specifications. However that singularity is not so effective to request a corrective action. Regarding MEC/SAT Subsystem Assembly specifications, they seem to be not too strictly and so the loops necessary to find a solution, which satisfies the tolerances, are usually few.

4.4.2 R_{IF2}/R_{MEC} defaults for ADPM2+

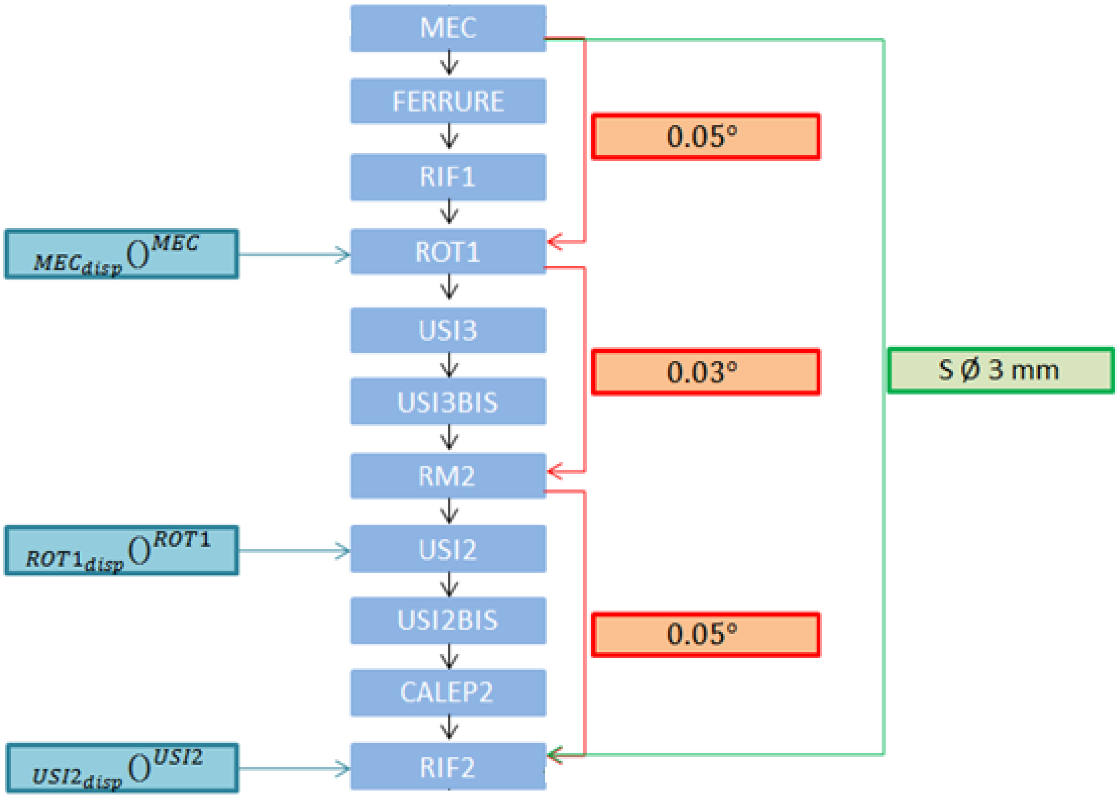

Figure 4.25. Subsystem assembly specifications for the block R_{IF2}/R_{MEC}

Regarding to Figure 4.25, the green block, which is a location specification, contains inside three red blocks, that are related to orientation defaults.
The location defaults for this block, according to the specifications, must be contained in a sphere of 3 mm:

$$\sqrt{x^2 + y^2 + z^2} \leq 3mm \tag{4.109}$$

This specification (with the spherical range) leads to a non-uniform distribution, as displayed in the following histograms, since now the three coordinates must satisfy together the same tolerance. That means it would be improbable having simultaneously three high values. Indeed the most of the values are concentrated around the zero value.
For that block only two examples are given since the distribution trend is similar for all the intermediate reference systems.

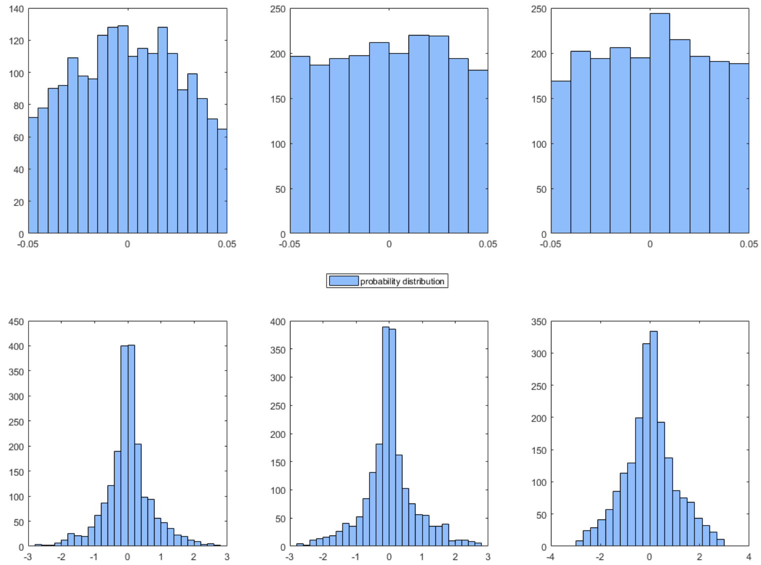

Figure 4.26. Default distribution for R_{FERR}/R_{MEC}

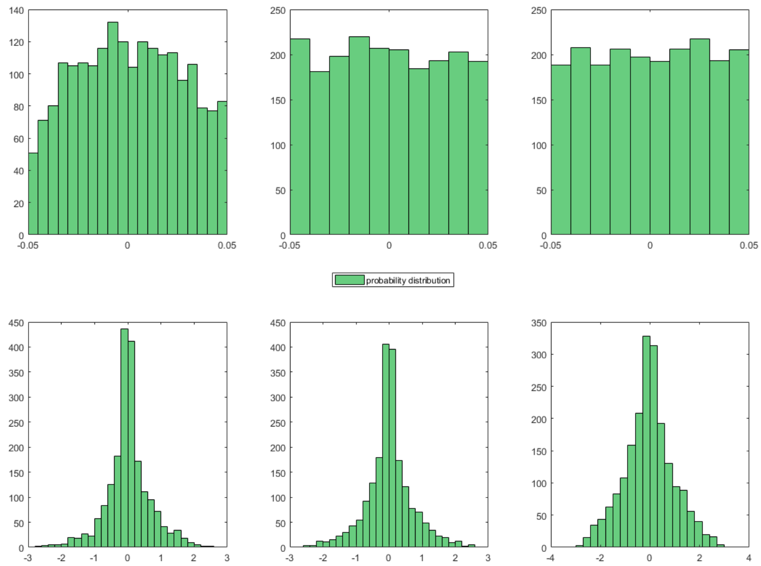

Figure 4.27. Default distribution for R_{IF1}/R_{FERR}

In Figure 4.28 and 4.29 two histograms representing a data summary for this block for one case. Since RIF2/MEC specification contains inside other three constraints, it is necessary to satisfy before the inner ones. Each column represents the number of loops necessary to find an acceptable default matrix for the inner specifications. In the average, the total attempts are more than 500 for one case, so that means several loops are performed before to find a matrix which satisfies the specifications.

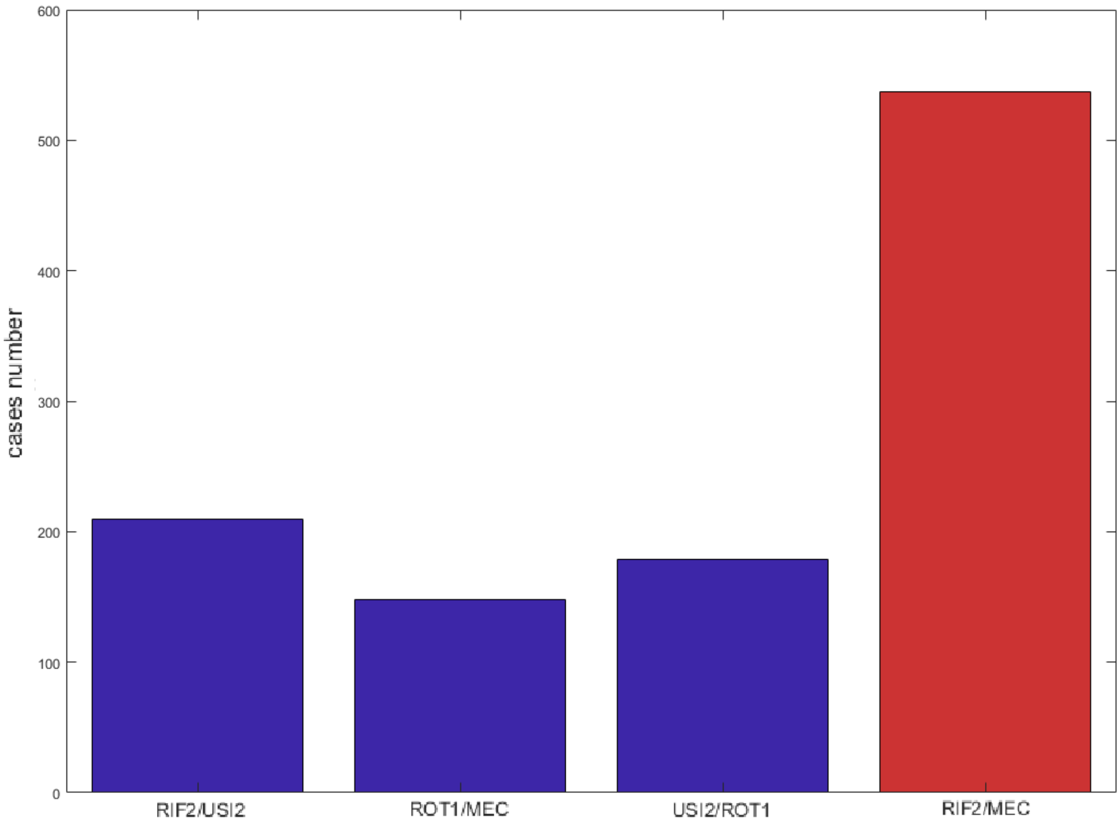

Figure 4.28. Attempts for each orientation block included in the location block R_{RIF2}/R_{MEC} - SIMULATION 1 RESULTS

In both simulation the intermediate block RIF2/USI2 is the one that register the highest loops number. This result means that, among the three intermediate blocks, RIF2/USI2 specification is the most difficult one to satisfy.

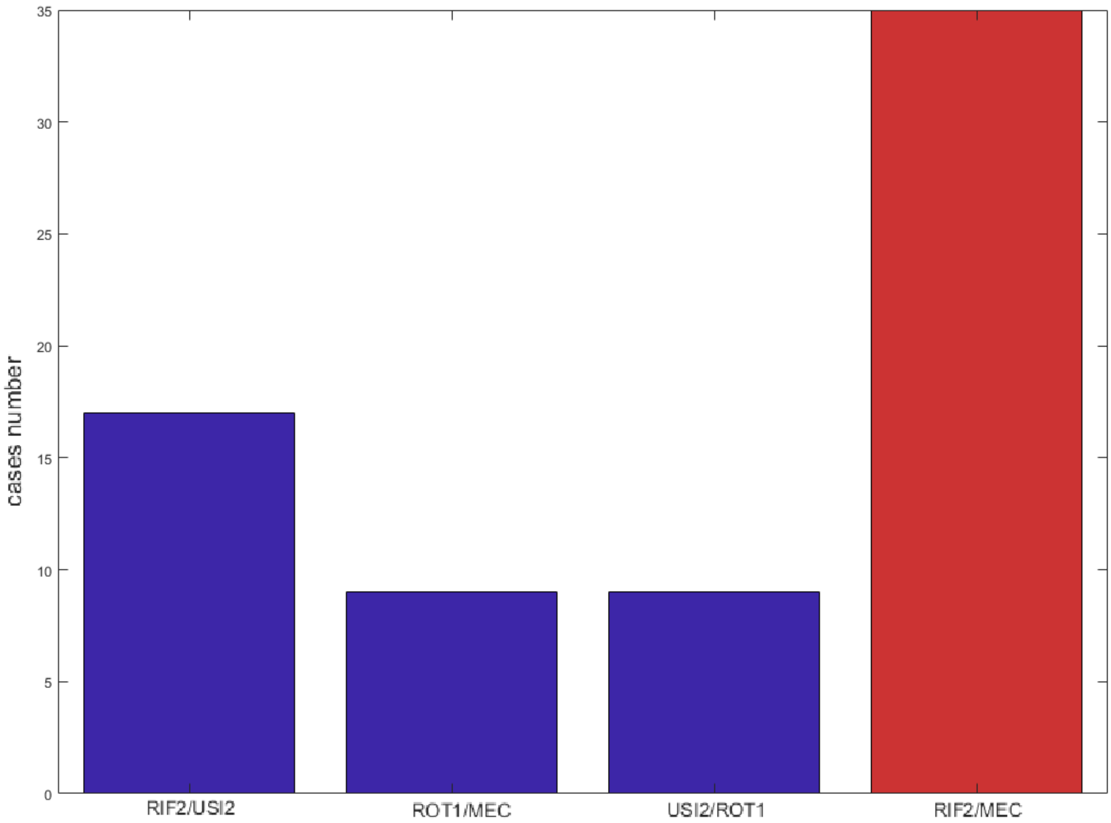

Figure 4.29. Attempts for each orientation block included in the location block R_{RIF2}/R_{MEC} - SIMULATION 2 RESULTS

Possible solutions to the non-uniform distribution

- The computation is not modified considering that the values closest to the borders would not be drawn as often as the ones around the zero value;
- The distribution is modified in order to make it uniform as much as possible. In Figure 4.30 the graphic explanation of the method;
- Changing type of distribution. One possible alternative is the Gaussian distribution.

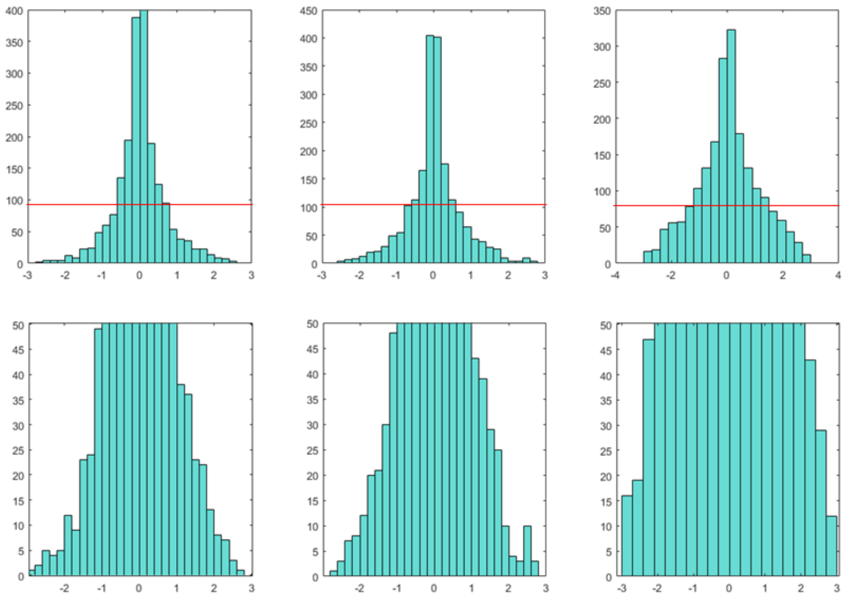

Figure 4.30. Possible solution to the non uniform output distribution

4.4.3 R_V/R_{IF2} and R_{CP}/R_V defaults for ADPM2+

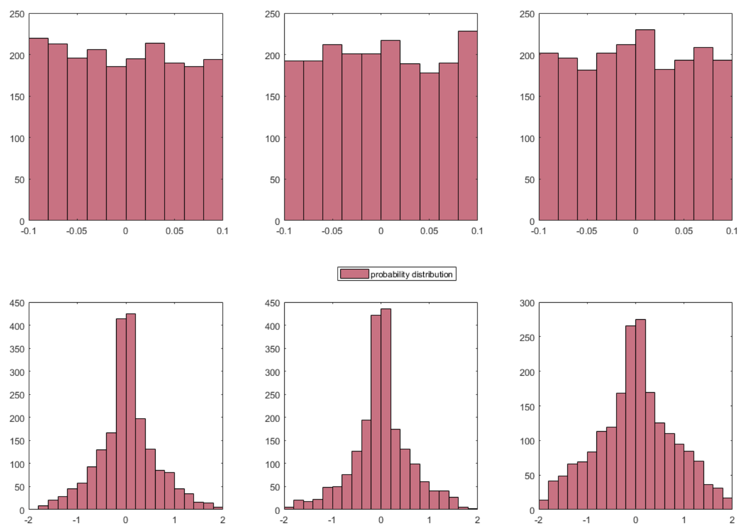

Figure 4.31. Default distribution for R_V/R_{IF2}

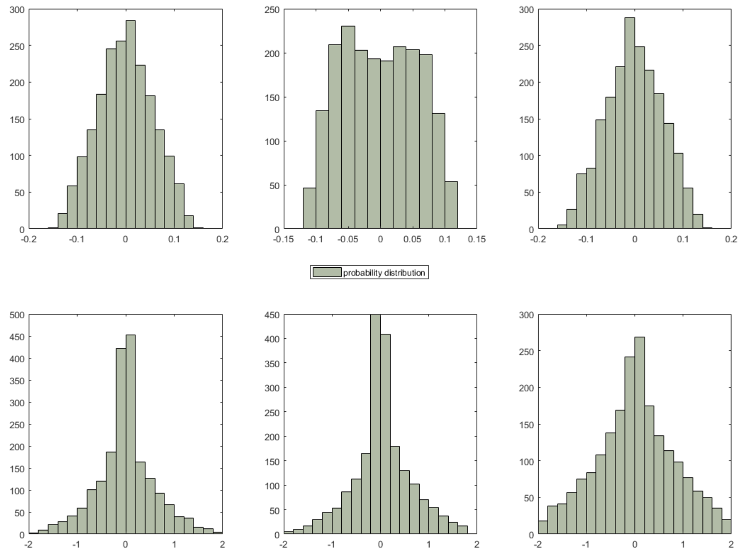

Figure 4.32. Default distribution for R_{CP}/R_V

These distributions follow the trend seen for R_{IF2}/R_{MEC}. Moreover R_{CP}/R_V orientation defaults have similar aspects to the triangular distribution since the values closer to the borders lead more easily out of specification.

Chapter 5

Solver

Once defined the mathematical model and the input, it is necessary to verify if the AIT specifications are satisfied. The AIT specifications are those ones that define if the reflector is well oriented and well located in deployed and in stowed configurations. Indeed the final goal of the study is to offset the defaults using the adjustment capabilities in order to lead the antenna in the AIT specifications.
The aim of the solver is to find the unknown parameters, that are the adjustment capabilities, and to solve the equations' system, so as to satisfy the AIT specifications.

5.1 AIT specifications

As previously explained, the AIT specifications are the constraints of the study, which have to be satisfied in order to achieve the correct orientation and location of the reflector. Following the AIT specifications are described for the deployed and the stowed configurations.

5.1.1 Deployed configuration

The AIT specifications define the tolerance in location and in orientation on the reflector in deployed configuration. The reference system used for the verification is the RVD reference system. It is necessary to compare the RVD reference system achieved by inserting the defaults in the model along the ADPM2+ model and the RVD computed respect to the feed and achieved by inserting defaults on RCFA reference system. The AIT specification for deployed configuration are given in SATELLITE axis, so the comparison must be performed in SATELLITE axis, as presented following:

IN ORIENTATION

$$_{SAT_{disp}}()^{SAT_{ideal}} = _{SAT_{disp}}()^{RVD} *_{RVD}()^{SAT_{ideal}} \tag{5.1}$$

IN LOCATION

$$\begin{Bmatrix} \Delta xAIT \\ \Delta yAIT \\ \Delta zAIT \end{Bmatrix}^{SATAXIS} = \begin{Bmatrix} \Delta xRVD \\ \Delta yRVD \\ \Delta zRVD \end{Bmatrix}^{SATAXIS} - \begin{Bmatrix} \Delta xRVD' \\ \Delta yRVD' \\ \Delta zRVD' \end{Bmatrix}^{SATAXIS} \tag{5.2}$$

Where RVD represents the reference system displaced by the defaults along the ADPM2+ chain, while RVD' is the reflector reference system displaced achieved by the RCFA (feed) reference system.

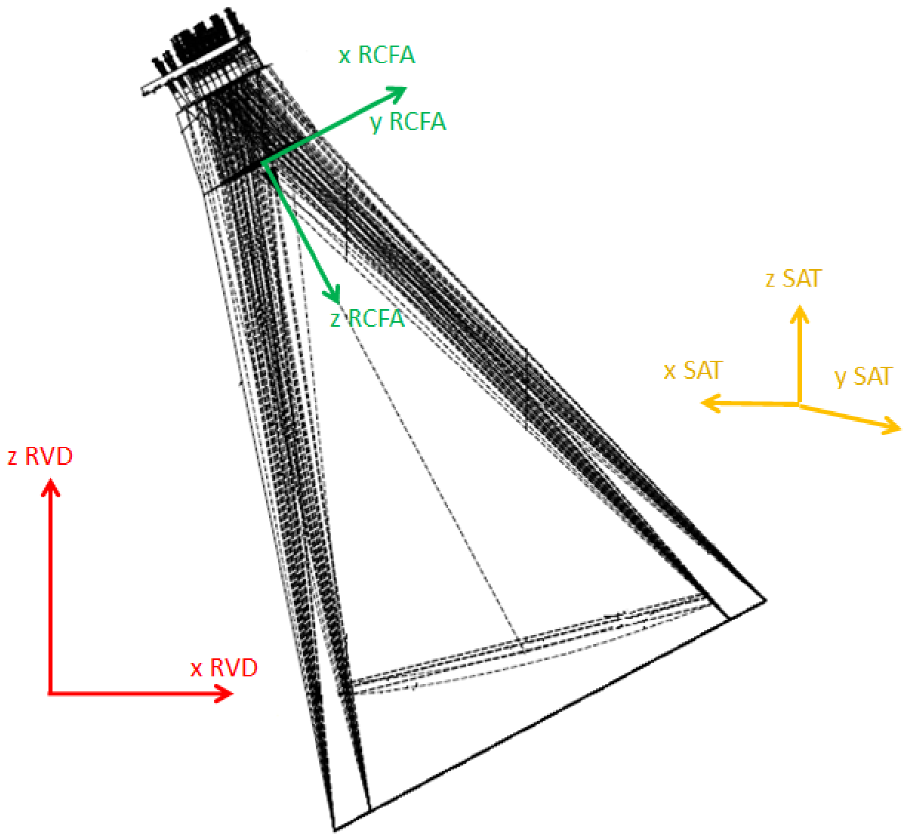

Figure 5.1. Reference systems involved in AIT specification for deployed configuration

	REF.AXIS	*SPECIFICATION*
RVD IN ORIENTATION	x_{SAT}; y_{SAT}; z_{SAT}	0.01°; 0.01°; 0.08°
RVD IN LOCATION	x_{SAT}; y_{SAT}; z_{SAT}	0.5, 0.5, 0.5 mm

Table 5.1. AIT specification for deployed configuration

5.1.2 Stowed configuration

The AIT specifications define the tolerance in location and in orientation on the reflector in stowed configuration. They permit a perfect stocking of the reflector. The reference systems used for the verification are the RCHRM reference system for the correct location of the HRM2Xs support and LLD CENTER reference system for the correct location of the LLD.

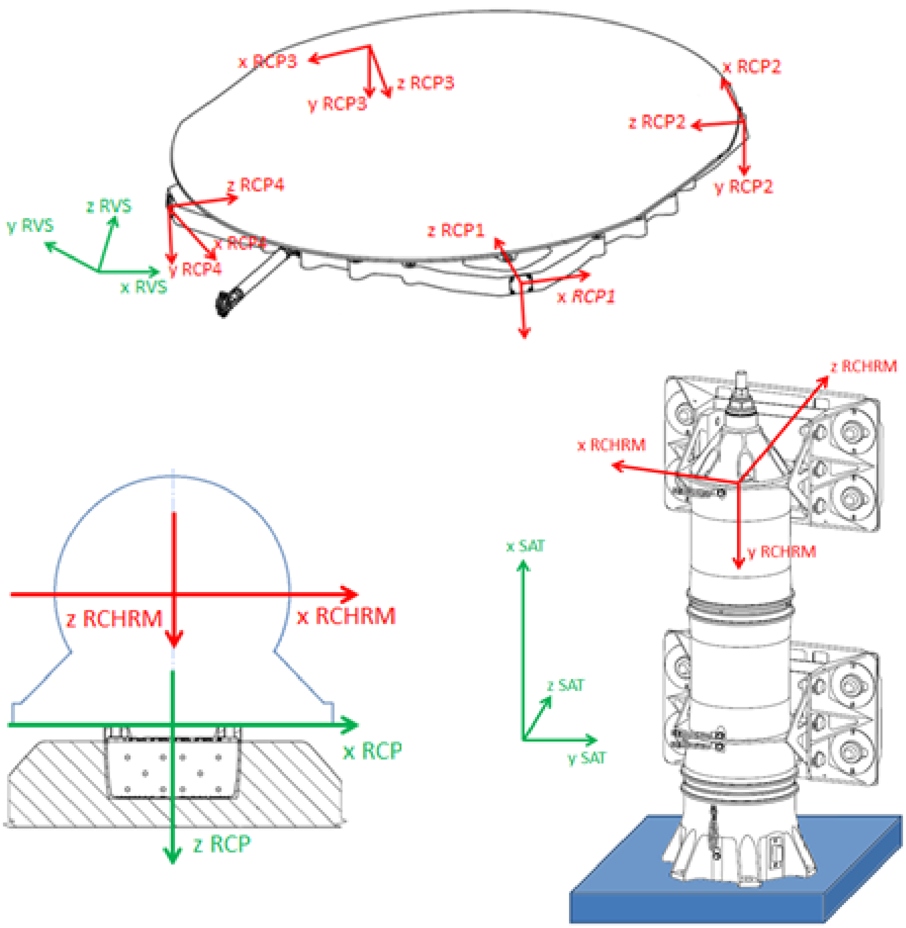

Figure 5.2. Reference systems involved in AIT specification for HRM2X configuration

Regarding the HRM2X comparison it is necessary to compare the reference system achieved by inserting the defaults in the model along the HRM2X model and the RCHRM computed respect to the satellite and achieved by inserting defaults on the ADPM2+ model. The AIT specification for stowed configuration are given in SATELLITE axis, so the comparison must be performed in SATELLITE axis, as presented following:

IN ORIENTATION

$$_{SAT_{disp}}()^{SAT_{ideal}} =_{SAT_{disp}} ()^{RCHRM} *_{RCHRM} ()^{SAT_{ideal}} \tag{5.3}$$

IN LOCATION

$$\begin{Bmatrix} \Delta xAIT \\ \Delta yAIT \\ \Delta zAIT \end{Bmatrix}^{SATAXIS} = \begin{Bmatrix} \Delta xRCHRM \\ \Delta yRCHRM \\ \Delta zRCHRM \end{Bmatrix}^{SATAXIS} - \begin{Bmatrix} \Delta xRCHRM' \\ \Delta yRCHRM' \\ \Delta zRCHRM' \end{Bmatrix}^{SATAXIS} \tag{5.4}$$

Where RCHRM represents the reference system displaced by the defaults along the HRM model, while RCHRM' is the HRM reference system displaced achieved by the ADPM2+ model.

	$REF.AXIS$	$SPECIFICATION$
RCHRM IN LOCATION	x_{SAT}; y_{SAT}; z_{SAT}	S 1 mm

Table 5.2. AIT specification for HRM2X configuration

Regarding the LLD comparison it is necessary to compare the reference system achieved by inserting the defaults in the model along the LLD model and the LLD CENTER computed respect to the satellite and achieved by inserting defaults on the ADPM2+ model.

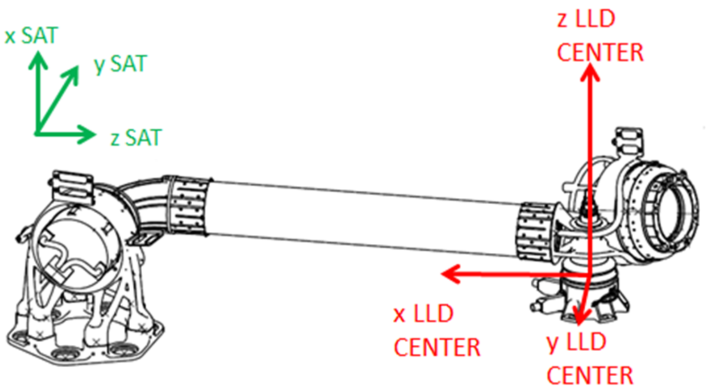

Figure 5.3. Reference systems involved in AIT specification for LLD configuration

As for the HRM, the AIT specification for stowed configuration are given in SATELLITE axis:

IN ORIENTATION

$$ {}_{SAT_{disp}}()^{SAT_{ideal}} = {}_{SAT_{disp}}()^{LLDCENTER} * {}_{LLDCENTER}()^{SAT_{ideal}} \tag{5.5} $$

IN LOCATION

$$ \begin{Bmatrix} \Delta xAIT \\ \Delta yAIT \\ \Delta zAIT \end{Bmatrix}^{SATAXIS} = \begin{Bmatrix} \Delta xLLDCENTER \\ \Delta yLLDCENTER \\ \Delta zLLDCENTER \end{Bmatrix}^{SATAXIS} - \begin{Bmatrix} \Delta xLLDCENTER' \\ \Delta yLLDCENTER' \\ \Delta zLLDCENTER' \end{Bmatrix}^{SATAXIS} \tag{5.6} $$

Where LLD CENTER represents the reference system displaced by the defaults along the LLD model, while LLD CENTER' is the LLD reference system displaced achieved by the ADPM2+ model.

	REF.AXIS	*SPECIFICATION*
LLD IN LOCATION	x_{SAT}; y_{SAT}; z_{SAT}	S 1 mm

Table 5.3. AIT specification for LLD configuration

5.2 Adjustment capabilities

The solver has the goal to offset the defaults by using the available adjustment capabilities. As previously described, in the mathematical models, the adjustment capabilities are various and with different working.
Following the adjustment capabilities for the ADPM2+ are presented for relevance:

- **Motor capabilities:** motors are the simplest way to perform a correction since they do not need machining and their corrections do not require much time. These capabilities are useful both for the deployed configuration and for stowed configuration in order to reach the perfect stocking of the reflectors. Usually the magnitude of the correction is no higher than one degree, so that means no more than 100 motor steps.

- **Peliable shims:** these capabilities have the function to displace the reflector only in location. They are located at the base of the ADPM2+ and, considering the plane which identifies the base of the bracket of the ADPM2+ motor 1, the peliable shims are out of plane adjustments. Their capabilities are between -10 mm and 10 mm.

- **Slotted washer:** they are located in the plane of the base of the ADPM2+ motor 1 bracket. Their capabilities are effective to perform corrections along the two plane coordinates. Their capabilities, in polar coordinates, are equal to radius in the range 0 to 10 mm.

- **Machining shims:** there are 3 machining shims available on the ADPM2+. Their function is to correct both the orientation and the location of the reflector. Their capabilities are computed by defining two angles: the α angle, which identifies the direction of the usinage, while the β angle defines the machining angle. If for the α angle there are not constraints, while for the β angle the range is defined as follows:

  1. First machining shim has a beta capability between 0.05° and 0.5°;
  2. For the second and the third machining shims the range is between 0.05° and 1.1°.

- **Clocking capability:** it is located at the base of the ADPM2+ motor 1 bracket. Its capability is in the range between -0.3° and +0.3°.

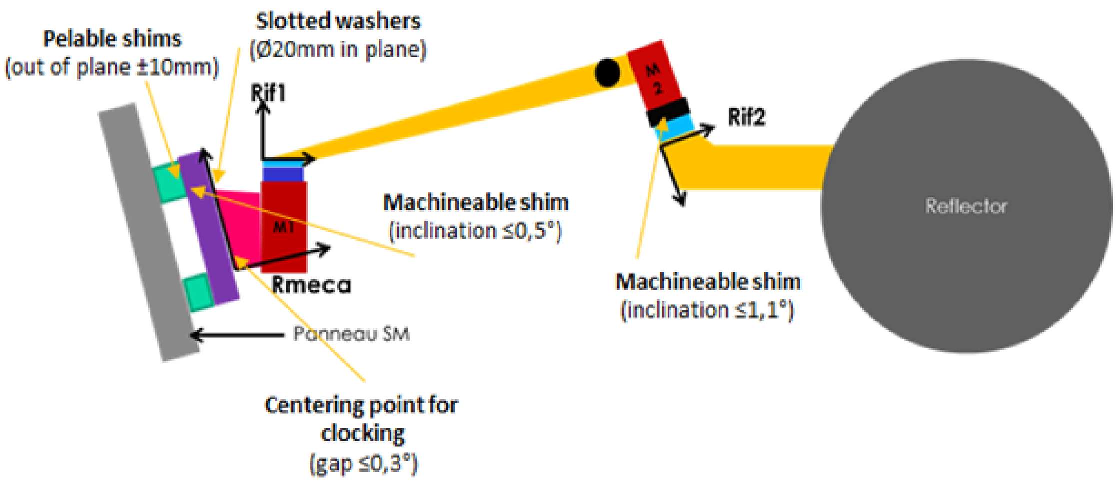

Figure 5.4. Scheme of the ADPM2+ adjustment capabilities

Following the adjustment capabilities for HRM2X are listed:

- **Peliable shims:** these capabilities has the function to displace the reflector only in location for a perfect stocking. They are located at the base of the HRM2X. Their capabilities are between -7 mm and 7 mm.

- **Slotted washer:** they are located in the plane of the base of the HRM2X pod and in the plane of the interface bracket of the reflector. Their capabilities, in polar coordinates, are equal to a radius in the range between 0 to 6 mm for HRM2X pod, while in the range 0 to 10 mm for the interface bracket.

- **Slotted holes:** they are located out of the plane of the interface bracket of the reflector. Their capabilities are in the range 0 to 10 mm.

- **HRM2X orientation adjustments:** there are three adjustment capabilities on the HRM2X: one in the range from 0° to 360° around z HRM MEC axis and the remaining adjustments are in the range between -1° and 1° around x HRM MEC axis and y HRM MEC axis.

However in that solver the HRM2X orientation adjustments are not taken into account, but their effect on the bracket location is taken into consideration by reducing the capabilities of the slotted washer and the slotted holes of the interface bracket from 10 mm to 8 mm. That reduction implies that even if the adjustments in rotation are used at the maximum of their capabilities, their effects are still correctable by the other capabilities. Indeed, considering the distance between the RCHRM reference system origin and the interface bracket equal to 92 mm, the maximum displacement due to the adjustment rotation is:

$$\Delta = 92\, mm * tang 1^{\circ} = 1.606\, mm \tag{5.7}$$

So reducing the capability to 8 mm it is always possible to offset the displacement due to the rotation. Moreover the specifications in rotation for the HRM2X suggest to have no more than 1° around each RCHRM axis. That condition is always feasible using the orientation adjustments in their operating capabilities.

At the end, the adjustment capabilities for LLD are presented following:

- **Peliable shims:** these capabilities has the function to displace the reflector only in location for a perfect stocking. They are located at the base of the LLD. Their capabilities are between -5 mm and 5 mm;

- **Slotted washer:** they are located at the base of the LLD pod. Their capabilities, in polar coordinates, are equal to a radius in the range between 0 to 7 mm for the LLD pod.

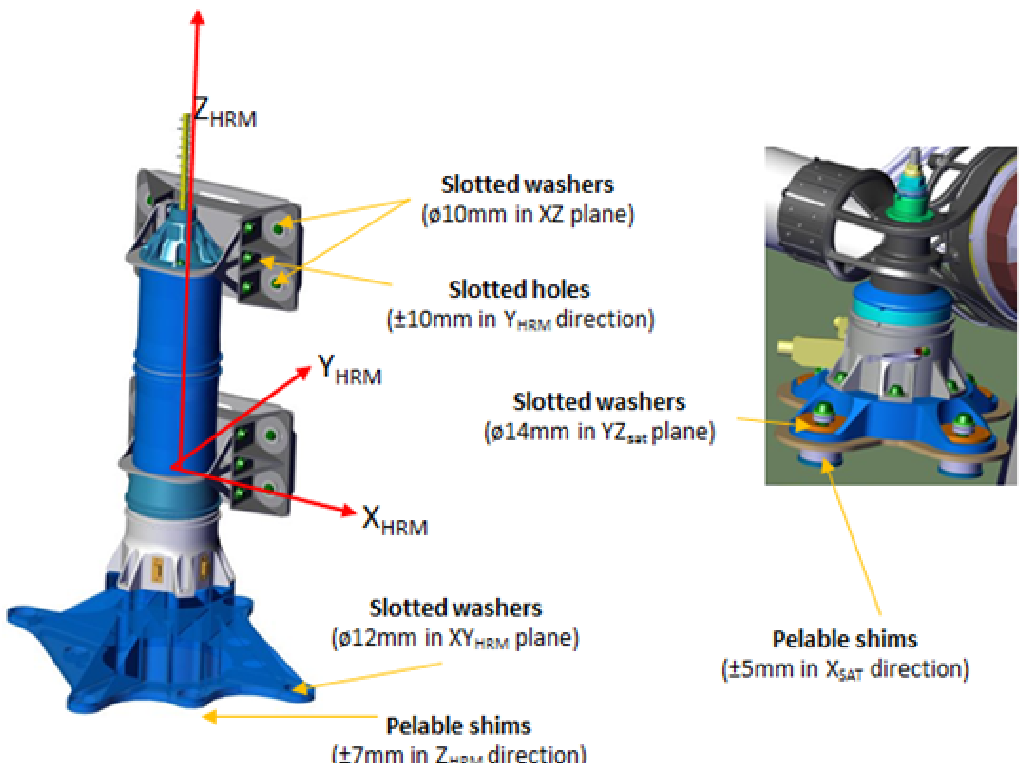

Figure 5.5. Scheme of the HRM2X adjustment capabilities

In table In 5.4 there is a list of all the adjustment capabilities as inserted in the computation:

Adjustment capability	Range
1) MOTOR 1 ANGLE IN DEPLOYED CONFIGURATION	-360°;360°
2) MOTOR 2 ANGLE IN DEPLOYED CONFIGURATION	-360°;360°
3) MOTOR 1 ANGLE IN STOWED CONFIGURATION	-360°;360°
4) MOTOR 2 ANGLE IN STOWED CONFIGURATION	-360°;360°
5) PELIABLE SHIMS OF ADPM2+	-10;10 mm
6) DIRECTION OF THE USINAGE OF MACHINING SHIM 1	-180°;180°
7) USINAGE ANGLE OF MACHINING SHIM 1	0.05°;0.5°
8) RADIUS FOR ADPM2+ MECH CORRECTION	0;10 mm
9) ANGLE OF ADPM2+ MECH CORRECTION	-180°;180°
10) ANGLE FOR CLOCKING CORRECTION	-0.3°;0.3°
11) DIRECTION OF THE USINAGE OF MACHINING SHIM 3	-180°;180°
12) USINAGE ANGLE OF MACHINING SHIM 3	0.05°;1.1°
13) DIRECTION OF THE USINAGE OF MACHINING SHIM 2	-180°;180°
14) USINAGE ANGLE OF MACHINING SHIM 2	0.05°;1.1°
15) PELIABLE SHIMS OF LLD	-5;5 mm
16) RADIUS FOR LLD MECH CORRECTION	0;7 mm
17) ANGLE OF LLD MECH CORRECTION	-180°;180°
18) PELIABLE SHIMS OF HRM2X	-7;7 mm
19) RADIUS FOR HRM2X MECH CORRECTION	0;6 mm
20) ANGLE OF HRM2X MECH CORRECTION	-180°;180°
21) ANGLE AROUND LCHRM x AXIS	-1°;1°
22) ANGLE AROUND LCHRM z AXIS	-1°;1°
23) ADJ CAP ALONG Z LCHRM	-8;8 mm
24) RADIUS FOR LCHRM CORRECTION	0;8 mm
25) ANGLE OF LCHRM CORRECTION	-180°;180°
26) ANGLE AROUND UCHRM x AXIS	-1°;1°
27) ANGLE AROUND UCHRM z AXIS	-1°;1°
28) ADJ CAP ALONG Z UCHRM	-8;8 mm
29) RADIUS FOR UCHRM CORRECTION	0;8 mm
30) ANGLE OF UCHRM CORRECTION	-180°;180°

Table 5.4.

The adjustment capabilities from the 18 to the 30 are regarding only one HRM2X. They have to be repeated for all the HRM2X.

5.3 Solving method

The solver used to find a solution for the that problem is the Matlab function Lsqnonlin [5]. That function solves non-linear least-squares (non-linear data fitting) problems[6]. In particular it solves nonlinear least-squares curve fitting problems of the form:

$$\min_x ||f(x)||_2^2 = \min_x (f_1(x)^2 + f_2(x)^2 + ... + f_n(x)^2) \tag{5.8}$$

That solver is particularly useful since it lets the user to define boundaries to the independent parameters, $x_1, x_2, \ldots, x_n$, which in this study correspond to the adjustment capabilities. Thus, for each x parameter a lower and an un upper bounds are defined.
Finally the solver asks to the user to define the objective functions, which have to be minimize in order to approach to the solution. The objective functions in that computation are the equations of comparison between the ideal configuration and the one modified by the defaults. These equations are the ones used to verify that the AIT specifications are satisfied and that means for each AIT specification corresponds an objective function. Thus considering to offset the deployed and the stowed configuration in orientation and in location, there are 36 objective functions to minimize for each antenna:

- 6 equations for the deployed configuration;
- 6 equations for each HRM2X (in total 24 equations for the four HRM2X);
- 6 equations for the LLD.

Furthermore, there are two antennas per each side of the satellite linked together by the HRM2Xs. In particular, the HRM2X pod adjustment capabilities are in common for both antennas. So if the HRM2X POD adjustment capabilities are used to offset the defaults, the solver requires to insert the objective functions for both antennas in the computation.

5.3.1 Residual uniformity

The solver tries to find a minimum of the residual of each objective function. However, not all the residuals has the same magnitude since rotational residuals are expressed in degree while location residuals are expressed in millimeter. For this reason, the following correction is performed in order to make uniform the residuals.
Firstly, the average residual for each objective function is computed, as displayed in Figure 5.6, 5.7, 5.8, 5.9, 5.10 and 5.11. Each figure represents the orientation and location residual for each specification type.

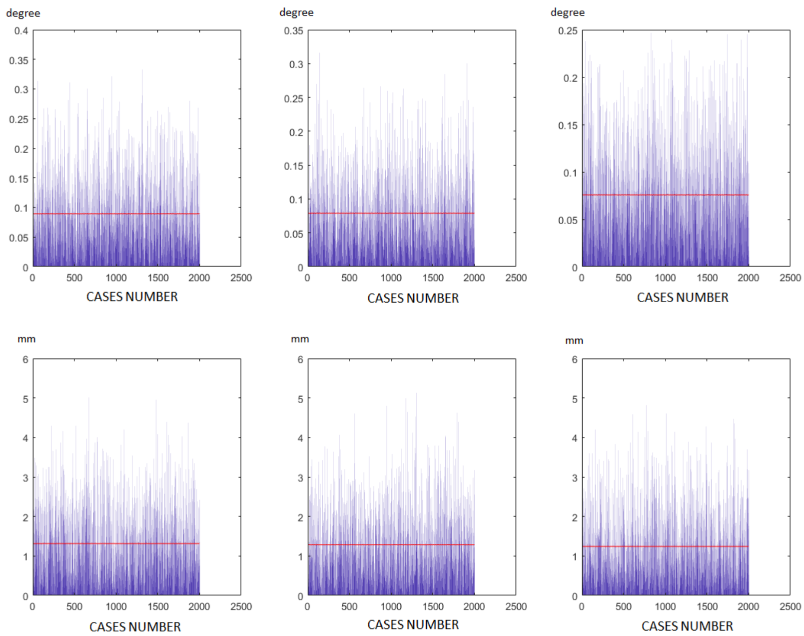

Figure 5.6. Residuals for RVD reference system

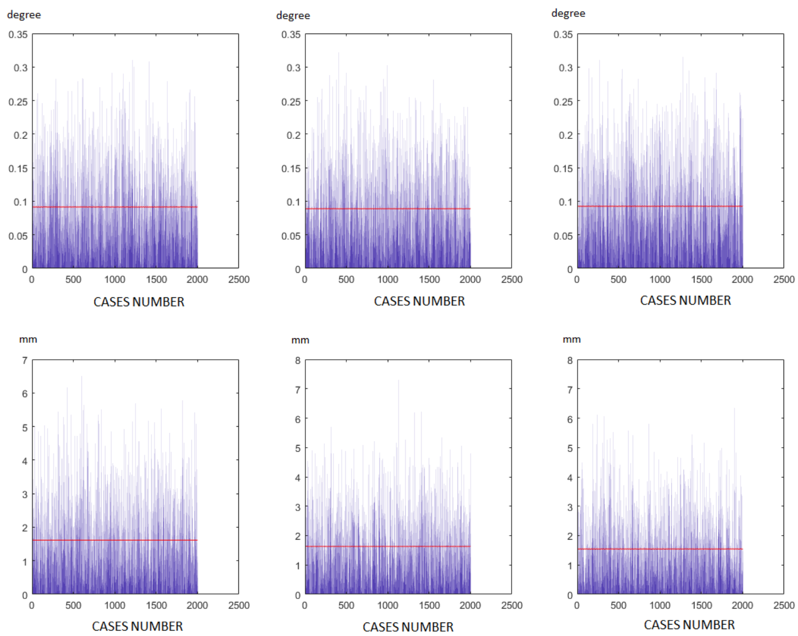

Figure 5.7. Residuals for LLD reference system

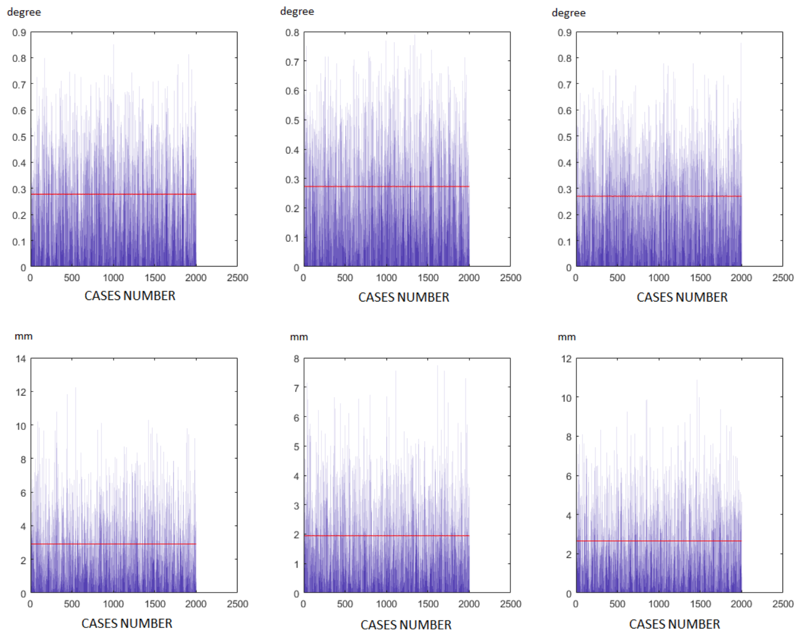

Figure 5.8. Residuals for RCHRM1 reference system

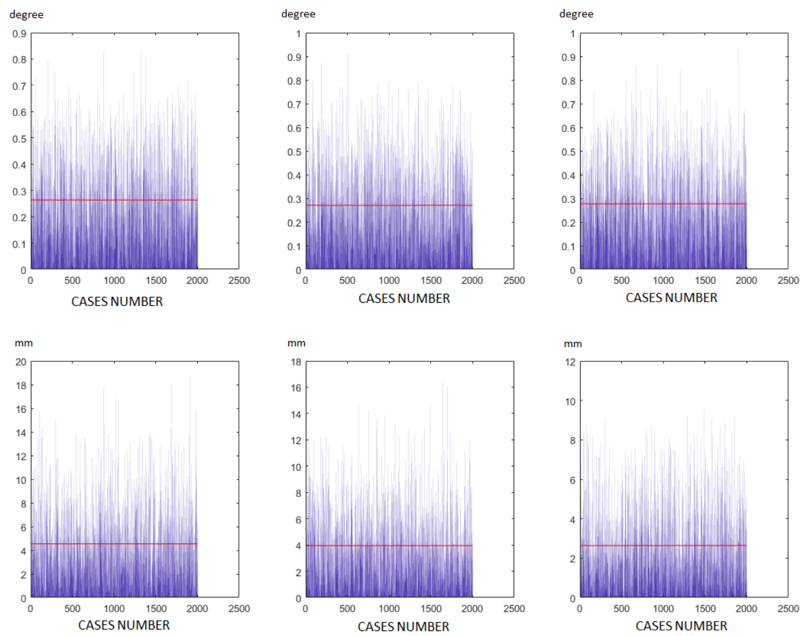

Figure 5.9. Residuals for RCHRM2 reference system

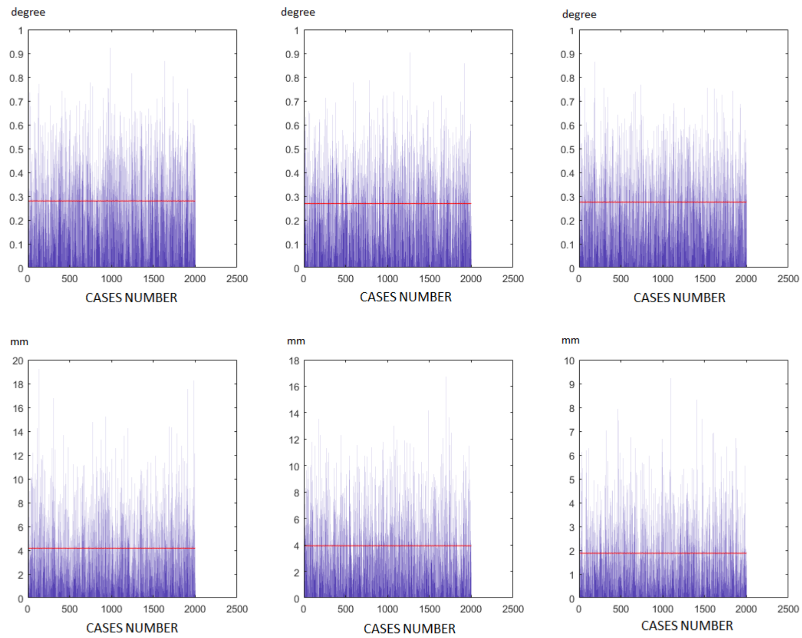

Figure 5.10. Residuals for RCHRM3 reference system

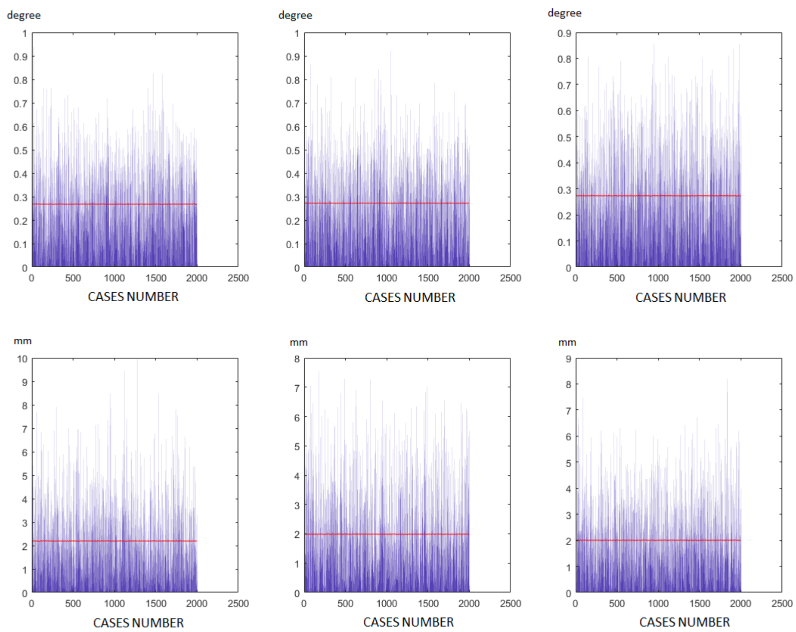

Figure 5.11. Residuals for RCHRM4 reference system

The previous figures showed the results of 2000 simulations cases. The residuals of each objective function is represented in each graphics and they are computed by inserting the default matrices, which are randomly created, in the antenna mathematical model.
As visible from the graphics, the proportion between the averages of the orientation and location residuals for each type of specifications is about 15. Consequently, a k constant equal to 15 is multiplied to the objective function regarding the orientation.
Performing the resolution in that way the solver is not influenced by preferring some adjustment capabilities rather others.

5.3.2 Preferences on the solving

Some of the AIT specifications are stricter rather than others. In particular specifications in orientation and in location for the deployed configuration are stricter than the ones for stowed configuration. Specially the specifications in orientation for the stowed configuration are not a primary request. For this reason another k factor is multiplied to the residuals in order to give relevance to some objective functions.
In that computation a k factor equal to 0.1 is multiplied to all the objective functions regarding the orientation for the stowed configuration.

5.3.3 Solving conditions

The solver has the goal to find the minimum of the quadratic sum of the all objective functions. However, the solver is not set to insert a constraint for the output quantity. That means it is necessary to verify the AIT specifications once the solver has found a solution.
In case the solution does not satisfy the AIT specifications, another attempt to find the solution is performed. Since the solver needs initial values vector for the independent parameters x (the adjustment capabilities), each time random values, in the capabilities ranges, are given to the solver.

Chapter 6

Results

The results are divided in three different parts:

- The first part regards the check of the adjustment capabilities. That means verifying they are sufficient to offset the defaults for every default configuration. Moreover it is necessary to verify if the range capability of the adjustment is well designed or it needs to be extended in order to improve the efficacy of the adjustment.
- The second part regards the optimization process. This study focuses on finding different ways to align the reflectors and giving good practices to the alignment team to simplify the correction of the antennas.
- The last one has the goal to verify if the adjustment capabilities are still able to offset the defaults, whose specifications are increased. That means the configuration has more probability to be further from the ideal one.

6.1 Verification of the adjustment capabilities

The first simulation, with the goal to cover the 95% of the input default, is performed by simulating 10000 different initial default matrices configurations. The first verification is linked to the efficacy of the adjustment capabilities. Indeed the simulation verify if all the reflector configurations modified by the errors can be offset by using all the adjustment capabilities.
The second goal is to search if the adjustment values cover the entire design capabilities range. There could be three types of conclusion by analyzing the results:

- The distribution of the adjustment values cover the entire range provided;
- The values cover only part of the range;

- The values cover the entire range and the values density close to the range limits is high. That means probably the range should be extended in order to exploit the adjustment efficacy.

6.1.1 Simulation 1: Part 1

As previously defined, the first simulation is performed by evaluating 10000 different default matrices. Figure 6.1 shows that using all the adjustments capabilities is always possible to offset the defaults and satisfying the AIT specifications. However, that default coverage could not include cases, which are defined as worst case. These cases affect strongly the reflector configurations and their corrections result to be more complicated.

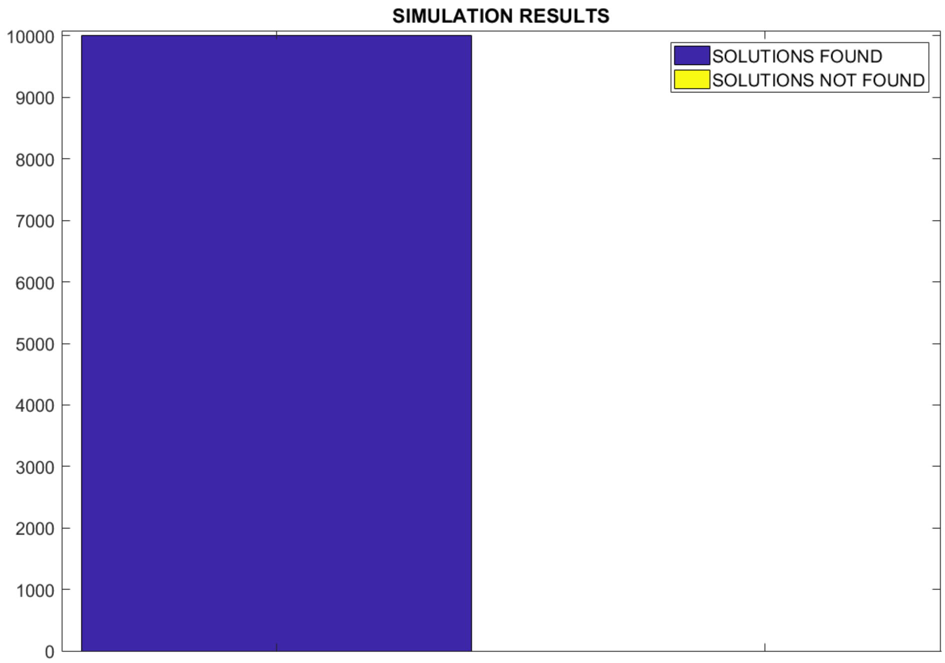

Figure 6.1. Simulation 1 results

The blue column represents the solution solved while the yellow represents the unsolvable cases. The yellow one is not visible since all the cases are solved and they satisfy the AIT specifications.
So from this simulation it seems that the adjustment are well designed to offset every defaults configuration.

6.1.2 Simulation 1: Part 2

That part shows for each adjustment capability their values distribution for 10000 cases. That graphics are made in histogram format and each column represent how many times the adjustment capability assumes that specific value. All the graphics represent the distribution for antenna 1 (inner antenna) and antenna 2 (outer antenna) located in the same satellite side.
Firstly motor 1 and 2 are showed both for deployed (D) and stowed configurations (S). The distributions of the motors adjustments point out that:

- The distribution follows a Gaussian trend, whose central value is for all the cases about 0° value. Thus, most of the times the motors are used only for few steps. Considering that the step value for both motors for MS1 is 0.009375°, the necessary steps are few;
- The maximum value does not overcome, in absolute value, 1.05°. In terms of steps, in no cases the steps are higher than 108;
- Regarding motor 1 the distribution is the same for both antennas;
- Regarding only the deployed configuration, the motor 1 correction is double compared to the motor 2 correction;
- Regarding the stowed configuration, the motor 1 correction is of the same magnitude of motor 2 correction;
- About 92% of the cases are solvable using motor 1 capability between -0.5 ° and 0.5 ° for deployed configuration;
- About 99.2% of the cases are solvable using motor 2 capability between -0.5 ° and 0.5 ° for deployed configuration;

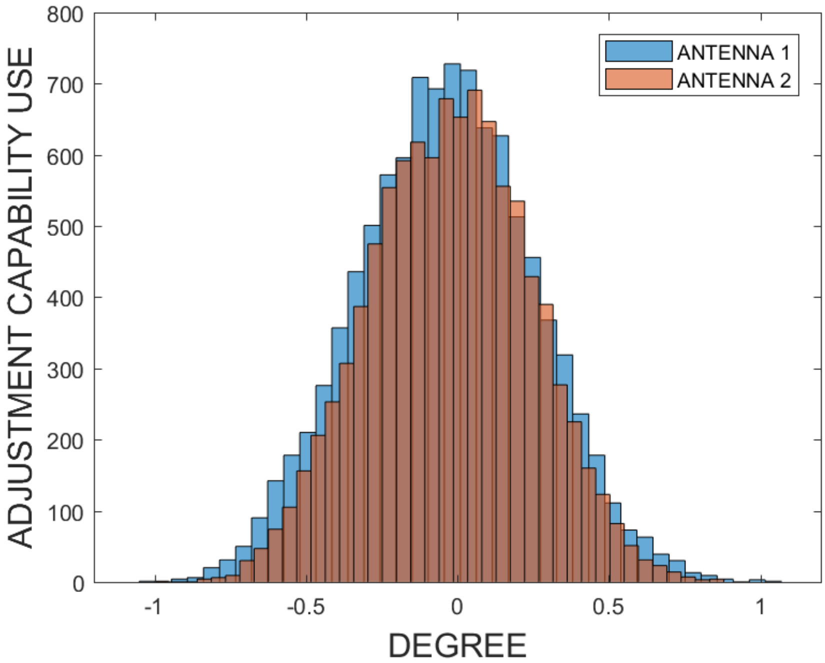

Figure 6.2. Motor 1 angle for deployed configuration

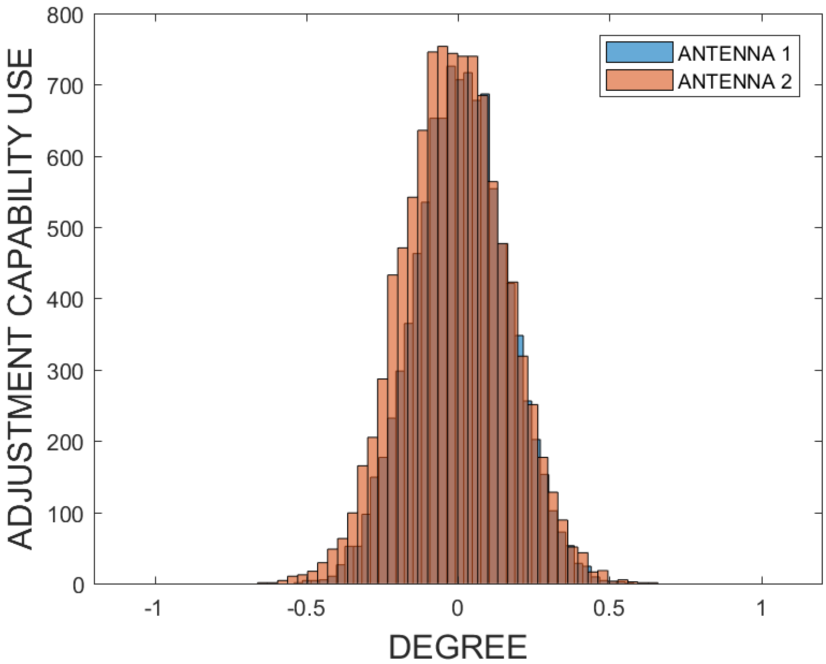

Figure 6.3. Motor 2 angle for deployed configuration

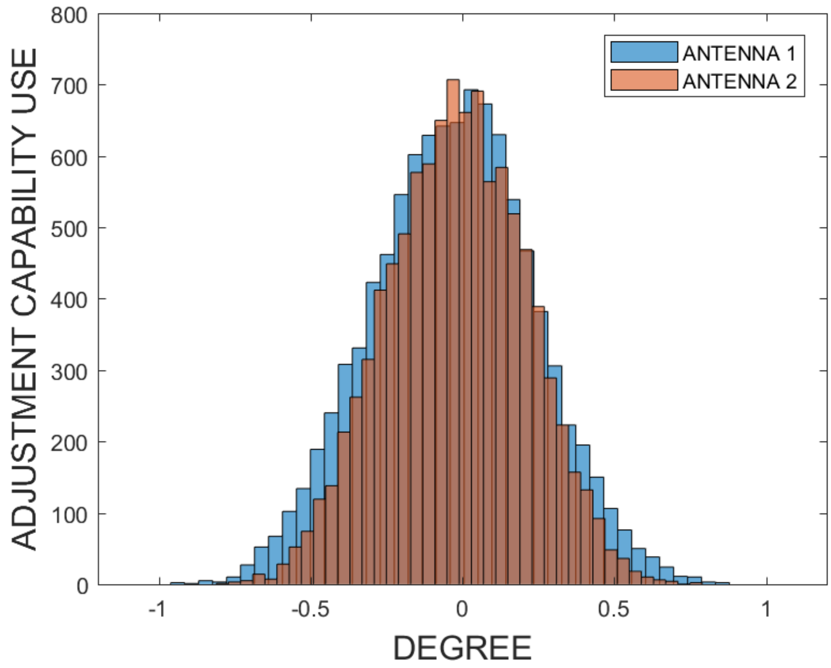

Figure 6.4. Motor 1 angle for stowed configuration

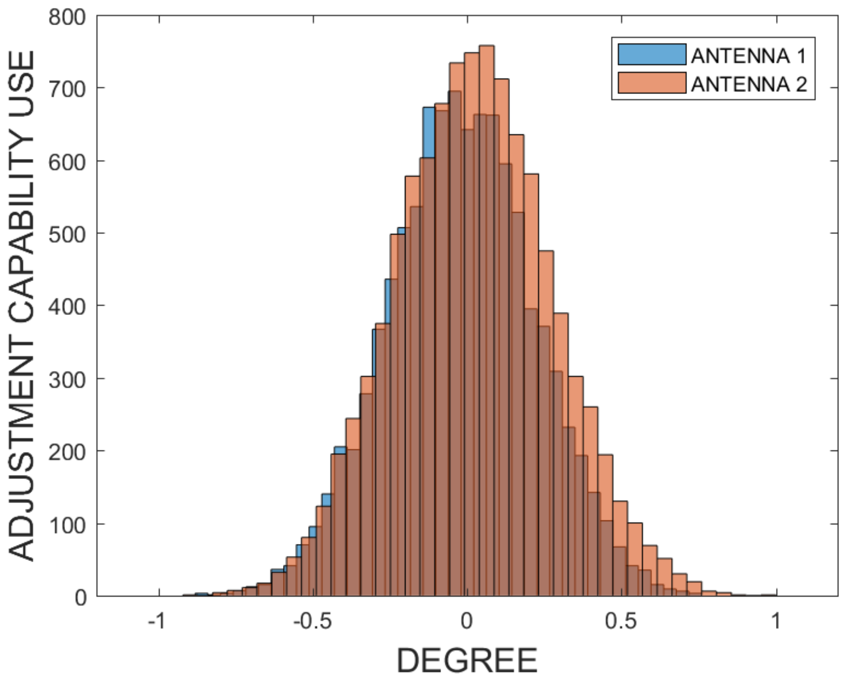

Figure 6.5. Motor 2 angle for stowed configuration

Figure 6.6, 6.7 and 6.8 show the distribution for the ADPM2+ location capabilities at the base of motor 1 bracket. Peliable shims are the out of plane correction, while the slotted washers are in the plane correction.
The graphics in Figure 6.7 and 6.8 represent the capabilities of the slotted washers according to polar coordinates. Indeed the first one displays the distribution of the radius, while the second one shows the distribution of the polar angle.

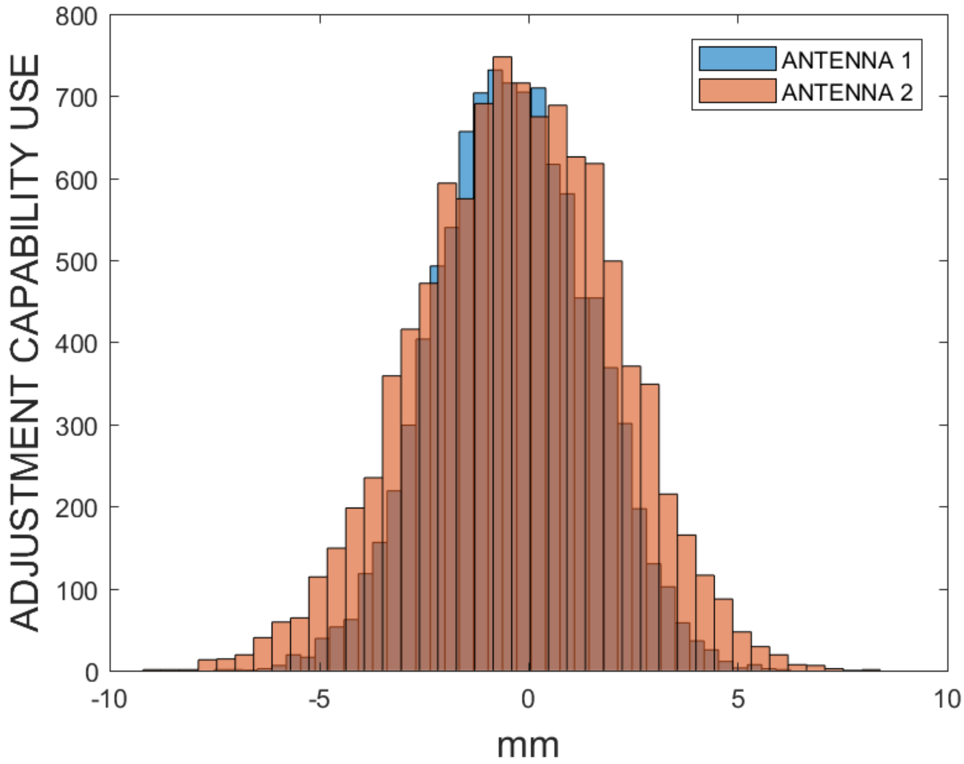

Figure 6.6. ADPM2+ Peliable shims

Some comments could be done also for these graphics:

- The distribution of the peliable shims follows a Gaussian trend with a central value close to zero;
- The peliable shims correction values for both antenna do not cover the entire range available. In particular, for the first antenna the distribution is limited in the range between -6 mm and 6 mm;
- The second antenna requires in average higher peliable shims corrections compared to the first antenna;

- Regarding the slotted washers correction the most of the values are located close to 2 mm. Only a peak in 0 mm is evident;
- Regarding the slotted washers correction the distribution do not cover all the range available but the maximum value is lower than the maximum capability of 10 mm;
- There is not evident difference between the slotted washers distributions of the two antennas.
- The polar angle is distributed almost uniformly in its range, except for two peaks at the boundaries.

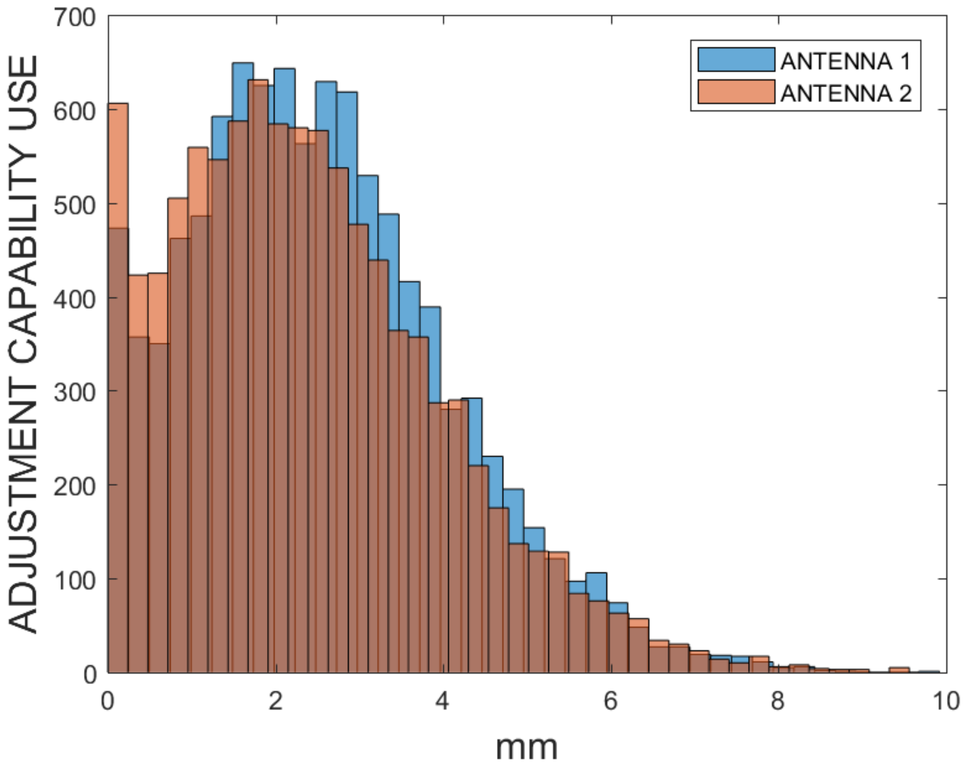

Figure 6.7. Radius for the ADPM2+ slotted washers

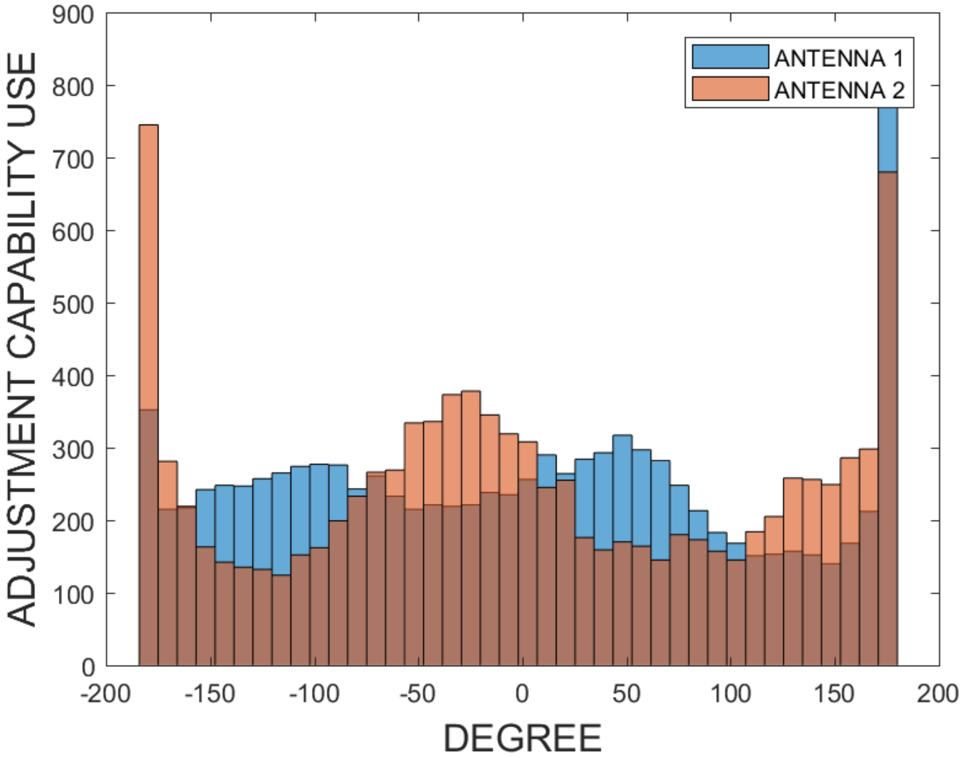

Figure 6.8. Angle of the direction adjustment for the ADPM2+ slotted washers

Figure 6.9 displays the values distribution for the clocking correction.
About the clocking angle correction:

- The value distribution is similar to a triangular distribution, whose peak is close to 0° value;
- The values cover all the range designed and even the boundaries values are used at least 60 times. It could be interesting extending the range available exploiting the entire adjustment capacity;
- There are not evident differences between the two antenna distributions.

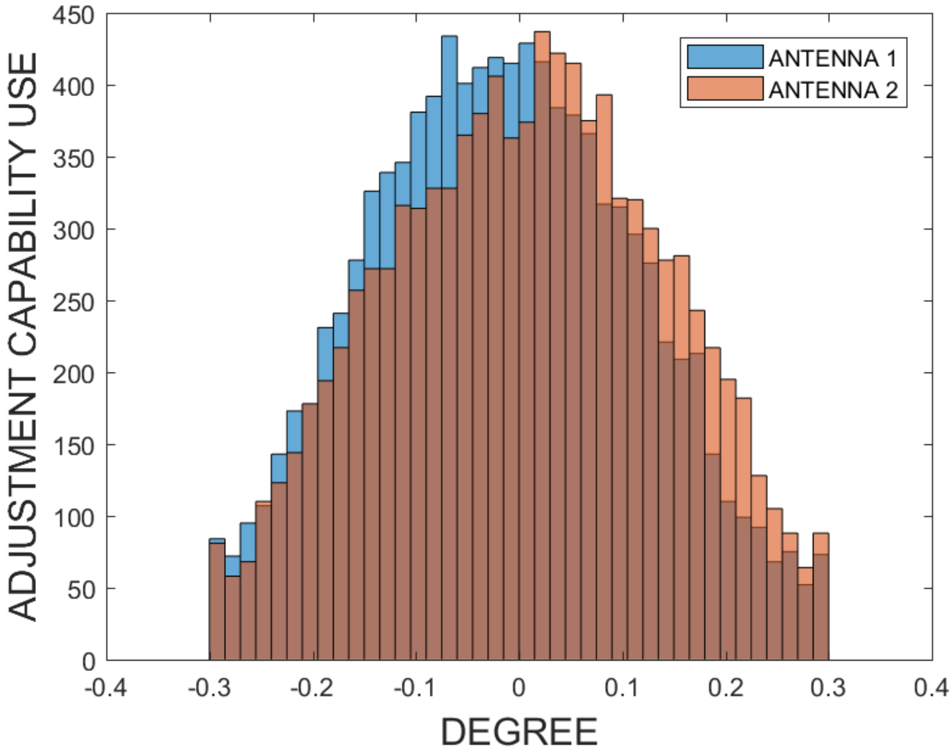

Figure 6.9. Clocking angle

Finally, the distributions regarding the use of the machining shims. For each machining shim two angles are provided, the α angle identifies the direction of the usinage, while the β angle defines the machining angle. The β angle capability of the first machining is in the range between 0.05° and 0.5°, while for the second machining shim it is in the range between 0.05° and 1.1°.

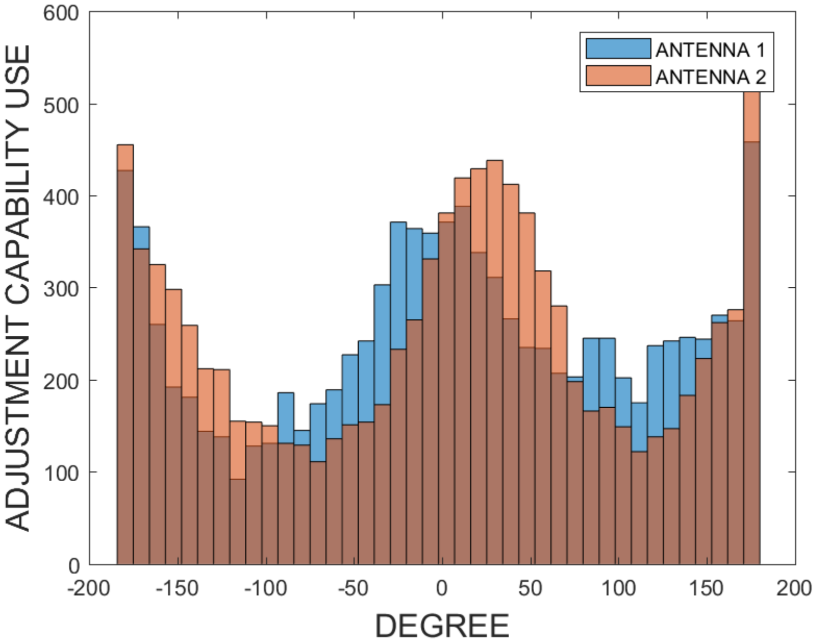

Figure 6.10. α angle for machining shim 1

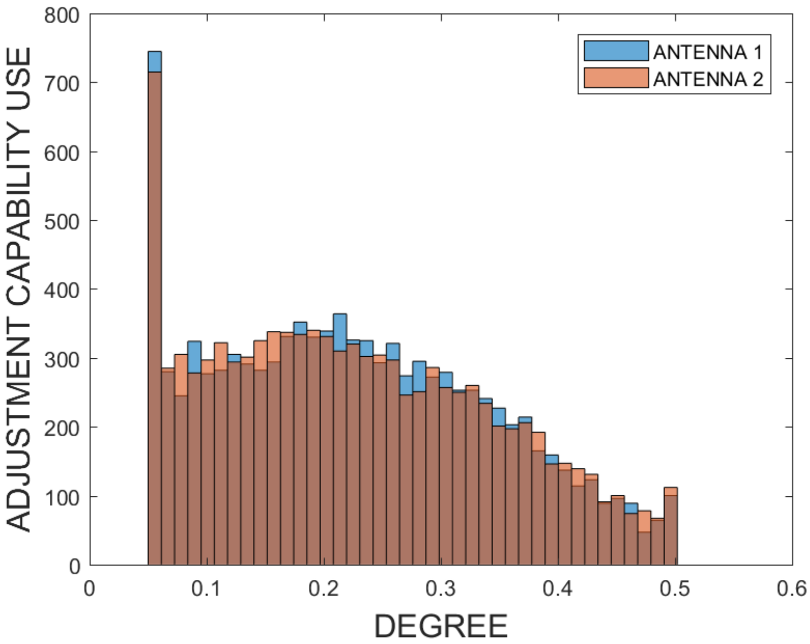

Figure 6.11. β angle for machining shim 1

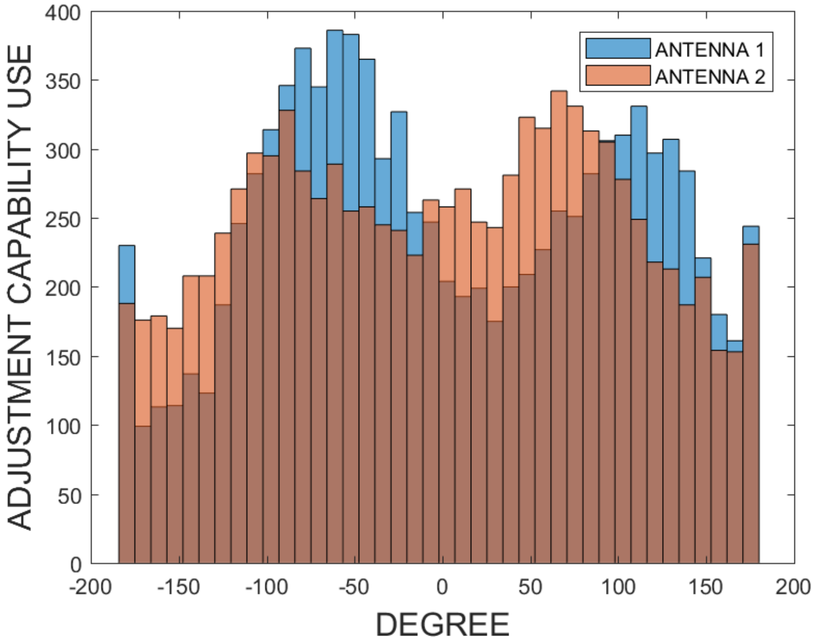

Figure 6.12. α angle for machining shim 2

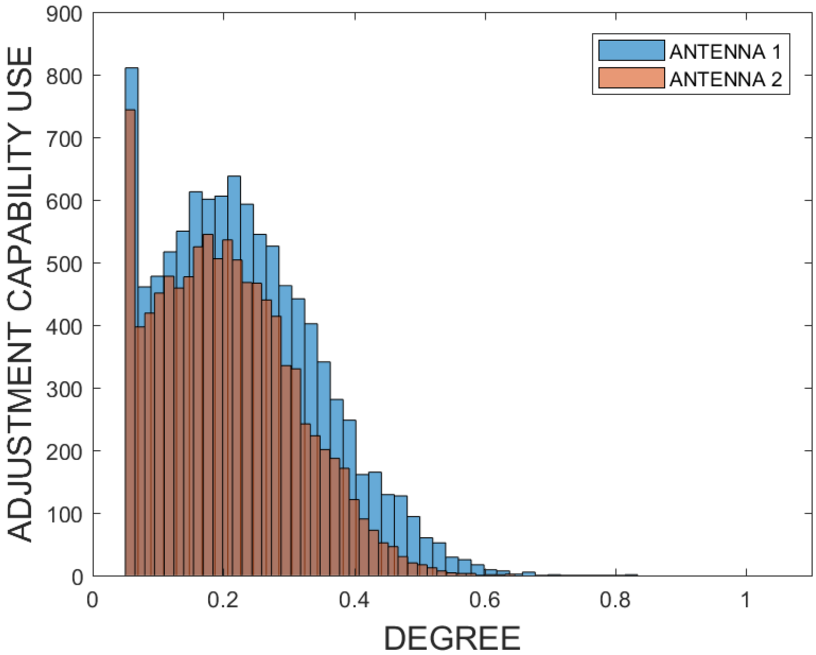

Figure 6.13. β angle for machining shim 2

Following some details pointed out by the previous figures:

- Regarding the α angles, for the machining shim 1 there are three peaks, two at the boundaries and the last one is located close to the 0° value. While the second shim has two peaks, located about -80° and 80°;
- Regarding the β angle for the first shim the distribution is decreasing towards the right limit. Moreover a peak is evident in the left limit. The values cover all the range designed and there are still 100 uses of the maximum capacity.
- Regarding the β angle for the second shim the distribution is decreasing towards the right limit. There are two peaks: the first one at the left limit and the second one is located close to 0.25°. The values do not cover the entire range designed. Indeed, although the maximum capacity is 1.1°, the maximum value used is 0.85°.
- There are not evident differences between the two antennas distributions for both machining shims.

There are some final considerations about all the previous distributions. The first one regards the limitation of the machining range since due to production feasibility it cannot be possible machining the shims below a specific angle. In this computation that limit is fixed at 0.05°.
Moreover that limitation has a benefit to the motors distributions since permitting the solver to find solutions using very low values (<0.05°) for the machining shims has the effects to increase the motor angles for the correction.
Finally it could be effective the modification of the capabilities range in order to exploit to the best the adjustments .

6.2 Optimization process

This chapter analyzes different combinations of adjustment capabilities in order to offset the defaults and to lead the antenna inside the AIT specifications.
The goal is to simplify the procedure of alignment preferring for first those adjustments which are easily manageable and easily to perform. Only in case these adjustments seem to be insufficient to offset the defaults, then other capabilities are added to the computation.
Before analyzing the results from each simulation, a brief focus is made on the adjustment capabilities preferences. They are presented following in order of preference:

- **Motor capabilities:** they are always used since their correction is easily to perform;

- **ADPM2+ translation capabilities:** they include both the peliable shims and the slotted washers at the base of motor 1 bracket. Their correction is necessary to locate the reflector in the correct position. Then these types of correction do not require long work time and high costs;

- **Machining shims:** their corrections require time since their manufacture is not made by the alignment team. They are used only if the first two adjustment capabilities group fail the correction.

- **Clocking angle:** that adjustment is not easily performable and requires new measurements each time the motor 1 bracket is moved;

- **HRM2X pod capabilities:** these adjustments are the most difficult to perform since they are linked to both antennas configuration (on the same satellite side). Moreover avoiding the use of the HRM2X pod highly affects the solver because each antenna model is solved independently from the other one. Consequently, it brings benefits to the solving complexity and so to the computational time.

Regarding the other HRM2X adjustment capabilities and the LLD adjustment capabilities, they are always used to offset the defaults.

6.2.1 Simulation 2: Avoiding the use of the HRM2X POD adjustments

That simulation prove that, in the default coverage analyzed, the HRM2X pod adjustment capabilities cannot be used for every defaults configuration.
The simulation regards 10.000 cases, and so 10.000 initial defaults matrices created randomly with the Montecarlo method. As defined for the previous simulation, that default coverage do not include all the possible default configurations and that means the worst case could not be taken into account.

The Figure 6.14 diplays that for all the cases a solution is found without using the HRM2X pod adjustment capabilities.

This simulation result is a useful information for the alignment team since they do not have to handle the HRM2X pod adjustments in order to correct the antenna configuration.

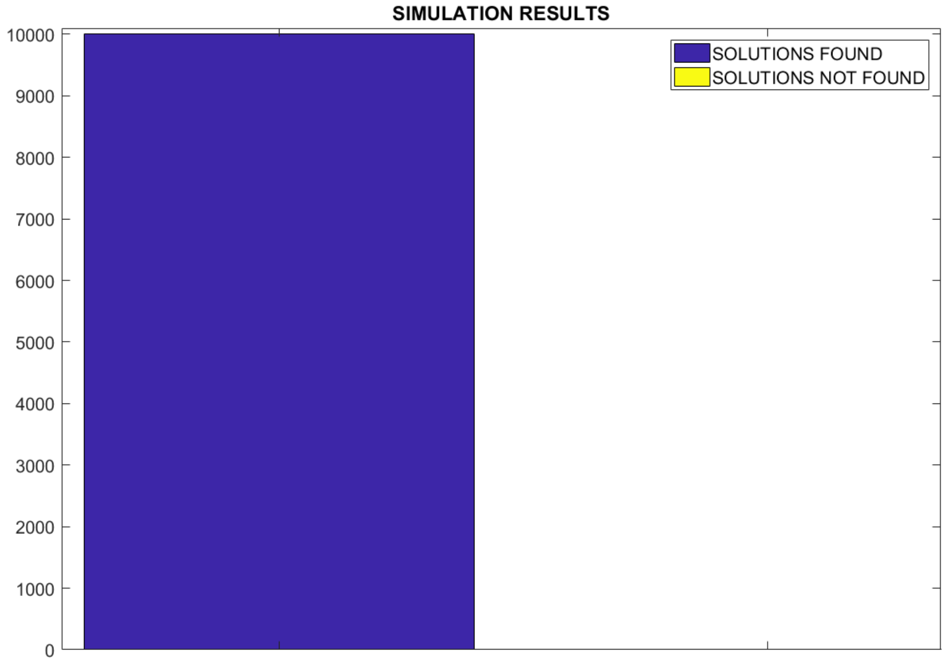

Figure 6.14. Simulation 2 results

6.2.2 Simulation 3: Avoiding the use of machining shim 1

A new optimization process is performed for the simulation 3. In particular, the solver is asked to find a solution without using the machining shim 1 and at the HRM2X pod adjustment capabilities.

As previously introduced, the machining shims are specifically manufactured and that process requires time and cost. For this reason, it would be preferable avoiding the use of the machining shims when that is possible. In addition the adjustment capabilities of the HRM2X pod should not be used since their corrections are the most complicated to perform.

The number of cases simulated is 1.000. As visible in Figure 6.15 a solution is founded for all the cases. That means the offset of the defaults is possible without performing corrections with the machining shim 1 and the adjustment capabilities of the HRM2X pod.

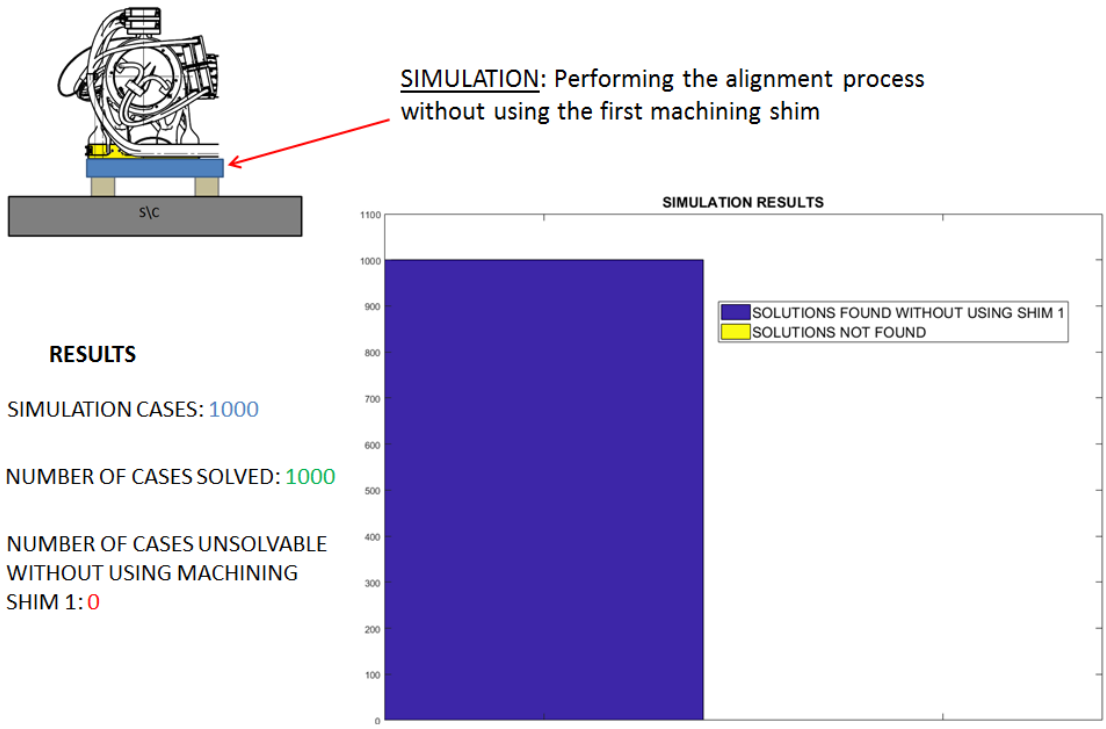

Figure 6.15. Simulation 3 results

6.2.3 Simulation 4: Use the least adjustment capabilities

Differently from the previous simulations, that simulation performs the resolution of the problem with the least adjustment capabilities. So that means the solver is asked to solve it firstly with only few parameters. Then in case of no solution satisfying the AIT specifications, the number of the adjustment capabilities available to find a solution increases.

In order to execute that simulation, a preference of the adjustments to use for first is supposed.
In Figure 6.16 a schematic representation of the preference order:

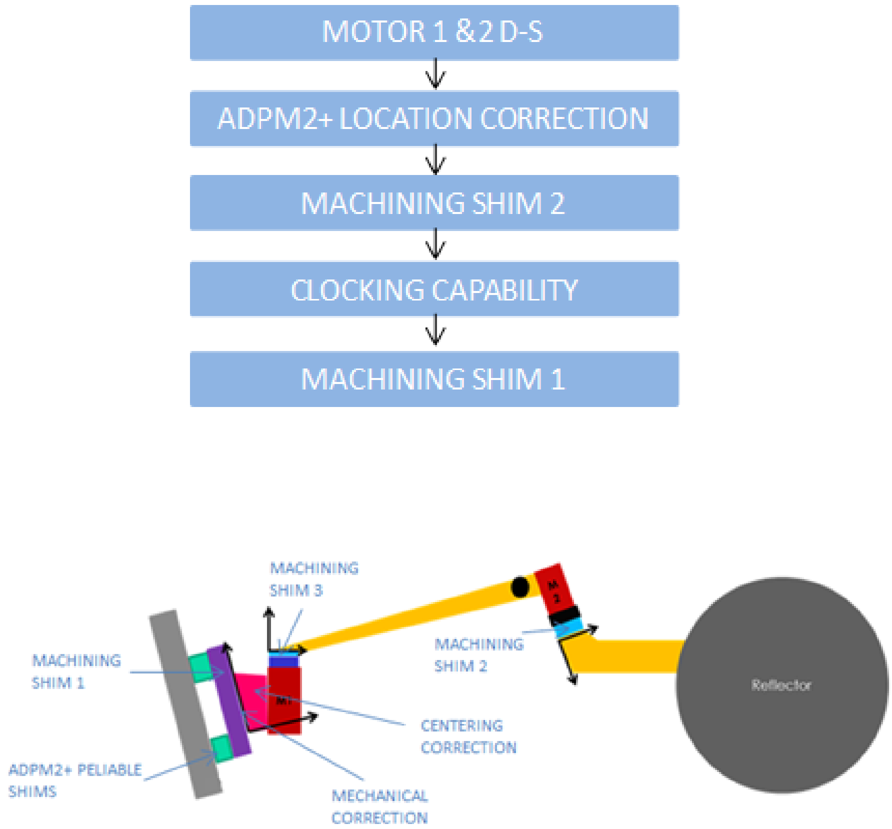

Figure 6.16. Adjustment capabilities preference

That preference order is supposed in according to the considerations previously described. Moreover the HRM2X pod adjustment capabilities are not taken into account.
Following some consideration are given for that simulation:

- Each time a solution is found, a new case is simulated without trying to solve it with more adjustment capabilities;
- Only with Motors 1 and 2 the correction of the defaults seems to be not achievable regarding the AIT specifications;
- For antenna 1 motors capabilities and ADPM2+ translation capabilities are sufficient to offset the defaults in 15% of the total cases. While for antenna 2 only the 10%;
- If with the second group of adjustment capabilities the solution is not still found, the second machining is added to the previous adjustments. With this capabilities the percentage of solving is 85% and 90% respectively for antenna 1 and antenna 2;

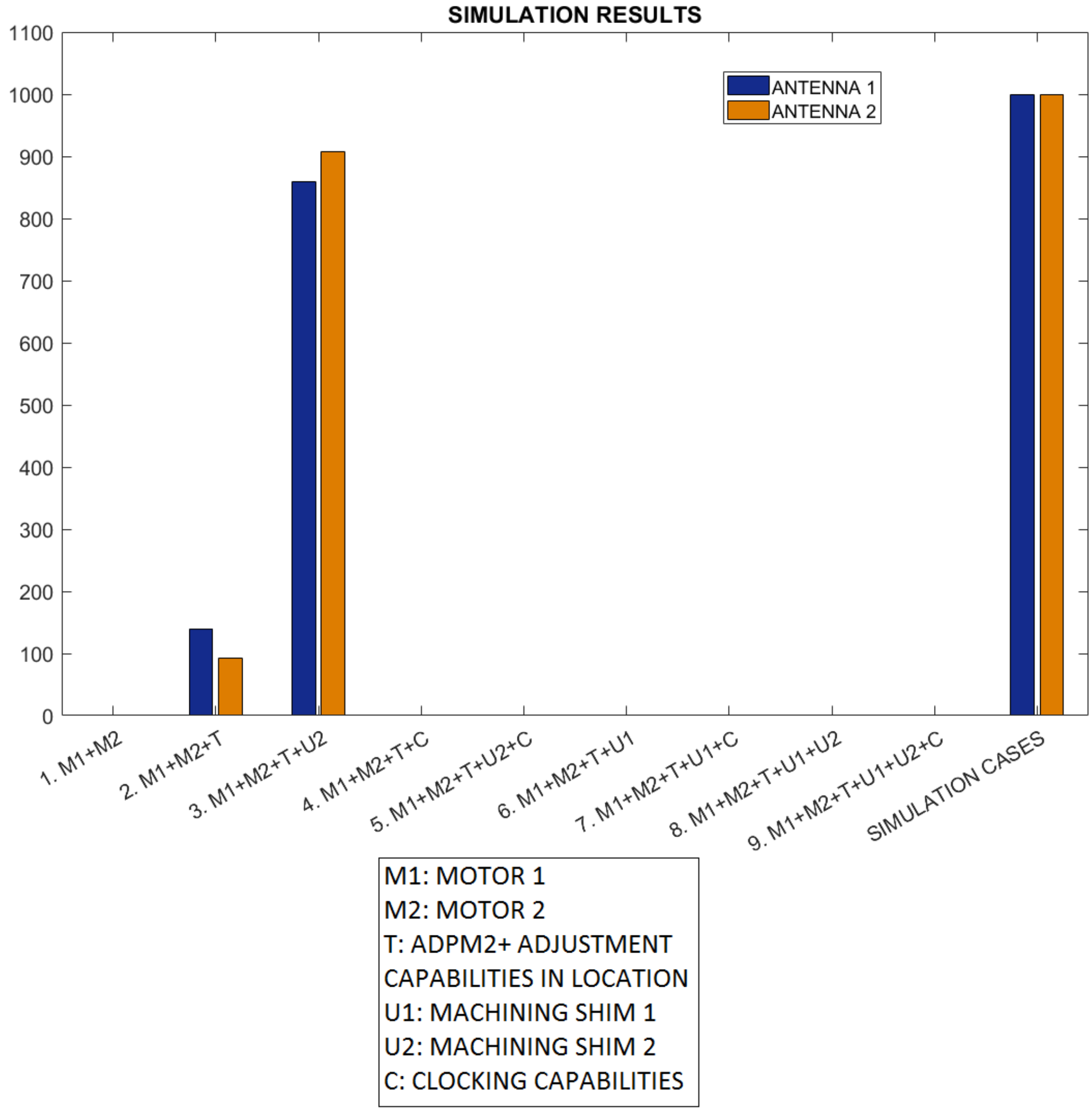

Figure 6.17. Simulation 4 results

- Only by using motors, ADPM2+ translation capabilities and the second machining shim (together with the LLD and HRM2X capabilities except for the HRM2X pod ones) the antenna configuration is correctable;
- Clocking capability is never used;
- The first machining shim 1 is never used, according to the simulation 3 results.

The results provided for that simulation are valid only for the default coverage analyzed and so that means the worst case could not be included affecting the simulation results.

Finally a brief focus on the solving method is necessary. For each case it is asked to the solver to find a solution, but it could happen that the solution given by the solver does not satisfy the AIT specifications. Consequently, a new initial vectors of the independent parameters (the values of the adjustment capabilities from what the solver starts to evaluate the minimum of the objective functions) is passed to the solver. That process is repeated 6 times for each group of adjustment capabilities. Moreover, if the solution is founded with a combination of adjustments which includes clocking or the first machining shim, the simulation is repeated from the beginning increasing the iteration loops from 6 to 30. If the simulation provides a new solution which includes again clocking capability or the first machining shim 1, the iteration loops are increased to 60.

6.2.4 Simulation 5: : Verification of the efficacy of the adjustment capabilities

As performed for the fourth simulation, various combinations of the adjustment capabilities are defined to find a solution to the problem. Differently from the previous simulation all the combinations are performed in order to evaluate the efficacy of the adjustment capabilities. However, in that simulation the iteration loops are fixed to 20 since the computational time requested for that simulation is high. For this reason it would be necessary to increase the loops in order to achieve more confident results.

Some comments to these results:

- As seen in the previous simulation the three first column respect the results of the previous simulation;
- Clocking capability, added to motors and ADPM2+ translation adjustment, is not effective;
- The remain columns are always effective to offset the defaults, except for the sixth combination. That group includes motors capabilities, ADPM2+ translation adjustments and the first machining shim, and so it is the corresponding group of the third one but with machining shim 1. It is possible to see that few cases (5%) are unsolvable using the first machining shim, while they are solvable using the second one.

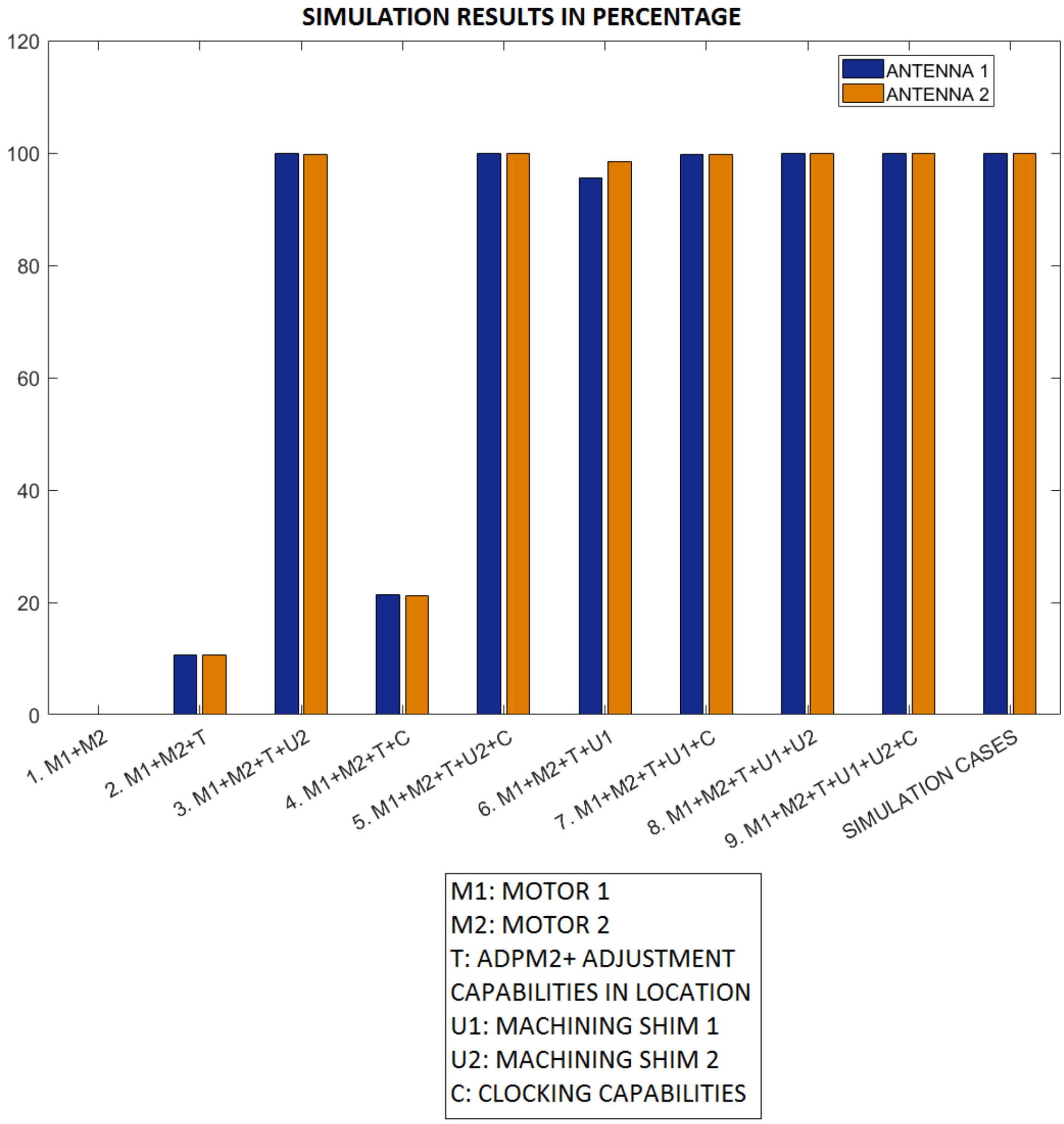

Figure 6.18. Simulation 5 results

- The results are valid only for the defaults coverage analysed. That means the worst case could not be included in it.

The most useful information regards the third consideration, since in case the alignment is performed with a only one machining shim, the solution is firstly to be searched with the second machining shim.

6.2.5 Simulation 6: : Input in the computation the machining shim 3

In the mathematical model a third machining shim is inserted in order to verify its efficacy on the correction of the defaults. Even if the adjustment capabilities are sufficient to offset the defaults as proved in the first simulation, the insertion of the third shim could bring useful for the optimization process.

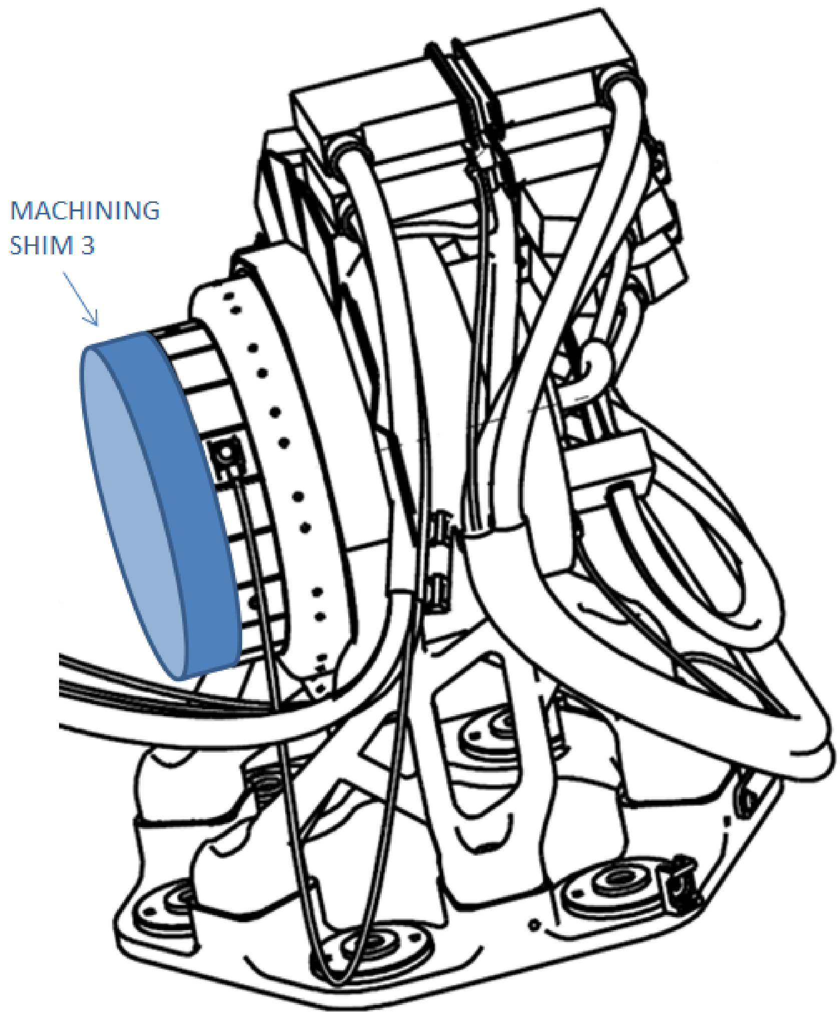

Figure 6.19. Machining shim 3 geometry

The results of this simulation point out that:

- As already came out for the previous simulations, the motors alone are insufficient to offset the defaults;
- The second combination of adjustments (M1+M2+T) leads to the same results of

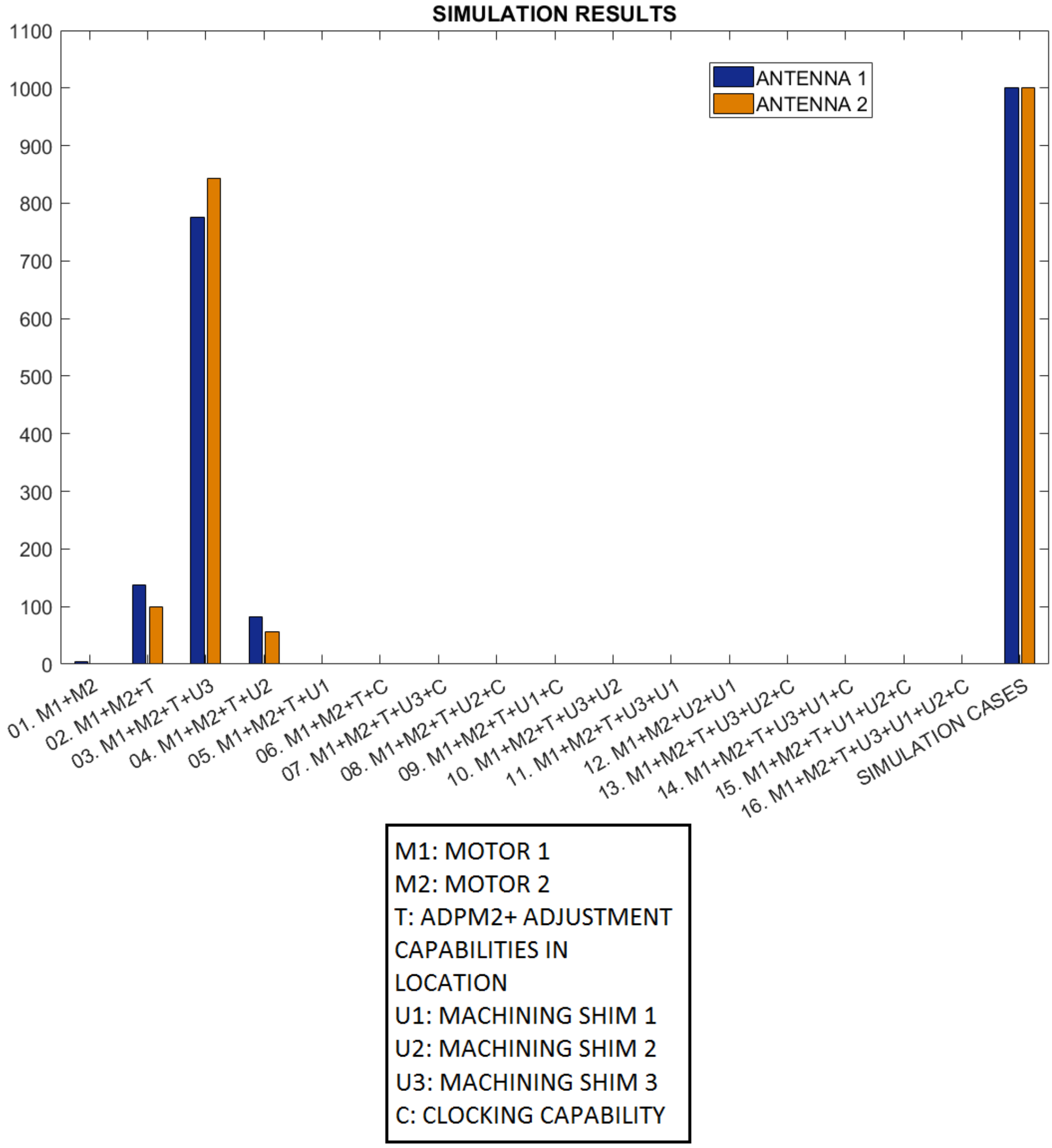

Figure 6.20. Simulation 6 results

the previous simulations;

- Differently from the machining shim 2, the third is not able to offset the defaults and satisfy the AIT specifications for all the cases;

- The remaining cases are offset using the combination with the machining shim 2.

- As seen for the previous analysis the machining shim 1 and the clocking capability is never used.
- The results are valid only for the defaults coverage analysed. That means the worst case could not be included in it.
- The maximum iteration loops is fixed to 6. If the solution includes the use of the first or the second machining shim or the clocking capability the maximum is firstly increased to 30 and then to 60.

6.3 Extension of the default ranges

In this chapter the default ranges are extended in order to verify if the adjustment capabilities are still able to offset the defaults. Indeed since the Subsystem Assembly specifications take into account only some possible sources, the defaults could be underestimated affecting in this way the previous results.
For this reason, the following simulations display how an increase of the defaults ranges affects the correction capability.

6.3.1 Simulation 7: Increase of RCp/Rv location defaults range

Firstly there is the need to verify if the adjustment capabilities can correct the antenna configuration in deployed and stowed position when the range of the defaults regarding the RCP and RV reference systems are increased from a spherical specification of 3 mm to 5 mm.
Moreover that computation is performed trying to avoid the use of the first machining shim and the adjustment capabilities of the HRM2X pod.

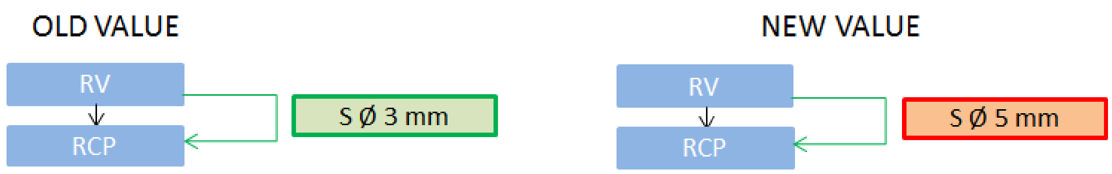

Figure 6.21. Modification of the default range for RCP in RV

The results show that for each default matrix, the adjustment capabilities are able to correct the antenna configuration satisfying the AIT specification.

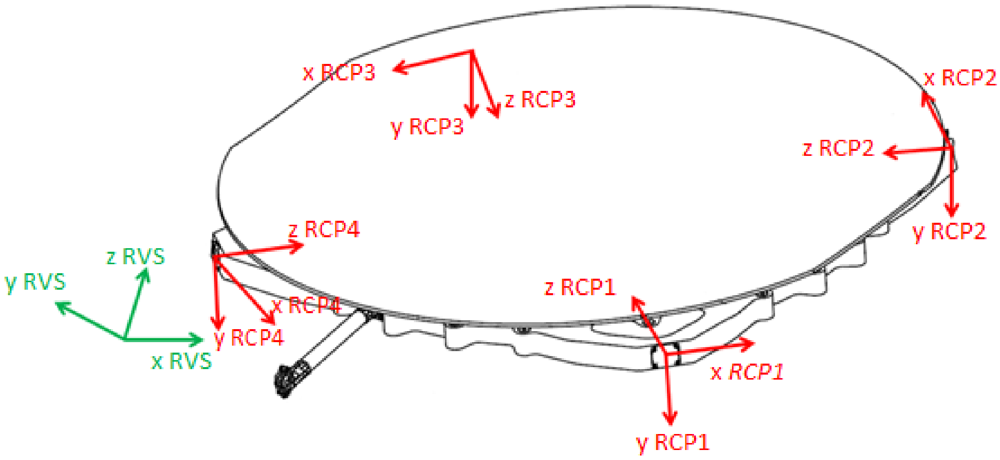

Figure 6.22. Scheme of the reflector geometry

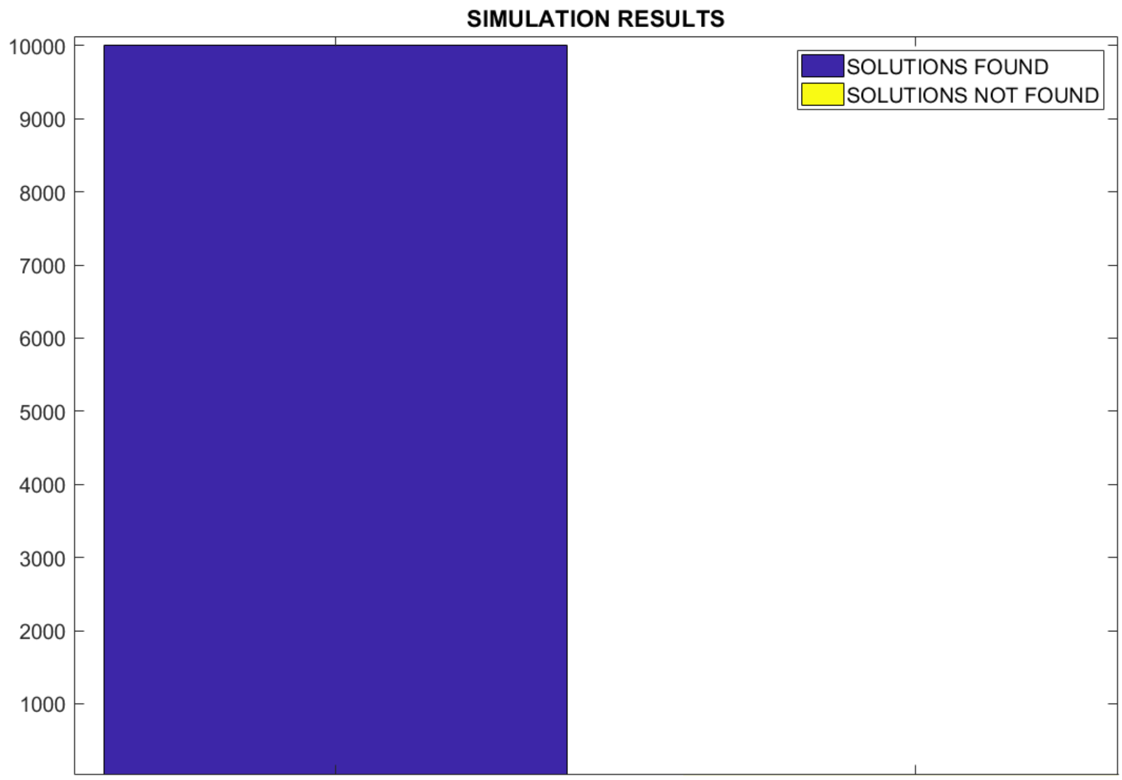

Figure 6.23. Simulation 7 results

Some considerations about that simulation:

- 10000 cases are performed.

- Even if the defaults regarding RCP/Rv reference systems are 66% bigger than the ones defined by the Subsystem Assembly Specifications, the adjustment capabilities are able to offset them;
- The first machining is not included into the computation;
- The results are valid only for the default coverage analyzed;
- The worst case might require the use of the first machining shim.

6.3.2 Simulation 8: Modification of all the Subsystem Assembly Specifications of ADPM2+

Finally a new simulation is performed with the goal to carry out the trickiest corrections possible by increasing all the default ranges defined by the Subsystem Assembly Specifications.

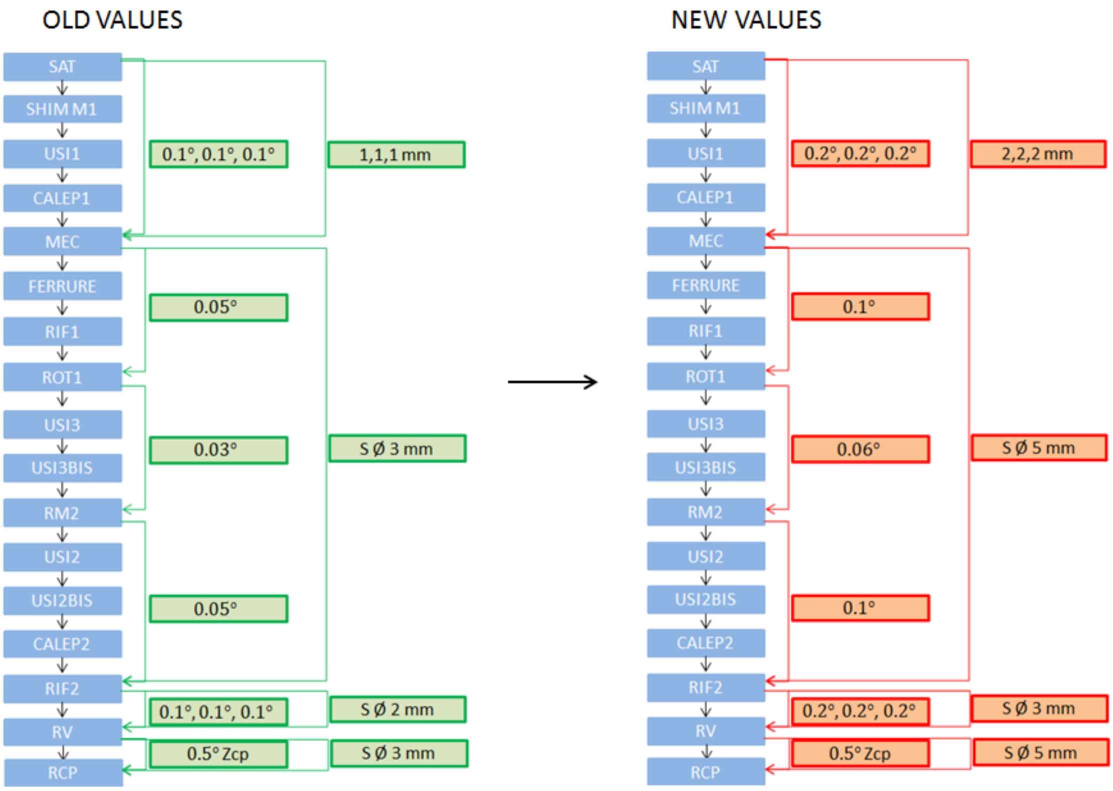

Figure 6.24. Modification of the default ranges

In Figure 6.24 all the new values for the defaults ranges are defined. In that way also unknown default sources could be taken into account and so a conservative computation is executed.

Three different ways of solving are simulated:

- Using all the adjustment capabilities except for the HRM2X pod ones and the first machining shim;
- Using all the adjustment without taking into account only the HRM2X pod capabilities;
- Solve the problem using all the available adjustments.

In Figure 6.25 a histogram representation of the number of cases unsolved for each type of simulation:

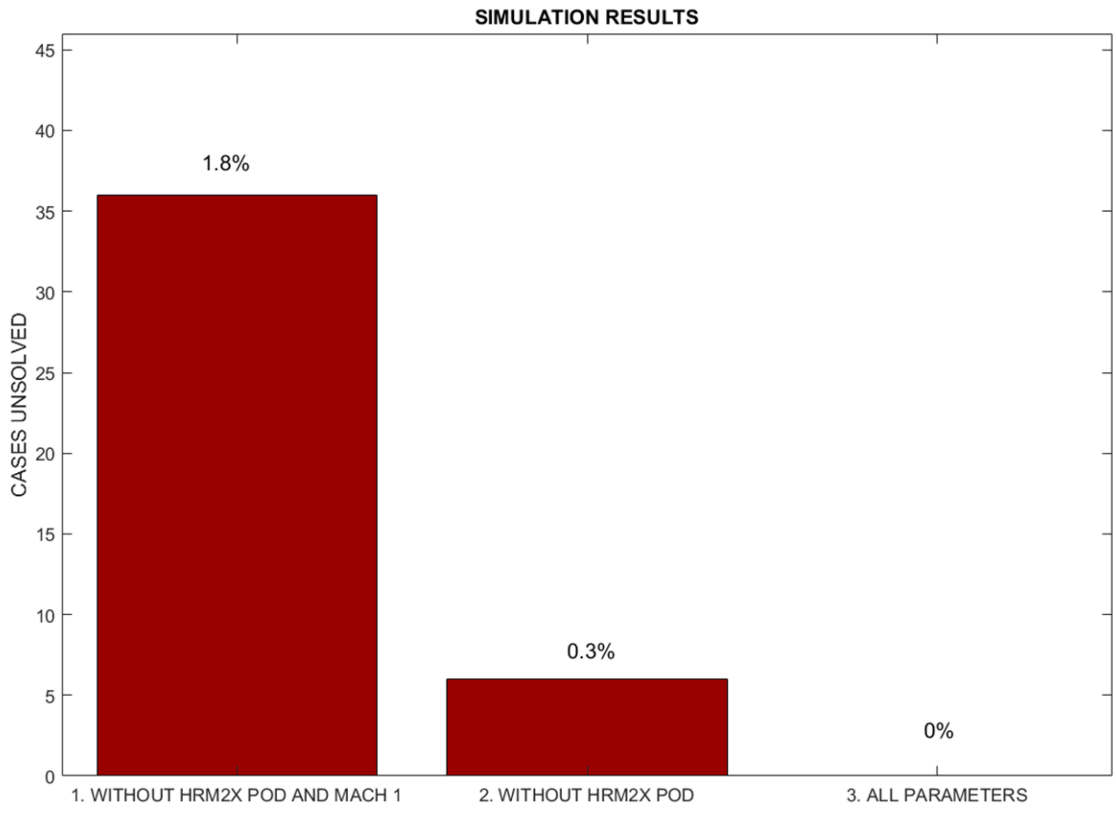

Figure 6.25. Simulation 8 results

Following some comments to these results:

- For all the cases the percentage of the cases unsolved is very low ($< 2\%$).
- Obviously the highest unsolved cases came out from the first type of simulation performed, since the number of adjustments in input are less than the other ways of solving;
- If the solver cannot use the adjustments of the HRM2X pod, the cases unsolved are only 0.3%.
- By using all the parameters, all the cases are solved. That result is really important since that means even if the Subsystem Assembly specifications do not take into account all the possible default sources, the adjustment capabilities are still able to offset the defaults and satisfy the AIT specifications;
- The default ranges could not be enough wide to take into account the effect of all the unknown defaults sources. It can be interesting to run new simulations extending even more the ranges.
- These results are valid for the default coverage analyzed. It can be possible that the worst case is not included in the computation.

Chapter 7

Conclusion

This study has analyzed the effects of the defaults on the antenna configuration in order to verify the efficacy of the adjustment capabilities available on the ADPM2+, HRM2X and LLD.
The first upshot is that each default has a different weight on the reflector sensitivity. In particular the insertion of a small default along all the chain points out that an error inserted along Motor 1 axis and Motor 2 axis leads to the biggest displacements of the Vertex reference frame.
Secondly Montecarlo simulations verified that every default configuration is offset by using the adjustment capabilities designed for the correction. However, these results are valid only for the default coverage analyzed. It could be that the worst case, which is the most difficult default configuration to offset, is not included in the computation.
Moreover the distributions of the adjustment capabilities are analyzed through histogram representations. These graphics display that some adjustment capabilities are not used at their maximum capability. So it could be interesting to verify if reducing the capability, the AIT specifications are still satisfied.
Once verified the efficacy of the adjustment capabilities, the optimization process is performed. This part makes evident that some of the adjustments can be useless. In particular the first machining shim, the clocking capability and the adjustment capabilities of the HRM2X pod seem to be avoidable in order to find the solution to the problem. That conclusion is a useful information for the alignment team since the machining of the shim requires more time and cost respect to the other adjustments. Moreover verifying that, the machining shim can be useless, can lead to a future design with only one shim and avoiding one shim per each antenna means to decrease the antenna subsystem weight of about 1 Kg, affecting strongly the launch cost. Indeed from a raw computation the gain for the weight reduction is about 25000 euros per Kg.

While the decision to avoid the adjustment capabilities of the HRM2X pod is chosen since they are difficultly manageable because their corrections affect both antenna configurations.
That optimization process is performed in order to give good practices to the AIT team in order to make the alignment process easier and performable in less time. Indeed, the results of this thesis could make the process four hours faster, which converted in labor cost is about a reduction of 5000 euros on the total cost per satellite.
Last part of the study is focused on the effect of defaults extension. In particular, the simulation verifies if the adjustments are still able to satisfy the AIT specifications with an increase of the default ranges. Indeed, the last simulation displays that, even if the Subsystem Assembly Specifications do not take into account all the default sources, by using all the parameters the configuration is still correctable.
It would be useful to extend even more the defaults in order to reach more confident results. Moreover all the results are valid for the default coverage analyzed, so new simulations should be performed to reach the 95% of the coverage of the output quantity and validate the results.
Despite the design for ADPM2+ is already defined, these thesis results could address the designs of the future antennas configuration.

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