SENTINEL-2 PROPERTIES FOR GPS POD

COPERNICUS SENTINEL-1, -2 AND -3 PRECISE ORBIT DETERMINATION SERVICE (SENTINELSPOD)

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DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	01/04/2016	18	First version
1.1	30/03/2017	18	Update applicable documents (section 1.4.1). Update all references to Sentinel-2A to Sentinel-2 to make this document applicable to both satellites.
1.2	07/05/2018	19	Include the format of Manoeuvre history File and Outages file (section 4.3 & section 4.4)
1.3	21/01/2019	19	Update the format of the NAPEOS attitude files (section 4.1)
1.4	16/09/2019	19	Added reference to quaternions file format in section 2 and removed explicit description from section 4. Include table with acronyms (section 1.3) Updated list of applicable and reference documents (section 1.4)

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1. INTRODUCTION

1.1. PURPOSE

This document describes the required information concerning Sentinel-2 in order to carry out GNSS based POD processing. In particular, the nominal attitude of the satellite, the GPS antennae configuration parameters, and the format of the NAPEOS internal files for attitude and mass history file are described. Unless specified otherwise, all the information contained in this document is applicable to both Sentinel-2A and -2B.

1.2. SCOPE

This document has been prepared by GMV in the frame of the Provision of the Precise Orbit Determination Service for the Sentinel missions.

1.3. DEFINITIONS AND ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 1-1: Acronyms

Acronym	Definition
AOC	Attitude, Orbit and Control
AOCS	Attitude and Orbit Control System
BOL	Beginning Of Life
CFRP	Carbon Fiber Reinforced Polymer
DIL	Document Item List
ESA	European Space Agency
ESOC	European Space Operation Centre
FOS	Flight Operations System
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MACP	Manoeuvre Acceleration Profile
MLI	Multi Layered Insulation
MSI	Multi-Spectral Instrument
NAPEOS	NAvigation Package for Earth Orbiting Satellites
OCP	Optical Communication Payload
ORF	Orbital Reference Frame
PDI	Product Data Item
POD	Precise Orbit Determination
SAD	Satellite Ancillary Data
UTC	Coordinated Universal Time
XML	Extensible Markup Language

1.4. APPLICABLE AND REFERENCE DOCUMENTS

1.4.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

Table 1-2: Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]	Sentinels POD Service File Format Specification	GMES-GSEG-EOPG-FS-10-0075	1.23	16/09/2019

1.4.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, extend or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

Table 1-3: Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	Sentinel-2 Flight Operations Manual Volume 1 (AOC)	GS2.UM.ASD.SY.00016	3.0	12/03/2015
[RD.2]	AOCS Coordinate Systems Document	GS2.TN.ASD.SY.00035	3.0	15/08/2011
[RD.3]	Sentinel-2A Inputs for POD	N/A	1.0	N/A

2. SENTINEL-2 ATTITUDE CONFIGURATION

Sentinel-2 provides the attitude of the satellite in the SAD PDI packages (L0 binary data). The information provided is time tagged quaternions defining the rotation between J2000 and the attitude of the satellite. They are decoded into a quaternions file. Its format is described in [AD.1].

2.1. SENTINEL-2 NOMINAL ATTITUDE MODE

According to [RD.1] and [RD.3], the **Geometry frame** is defined as (see section 4.1):

- The origin is located in the plane of attachment to the launcher and in the centre of the attachment ring.
- The X axis is perpendicular to the Satellite/Launcher separation plane, pointing positively from the separation plane towards the Satellite.
- The Y axis completes the right-handed orthogonal system.
- The Z axis is pointing towards the satellite side which is nominally nadir pointing

The **Body frame** is defined:

- The origin is at the spacecraft centre of mass.
- The X, Y, and Z axes are aligned with the Geometry Frame axes.

The following figure shows these axes:

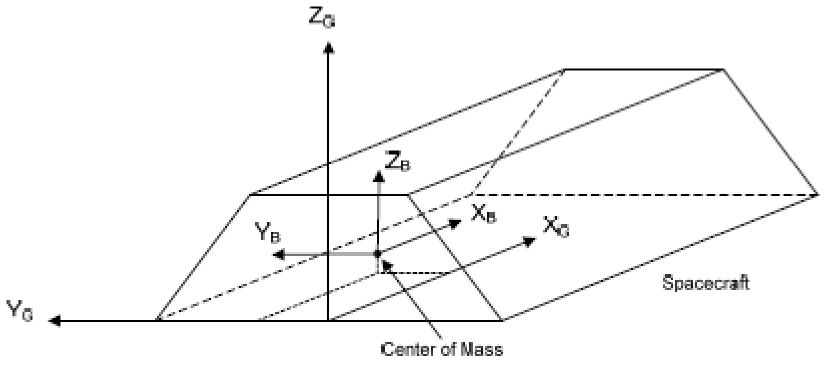

Figure 2-1: Sentinel-2 Mechanical Reference Frame

All spacecraft mechanical and geometric parameters will ultimately be referenced to this geometry reference system including unit positions and mass properties.

The **Spacecraft Attitude Definition** is defined as the orientation of the spacecraft Yaw Steering Frame (YF) with respect to the Orbital Reference Frame (ORF).

When the two reference frame are not aligned the yaw, roll, and pitch angles are defined as the sequence of three rotations (classical Euler 3-1-2 sequence) required to move from the orbital reference frame to the Control Reference Frame.

The definition of the Orbital Reference Frame (ORF) will vary according to the satellite mode. In case of Sentinel-2, there is only one nominal mode.

In a **Nominal Mission Mode**, the Spacecraft Attitude is defined as the rotation between the Nadir Reference Frame and the Control Reference Frame.

The Control Reference Frame (X_{CRF}, Y_{CRF}, Z_{CRF}) of Sentinel-2 is defined as (see section 5.3 in [RD.3]):

- The origin of the frame is the Spacecraft centre of mass
- The orthogonal axes X_{CRF}, Y_{CRF}, Z_{CRF}, parallel to the Spacecraft Body Fixed Reference Frame (X_{SG}, Y_{SG} and Z_{SG})

Where the Spacecraft Body Fixed Reference Frame is defined as (see section 1.4.10 in [RD.1]):

- The origin of the frame is the Spacecraft centre of mass
- the orthogonal axes X_{SG}, Y_{SG} and Z_{SG}, parallel to the Spacecraft Reference Frame (X_{SC}, Y_{SC}, Z_{SC})

Where the Spacecraft Reference Frame is defined as (see section 4.1 in [RD.3]):

- The origin is located in the plane of attachment to the launcher and in the centre of the attachment ring.
- The X axis is perpendicular to the Satellite/Launcher separation plane, pointing positively from the separation plane towards the Satellite.
- The Y axis completes the right-handed orthogonal system.
- The Z axis is pointing towards the satellite side which is nominally nadir pointing.

The **Nadir Reference Frame** is described in section 3.7 of [RD.3] (no details are provided here).

The attitude provided by the SAD PDI files file is the rotation (Yaw Steering law described in section 3.8 of [RD.3]) between the **Nadir Reference Frame and Control Reference Frame** (**CoG + Mechanical Axes) plus the rotation from Nadir Reference frame to J2000 reference frame.**

2.2. SENTINEL-2 NOMINAL ATTITUDE LAW

In order to implement the previously described attitude mode of Sentinel-2, the following algorithms are needed, according to [RD.3]. The attitude of Sentinel-2 expressed in J2000 reference frame is composed of two rotations:

- Rotation from J2000 to the Nadir reference Frame as described in section 3.7 of [RD.3].
- Rotation (around Z axis, yaw rotation) from the Nadir reference frame to the Satellite Body Fixed Reference Frame as described in section 3.8 of [RD.3].

According to [RD.3] the required spacecraft pointing and attitude during extended observation is a specified roll angle up to ±20.38 deg. The quaternions are reflecting this attitude mode if extended observations are performed.

3. CONFIGURATION OF SATELLITE AND GPS ANTENNAS OF SENTINEL-2

3.1. CENTRE OF GRAVITY (COG) AND MASS OF SENTINEL-2

The mass and location of the CoG at BOL in deployed configuration of Sentinel-2 is provided in [RD.2] with the following values (updated with first mass history file):

Mass: 1129.541 kg

CoG_X: +1.33100 m

CoG_Y: -0.06600 m

CoG_Z: +0.03500 m

These values agree with the definition of the Mechanical Axes.

The evolution of mass and location of the CoG is given by the mass history file (s2a.mhf, s2b.mhf), provided as input from the Sentinel-2 FOS.

3.2. GPS ANTENNA COORDINATES OF SENTINEL-2

The source for the location of the GPS Antennas is personal communication with FOS.
The values provided are:

Table 3-1: GPS antennae coordinates

	X (mm)	Y (mm)	Z (mm)
Antenna 1	232.0	227.5	-810.0
Antenna 2	232.0	-72.5	-810.0

The following figure shows a view of the location of the GPS antennas (extracted from [RD.1])

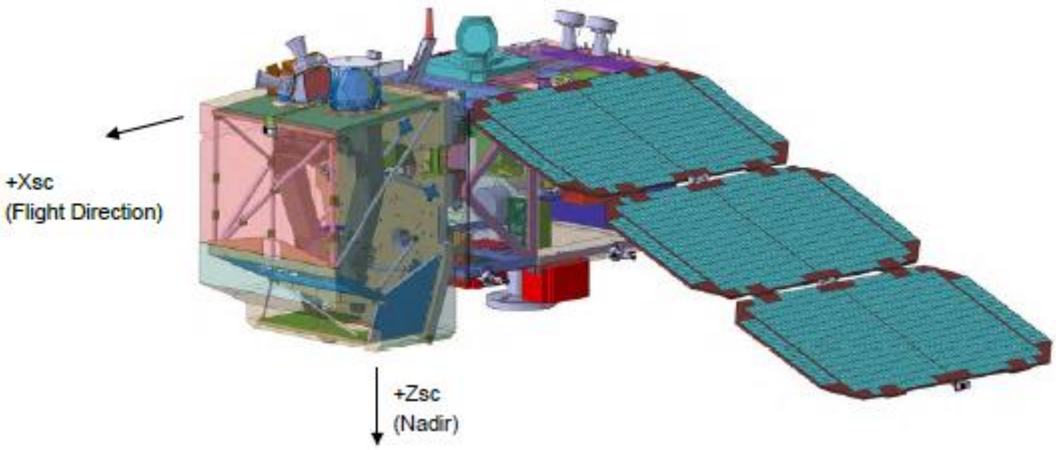

Figure 3-1: Sentinel-2 deployed configuration drawing

The antenna reference point w.r.t. antenna reference frame is the following:

Table 3-2: GPS antennae reference point

	X (mm)	Y (mm)	Z (mm)
Antenna 1	0.0	0.0	97.0
Antenna 2	0.0	0.0	97.0

3.3. GPS ANTENNA DIRECTION OF SENTINEL-2

The source for the direction of the GPS Antennas is personal communication with FOS.

[RD.1] does not provide any rotation matrix or Euler angles directly, but a couple of displays allow for some initial values.
The following figure, extracted from [RD.1] in page 54, shows that the antennas are rotated around 15-180 degrees around y axis; the 180 degrees are needed to point the antennas in the –Z direction.

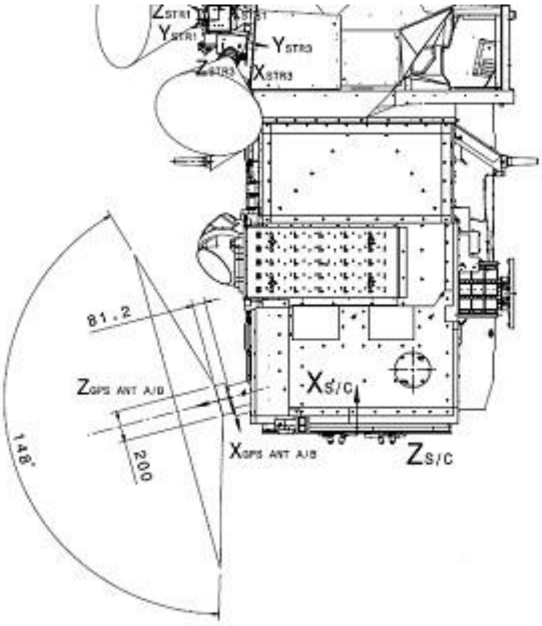

Figure 3-2: Sentinel-2 antenna orientation detail

Therefore the direction of the antenna is provided by the following set of rotations:

Table 3-3: Euler angles describing GPS antennae orientation

Rotation from Mechanical Axis to antenna direction	
Roll (X axis)	0 deg
Pitch (Y axis)	15-180 = -165 deg
Yaw (Z axis)	0 deg

A rotation matrix to describe the orientation of the antenna is defined. The values are the following:

Table 3-4: Rotation matrix describing GPS antennae orientation

GPS-A		
-0.966	0.000	-0.259
0.000	1.000	0.000
0.259	0.000	-0.966
GPS-B		
-0.966	0.000	-0.259
0.000	1.000	0.000
0.259	0.000	-0.966

These rotation matrixes can be converted to Euler Angles with the following formulas (convention 321):
Yaw = atan2(rot(1,2),rot(1,1))
Pitch = asin(-rot(1,3))
Roll = atan2(rot(2,3),rot(3,3))
Where the convention of atan2 here is atan2(y,x)

Which these formulas the Euler Angles are:

Table 3-5: Extracted Euler angles describing GPS antennae orientation

Direct Rotation Matrix		
	GPS-A	GPS-B
Roll	0	0
Pitch	-165	-165
Yaw	0	0

4. NAPEOS DB FORMAT SPECIFICATION

4.1. SENTINEL-2 MASS HISTORY FILE NAPEOS FORMAT

Sentinel-2 FOS provides the mass and centre of gravity evolution in an XML format. This information is converted into a NAPEOS file with the following format:

Table 4-1: Mass history file format description

Key	Type	Description
Year	Integer,i4	Year
Month	Integer,i2	Month
Day	Integer,i2	Day
Hour	Integer,i2	Hour
Minute	Integer,i2	Minute
Seconds	Real, f6.3	Seconds
Mass	Real, f9.3	Mass of the satellite (kg)
CoG_x	Real, f8.5	Location of the x component of the CoG with respect to the Mechanical Axis (meters)
CoG_y	Real, f8.5	Location of the y component of the CoG with respect to the Mechanical Axis (meters)
CoG_z	Real, f8.5	Location of the z component of the CoG with respect to the Mechanical Axis (meters)

Example:

```
2014  1  1  0  0  0.000  2158.777  0.00400 -0.00900  2.00500
2014  4 14  9  0  0.000  2158.777  0.00400 -0.00900  2.00500
2014  5 26  9  0  0.000  2157.461  0.00400 -0.00900  2.00600
2014  6 10 10  0  0.000  2157.025  0.00400 -0.00900  2.00600
```

4.2. SENTINEL-2 MANOEUVRE HISTORY FILE NAPEOS FORMAT

Sentinel-2 FOS provides the manoeuvre acceleration profile (MACP) files with the following format:

Table 4-2: Manoeuvre history file format description (header)

Key	Type	Description
Epoch	Epoch, a23	File last update epoch as YYYY/MM/DD-HH:MM:SS.SSS
ESOC ID	Integer,i3	Satellite ESOC ID (266 for S2A and 267 for S2B)

Table 4-3: Manoeuvre history file format description (body)

Key	Type	Description
Epoch	Epoch, a23	Burn start or stop time (UTC) as YYYY/MM/DD-HH:MM:SS.SSS
Acceleration	Real, f15.8	First component of acceleration in km/s^2
Acceleration	Real, f15.8	Second component of acceleration in km/s^2
Acceleration	Real, f15.8	Third component of acceleration in km/s^2
Manoeuvre	Integer, i1	Record flag. If >0, this is a manoeuvre start record. If 0, it is a manoeuvre end

Key	Type	Description
start-end flag		record. On a start record: - value 1 indicates that the components are radial, along-track and cross-track respectively - value 2 that they are along the J2000.0 X-, Y- and Z- axes respectively

Example:

```
2018/04/11-10:00:03.026 266
2016/04/29-07:25:31.282    -0.62906997D-08 0.89614348D-10-0.50554106D-06    1
2016/04/29-07:27:12.407    -0.62906997D-08 0.89614348D-10-0.50554106D-06    0
2016/04/29-15:39:26.552    -0.63265823D-08-0.21231811D-08-0.50738033D-06    1
2016/04/29-15:41:07.552    -0.63265823D-08-0.21231811D-08-0.50738033D-06    0
```

4.3. SENTINEL-2 OUTAGES NAPEOS FORMAT

The outages file is computed based on the existing gaps in the SAD PDIs inputs combined with the manoeuvre file information. This information is converted into a NAPEOS file with the following format:

Table 4-4: Outages file format description (header)

Key	Type	Description
Epoch	Epoch, a23	File last update epoch as YYYY/MM/DD-HH:MM:SS.SSS
File Title	String, a12	OUTAGES FILE
ESOC ID	Integer,i3	Satellite ESOC ID (266 for S2A and 267 for S2B)

Table 4-5: Outages file format description (body)

Key	Type	Description
Epoch	Epoch, a23	Outage start epoch as YYYY/MM/DD-HH:MM:SS.SSS
Epoch	Epoch, a23	Outage end epoch as YYYY/MM/DD-HH:MM:SS.SSS
Outage type	String, a3	Type of outage. It may be: input gap (GAP), manoeuvre (MAN) or a combination of both (MIX)

Example:

```
2018/04/18-03:10:06.000                         OUTAGES FILE     266
2000/01/01-00:00:00.000 2016/04/27-04:43:04.000 GAP
2016/04/28-16:44:34.000 2016/04/29-10:44:14.000 GAP
2016/04/29-15:39:26.000 2016/04/29-15:41:07.000 MAN
2016/05/03-12:51:38.000 2016/05/03-12:53:19.000 MAN
2016/05/05-15:03:47.000 2016/05/06-07:55:35.000 GAP
2016/05/09-14:36:29.000 2016/05/09-23:59:59.000 MIX
```

5. SATELLITE DESCRIPTION

5.1. SPACECRAFT GEOMETRICAL MODEL

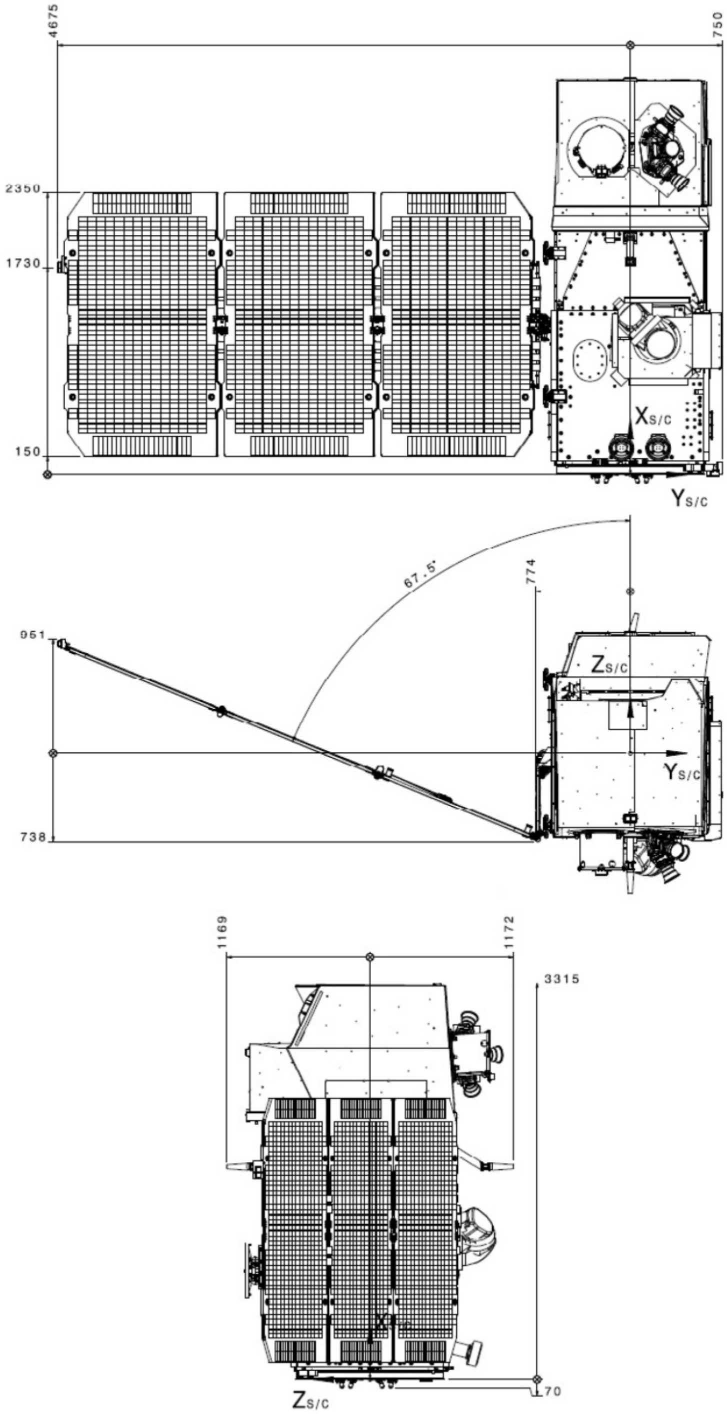

Figure 5-1: Sentinel-2 drawings: deployed and stowed configuration

The figure extracted from [RD.3] shows the overall satellite and solar array dimensions.

The resulting projected areas are summarized in the following table (from [RD.3]):

Table 5-1: Solar array projected area values

View along	Solar array position	Projected area [m^2]
X-axis	0 deg	2.79
X-axis	90 deg	10.82
Y-axis	0 deg	5.54
Z-axis	0 deg	12.57

5.2. SOLAR ARRAY

During sunlit the solar array is permanently re-orienting the solar panels towards the sun to optimise the solar flux input ([RD.3]). The solar array will rewind as soon as the satellite enters the eclipse phase. The following two figures show schematically the solar array rotation.

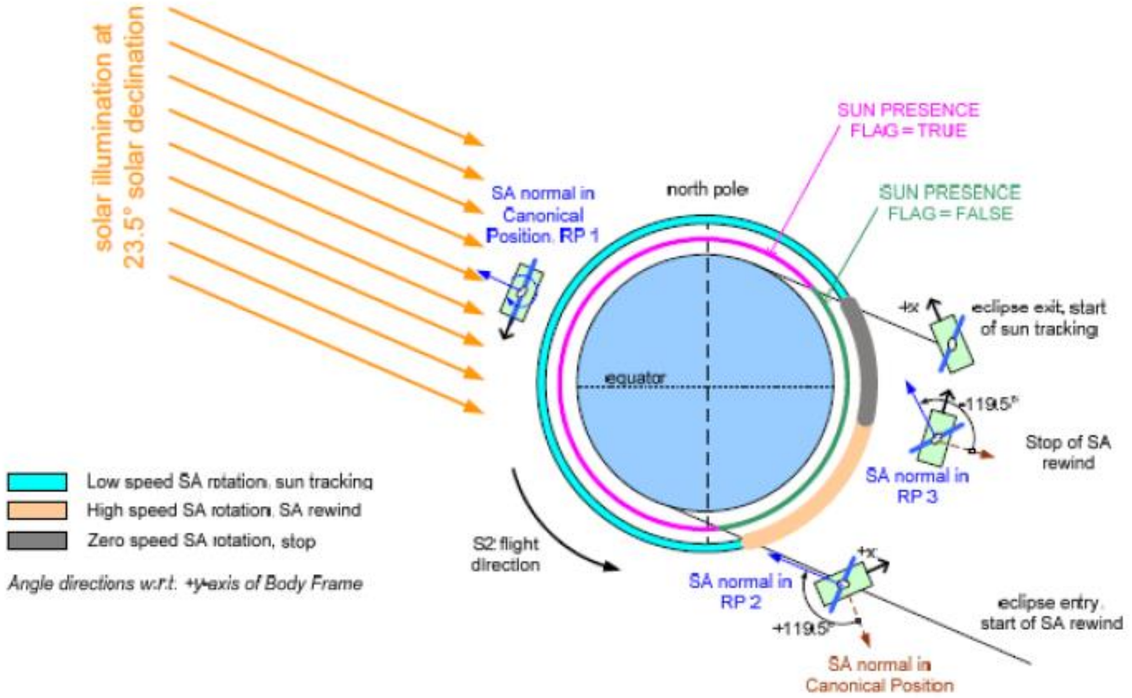

Figure 5-2: Sentinel-2 solar array orientation diagram

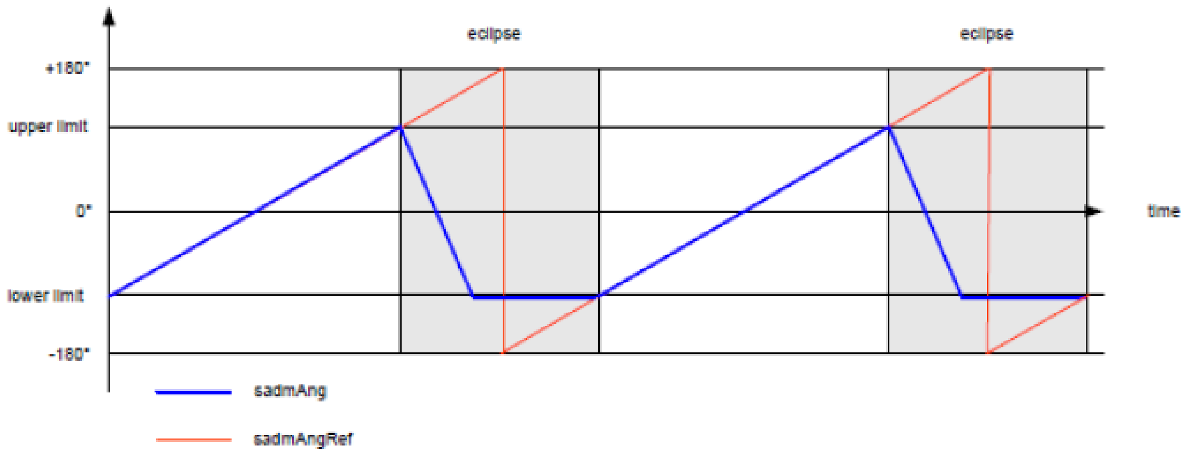

Figure 5-3: Sentinel-2 drawings: pointing law

The actual rotation of the solar array is shown with the blue line. The angular velocity is 0.06˚/s during sun-tracking and 0.205°/s for the rewind.

The rotation angle in both directions required for the nominal operation of the solar array is ±119.5°.

5.3. THERMO OPTICAL SURFACE PROPERTIES

Surface properties are an extract from [RD.3].

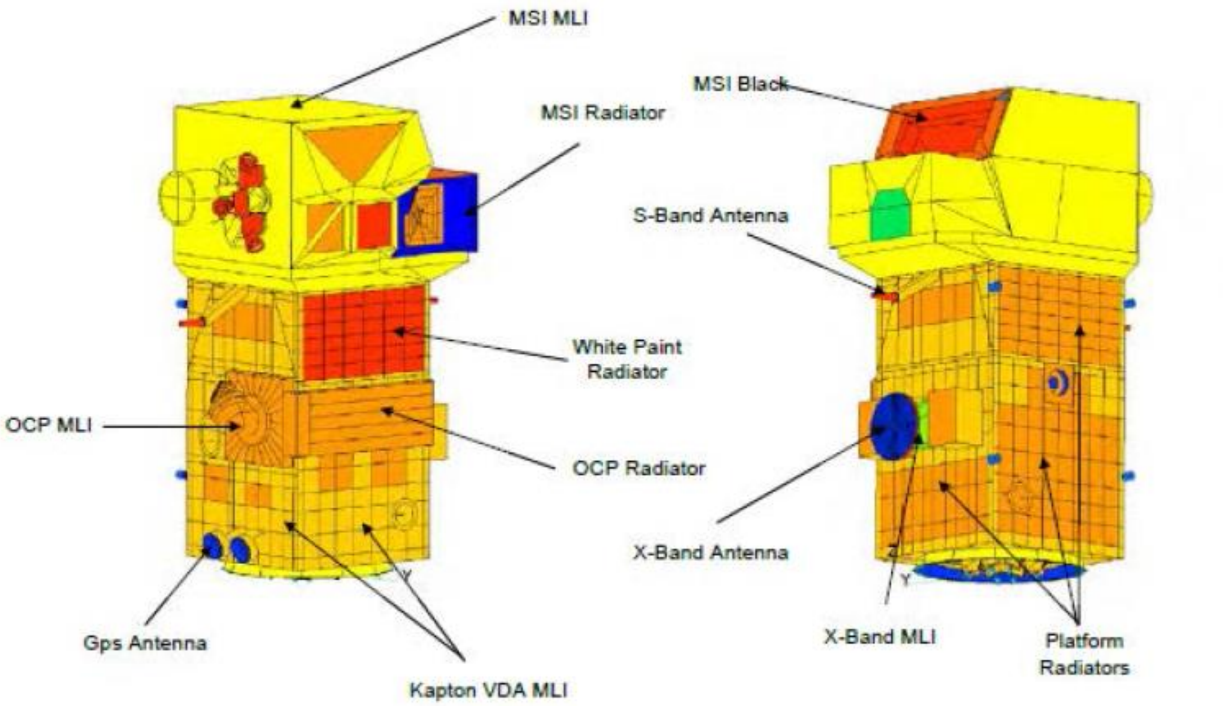

Figure 5-4: Sentinel-2 types of surface material according to thermos optical properties

The following table lists the spacecraft surface properties (from [RD.3]):

Table 5-2: Sentinel-2B surface properties

Surface	Assigned to	Infrared emissivity	Solar absorptivity	Solar diffuse reflection	Solar specular reflection
Solar cells	Solar array front side	0.815	0.91	0.09	0
CFRP	Solar array back side	0.8	0.92	0.08	0
MLI	All MLI	0.61	0.35	0.05	0.6
Radiator	Platform and OCP radiator	0.8	0.09	0.04	0.87
White paint radiator	MSI radiator and white paint radiator	0.91	0.15	0.85	0
MSI black	MSI black	0.9	0.95	0	0.05
S-Band Antenna	S-Band Antenna	0.9	0.95	0.05	0
X-Band Antenna	X-Band Antenna	0.07	0.41	0.12	0.47
GPS Antenna	GPS Antenna	0.75	0.49	0.51	0

END OF DOCUMENT

