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TECHNICAL NOTE

Swarm instrument positions related to GPS receiver data processing

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Reference **ESA-EOPSM-SWRM-TN-3559**
Issue/Revision **1.1**
Date of Issue **24/06/2019**
Status **Approved**

APPROVAL

Title Swarm instrument positions related to GPS receiver data processing	
Issue Number 1	**Revision Number** 1
Author Christian Siemes	**Date** 24/06/2019
Approved By	**Date of Approval**
Jerome Bouffard	

CHANGE LOG

Reason for change	Issue Nr.	Revision Number	Date

CHANGE RECORD

Issue Number 1	**Revision Number** 1		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

DISTRIBUTION

Name/Organisational Unit

European Space Agency
Agence spatiale européenne

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1 INTRODUCTION

Precise orbit determination, the estimation of non-gravitational accelerations and other applications using Swarm GPS receiver data require accurate knowledge of the GPS antenna phase centre position with respect to the spacecraft centre of mass. Further, the GPS antenna phase centre varies with respect to the direction (azimuth and elevation) towards the tracked GPS satellite, which is commonly modelled through phase centre variation maps. A laser retroreflector is mounted on the nadir side of the Swarm satellites for the purpose of orbit validation by means of satellite laser ranging.

2 PURPOSE OF THE DOCUMENT

This document provides the positions of the following in the spacecraft reference frame:

- GPS antenna phase centre (main unit)
- Time-varying satellite centre of mass
- Laser retroreflector

In addition, the document describes the GPS antenna phase centre variation maps for the main unit, which were determined from in-flight data and are used for the precise orbits provided on the Swarm server (SP3xKIN and SP3xCOM files). Since the redundant GPS antenna was not used until now, its phase centre variation maps could obviously not yet be determined from in-flight data. Finally, the document describes the satellite mass and spacecraft attitude quaternions.

3 REFERENCE DOCUMENTS

[1] J. van den IJssel, B. Forte and O. Montenbruck (2016) Impact of Swarm GPS receiver updates on POD performance. Earth, Planets and Space, 68:85. DOI 10.1186/s40623-016-0459-4

[2] G. Allende-Alba, O. Montenbruck, A. Jäggi, D. Arnold, F. Zangerl (2017) Reduced-dynamic and kinematic baseline determination for the Swarm mission. GPS Solutions, 21:1275–1284. DOI 10.1007/s10291-017-0611-z

[3] Swarm Level 1B data handbook (online version)
https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/data-handbook

[4] M. Rothacher, R. Schmid (2010) ANTEX: The Antenna Exchange Format, Version 1.4.
https://kb.igs.org/hc/en-us/articles/216104678-ANTEX-format-description

4 GPS ANTENNA PHASE CENTRE POSITION

The position of the GPS antenna phase centre and the laser retroreflector were characterized on ground and are reported in Table 1 and Table 2, respectively.

Table 1 Position of the GPS antenna phase centre in the spacecraft reference frame

	X	Y	Z
Swarm A	-1.65026 m	0.00096 m	-0.80586 m
Swarm B	-1.65100 m	0.00176 m	-0.80568 m
Swarm C	-1.65018 m	0.00103 m	-0.80555 m

Table 2 Position of the laser retroreflector in the spacecraft reference frame

	X	Y	Z
Swarm A	-2.41956 m	0.52075 m	-0.03105 m
Swarm B	-2.41956 m	0.52173 m	-0.03129 m
Swarm C	-2.42010 m	0.52112 m	-0.03166 m

5 TRANSFORMATION FROM GPS ANTENNA REFERENCE FRAME TO SPACECRAFT REFERENCE FRAME

Transformation from GPS antenna reference frame to spacecraft reference frame is defined by the quaternions $q_1 = 0$, $q_2 = -1$, $q_3 = 0$ and $q_4 = 0$ for Swarm A, B and C. Note that q_4 is the scalar part of the quaternion and $[q_1, q_2, q_3]$ form the vector part. The quaternion corresponds the rotation matrix

$$R = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix},$$

which is a rotation about the y-axis by 180°. In a nominal situation, the x-axis of the spacecraft reference frame is pointing approximately into flight direction, the z-axis of the spacecraft reference frame is pointing approximately into nadir direction, and the y-axis is pointing approximately into cross-track direction, completing the right-handed spacecraft reference frame. Consequently, the x-axis of the antenna reference frame is pointing approximately into anti-flight direction, the z-axis of the antenna reference frame is pointing approximately into zenith direction, and the y-axis is pointing approximately into cross-track direction, completing the right-handed spacecraft reference frame. The spacecraft and GPS antenna reference frames are indicated in Figure 1.

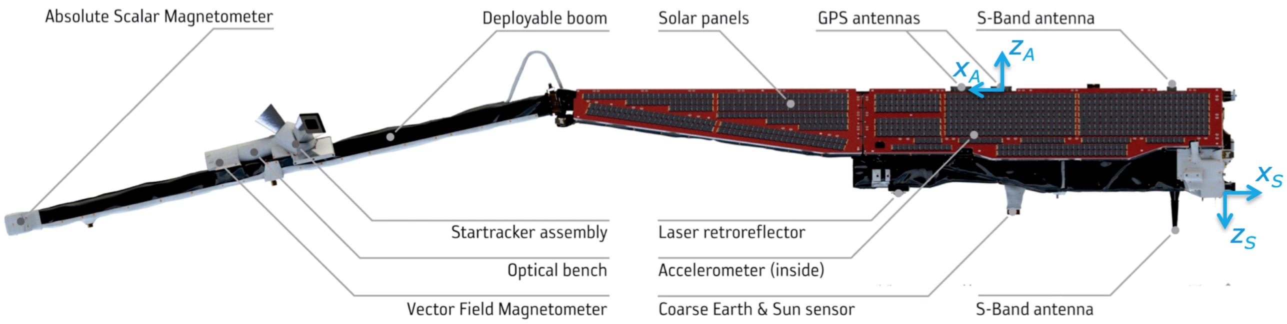

Figure 1 Indication of the spacecraft (S) and GPS antenna (A) reference frames as well as instrument positions (image credits: ESA/ATG medialab)

6 GPS ANTENNA PHASE CENTRE VARIATION MAPS

The Swarm GPS antenna phase centre variation maps are illustrated in Figure 2 and are available in ANTEX format [4] on the Swarm web page (http://earth.esa.int/swarm). As explained above, the phase centre variation maps are estimated from in-flight data and apply to the main GPS antenna. Further, they were determined from RINEX observation files of baseline 03, i.e. prior to the introduction of integer carrier phase ambiguities in RINEX observation files of baseline 04. It is expected that the phase centre variation maps for carrier phase observations with integer ambiguities are slightly different [2] .

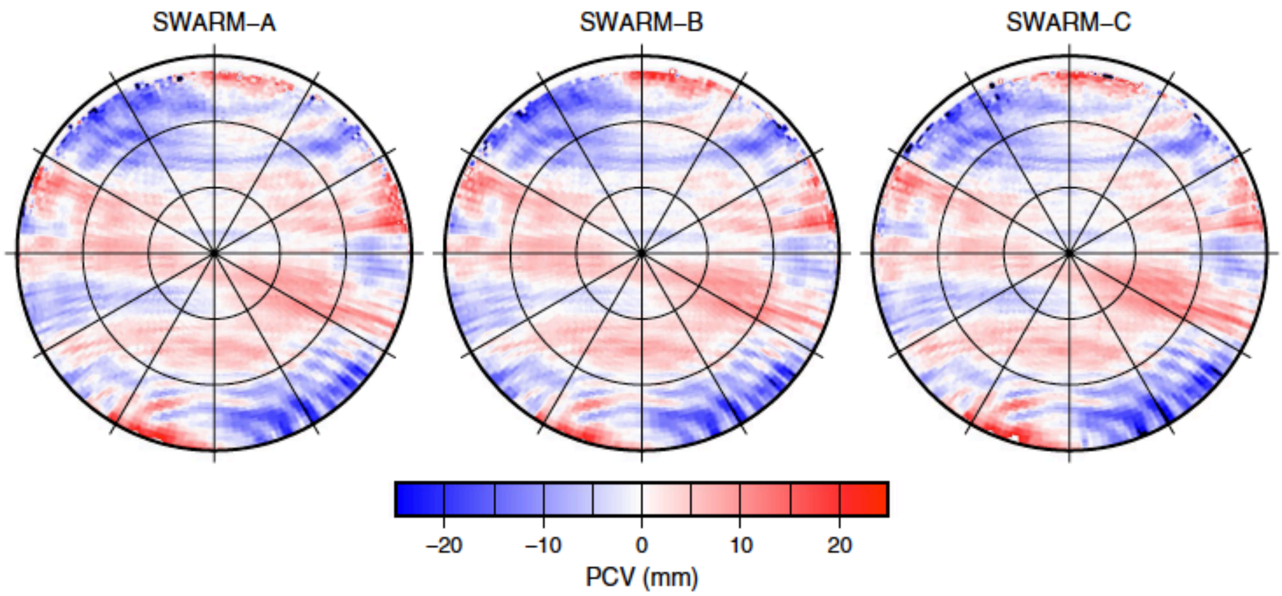

Figure 2 Swarm GPS antenna phase centre variation maps. Figure reproduced from [1] .

7 SATELLITE MASS

The satellite mass is provided in the SC_xDYN_1B files [3] . It is obviously not constant, but decreases slowly as fuel is consumed due to thruster activations for attitude and orbit control. The mass of the satellites at launch was approximately 472 kg, which includes approximately 106 kg of fuel. It should be noted that the remaining fuel mass is inferred from the pressure in the cold-gas tanks. Since the pressure also depends on the temperature, a very small variation of the inferred satellite mass is observed at the orbital frequency.

8 SATELLITE CENTRE OF MASS

The position of the satellite centre of mass in the spacecraft reference frame is provided in the SC_xDYN_1B files [3] . Since the remaining fuel mass slowly decreases over time and the tanks are not perfectly placed around the satellite centre of mass, the position of the satellite centre of mass slowly changes during mission lifetime (mainly drifts along x-axis of the spacecraft reference frame).

Table 3 Approximate position of the satellite centre of mass in the spacecraft reference frame. The more precise position is provided in the SC_xDYN_1B files

	X	Y	Z
Swarm A/B/C	-1.95 m	0.00 m	-0.33 m

9 SATELLITE ATTITUDE QUATERNIONS

Three star sensors measure the attitude of the Swarm satellites. Their data is combined to obtain the attitude quaternions describing the orientation of the spacecraft reference frame with respect to the terrestrial reference frame. These combined attitude quaternions are contained in the STRxATT_1B files [3] .