Phase Centre Calibration of the Galileo Satellite Navigation Antenna

IGS workshop 2017, Paris (France) Antennas & Biases Session

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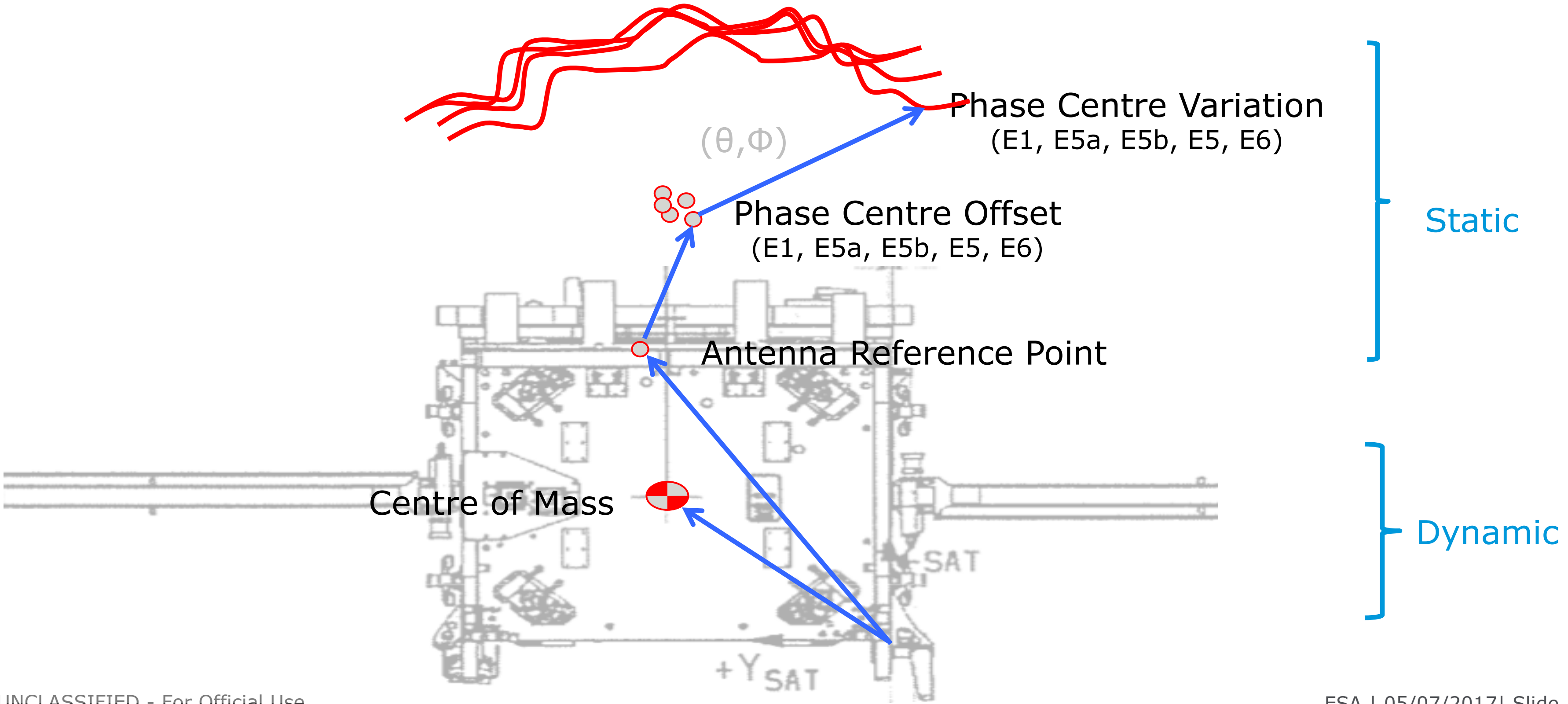
Summary

1. Introduction
2. Metadata information to correct phase measurements
    - Antenna Phase Centre Offset (PCO)
    - Antenna Phase Centre Variation (PCV)
    - Antenna Reference Point (ARP)
    - Centre of Mass (CoM)
    - User direction (attitude)
3. Galileo Metadata and IGS
4. Conclusions

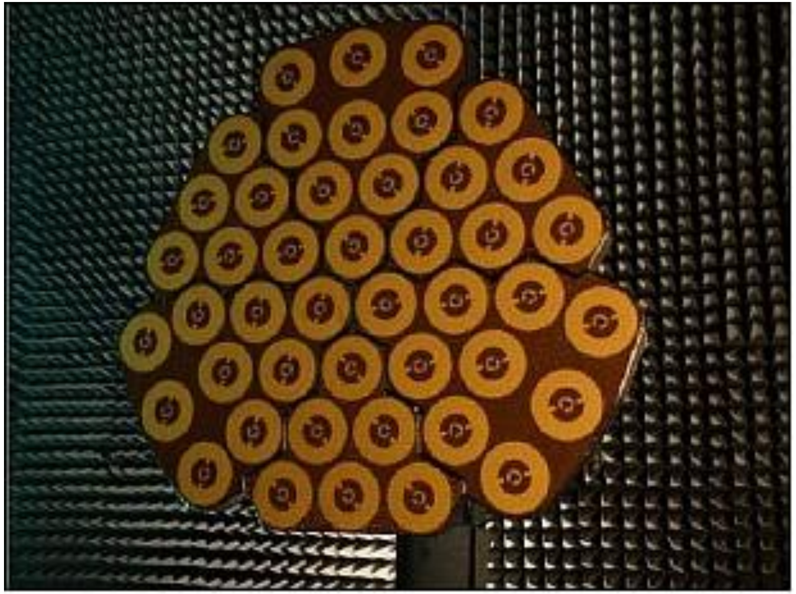
Introduction – Metadata for NAVANT correction



Antenna - types

Two antenna types

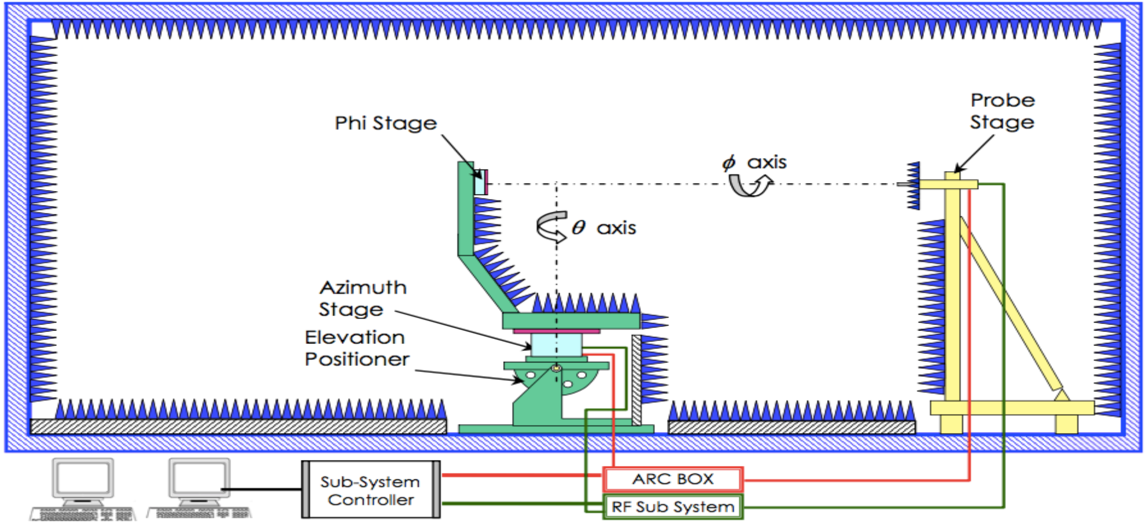
GSAT01xx - EADS CASA



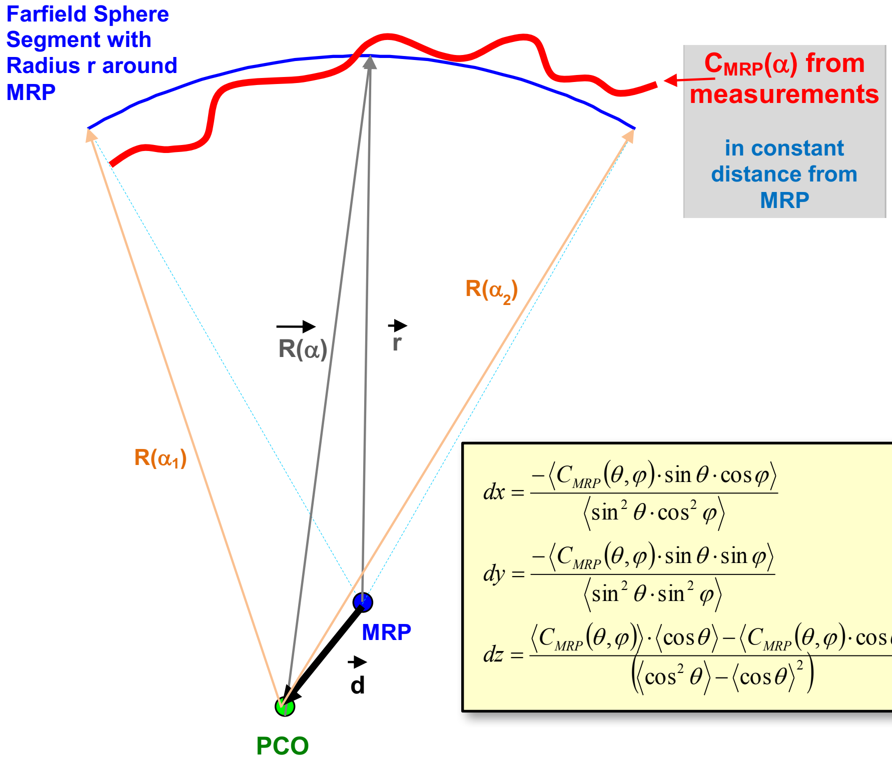
GSAT02xx - Thales Alenia

Antenna – chamber calibration

- Individual for each navigation antenna by manufacturer
- Directional in azimuth (Φ) and nadir (θ)
- Each single frequency bands (E1, E5a, E5b, E5, E6)



Antenna – Phase Centre offset (PCO)



$$dx = \frac{-\langle C_{MRP}(\theta,\varphi)\cdot \sin\theta \cdot \cos\varphi \rangle}{\langle \sin^2\theta \cdot \cos^2\varphi \rangle}$$

$$dy = \frac{-\langle C_{MRP}(\theta,\varphi)\cdot \sin\theta \cdot \sin\varphi \rangle}{\langle \sin^2\theta \cdot \sin^2\varphi \rangle}$$

$$dz = \frac{\langle C_{MRP}(\theta,\varphi)\rangle \cdot \langle \cos\theta \rangle - \langle C_{MRP}(\theta,\varphi)\cdot \cos\theta \rangle}{\left(\langle \cos^2\theta \rangle - \langle \cos\theta \rangle^2\right)}$$

Delay pattern C_{FF} on farfield sphere in distance r around MRP:

$$C_{FF}(\alpha, r) = C_{MRP}(\alpha) + r$$

Range from PCO to sphere around MRP:

$$R(\alpha) = r - \vec{d} \circ \hat{r}(\alpha)$$

PCO: Find d, where $R(\theta)$ is most similar to $C_{FF}(\theta, r)$

Minimize $res(\vec{d}) = \left\langle \left(C_{PCO}(\alpha,\vec{d})\right)^2 \right\rangle - \left\langle C_{PCO}(\alpha,\vec{d}) \right\rangle^2$

with $C_{PCO}(\alpha,\vec{d}) = C_{MRP}(\alpha) + \vec{d} \circ \hat{r}(\alpha)$

< > *(weighted) averaging over* α *(field of view)*

Note, α *represents the observation direction (off-axis angle* θ *and azimuth angle* φ*)*

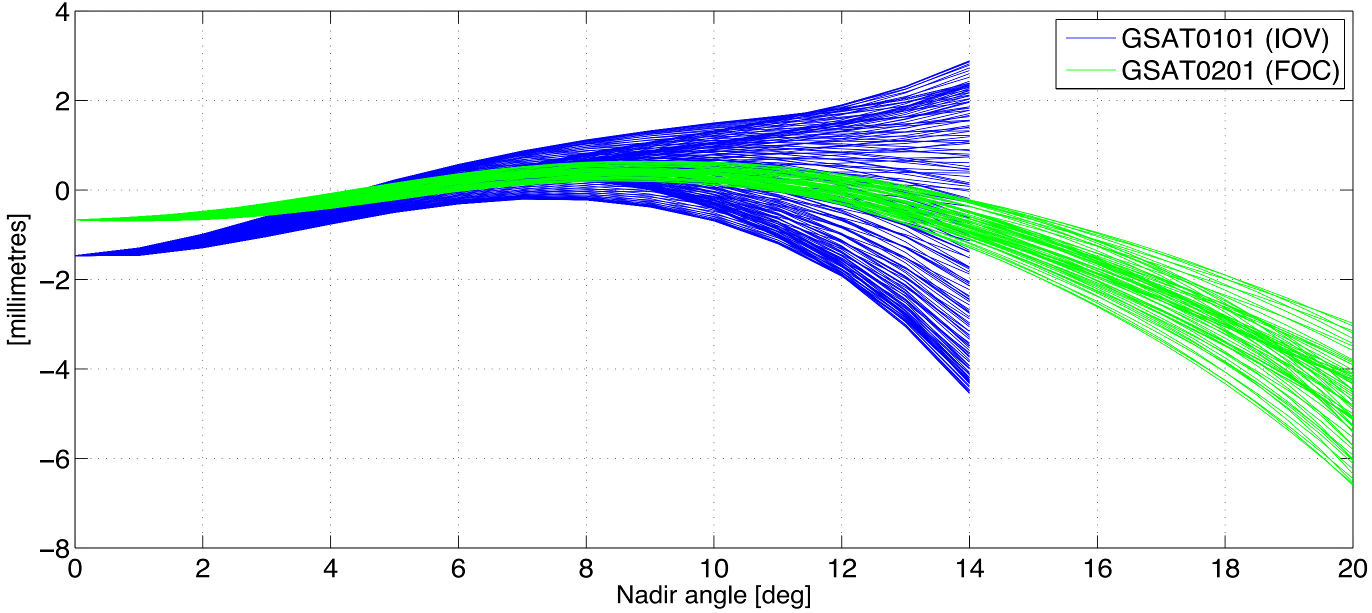
Antenna – Phase Center Variation (PCV)

- Azimuthal values [0°,360°]
- Zenith values from 0° to 14° (GSAT01) and 20° (GSAT02)
- All 5 single frequencies

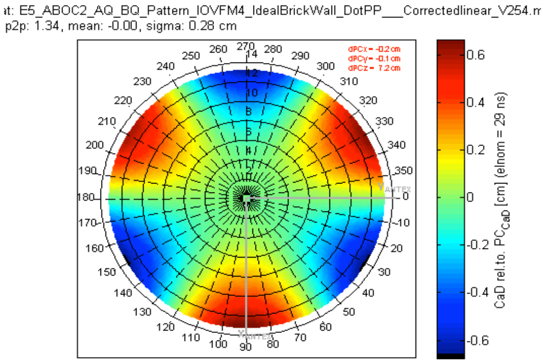
```
GALILEO-1           E11                 E101      2011-060A TYPE / SERIAL NO
CHAMBER             ESA                    1      09-FEB-12 METH / BY / # / DATE
     2.0                                                    DAZI
     0.0  14.0   1.0                                        ZEN1 / ZEN2 / DZEN
     5                                                      # OF FREQUENCIES
GALILEO-2           E18                 E201      2014-050A TYPE / SERIAL NO
CHAMBER             ESA                    1      12-FEB-16 METH / BY / # / DATE
     5.0                                                    DAZI
     0.0  20.0   0.5                                        ZEN1 / ZEN2 / DZEN
     5                                                      # OF FREQUENCIES
```

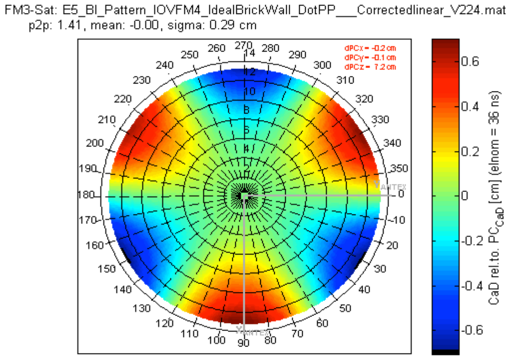
Antenna – Phase Center Variation (PCV)

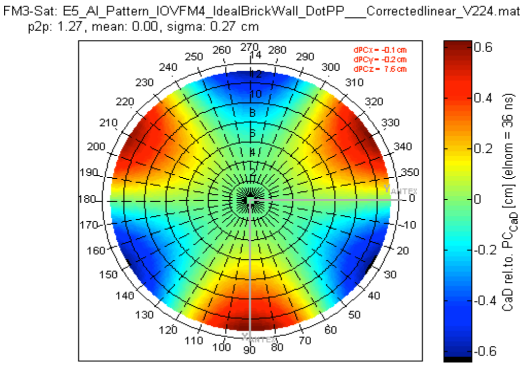
- Azimuthal values [0°,360°]
- Zenith values from 0° to 14° (GSAT01) and 20° (GSAT02)
- All 5 single frequencies

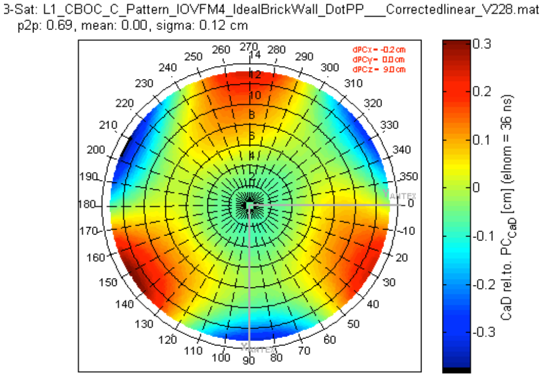


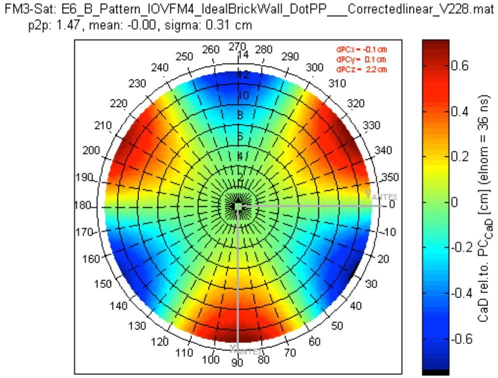
Antenna - PCV Azimuthal components

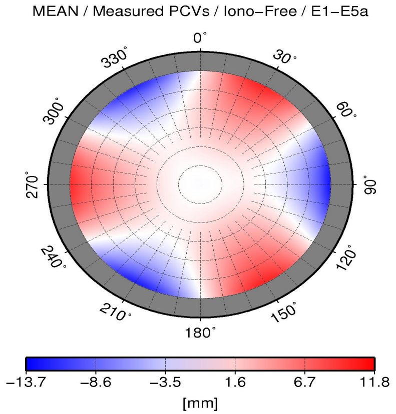








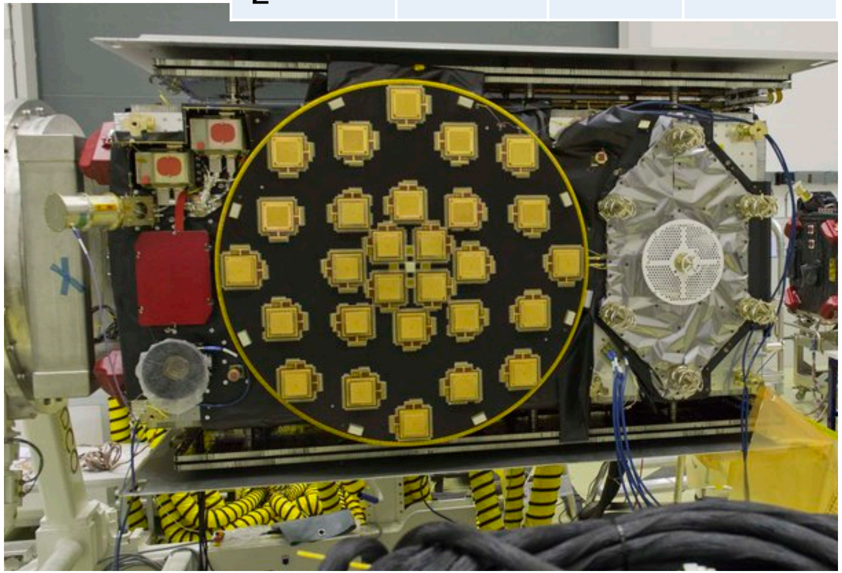




Antenna Reference Point

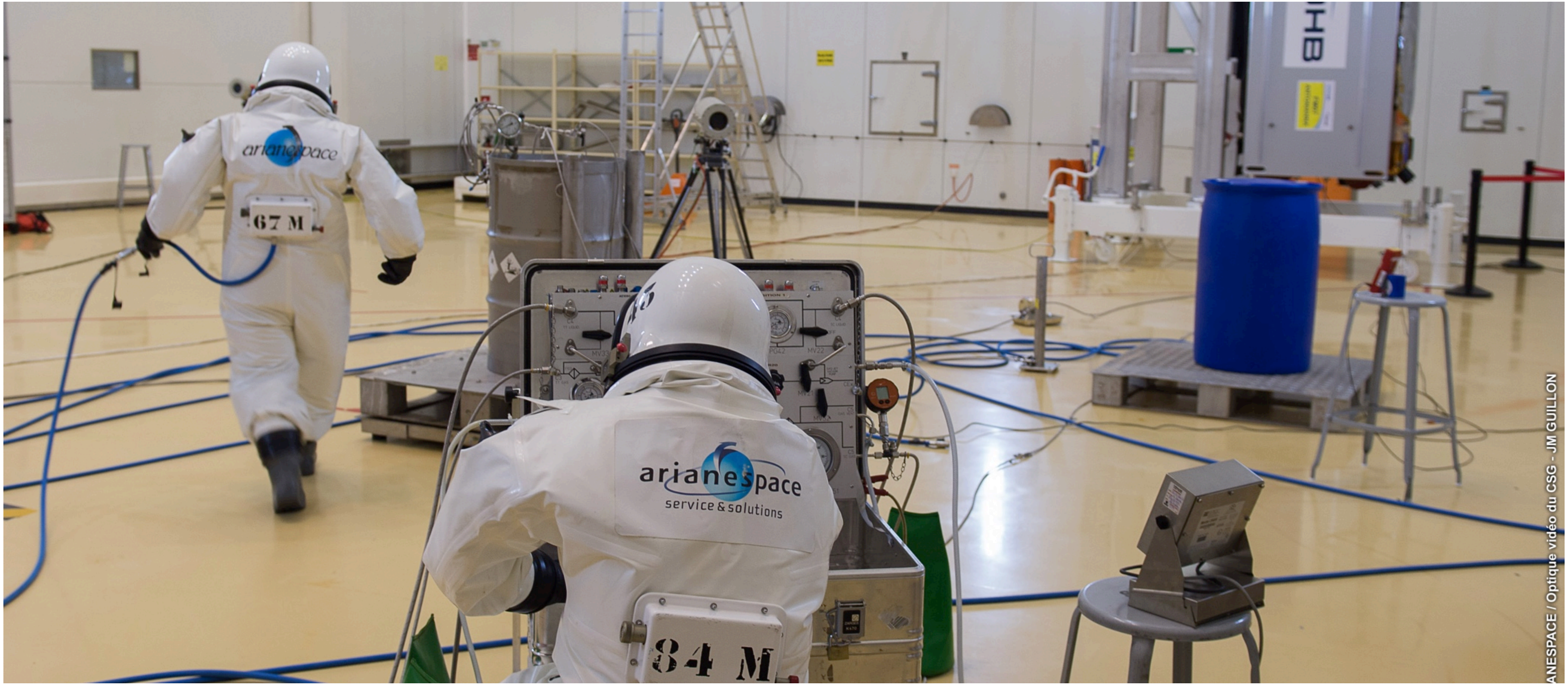
- Antenna integrated on body frame
- Physical point on the satellite [mm]

	X	Y	Z
GSAT01	1375.5	600.0	1100.5
GSAT02	140.0	0.0	1215.0

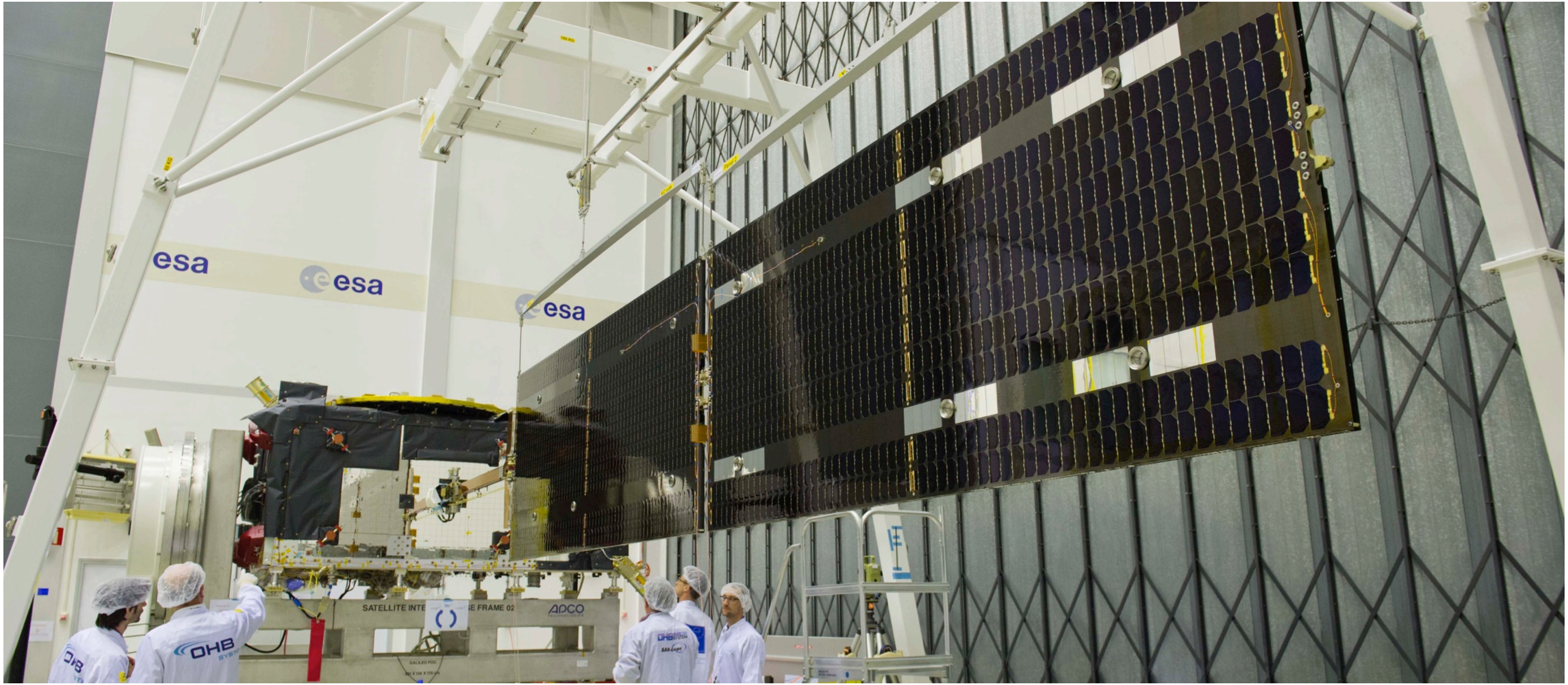


Centre of Mass – dry measurement in stow

Centre of Mass – tank filling

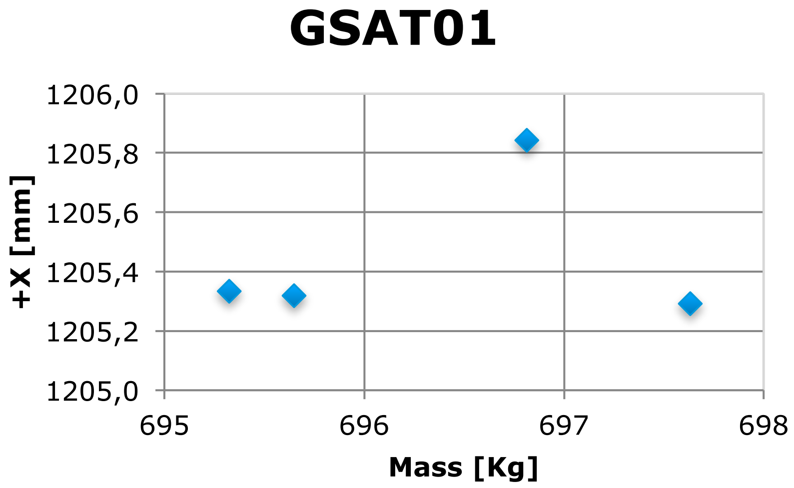


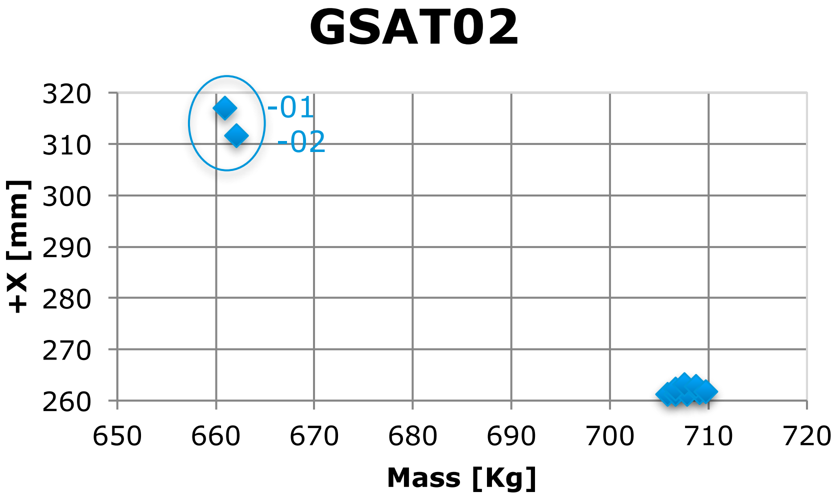
Centre of Mass – Solar array deployment



Centre of Mass - Values

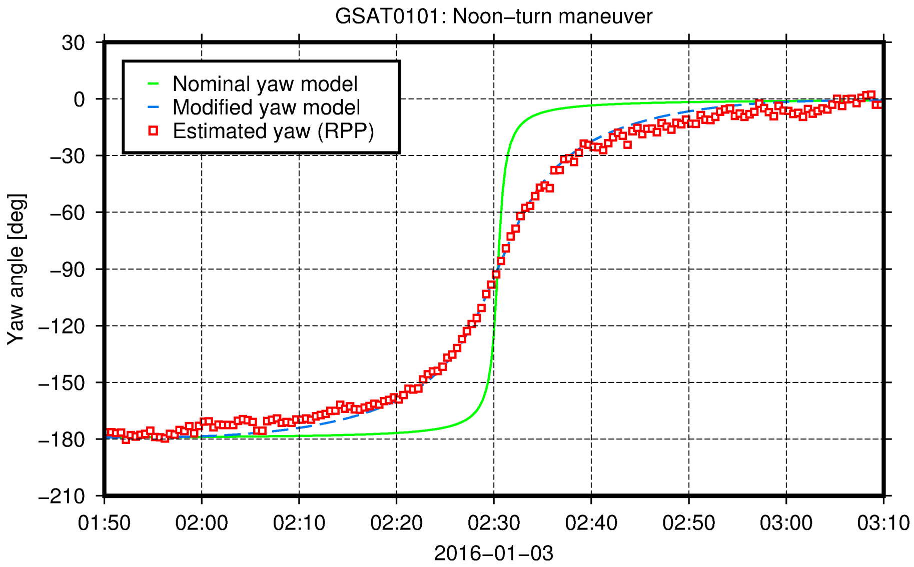
- Dynamic information, with value after any maneuver sent to ILRS
- Agreement between S/C well below 1 cm

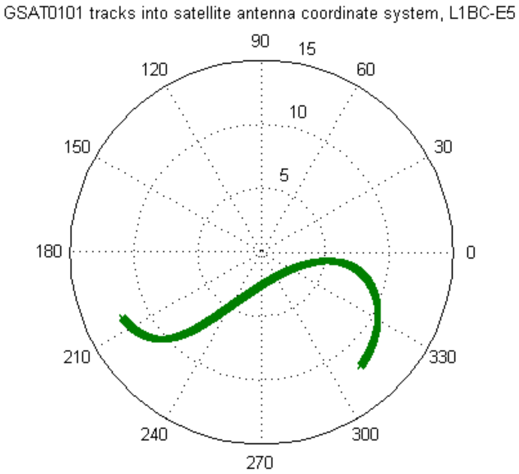




User direction - Attitude

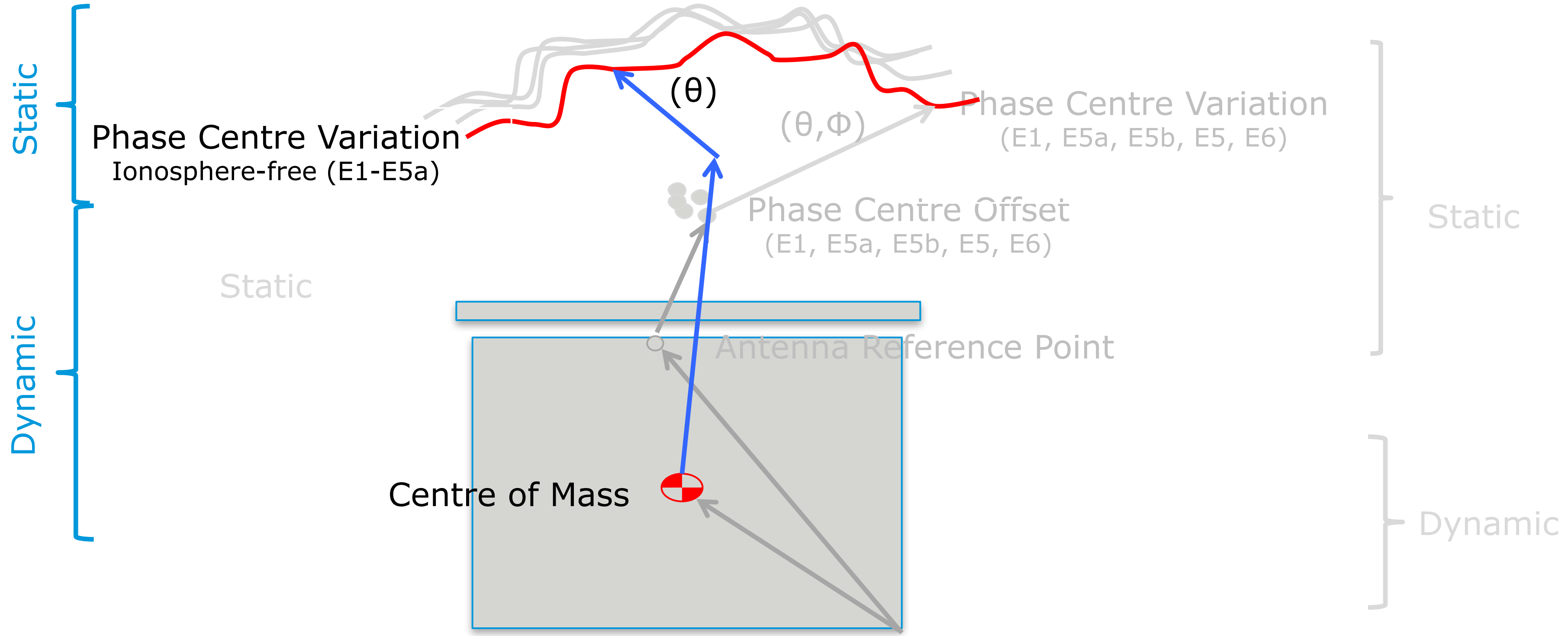
- Azimuthal correction requires Satellite yaw modeling
- Orientation accuracy better than ground antennas[1]





[1] *Source: F.Dilssner, Galileo IOV Spacecraft Metadata and Its Impact on Precise Orbit Determination, EGU2017*

Metadata versus IGS

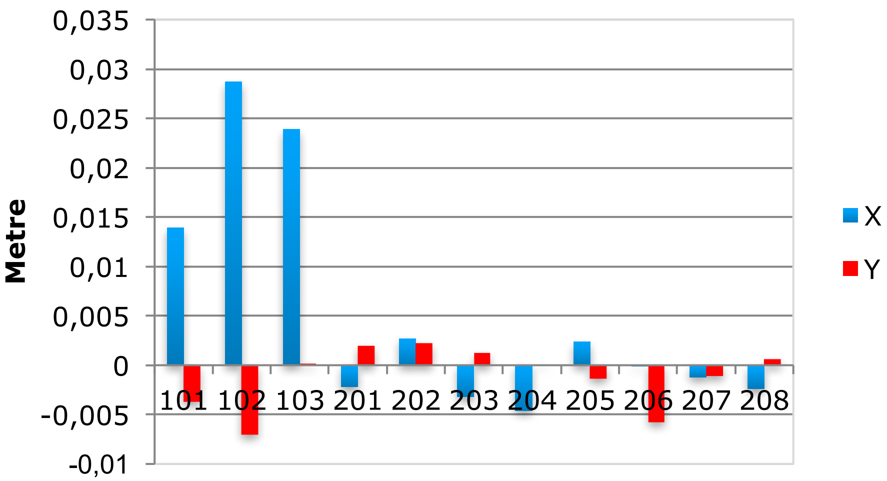


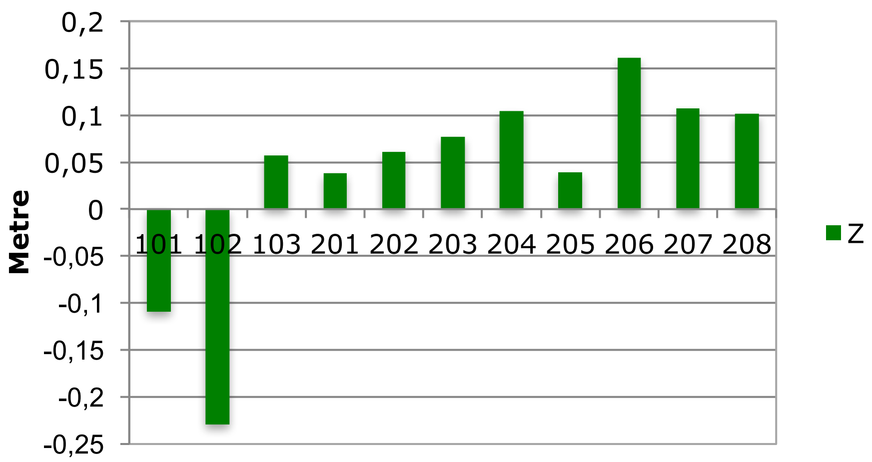
Metadata versus IGS

	Galileo (GSAT_wwww.atx)	IGS (IGS14.atx)
Source	Measured on ground	Estimated in space
Types	Per single Satellite	per family (IOV,FOC-L3,FOC)
Frequencies	Single Frequency (E1,E5a,E5b,E5,E6)	Ionosphere-free (E1-E5a)
Static data	PCV – PCO (θ,Φ) PCO - ARP ARP - SRF	PCV – PCO (θ) =0
Dynamic data	CoM - SRF	PCO – CoM
Frame	Satellite Reference Frame	Antex
Attitude	Normal + Modified	Normal

Metadata versus IGS

- Estimated in Space using NAPEOS versus measured on ground
- Accuracy of estimated in space affected by models accuracy (e.g. SRP)





Summary and conclusions

Metadata for Galileo antenna phase center corrections

- Antenna Phase Centre Offset (PCO), Variation (PCV) and Reference Point (ARP)
- Satellite Centre of Mass (CoM) and Attitude (user direction)

Benefit

- Tie GNSS phase measurements consistently to the spacecraft CoM
- Especially relevant for GNSS-based realization of terrestrial scale, independent of SLR/VLBI
- Galileo is the first GNSS disclosing the full range of metadata for each antenna and carrier frequency
- Radial antenna offsets for other GNSS become accessible without the need to adopt any external scale

Status

- GSAT01 released during Initial Service Declaration (Dec-2016)
- GSAT02 under release process.

Recommendation

- ANTEX format update to handle COM / ARP

Location

- https://www.gsc-europa.eu/support-to-developers/galileo-iov-satellite-metadata#2
- https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_missions/current_missions/ga01_com.html


THANKS for your attention

BACK-UP slides

BA

Introduction - request by IGS

Requested by Scientific community

- Galileo scientific advisory committee (GSAC)
- International GNSS Service (IGS)

- *navigation antenna phase center offsets* in the body-fixed reference frames w. r. t. the satellites' centers of mass for each carrier frequency and for all Galileo satellites (together with the definition of the body-fixed reference frames).
- *attitude models* for the Galileo satellites (which are of particular importance, if the antenna phase center is not located on the axis connecting the satellite's center of mass with the center of mass of the Earth).

IGS

International GNSS Service
Formerly the International GPS Service

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http://igs.org

International Association of Geodesy
International Union of Geodesy and Geophysics
Global Geodetic Observing System

IAG GGOS

20. August 2012

Mr. Paul Flament
Galileo Programme Manager
European Commission
Enterprise and Industry Directorate
Rue de Mot, 28
B-1049 Brussels

cc: Gerhard Beutler, Bertram Arbesser-Rastburg

Dear Mr. Flament,

Prof. Gerhard Beutler, Chair of ESA's Galileo Science Advisory Committee (GSAC), requested in his letter of October 13, 2011 access to meta data related to the Galileo satellites and sensor stations for the scientific community. On behalf of the International GNSS Service (IGS) I strongly support this request and would like to add a few remarks from the IGS perspective.

The information and data requested by Prof. Beutler are essential for the precise modeling of observations and orbits of the Galileo satellites, for the consistent and interoperable integration of Galileo products into the highest quality products of the IGS, and for a consistent alignment of terrestrial reference frames. Our products serve Earth system research, hazards detection, and many more applications relevant to society as a whole.

The list provided by Prof. Beutler represents in essence a complete list of the required information. From the IGS perspective the following subset of information is needed urgently in the nearest future. This information is crucial for a correct high precision modeling of the Galileo observables, in particular for the consistent determination of satellite clock corrections:

- *navigation antenna phase center offsets* in the body-fixed reference frames w. r. t. the satellites' centers of mass for each carrier frequency and for all Galileo satellites (together with the definition of the body-fixed reference frames).
- *attitude models* for the Galileo satellites (which are of particular importance, if the antenna phase center is not located on the axis connecting the satellite's center of mass with the center of mass of the Earth).

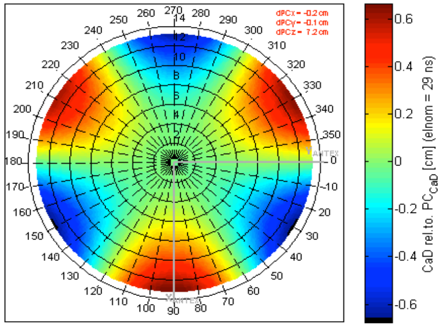
The IGS would be most obliged, if the above information could be made available to the scientific community with highest priority.

Sincerely yours

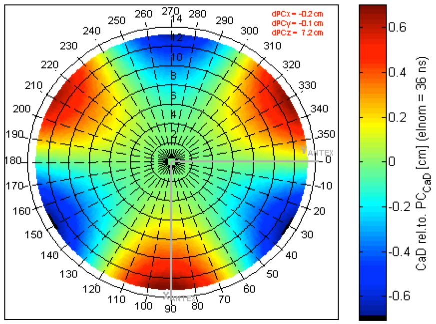
Prof. Urs Hugentobler
Chairman
IGS Governing Board

Antenna - PCV Azimuthal components GSAT01

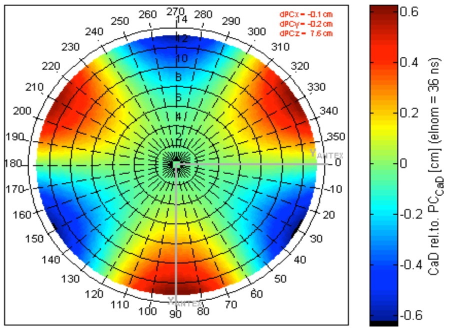
at: E5_ABOC2_AQ_BQ_Pattern_IOVFM4_IdealBrickWall_DotPP___Correctedlinear_V254.m
p2p: 1.34, mean: -0.00, sigma: 0.28 cm



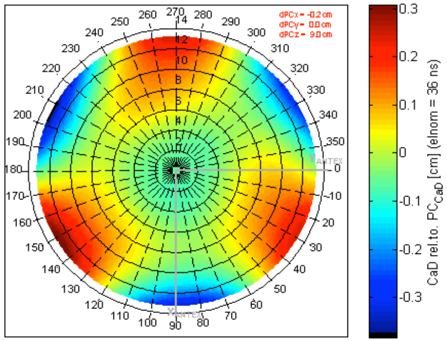
FM3-Sat: E5_BI_Pattern_IOVFM4_IdealBrickWall_DotPP___Correctedlinear_V224.mat
p2p: 1.41, mean: -0.00, sigma: 0.29 cm



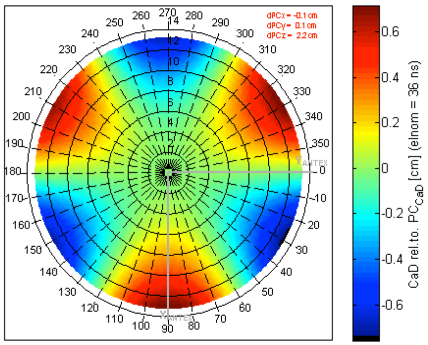
FM3-Sat: E5_AI_Pattern_IOVFM4_IdealBrickWall_DotPP___Correctedlinear_V224.mat
p2p: 1.27, mean: 0.00, sigma: 0.27 cm

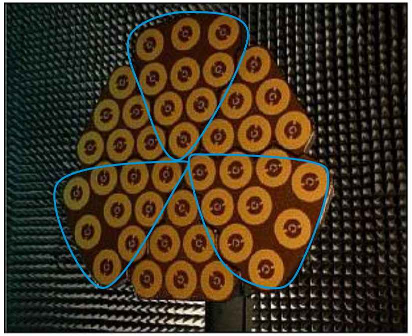


3-Sat: L1_CBOC_C_Pattern_IOVFM4_IdealBrickWall_DotPP___Correctedlinear_V228.mat
p2p: 0.69, mean: 0.00, sigma: 0.12 cm

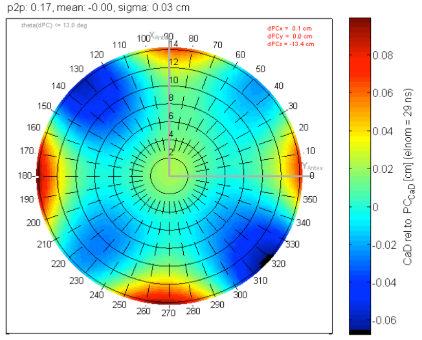


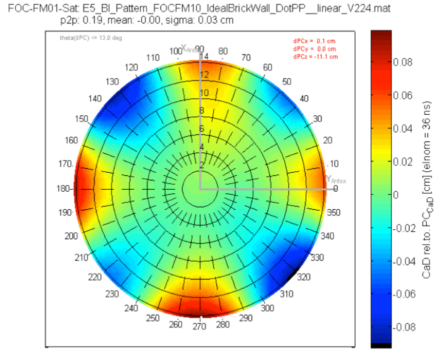
FM3-Sat: E6_B_Pattern_IOVFM4_IdealBrickWall_DotPP___Correctedlinear_V228.mat
p2p: 1.47, mean: -0.00, sigma: 0.31 cm

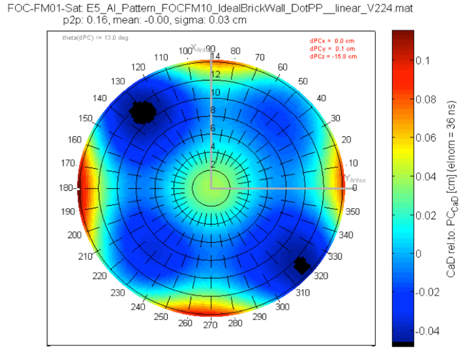


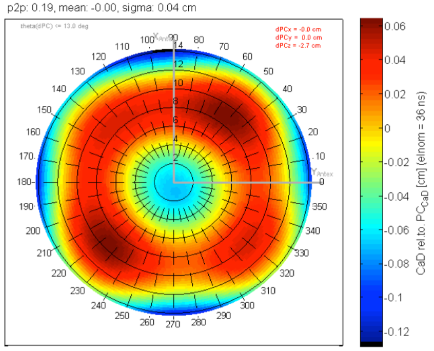


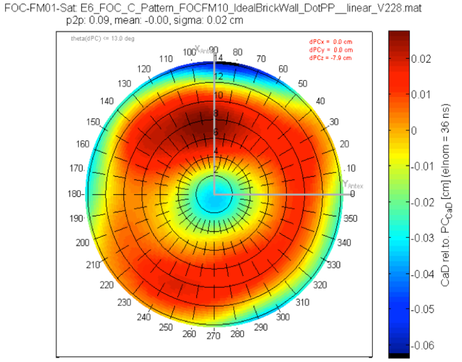
Antenna - PCV Azimuthal components GSAT02

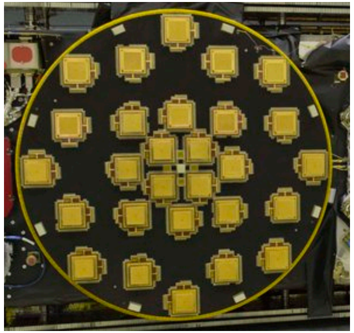






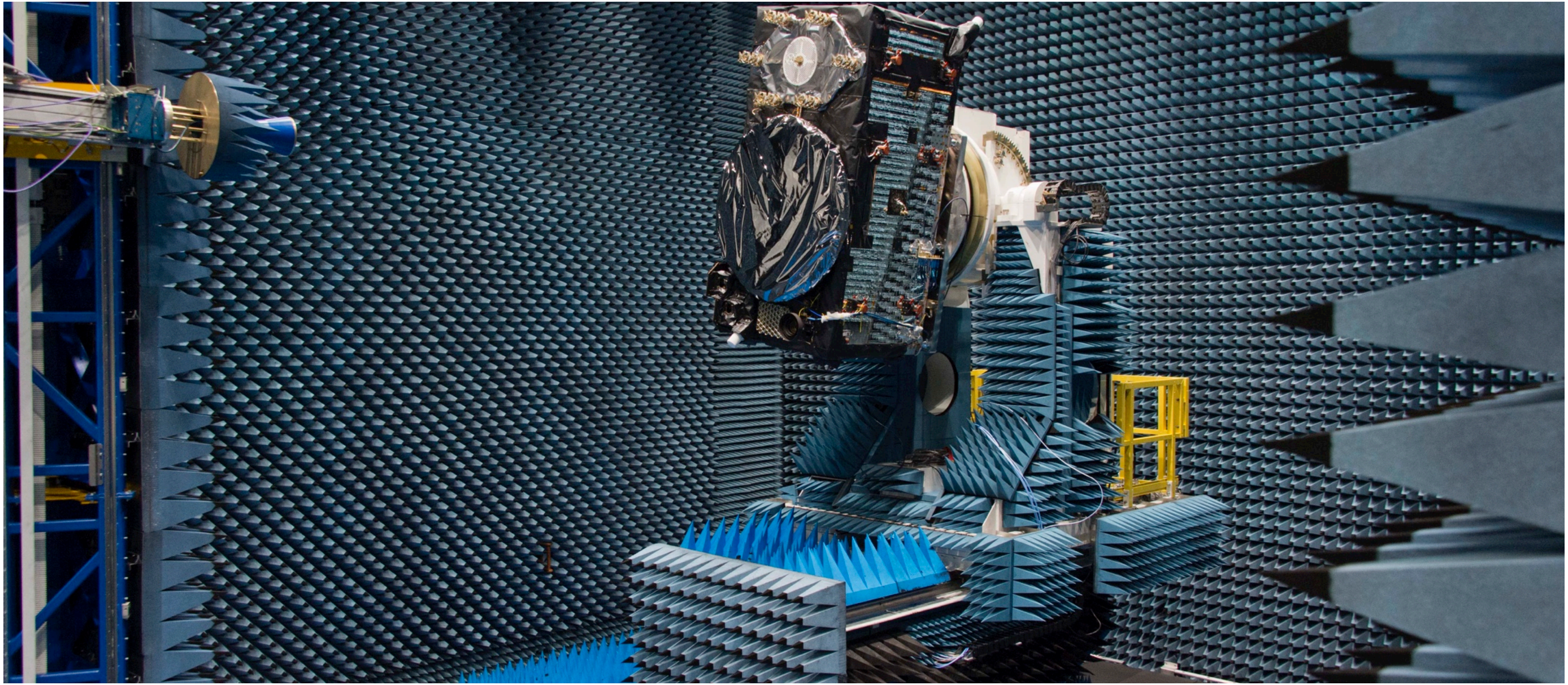






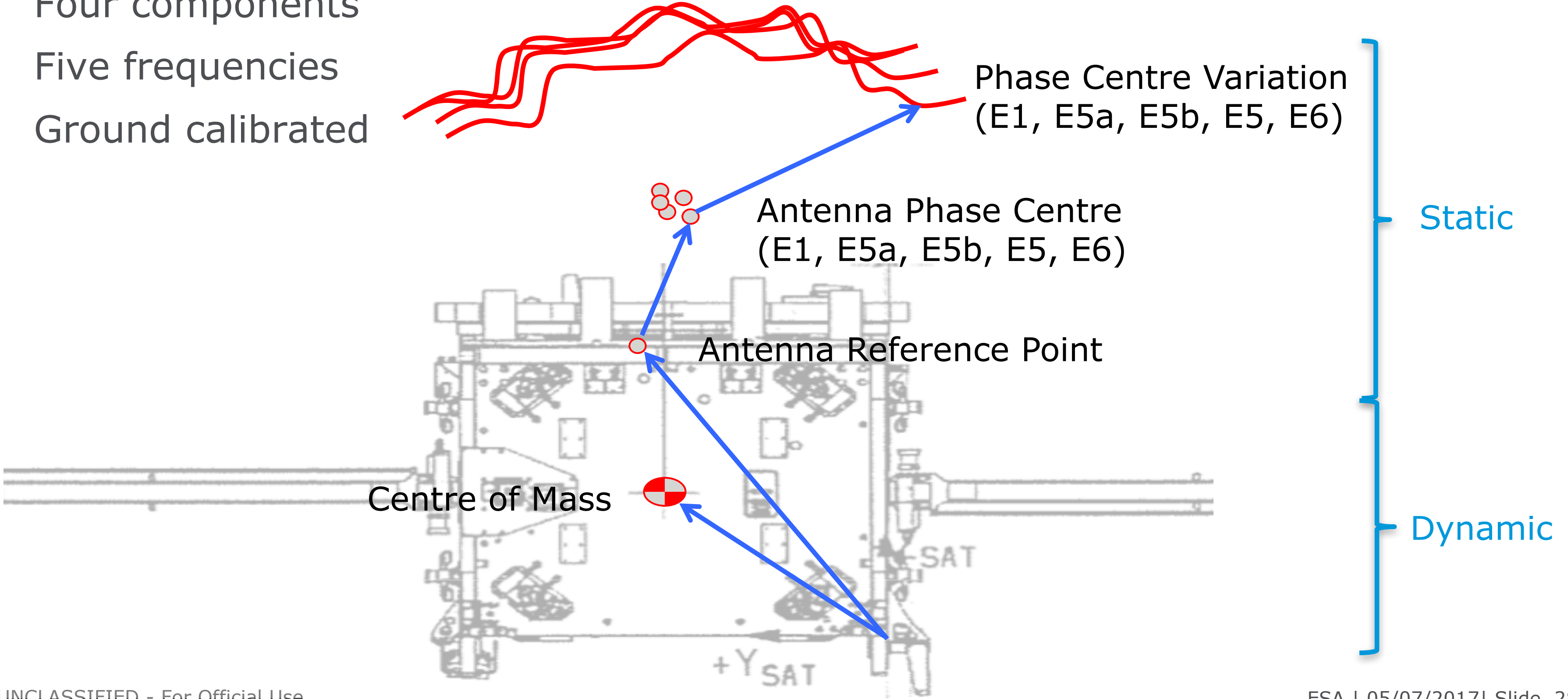

esa

Antenna – chamber calibration



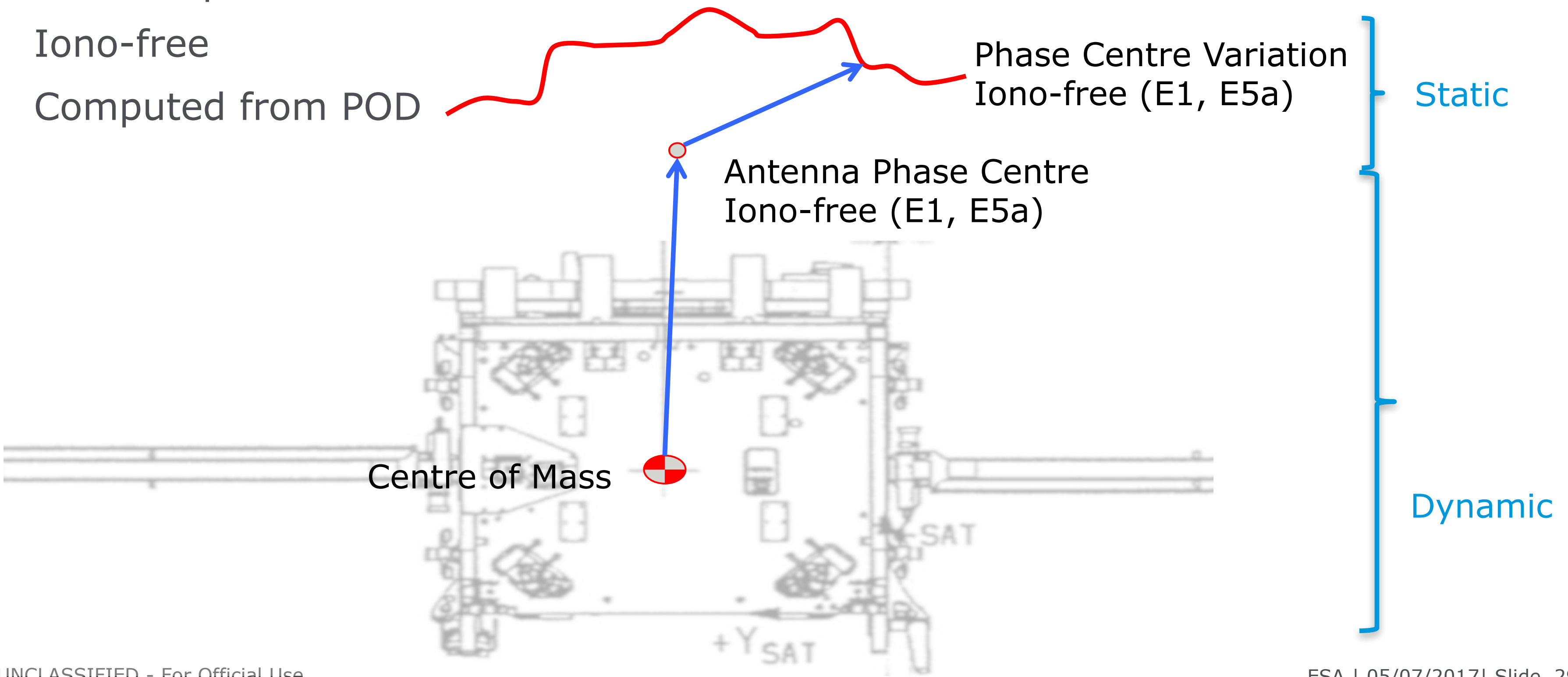
Antenna correction information from Galileo

- Four components
- Five frequencies
- Ground calibrated

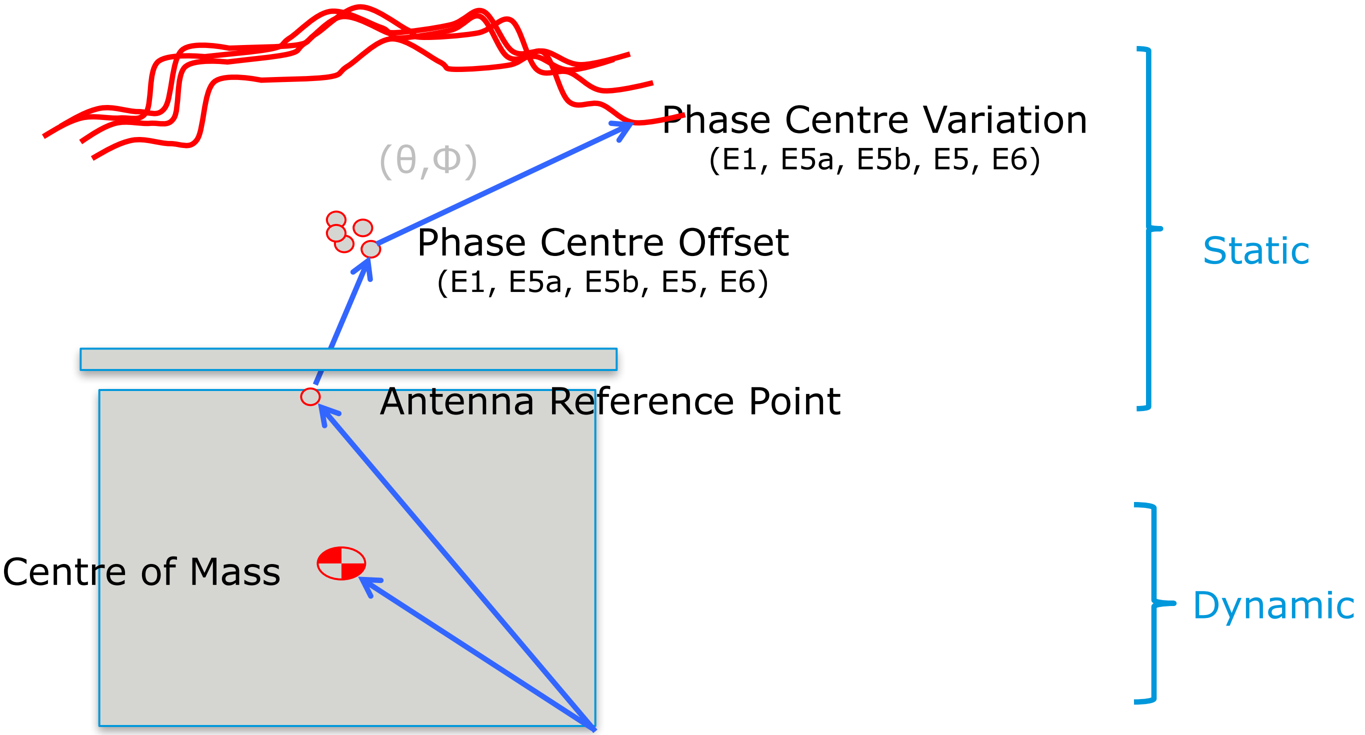


Antenna correction information in IGS

- Two components
- Iono-free
- Computed from POD



Antenna correction information from Galileo



Metadata content

Requested by

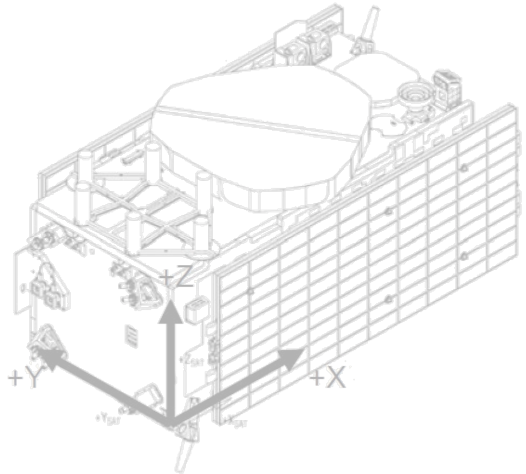
- Galileo scientific advisory committee (GSAC)
- International GNSS Service (IGS)

Status

- Galileo IOV Satellite Metadata released during Initial Service Declaration (Dec-2016).
- Galileo FOC metadata to be released (Q3,2017).

Content

- Attitude Law
- Mass and Centre Of Mass evolution
- Navigation Antenna Phase Centre Corrections
- Geometry and optical properties
- Laser Retro Reflector Location
- Satellite Group Delay



Metadata location

https://www.gsc-europa.eu/support-to-developers/galileo-iov-satellite-metadata#2

https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_missions/current_missions/ga01_com.html