Phase Centre Calibration of the Galileo Satellite Navigation Antenna

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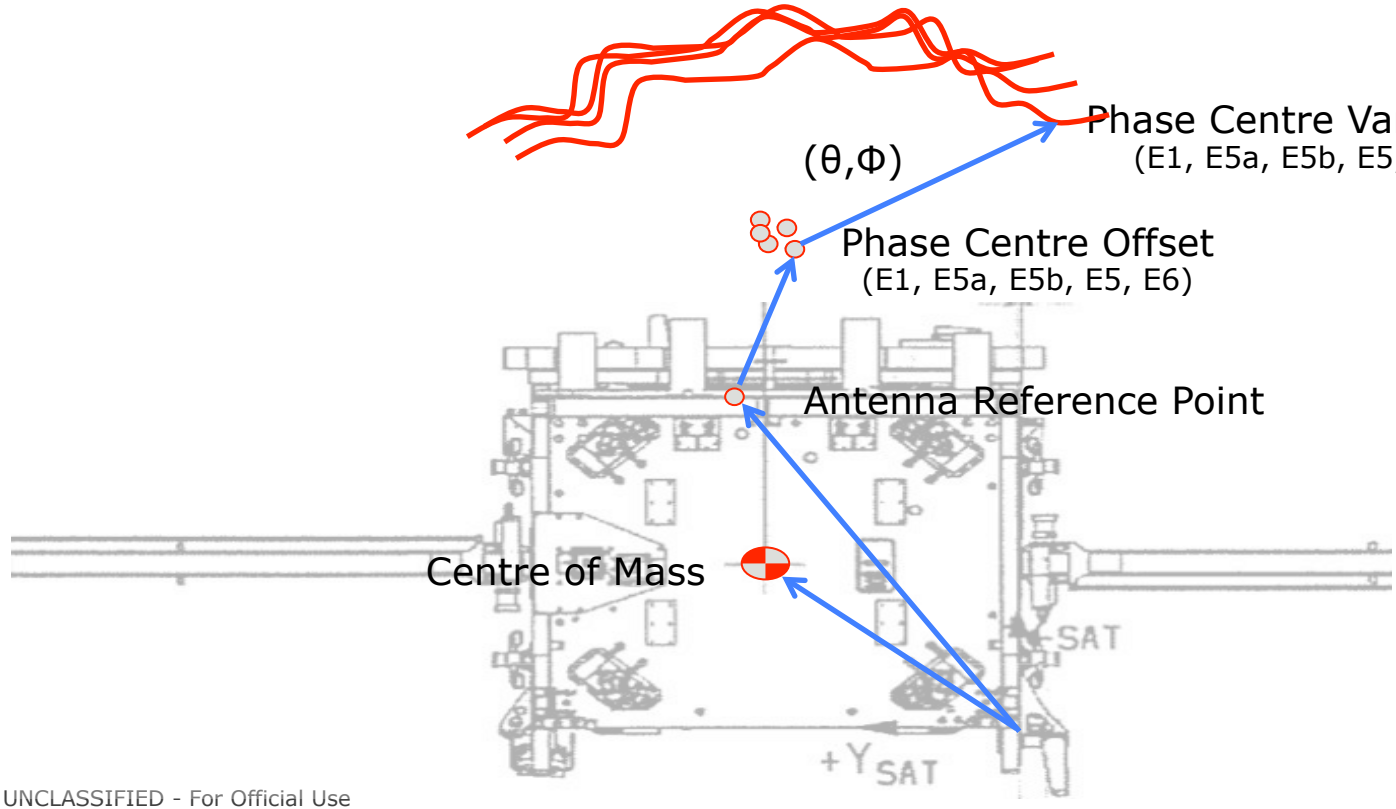
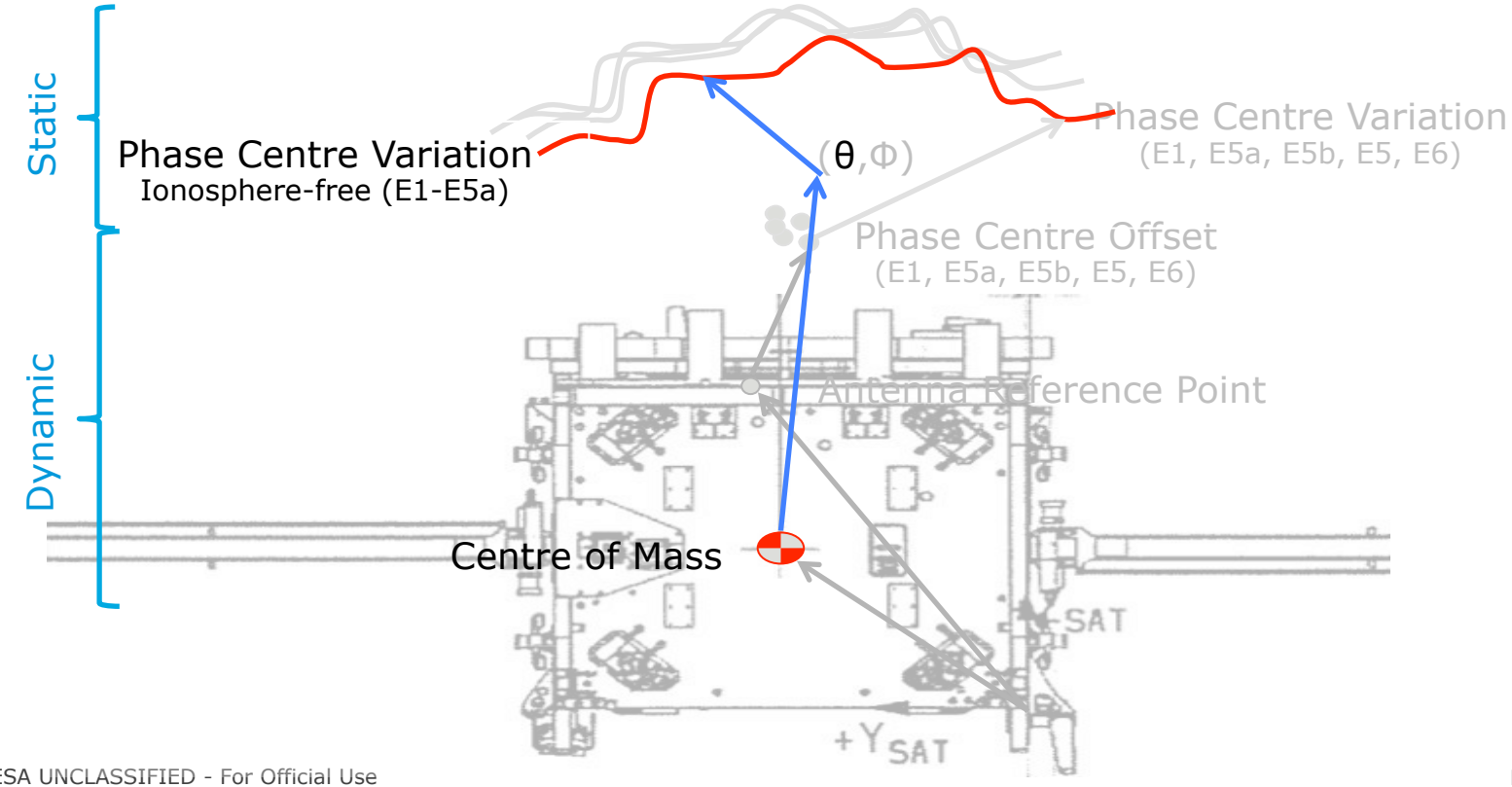
Summary

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

Introduction – Galileo Antenna Metadata



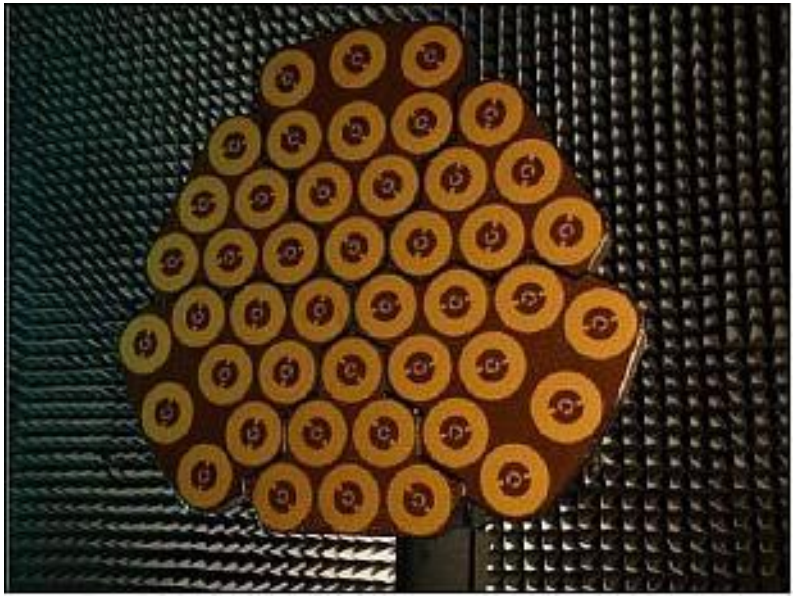
Introduction – IGS Antenna data



Antenna - types

Two antenna types

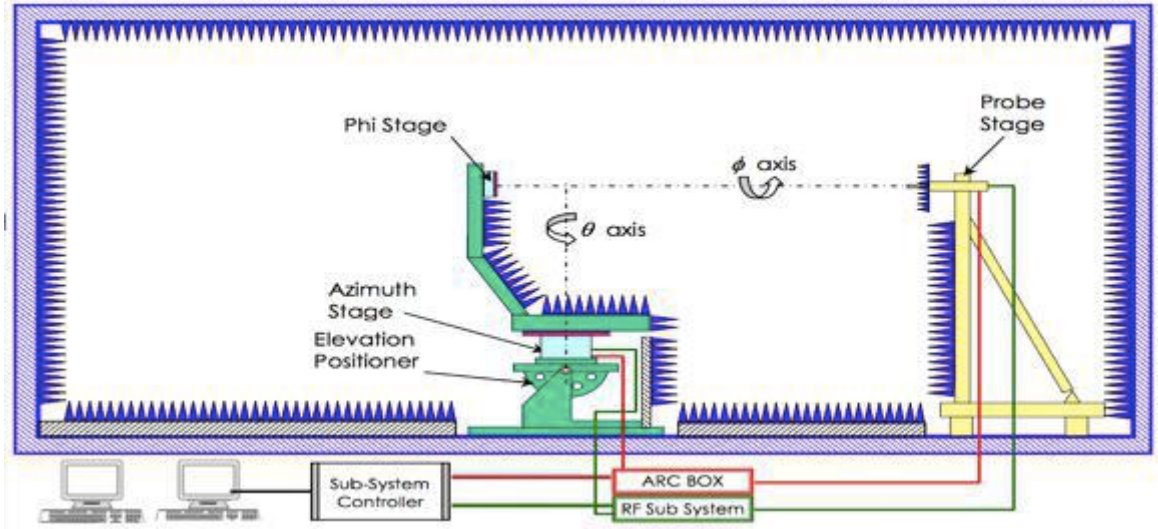
GSAT01xx - EADS CASA



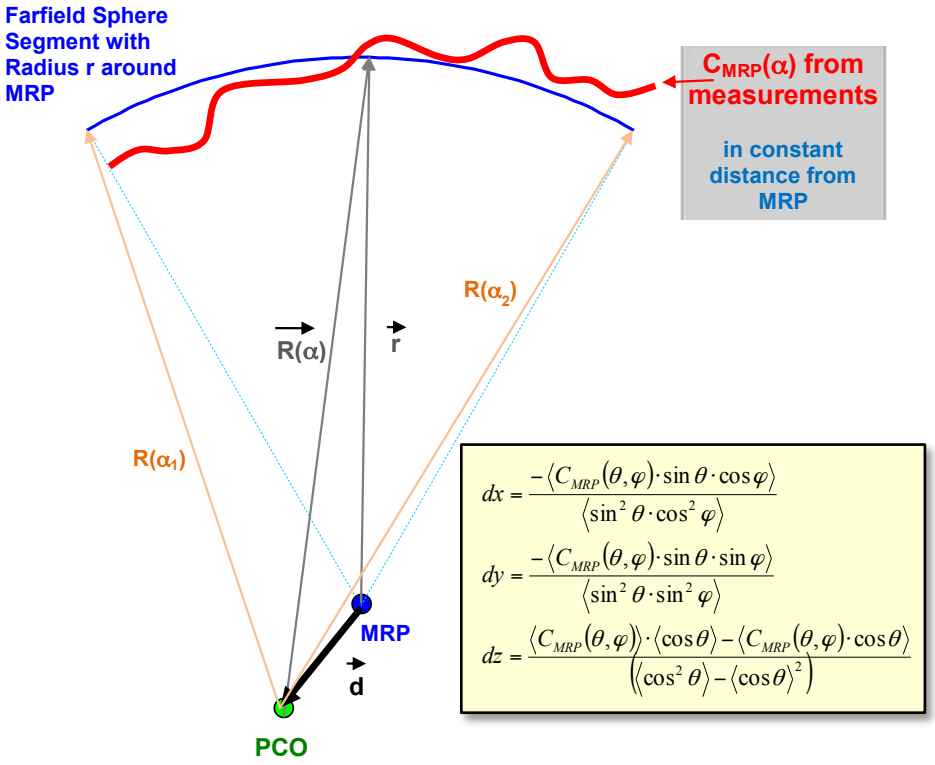
GSAT02xx - Thales Alenia

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)

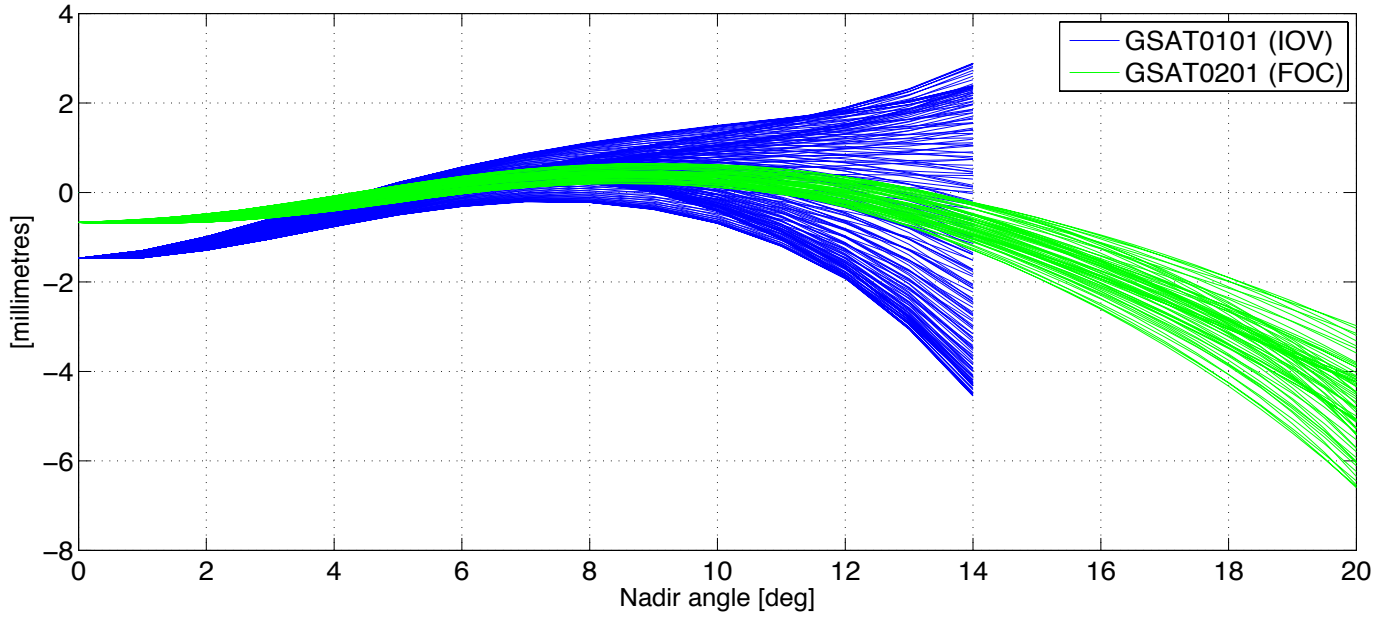
Antenna – Phase Center Variation (PCV)

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

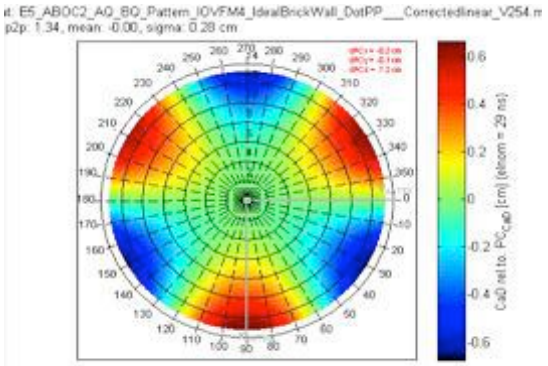
```
GALILEO-1           E11                 E101      2011-060A TYPE / SERIAL NO
CHAMBER             ESA                      1    09-FEB-12 METH / BY / # / DATE
     2.0                                                    DAZI
     0.0  14.0   1.0                                       ZEN1 / ZEN2 / DZEN
     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
```

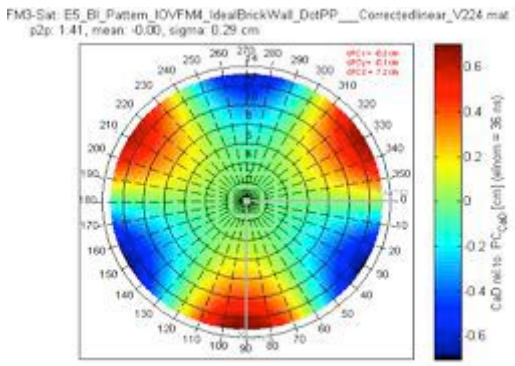
Antenna – Phase Center Variation (PCV)

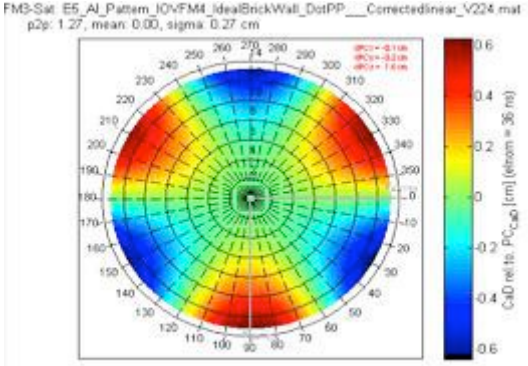
- Azimuthal values [0°,360°]
- Zenith values from 0° to 14° (GSAT01) and 20° (GSAT02)
- All 5 single frequencies (e.g. E1 signal).

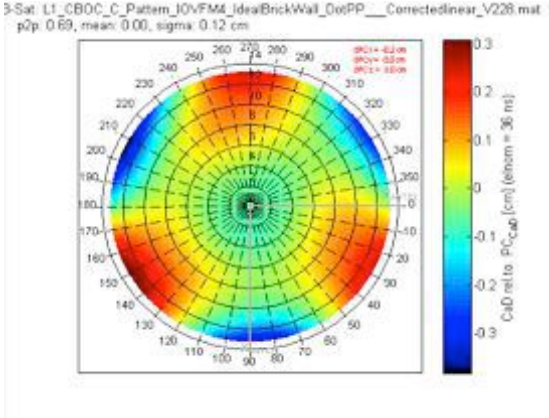


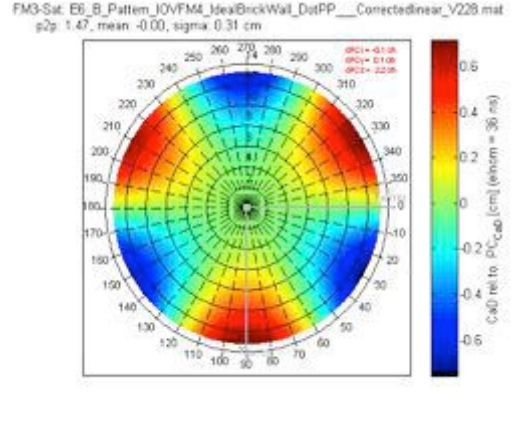
Antenna - PCV Azimuthal components (GSAT01)

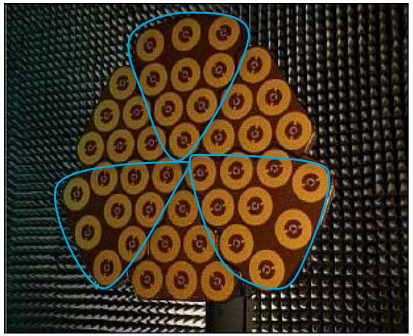






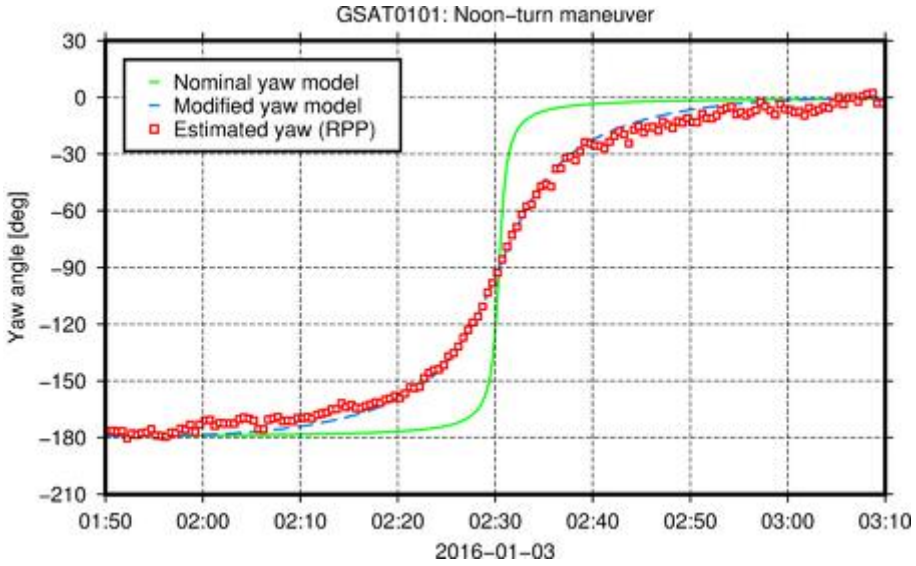


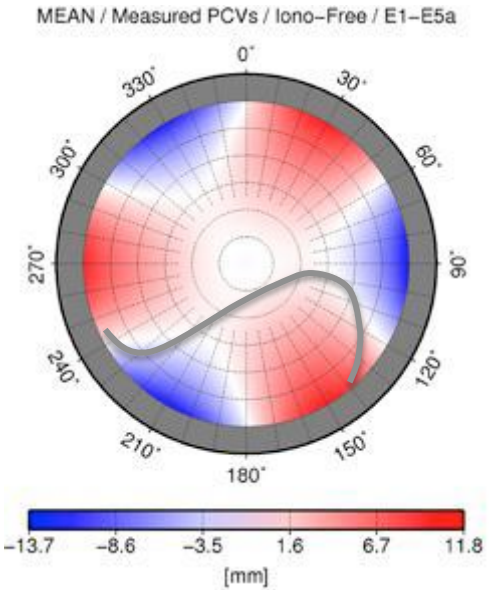




Antenna - User direction (attitude)

- Azimuthal correction requires Satellite yaw modeling (e.g. GSAT0101)
- Orientation accuracy better than ground antennas[1]



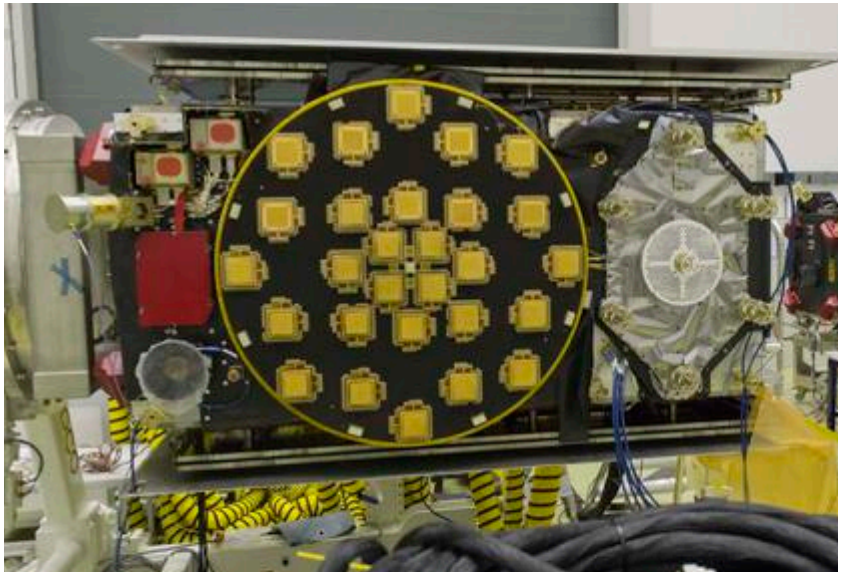


[1] *Source: F.Dilssner, Galileo IOV Spacecraft Metadata and Its Impact on Precise Orbit Determination, EGU2017*

Antenna Reference Point

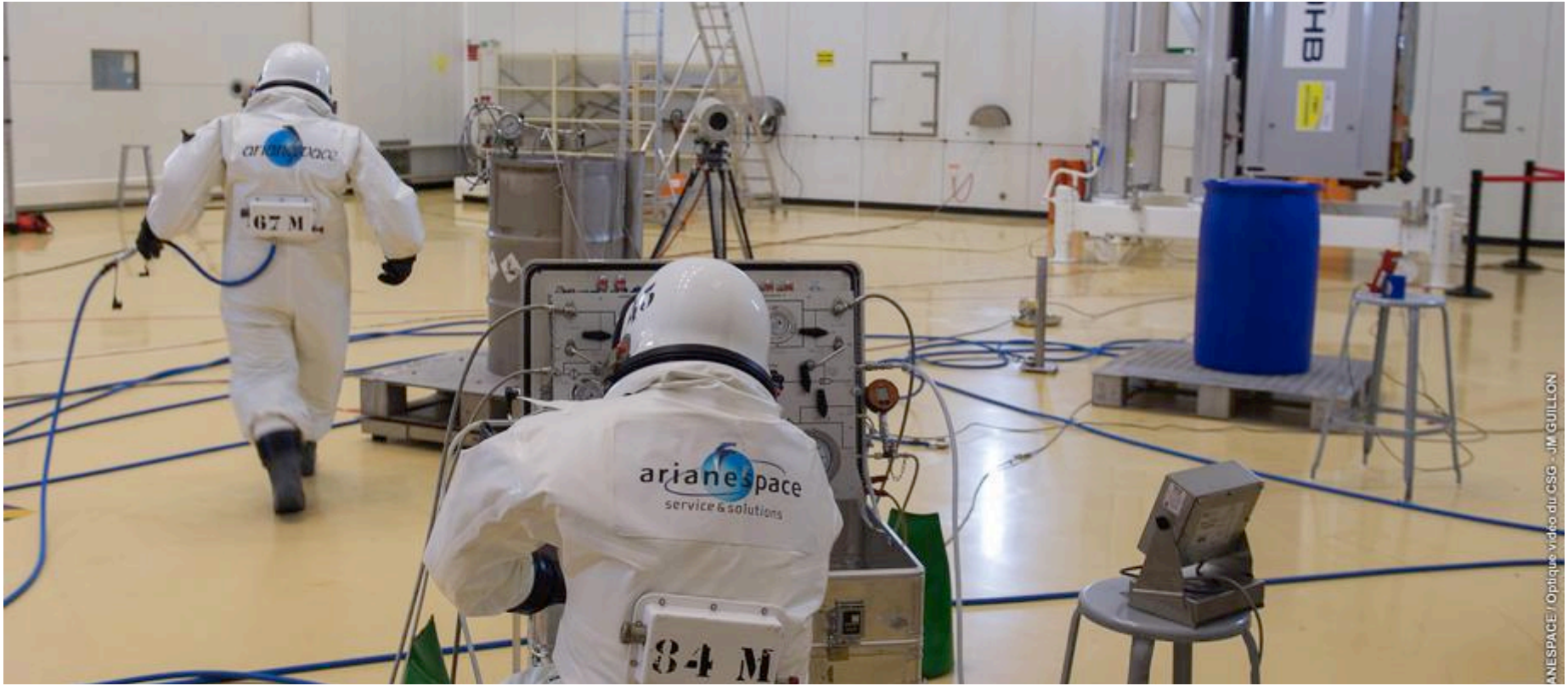
- Antenna integrated on body frame
- Physical point on the satellite [mm]

	X	Y	Z
GSAT01	1375.5	600.0	1100.5
GSAT02	140.0	0.0	1215.0

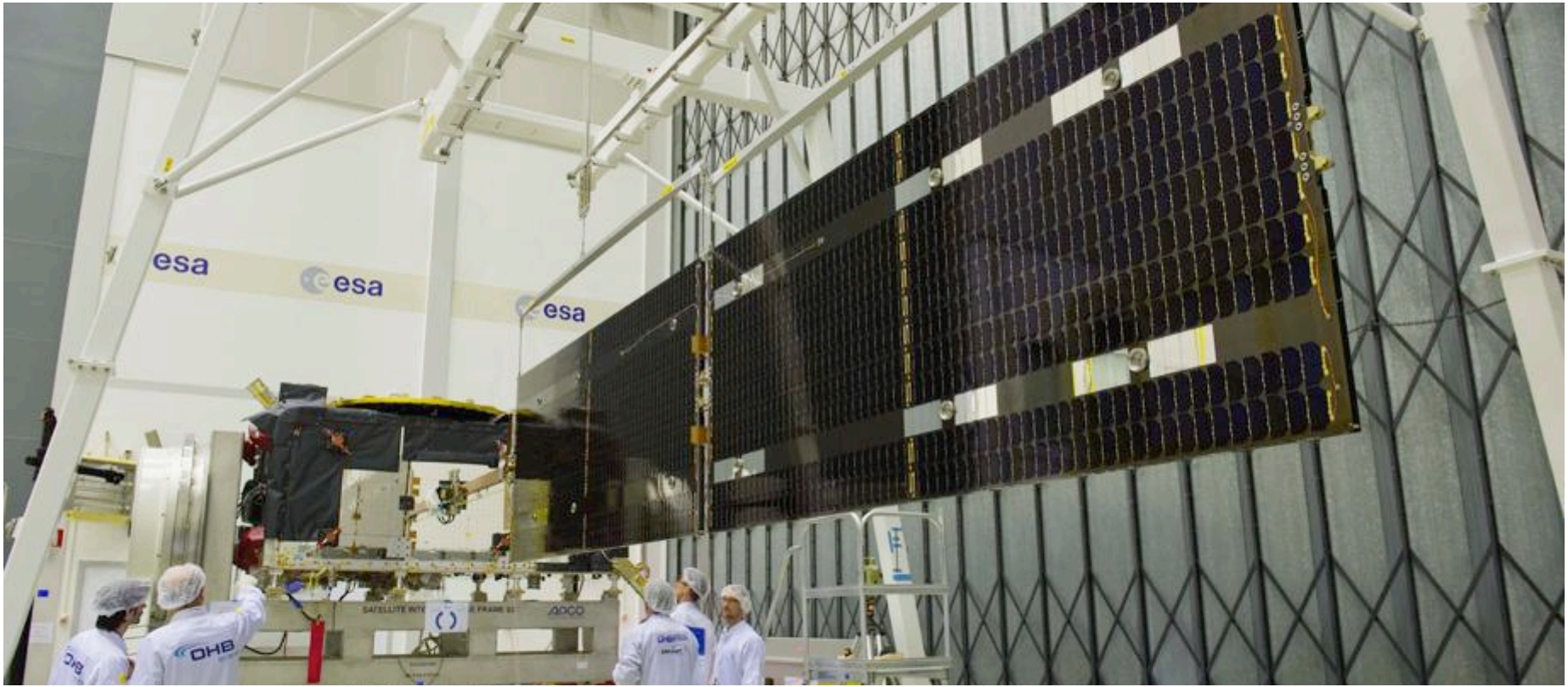


Centre of Mass – dry measurement in stow

Centre of Mass – tank filling

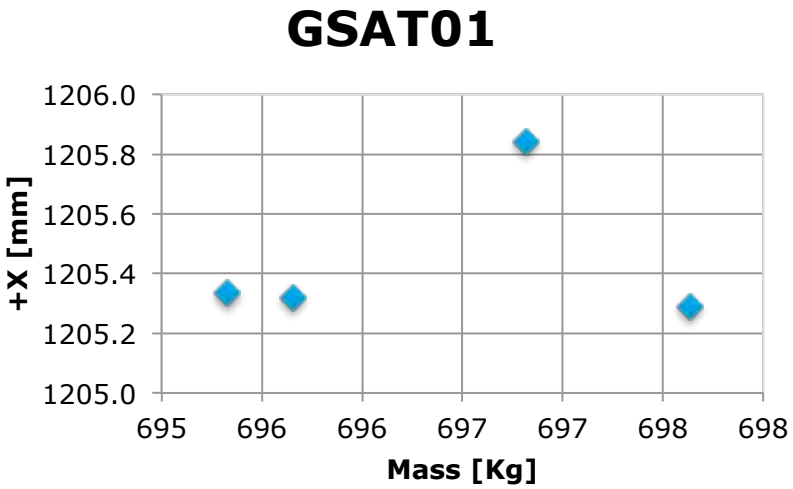


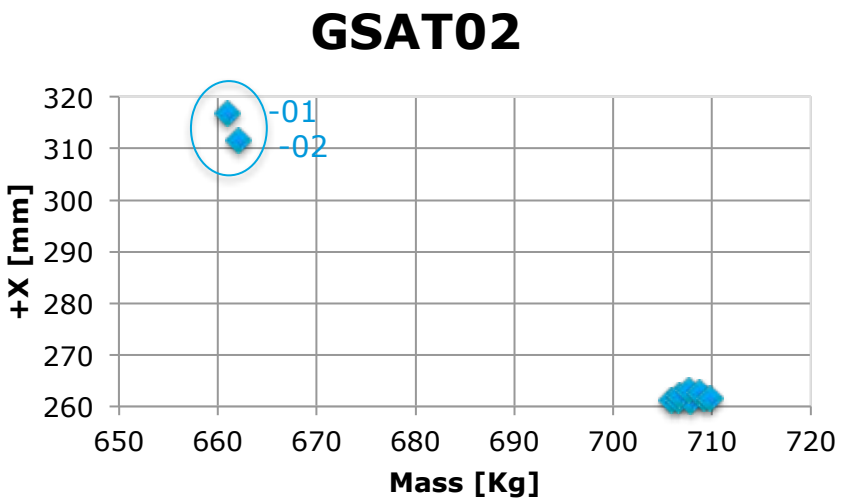
Centre of Mass – Solar array deployment



Centre of Mass - Values

- Dynamic information. Value after any maneuver sent to ILRS
- Agreement between S/C well below 1 cm



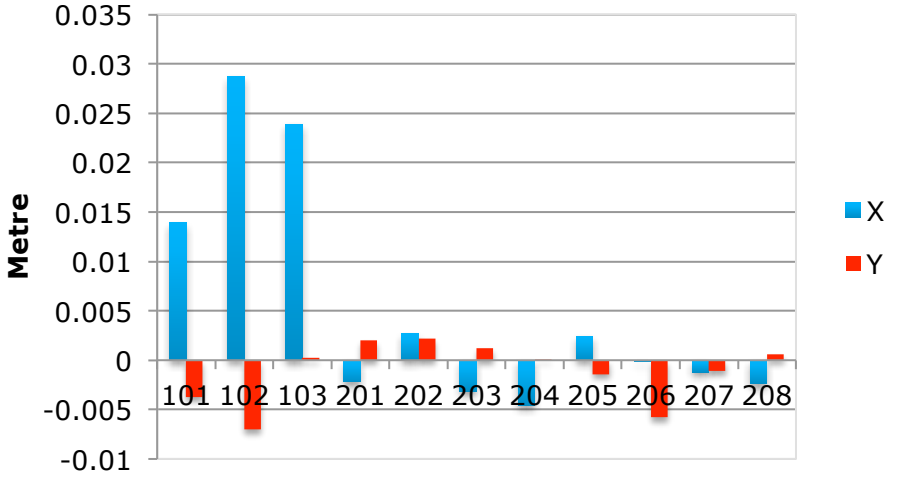


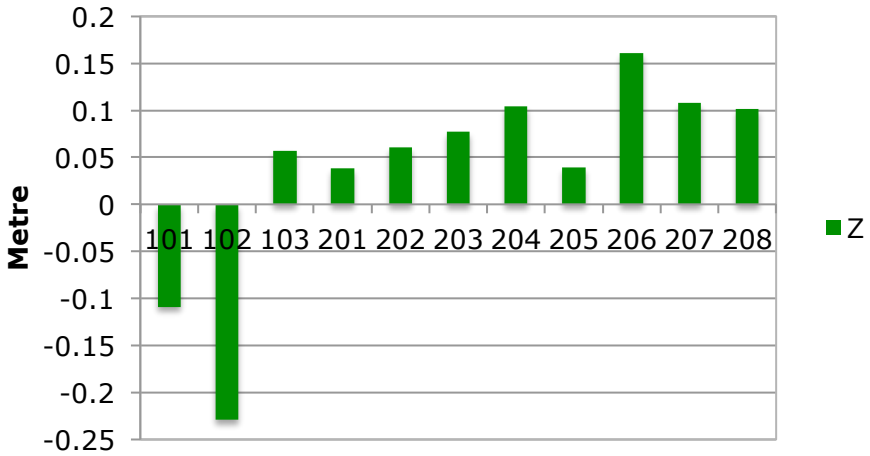
Metadata versus IGS

	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)
Data-static	PCV – PCO (θ,Φ) PCO - ARP ARP - SRF	PCV – PCO (θ)
Data-dynamic	CoM - SRF	PCO – CoM
Attitude	Normal + Modified	Normal
Frame	Satellite Reference Frame	Antex

Metadata versus IGS

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





Summary and conclusions

Calibrated 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