Galileo Satellite Antenna Modeling

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GNSS Satellite Antenna Modeling

- Precise satellite orbits refer to the center of mass
- GNSS measurements refer to the actual phase center of the transmit antenna

- Phase Center Offset (PCO)
  - Center of mass
  - Mean phase center

- Phase Center Variation (PCV)
  - Correction depending on the nadir angle $n$ (and the azimuth) of the observation direction as seen from the satellite
The Galileo Satellites

In-Orbit Validation (IOV)
- 4 satellites launched in 2011 and 2012

Built by Astrium

Full Operational Capability (FOC)
- 4 satellites launched in 2014 and 2015
- Contract for 22 satellites

Built by OHB
Galileo IOV Antenna

- Dual band right hand circular polarized
- Array of 45 photo-printed stacked patch elements
Galileo FOC Antenna

- Similar to GIOVE-A antenna
- Dual band right hand circular polarized
- Array of 28 stacked patch elements
IGS Multi-GNSS Experiment (MGEX)

- No public information about Galileo PCOs and PCVs available
- Conventional Galileo IOV PCOs based on images and models of the satellites

<table>
<thead>
<tr>
<th>Satellite</th>
<th>$x_{MGEX}$ [cm]</th>
<th>$y_{MGEX}$ [cm]</th>
<th>$z_{MGEX}$ [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galileo IOV</td>
<td>$-20.0$</td>
<td>$0.0$</td>
<td>$+60.0$</td>
</tr>
<tr>
<td>Galileo FOC</td>
<td>$+15.0$</td>
<td>$0.0$</td>
<td>$+100.0$</td>
</tr>
</tbody>
</table>

- PCVs ignored
- Nominal yaw steering attitude assumed
## GNSS Processing

<table>
<thead>
<tr>
<th></th>
<th>AIUB</th>
<th>DLR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Software</strong></td>
<td>Bernese GNSS Software 5.3</td>
<td>Napeos 3.3.1</td>
</tr>
<tr>
<td><strong>GAL stations</strong></td>
<td>~ 85</td>
<td>~ 70</td>
</tr>
<tr>
<td><strong>GPS stations</strong></td>
<td>~ 130</td>
<td>~ 130</td>
</tr>
<tr>
<td><strong>Differencing</strong></td>
<td>Double difference</td>
<td>Undifferenced</td>
</tr>
<tr>
<td><strong>Arc length</strong></td>
<td>3 days</td>
<td>1 day</td>
</tr>
<tr>
<td><strong>Orbit model</strong></td>
<td>Enhanced ECOM</td>
<td>A priori box model and 5 ECOM parameters</td>
</tr>
<tr>
<td><strong>PCO interval</strong></td>
<td>1 week</td>
<td>1 day</td>
</tr>
</tbody>
</table>

GPS PCVs and PCOs fixed to igs08.atx
DLR PCO Time Series IOV-3

X Offset [cm]

Y Offset [m]

Z Offset [cm]

2013

2014

2015

Apr

Jul

Oct

Jan

Apr

Jul

Oct

Jan
Systematic Effects in Galileo IOV PCO Estimates

- X Offset [cm]
- Y Offset [cm]
- Z Offset [cm]

RMS X Offset [cm]
RMS Y Offset [cm]
RMS Z Offset [cm]
Mean Galileo PCOs

**AIUB**: Combination on NEQ level

**DLR**: Outlier rejection for
- $\text{RMS}_{X,Y} > 5 \text{ cm}$
- $\text{RMS}_Z > 20 \text{ cm}$
Validation

- Orbit solutions with MGEX and DLR PCOs for 2014

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<tr>
<th>Satellite</th>
<th>MGEX</th>
<th>DLR</th>
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</thead>
<tbody>
<tr>
<td>IOV-1</td>
<td>-0.3</td>
<td>-1.2</td>
</tr>
<tr>
<td>IOV-2</td>
<td>-0.2</td>
<td>-1.2</td>
</tr>
<tr>
<td>IOV-3</td>
<td>-0.2</td>
<td>-1.3</td>
</tr>
<tr>
<td>IOV-4</td>
<td>-0.7</td>
<td>-1.5</td>
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</table>

<table>
<thead>
<tr>
<th>Satellite</th>
<th>STD</th>
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</thead>
<tbody>
<tr>
<td>IOV-1</td>
<td>5.0</td>
<td>4.9</td>
</tr>
<tr>
<td>IOV-2</td>
<td>5.0</td>
<td>4.8</td>
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<tr>
<td>IOV-3</td>
<td>4.9</td>
<td>4.7</td>
</tr>
<tr>
<td>IOV-4</td>
<td>4.2</td>
<td>4.1</td>
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</tbody>
</table>
Summary and Outlook

- Pronounced beta-dependent effects in horizontal PCO estimates, strong correlations with solar radiation pressure parameters
- Few cm level agreement of AIUB/DLR mean PCOs for FOC X/Y and IOV Y offsets, discrepancies for IOV X offsets, 5-10 cm level agreement for Z offsets
- Application of new PCO values results in improved consistency of orbit products
- PCV estimation pending
- Pronounced azimuth-dependent pattern in Galileo IOV residual maps
- Extension of analysis interval for Galileo FOC, inclusion of FOC-2, 3, 4

IOV residual map, 1st iteration