THE GALILEO PROGRAMME

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European Commission
Directorate-General for Defence Industry and Space

“Workshop on GNSS Data Processing for High-Accuracy Positioning using Low-Cost Receiver Systems”
Thailand, 19 January 2021
Galileo

- Accurate, global navigation
  - < 1m position
  - < 5ns timing
- Almost 2 billion devices
  - Probably in your phone!
- First global mass-market dual frequency GNSS (E1/E5)
  - 1164-1215 and 1559-1591 MHz
- Search and Rescue service integrated into Cospas-Sarsat (has saved lives!)

- Coming, Navigation Message Authentication
- Coming, 20cm service in third frequency (E6/L6)
  - 1260-1300MHz
- Coming, unique authentication (E6/L6)
- Next generation already planned
2020 Where are we?

- World class space programme
  - Copernicus
  - EGNOS
  - Galileo

- Managed by European Commission’s new **Directorate General for Defence Industry and Space**

- And newly created: EU Space Programme Agency (EUSPA) - formerly the GSA

- System design by ESA

- New budget (under discussion in European Parliament) about €13bn
  - Operational
  - Developmental
  - Research
Galileo Deployment History

2005
DEVELOPMENT
SYSTEM TESTBED
GIOVE A/B

2013
IN-ORBIT VALIDATION
4 satellites
initial ground
infrastructure

2015/2016
INITIAL GALILEO SERVICES
OS, SAR, PRS, CS demonstrator

2017/2019
EXPLOITATION
PHASE
FOC1 System

2020+
24 operational
satellites
and complete ground
infrastructure

After 2020++
TOWARD
GALILEO 2nd
GENERATION

G2G
Galileo Constellation Status: STABLE

- 26 satellites in orbit
- L3 sats
- 1 spare
- 1 unavailable
- 2 no SAR (by design)
EGNOS SBAS

- Augments GPS
- Provides integrity data for Safety of Life applications
  - precision landings
  - rail/road tolling/RPAS
- Enables affordable precision farming
  - < 0.5m accuracy
- In service since 2011
- Covers EU+
  - Extensions planned

- EGNOS/Galileo alone estimated to bring net benefits €60bn+ to EU economy (up to 2027)
Galileo Ranging Performance

- Decreasing ranging error trend due to increasing number of satellites and ground infrastructure improvements
- **Ranging accuracy (95%) 0.25 m** all satellites in July 2020 (FNAV)

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**Pinpoint**

**STABLE ACCURACY ~25cm**

Like clockwork

Galileo Timing Performance

- **Broadcast UTC Offset**: 
  - $\sim 2.5\text{ns (95%)} < 30\text{ns IS target}$

- **GGTO accuracy**: 
  - $\sim 4.2\text{ns (95%)} < 20\text{ns IS target}$

- Evaluated with calibrated timing GPS/Galileo receiver operated at a European UTC(k) laboratory (PTB, INRIM)
Reliable (mostly)

Service Availability

- And under scrutiny!
  - GRC and EU Member States Networks
  - IGS
  - IGMA
  - www.galmon.eu
## Performance in detail

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<tbody>
<tr>
<td><strong>Ranging accuracy</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(DF, 95%)</td>
<td>Worst Satellite month</td>
<td>&lt; 7.0 m</td>
<td>0.45</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>Constellation Average</td>
<td>&lt; 2.0 m</td>
<td>0.22</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Ranging accuracy</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(SF, 95%)</td>
<td>Worst Satellite month</td>
<td>&lt; 7.0 m</td>
<td>0.75</td>
<td>0.56</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Constellation Average</td>
<td>&lt; 2.0 m</td>
<td>0.45</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>Availability of F/NAV Global PDOP ≤ 6</strong></td>
<td></td>
<td>≥ 77%</td>
<td>98.40%</td>
<td>99.999%</td>
<td>99.94%</td>
</tr>
<tr>
<td><strong>Availability of Positioning at Average User Location</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dual Frequency</td>
<td>≥ 77%</td>
<td>99.42%</td>
<td>100%</td>
<td>99.94%</td>
<td>99.96%</td>
</tr>
<tr>
<td>Single Frequency</td>
<td>≥ 77%</td>
<td>99.24%</td>
<td>100%</td>
<td>99.99%</td>
<td>99.95%</td>
</tr>
<tr>
<td><strong>Availability of Positioning at Worst User Location</strong></td>
<td></td>
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<tr>
<td>Dual Frequency</td>
<td>≥ 70%</td>
<td>97.47%</td>
<td>100%</td>
<td>99.94%</td>
<td>99.66%</td>
</tr>
<tr>
<td>Single Frequency</td>
<td>≥ 70%</td>
<td>96.98%</td>
<td>100%</td>
<td>99.91%</td>
<td>99.61%</td>
</tr>
<tr>
<td><strong>“Per Slot” Availability of SiS</strong></td>
<td>(monthly, OS, healthy SF/DF – OS-SDD MPL)</td>
<td>&gt; 87%</td>
<td>≥ 96.29%</td>
<td>≥ 98.10%</td>
<td>≥ 98.17%</td>
</tr>
<tr>
<td><strong>UTC Time Diss. Uncertainty</strong></td>
<td>(DF, 95% over last 12 months – OS SDD MPL)</td>
<td>&lt; 30 ns</td>
<td>14.4</td>
<td>14.4</td>
<td>13.6</td>
</tr>
<tr>
<td><strong>Availability of UTC dissemination (%)</strong></td>
<td></td>
<td>&gt; 87%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>GST-GPS time offset uncertainty</strong></td>
<td>(95% over last 12 months – OS SDD MPL)</td>
<td>&lt; 20 ns</td>
<td>13.7</td>
<td>13.4</td>
<td>12.4</td>
</tr>
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Accurate, and precise

HAS (High Accuracy Service)

Current
• **Defined:**
  – HAS SIS ICD
  – Based on RTCM format with Galileo-specific features
  – Launching “Phase 1” EU coverage
  – “Phase 2” improves performance with more stations, ionospheric corrections for better global service
• **Infrastructure**: HAS Data Generator module at CDR phase and progressing steadily
• **Testing**: Promising performance in tests using current Galileo monitoring stations

Next Steps
• SIS testing with HAS Demonstrator.
• HAS Data Generator completion
• Begin operational validation
  – phase 1 service declaration 2022-23
OSNMA
(Open Service Navigation Message Authentication)

**Current**
- **Defined** OSNMA scheme
- **Infrastructure**: OSNMA module qualified and integrated
- **Testing**: Internal testing
- **Receivers and Applications**:
  - Receiver Guidelines produced
  - OSNMA receivers and software available
  - OSNMA is a cornerstone of newly drafted **Smart Tachograph Regulation**

**Next Steps (2021)**
- **Infrastructure**: consolidate to ensure high robustness before Declaration
- **Testing**: open testing before service and operational validation
- **Receivers and applications**: Publication of official SIS ICD and Receiver Guidelines
Secured

CAS (Commercial Authentication Service)

- Stronger protection than OSNMA
  - Eg for insurance, financial transactions
- Encrypted navigation signal
- System capabilities and timeline agreed
- Feasible service concept proposed and under discussion
• Search And Rescue localisation service
  – Up and Running with excellent performance
  – detection in <5 minutes, not 4 hours; and 500m, not 5 km

• Return Link Service
  – Service Declaration on 21st January 2020
  – Compatible beacons – already half of manufacturers
  – Worldwide service – already 18 states, beacon approval

• eCall (automatic call localisation for car accidents)
  – In service for more than 2 years (now fitted to all new cars)

• Galileo used in E112 emergency call location (E911)
Resilient

- Robust timing service under definition
- Resilience - the key principle for G2G

- July 2019 Event - Inquiry board recommendations
- Substantial programme steering
  - Maintain navigation in case of multiple element failure – graceful degradation
  - Improve upgrade deployment capabilities
  - Review redundancy for some elements of the service delivery in the light of existing and new services
  - Review operational processes and procedures
  - Continuous reinforcement of cyber security
- Customer centric approach
- GSC registered users still on the rise
- GSA Market Teams in continuous exchange with user communities
  - Market Report (Oct 2019) and User Technology Report (End 2020)
  - Power-efficient positioning for The Internet of Things
  - Guidelines for rail receivers supporting EGNSS in ERTMS
  - Adoption of Galileo in Prague public transport
  - SAR beacons remote activation for fishing vessels
  - Galileo Green Lane App (COVID border crossing)
Defended

• Working with EU Member States to keep GNSS spectrum free from interference
  – European GNSS Interference Task Force (plug-in jammers)

• Working with international partners to defend GNSS spectrum and monitor GNSS performance (UN-ICG)

• Working (with BeiDou) towards better co-existence between GNSS and amateur radio users (WRC-23 AI 9.1b, 1240-1300MHz)
Accelerated

• L3 satellites have joined the operational constellation
• OS SISI ICD 2.0 with new features (backward compatible)

G2G

G2G Service Portfolio and High Level Mission Objectives agreed with Programme Stakeholders

Service evolutions include:
• Advanced Timing Services
• Space Service Volume
• ARAIM – coming back to serving SoL communities
• Emergency Warning Services
• Search And Rescue – Innovative service based on the return link
• Ionosphere Prediction Service
• Signals Evolution – increased performance at user level (reduced power consumption, TTFF, accuracy, authentication, etc.)
• SAR 2nd Generation Beacons
Documented

SEARCH AND RESCUE Service

- MEOSAR operational as part of COSPAS SARSAT in December 2016
  - Detects standard 406 MHz emergency beacons
  - Faster beacon detection (was 4hrs, now <5mins)
  - Better position accuracy (was 10km, now <1km)
  - Major contribution by Galileo

- EU Coverage 3 MEOLUTs
- 4th station in Indian Ocean

- Return Link Service ready
  Successful performance – remarkable latency
  Manufacturers building RLS capable beacons
  Successfully tested at sea with US Coastguard, near Maryland
# Galileo SAR Performance

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<tbody>
<tr>
<td>Valid message detection probability</td>
<td>≥ 99%</td>
<td>96.5%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Localisation probability (1 burst)</td>
<td>≥ 90%</td>
<td>99.1%</td>
<td>100%</td>
<td>99.7%</td>
<td>99.9%</td>
</tr>
<tr>
<td>Localisation probability (up to 12 bursts)</td>
<td>≥ 98%</td>
<td>99.7%</td>
<td>≥ 99.9%</td>
<td>100%</td>
<td>99.9%</td>
</tr>
<tr>
<td>Localisation success within 5 km (1 burst)</td>
<td>≥ 90%</td>
<td>98.1%</td>
<td>≥ 99.5%</td>
<td>≥ 99.6%</td>
<td>99.2%</td>
</tr>
<tr>
<td>Localisation success within 5 km (up to 12 bursts)</td>
<td>≥ 95%</td>
<td>99.1%</td>
<td>≥ 99.9%</td>
<td>≥ 100%</td>
<td>99.9%</td>
</tr>
<tr>
<td>Minimum SAR Transponder Avail. (Worst Case)</td>
<td>&gt; 95%</td>
<td>52.35%</td>
<td>91.90%</td>
<td>92.91%</td>
<td>93.70%</td>
</tr>
</tbody>
</table>

**MEOLUT Availability**

<table>
<thead>
<tr>
<th>in “Nominal” status</th>
<th>LNC</th>
<th>MSP</th>
<th>SBG</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 95%</td>
<td>98.4%</td>
<td>99.2%</td>
<td>98.7%</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>in “Nominal + Degraded” status</th>
<th>LNC</th>
<th>MSP</th>
<th>SBG</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 97.5%</td>
<td>99.2%</td>
<td>99.4%</td>
<td>98.8%</td>
</tr>
</tbody>
</table>

**SAR Forward Link Service Availability**

| ≥ 99% | 99.85% | 99.90% | 99.91% | 99.87% |

**SAR Return Link Service Availability**

| ≥ 95% | 100% | 100% | 99.99% | 99.99% |

**SAR RLM Delivery Latency < 15 [min]**

| ≥ 99% | 99.70% | 99.97% | 99.97% | 99.83% |
Satellites GSAT201/202 (‘L3’ satellites), launched 22 August 2014, did not reach nominal orbit

Partial orbit recovery performed by ESA in 2014/2015

System and satellite S/W updated to handle the different orbit

L3 have broadcast navigation messages since August 2016;

- no degradation observed/reported by users
- majority of user segment already track these satellites
- user feedback indicated eagerness for healthy flag to enable use in PVT solutions

Ranging performance is in line with those observed for the other satellites,

L3 almanac information not included in the OS Navigation Message broadcast by any Galileo satellite - L3 satellites information published by the GSC

L3 satellites declared operational 30 November 2020