Galileo

7th ITFS, Rome, Italy, 3-5 November 2009

Dr. Stefan Bedrich
Outline

- Motivation
- System Architecture
- Signals and Services
- Implementation
- Summary
Galileo – Why? (1/2)

- Ever increasing dependence of economy and social life on globally uniform navigation and timing infrastructure

- GPS proved to be a massive technological and economical factor

- Europe needs control over an independent system and its technology
Galileo – Why? (2/2)

- Decision in 2001 to implement an independent, but compatible and interoperable system

- Improved performance with minimum impact on user equipment cost:
  - Better performance (modern signal codes for reduced multipath)
  - Additional services (5 vs. 2 in GPS)
  - Integrity feature (new; N/A in GPS)
  - Service guarantee (civil system; N/A in GPS)

- GPS + Galileo = double number of satellites (improves both accuracy and robustness)
Galileo System

MEO constellation
- 23200 km altitude
  (29600 km radius)
- 14h 05m (17 revs in 10 d)
- 56° inclination
- 3 orbital planes

30 satellites
- 27 operational
- 3 spares
- 9 + 1 per plane

Two launchers
- Soyuz (2 S/C)
- Ariane-5 (4 S/C)
Galileo Satellites

- Mass 680 kg (launch mass)
- 1.5 kW electrical power
- Size 1.2m x 1.1m x 2.7m
- Lifetime >12 Jahre
- 3-axis stabilized
- 4 reference clocks
  - 2 x Rb $\left(5 \cdot 10^{-13}/100s\right)$
  - 2 x H-Maser $\left(5 \cdot 10^{-14}/10000s\right)$
- Laser retro reflector
- Navigation payload ~80 kg (850W)
- SAR transponder ~20 kg
Navigation Payload

(PHM = H-maser clock; RAFS = Rb clock)

Source: Astrium
Onboard Clocks

Rb

3.3 kg
2.4 l

H-maser

18 kg
45 l

FREQUENCY STABILITY
Closed-Loop System Architecture

1. **Ground Control Segment (GCS)** manages Galileo spacecraft (orbits, relative spacing, health status, ...)

2. **Ground Mission Segment (GMS)** manages payload (navigation signal power levels, coding, encryption, ...)

3. World-wide network of fixed signal monitoring stations (GSS, > 30) monitors navigation signals

4. Data are fed back by terrestrial links in real-time from monitoring stations to control center (GCC)

5. Two redundant GCCs: Oberpfaffenhofen/D, Fucino/I
Galileo Ground Segment

Source: ESNIS
Ground Control Centre (GCC) Oberpfaffenhofen

- Located on campus of DLR (German aerospace research centre) in Oberpfaffenhofen (25km southwest of Munich)
- Inauguration September 2008
- Staff ca. 100 people
- Installation of all technical equipment (servers, consoles, antennas) on-going
- Operational since mid 2009 to support launch and operations of IOV satellites
- Dimensioned to fully support FOC phase as one of two redundant GCC’s
Galileo Frequency Bands: E5, E6, L1

**Notes:**
- ARNS = Aeronautical Radio Navigation Service
- RNSS = Radio Navigation Satellite Service
- SAR = Search and Rescue Service

Source: GJU (2005)
Galileo Signal Structure

**E5A Signal:**
- Data + Pilot
- BPSK modulation
- Rate: 10.23 Meps
- Rate: 50 sps
- Services: OS/CS/SOL

**E5B Signal:**
- Data + Pilot
- BPSK modulation
- Rate: 10.23 Meps
- Rate: 250 sps
- Services: OS/CS/SOL

**E5P Signal:**
- BOCcos(10,5) modulation
- Rate: 5.115 Meps
- Rate: 1000 sps
- Services: PRS

**E6C Signal:**
- Data + Pilot
- BPSK modulation
- Rate: 5.115 Meps
- Rate: 1000 sps
- Services: CS

**L1P Signal:**
- BOCcos(15,2,5) modulation
- Rate: 1.023 Meps
- Rate: 250 sps
- Services: OS/CS/SOL

Source: GJU (2005)
Open Service (OS)

- For mass market users
- Global availability
- One or two frequencies usable
- No fees

<table>
<thead>
<tr>
<th></th>
<th>Single frequency</th>
<th>Dual frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal positioning</td>
<td>15 m</td>
<td>4 m</td>
</tr>
<tr>
<td>Vertical positioning</td>
<td>35 m</td>
<td>8 m</td>
</tr>
<tr>
<td>Velocity (95%)</td>
<td>0.5 m/s</td>
<td>0.2 m/s</td>
</tr>
<tr>
<td>Time (relative to UTC)</td>
<td>30 ns</td>
<td>30 ns</td>
</tr>
<tr>
<td>Availability (global)</td>
<td>99.5%</td>
<td>99.5%</td>
</tr>
</tbody>
</table>
Commercial Service (CS)

- For commercial market/users (upon registration)
- Same basic performance as Open Service
- Supplementary: guarantee of service (availability)
- User fees
- Controlled access to CS codes and NAV messages by encryption
Safety-of-Life Service (SoL)

- For Safety of Life market/users
- Same basic performance as Open Service
- Supplementary: integrity information
- User fees under discussion
- Controlled access to SoL codes and NAV messages by authentication (certified receivers)

<table>
<thead>
<tr>
<th></th>
<th>Single frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert limit (horizontal)</td>
<td>12 m</td>
</tr>
<tr>
<td>Alert limit (vertical)</td>
<td>20 m</td>
</tr>
<tr>
<td>Time to alert</td>
<td>6s</td>
</tr>
<tr>
<td>Integrity risk</td>
<td>$2 \cdot 10^{-7} / 150s$</td>
</tr>
<tr>
<td>Continuity over 15s</td>
<td>99.999%</td>
</tr>
</tbody>
</table>
Public Regulated Service (PRS)

- For public authorities (government, police, military, …)
- Same basic performance as Open Service
- Supplementary: integrity information + service guarantee ("PRS has it all")
- User fees under discussion
- Controlled access to PRS codes and NAV messages by encryption and authentication
Galileo Project Phases and Cost

<table>
<thead>
<tr>
<th>Year</th>
<th>IOV</th>
<th>FOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Development & Validation
- 1.1 b€
- 2 test satellites, 4 operational satellites, ground infrastructure

### Deployment
- 2.3 b€
- 26 operational satellites, ground infrastructure

### Ops & Maintenance
- 220 m€/year
- Routine operations, replenishment

**ESA, GSA**

**Concess., ESA**

**ESA / Concessionaire ?**

Same cost as for other infrastructure projects:
- Tunnel for TGV train Lyon-Torino
- 250 km new highway
GIOVE-A

■ First Galileo Test Satellite
  ■ 600 kg, 700 W
  ■ Body 1.3x1.6x1.8 m³; 3.5m² solar panels
  ■ Built by SSTL UK (30 Mio€)

■ Purpose
  ■ Frequency filing
  ■ Navigation signal assessment

■ Activities
  ■ Launched 28 Dec. 2005
  ■ First signals 12 Jan. 2006
  ■ Orbit determination and clock validation started in May/June 2006
GIOVE-B

- Second Galileo Test Satellite
  - 523 kg, 940 W
  - Body 1x1x2.4 m³; 3m² solar panels
  - Built by Galileo Industries (130 Mio€)

- Purpose
  - Technology verification
  - MEO radiation assessment

- Activities
  - Launched 26 April 2008
  - First signals 7 May 2008
  - Experimentation program started in June/July 2008
GIOVE Launch Preparations

Source: ESA
GIOVE User Equipment

- GIOVE Experimental Sensor Station (GESS)
- GeNeRx Test Receiver (Septentrio)
- NovAtel L1/E5a card
Summary

- Increasing demand for navigation related tasks and worldwide services
  - Mass market (car and mobile phone)
  - Safety critical navigation (aeronautics, safety-of-life)
- Galileo will provide new powerful signals and services
  - Three frequencies, large bandwidths
  - More and better codes
  - Increased data rates
- Galileo is on its way
  - GIOVE-A and GIOVE-B launched
  - IOV satellites launch due Dec 2010
  - FOC contracts under negotiation