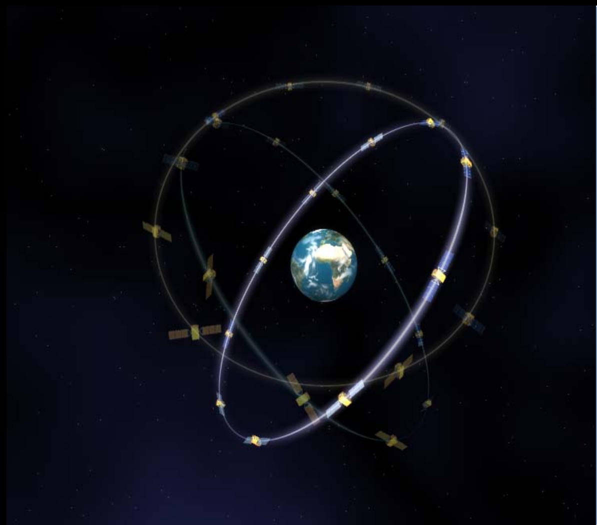
Galileo Overview



Franco EMMA
GALILEO Programme Representative in China
EUROPEAN SPACE AGENCY

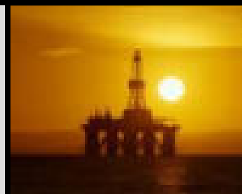
Presentation Outline

- Part 1
  - Services and Performance Summary
  - Signal Baseline
- Part 2
  - IOV Phase
  - System Architecture and Components
  - GSTBV1/GSTBV2
- Conclusions

Part 1

Services Performance and Signal Baseline

Galileo Services

Navigation	Open Access	Free to air; Mass market; Simple positioning and timing	
	Commercial	Encrypted; Guaranteed service	
	Safety of Life	Open Service + Integrity and Authentication of signal	
	Public Regulated	Encrypted; Integrity; Continuous availability	
SAR	Search and Rescue	Near real-time; Precise; Return link feasible	

Performance Summary

- **H/V Position Accuracy:**
  - **4/8 m World-wide without augmentations (typical)**
  - **1 cm based on wide area corrections (TCAR)**
- **Integrity:**
  - **ICAO (aviation) standard**
  - **Time to Alert : 6 sec**
- **Timing:**
  - **World-wide Time dissemination**
  - **30 ns Synchronised to UTC**

GALILEO Signals

- **Each Galileo Satellite will broadcast 6 RHCP navigation signals denoted:**
  - L1F for OS and SOL
  - L1P for governmental use
  - E6C for CS
  - E6P for governmental use
  - E5a for OS
  - E5b for OS, CS and SOL
- **The signals will occupy three separate frequency bands from 1.1 GHz to 1.5 GHz.**
- **Signals will overlay in two frequency bands with GPS.**

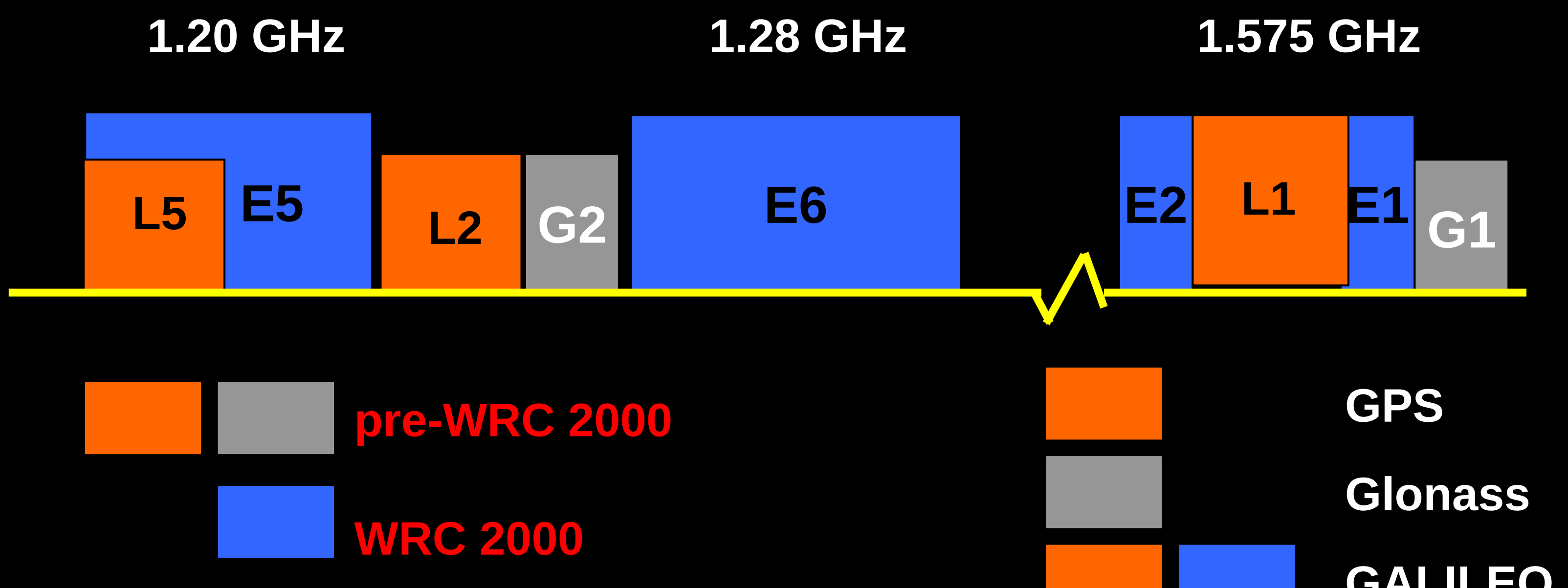
SIS Definition

- ☞ **Frequency Plan**
- ☞ **Signal Baseline Overview**

Frequency Spectrum

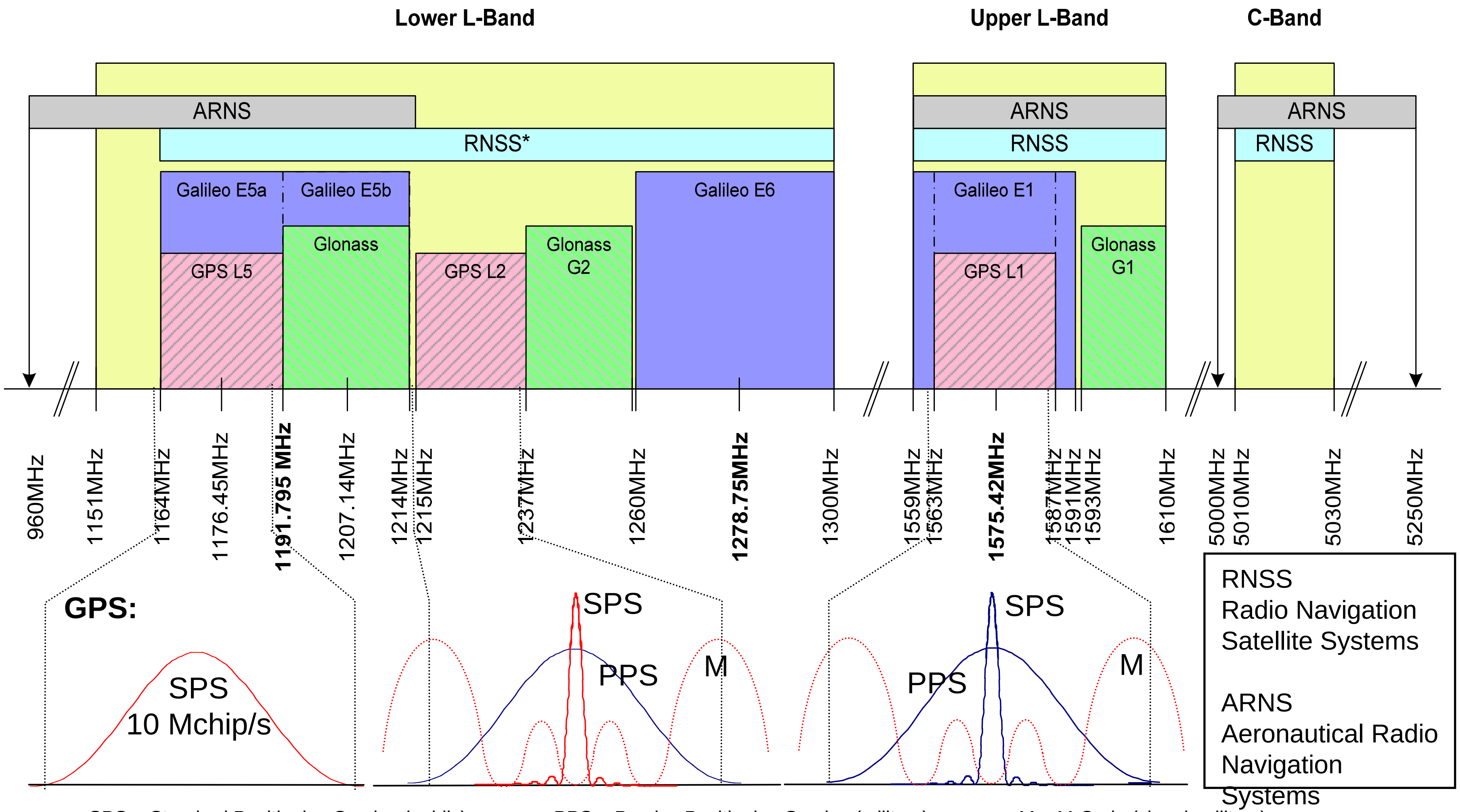
GPS / GLONASS / GALILEO

Compatibility and Interoperability



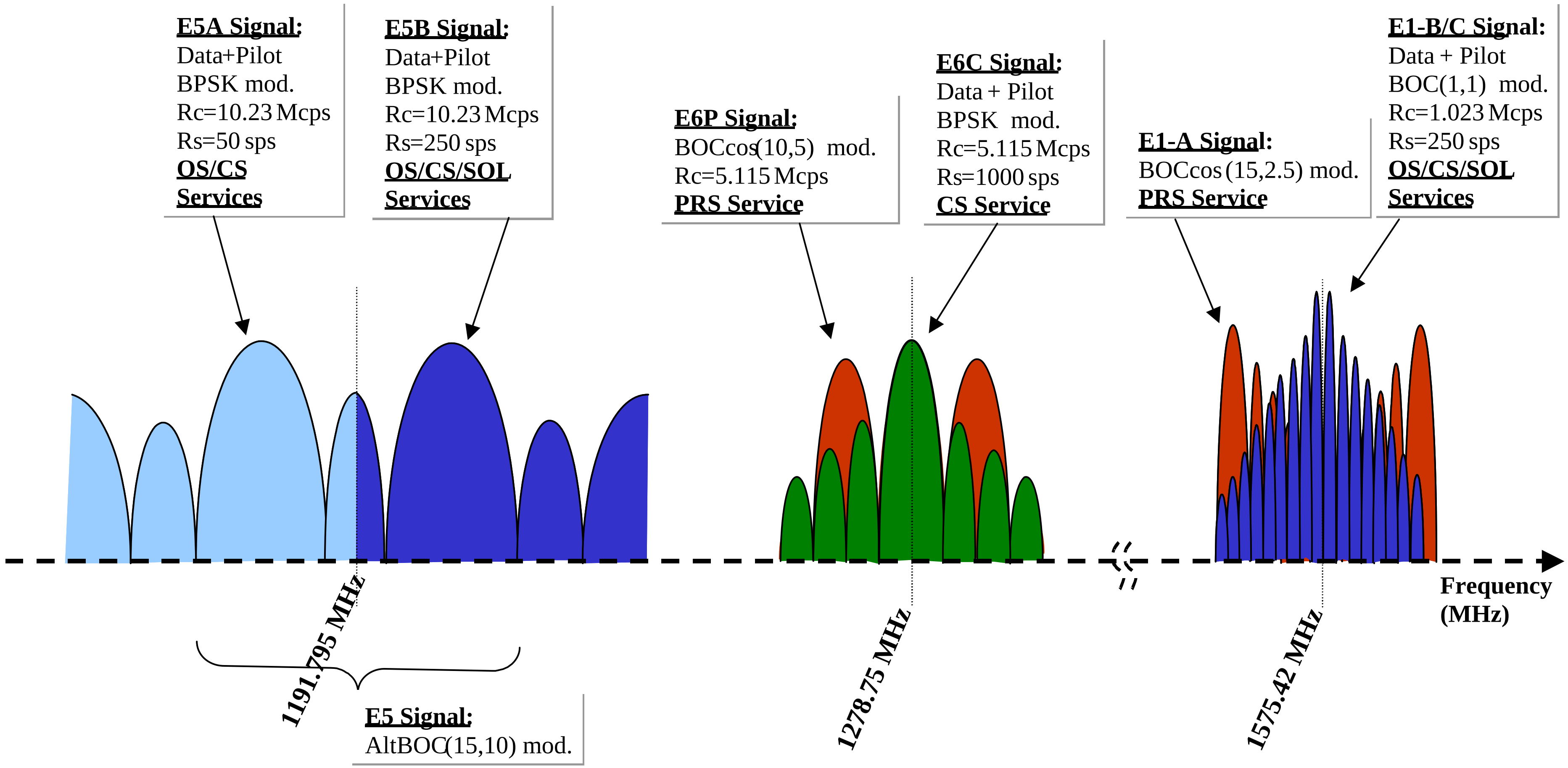
World Radio Conference allocations

Galileo Frequency Plan Overview



SPS = Standard Positioning Service (public) PPS = Precise Positioning Service (military) M = M-Code (signal, military)

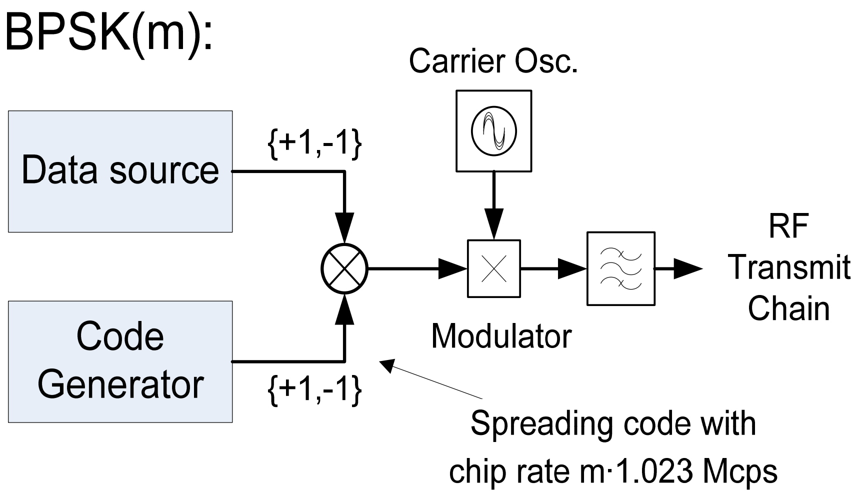
Galileo Signals Baseline Overview

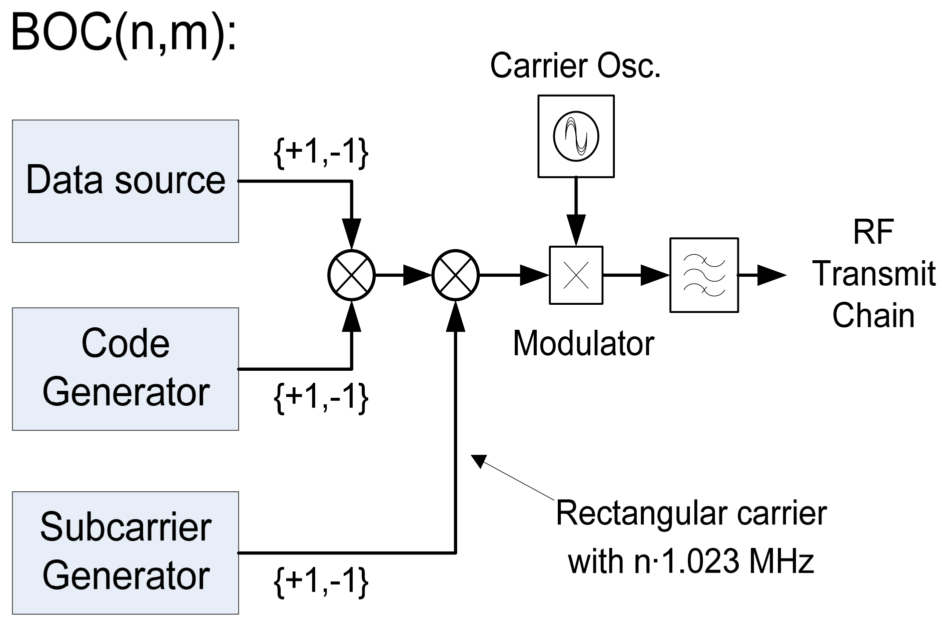


Navigation signal and channel are not the same

BOC Modulation Scheme 1/

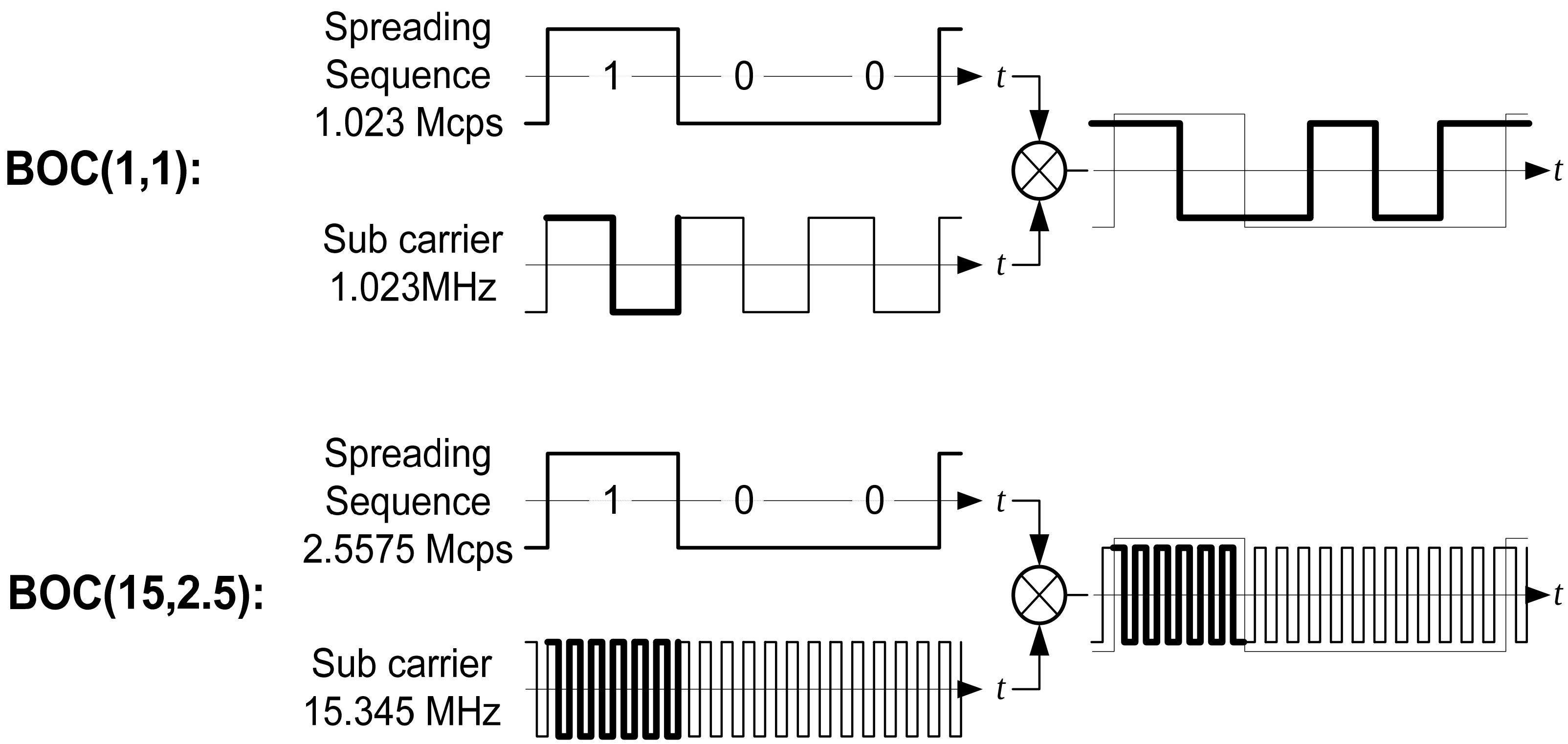
- BOC = Binary Offset Carrier: BOC(n,m)
  - Spreading code at m·1.023Mcps
  - Modulated on rectangular subcarrier at n·1.023MHz
    - Line spectrum at odd multiples of n·1.023MHz





BOC Modulation Scheme 2/

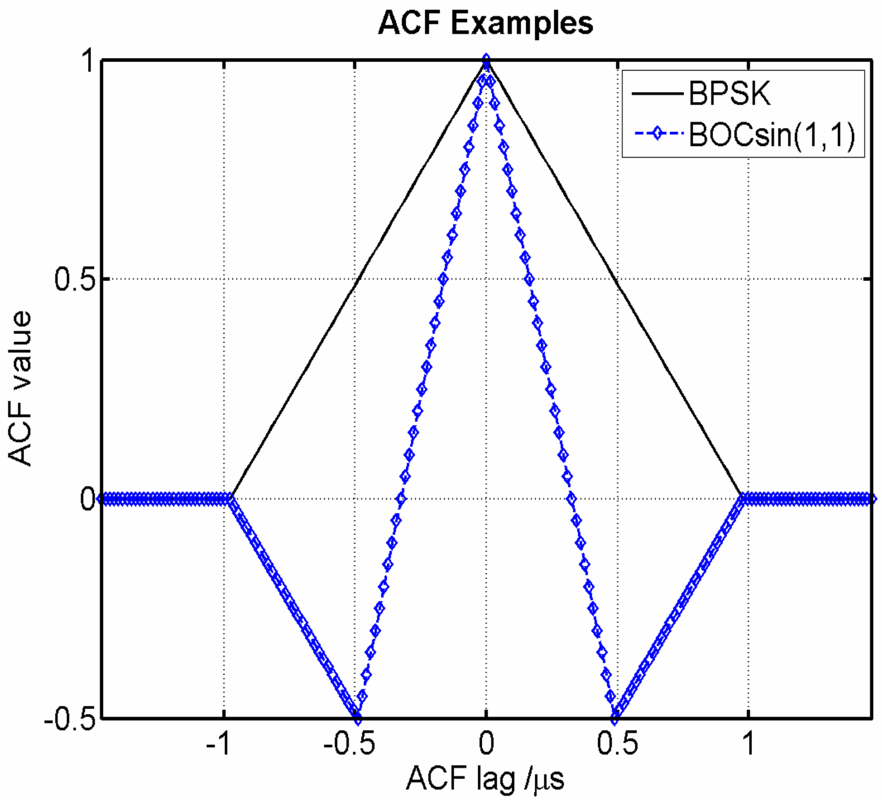
- **Resulting signal is still binary**

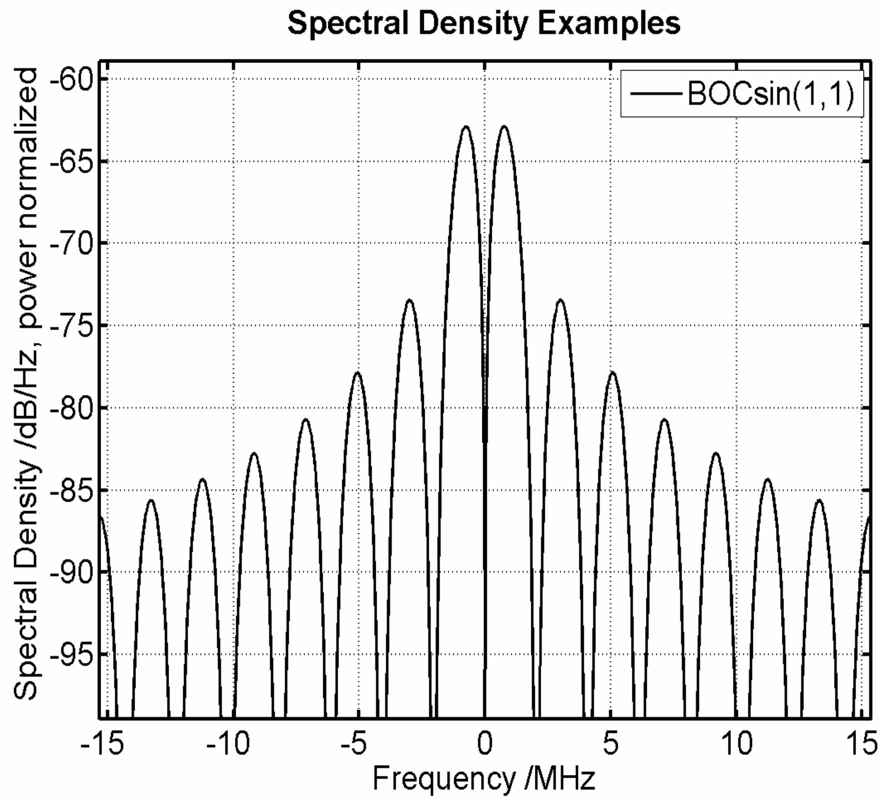


  - Autocorrelation oscillates
  - BPSK spectrum imaged by subcarrier spectrum

BOC Modulation Scheme 3/

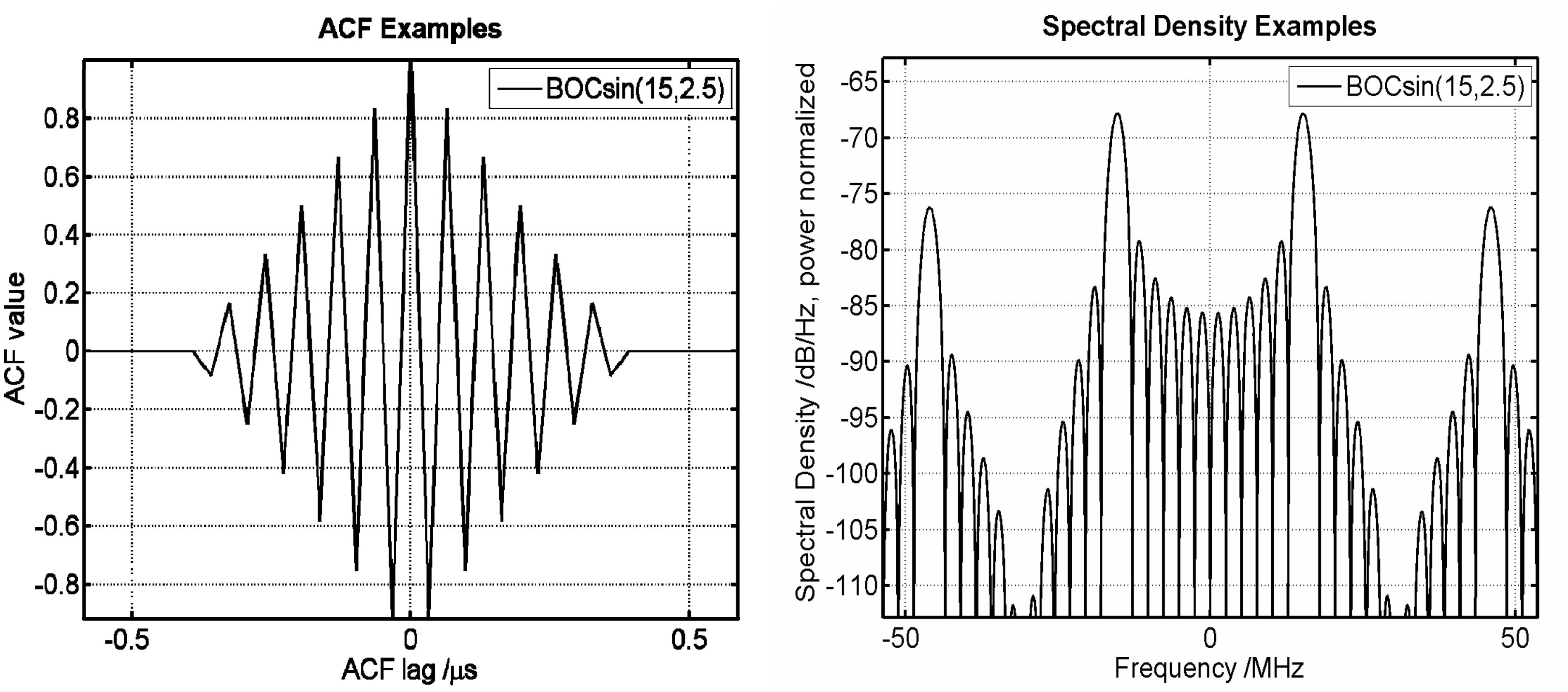
- BOC(1,1) Example (not band limited)
  - Only slightly more complex than BPSK(1)





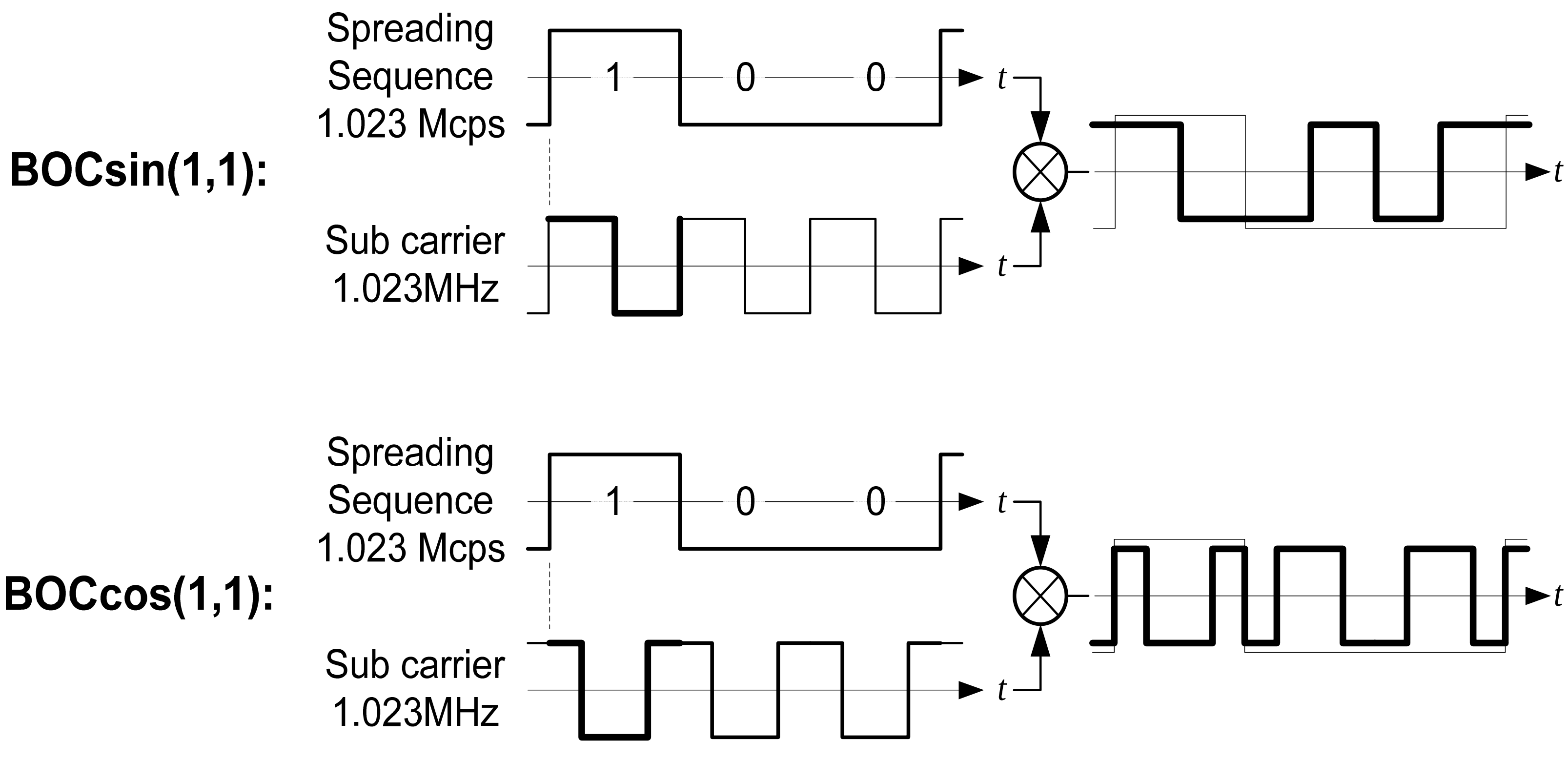
BOC Modulation Scheme 4/

- BOC(15,2.5) Example (not band limited)
  - High performance, but
  - already the ideal ACF is complex: Difficult to track



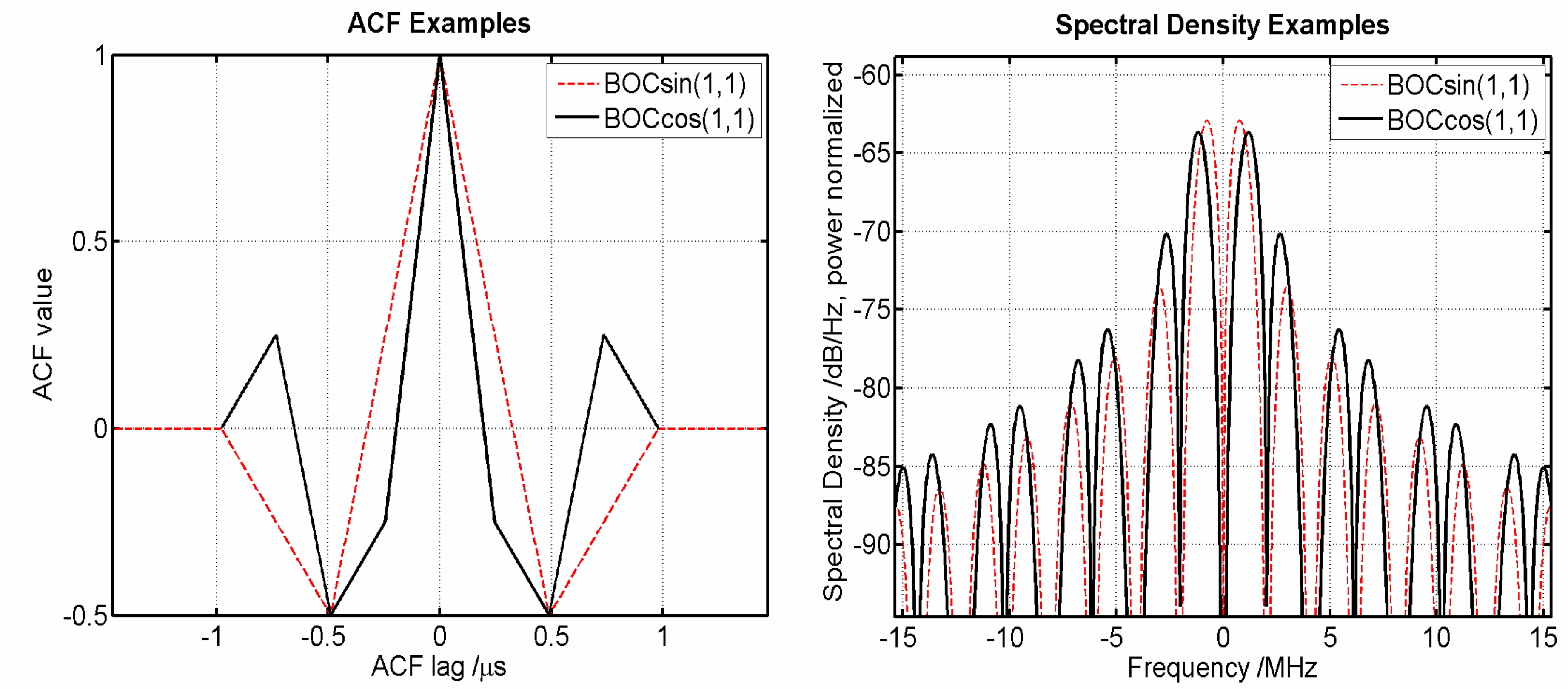
BOC Modulation Scheme 5/

- Additional Degree of Freedom: Subcarrier phase
  - Determined by relation to spreading code transitions
  - Two realizations: BOCsin (BOC), and BOCcos (BOCc)



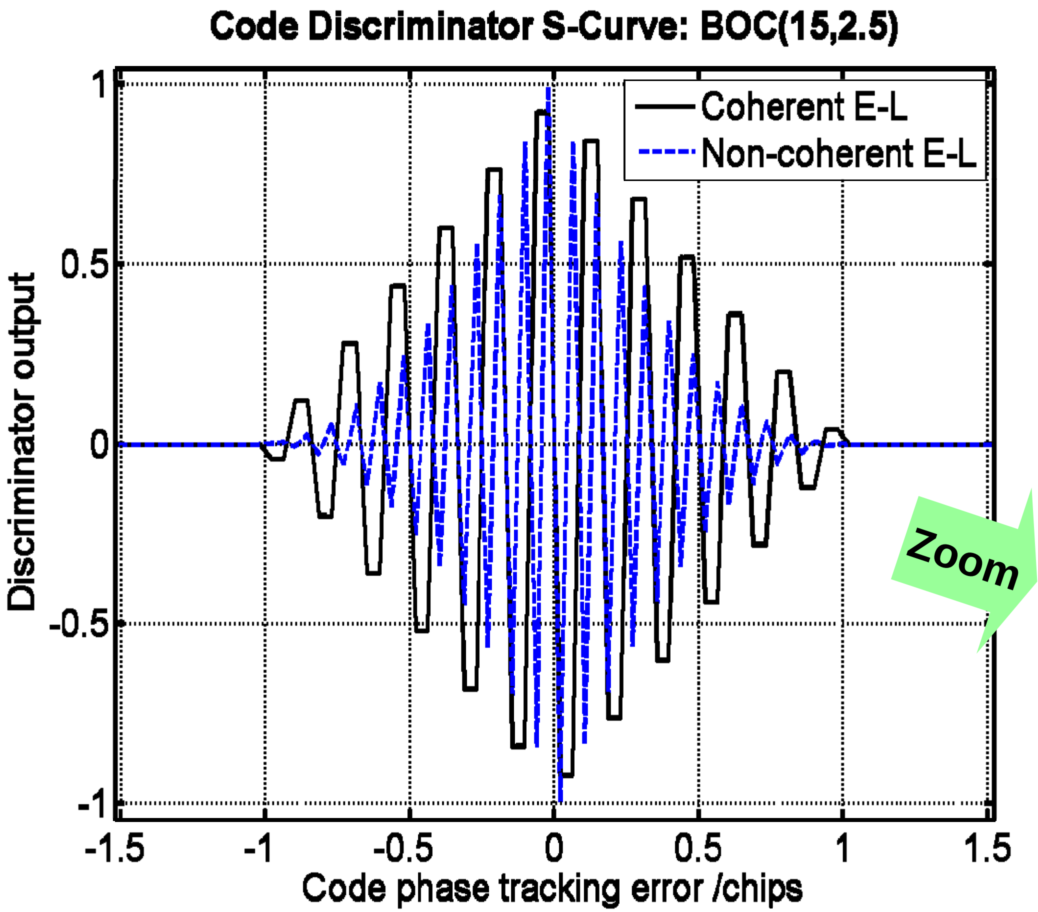
BOC Modulation Scheme 6/

- Example: BOCcos(1,1) compared to BOCsin(1,1)
  - BOCcos: Energy shifted to higher frequencies

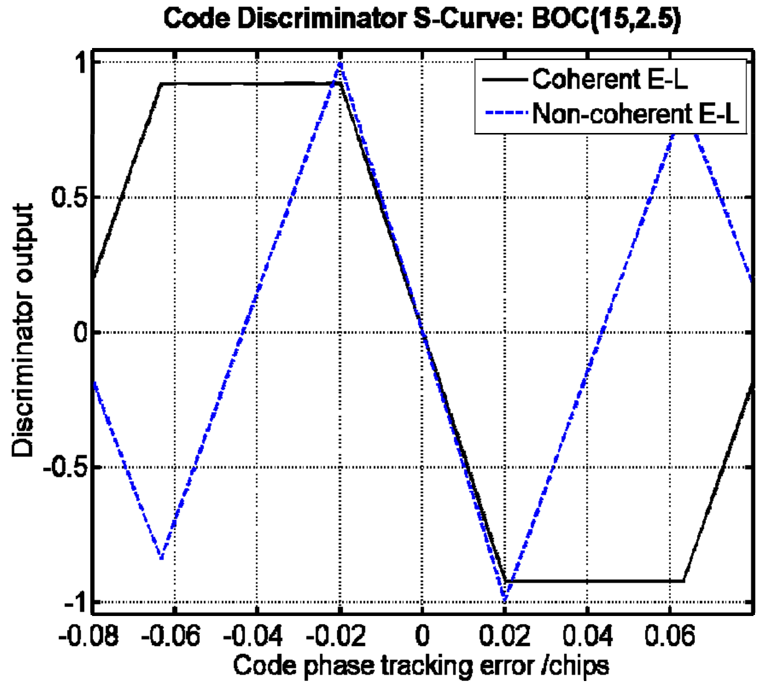


BOC Modulation Scheme 7/

- S-Curve Example for BOC(15,2.5)



- **Ambiguous points of operation**
- **Will require support algorithms to find and maintain centre point**



Summary of Galileo Signal Baseline

- Signal designed to carry different components
  - Very wide band in some cases in excess of 70 MHz
  - Protection against multipath
- Interplex multiplexing scheme for constant envelop signal
- BOC cos modulations increase compatibility of signals with existing navigation signals
- Three carries frequencies, civil users may benefit from the use of two signals. Increased accuracy achievable
- Need to design receivers with proper algorithms for tracking of BOC signals

Galileo

where are we now?

Galileo is in its IOV Phase

- Contract signed on 21th December 2004
- Development of all space, ground and user components, including their interfaces, prior to full system deployment
- Verification of Performance
- Verification of Operational procedures
- Reduction of deployment risks

Development Heritage

- **Definition Phase started in 2000 and was completed in 2003.**
- **Critical technology developments completed*:***
  - Atomic clocks, satellite navigation antennas, signal generator, receivers,
  - Ground segment algorithms (high precision orbit determination, integrity)
- **Pilot System under development:**
  - GSTB-V1 completed.
  - GSTBV2 ongoing:
    - First GSTB-V2/A satellite launched on 28th December 2005. First signal emission and acquisition on 12th of January 2006.
    - GSTBV2B due for launch in 2007

Experimental Ground Segment (GSTB-v1)

- **Galileo performance requirements demand**
  - **Very precise satellite orbit prediction capability (65cm)**
  - **Very Precise Satellite clock Synchronisation (1.5ns over 100 minutes}**
  - **Low integrity risk in detecting system failures (satellite or ground)**
  - **Overall high availability (99.5%)**

This is one order of magnitude better than today's systems.

Requires advanced ground segment processing algorithms.

Algorithms have been experimented today with GSTB-v1 using GPS signals and a dedicated network of GPS ground stations.

GSTB-V1 Sensor Stations Network

The Galileo network of reference stations will also be global.

GSTB-V2 Pilot System

- **First European satellite placed in a medium-Earth orbit.**
- **Frequency filings.**
- **Test case for a new generation of navigation signals**
- **Will carry the most stable clock (H-maser) ever flown in space. (for GIOVE B)**

GSTB-V2 A Satellite

Prime Contractor Surrey Satellite Technology Ltd. UK

Lift-off mass: 450 kg

Power demand: 660 W

Stowed Dimensions: 1.3 m x 1.8 m x 1.6 m

The GSTB-v2-A satellite will:

transmit Galileo signals from one of the orbits to be used by the constellation.
test various critical technologies, including the rubidium atomic clock and the signal generator.
measure the physical parameters of the orbit and the particular environment in which the future constellation is to operate.

GSTB-V2 A Satellite - Status

GSTB-v2 A satellite in the integration hall.
The antenna is on the top face

Satellite Qualification campaign started in July 2005 at ESTEC

Environmental Test Campaign was initiated in August 2005

Passed the thermal balance/ vacuum and vibration tests at ESTEC

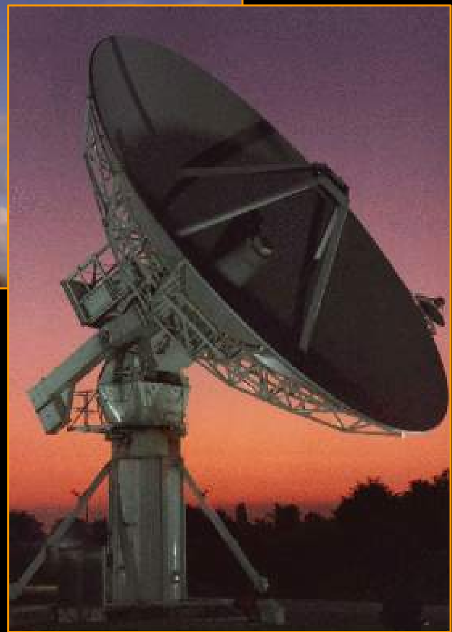
Mission analysis performed

Launch 28th December 2005

GSTB-V2A Ground Segment

Chilbolton Observatory

25m dish



RAL Facilities, Oxford

12m S-Band dish

Ground control:

Fully in line with the previous SSTL mission

4 Ground stations

- SSTL
- Kuala Lumpur
- RAL
- Redu

In Orbit Test

Under control for the technical implementation

Ground stations

- RAL Chilbolton Observatory
- RAL Oxford

GSTB-v2 B Satellite

Prime Contractor Galileo Industries

Lift-off mass 523 kg

Power demand 940 W

Stowed Dimensions: 1 m x 1 m x 2.4 m

The GSTB-v2-B satellite will:

- **transmit the Galileo signals from one of the orbits to be used by the constellation.**
- **test various critical technologies, including the rubidium atomic clock, the passive hydrogen maser clock and the signal generator.**
- **measure the physical parameters of the orbit and the particular environment in which the future constellation is to operate.**

GSTB-V2-B Ground Segment

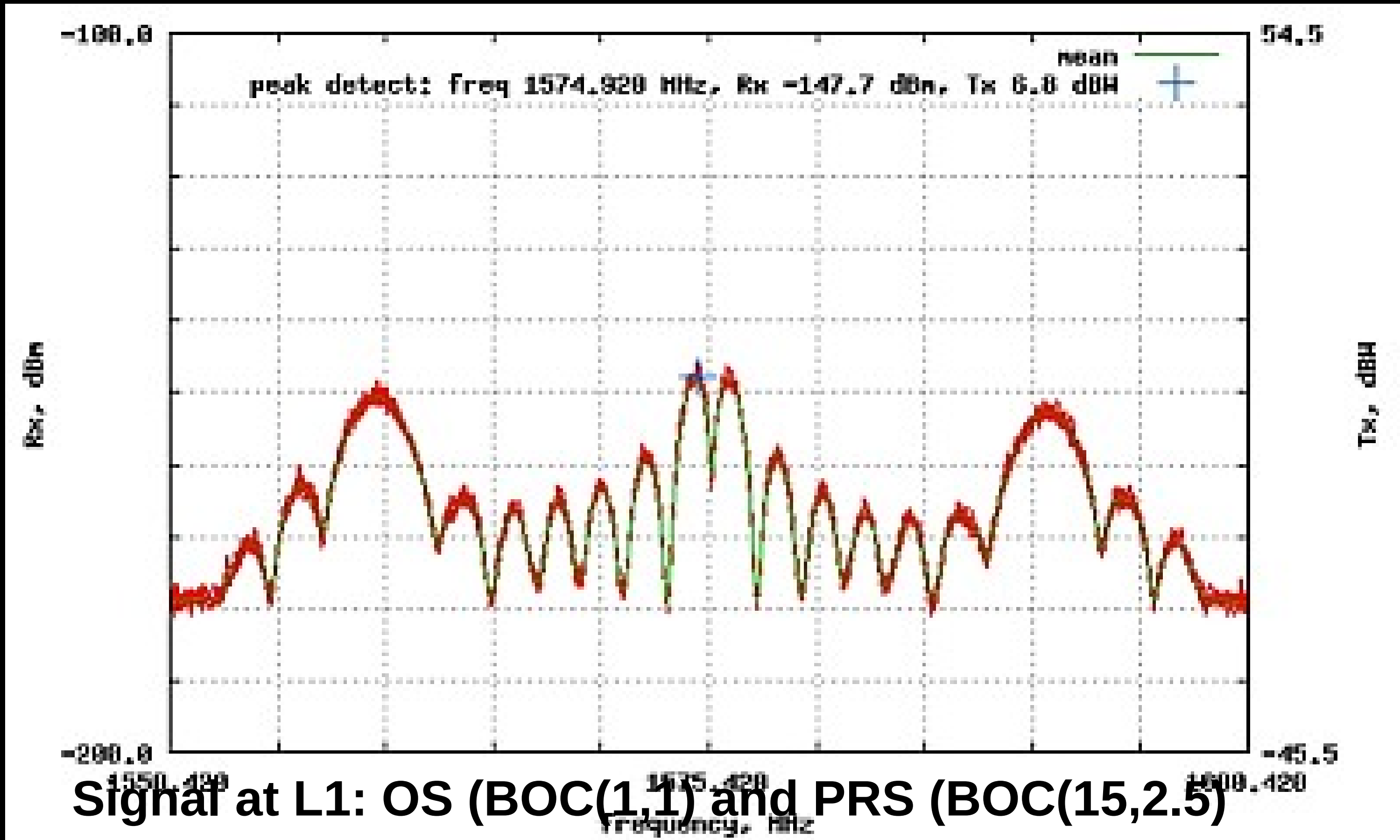
Control Centre in Fucino (Italy)

Communications Network:

- **S-Band TT&C Network, with a telecommand uplink data rate of 2000 bps and a telemetry downlink data rate of 31250 bps.**
- **For LEOP: Dongara (Australia), Kiruna (Sweden), Santiago (Chile) and Fucino (Italy)**
- **For commissioning and routine operations: Kiruna (Sweden) & Fucino (Italy)**
- **Launch in 2007**

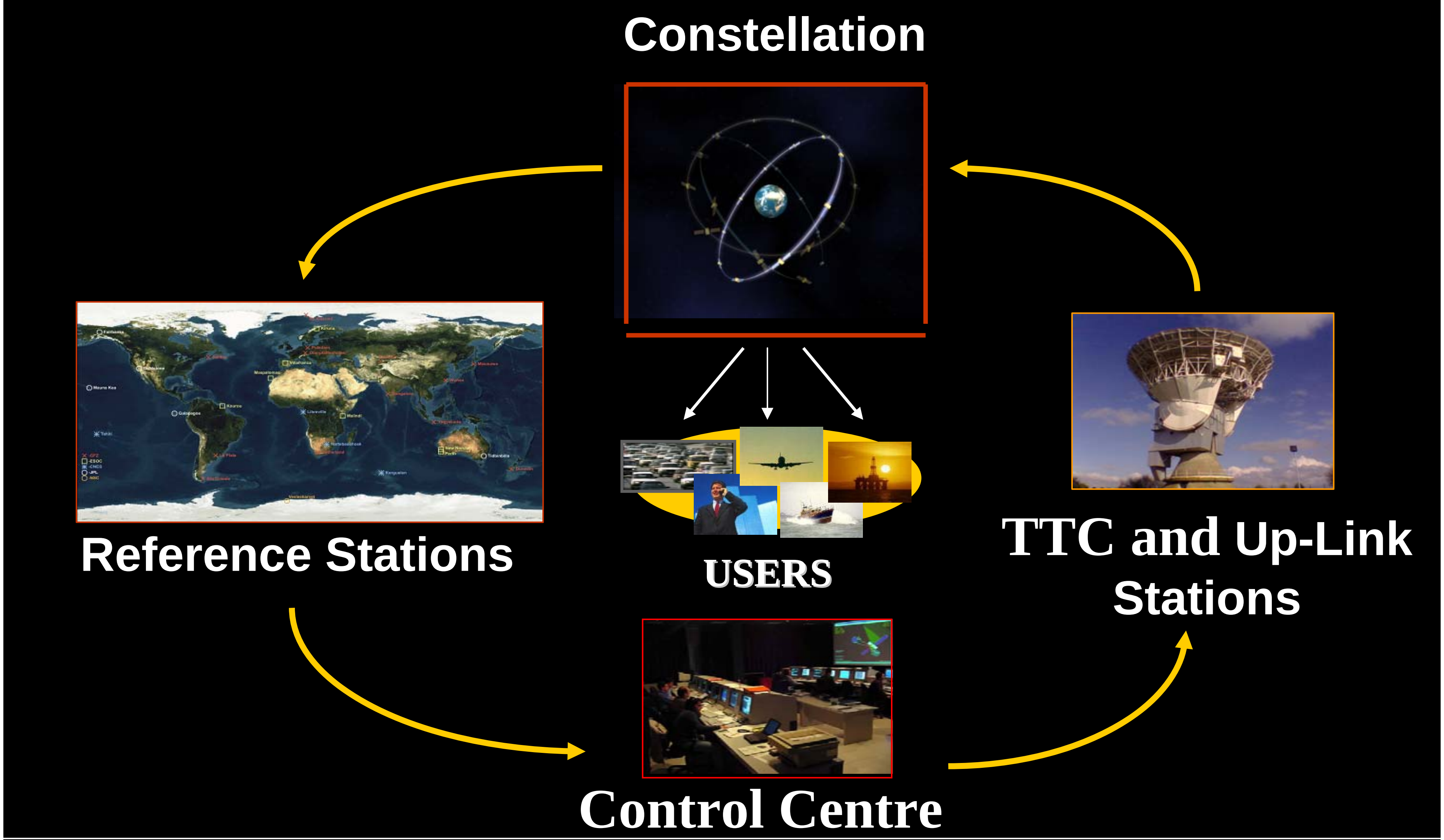
In-orbit testing facility in Redu, Belgium.

GIOVE-A Signal



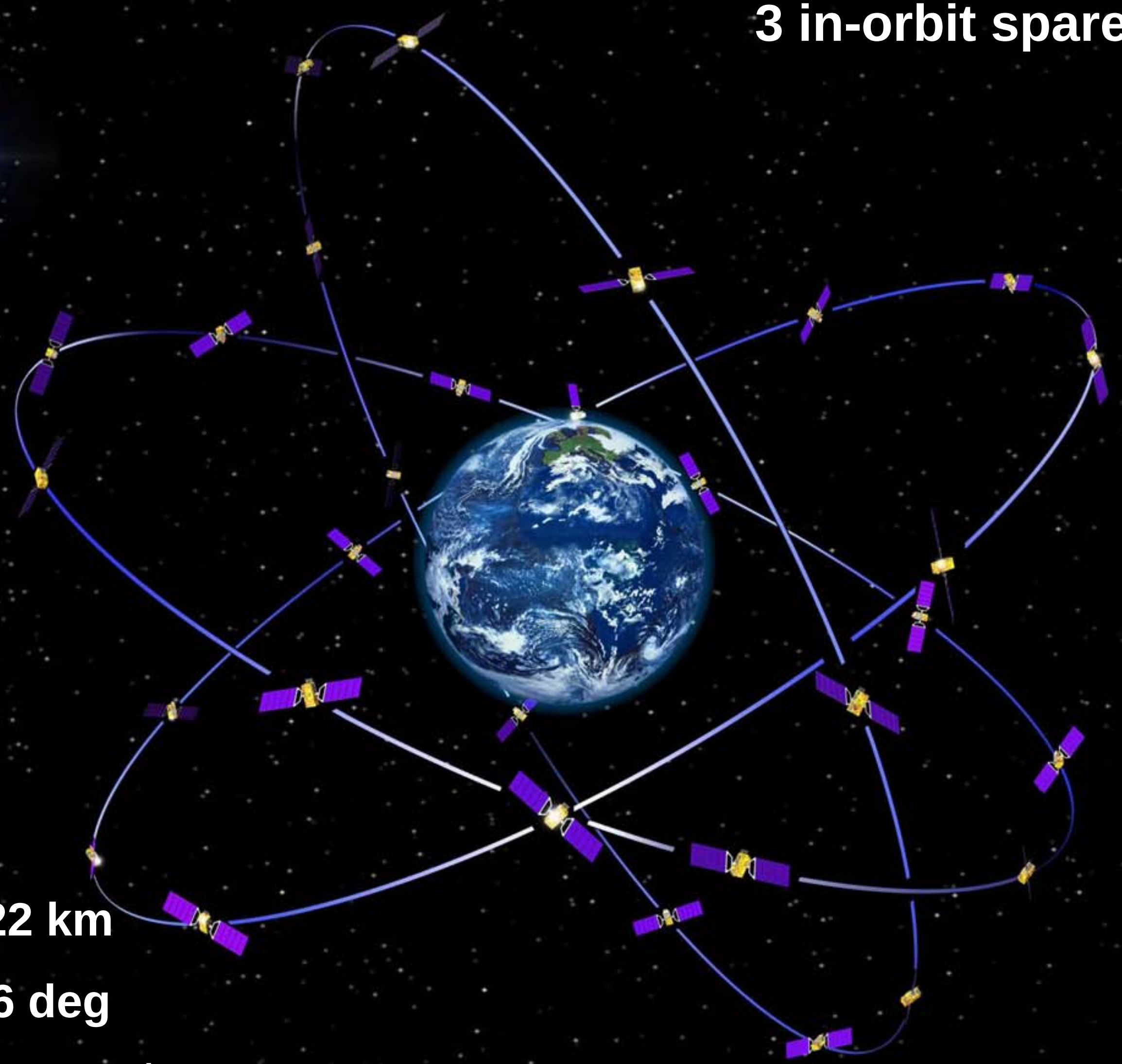
Signal at L1: OS (BOC(1,1) and PRS (BOC(15,2.5)

GALILEO Architecture



Walker 27/3/1

3 in-orbit spares (1/plane)

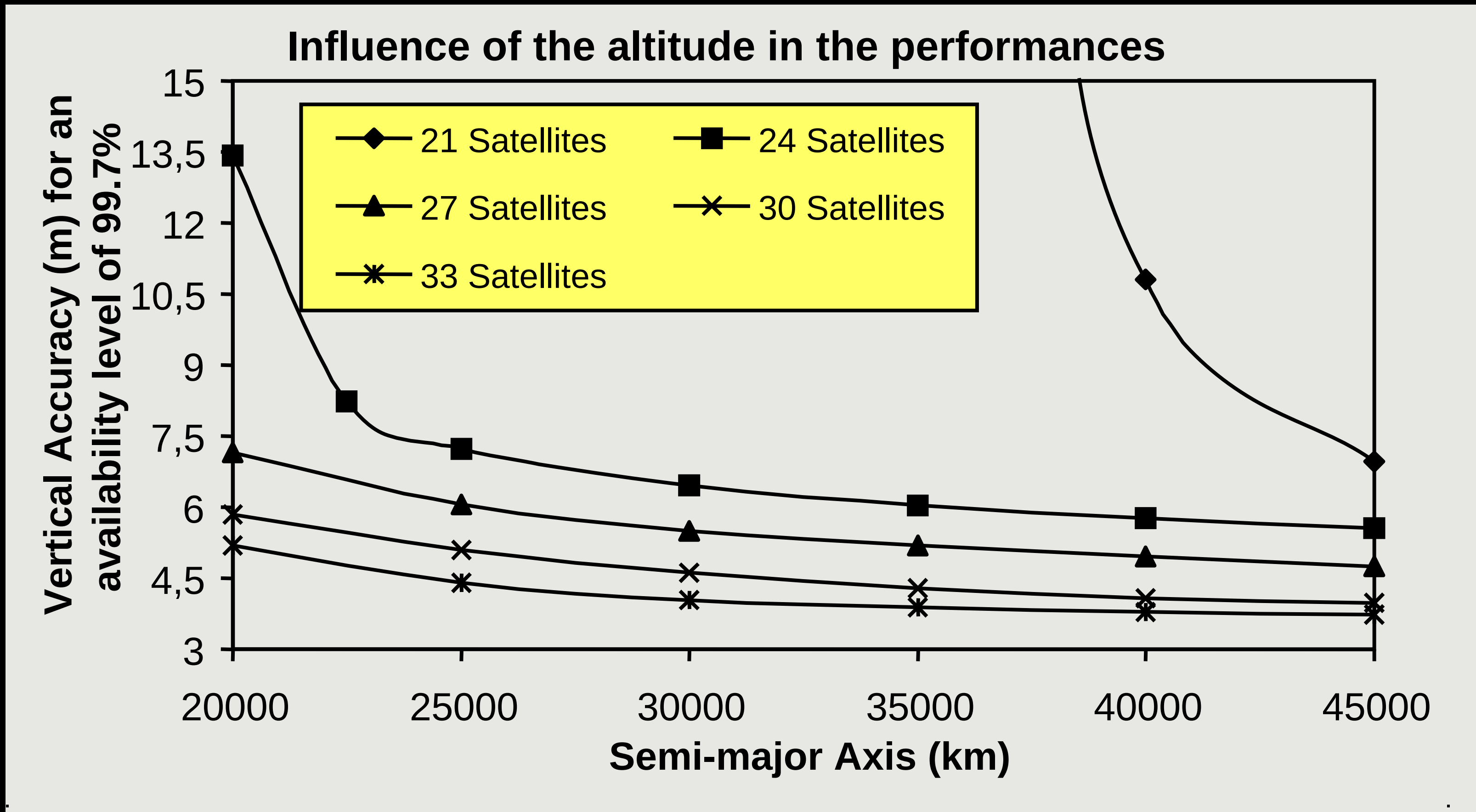


Altitude 23222 km

Inclination 56 deg

Period: 14 hr 22 min
Ground track repeat about 10 days

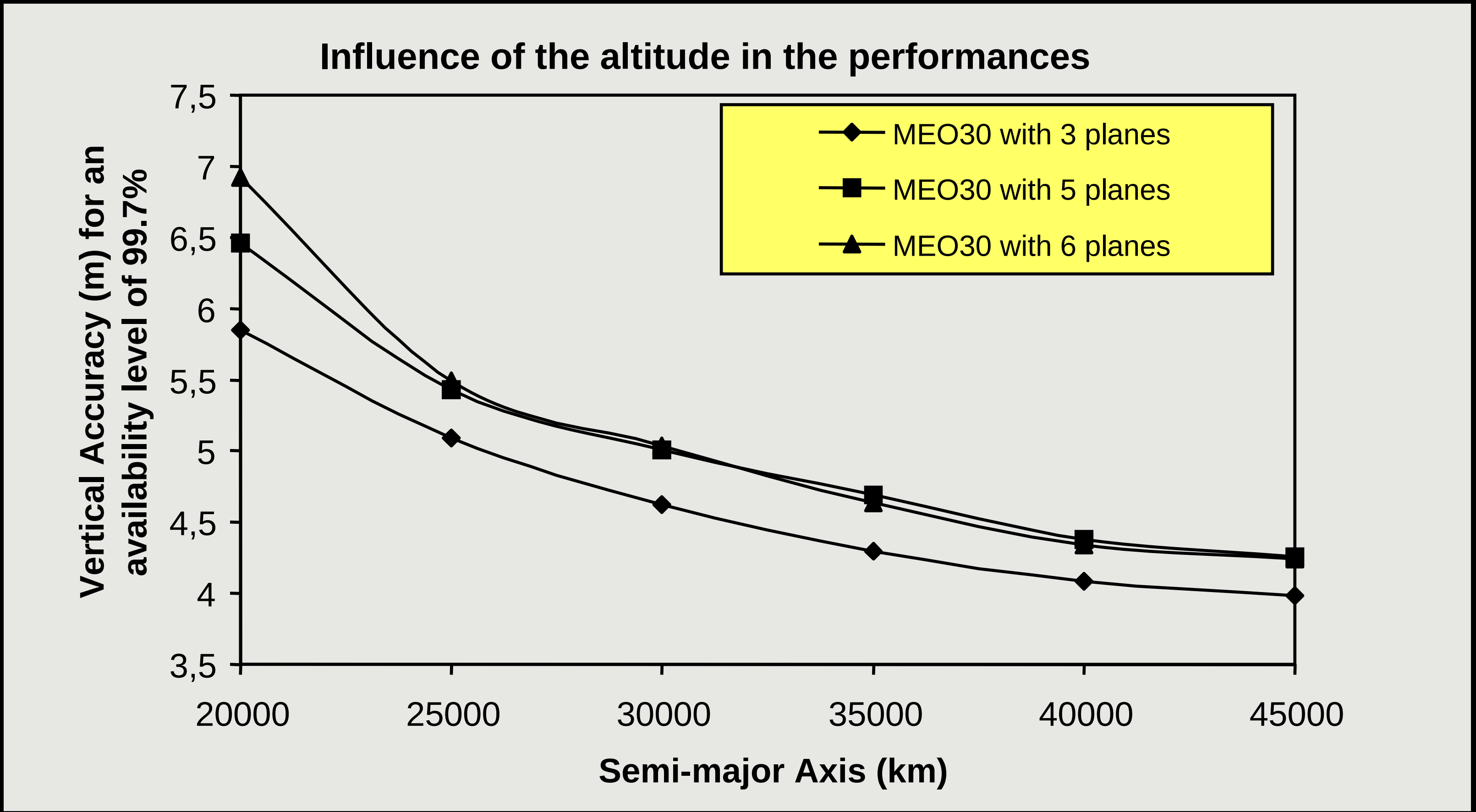
Orbit Altitude & No. of Satellites wrt Vertical Accuracy



For altitudes above 23000 Km no major benefit with more than 30 satellites

Minimum number of satellites is 24

Orbit Altitude & No. of Planes wrt Vertical Acuracy



3-plane constellations are the best for this range of altitude and # of satellites

Low number of planes allow lower deployment costs and easier maintenance and replenishment strategies

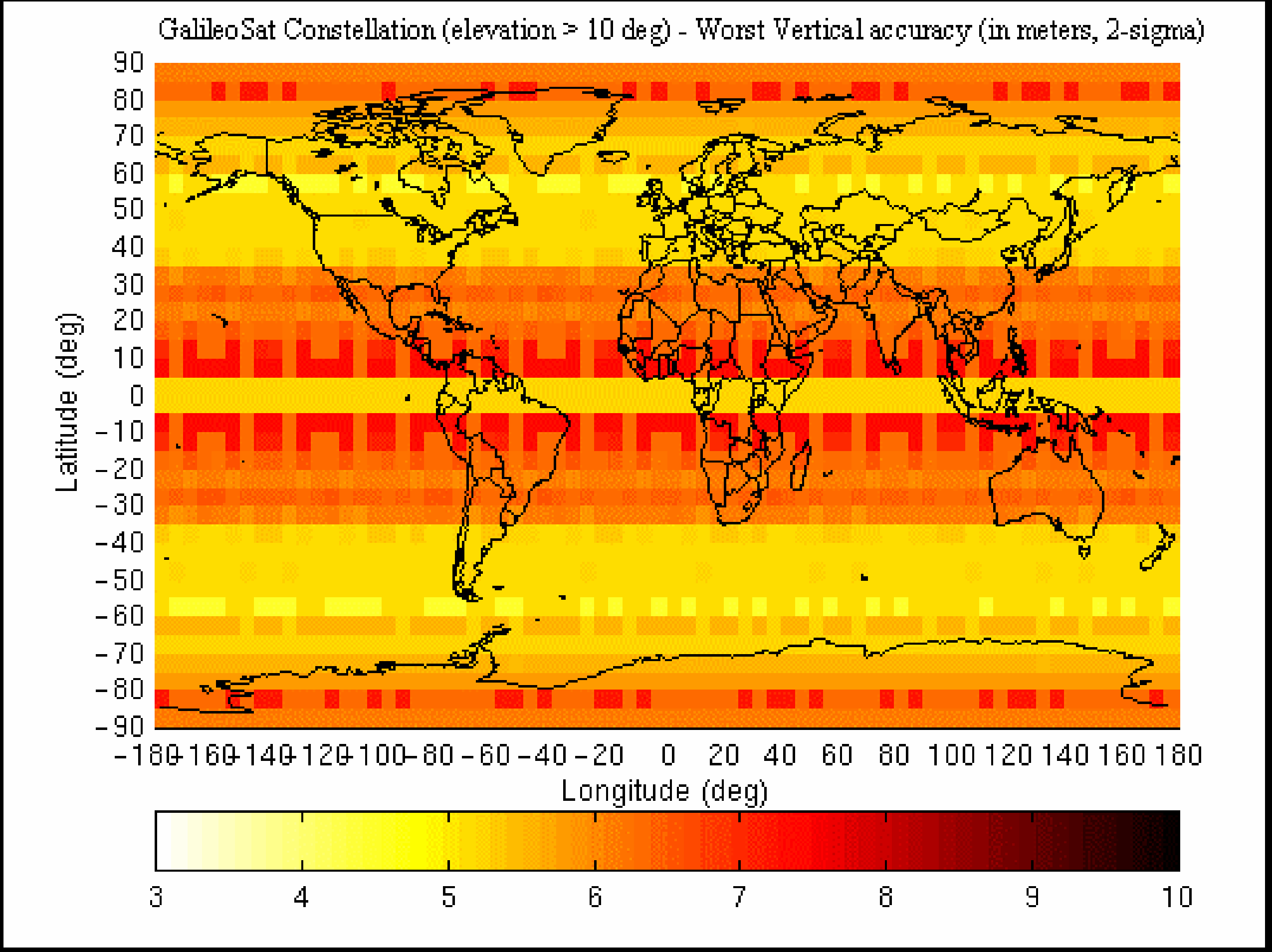
Galileo Orbits Summary

- Galileo foresees more satellites and at a higher altitude. This leads to a better service for users with obstructed field of view.

- Galileo constellations uses 3 planes wrt 6 planes for GPS. This leads to lower operational costs. GPS is now considering to move to a 3 plane constellation in conjunction with an increase in the number of satellites.

- Galileo altitude chosen to produce an orbit non-resonant with the gravity field of the Earth. Same concept than in GLONASS. This leads to lower operational burden due to minimization of need for maneuvers. GPS makes about 2 maneuvers per year per satellite.

Vertical Accuracy with Complete Constellation (27 SVs)



Better than 7.5 m (95%) anywhere in the world

Between 4-6 meter (95%) at European latitudes

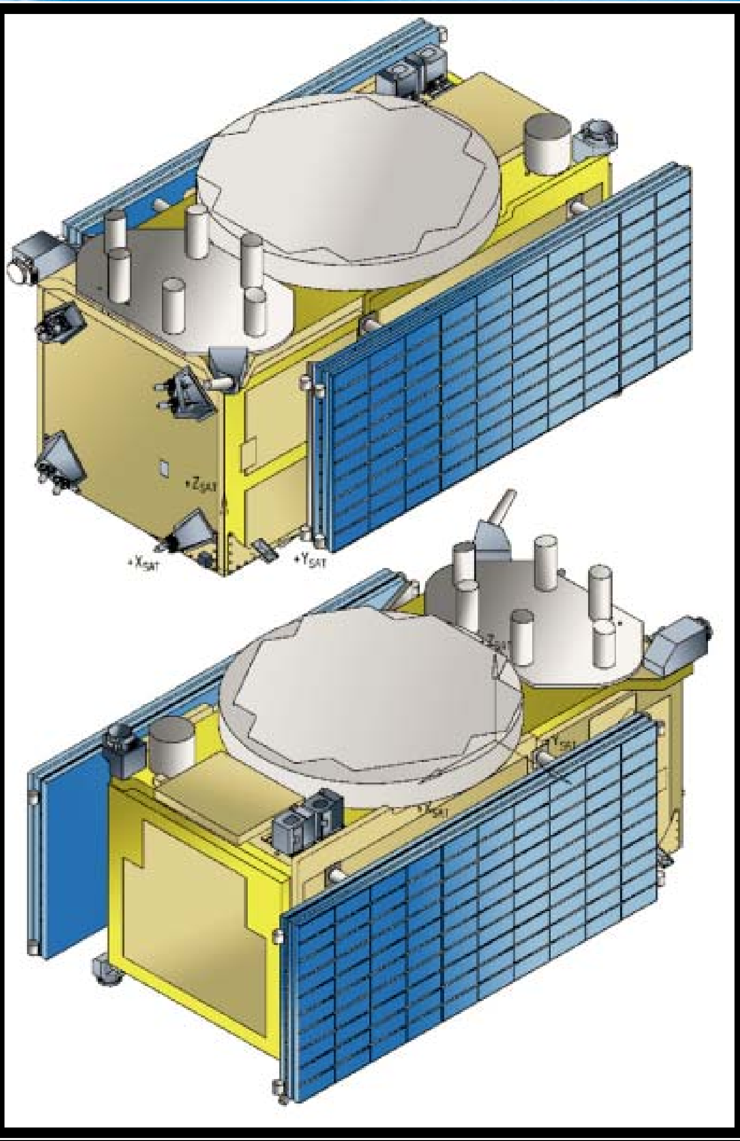
GALILEO Satellite

Dimensions:

2.7 x 1.2 x 1.1 m^3

Overall Spacecraft:

730 Kg / 1.8 kW



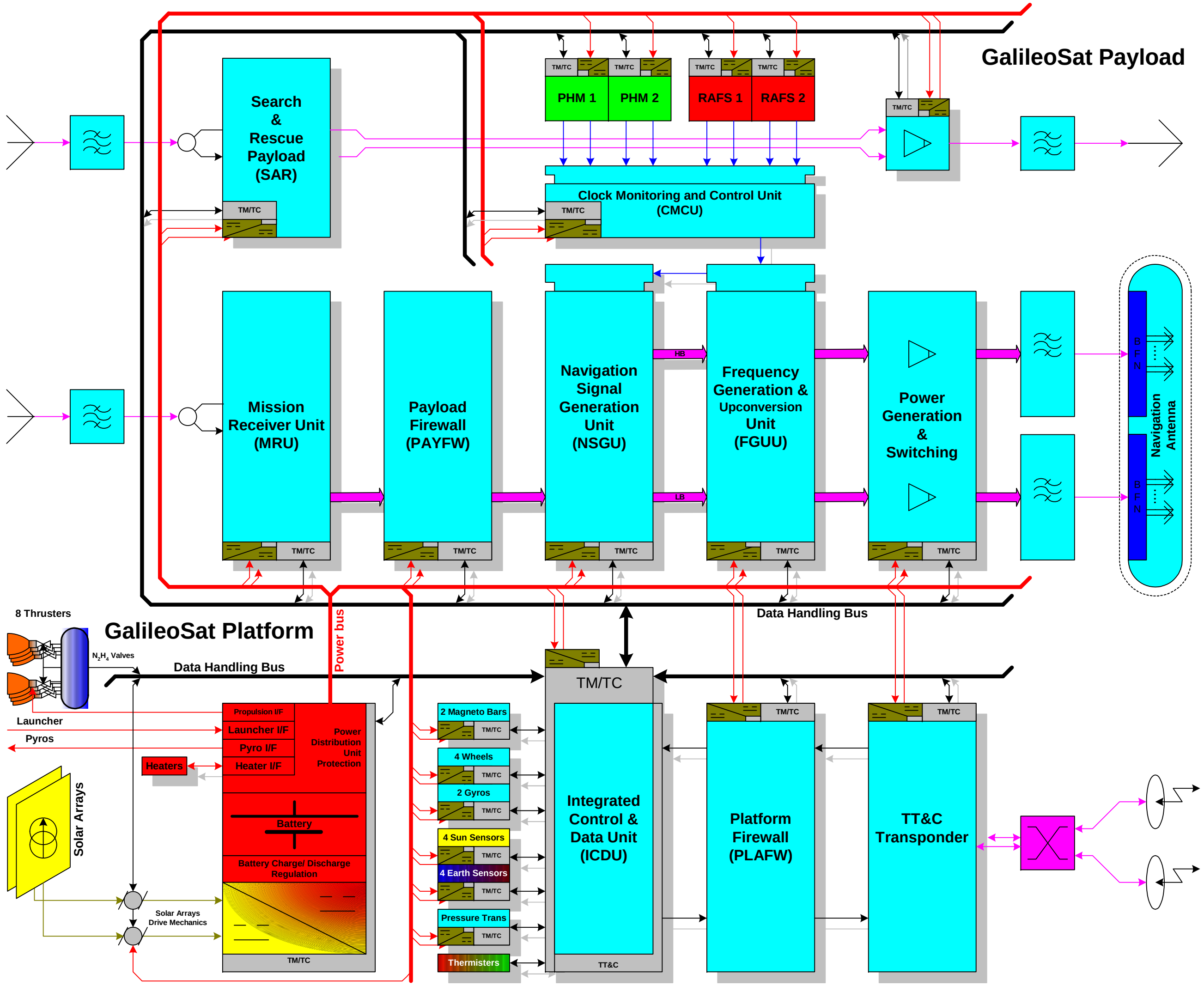
Navigation payload

140 Kg / 900 W

SAR transponder:

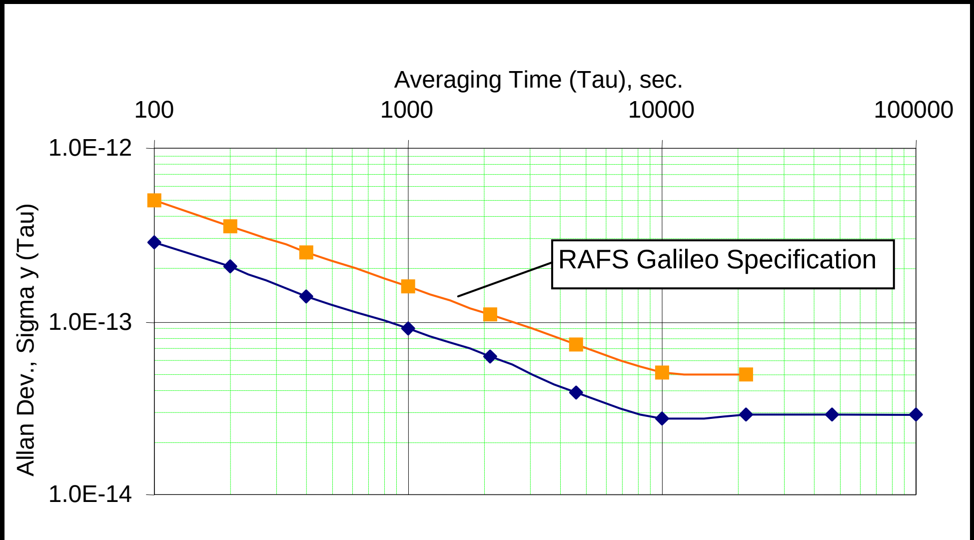
appr. 9 Kg/45W

Galileo Payload



Rubidium Atomic Clock

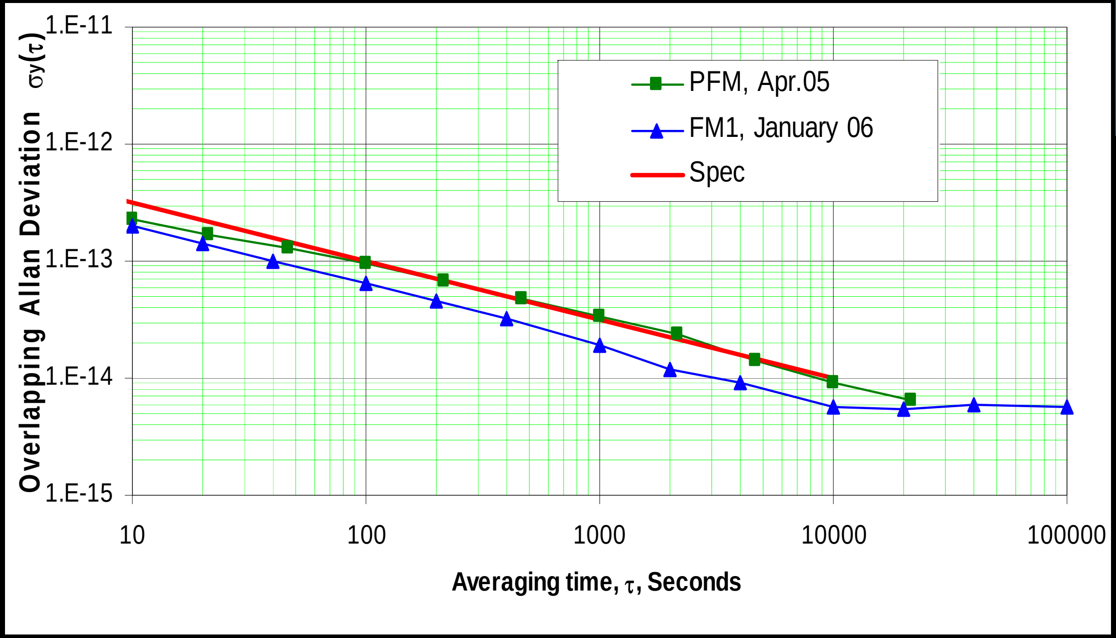
weight and volume: 3.3 Kgs and 2.4 l.
time stability: better than 5 nsec per day



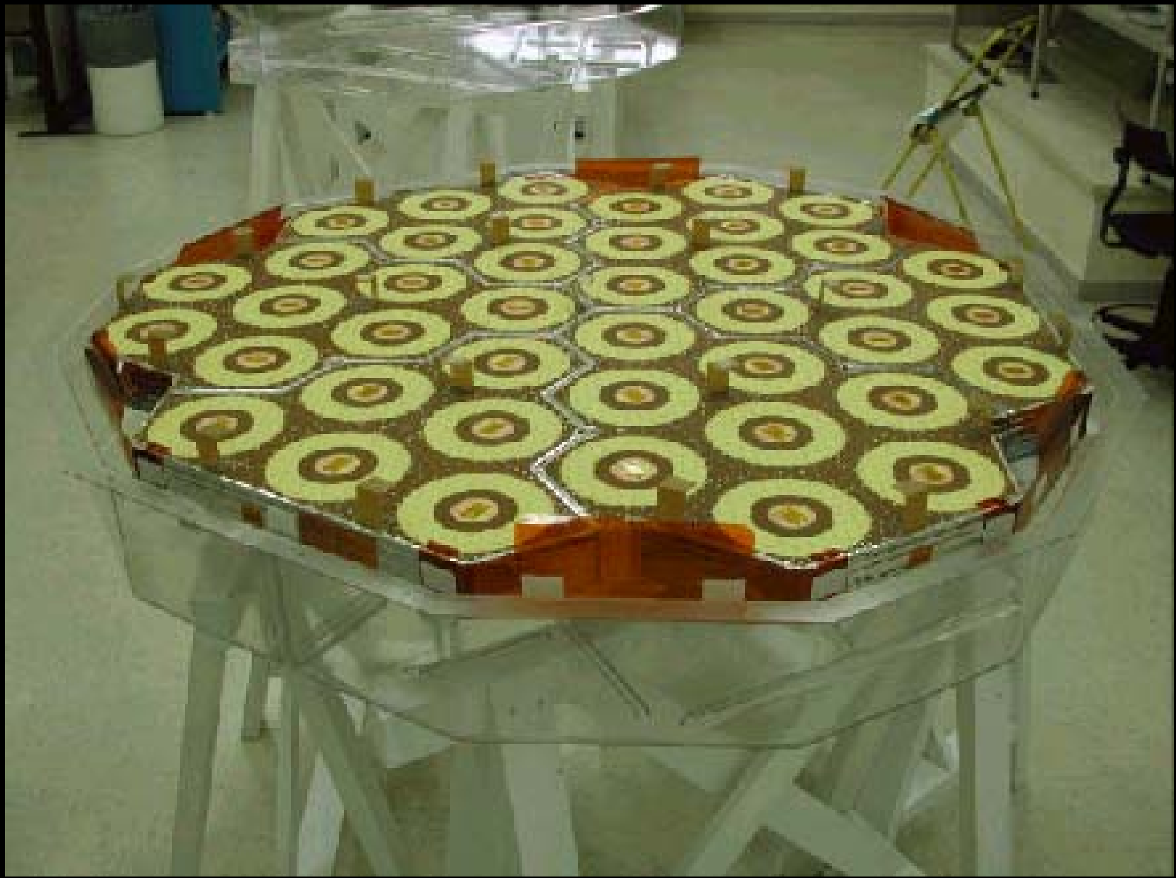
measured data

Hydrogen-Maser Atomic Clock

weight and volume: 18 Kg and 45 l.
time stability: better than 1 nsec per day.



Satellite Navigation Antenna

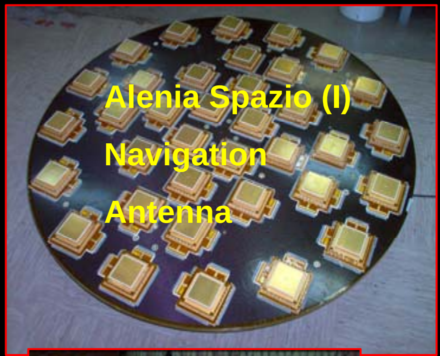


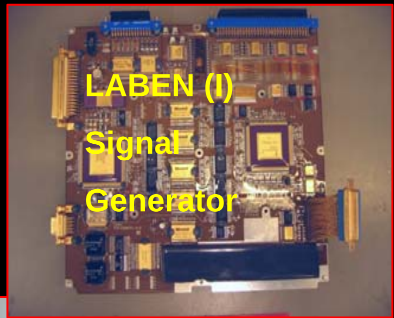
Phase array type.

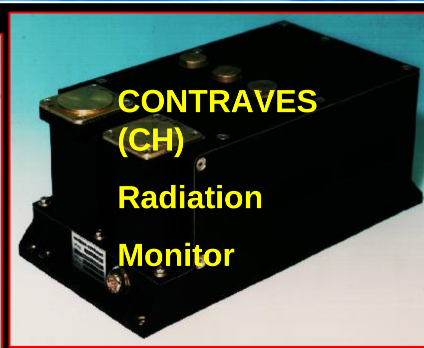
Isoflux pattern to equalize received power level on ground.

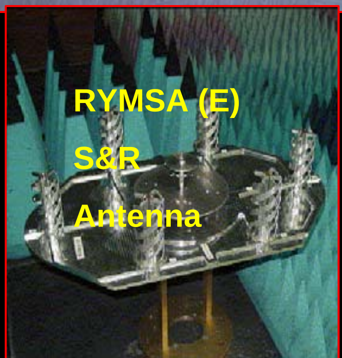
Broadband frequency response to cover all the Galileo frequency bands with high performance

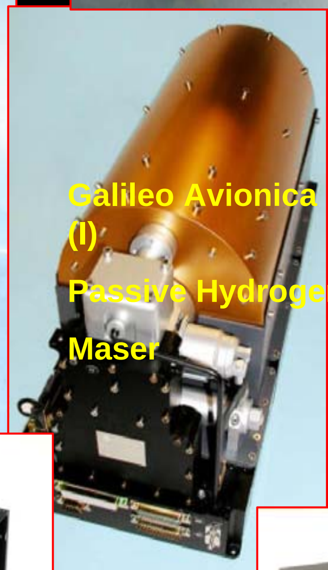
Technology Developments for Pilot Satellites

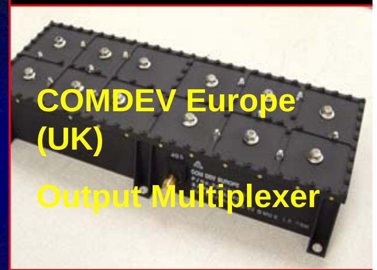


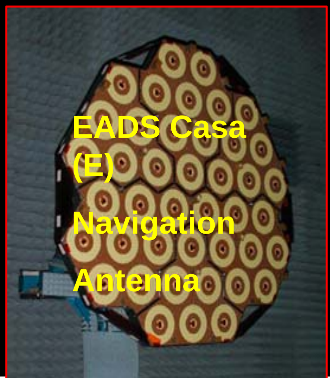


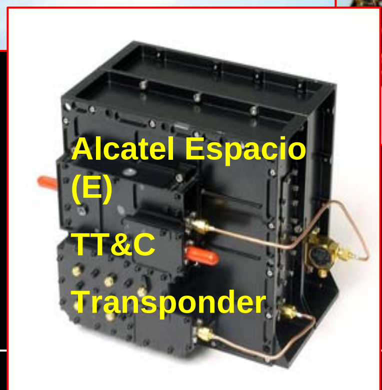






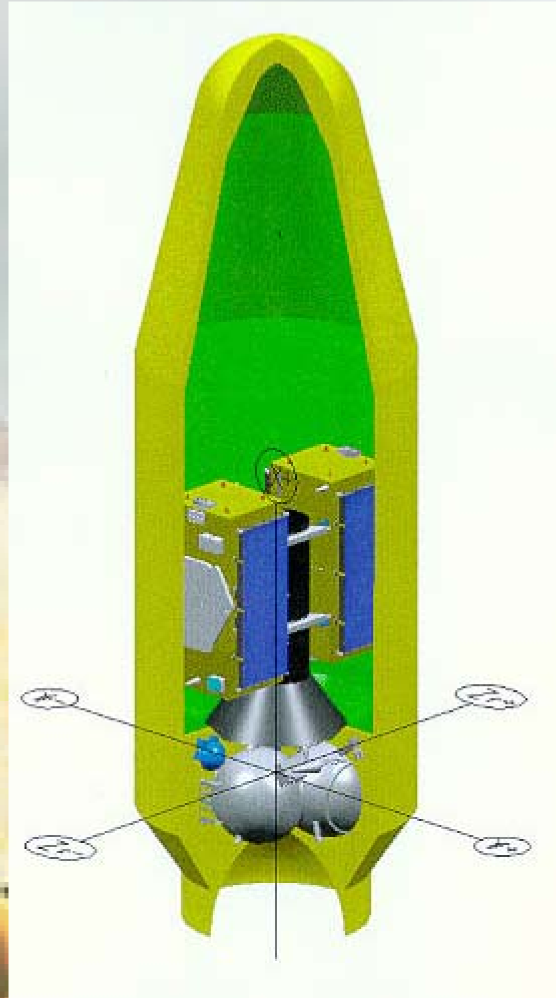






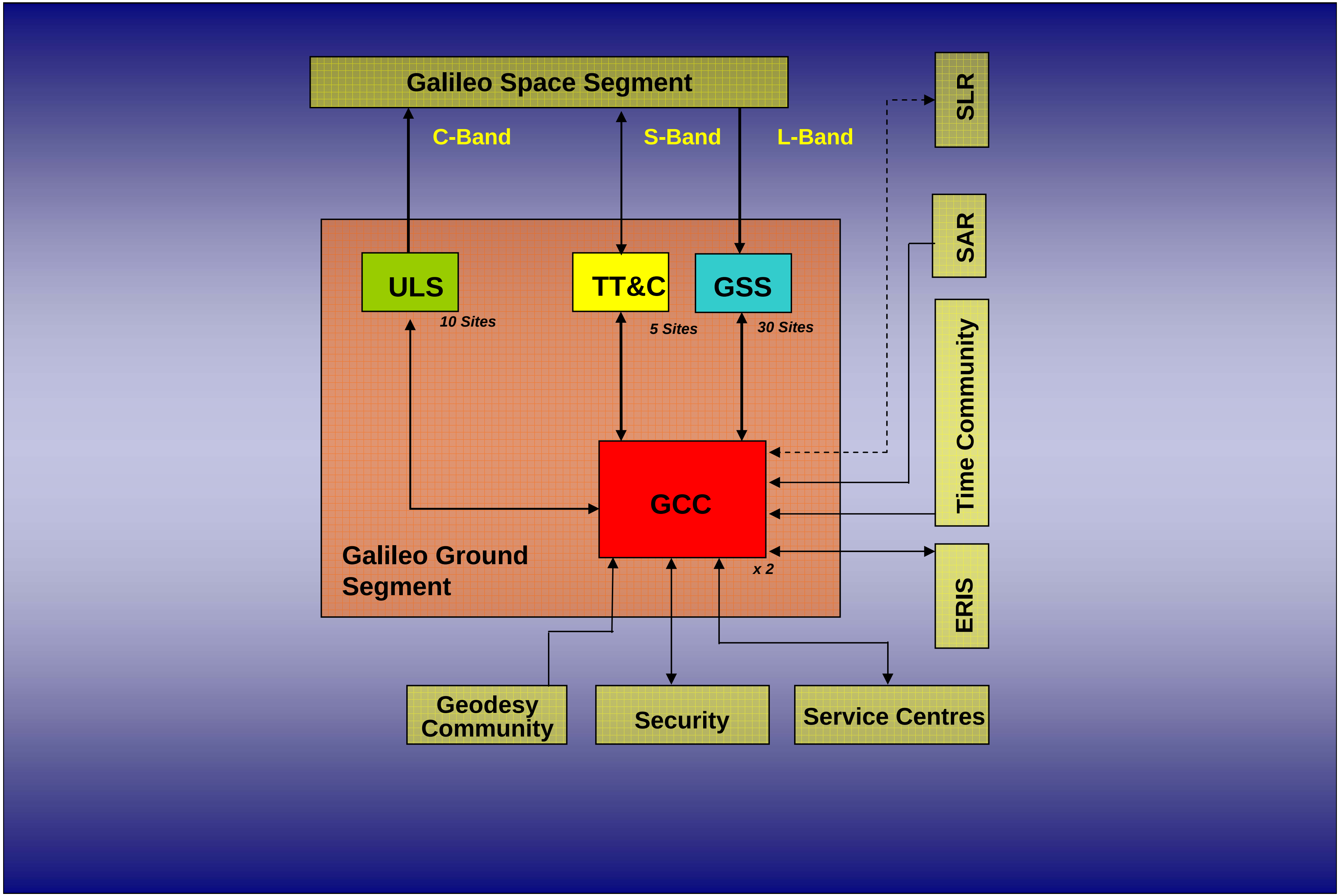
Launch

- Direct injection into MEO orbit
- Multiple launch capability with Ariane 5 (up to 6 S/C)
- Soyuz 2-1b-Fregat can launch 2 MEOs
- Combinations of launchers allow all phases to be fulfilled & offer flexibility



2 Spacecraft in Soyuz Fairing

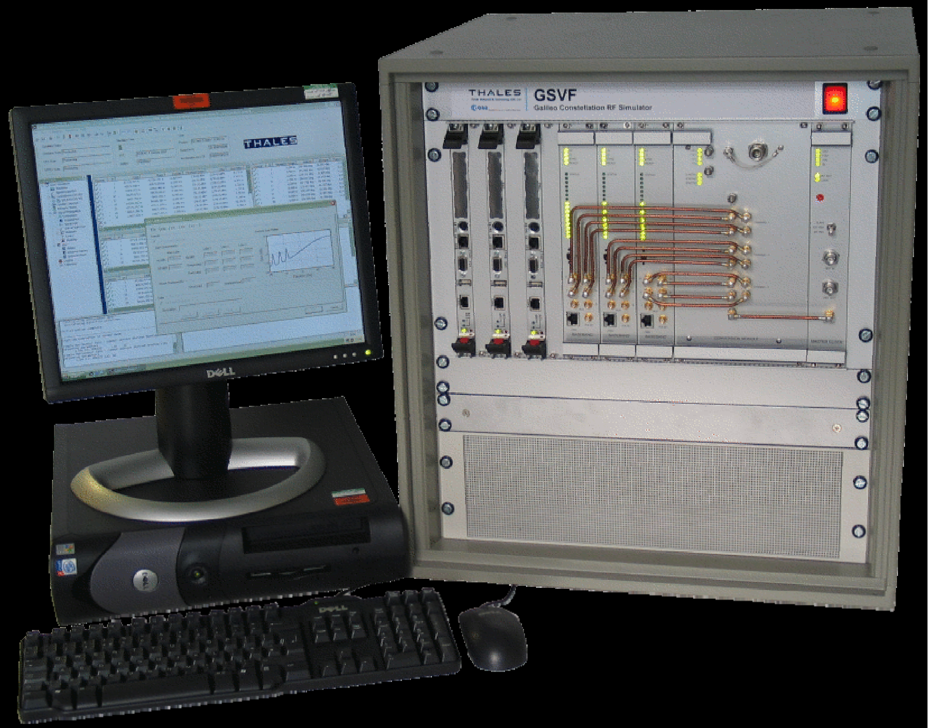
Ground Segment Architecture



Receivers and System Simulators

Galileo Constellation Signal Simulator

Thales Research & Technology (UK) Ltd



Receiver developed by Septentrio (B)

Conclusions

- The Services and main performance of Galileo have been presented showing the improvement brought by Galileo to GNSS
- The Galileo IOV phase is well underway and will be concluded by end 2008
- The ongoing developments for the system component have been shown
- The Galileo System Test Bed 1 has been completed
- The Galileo System Test Bed V2 2 will be completed by 2007