From Science From Science From Science From Science



DAS SATELLITENNAVIGATIONS-SYSTEM GALILEO

Guenter W. Hein Emeritus of Excellence Universität der Bundeswehr München To Science To Science To Science To Science

CURRENT AND PLANNED SATELLITE NAVIGATION SYSTEMS



2020



GLOBAL CONSTELLATIONS GPS 24+3 GLONASS 24+ Galileo 24+3 BeiDou 35 27 MEO+3 IGSO+5 GEO

REGIONAL **CONSTELLATIONS** QZSS 4+3 IRNSS 7 SBAS (GEOs) WAAS 3 2 **MSAS** 3 EGNOS 2 GAGAN 3 **SDCM BDSBAS3**

DEPLOYMENT OF GALILEO



GALILEO STATUS 22 APRIL 2016

12 Satellites in Orbit



Next Launches:

Sat 13,14
 24 May 2016 Sojus
 Sat 15,16,17,18
 Q4/2016 Ariane 5

Position is Based on Time

Signal leaves satellite at time "T"





Signal is picked up by the receiver at time "T + 3"

Distance between satellite and receiver = "3 times the speed of light"

Pseudo Random Noise Code





Signals From Two Satellites



Three Satellites (2D Positioning)



Three Dimensional (3D) Positioning



Progress in

high-precision atomic clocks and Einstein's Relativity Theory

enable satellite navigation to use time signals

Galileo's Ultra-Precise H-Maser Clocks



Relativistic Geodesy



Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world. Quoted in interview by G. S. Viereck, 1929

... open new grounds

in space-time metrology !

Relativistic Effects on GNSS

1. Einstein gravitational blue shift effect

- Clocks run faster when they are far away from a center of \succ gravitational attraction
- 45 700 ns/d \succ

2. Time dilatation or special relativistic Doppler effect of second order

- Clocks in motion run slow
- 7 100 ns/d \succ

3. Sagnac effect and gravitomagnetic field of rotation

Earth rotation corrections

Compensation: Change of nominal satellite clock frequency prior to launch (10.23 to 10.22999999543 MHz) and correction of about 7m by clock polynomial.

Galileo Clocks: Where are we today?

Galileo on-board clocks: Two technologies (PHM and RAFS) Supplied by Selex Galileo (I) and Spectratime (CH) Stability (ADEV) measured on ground:



The IOV satellites have proven that Galileo works!

Galileo IOV works (and it works very well....!)

Positioning



Timing



Dual Frequency Positioning Accuracy (PDOP <=5):

Horizontal (95%)
8 m in average
Vertical (95%)
9 m in average

Timing Accuracy: **10 nsec in avg**

- •67% availability with 4 IOV S/C
- •96% availability after 1st FOC launch (6 S/C)

Search And Rescue



SAR Beacons Localisation Accuracy:

Within 2 km (77% localisations)
Within 5 km (95% localisations)

Satellite navigation primarily delivers Position, Navigation, Time (PNT)

Moreover, Galileo provides also many data to Science!

... Galileo applications are not limited by technology, they are only limited by our imagination!

Galileo/GNSS Space Receivers



GRACE Mission

Science Goals

High resolution, mean & time variable gravity field mapping for Earth System Science applications.

Mission Systems

Instruments •KBR (JPL/SSL) •ACC (ONERA) •SCA (DTU) •GPS (JPL) Satellite (JPL/DSS) Launcher (DLR/Eurockot) Operations (DLR/GSOC) Science (CSR/JPL/GFZ)

Orbit

Launch: March 2002 Altitude: 485 km Inclination : 89 deg Eccentricity: ~0.001 Lifetime: 5 years Non-Repeat Ground Track Earth Pointed, 3-Axis Stable



... determine the Earth's gravity field !

Precise Galileo/GNSS Signals



... monitor the Earth's tectonic plates !

9982, 1997

Precise Galileo/GNSS Signals



20th Century Sea Level Rise: Eastern Pacific

... monitor global sea level rise !

Galileo Signal Multipath



... senses passively ice and sea surface !

Precise Galileo/GNSS Signals

- Daily repeatable fluctuations in SNR at fixed ground stations correspond to multipath
- Frequency related to source of the reflection
- Extract amplitude of SNR fluctuations at that frequency as a proxy for soil moisture



Comparison of GPS-derived surface reflection amplitude with soil moisture model based on local precipitation

K.M. Larson, E. Small, E. Gutmann, A. Bilich, and P. Axelrad, GPS Solutions, 2007

... monitor soil moisture fluctuations !

Galileo/GNSS Occultation Data



... enable ionospheric tomography !

Galileo Ionospheric Measurements

Ionospheric detection of gravity waves induced by Tsunamis. Geophys. J. Int. (2005), 160, 840-848



... detect atmospheric waves generated by earthquakes and tsunamis !

Tropospheric Delays in Galileo Signals



Integrated Water Wapor +6hr Mean: -0.29 Min: -5.45451 Max: 3.697 Var: 0.894 6 -5 -4 -3 -2 IWV [kg / m**2]

... improve the weather forecast !

Galileo Authentication



... fights against product piracy !

Galileo Precise Time Signals

Time tag accurately voltage and current (magnitude and phase) on generation, transmission and distribution lines within microseconds





... synchronize and monitor power networks !



Galileo Galilei *1564 \$1642

