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Galileo: Impact on Spacecraft Navigation System

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Abstract. This article reviews the future impact of Galileo on spacecraft navigation systems. It outlines the Galileo benefits for spacecraft navigation systems, including the number of available frequencies and services, up to 3 separated frequencies for one service; application of the Three Carrier Ambiguity Resolution (TCAR) technique for substantial improved spacecraft attitude determination algorithms; high data rates for improved signal acquisition - Time To First Fix (TTFF) and reacquisition receiver behavior, and so on. It is the author's belief that the real impact from Galileo for new spacecraft navigation systems is driven by the interoperability between Galileo and GPS and subsequently the dual use of both systems. This feature will generate new ideas and concepts, which will lead to advanced spacecraft navigation systems with a maximum degree of on-board autonomy.

Key words: Galileo, Space Applications.

1 Introduction

Diminishing budgets for spacecraft design, manufacturing and operations are driving parameters for future space mission planning. Beside this, also new, more challenging and complex requirements for space missions into Low Earth Orbit (LEO), increasing the necessity for improvement of existing spacecraft navigation systems and the development of new navigation systems aiming for maximization of on-board autonomy. This is especially true for planned commercial and scientific LEO missions with new concepts of satellite formations and constellations like Starsys, Celestri, RapidEye, FUEGO, TerraSar. Another example is the International Space Station (ISS). These missions can also request relative navigation.

In order to be compliant with these new requirements, spacecraft Navigation Systems based on GPS already playing a key role. Within the last decade, the number of LEO satellite missions (e.g. Globalstar, CHAMP, GRACE, SAC-C, BIRD, FedSat to name a few) with a GPS receiver as the prime source for satellite position and time, has substantially increased. The advantages of spacecraft navigation systems, based on observations from Global Navigation Satellite Systems (GNSS) like the US Global Positioning System, NAVSTAR GPS, the Russian GLONASS and the upcoming European Global Satellite Navigation System - Galileo are: GNSS sensors are light weight, small sized and have relatively low power consumptions. Further, depending on receiver type and integration on the USER satellite, such navigation systems can provide absolute and/or relative 3-D position, velocity, time, 3-axis attitude and real time orbit determination. The information is available on-board and can therefore be used for intelligent data fusion and on-board preprocessing. These features are essential for implementation of maximum on-board autonomy, which is the key for many future satellite missions.

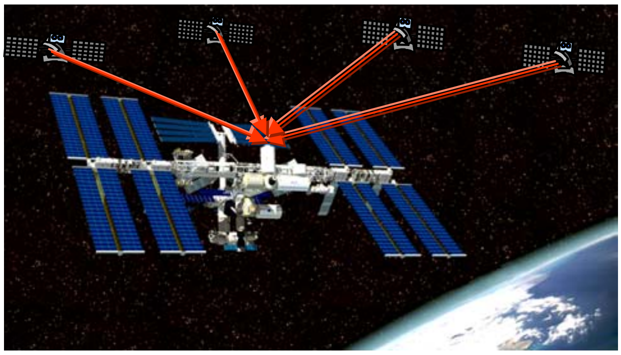

Fig. 1 GNSS – Example for Space Applications.

The use of GNSS signals for space applications is in first instance, depending on:

- Line-of-sight visibility conditions between USER spacecraft and GNSS constellation

- Receiver dependant Signal-to-Noise-Ratio (SNR) threshold for acquisition and tracking of GNSS signals
- Receiver characteristic for high dynamic environment and the related Doppler frequency shift

2 Existing GNSS – GPS and GLONASS

The status of the existing Global Navigation Satellite Systems and their support for spacecraft missions can briefly be described in the following way:

- US American NAVSTAR GPS system is fully operational since 1995. Currently 28 Block II/IIA/IIR satellites are in operation. A modernization program is under way. GPS is designed in such a way that LEO spacecraft missions are supported. Two frequencies (L1 and L2) are available for the services provided by GPS. A number of GPS receivers for space applications have been developed and are commercially available.
- GLONASS is not fully operational yet (8 satellites are in operation, nominal configuration 24 satellites). The GLONASS design supports LEO spacecraft missions. GLONAS provides its services based on two frequencies. Combined GPS/GLONASS receivers for space applications existing, e.g. LAGARANGE receiver, however GLONASS plays a less important role for space applications because of the limited number of available satellites.

3 Galileo

Galileo will be the civil operated European Global Satellite Navigation System. It will consist of a space component, the Galileo constellation (see Fig. 2). The Galileo satellite constellation can be summarized as; WALKER constellation (27/3/1) + 3 active spares, which means 27 satellites in three Medium Earth Orbit planes with 1 active spare satellite per orbit plane, subsequently a total number of 30 Galileo satellites with 10 satellites per orbit plane is available for the provision of services. The orbits are circular with a semi-major axis of 29993.707 km. The inclination of the orbital planes is 56 degrees. The period for one orbit revolution is 14 hours 4 min. The ground track will repeat each 10 days. The available power on-board a Galileo satellite will be around 1.6kW. The Galileo satellites itself will be 3-axis stabilized with an Earth pointing (nadir) orientation. A ground component, which will be used for the operations of the Galileo SV's including orbit determination and time synchronization and also determination of the Galileo integrated global integrity information. The third component is the user component.

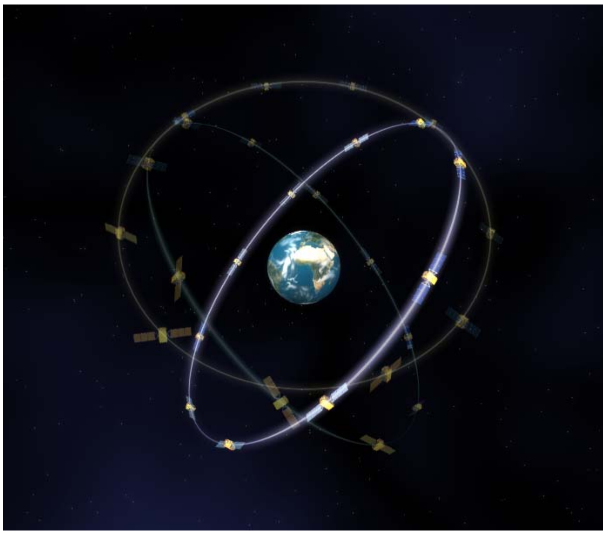

Fig. 2 Galileo Constellation, WALKER (27/3/1) + 3.

Galileo shall be fully operational in 2008 and will offer the following services (detailed description of services can be found in (European Space Agency,2003):

- Open Service (OS)
- Safety-of–Life Service (SoL)
- Commercial Service (CS) - guarantee of services is possible
- Public Regulated Service (PRS)
- Search and Rescue (SAR)

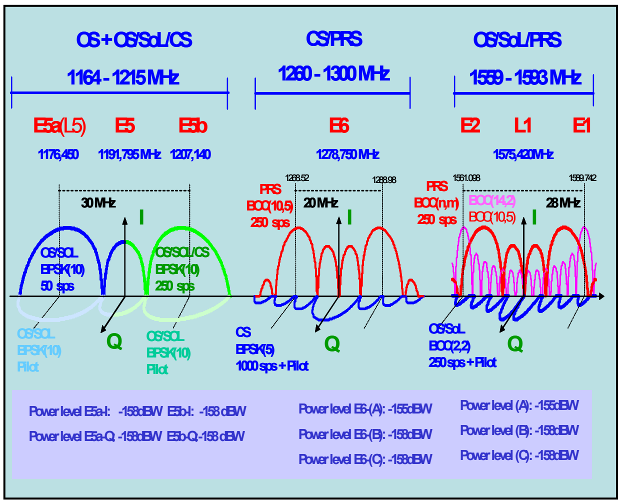

Fig. 3 Galileo Frequencies and Services.

The allocation between Galileo services and frequencies is outlined in Fig. 3.

Galileo is designed from the beginning for the dual use of GPS and Galileo. The interoperability between Galileo and the civil GPS is implemented via the use of certain standards for time reference (Galileo System Time will be synchronized to International Atomic Time (TAI)) and the terrestrial reference frame. The Galileo Terrestrial Reference Frame (GTRF) will be the physical realization of the International Terrestrial Reference System (ITRS).

4 Galileo support of space applications

Galileo has no specific system requirement for the direct support of spacecraft missions (see Enderle et al., 2002). However, the service coverage area of Galileo includes explicitly aeronautical users. For this reason a coverage area of about 20 km altitude above the Earth's surface can be assumed. This assumption would correspond to a Galileo satellite emitting antenna half cone angle (3dB threshold) of 12.2 deg. Based on the altitude of the Galileo constellation (23615.707 km) and having the individual Galileo satellite emitting antenna pointing towards the centre of the Earth with a half cone angle of 12.2 deg (see Fig. 4), the Galileo signals can still be used for space applications, at least to a certain degree.

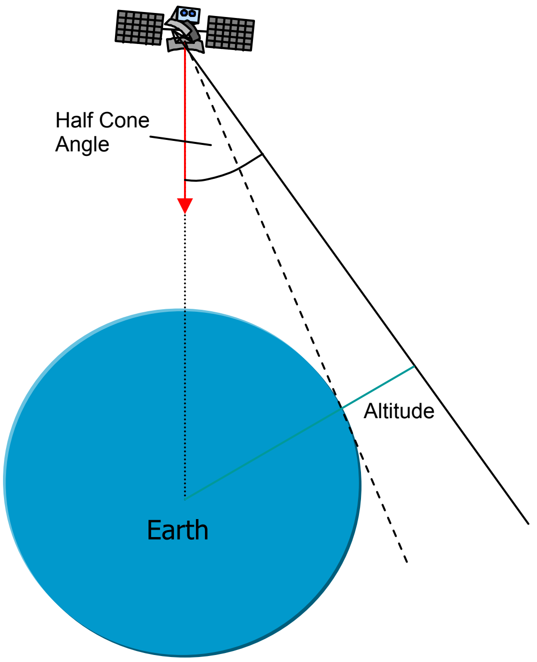

Fig. 4 Half Cone Angle of Galileo emitting antenna.

It must also be outlined that at this stage the design of the Galileo satellite emitting antenna is not finalised and therefore the antenna pattern is only tentative. In any case, Galileo signals can also be received outside the half cone angle of the emitting antenna with a reduced power density level.

Results of a conducted visibility analysis (half cone angle of 12.2 deg) for a USER spacecraft in various orbit scenario for Galileo alone and the dual use of Galileo together with GPS are given in Fig. 5 and Fig. 6. See ref. (Enderle et al., 2002) for a more detailed analysis.

In Fig. 5, it can be seen that the Galileo signals can not be used in the Geostationary Orbit (GEO) and only in a very limited way in Geo Transfer Orbit (GTO). The stand alone use of Galileo for a spacecraft USER in LEO provides visibility probabilities of 75% for 2 and about 9% for 4 visible Galileo satellites. Again, it has to be outlined that this is a very conservative approach, because of the restriction to only 12.2 deg half cone angle for Galileo signals.

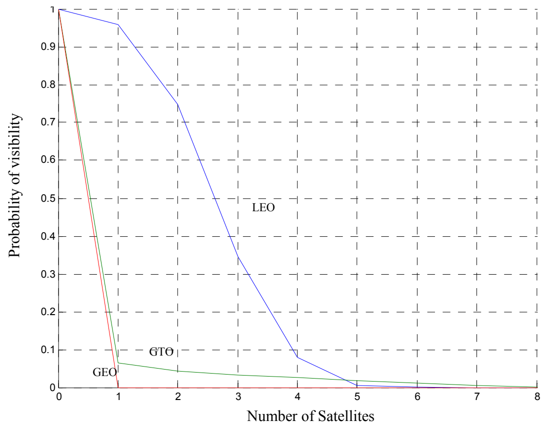

Fig. 5 Probability for visible Galileo satellites for a USER spacecraft in various orbit scenarios. Half cone angle 12.2 deg and masking angle 10 deg.

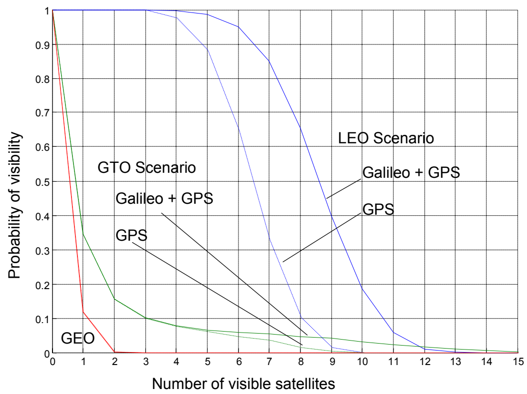

Fig. 6 Dual use of Galileo and GPS signals. Probability for visible Galileo and GPS satellites for an USER spacecraft in various orbit scenarios. Half cone angle 12.2 deg and masking angle 10 deg.

Fig. 6 shows the improvements, resulting from dual use of Galileo and GPS signals. As it can be seen, Galileo has no effect for GEO applications and very limited impacts on GTO applications compared to the use of GPS alone. Concerning visibility improvements for space applications in LEO, it can be said that the additional use of Galileo signals will increase the probability of 4 visible satellites from about 97% to over 99.5% but more importantly, the probability for 5 or more visible satellites will substantially be increased.

5 Galileo – Benefits for Spacecraft Navigation Systems

New spacecraft navigation systems will benefit from Galileo in many aspects. These benefits include:

- The number of available frequencies and services, up to 3 separated frequencies for one service
- Application of the Three Carrier Ambiguity Resolution (TCAR) technique for substantial improved spacecraft attitude determination algorithms
- High data rates for improved signal acquisition - Time To First Fix (TTFF) and reacquisition receiver behavior
- Quality of Pilot Tone ranging signals (no data on signal) for high ranging accuracy
- Available frequency bandwidth for Galileo signals will provide robustness against multipath effects
- Flexibility in receiver design and complexity with respect to space mission requirements will allow mission tailored receiver concepts. From single frequency receiver concepts to complex multi frequency concepts
- Integrity information will also be available, if necessary

The main benefits, listed above will definitely have an influence, however, it is the authors believe that the real impact from Galileo for new spacecraft navigation systems is driven by the interoperability between Galileo and GPS and subsequently the dual use of both systems. This feature will generate new ideas and concepts, which will lead to advanced spacecraft navigation systems with a maximum degree of on-board autonomy.

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