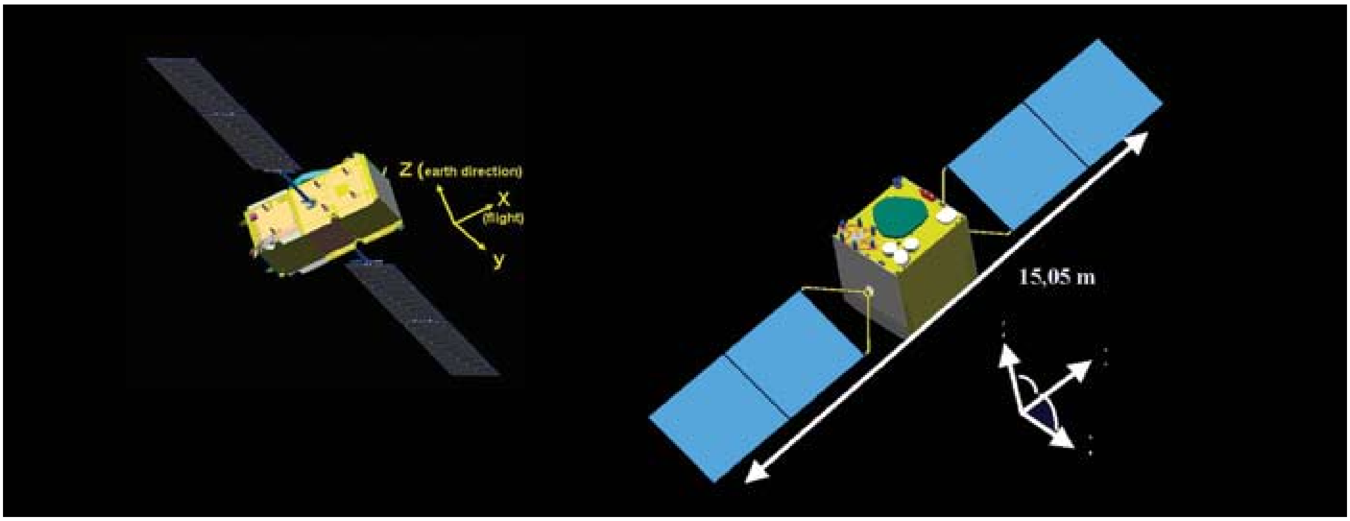
Architecture for a Future C-band/L-band GNSS Mission

Part 1: C-band Services, Space- and Ground Segment, Overall Performance



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left: (Galileo IOV Extension) for PRS-C services only; right: Overall view of Galileo C/L-band satellite

Almost all GNSS navigation signals operate in the crowded L-band portion of the radio frequency spectrum. In the past, C-band spectrum has been considered – and rejected – for GNSS services due to a couple of substantial obstacles, despite some distinct technical advantages. However, continued proliferation of signals in L-band and advances in electronics and spacecraft technologies have prompted a new look at C-band for future GNSS services. This article is the first of a two-part series describing the results of a new European Space Agency–sponsored study on the subject.

Within the European Space Agency (ESA) GNSS Evolution program, EADS Astrium has led a team analyzing the potential benefits, performance, and technical requirements for adding a C-band navigation capability to existing L-band services on a second-generation Galileo.

The C-band issue is not new. Between 1998 and 2004, U.S. and European researchers undertook significant work on this subject. One of the factors that led to the decision at that time *not* to choose C-band for Galileo was that the required satellite payload power would have been difficult to provide.

However, C-band has returned as a candidate for GNSS systems. Among the main reasons for renewed interest in C-band is that its frequency (5010 - 5030 MHz) is rather untouched compared to the L-band, where existing and new navigation satellite systems have proliferated. Moreover, C-band offers a variety of technical characteristics compared to L-band that make it particularly attractive for regulated and safety-critical applications.

The provision of a C-band navigation signal on a future GNSS would make sense if a new set of services can be offered (with markets behind them) and the satellite power requirements and associated link budget deficiencies can be solved.

In this issue, we introduce the first of a two-part column examining the potential for incorporating C-band technology into a GNSS system. The first part discusses prospective C-band services and applications, signal propagation and user equivalent range error (UERE), spacecraft payload design, satellite constellation, and end-to-end performance.

In the July-August issue of *Inside GNSS*, the second part of the column will focus on C-band signal design for GNSS given the constraints of other C-band services, optimal navigation message design, C-band user equipment design in the context of expected applications, and identification of critical technologies needed to prepare C-band for use in a future GNSS constellation.

The Scope of the C-Band Project

In order to show the benefits of a future C-band navigation in addition to the L-band system used by GNSSs, including the Global Positioning System and Galileo, the C-band analysis included an architecture study that considered likely technology developments through 2020.

The main justification for offering an additional C-band navigation capability would be to provide new GNSS services for new or existing applications. Consequently, a detailed user market analysis was performed in light of present and future market trends and parallel developments in user receiver design. We will discuss the outcomes of these analyses a little later in this article.

For the identified services, we then performed satellite constellation analyses in order to derive the required navigation parameters: number of the satellites available for the user, dilution of precision (DOP), positioning performance, and so forth.

We simulated the performance of various candidate signals in order to identify robust C-band signals that fulfil the C-band user requirements. In analyzing C-band signal propagation, we applied the latest atmospheric models. Appropriate C-band GNSS signals were then designed, considering the spectral constraints imposed by adjoining C-band services, such as radio astronomy (RA) and microwave landing systems (MLS).

On the user equipment side, we investigated appropriate receiver architectures and derived link budgets for various services to verify the design.

Parameter Service	HDOP	VDOP	Availability @ 10° user elevation	Continuity	Antijamming A/J	UERE Target (1σ) CRLB @ 30dBHz
SPR-C	1.1	2.6	99.8	10-5/15s	> 40 dB	0.8 m
PRS-C	1.1	2.6	99.5	10-5/15s	> 40 dB	1.1 m

TABLE 1. Budgets for the proposed C-band services

C-Band Service Analysis

A detailed market and user receiver analysis has identified two baseline C-band services: A Service with Precision and Robustness (SPR-C), with global coverage, and a Public Regulated Service in C-band (PRS-C) with spot beam coverage over two selectable service areas.

The SPR-C would provide users with additional robustness, protection, and precision for non–security-related critical infrastructures and applications for which vulnerability is a threat. In this regard, C-band offers the following advantages: no spectrum proliferation, smaller signal propagation effects from the ionosphere and unintentional interference, and higher jamming resistance compared to the L-band for same C/N_0.

As envisioned by the C-band service analysis, the SPR-C could support professional satellite navigation in situations where L-band signals are degraded and would provide additional value-added elements with the navigation message, such as clock and tropospheric correction data. The service would be protected against spoofing by authentication.

Table 1 summarizes the performance definitions of the proposed SPR-C and PRS-C services.

The 1σ UERE budget of the SPR-C would equal or be less than 1.1 meters with a target of 0.8 meters, considering the noise contribution to be that of the Cramér-Rao Lower Bound (CRLB, computed at C/N_0 = 30dB-Hz). The integrity level to be provided by SPR-C has not yet been defined because the performance of multi-constellation RAIM (receiver autonomous integrity monitoring) still needs to be assessed in context of future GNSS integrity concepts.

The SPR-C will make use of authentication to provide robustness against spoofing and will provide an anti-jamming resistance of 40 decibels. SPR-C signals would be spectrally decoupled from those of the PRS-C. A proposed business model for SPR-C is leading in the direction of charging a subscription fee for a prepaid access card to the service and the authentication data.

For its part, the Galileo PRS-C service is defined as an additional local, flexible option to add robustness to the baseline, Earth-coverage L-band PRS planned on E1 and E6. Two high-power spot beams would provide coverage anywhere on the surface of the Earth with "footprints" 1,500-kilometer in diameter.

PRS-C would provide a high level of protection/security against threats that result in reductions of national security, law enforcement, and safety in local geographic areas of interest.

As with the SPR-C, additional data, like clock correction and tropospheric correction data from weather services would be provided to improve the UERE budget so as to achieve the target values presented in Table 1. Code encryption would protect the PRS-C against spoofing.

The proposed business model for the PRS-C is based on charging for subscription and initial loading of the crypto keys.

Satellite Constellation with C-Band

Navigation service requirements such as availability and position dilution of precision (PDOP) have a direct effect on the

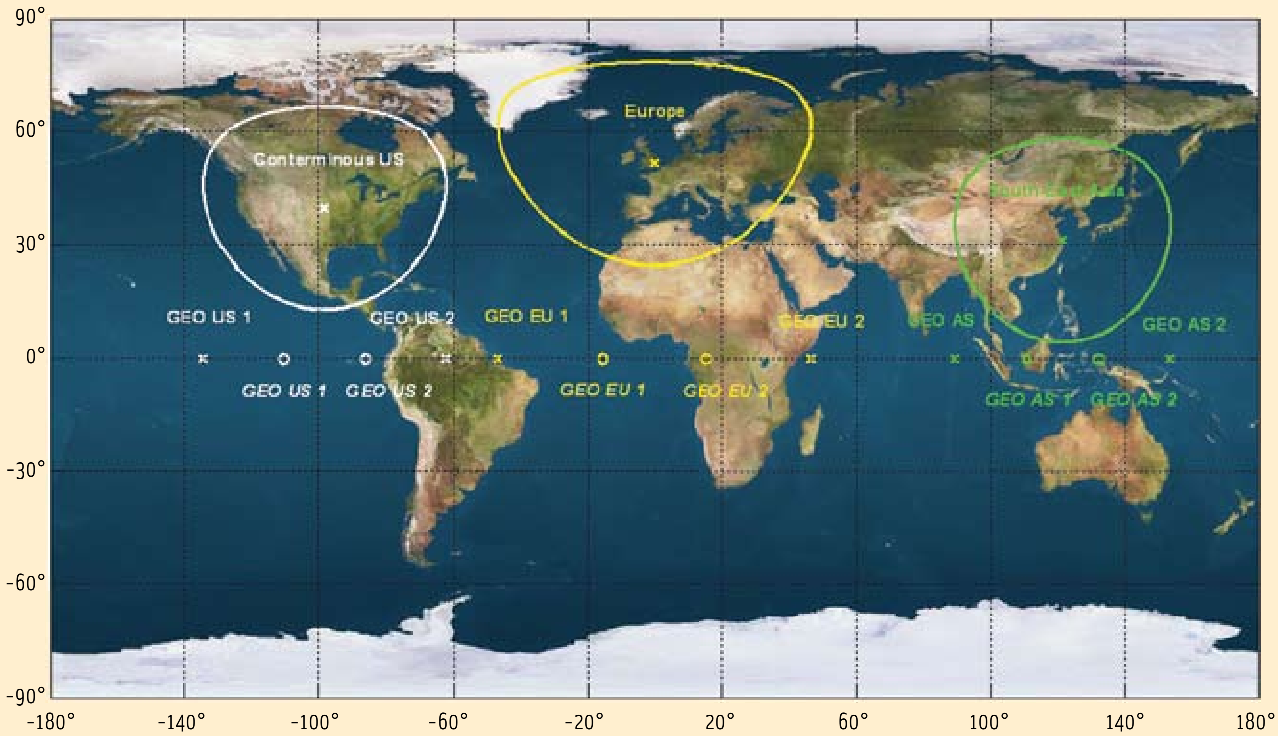

FIGURE 1 Beam-switching mode, service areas, and augmenting GEO satellites

configuration of the satellite constellation. Consequently, a variety of constellations were analyzed in order to find the best solution.

The C-band study conducted a trade-off analysis of a global and a regional SPR-C service. A regional SPR-C would provide continuous service over three selected industrial areas, covering North America, Europe and Eastern Asia (each area covering a circle of roughly 6,000 kilometers in diameter on the Earth's surface).

If all available satellites are pointed toward the same service area in a "beam steering" mode, only one industrial region can be covered (i.e., Europe). In this case, the average PDOP value is the same as for a global coverage system. The main advantage of such a regional service is that it requires less transmitter power compared to a global service. In turn, that reduces payload and spacecraft size, mass, and power requirements.

For covering the three industrial service areas at the same time, a "beam switching" mode was devised, defining a satellite-pointing rule that provides maximum PDOP over each area. Nevertheless, since in this mode three areas need to be covered by a sufficient number of satellites, signal availability and PDOP values decrease. Increasing the visibility to satellites for three areas would require enlargement of the Galileo constellation (27 operational satellites).

We investigated alternative configurations with two geostationary orbit (GEO) satellites to augment the SPR-C service: one placing the GEOs at the edge of the service area and another with the GEOs closer to the center. This configuration provides slightly better visibility at higher latitudes and slightly worse DOP. **Figure 1** shows the three service areas and the possible GEO locations for each.

We also considered other augmenting configurations, such as inclined geosynchronous orbits (IGSO) or Molniya orbits, with the idea of increasing depth of coverage in northern latitudes for the three service areas. The IGSO configuration would provide a three-satellite regional constellation over each service area.

The Molniya constellation would be global, composed by nine satellites in highly elliptical orbits distributed among three equi-spaced ground tracks (three satellites per ground track), that would added to the nominal Galileo constellation along with the GEOs.

Table 2 summarizes the results of our analysis of the SPR-C constellation options. Most promising for providing services to three 6,000-kilometer areas is a Molniya constellation consisting of nine satellites optimized for the selected service areas, which would operate together with the Galileo MEO constellation plus two GEOs (configuration 4 in Table 2).

However, the additional development and launching costs of additional Molniya and GEO satellites need to be compared with an enlarged Galileo spacecraft for a global SPR-C service.

Table 3 displays the results for the PRS-C services. Provision of only one PRS-C service via the Galileo constellation is no problem (Case 6). Serving two areas concurrently with the same PRS-C signal from one satellite reduces the visibility because the number of satellites for user elevation angles of 10 degrees has to be split between two service areas

(Case 7). In addition these two service areas need to be at least 6,000 kilometers apart; otherwise visibility and PDOP degrades too much.

Although Galileo with a three-satellite IGSO constellation does bring some advantages (Case 8), the best improvement in terms of visibility and PDOP is achieved by the Galileo MEO plus Molniya constellation (Case 9). However, this solution would also be the most expensive one.

Further improvements in navigation performance would be to increase the number of Galileo satellites (Case 10) and (Case 11) or to offer two independent transmit channels for two service areas (Case 6 with two PRS-C services).

The final trade-off analysis shows that the solution based on 27 operational Galileo MEO satellites (Case 1, Case 6) best fits the SPR-C and PRS-C service concept. The performance is in line with the user requirements.

C-Band Ground Segment

The Galileo ground segment needs to be modified to consider the additional use of C-band signals. The extended ground segment will provide new navigation message data, including improved tropospheric corrections based on numerical weather data, and the mission planning for PRS-C operations.

The Galileo architecture remains valid for the C-band services. Upgrades of a subset of ground sensor stations (GSSs) will be necessary to include C-band signal tracking capabilities in order to determine the biases associated with the spacecraft, C-band antenna, and RF chain.

Using directional antennas for the C-band GSS, C-band measurements would be less noisy and, hence, would allow improving the orbit determination and time synchronization (OD&TS) performance of the Galileo constellation.

In summary, the ground segment architecture will consist of a worldwide network of 40 stations for L-band OD&TS, plus a subset of upgraded GSSs with C-band tracking capabilities.

In order to find the optimum subset of GSSs for C-band we performed an analysis, maximizing the constellation visibility and the depth of coverage (DOC), the number of stations which are simultaneously tracking a specific satellite. Figure 2 illustrates the minimum, average, and maximum RMS position error obtained for a simulated time period of three days, taking into account 12 GSSs. The mean RMS stabilizes at a value slightly below 10 centimeters. The OD&TS error does not change when the number of stations is increased from 12 to 18 and is only slightly worse than that

Configuration	Auxiliary GEOs required	Minimum Visibility	Average Visibility	Maximum PDOP	Average PDOP
1. SPR-C global, 27 - Galileo	No	6	9-10	2.8	1.6
2. SPR-C Beam Steering 6000 km – partial coverage allowed, 27 - Galileo	No	6	9-10	2.8	1.5
3. SPR-C Beam Switching 6000 km (3 areas) 27 - Galileo	Yes, 2 SC at 1/3 and 2/3 longitude of the circle diameter	6 for latitudes < 45° 4 for latitudes up to 70°	7	25 for latitudes < 60° >33 for latitudes > 60°	4
4. SPR-C Beam Switching 6000 km (3 areas) 27 – Galileo + 9-Molniya	Yes, 2 SC at 1/3 and 2/3 longitude of the circle diameter	6 for latitudes < 72°	9	12 for latitudes > 60° 8 for latitudes < 60°	4
5. SPR-C Beam Switching 6000 km (3 areas) 36 - Galileo	No	4 for latitudes < 72°	6	22 for latitudes > 60° 8 for latitudes < 60°	4

TABLE 2. Constellation performances for the SPR-C service

Configuration	Auxiliary GEOs required	Minimum Visibility	Average Visibility	Maximum PDOP	Average PDOP
6. PRS-C 1500km (anywhere) 27 - Galileo	No	6	9-10	2.8	1.6
7. PRS-C (2 areas of 1500 km diameter) 27 - Galileo	No	4 (6000 km separation, high latitude)	5 (6000km separation, high latitude)	2.8	2.7 (6000km separation) 1.9 (maximum separation)
8. PRS-C (2 areas of 1500 km diameter) 27- Galileo + 3 IGSO per service area	No	4	7	2.3	2
9. PRS-C (2 areas of 1500 km diameter) 27 - Galileo + 9 Molniya	No	4	10	1.8	1.6
10. PRS-C (2 Areas of 1500 km diameter) 30-Galileo	No	4 for latitudes < 72° 3 for latitudes > 72°	6	2.3	2
11. PRS-C (2 Areas of 1500 km diameter) 36-Galileo	No	4	8	2.1	1.8

TABLE 3. Constellation performances for PRS-C

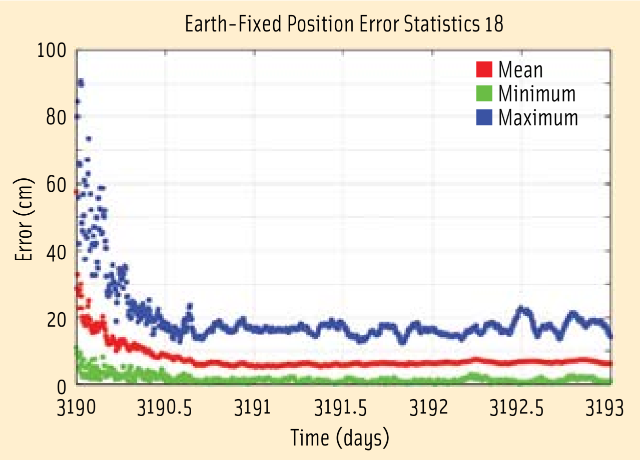

FIGURE 2 OD&TS performance for C-band network with 12 ground sensor stations

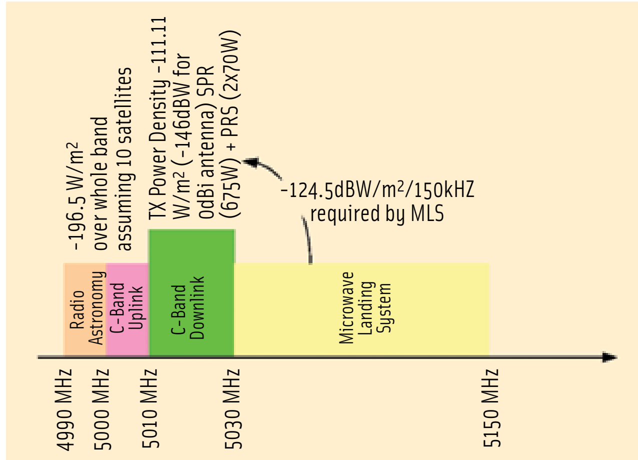

FIGURE 3 Frequency neighbors of the C-band downlink signal

predicted when using the whole fully operational capability (FOC) Galileo network.

Therefore, the optimum number of GSSs with additional C-band functionalities is 12. With 12 GSSs, a DOC value of three (DOC-3) is guaranteed with 98.6 percent availability, a value sufficient for OD&TS performance estimation purposes.

C-Band Transmit Power Requirement

For both C-band services, we calculated link budgets in order to determine the DC power required at the payload level. These will be described later in the end-to-end performance section.

Table 4 shows the required DC power at the payload antenna output in order to provide the following two service concepts:

- A global SPR-C global service plus two independent spot-beam PRS-C services each with a 1,500-kilometer service area or
- Two independent spot-beam PRS-C services each with a 1,500-kilometer service area.

Obviously, the SPR-C requires the largest power due to the fact that it is offered globally. These power budgets have an substantial effect on the payload and satellite design, which is described in the following section.

C-Band Payload Design

The preferred payload architecture would accommodate the C-band payload on a spacecraft in combination with the current Galileo L-band payload.

With this objective in mind, we will now cover the following points:

- general payload architectures to perform the beam forming for PRS-C
- RF front-end technologies, such as frequency up-conversion principles
- possibilities of high-power amplification and effects on power budget and signal distortion
- trade-off between antenna design and signal generator payload
- interference with mission up-link receiver and preservation of ITU regulatory
- power and mass budgets

The design of the most appropriate C-band signals will be described in the July/August issue of *Inside GNSS*. However, as the signal design is one driver for the payload design, we will briefly introduce it here.

The constraints on the downlink C-band signal selection are the limited bandwidth (5010-5030 MHz), the requirements set at the ITU level for compatibility with radio astronomy (4990-5000 MHz), microwave landing systems (5030-5150 MHz), and the Galileo mission uplink receiver (5000-5010 MHz), as illustrated in Figure 3.

The general objective of the signal and payload design was to trade off baseband signal design and compatibility with the aforementioned constraints. Out-of-band (OOB) emissions caused by

	Service Concept	Required Tx Power
1	One global SPR-C: Two PRS-C spot beams (1,500 km): Sum:	675 W 140 W 815 W
2	Two PRS-C spot beams (1.500 km):	140 W

TABLE 4. Required transmitter power for two different C-band service concepts

intermodulation products introduced by the payload's high power amplifier (HPA) were taken into account in the trade-off. We performed simulations in order to display the effect of the payload HPAs on different signal types under these constraints.

Finally, Gaussian minimum shift keying (GMSK) has been chosen as the baseline signal for both C-band services.

The proposed payload architecture consists of the existing Galileo architecture with enhancements to incorporate the C-band signal generation (Figure 4). This payload architecture would retain most of the existing design for the signal generation part while adding elements for the C-band solution: an enhanced navigation signal generator unit (NSGU) integrating L- and C-band within a single unit and a frequency generation and upconversion unit (FGUU) for C-band.

The RF front-end of the payload consists of a separate L-band and C-band section. The L-band output section incorporating the high power amplifiers, the output filter, the coupler and

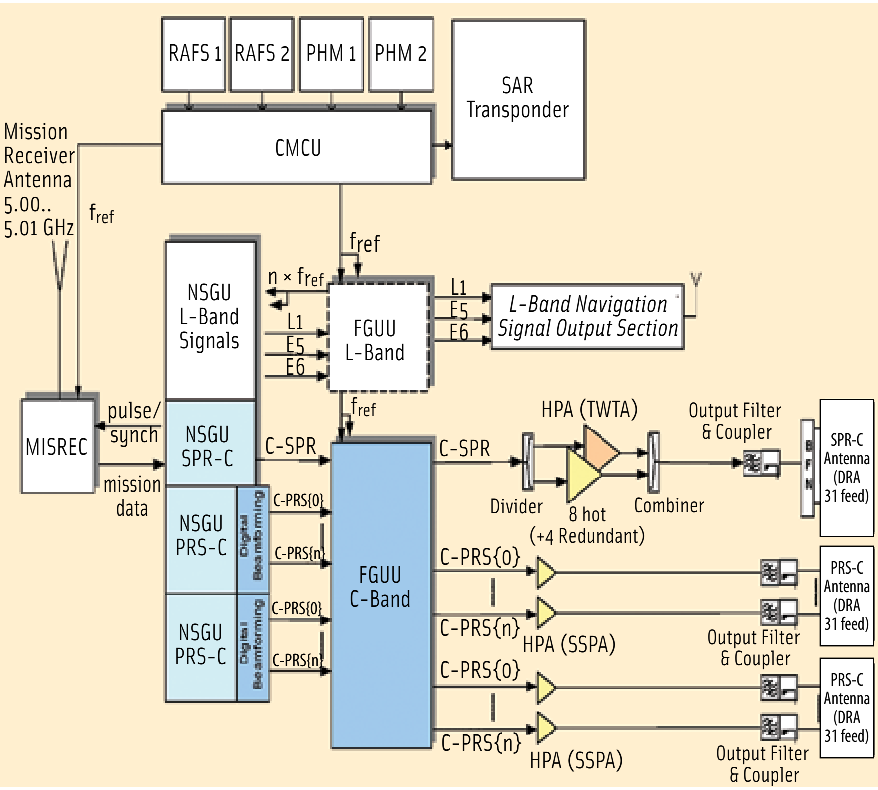

FIGURE 4 Combined L/C-band payload architecture with digital beam-forming for PRS-C: RAFS, rubidium atomic clock frequency standard; PHM, passive hydrogen maser; CMCU, clock monitoring and control unit; MISREC, mission uplink receiver; NSGU, navigation signal generation unit; FGUU, frequency upconversion unit

antenna is assumed to be similar respectively unchanged to the current Galileo system. Due to the expected enhancement of high power amplifier's efficiency in the coming years, power allocated today for L-band could be reallocated for C-band.

The navigation output section for the C-Band signals consists of one SPR-C and two PRS-C RF chains. The SPR-C solution requires high RF power — on the order of 600 to 700 watts — due to the plans for global coverage, which leads to the use of travelling wave tube amplifiers (TWTA). With today's C-band TWTA technology, at least eight TWTAs need to be working in parallel and adding another four TWTAs must be considered to provide sufficient redundancy.

A possible solution to enable beam-steering for PRS-C is to apply digital beam-forming. Because in this case every single antenna feed is excited with individual configurable signal lines from the NSGU, we need as many numbers of channels to be amplified as there are available antenna feeds.

A trade-off analysis of the number of antenna feeds, signal performance, and payload effort has been performed in the study. Every channel needs to be amplified to provide RF power on the order of five watts, which leads to the use of solid state power amplifiers (SSPAs).

Navigation Signal Output Filter. Power amplifiers in general exhibit nonlinear distortions in both amplitude (AM/AM) and phase (AM/PM). This causes spectral regrowth of the signal, which leads to adjacent channel interference and becomes an issue due to the stringent requirements of the adjacent bands.

The numerical values of the spectral re-growth of all signal candidates in conjunction with each HPA type (TWTA, SSPA) have been calculated and show, as expected, that the GMSK modulated signals do not lead to spectral regrowth due to their constant envelope nature.

Based on the Galileo mission receiver link budget file, we investigated the maximum tolerable leaking of OOB components of the navigation signal into the mission receiver. From this calculation a leaking on the order of 130 dBW seems to be acceptable without the need to increase the Galileo Ground Mission Segment (GMS) or the transmission power of the European Regional Integrity Stations (ERIS).

The analyses show that an OMUX filter slope of -25dB/10MHz provides sufficient attenuation to protect the mission up-link receiver in case GMSK signals are used, assuming a decoupling of the transmission-to-mission-receiver antenna of at least -110 decibels.

Payload Architecture for a Global SPR-C Service

The selected payload architecture for the global SPR-C service consists of an NSGU and an FGUU.The signal is amplified by a set of parallel switched TWTAs.

After amplification the signals need to be combined properly and any OOB emission, filtered by the passive output filter. Finally, a globally illuminating antenna would serve as transmission antenna for the SPR-C signal.

For the SPR-C a fixed direct radiating array (DRA) with a 170-millimeter diameter and a gain of 14 decibels is proposed.

The C/-L Band payload design includes also an analysis in order to find the most appropriate payload-antenna design for the PRS-C service. The antenna simulations and payload considerations concluded that a feed array diameter of 370 millimeters, together with a feed element spacing of 62-millimeters, results in a DRA with 31 feeds — a reasonable number for the antenna design. This general antenna baseline was selected for the C-band payload.

Payload Architecture Trade-off

Three different payload architectures were analyzed in order to find the most appropriate one for the PRS-C services: digital beam-forming, RF high power beam-forming, and use of a single reflector antenna with mechanical steering.

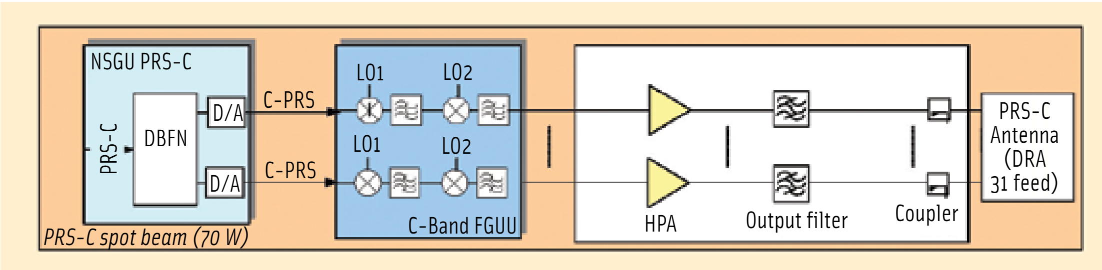

FIGURE 5 Proposed Architecture 1 for PRS-C payload (digital beam-forming network)

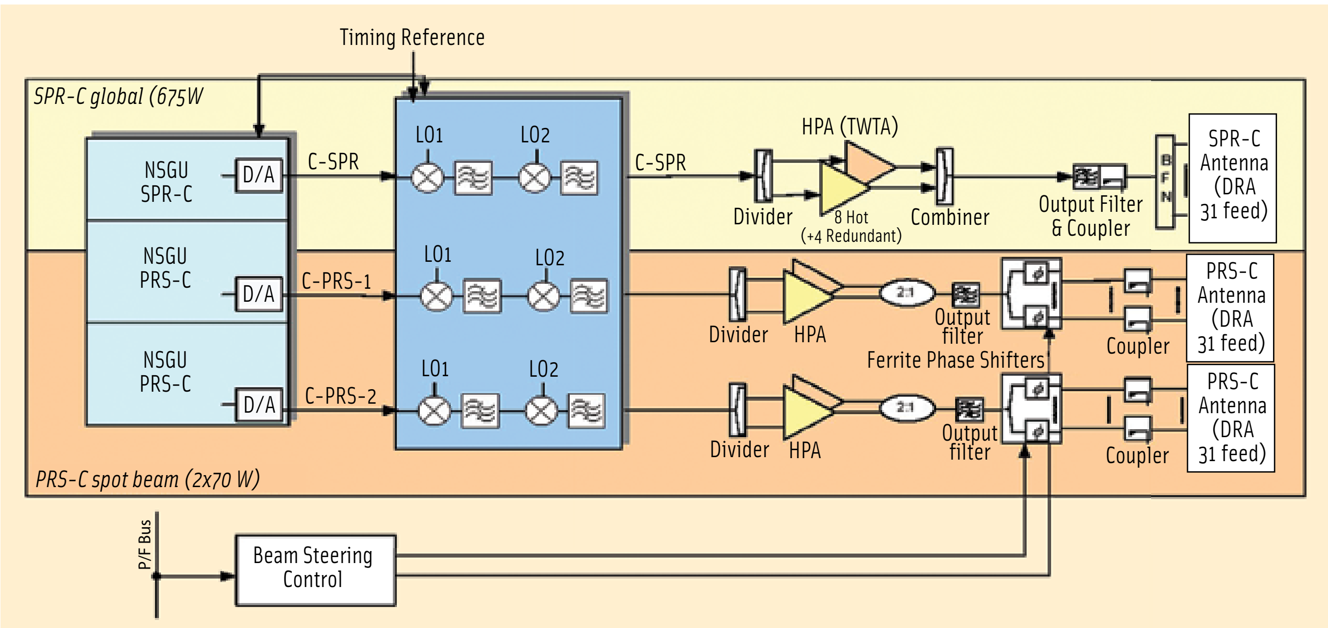

FIGURE 6 Payload Architecture 2 for PRS-C (RF high-power BFN)

The third alternative would use a single-feed reflector antenna, steering the beam by the mechanical movement of the feed, the reflector, or the whole antenna. This is the simplest architecture with the best overall power efficiency. However, the architecture has several substantial risks and will not be considered further here.

Digital Beam-Forming. The proposal would generate the PRS-C service using digital beam-forming for the two single beam PRS-C array antennas with 31 feeds. The major challenge of this approach arises from the complexity of having 31 identical channels running in parallel, because at least the analog parts (RF mixer, RF filters, amplifier, and so on) of this proposed design will show slightly different characteristics among the channels and are subject to aging effects. Furthermore the phase-synchronous distribution of the local oscillator signals with low skew over temperature is a tedious task requiring careful elaboration.

Figure 5 shows the payload architecture for a PRS-C service based on digital beam-forming (Architecture 1).

RF High-Power Beam-Forming. In contrast to digital beam-forming, Payload Architecture 2 would implement beam-forming of the PRS-C signals after amplification using ferrite phase shifters. This eases the calibration of the payload and enables the use of TWTAs. Figure 6 shows Payload Architecture 2 with a RF high power beam forming network.

Compared to a digital BFN solution, this option has a disadvantage in the drift of the characteristics of the phase shifters over temperature and/or time. However, compared to the digital beam-forming architecture, fewer sources of phase and amplitude tracking errors exist because the architecture relies on a single RF chain up to the high-power phase shifters.

Furthermore, temperature stability of the RF chain, which is one of the mayor contributors to group delay stability, might be easier to achieve with this architecture. Finally, with a centralized HPA only one output filter is required. Thus, in contrast to the low-power BFN architecture, the spacecraft accommodation for the output filter is much more relaxed.

Power and Mass Budgets

Several factors drive the requirement for payload power:

- power efficiency of the HPA
- the need to control amplification so as to ensure that signal distortions and OOB emissions are within acceptable limits
- beam-forming network architecture

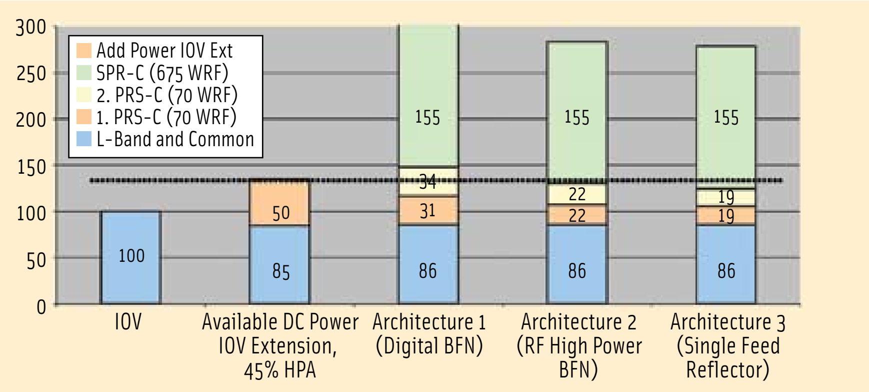

FIGURE 7 Power of different Payload Architectures relative to Galileo IOV satellite

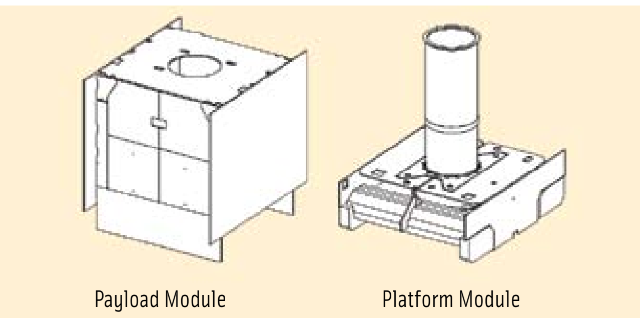

FIGURE 8 EUROSTAR 3000 bus general layout

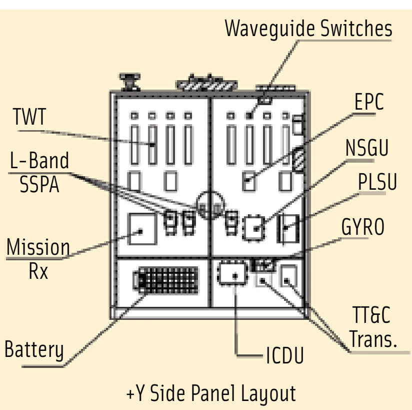

FIGURE 9 View on the C/L-band Payload showing also part of the set of TWTAs (Y-side panel)

- number of antenna feeds
- cable and filter losses.

We investigated the payload mass and power budget, taking into account the additional C-band elements and the three different PRS-C payload architectures.

Figure 7 shows the power of different C-/L-band payload architectures relative to the Galileo IOV satellite. The payload power of the Galileo IOV satellite is normalized to 100 and is shown in the first column.

The second column shows the additional power which can be gained by enlargement of the radiation areas and more efficient L-band HPAs (Extended Galileo IOV satellite). The required L-band DC power due to higher HPA efficiency expected in the next 10 years (personal information, Astrium) will reduced by 15% and the additional power available for an extended Galileo IOV satellite with L-band and C-band is marked by the dotted line.

The third column shows the required power for a global SPR-C and two spot-beam PRS-C services, which is about three times the power of the present Galileo IOV satellite. Such high power consumption can be offered only by a new generation of Galileo satellites with a size twice the present Galileo IOV satellite. Hence, for Architecture 1 (Digital BFN) with an extended Galileo IOV satellite, one PRS-C service could be offered.

For Architecture 2 (RF High Power BFN) the power efficiency is better than with digital beam-forming and two separate PRS-C services could be offered by an extended Galileo IOV satellite. Architecture 3 shows better results but has several technical risks as mentioned earlier and thus is discarded. In conclusion, the most attractive solution from power budget point of view is Architecture 2.

Compared to the Galileo L-band IOV satellite the mass increase by additional C-band services is significant. The mass impact of a PRS-C service in Architecture 1 and Architecture 2 is larger than the SPR-C because of the active BFN.

The mass estimation shows that, compared to L-band, the mass of a common C-band L-band payload is doubled.

Spacecraft Accommodation

The C-band/L-band payload architecture design has been taken as an input for the space segment in order to analyze the accommodation on the spacecraft and launcher. The accommodation analysis was performed for the two C-band service concepts displayed in Table 4 using Architecture 1 because it also covers the slightly relaxed power and mass requirements of Architecture 2.

Service Concept 1: The overall payload power for a combined C- and L-band payload is roughly three kilowatts. This value together with the mass budget is one of the input parameters for the spacecraft accommodation analysis.

The C/L-band payload budget has been considered in the overall spacecraft analysis, which, based on the Galileo mission analysis, has been extended. Taking the initial parameters into account, it becomes obvious that a satellite considerably larger than the current Galileo structure is required.

The power requirements, the thermal needs, and the mounting area needs are the drivers that have defined the size of the satellite. A modified EUROSTAR 3000 satellite bus has been selected as a potential candidate to provide a solution (see Figure 8).

To provide a thermally stable area for the RAFS and hydrogen maser clocks, the +X enclosure panel would be modified to allow for the mounting of equipment. When yaw steering is used, this side of the satellite can then be maintained in permanent shadow (Figure 9).

The Galileo C/L-band mission analysis shows that the spacecraft power would require two Galileo batteries

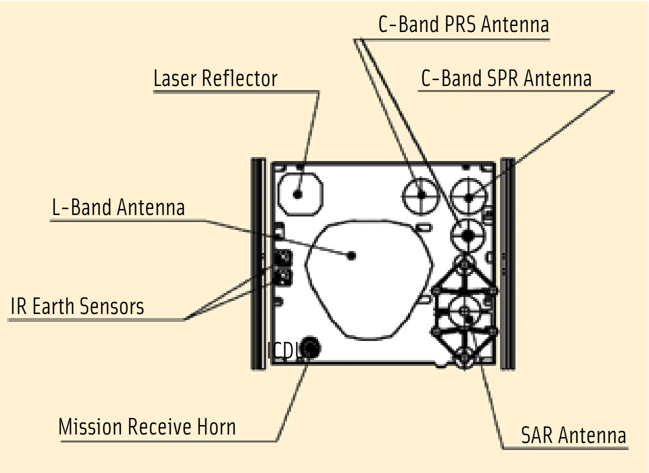

FIGURE 10 View on the C/L-band antenna side (Z-side panel)

(compared to the present Galileo IOV satellites). Two Galileo C/L band satellites would fit on an Ariane 5 launcher; one would fit on a Soyuz launcher.

Figure 10 displays the equipment accommodation on the z-side of the platform. Beneath the large L-band antenna, the three C-band antennas are visible. Additionally the search and rescue payload, the antenna of the mission uplink receiver, and infrared Earth sensors are accommodated.

A three-dimensional view of the Galileo C/L-band satellite for a global SPR-C and two spot-beam PRS-C services is shown (right side) on the opening page of this article.

Service Concept 2. An illustration of the extended Galileo IOV configuration with enhanced platform and extension of radiation areas is shown on the opening page of this article (left side).

Up to two PRS-C services using payload architecture 2 would fit on such a spacecraft. Two extended Galileo IOV satellites would fit on a Soyuz launcher, four extended Galileo IOV would fit into an Ariane 5 launcher.

End-to-End Performance

The overall performance of the SPR-C and PRS-C services has been analyzed by calculating link budgets for different receiver classes in simulated application scenarios. The analysis poses a kind of worst-case scenario for the C-band because of the substantial effects of tropospheric water vapor content there.

The link budgets include a section with the constants, service requirements (availability of service derived from the Galileo baseline), payload parameters, the atmospheric environment based on detailed analysis, and receiver requirements.

Additional discussion of the application scenarios, along with detailed tables showing the link budget parameters and values can be found on the *Inside GNSS* website: <www.insidegnss.com>.

Conclusions

We performed a detailed system study in order to analyze the advantages and the effect of an additional C-band GNSS navigation system. Two C-band services have been identified that fill niches not covered by the present Galileo L-band signals: a global Service of Precision and Robustness and two independent spot-beam Public Regulated Services.

The constellation analysis shows that a set of 27 Galileo C/L-band satellites provides sufficient navigation performance. The payload accommodation analysis shows that around three kilowatts are required for a combined C/L-band satellite offering the SPR-C and two PRS-C services. The proposed new C/L-band Galileo spacecraft design is based on a EUROSTAR 3000 bus, with two EUROSTARs fitting into an Ariane 5 launcher or one on a Soyuz launcher.

In case only two independent PRS-C services would be offered, an extended Galileo IOV platform with more efficient HPAs would be sufficient. This platform is half the size of the EUROSTAR 3000 solution, which means that four extended Galileo satellites offering L-band and spot-beam C-band services would fit on one Ariane 5 launcher and two on a Soyuz rocket.

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Manufacturers

The OD&TS performance assessment of the proposed C-band GSS network was conducted using the GNSS+ software from **DEIMOS Space**, Madrid, Spain, developed in the frame of an ESA contract.

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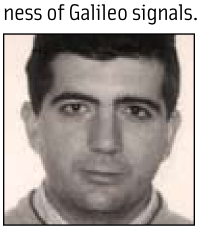

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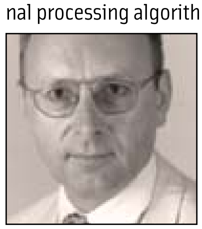

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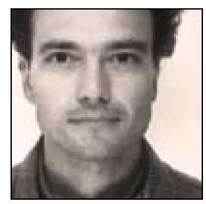

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Additional Resources

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