

EGNOS GEO Replenishment: Planning for the Future

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Abstract:

EGNOS - the European Geostationary Navigation Overlay Service - is being developed by the European Tripartite Group and will become operational in 2004. EGNOS is designed as a satellite-based augmentation to GPS (and GLONASS). It will significantly improve the performance available from these two systems, facilitating precision applications for a wide range of users.

EGNOS relies on the availability of Geostationary satellites equipped with navigation payloads to broadcast a GPS look-alike signal to users containing integrity and wide-area differential corrections. The operational system will use three satellites to disseminate these data to users: Inmarsat III Atlantic Ocean Region-East (AOR-E) at 15.5°W; Inmarsat III Indian Ocean Region (IOR) at 64°E; and ESA ARTEMIS at 21.5°E. EGNOS currently has Contract leases on the navigation payloads on the Inmarsat AOR-E and IOR satellites. The European Space Agency (ESA) has implemented a third navigation payload on its ARTEMIS Geostationary satellite, to be launched in 2001. Considering the specifications of these three GEOs, they are likely to end their nominal operational lifetime between 2007 and 2009. EGNOS, on the other hand, is currently planned to have fifteen-year lifetime starting in 2004. Hence it follows that arrangements have to be put in place to ensure navigation payload availability from 2004 through to 2018.

This paper aims at identifying and discussing a number of possible options to guarantee GEO continuity during EGNOS operational life.¹

1 – Introduction

The EGNOS System - the European Geostationary Navigation Overlay Service - is being developed in Europe to provide GPS (and GLONASS) regional augmentation services to aviation, maritime and land users [1]. The EGNOS System is being designed to serve the needs of all modes of transport in the European Region, namely: civil aviation; maritime and in-land water navigation and docking; and rail and road transport and traffic monitoring systems. EGNOS is being developed by ESA, on behalf of the European Tripartite Group and will become operational in 2004.

¹ The material presented here is only for technical discussion and does not reflect in any way EGNOS position for the EGNOS GEO replenishment, nor the position of any of the institutions for which the authors work.

The EGNOS Advanced Operational Capability (AOC) relies on navigation payloads on the following three satellites to disseminate ranging, integrity and correction data to users:

1. Inmarsat III Atlantic Ocean Region-East (AOR-E) at 15.5°W.
2. Inmarsat III Indian Ocean Region (IOR) at 64°E.
3. ESA Advanced Relay and Technology Mission Satellite (ARTEMIS) at 21.5°E.

Considering the specifications of these three GEOs, there are likely to end their nominal operation lifetime between 2007 and 2009, although the two current Inmarsat leases are due to expire in 2001. EGNOS is currently planned to have fifteen-year lifetime starting in 2004. Hence it follows that arrangements have to be put in place to ensure navigation payload availability from 2004 through to 2018.

This paper aims at opening this debate by presenting a number of possible options to guarantee GEO continuity during EGNOS operational life. Within this paper, "EGNOS GEO replenishment" refers to a strategy to ensure the availability of navigation transponders at or near the current locations. Three options are addressed in this paper, namely:

- ❑ the use of leased transponders (i.e. next generation of Inmarsat Satellites);
- ❑ piggy-back payloads on satellites "of opportunity";
- ❑ and dedicated satellites.

A brief review of the EGNOS system is provided in Section 2. Section 3 summarises the current EGNOS AOC GEO configuration, and considers the system requirements for GEO satellites. The various GEO replenishment options are presented in Section 4, before summarising the findings of this paper in Section 5.

2- Overview of the EGNOS system

This section provides a summary description of the EGNOS AOC architecture [1]. The EGNOS Reference architecture is depicted in Figure 1. It is composed of four segments: ground segment, space segment, user segment and support facilities.

The EGNOS *Ground Segment* consists of GNSS (GPS, GLONASS, GEO) *Ranging and Integrity monitoring Stations* (called RIMS) which are connected to a set of redundant control and processing facilities called *Mission Control Centre* (MCC). The system will deploy 34 RIMS located in mainly in Europe and 4 MCCs located in Torrejon (E), Gatwick (UK), Langen (D) and Ciampino (I). RIMS are equipped with external oscillators and dual frequency GPS/GLONASS/GEO receivers to track the three satellite constellations. These tracked data are then transmitted over the EGNOS Wide Area Network (EWAN) to the Master Control Centres (MCC). The MCCs produce the so-called EGNOS data products – Wide Area Differential (WAD) corrections and integrity information for each satellite. The data products are then transmitted to the Navigation Land Earth Stations (NLES) where they are scheduled to meet time-to-alarm requirements, packed into the standard message form, modulated on a GPS look-alike signal, and uplinked to the EGNOS GEOs. The system will deploy 2 NLESs (one primary and one back up) per GEO navigation transponder and an NLES for Test and Validation purposes, located in Torrejon (E), Fucino (I), Aussaguel (F), Raisting (D), Goonhilly (UK), and Sintra (P) respectively. Each GEO broadcasts a GPS look-alike signal that is modulated with the EGNOS data products. This is beneficial because each GEO ranging signal can be included in the navigation solution. However, it is also important

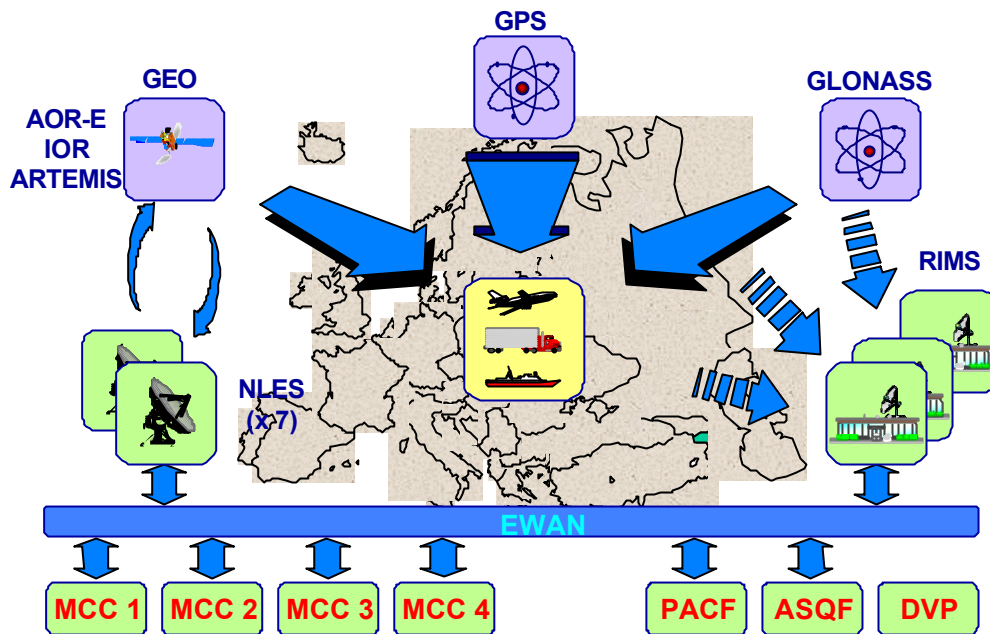


Figure 1 EGNOS AOC Architecture

to emphasise that the use of this signal is just one convenient solution for delivering the SBAS data products to the users.

The EGNOS AOC *space segment* consists of three navigation payloads on Geostationary Earth Orbit (GEO) satellites. Two of these are on Inmarsat's third generation satellites stationed at 15.5° W (Atlantic Ocean Region East (AOR-E)) and 64° E (Indian Ocean Region (IOR)). The third is on the European Space Agency's ARTEMIS satellite that will be stationed at 15° E and launched in 2000/2001. The navigation payloads on all these satellites are essentially bent-pipe transponders such that a message uploaded to the satellite is broadcast to all users in its Geostationary Broadcast Area (GBA) (see Figure 2). Those three satellites are expected to be operational up to 2007-2009. A GEO replenishment policy needs, therefore, to be defined to guarantee 15 years of operational life for EGNOS

The EGNOS *User Segment* consists of an EGNOS Standard receiver, to verify the Signal-In-Space (SIS) performance, and a set of prototype User equipment for civil aviation, land and maritime applications. That prototype equipment will be used to validate and eventually certify EGNOS for the different applications being considered.

Finally, the EGNOS support facilities include the Development Verification Platform (DVP), the Application Specific Qualification Facility (ASQF) located in Torrejon (Spain) and the Performance Assessment and System Checkout Facility (PACF) located in Toulouse (France). Those are facilities needed to support System Development, Operations and Qualification.

3- EGNOS AOC – Current GEO Configuration and Requirements

The EGNOS Advanced Operational Capability (AOC) relies on navigation payloads on the following three satellites to disseminate ranging, integrity and correction data to users.

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- ❑ Inmarsat III Indian Ocean Region (IOR) at 64°E.

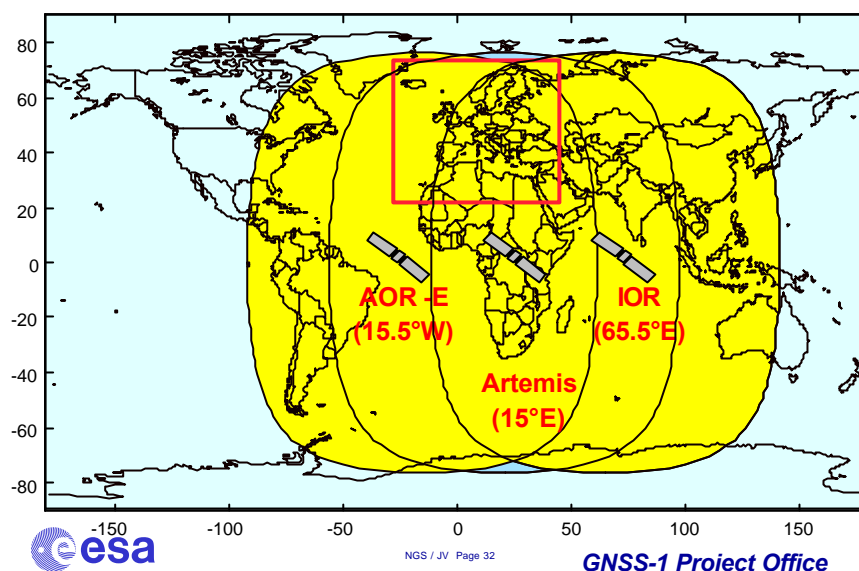


Figure 2 EGNOS AOC GEO Broadcast Areas

□ ESA ARTEMIS at 21.5°E.

The ETG currently has five-year leases for the navigation payloads on the two Inmarsat III satellites that expire in 2001. They each have a nominal 13-year life, and should be operational until 2008/9. A comprehensive description of the Inmarsat-3 Navigation Augmentation Payloads on AOR-E and IOR can be found on [2].

ESA's ARTEMIS satellite is a communications technology demonstration satellite for data relay, land mobile, and navigation applications. It was originally intended that ARTEMIS should be launched in mid-2000 on a Japanese H2-A launcher, although the exact launch date still has to be confirmed. A comprehensive description of the Artemis NAV-P/L and on its performance impact on EGNOS AOC can be found in [3] and [4], respectively. The block diagram of the ESA Artemis NAV-P/L is given in Fig. 4. The part inside the dashed box is contained into the terminal, whose photo (PFM model) is shown in Fig. 5. The measured performances of the P/L are given in Table 1. The NAV-P/L already integrated on the Artemis satellite can be seen in Fig. 6.

Receive Frequency	13875 MHz
Transmit Frequencies	12748 MHz, 1575.42 MHz
Useful Bandwidth	4 MHz
G/T	> -2.3 dB/K
EIRP	> 17 dBW Ku, > 27 dBW L
Frequency stability	$2 \cdot 10^{-11}$ (1s to 10 s), 10^{-9} (24 h), $2 \cdot 10^{-7}$ (life)
Mass & Power	28 kg & 130 Watts DC

Table 1: Artemis NAV Payload specified performance

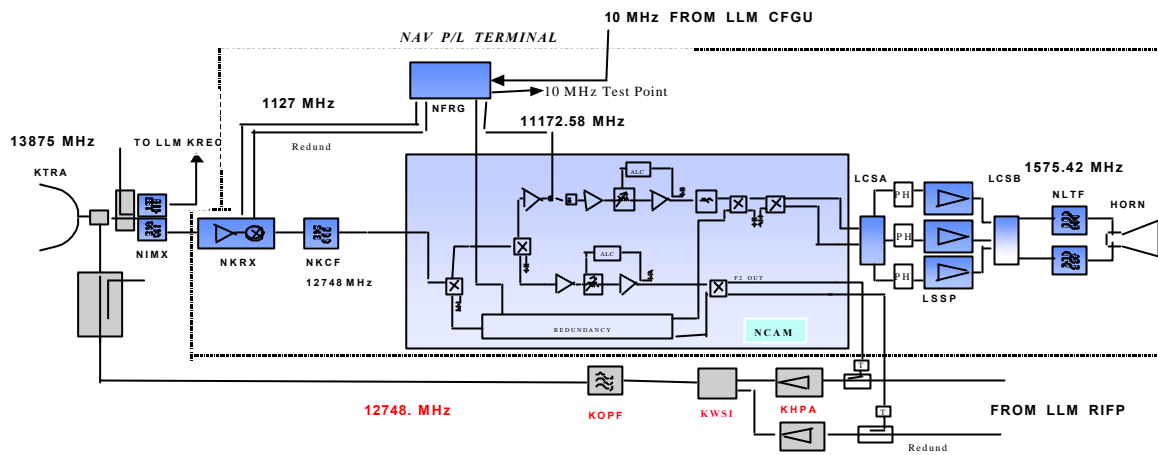


Figure 3 ARTEMIS NAV P/L Block Diagram

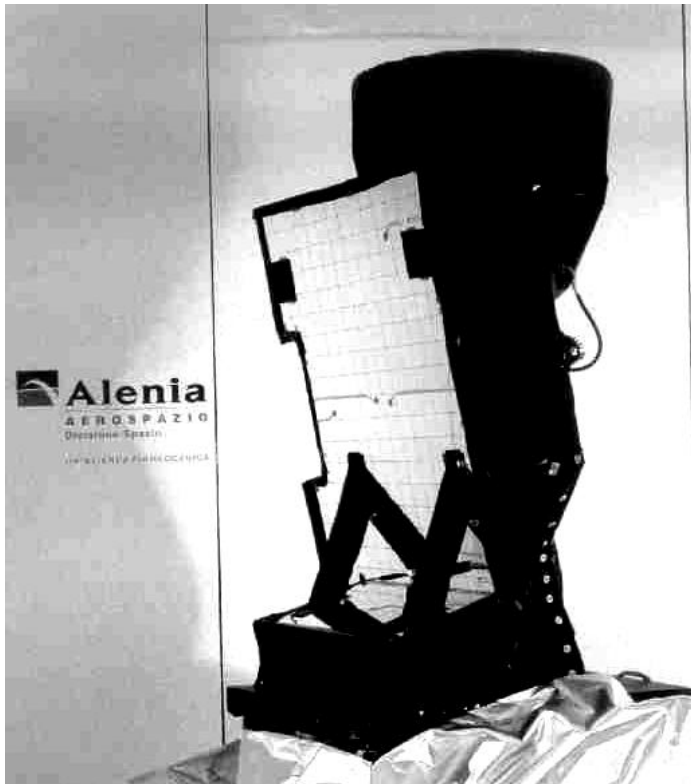


Figure 4 PFM model of the ARTEMIS NAV P/L

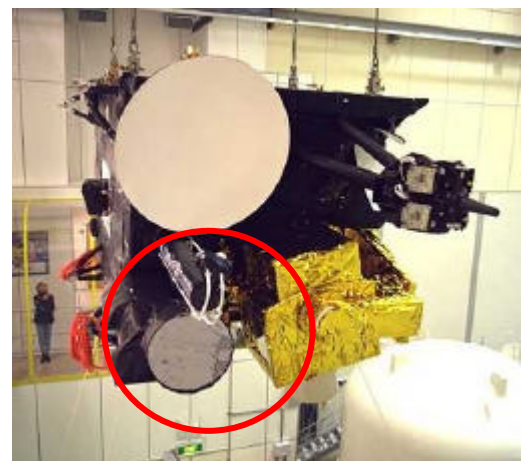
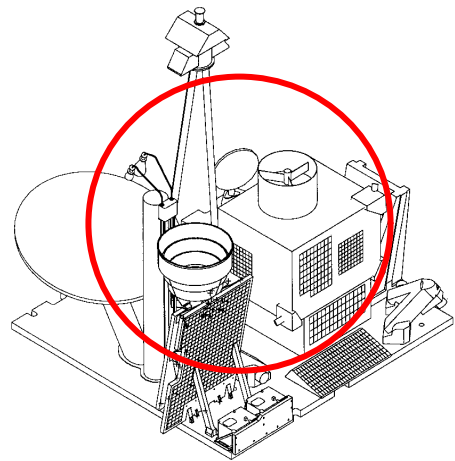


Figure 5 NAV P/L integrated on the ARTEMIS satellite

In general, the GEO orbital positions for any SBAS system should be selected with the intention of optimising the following performance features:

- ❑ GEO coverage: so that double coverage is guaranteed in the service area;
- ❑ Maximise the contribution of GEOs to the Horizontal and vertical dilution of precision (in turn, to the availability of the system);
- ❑ Maximise the GEO-visibility angle diversity in the service area, so that, the minimum GEO observable angle at high latitudes is optimised (i.e. the risk of GEO blocking is minimised).

Other GEO-related requirements for the EGNOS AOC system are summarised in Table 2.

1	There shall be dual GEO coverage at all points within the ECAC landmasses.
2	There shall be at least 1 ground (or in-orbit) GEO spare that could be operational within 3 months of a major GEO failure.
3	There shall be a well-defined GEO replenishment policy.

Table 2: EGNOS GEO System Requirements

It is interesting to see that current EGNOS AOC GEO constellation is quite optimal with respect to the above points. Indeed:

- ❑ It guarantees double coverage at any point of the ECAC region (see the shaded region in Figure 2). Furthermore, the current EGNOS AOC configuration guarantees triple GEO coverage for most of the ECAC landmasses (within which the most demanding requirements are to be met, i.e. Precision Approach).
- ❑ Because of the geometry, the impact of the GEOs on Horizontal and vertical DOP values is quite remarkable (e.g. assuming that an EGNOS AOC GEO satellite had an equivalent UDRE than a GPS satellite, it would imply an impact in the availability equivalent to that of 3 GPS satellites)
- ❑ The GEO minimum visibility angle from any position is optimised: Figure 6, shows elevation angle visibility curves linked to the two Inmarsat and the ESA Artemis satellites and Fig-8 shows the resulting elevation in the ECAC area, when the best of the three possible GEOs (in terms of elevation) is used. It may be concluded that below 60degrees North of latitude (largest part of Europe), the minimum elevation will always be above 20 degrees, between 60 and 65 degrees North elevation will always be above 15 degrees, between 65 and 70 degrees North, elevation will always be above 10 degrees.²

We may conclude, then, that it is desirable to keep current EGNOS GEO orbital position as a reference for future GEO replenishment.

² Incidentally, the EGNOS Test Bed [5], which is a prototype of the EGNOS system fully operational since Feb. 2000, is currently transmitting only through the Inmarsat AOR-E. The ESTB will be upgrade during May/June 2000, to transmit also through the Inmarsat IOR satellite. This will allow to perform real time tests at high latitudes and to see the actual impact of low elevations when the two GEOS may be accessed

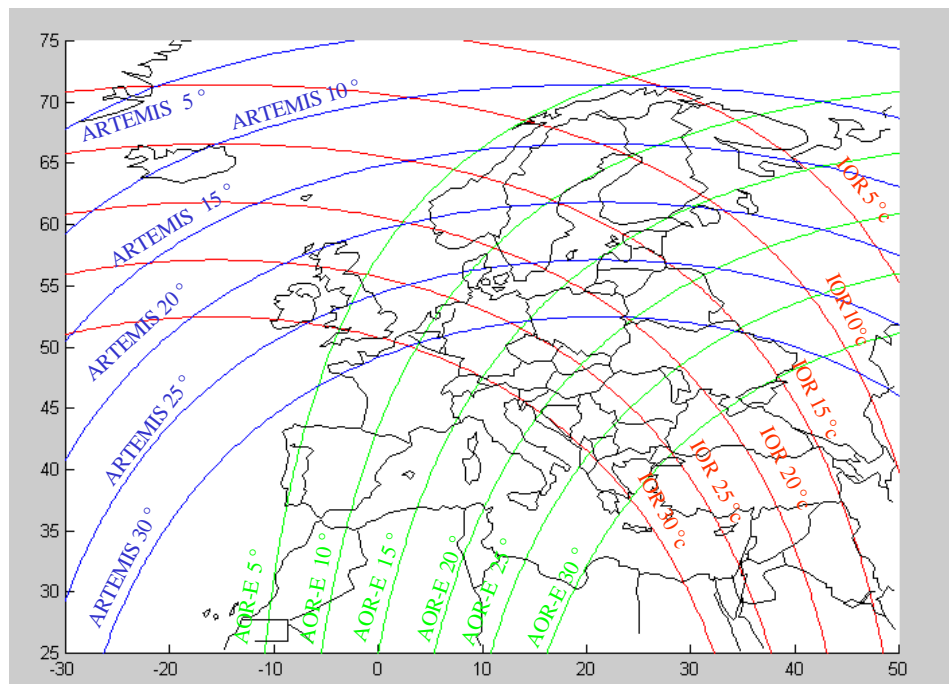


Figure 7 EGNOS GEO elevation curves overlaid on the EGNOS core service area

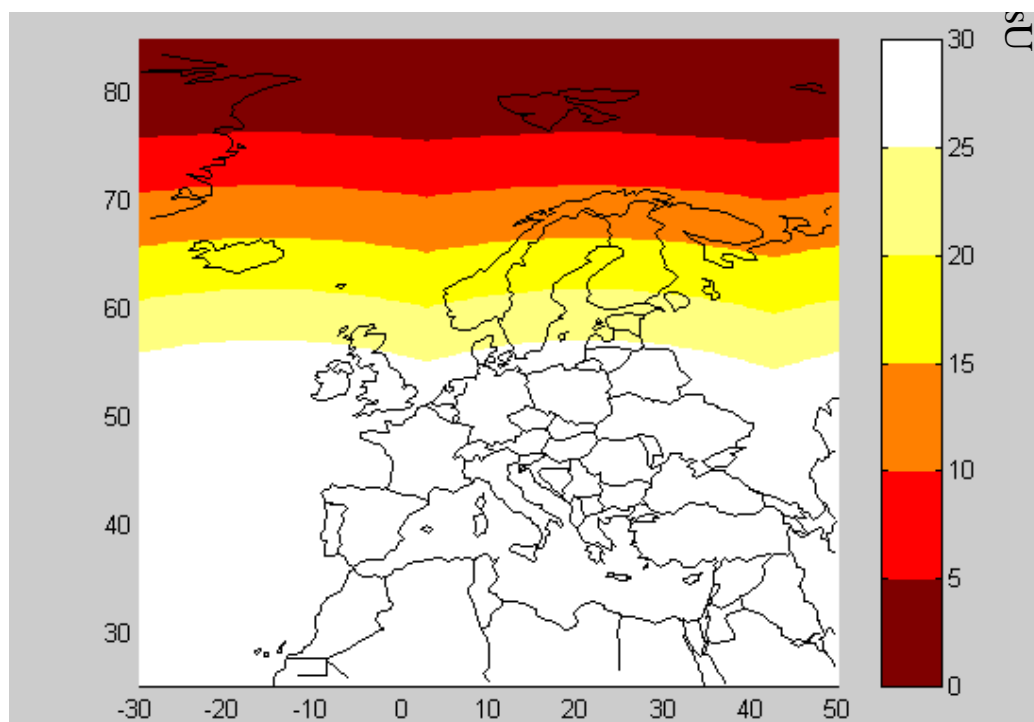


Figure 8 Maximum elevation angle in the EGNOS core area when the best of the three GEOs is used

4- Discussion on possible GEO Replenishment options

The following three options are identified here for the EGNOS GEO replenishment:

1. Next Generation of Inmarsat Satellites
2. Piggy Back Navigation Payload in a planned GEO multi-mission satellite
3. In the context of integration of EGNOS into Galileo, the implementation of GALILEO GEOs providing EGNOS links.

These three options are further described and discussed in next three sections.

4.1- Next Generation of Inmarsat Satellites

4.1.1 Description of option:

It is the authors understanding (based on some personal communications with Inmarsat) that Inmarsat is currently envisaging building three Inmarsat IV series satellites. Two of these will be stationed at the current Indian Ocean Region (IOR) and Atlantic Ocean Region West (AOR-W) positions. There will be a dual frequency navigation payload on board these satellites. The first frequency will be at the GPS L1 frequency (1575.42 MHz) modulated with data according to the RTCA WAAS MOPS - i.e. replicating the current Inmarsat III signals. The second frequency will be either at L5 or E5. Plans for configuring the second frequency are contingent upon the outcome of the World Radio Conference planned May/June 2000. One configuration under consideration could incorporate both L5 and E5 into the satellite payload and allow for in-orbit selection by ground command. It is expected that the first satellite will be delivered about 38 months after contract signature (contract signature is expected mid 2000), and I4 could be launched in 2004.

The following assumptions may be made for the purpose of the GEO Replenishment Options Trade-off:

1. Two I4 satellites will be launched in 2004 into the AOR-W and IOR positions.
2. The I4 satellites will be enhanced to have a nominal 14-year lifetime.

4.1.2 Potential Advantages

- ❑ If this new generation is launched in 2005, this option could provide GEO cover in the medium/long-term for the nominal AOR-E and IOR positions.
- ❑ If the new generation is launched in 2008, this option could provide GEO cover in the medium/long-term for the nominal AOR-E and IOR positions.
- ❑ Certainly, compatibility with current Inmarsat III would minimise EGNOS architectural changes (reuse of NLES and Long-loop shall be possible).

4.1.3 Potential Drawbacks

- ❑ The lack of I4 planned to replace AOR-E.
- ❑ Lack of replacement for the Artemis Satellite orbital position.

- ❑ Launch dates are linked to Inmarsat commercial priorities.

4.2- Piggy Back Navigation Payload in a planned GEO multi-mission satellite

4.2.1 Description of option:

The characteristics of the NAV P/L in terms of dimensions and weight (20-30 Kg), lead to consider as a valid option to use a host platform among those planned in near and long terms, and to embark a dedicated Navigation P/L as a piggy back P/L. This option was indeed followed in the case of ESA Artemis satellites ([3] and [4]), where a last-minute decision to embark a NAV P/L on board Artemis was taken and, a piggyback NAV P/L developed, independently tested, and further tested once integrated into Artemis platform.

Based on the development of the Navigation Payload on board the Artemis satellite, ESA awarded a Contract to study the characteristics of this kind of payload. In particular the modifications and improvements of the qualified flight-unit have been identified in order to minimise the interfaces with the hosting satellite, and to propose a true SBAS “piggy-back” terminal. This concept has been named SBAS Navigation Payload (SNAV) and should be adaptable to a large variety of GEO commercial satellites. The SNAV concept is described in some detailed in [6]. A block diagram of the SNAV Payload concept is illustrated in Fig. 9.

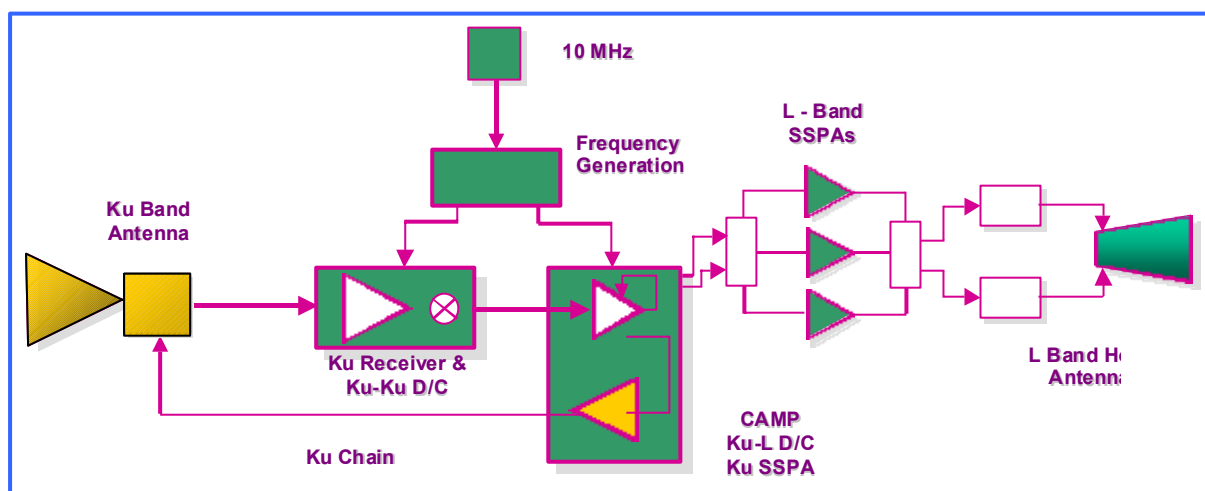


Figure 9: Self-Standing Nav payload –SNAV- schematic block diagram

In addition, it is important to note that all existing GEO NAV P/L have been developed by European Industry (Alcatel developed MTSAT NAV P/L; MMS developed Inmarsat III NAV P/Ls and ALENIA Aerospace developed ESA Artemis satellite). This approach seems therefore likely feasible in Europe.

A realistic schedule assumes the following: identifying a potential host and agreeing contracts takes between 6 and 12 months; the development phase (design, build, integration and test) takes about 2.5 years; and a further six months is required to launch the satellite and bring it to operational readiness in orbit. A fourteen-year operational life may be assumed for most of commercial GEO satellites.

4.2.2 Potential Advantages

- ❑ Relatively cheap and fastest way of putting in orbit a NAV P/L;

- ❑ Concept well understood and already proven.

4.2.3 Potential Drawbacks

- ❑ Orbital position depends on satellite primary mission which is not navigation;
- ❑ Some design and performance constraints may exist to accommodate the NAV P/L compatible with the other primary P/Ls

4.3– Galileo GEOs for EGNOS

4.3.1 Description of option:

In the context of integration of EGNOS into Galileo (currently under analysis at ESA and the European Commission), the implementation of GALILEO GEOs could provide EGNOS links. It is clear that the EGNOS services (GPS-like signals through GEO's, integrity of GPS, wide-area differential corrections) will need to be provided in parallel (or integrated) to the introduction of the Galileo signals. If geostationary satellites are finally retained as part of the Galileo space segment to transmit, in addition to the specific requirements driven by the Galileo mission, the EGNOS signals, this should be a natural option for the GEO replenishment of EGNOS AOC.

This scenario, therefore, would consist of providing the EGNOS services through the GALILEO GEO satellites. GALILEO schedule currently assumes that satellite will be operational in the 2008 timeframe. A fourteen-year life may be assumed for those GEOs.

4.3.2 Potential Advantages

- ❑ Smooth integration of EGNOS into Galileo Project;
- ❑ Current baseline for the integration of the of EGNOS into GALILEO includes the option of providing GEO satellites in Europe in adequate orbital positions to replace EGNOS GEOs.

4.3.3 Potential Drawbacks

- ❑ Galileo baseline system is not yet frozen. Some uncertainty still exists on the use or not of GEOs as a complement to the MEO satellites.
- ❑ Galileo GEOs become conditioned (at least in part) to EGNOS RF and frequency NLES constraints.

5- Summary

EGNOS AOC will start operations in 2004. The EGNOS AOC system will use three satellites to disseminate these data to users: Inmarsat III Atlantic Ocean Region-East (AOR-E) at 15.5°W; Inmarsat III Indian Ocean Region (IOR) at 64°E; and ESA ARTEMIS at 21.4°E. Considering the specifications of these 3 GEOs, there are likely to end their nominal operation life time between 2007 and 2009. EGNOS, on the other hand, is currently planned to have fifteen-year lifetime starting in 2004. Hence it follows that arrangements have to be put in place to ensure navigation payload availability from 2004 through to 2018.

Through an analysis of the current EGNOS AOC configurations and on the GEO EGNOS requirements, it has been concluded that the current EGNOS AOC configuration is quite adequate: optimal coverage for ECAC, optimises the minimum GEO elevation at any point in ECAC, and significantly improves the EGNOS availability. Moreover, it may also be concluded that it is desirable to maintain the current EGNOS GEO orbital positions as a reference for future GEO replenishment.

This paper opens the EGNOS GEO replenishment debate by presenting a number of possible options to guarantee GEO continuity during EGNOS operational life. Three options have been identified here, namely: 1) replace EGNOS GEOs by next Generation of Inmarsat Satellites; 2) Piggy Back Navigation Payload solutions in planned GEO multi-mission satellites; 3) the implementation of GALILEO GEOs providing EGNOS links. The advantages and drawbacks of these options have been addressed in the paper. The next stage is to identify a strategy for each GEO position based on a trade-off between risk, timeliness, and cost-effectiveness.

Although it is possible to guarantee EGNOS AOC operations until 2007-2009 (based on the current GEO space segment), there is a need to define both a policy and a strategy for GEO replenishment. It is the wish of the authors that this paper is a good starting reference for this exercise.

6- References

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