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WORLD WIDE RADIONAVIGATION SYSTEM

Evaluation of GALILEO Performance against Maritime GNSS Requirements

Submitted by the European Commission

SUMMARY

Executive summary:	GALILEO will be the European contribution to the Global Navigation Satellite System (GNSS). GALILEO is a global civil system comprising a constellation of satellites in Medium Earth Orbit. The system is designed to be interoperable with other existing global radio-navigation systems (GPS and GLONASS). The purpose of the present document is to provide a preliminary assessment of the Galileo navigation service requirements, as laid down in the most recent issues of the GALILEO reference documents, in view of the maritime requirements set forth in various IMO resolutions related to GNSS.
Action to be taken:	Paragraphs 21-22
Related documents:	MSC 76/INF.4, resolution A.815(19), resolution A.915(22), SOLAS Convention

INTRODUCTION

1 GALILEO will be the European contribution to the Global Navigation Satellite System (GNSS). GALILEO is a global infrastructure comprising a constellation of satellites in Medium Earth Orbit and its associated ground segment. The GALILEO programme also includes the development of user equipment, applications and services. The system is designed to be interoperable with other existing global radio-navigation systems. It is a civil system, operated under public control.

2 The Galileo programme is at present jointly managed and financed by the EC and ESA under a mandate from their member states. GALILEO shall enter into full operation in 2008.

3 Mission's objectives and main system characteristics of GALILEO where presented to the Maritime Safety Committee during its seventy-sixth session.

"11.39 The Committee noted with interest the information provided by the European Commission (MSC 76/INF.4) on the World Wide Radionavigation System Œ Galileo services and architecture, including the current baseline of the GALILEO satellite navigation system; and decided to bring document MSC 76/INF.4 to the attention of the COMSAR and NAV Sub-Committees."

"20.29 Endorsing a proposal by NAV 48, the Committee decided to include, in the Sub-Committee™s work programme, the following new subitems under the item on in World-wide radionavigation system (WWRNS):

- *subitem 1 - New developments in the field of GNSS, especially Galileo, with a target completion date of 2005;*

- *subitem 2 - Review and amendment of IMO policy for GNSS (resolution A.915(22)), with a target completion date of 2005; and*

- *subitem 3 - Recognition of radionavigation systems as components of the WWRNS (resolution A.815(19)), with a target completion date of 2005."*

4 The purpose of the present document is to provide a preliminary assessment of the Galileo navigation service requirements, as laid down in the most recent issues of the GALILEO reference documents[1], in view of the maritime requirements set forth in various IMO resolutions related to GNSS.

5 The study performed analyses the main service parameters (accuracy, integrity, continuity and availability) with respect to the very specific requirements given in two relevant IMO resolutions:

IMO resolution A.815(19) on *World-wide Radionavigation System (WWRNS)* gives a set of criteria on general and institutional issues as well as operational performance requirements for all satellite-based and terrestrial navigation systems which are to be accepted for use on ships on international voyage under IMO regulation.

IMO resolution A.915(22) on *a revised maritime policy for a future global navigation satellite system GNSS)* sets out IMO's policy on institutional and operational requirements for future satellite-based radionavigation systems and points to the directions for future amendments of A.815(19).

GALILEO SAFETY OF LIFE SERVICE PERFORMANCE

6 A reminder of the GALILEO global safety of life service performance requirement is presented in Table 1. These requirements are expressed using four classical parameters:

- Accuracy of the position at 95%

- Integrity (characterized by an alert limit, a time to alert and an integrity risk)

[1] Mission High Level Definition, Issue 3 (Sept 02)and Galileo Mission Requirement Document, Issue 5 rev 0 (Oct 02)

- Continuity assessing the risk of unscheduled service disruption due to a loss of either accuracy or integrity performance. It is defined with reference to an interval of time related to the duration of a typical operation.

- Availability assessing the statistical probability, over the life time of the system, to meet the accuracy and integrity requirements.

7 The relationship between these parameters is illustrated in Figure 1.

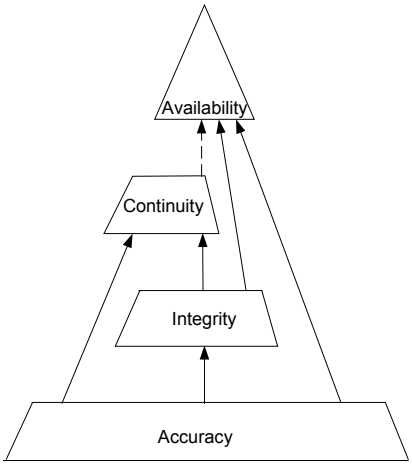


Figure 1 *: Inter-relationship between performance parameters*

		Safety-Of-Life Service	
Type of Receiver	**Carriers**	Dual or Triple Frequency	
	Computes Integrity	Yes based on global integrity service of GALILEO	
	Ionospheric correction	Based on dual-frequency measurements	
		Time Critical	***Non Time Critical***
Accuracy (95%)		H: 4 m V: 8 m	H: 220 m
Integrity	**Alarm Limit**	*H: 12 V 20 m*	*H: 556 m*
	Time-To-Alarm	*6 seconds*[2]	*10 seconds*
	Integrity risk	*$3.5x10^{-7}$ / 150 s*	*10^{-7}/hour*
Continuity Risk		*10^{-5}/15 s*	*10^{-4}/hour – 10^{-8}/hour*
Certification/Liability		Yes	
Availability of integrity		99.5%	
Availability of accuracy		99.8 %	

Table 1 *Service performances for the Galileo Safety of Life Service*

IMO RESOLUTION A. 915(22)

8 The requirements expressed for general navigation in resolution A.915(22) are reminded in Table 2. The same four basic parameters are used to define the required performance. However, it is to be noted that the integrity, continuity and availability requirements are

[2] The actual value is TBC pending the results of the feasibility phase.

expressed using different time intervals than the one adopted to specify GALILEO. It is important that a clear mapping of both sets of requirements is provided.

	System level parameters				Service level parameters			
	Absolute Accuracy	**Integrity**			**Availability % per**	**Continuity % over**	**Coverage**	**Fix interval[2] (Sec)**
	Horiz (metres)	**Alert limit (metres)**	**Time to alarm[2] (Seconds)**	**Integrity risk (per 3 hour)**	**30 days**	**3 hours**		
Ocean	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Port App & restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Notes: *1: Continuity is not relevant to ocean and coastal navigation*
2: More stringent requirements may be necessary for ships operating above 30 knots

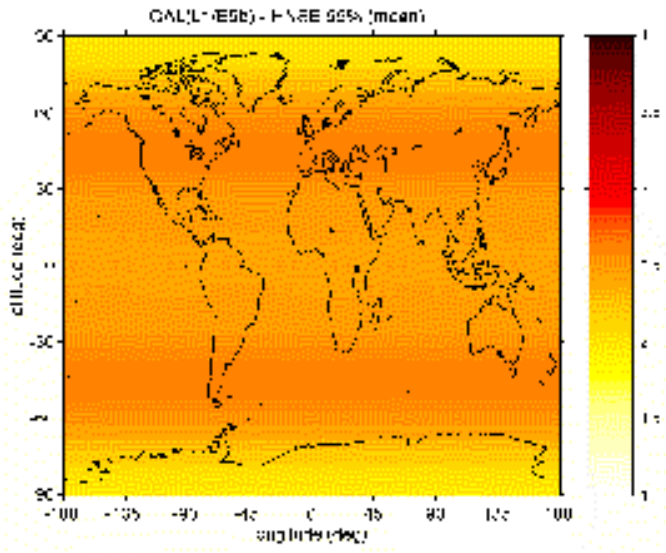
Table 2 : *Minimum maritime user requirements for general navigation*

TRACEABILITY OF REQUIREMENTS AND COMPLIANCE TO IMO RES 915

Accuracy

9 Both GALILEO and IMO requirements correspond to a 95% confidence level and they can therefore be directly compared.

The SoL service of GALILEO based on a dual frequency receiver far exceeds the expressed requirement for navigation in Ocean, Coastal, Port approach and restricted waters operations.



Integrity

10 There are two mission integrity risks specified for GALILEO.

- The first one, called critical level is $3.5*10^{-7}$ over any 150s time interval. This is further allocated to signal in space ($2*10^{-7}$ / 150s) and user receiver ($1.5*10^{-7}$ / 150s) as follows.

- The second one, called non critical level is 10^{-7}/hour and only includes signal in space contributions.

11 It is important to note that the signal in space risk (SIS risk) includes non integrity events resulting from :

a) unfortunate error combination in nominal conditions (no system failure)

b) error affecting the user position due to a system failure

12 The risk from the first component is mitigated by users in computing an error position bound (also called protection level) with a given confidence level depending on its application and based on parameters transmitted by the system.

13 The risk from the second component is directly linked to the failure modes of the GALILEO system. This means that the system design has to cope with the most demanding performance level. In our case the system design meets 10^{-7}/150s against an Horizontal Alert Limit of 12 meters (well below the HAL required for Oceanic, Coastal, Port approach and restricted waters operations) . This is equivalent to $2.5*10^{-6}$/hour.

14 Assuming that a position bound is computed in the receiver with a confidence level of 10^{-7}/hour, a maritime user will be subject to an overall integrity risk equal to:

SIS Integrity Risk for Maritime User=10^{-7}/hour+$2.5*10^{-6}$/hour =**$7.8*10^{-6}$ per 3 hours which is less than the specified integrity risk**

In addition, the GALILEO specified time to alert is fully compliant to IMO requirements of 10 s for non-local applications.

Continuity

15 The specified continuity of GALILEO corresponds to the continuity risk of losing either the system accuracy or the system integrity. For events where the integrity function is lost, the system may still provide a valid position solution within its specified accuracy requirement. There are therefore two contributors to the continuity risk :

- Event conducting to a loss of the integrity function due to an error bound (protection level) exceeding the specified alert limit for the intended operation. For the GALILEO system, this was assessed against a 12 meters horizontal alert limit and a 20 meter vertical alert limit. However, for the maritime community, the applicable horizontal alert limit is 25 meters and there are no relevant vertical alert limit. This means that the continuity risk corresponding to this first category

for the maritime sector is significantly lower than the one taken into account during system specification (based on more demanding aviation needs).

- Event conducting to a loss of the navigation function due to a system failure or bad user satellite visibility.

The GALILEO specification is 10^{-5}/15 s which translates into 0.9928 / 3 hours. This is below the specified IMO Requirements of 0.9997 / 3 hours. However, as stated above the GALILEO requirement cannot be directly compared to the IMO requirement. In fact, it is highly likely that the IMO requirement is met by the current system baseline. Detailed simulations have to be performed for the maritime domain to confirm this view.

Availability

16 Similarly, there are two separate requirements for availability corresponding to the availability of positioning function and the availability of the integrity function.

The minimum availability of the positioning function specified in 99.8% and is consistent with the IMO requirement.

17 The availability of the integrity function is assessed against tight alert limits (12 meters horizontal and 20 meters vertical) corresponding to the most stringent aeronautical application. The specification is 99.5% but because maritime alert limit is only horizontal and more relaxed, the availability will be higher.

Further simulations are required to evaluate the exact performance delivered by the system for maritime operations.

Summary

18 The GALILEO Safety Of Life service, based on the use of two frequency signals, should meet all IMO requirements for Oceanic, Coastal, Port approach and restricted waters operations.

CONCLUSIONS AND RECOMMENDATIONS

19 The analyses performed so far in the GALILEO programme indicate that the IMO requirements for Oceanic, Coastal, Port approach and restricted waters operations as stated in resolution A.915(22), can be met by the GALILEO stand-alone system using the Safety Of Life service.

20 In addition, the GALILEO Mission Requirement Document is currently being revisited and it was recently decided to add the performance requirement, as expressed by IMO, to be directly applicable to the system design. This will further ensure that GALILEO delivers a service fully in line with the expectations of the Maritime international community.

21 However, it is recommended that work is continued, under the advice of experts from the NAV subcommittee, to refine the results presented and to consolidate the demonstration of compliance of GALILEO with IMO requirements.

22 Finally, further simulations are required to assess, in details, the performance of :

- GALILEO degraded mode when a single frequency is available
- GALILEO when combined with existing GPS using independent integrity mechanism such as RAIM.

These results will be presented to subsequent meetings of the Sub-Committee.