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Part 3: Performance requirements

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Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

The present document is part 3 of a multi-part deliverable. Full details of the entire series can be found in part 1 [7].

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

The increasing expansion of location-based applications aims to satisfy more and more complex and diversified user requirements: this is highlighted for example by the widespread adoption of multi-functional smart-phones or by the ever wider adoption of tracking devices (e.g. in transport), etc. This requirement for new and innovative location-based applications is generating a requirement for increasingly complex location systems.

The wide spectrum of location-based applications identified in ETSI TR 103 183 [i.1] calls for a new and broader concept for location systems, taking into account solutions in which GNSS technologies are complemented with other technologies to improve robustness and performance. The notion of **GNSS-based location systems** is introduced and defined in the present document.

Additional clauses and information related to the implementation in **GNSS-based location systems** of the various differential GNSS technologies, namely D-GNSS, RTK and PPP are also included in order to facilitate the use of this set of standards by manufacturers and service providers.

1 Scope

This multi-part deliverable addresses integrated GNSS based location systems (GBLS) that combine Global Navigation Satellite Systems (GNSS), with other navigation technologies, as well as with telecommunication networks in order to deliver location-based services to users. As a consequence the present document is not applicable to GNSS only receivers.

This multi-part deliverable proposes a list of functional and performance requirements and related test procedures. For each performance requirement, different classes are defined allowing the benchmark of different GBLS addressing the same applications.

The present document defines Performance Features applicable to GBLS and specifies the conditions and requirements for these Performance Features.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents are necessary for the application of the present document.

[1] European GNSS (Galileo) Open Service (Issue 1.1): "Signal In Space Interface Control Document".

[2] IS-GPS-200D: "Navstar GPS Space Segment/Navigation User Interfaces", March 7, 2006.

[3] IS-GPS-705D: "Navstar GPS Space Segment/User Segment L5 Interfaces", September 24, 2013.

[4] IS-GPS-800D: "Navstar GPS Space Segment/User Segment L1C Interfaces", September 24, 2013.

[5] "Global Navigation Satellite System GLONASS Interface Control Document", Version 5.1, 2008.

[6] BDS-SIS-ICD-B1I-2.0 (December 2013): "BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal (Version 2.0)".

[7] ETSI TS 103 246-1: "Satellite Earth Stations and Systems (SES); GNSS based location systems; Part 1: Functional requirements".

[8] ETSI TS 103 246-2: "Satellite Earth Stations and Systems (SES); GNSS based location systems; Part 2: Reference Architecture".

[9] RTCM 10402.3: "Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service".

[10] RTCM 10401.2: "Standard for Differential Navstar GPS Reference Stations and Integrity Monitors (RSIM)".

[11] RTCM 10403.2: "Differential GNSS (Global Navigation Satellite Systems) Services".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 103 183: "Satellite Earth Stations and Systems (SES); Global Navigation Satellite Systems (GNSS) based applications and standardisation needs".

[i.2] IEEE 802.11™: "IEEE Standard for Information technology--Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.3] IEEE 802.15™: "Wireless Personal Area Network".

[i.4] IEEE 802.15.1™: "IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)".

[i.5] IEEE 802.15.4a™: "IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs): Amendment 1: Add Alternate PHY".

[i.6] ETSI TS 145 001: "Digital cellular telecommunications system (Phase 2+); Physical layer on the radio path; General description (3GPP TS 45.001)".

[i.7] ETSI TS 125 104: "Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD) (3GPP TS 25.104)".

[i.8] ETSI TS 136 171: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for Support of Assisted Global Navigation Satellite System (A-GNSS) (3GPP TS 36.171)".

[i.9] R. Grover Brown and Gerald Y. Chin: "GPS RAIM: Calculation of Threshold and Protection Radius Using Chi-Square Methods - A Geometric Approach", Global Positioning System: Inst. Navigat., Volume V, pages 155-179, 1997.

[i.10] Juan Blanch et al.: "An Optimized Multiple Hypothesis RAIM Algorithm for Vertical Guidance", Proceedings of ION GNSS 2007, Fort Worth (TX) September 2007.

[i.11] Miguel Azaola et al.: "Isotropy-Based Protection Levels: a Novel Method for Autonomous Protection Level Computation with Minimum Assumptions", NAVITEC 2008, Noordwijk (The Netherlands), December 2008.

[i.12] Clark B., Bevly D.: "FDE Implementations for a Low-Cost GPS/INS Module", 22nd International Meeting of the Satellite Division of The Institute of Navigation, Savannah, GA, September 22-25, 2009.

[i.13] Walter T., Enge P., Blanch J. and Pervan B.: "Worldwide Vertical Guidance of Aircraft Based on Modernised GPS and New Integrity Augmentations", Proceedings of the IEEE Volume 96, Number 12, December 2008.

[i.14] Gratton L., Joerger M., Pervan B: "Carrier Phase Relative RAIM Algorithms and Protection Level Derivation", Journal of Navigation Volume 63, Number 2, April 2010.

[i.15] Lee Y: "Optimization of Position Domain Relative RAIM", ION GNSS 21st International Technical Meeting of the Satellite Division, Savannah, GA, September 16-19, 2008.

[i.16] M. Spangenberg PhD Thesis: "Safe navigation for vehicles", Ecole doctorale Mathématiques, Informatique et Télécommunications de Toulouse, Laboratoire de Télécommunications Spatiales et Aéronautiques (TéSA), June 2009.

[i.17] J.L. Farrell: "Full integrity testing for GPS/INS", Journal of the institute of navigation Volume 53, Number 1, Spring 2006, USA.

[i.18] Clark B., Bevly D.: "FDE Implementations for a Low-Cost GPS/INS Module", 22nd International Meeting of the Satellite Division of The Institute of Navigation, Savannah, GA, September 22-25, 2009.

[i.19] DO-316: "Minimum Operational Performance Standards for Global Positioning System/Aircraft Base Augmentation System".

[i.20] Void.

[i.21] IALA Guideline No 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 - 325 kHZ - Edition 1, May 2015.

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

assistance: use of position data available from a telecommunications network to enable a GNSS receiver to acquire and calculate position (A-GNSS) under adverse satellite reception conditions

authentication: provision of assurance that the location-related data associated with a location target has been derived from real and not falsified signals

availability: percentage of time when a location system is able to provide the required location-related data

Class A, B, C: categorization of the performance level of the GBLS for a given performance feature

NOTE: In all cases Class A is the highest performance class and C is the lowest.

carrier phase measurement: measure of the range between the satellite and receiver expressed in units of cycles of the carrier frequency

continuity: likelihood that the location system functionality will be available during the complete duration of the intended operation if the system is operational at the beginning of the operation

D-GNSS: technique aiming at enhancing position accuracy and integrity of a GNSS receiver by using differential pseudorange corrections and "do not use flag" for faulty satellites delivered by a GNSS reference station located at a known location

NOTE: In the present document, the term D-GNSS refer to conventional differential GNSS.

electromagnetic interference: any source of RF transmission that is within the frequency band used by a communication link, and that degrades the performance of this link

GNSS based location system (GBLS): location system using GNSS as the primary source of positioning

GNSS only receiver: location receiver using GNSS as the unique source of positioning

Horizontal Dilution Of Precision (HDOP): measure of position determination accuracy that is a function of the geometrical layout of the satellites used for the fix, relative to the receiver antenna

integrity: measure of the trust in the accuracy of the location-related data provided by the location system and the ability to provide timely and valid warnings to users when the location system does not fulfil the condition for intended operation

jamming: deliberate transmission of interference to disrupt processing of wanted signals (which in this case are GNSS or telecommunications signals)

NOTE: Spoofing is considered to be a deceptive form of jamming.

latency: measure of the time elapsed between the event triggering the determination of the location-related data for a location target and the availability of the location-related data at the user interface

localisation: process of determining the position or location of a location target

location: 3-dimensional position or location

location-based application: application which is able to deliver a service to one or several users, built on the processing of the location information (location-related data) related to one or several targets

location-related data: set of data associated with a given location target, containing at least one or several of the following time-tagged information elements:

- location target position,
- location target motion indicators (velocity and acceleration), and
- Quality of Service indicators (estimates of the position accuracy, reliability or authenticity)

location system: system responsible for providing to a location based application the location-related data of one or several location targets

location target: physical entity on whose position the location system builds the location-related data

NOTE: This entity may be mobile or stationary.

Observed Time Difference Of Arrival (OTDOA): time interval observed between the reception of downlink signals from two different cells (in a cellular telecoms system)

NOTE: If a signal from cell 1 is received at the moment t_1, and a signal from cell 2 is received at the moment t_2, the OTDOA is $t_2 - t_1$

performance feature: set of performance requirements for a given location-related data category produced by the GBLS

position: 3-dimensional position or location

positioning: process of determining the position or location of a location target

Precise Point Positioning (PPP): Differential GNSS technique that uses a worldwide distributed network of reference stations to provide, in quasi real time, a highly accurate geodetic positioning of a receiver

privacy: function of a location system that aims at ensuring that the location target user private information (identity, bank accounts, etc.) and its location-related data cannot be accessed by a non-authorized third party

Protection Level (PL): upper bound to the positioning error such that the probability: $P(\varepsilon > \mathrm{PL}) < I_{risk}$, where I_{risk} is the integrity risk and ε is the position error

NOTE: The protection level is provided by the location system, and with the integrity risk, is one of the two sub-features of the integrity system.

pseudorange: pseudo distance between a satellite and a navigation receiver computed by multiplying the propagation delay determined by the receiver with the speed of light

Pseudo Range Correction (PRC): simple difference between a pseudorange measured by a GNSS reference station, set at a known location and the estimated range between the satellite and this known location

Real Time Kinematic (RTK): particular Differential GNSS technique that provides, in real time, highly accurate positioning of a target based on carrier phase measurements

NOTE 1: In the RTK context, the target is called the "rover", as opposed to the stationary reference station(s). RTK makes use of the carrier phase measurements, both in the reference station and in the rover, and this technique allows the ambiguities affecting these accurate measurements to be resolved.

NOTE 2: If the reference station is at an accurately known location, the rover can compute its accurate geodetic (or absolute) location. Alternatively, if the reference station's geodetic location is only roughly known, RTK can still provide high accuracy, but only on a relative and not absolute basis.

reference receiver: receiver placed at a known and surveyed position used for differential GNSS technique

NOTE: A reference receiver is an essential component of a reference station.

reference station: station placed at a known and surveyed position aiming at determining and sharing the systematic errors of at least one GNSS constellation

security: function of a location system that aims at ensuring that the location-related data is safeguarded against unapproved disclosure or usage inside or outside the *location system*, and that it is also provided in a secure and reliable manner that ensures it is neither lost nor corrupted

spoofing: transmission of signals intended to deceive location processing into reporting false location target

time-to-alert: time from when an unsafe integrity condition occurs to when an alerting message reaches the user

User Differential Range Error (UDRE): 1-sigma estimate of the pseudorange correction range error

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
A-GNSS	Assisted GNSS
DGNSS	Differential GNSS
D-GNSS	Differential GNSS
EGNOS	European Geostationary Navigation Overlay System
EMI	Electro-Magnetic Interference
EN	East/North
E-UTRA	Evolved - UMTS Terrestrial Radio Access
FFS	For Further Study
FM	Frequency Modulation
GBLS	GNSS based Location System
GIC	GNSS Integrity Channel
GLONASS	Global Navigation Satellite System (Russian based system)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile communications
HDOP	Horizontal Dilution of Precision
HPE	Horizontal Positioning Error
HPL	Horizontal Protection Level
IALA	International Association of Lighthouse Authorities
IM	Integrity Monitor
IMO	International Maritime Organization
INS	Inertial Navigation Sensor
ITS	Intelligent Transport Systems
LoS	Line of Sight
LTE	Long-Term Evolution
n/a	Not Applicable
NRTK	Network RTK
OS	Open Service
OTDOA	Observed Time Difference of Arrival
PL	Protection Level

PPP	Precise Point Positioning
PVT	Position, Velocity and Time
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radio Frequency
RMS	Root Mean Square
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SF	Scale Factor
TSP	Total Spoofing Power
TTFA	Time To Fix Ambiguity
TTFF	Time-To-Tirst-Fix
UDRE	User Differential Range Error
UMTS	Universal Mobile Telecommunications System
UTRA	UMTS Terrestrial Radio Access
Wi-Fi	Wireless Fidelity
WPAN	Wireless Personal Area Network

4 Overview of GNSS based Location System Performance Features and Classes

4.1 GNSS based Location System (GBLS)

The present document defines the performance requirements applicable to GNSS based Location System (GBLS) location-related data.

GBLS Functional Requirements and Reference Architecture in ETSI TS 103 246-1 [7] and ETSI TS 103 246-2 [8] shall apply. A GBLS intends to provide one or more users with location-related data associated with one or more location targets. Figure 1.A is an extract of ETSI TS 103 246-2 [8] and depicts the GBLS high level architecture, level 1, and Figure 1.B depicts the level 2 architecture.

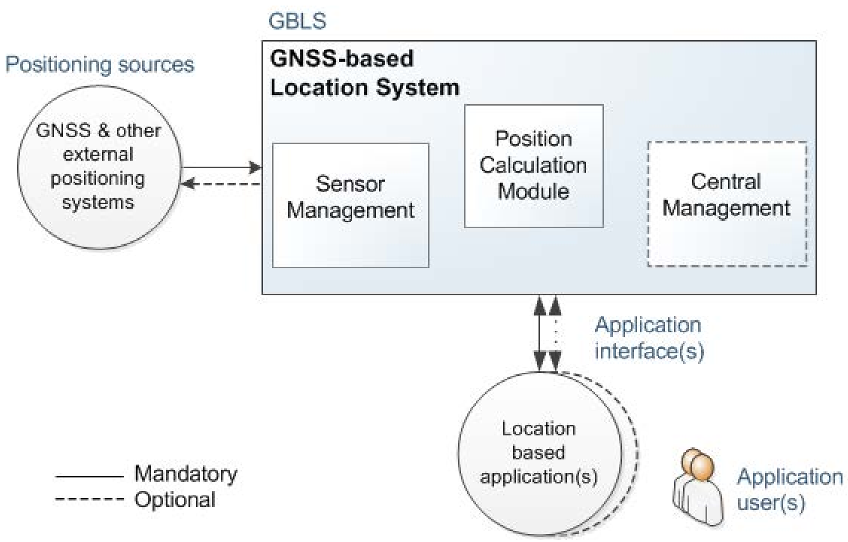


Figure 1.A: GNSS based Location System (GBLS) Architecture (level 1)

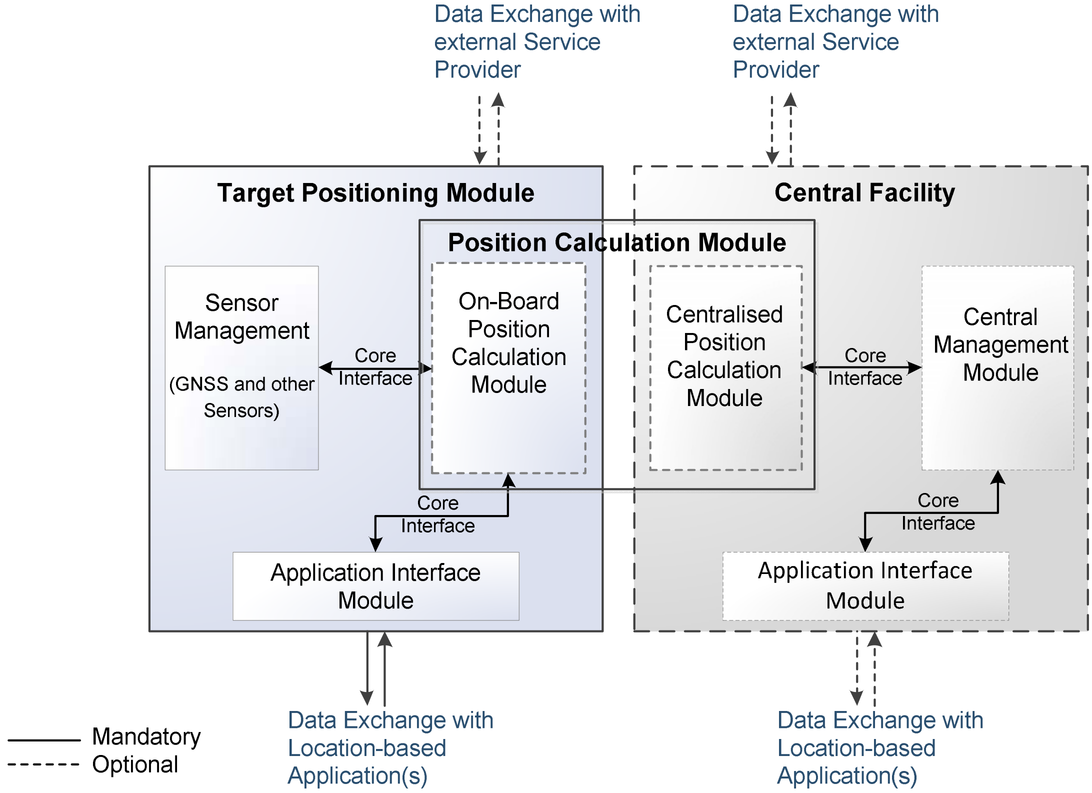


Figure 1.B: GNSS based Location System (GBLS) Architecture (level 2)

4.2 Performance Features

Location-related data delivered by a GNSS based Location System is required to meet a number of performance requirements, derived from GBLS Functional requirements ETSI TS 103 246-1 [7]. These performance requirements are grouped in categories called Performance Features.

A detailed definition of each Performance Feature with its attributes and metrics is given in clause 5. Table 1 lists the Performance Features included in this technical specification and other additional features identified but left for further study (FFS).

Table 1: GBLS Performance Features

Performance Feature	Corresponding clause
Horizontal Position Accuracy	5.2
Vertical Position Accuracy	5.3
GNSS Time Accuracy	5.4
Time-To-First-Fix	5.5
Position Authenticity	5.6
Robustness to Interference	5.7
GNSS Sensitivity	5.8
Position Integrity (Protection Level)	5.9
Position day-to-day repeatability	5.10
Time to fix ambiguity (TTFA)	5.11
Availability of Required Accuracy *(probability that PVT data is provided with a certain level of accuracy)*	*FFS*
EMI Localization Accuracy *(error of location measurement of an interfering signal)*	*FFS*
GNSS-Denied Accuracy *(error in PVT data when there is a loss of GNSS signal reception)*	*FFS*
Position Integrity (Time-to-Alert) *(the time from occurrence of an unsafe integrity condition to the issue of an alerting message)*	*FFS*
Position Integrity (Time-to-Recover-from-Alert) *(the time from cancellation of an unsafe integrity condition to removal of an alerting message)*	*FFS*
Accuracy of speed and acceleration *(horizontal and vertical)*	*FFS*
NOTE: Performance Features Position day-to-day repeatability and Time to fix ambiguity (TTFA) are relevant for highly accurate systems such as those that implement differential GNSS. In addition, TTFA applies for systems that need to determine the carrier phase ambiguities (RTK, NRTK, PPP).	

4.3 Class of Performance requirements

Associated with each Performance feature, a set of Performance requirements is defined for one or several use cases.

Three Classes of performance (A, B and C) are defined in order to categorize the performance level of the GBLS for a given Performance feature. In all cases Class A is the highest performance class and C is the lowest. The classes' contents in term of performance requirements are driven by the different implementations of the reference architecture ETSI TS 103 246-1 [7].

Performance features shall be considered independently of each other and for a given GBLS not all Performance features shall be necessarily addressed. The choice of applicable Performance features is left to users in accordance with the requirements of their targeted applications. The GBLS class of performance shall be established for each chosen performance feature and may not be the same for all of them.

For each Performance feature one or several use cases with different operational environments for each use case are considered, with corresponding metric measurements for Performance classes A, B and C. A Performance feature associated to a given use case and a given operational environment shall be considered independent to another combination. The choice of one or several use cases as well as the choice of operating environments with their corresponding Performance class is left to users in accordance with the requirement of their targeted applications. However, the compliance to a given Performance class (A, B or C) requires all metrics of the table to be met. The compliance to a Performance class does not require conformance to all use cases and all associated operational environments for that particular Performance feature.

Table 2 provides an example of selection of Performance Class for a specific GBLS application for Performance features, with different combinations of use cases with operational conditions and Performance classes.

Table 2: Example of selection of Performance Class for a specific GBLS application

Performance Features (defined in clause 5)	Use cases (defined in annex A)	Operational Environments (defined in annex A)	Selected Performance Class
Horizontal Accuracy	Static Location Target	Open Area	Class A
		Urban Area	Class B
	Moving Location Target	Urban Area	Class B
		Asymmetric Area	Class C
Vertical Accuracy	Static Location Target	Open Area	Class B
GNSS Time Accuracy	Performance Feature not considered for this specific application		
Time-to-first-fix	Static Location Target	Open Area Urban Area	Class C
Position Authenticity	Static Location target Interference (spoofing) scenario	Open Area	Class A
	Moving Location Target Interference (spoofing) scenario		Class B
Robustness to Interference	Moving Location Target 20 MHz deviation with J#2	Open Area	Class B
	Moving Location Target 10 MHz deviation with J#1		Class C
GNSS Sensitivity	Performance Feature not considered for this specific application		
Position Integrity & Protection Level	Moving Location Target	Urban Area	Class C

4.4 Use cases associated to Performance Features

For a Performance Feature, several use cases are defined, with associated performance requirements. A use case describes the applicable conditions and scenarios to be used for measuring the performance metrics. It sets the operational environment of the GBLS system, the location target motion, type of signals, etc. All these operating conditions are defined in clause A. The ranges of environments and receiver types have been chosen as the most representative of those commonly encountered today. Clause 5 defines the requirements for each feature in terms of an associated set of performance metrics (i.e. measurement parameters).

5 Performance Requirements

5.1 General

Clauses 5.2 to 5.12 define the performance requirements for each of the Performance features listed in clause 4. Considering given operating conditions, to comply with a Class of performance, the tested GBLS performances shall be equal to or better than the performance requirements of the corresponding column of the table.

The applicable GNSS and other signals are defined in clause A.2.

The performance features are defined in each case for a range of operating conditions, where applicable, including:

- Location target operational environments (see clause A.3):
  - Open area
  - Urban
  - Asymmetric area
- Location target motion types (see clauses A.4 and A.5):
  - Moving
  - Static

- GBLS types (Class A, B, C)
- Clear signal (non-interfered) or signal interference conditions (see clause A.6)
- Authenticity threat scenario and parameters (see clause A.7)
- Integrity threat scenario and parameters (see clause A.8)

5.2 Horizontal Position Accuracy

5.2.1 Definition

The Horizontal Position Accuracy is the difference (error) between the position of the location target reported by the GBLS and its true position projected onto the horizontal plane, at a given time (i.e. with a given timestamp).

The requirements for this feature can range from relaxed constraints for personal navigation applications, to more stringent ones for liability-critical applications, such as road charging, airport vehicle management, autosteering in agriculture, dangerous cargo tracking, etc.

5.2.2 Metrics

The metric used to characterize Horizontal Position Accuracy is the Horizontal Position Error over a specified time interval in terms of its:

- Mean value
- Standard deviation
- 95^{th} percentiles distribution

These metrics and their estimators are defined as follows:

- Let p be the true position of the location target.
- Let $\{\boldsymbol{p_i^*}\}_{\boldsymbol{i}\in[\mathbf{1},\boldsymbol{N}]}$ be the position estimates collected over a specified time interval (N samples), projected on the **local horizontal plane** (East/North (EN) reference frame) containing the location target true position.
- $\{\varepsilon\}_i$ is the positioning error vector, defined as $\{\varepsilon\}_i = p - \{p^*\}_i$. Note that the positioning errors are **signed numbers**.
- The mean value of the positioning error $\boldsymbol{m_\varepsilon}$ is estimated as follow:

$$\hat{m}_\varepsilon = \frac{1}{N}\left\|\sum_{i=1}^{N}\varepsilon_i\right\|$$ where: $\|x\|$ is the Euclidean norm of the vector x.

- The standard deviation $\boldsymbol{\sigma_\varepsilon}$ is estimated as follow:

$$\hat{\sigma}_\varepsilon = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left\|\varepsilon_i - \hat{\mu}_\varepsilon\right\|^2}$$ where: $\hat{\mu}_\varepsilon = \frac{1}{N}\sum_{i=1}^{N}\varepsilon_i$ is a two-dimensional vector.

The percentiles, noted $\sigma_{p^{th}}$ (i.e. respectively σ_{67} σ_{95}) are estimated using the nearest rank estimator for the p^{th} percentile:

$$\hat{\Gamma}_p^{(AC)} = Y^{(AC)}[n];$$

where: $Y^{(AC)} = sort\{\|\varepsilon^{(AC)}\|\}$ is a magnitude-ordered vector of N elements;

$\varepsilon^{(AC)}$ is the vector of the N measured errors $\varepsilon_i^{(AC)}\ i = 1 \ldots N$;

$n = \left\lceil \frac{p}{100} \cdot N \right\rceil$.

In addition to the above, when the use case considers a moving location target, the following metrics apply:

- the along-track error is the projection of the position error on the axis tangential to the location target trajectory, determined at the location target true position at the time the position was sampled by the GBLS;
- the cross-track error is the projection of the position error on the axis orthogonal to the location target trajectory, determined at the location target true position at the time the position was sampled by the GBLS.

Both of these errors are characterized by their mean value, and the 95th percentiles values.

Figure 2 illustrates these errors.

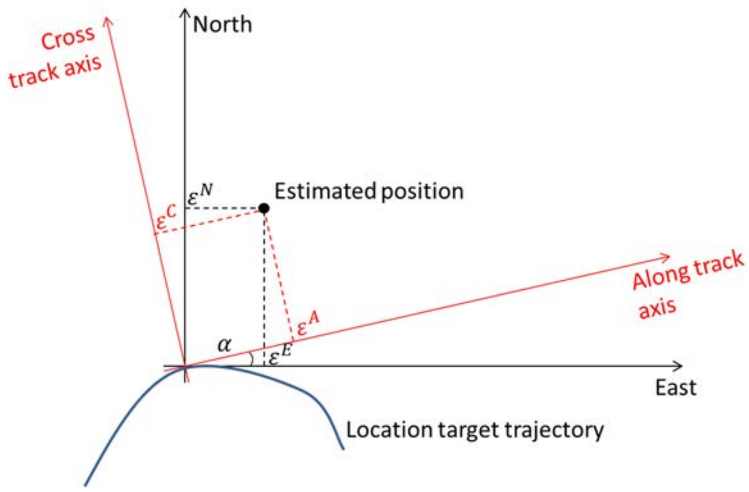


Figure 2: Definition of Cross-Track and Along-Track Position Errors

5.2.3 Performance requirements

5.2.3.1 Use case: Moving Location Target

5.2.3.1.1 Operational environment: Open area

The performance requirements are specified in table 3. The location target follows the trajectory defined in clause A.4.

Table 3: Performance requirements for Horizontal Position Accuracy, Moving location target, Open area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean error	1	4	8
Standard deviation	0,7	2	7
95th percentile	2	10	17
Mean cross track error	1,4	5,5	11
Cross track error - 95th percentile	2,8	14	24
Mean along track error	1,4	5,5	11
Along track error - 95th percentile	2,8	14	24

5.2.3.1.2 Operational environment: Urban area

The performance requirements are specified in table 4. The location target follows the trajectory defined in clause A.4.

Table 4: Performance requirements for Horizontal Position Accuracy, Moving location target, Urban area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	2	5	10
Standard deviation	2,4	5	14
95th percentile	4	17	35
Cross track error - Mean value	2,5	5,5	11
Cross track error - 95th percentile	5	20	40
Along track error - Mean value	5	13	25
Along track error - 95th percentile	10	25	50

5.2.3.1.3 Operational environment: Asymmetric area

The performance requirements are specified in table 5. The location target follows the trajectory defined in clause A.4.

Table 5: Performance requirements for Horizontal Position Accuracy, Moving location target, Asymmetric area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	1,8	5	9
Standard deviation	2	4	12
95th percentile	3,5	15	28
Cross track error - Mean value	2,2	4	10
Cross track error - 95th percentile	5	18	35
Along track error - Mean value	4,5	10	18
Along track error - 95th percentile	8	20	40

5.2.3.2 Use case: Static Location Target

5.2.3.2.1 Operational environment: Open area

The performance requirements are specified in table 6.

Table 6: Performance requirements for Horizontal Position Accuracy, Static location target, Open area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	1	4	8
Standard deviation	0,7	2	7
95th percentile	2	10	17

5.2.3.2.2 Operational environment: Urban area

The performance requirements are specified in table 7.

Table 7: Performance requirements for Horizontal Position Accuracy, Static location target, Urban area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	2	5	10
Standard deviation	2,4	5	14
95th percentile	4	17	35

5.2.3.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 8.

Table 8: Performance requirements for Horizontal Position Accuracy, Static location target, Asymmetric area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	1,8	5	9
Standard deviation	2	4	12
95th percentile	3,5	15	28

5.3 Vertical Position Accuracy

5.3.1 Definition

The Vertical Position Accuracy is the difference (error) between the position of the location target reported by the GBLS and its true position projected onto the vertical plane, at a given time (i.e. with a given timestamp).

This feature applies when vertical guidance is required, for instance to allow position coordinates provided to an emergency indoor caller to result in an "actionable location" for emergency response, especially in urban environments.

5.3.2 Metrics

The metrics are defined in the same way as for Horizontal Position Accuracy in clause 5.2.2, with "horizontal position" replaced by "vertical position".

5.3.3 Performance requirements

5.3.3.1 Use case: Moving Location Target

5.3.3.1.1 Operational environment: Open area

The performance requirements are specified in table 9. The location target follows the trajectory defined in clause A.4.

Table 9: Performance requirements for Vertical Position Accuracy, Moving location target, Open area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	2	8	16
Standard deviation	1,5	4	14
95th percentile	4	20	34

5.3.3.1.2 Operational environment: Urban area

The performance requirements are specified in table 10. The location target follows the trajectory defined in clause A.4.

Table 10: Performance requirements for Vertical Position Accuracy, Moving location target, Urban area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	4	10	20
Standard deviation	5	10	28
95th percentile	7	34	70

5.3.3.1.3 Operational environment: Asymmetric area

The performance requirements are specified in table 11. The location target follows the trajectory defined in clause A.4.

Table 11: Performance requirements for Vertical Position Accuracy, Moving location target, Asymmetric area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	4	10	18
Standard deviation	4	8	24
95th percentile	7	30	55

5.3.3.2 Use case: Static Location Target

5.3.3.2.1 Operational environment: Open area

The performance requirements are specified in table 12.

Table 12: Performance requirements for Vertical position accuracy, Static location target, Open area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	2	8	16
Standard deviation	1,5	4	14
95th percentile	4	20	34

5.3.3.2.2 Operational environment: Urban area

The performance requirements are specified in table 13.

Table 13: Performance requirements for Vertical Position Accuracy, Static location target, Urban area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	4	10	20
Standard deviation	5	10	28
95th percentile	7	34	70

5.3.3.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 14.

Table 14: Performance requirements for Vertical Position Accuracy, Static location target, Asymmetric area

Metric	Max position error (m)		
	Class A	Class B	Class C
Mean value	4	10	18
Standard deviation	4	8	24
95th percentile	7	30	55

5.4 GNSS Time Accuracy

5.4.1 Definition

GNSS Time Accuracy is the difference between the true GNSS time (reference time of the GNSS system) and the time computed by the GBLS System.

For example, applications requiring synchronization of assets distributed across wide geographical areas can use GNSS time as a reference.

5.4.2 Performance requirements

5.4.2.1 Use case: Moving Location Target

5.4.2.1.1 Operational environment: Open area

The performance requirements are specified in table 15. The location target follows the trajectory defined in clause A.4.

Table 15: Performance requirements for GNSS Time Accuracy, Moving location target, Open area

Metric	Maximum time error (ns)		
	Class A	Class B	Class C
Mean value	6	37	93
95th percentile	13	97	163

5.4.2.1.2 Operational environment: Urban area

The performance requirements are specified in table 16. The location target follows the trajectory defined in clause A.4.

Table 16: Performance requirements for GNSS Time Accuracy, Moving location target, Urban area

Metric	Maximum time error (ns)		
	Class A	Class B	Class C
Mean value	76	317	627
95th percentile	130	483	1 180

5.4.2.1.3 Operational environment: Asymmetric area

The performance requirements are specified in table 17. The location target follows the trajectory defined in clause A.4.

Table 17: Performance requirements for GNSS Time Accuracy, Moving location target, Asymmetric area

Metric	Maximum time error (ns)		
	Class A	Class B	Class C
Mean value	76	403	873
95th percentile	193	880	1 720

5.4.2.2 Use case: Static Location Target

5.4.2.2.1 Operational environment: Open area

The performance requirements are specified in table 18.

Table 18: Performance requirements for GNSS Time Accuracy, Static location target, Open area

Metric	Maximum time error (ns)		
	Class A	Class B	Class C
Mean value	6	17	70
95th percentile	17	50	117

5.4.2.2.2 Operational environment: Urban area

The performance requirements are specified in table 19.

Table 19: Performance requirements for GNSS Time Accuracy, Static location target, Urban area

Metric	Maximum time error (ns)		
	Class A	Class B	Class C
Mean value	216	260	520
95th percentile	440	483	927

5.4.2.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 20.

Table 20: Performance requirements for GNSS Time Accuracy, Static location target, Asymmetric area

Metric	Maximum time error (ns)		
	Class A	Class B	Class C
Mean value	403	517	670
95th percentile	653	850	1 557

5.5 Time-to-First-Fix (TTFF)

5.5.1 Definition

TTFF is the time taken by the GBLS to provide location-related data, starting either from the reception of a request, or from another triggering event (for instance for periodic or geo-dependent reporting).

The TTFF is defined for a cold-start condition, defined as the GNSS receiver having:

- no prior information;
- inaccurate estimates of its position, velocity and time; or
- inaccurate positions of any of the GNSS satellites.

In this case, the receiver will systematically search for all possible satellites.

Depending on GBLS capability, the GBLS positioning module can acquire **assistance data** (provided by the central facility for instance ETSI TS 103 246-2 [8]) to reduce the TTFF. Assistance data contains information on time and GNSS ephemeris, etc.

5.5.2 GBLS starting conditions

The following start conditions as defined in table 24 are used for the definition of performance requirements:

- **Assisted cold-start with fine time assistance.** At the start point, the GBLS is provided with assistance data, which may include estimates of, its position, velocity, and information on, or position knowledge of, relevant GNSS satellites. It also includes a good estimate of current time to the microsecond level of accuracy. This allows the GBLS to make an accelerated fix.
- **Assisted cold-start with coarse time assistance.** At the start point, the GBLS is provided with necessary assistance data, which may include estimates of its position, velocity, and information on, or position knowledge of, relevant GNSS satellites. It also includes an estimate of current time to the second level of accuracy. This allows the GBLS to make an accelerated fix.
- **Cold-start without assistance**.

NOTE 1: Cold-start only is considered because it offers discrimination between system configurations.

The starting conditions are detailed in table 21.

Table 21: Description of starting conditions

Assisted Condition	Max time error at GNSS sensor start	Max Position error at GNSS sensor start	GNSS Satellites Ephemeris	Precise Time of Week
Assisted cold-start with fine time assistance	±10 µs (retrieved from assistance data)	Retrieved from assistance data: Horizontal: ±3 km Altitude: ±500 m	Retrieved from assistance data	From assistance data
Assisted cold-start with coarse time assistance	±2 s (retrieved from assistance data)			Decoded from satellite data, or calculated as additional state of the navigation
Cold-start without assistance	None	Not known	Decoded from satellite data	Decoded from satellite data

Max time error: the time difference between the GNSS time provided in assistance data and the real GNSS time.

Max Position error: the difference between the estimated position of the receiver provided by the assistance server and the real position of the receiver.

GNSS Satellites Ephemeris: the current fine orbital parameters of GNSS satellites that should be visible from the position of the receiver and provided in assistance data.

GNSS Time of the Week: the time stamp broadcast by GNSS satellites in their navigation message and provided in assistance data.

NOTE 2: Assistance data allows the GBLS to restrict its search area for satellites signals and data in order to expedite the elaboration of a first position fix.

5.5.3 Performance requirements

5.5.3.1 Use case: Moving Location Target

5.5.3.1.1 Operational environment: Open area

The performance requirements are specified in table 22. The location target follows the trajectory defined in clause A.4.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 100 m.

Table 22: Performance requirements for TTFF, Moving location target, Open area

Metric	TTFF [s]		
	Class A	Class B	Class C
Mean value	1,6	2,5	30
Standard deviation	0,12	0,4	5
95th percentile	1,7	3,3	37

5.5.3.1.2 Operational environment: Urban area

The performance requirements are specified in tables 23 and 24. The location target follows the trajectory defined in clause A.4.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 100 m.

Table 23: Performance requirements for TTFF, Moving location target, Urban area.

Metric	TTFF [s]		
	Class A	Class B	Class C
Mean value	1,6	4,4	56
Standard deviation	0,16	1,4	8
95th percentile	1,8	7,2	69

Table 24: Performance requirements for TTFF, Moving location target, with interference (Medium level: -9 dB), Urban area

Metric	TTFF [s]		
	Class A	Class B	Class C
Mean value	3,8	21,0	60
Standard deviation	1,4	7,7	10
95th percentile	5,3	29,3	74

5.5.3.1.3 Operational environment: Asymmetric area

The performance requirements are specified in tables 25 and 26. The location target follows the trajectory defined in clause A.4.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 100 m.

Table 25: Performance requirements for TTFF, Moving location target, Asymmetric area

Metric	TTFF [s]		
	Class A	**Class B**	**Class C**
Mean value	1,5	5,4	n/a (see note)
Standard deviation	0,6	2,1	n/a (see note)
95th percentile	2	10	n/a (see note)
NOTE: Class C receivers do not have a requirement to achieve a position fix in the asymmetric area scenario.			

Table 26: Performance requirements for TTFF, Moving location target with interference (Medium level: -9 dB), Asymmetric area

Metric	TTFF [s]		
	Class A	**Class B**	**Class C**
Mean value	11	21	n/a (see note)
Standard deviation	6,6	7,7	n/a (see note)
95th percentile	22	30	n/a (see note)
NOTE: Class C receivers do not have a requirement to achieve a position fix in the asymmetric area scenario.			

5.5.3.2 Use case: Static Location Target

5.5.3.2.1 Operational environment: Open area

The performance requirements are specified in table 27. In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 100 m.

Table 27: Performance requirements for TTFF, Static location target, Open area

Metric	TTFF[s]		
	Class A	**Class B**	**Class C**
Mean value	1,6	2,5	30
Standard deviation	0,12	0,4	5
95th percentile	1,7	3,3	37

5.5.3.2.2 Operational environment: Urban area

The performance requirements are specified in table 28. In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 100 m.

Table 28: Performance requirements for TTFF, Static location target, Urban area

Metric (as per clause 4.2)	TTFF[s]		
	Class A	**Class B**	**Class C**
Mean value	1,5	3,5	56
Standard deviation	0,4	0,9	8
95th percentile	2	5,4	69

5.5.3.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 29. In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 100 m.

Table 29: Performance requirements for TTFF, Static location target, Asymmetric area

Metric	TTFF[s]		
	Class A	Class B	Class C
Mean value	2	5,4	n/a (see note)
Standard deviation	1,8	2,1	n/a (see note)
95^{th} percentile	7,4	9,7	n/a (see note)
NOTE: Class C receivers do not have a requirement to achieve a position fix in the asymmetric area scenario.			

5.6 Position Authenticity

5.6.1 Definition

Position Authenticity gives a level of assurance that the data for a location target has been derived from real signals relating to the location target.

GBLS authenticates the estimated positions by means of specific algorithms that detect, and possibly mitigate, the presence of structured RF interference (i.e. RF spoofing, see ETSI TS 103 246-1 [7]).

The position authenticity performance is defined by the ability of the GBLS to provide authentic positioning data (i.e. positioning data computed through the processing of true GNSS signals) and to promptly detect spoofing attempts (i.e. detection of false GNSS signals intentionally transmitted to deceive the GBLS).

5.6.2 Metrics

The Position Authenticity performance is defined in terms of:

- Probability of false alarm (P_{FA}): the probability that the GBLS falsely detects spoofed GNSS signals when there is no RF spoofing attack (clear scenario).
- Probability of detection (P_D): the probability that the GBLS detects spoofed GNSS signals during an RF spoofing attack; (interference scenario).

5.6.3 Performance requirements

5.6.3.1 Specific conditions and interference threat scenarios

The interference threat scenarios for position authenticity are defined in clause A.7.

These scenarios represent a typical spoofing attack against the GBLS. The scenarios can be easily replicated in a controlled environment and was used to derive the performance requirements given below.

The applicable operational environment is the Open Sky Plot (see clause A.3), either in clear or interference scenarios.

Two use cases are considered:

- Case 1: moving location target defined in clause A.5.
- Case 2: static location target.

Latency condition: the latency to provide authenticity shall not exceed 5 s.

5.6.3.2 Use case: Moving Location Target

5.6.3.2.1 Operational environment: Open area

The P_{FA} shall meet the levels specified in table 30.

Table 30: Performance requirements for P_{FA}, Moving location target, Open area

Maximum False Alarm probability (%)		
Class A	**Class B**	**Class C**
0,20	1,0	10

5.6.3.2.2 Operational environment: Interference (Spoofing) Scenario

The P_D shall meet the following requirements.

Table 31: Performance requirements for P_D, Moving location target, Spoofing scenario

Interference scenario (clause A.7)	Maximum Total Spoofing Power [dBW]	Maximum Error	Minimum P_D (%)		
			Class A	**Class B**	**Class C**
M-1	-143,5	$0,55 \times 10^{-6}$ s	85	75	68
	-142,5	$0,66 \times 10^{-6}$ s	92	85	80
	-141,5	$0,75 \times 10^{-6}$ s	98	95	90
M-2	-147,5	170 m	85	75	68
	-146,5	200 m	92	85	80
	-145,5	228 m	98	95	90
M-3	-147,5	57 m	85	75	68
	-146,5	70 m	92	85	80
	-145,5	78 m	98	95	90

5.6.3.3 Use case: Static Location Target

5.6.3.3.1 Operational environment: Open area

The P_{FA} shall meet the levels specified in table 32.

Table 32: Performance requirements for P_{FA} Requirement, Static location target, Open area

Maximum False Alarm probability (%)		
Class A	**Class B**	**Class C**
0,05	0,20	1,0

5.6.3.3.2 Operational environment: Interference (Spoofing) scenarios

The P_D shall meet the following requirements.

Table 33: Performance requirements for P_D, Static location target, Spoofing scenario

Interference scenario (clause A.7)	Maximum Total Spoofing Power (dBW)	Maximum Error	Minimum P_D (%)		
			Class A	Class B	Class C
S-1	-156,09	$0,48 \times 10^{-6}$ s	90	75	63
	-154,46	$0,58 \times 10^{-6}$ s	95	90	85
	-153,5	$0,68 \times 10^{-6}$ s	98	97	95
S-2	-156,09	145 m	90	75	63
	-154,46	175 m	95	90	85
	-153,5	205 m	98	97	95
S-3	-156,09	40 m	90	75	63
	-154,46	48 m	95	90	85
	-153,5	56 m	98	97	95

5.7 Robustness to Interference

5.7.1 Definition

GBLSs might be required to operate in RF environments subject to interference, in particular in the GNSS frequency bands.

Robustness to interference characterizes the ability of the receiver to operate under interference conditions and maintain an appropriate level of performance in terms of PVT degradation.

Robustness to Interference is the PVT degradation caused by interference sources and is defined in terms of:

- increase of the horizontal position error;
- decrease of availability of the position fix.

5.7.2 Metrics

The performance parameters which characterize the robustness to interference are the following:

- position fix accuracy (horizontal) with degradation under interference conditions;
- position fix availability as a function either of the jammer distance or the jamming-to-GNSS signal power ratio (J/S).

The robustness to interference is characterized by the maximum tolerable J/S, which is defined as that providing a position fix availability greater than 90 % with a maximum horizontal error of 100 m. The horizontal position error statistics provided are based on position fixes satisfying the condition of a maximum horizontal error of 100 m.

5.7.3 Performances requirements

5.7.3.1 Specific conditions and operational environment

The operational environment applicable to Robustness to Interference Performance Feature is the Open Area type, defined in clause A.3. The location target follows the trajectory defined in clause A.4. The jammers to be used are J#1 and J#2, defined in clause A.6.

5.7.3.2 Use case 1: 20 MHz FM deviation

The performance requirements are specified in tables 34 and 35.

Table 34: Performance requirements for Robustness to Interference with J#1

Metric	Performance requirement		
	Class A	Class B	Class C
maximum J/S (dB)	89,0	83,0	77,0
minimum Jammer distance (m)	28,0	45,1	64,5
Maximum Horizontal Position Error [m]			
Mean value	64,0	64,0	64,0
Standard deviation	15,7	15,7	15,7
95^{th} percentile	96,2	96,2	96,2

Table 35: Performance requirements for Position fix accuracy (Horizontal) with degradation under interference conditions with J#1

J/S [dB]			Maximum Horizontal Position Error [m]		
Class A	Class B	Class C	Mean value	95^{th} percentile	Standard deviation
< 85	< 78	< 72	46,7	50,1	1,9
85	79	73	52,6	59,1	3,6
86	80	74	52,5	63,5	4,5
87	81	75	55,2	61,9	3,1
88	82	76	52,7	74,2	8,4
89	83	77	64,1	96,2	15,7

- J/S (dB) figures characterize the interference power applied to the GBLS and are expressed in term of Jamming to Signal Ratio. The applicable J/S values are sorted by Class of GBLS (A, B, C) and increasing from the top to the bottom of the table.
- Maximum Horizontal Position Error (m) values characterize the GBLS maximum Horizontal accuracy error that can be tolerated when applying the corresponding J/S to the GBLS. As set in clause 5.7.2, the maximum tolerable error is 100 m whatever is the applied J/S.
- The performance Class of a GBLS is then determined by the interference power it tolerates for a given Horizontal accuracy error and not directly by the error resulting from the interference power. A Class A GBLS being more resistant to interference than a GBLS Class B or C, it tolerates higher J/S than those tolerated by Class B and C.

5.7.3.3 Use case 2: 10 MHz FM deviation

The performance requirements are specified in tables 36 and 37.

Table 36: Performance requirements for Robustness to Interference with J#2

Metric	Performance requirement		
	Class A	Class B	Class C
maximum J/S (dB)	70	64	58
minimum Jammer distance (m)	68	87	105
Maximum Horizontal Position Error [m]			
Mean value	52,6	52,6	52,6
Standard deviation	12,8	12,8	12,8
95^{th} percentile	87,6	87,6	87,6

Table 37: Performance requirements for Position fix accuracy (Horizontal) with degradation under interference conditions with J#2

J/S [dB]			Maximum Horizontal Position Error [m]		
Class A	Class B	Class C	Mean value	95th percentile	Standard deviation
< 67	< 61	< 55	44,2	46,5	1,1
67	61	55	48,6	65,3	6,4
68	62	56	49,2	65,9	6,4
69	63	57	50,1	79,7	11,3
70	64	58	52,6	87,6	12,8

- J/S (dB) figures characterize the interference power applied to the GBLS and are expressed in term of Jamming to Signal Ratio. The applicable J/S values are sorted by Class of GBLS (A, B, C) and increasing from the top to the bottom of the table.
- Maximum Horizontal Position Error (m) values characterize the GBLS maximum Horizontal accuracy error that can be tolerated when applying the corresponding J/S to the GBLS. As set in clause 5.7.2, the maximum tolerable error is 100 m whatever is the applied J/S.
- The performance Class of a GBLS is then determined by the interference power it tolerates for a given Horizontal accuracy error and not directly by the error resulting from the interference power. A Class A GBLS being more resistant to interference than a GBLS Class B or C, it tolerates higher J/S than those tolerated by Class B and C.

5.8 GNSS Sensitivity

5.8.1 Definition

GNSS Sensitivity is defined in terms of the maximum masking (attenuation) values tolerated by the GBLS while still allowing the provision of the required location-related data. It is respectively specified for Tracking and Acquisition.

5.8.2 Metrics

The Tracking Sensitivity is defined as the maximum attenuation (dB) which allows the receiver to provide a position fix.

The Acquisition Sensitivity is defined as the maximum attenuation (dB) which allows the receiver to have a first position fix within a given time.

5.8.3 Performance requirements

5.8.3.1 Operational scenario and specific masking conditions

The Location target follows the trajectory defined in clause A.4.

Two different environment types are used: Open area and Asymmetric area with specific masking conditions. The Sky Attenuation Conditions described in clause A.3.2 are used with attenuation values to compute the position fix delivered by the location-related data:

- Open sky masking condition: x_1 variable, x_2 set to 100 dB (table 39).
- Asymmetric visibility masking condition: x_1 set to 0 dB, x_2 set to 100 dB, x_3 variable (table 40).

GNSS Time assistance is provided for both environments. GNSS Time assistance is provided through assistance data and gives an estimation of the GNSS Time and other information to fasten the computation of a position fix. Two types of assistance are usually defined, fine time assistance and coarse time assistance (detailed in table 21).

Table 38 summarizes the applicable operational conditions for the Performance Feature GNSS Sensitivity.

Table 38: Specific conditions applicable to GNSS Sensitivity

Use case	Operational environment type	Location target Scenario	Masking parameters x1, x2 and x3 from clause A.3.2	Assistance data
Use case 1	Open area (clause A.3)	Moving Scenario (clause A.4)	Variable, see table 39	Fine-time assistance
Use case 2	Asymmetric area (clause A.3)	Moving Scenario (clause A.4)	Variable, see table 40	Coarse-time assistance

5.8.3.2 Use case 1: Open area and fine time assistance

The performance requirements are specified in tables 39 and 40. For all tables performance requirements are met if the receiver is able to provide a position fix with a horizontal position error and probability as defined above in clause 5.8.2.

Table 39: Performance requirements for GNSS Sensitivity, Open area and fine time assistance

Operational condition: Signal Power Attenuation [dB] (x1 and x2 defined in clause A.3.2)			Tracking/ Acquisition Sensitivity	Metrics	Performance requirements		
Class A	Class B	Class C			Class A	Class B	Class C
x1 = 33 x2 = 100	x1 = 28 x2 = 100	x1 = 18 x2 = 100	Tracking sensitivity	Horizontal position error with a probability greater than 90 %	< 100 m	< 100 m	< 100 m
x1 = 32 x2 = 100	x1 = 20 x2 = 100	x1 = 16 x2 = 100	Acquisition sensitivity	Horizontal position error with a probability greater than 90 %	< 100 m	< 100 m	< 100 m
				Time of the first position fix	< 300 s	< 300 s	< 300 s

5.8.3.3 Use case 2: Asymmetric area and coarse time assistance

The performance requirements are specified in table 40.

Table 40: Performance requirements for GNSS Sensitivity, Asymmetric area and coarse time assistance

Operational condition: Signal Power Attenuation [dB] (x1,x2 and x3 defined in clause A.3.2)			Tracking/ Acquisition Sensitivity	Metrics	Performance requirements		
Class A	Class B	Class C			Class A	Class B	Class C
x1 = 0 x2 = 100 x3 = 33	x1 = 0 x2 = 100 x3 = 28	x1 = 0 x2 = 100 x3 = 18	Tracking sensitivity	Horizontal position error with a probability greater than 90 %	< 100 m	< 100 m	< 100 m
x1 = 0 x2 = 100 x3 = 32	x1 = 0 x2 = 100 x3 = 20	x1 = 0 x2 = 100 x3 = 16	Acquisition sensitivity	Horizontal position error with a probability greater than 90 %	< 100 m	< 100 m	< 100 m
				Time of the first position fix	< 300 s	< 300 s	< 300 s

5.9 Position Integrity (Protection Level)

5.9.1 Definition

Position Integrity is the ability of the GBLS to measure the trust that can be placed in the accuracy of the location target position. It is relevant to Safety- and Liability-Critical applications (e.g. critical navigation, billing) where undetected large position errors can generate legal or economic consequences.

It is expressed through the computation of a protection level associated to a predetermined integrity risk (as a function of the type of end-user application) see [i.19]. Concerning in particular Liability-Critical applications, the ultimate purpose of an integrity solution is to provide the user with a horizontal protection level (HPL) which:

- guarantees horizontal position error (HPE) bounding up to the required integrity risk (e.g. 10^{-5} per independent sample);
- maximizes availability, e.g. the percentage of time that protection levels exist and remain below a pre-determined value (the alert limit).

In terms of integrity algorithms, they can be based on Receiver Autonomous Integrity Monitoring (RAIM), on ground monitoring approach with a GNSS integrity channel (GIC, e.g. EGNOS) or a combination of them. The operational context of users for Liability-Critical applications is assumed to be suitable for Multiple Failure & Multiple Constellation RAIM integrity algorithms with or without using GIC.

The integrity performance is defined by:

- The Position Integrity, expressed in terms of Protection Level expressed in metres at 95th percentile.
- The Integrity Risk, expressed as the probability that the position accuracy exceeds the position protection level.

NOTE: The integrity algorithms considered to define GBLS classes are based on usage of RAIM plus INS plus potential GIC for GPS, Galileo and GLONASS constellations. A number of algorithms have been assessed: see [i.9] to [i.18].

5.9.2 Operational conditions

The Operational environments defined in clause A.3 are applicable. For the Urban Area attenuation conditions, additional environmental features including Integrity Threats as defined in clause A.8 are applicable.

The location target follows the trajectory defined in clause A.4. The integrity risk is set to 10^{-5} per independent sample of time.

5.9.3 Use case: Moving Location Target

The performance requirements are specified in table 41.

Table 41: Performance requirements for Position integrity: Protection levels

Environment	Horizontal Protection Level (in metres at 95 percentile)		
	Class A	Class B	Class C
Open Area	1	10	18
Urban Area	10	30	110
NOTE: The integrity risk to be taken into account is defined above in clause 5.9.2.			

5.10 Position day-to-day repeatability in the Horizontal Plane

5.10.1 Definition

The day-to-day repeatability of the position characterizes the ablility of the GBLS to provide an estimation of its position which is stable in time when the GBLS repeats the same trajectory. This performance shows that the position error is mainly due to the effect of the Gaussian thermal noise in the receiver, and not due to systematic errors like orbito-synchro, ionospheric delays, or multipath that are not strictly reproductible from one time to another.

The position day-to-day repeatability is measured by computing the difference between the horizontal position of the location target reported by the GBLS at a given time and the position of the location target reported by the GBLS one day later, one month later, or even one year later, assuming the target is moving along the same trajectory.

The requirements for this feature can range from relaxed constraints for personal navigation applications, to more stringent ones for applications such as machine control and autosteering in construction or agriculture, dangerous cargo tracking, etc.

5.10.2 Metrics

The metric used to characterize the position day-to-day repeatability is the difference in horizontal Position estimations over *M* trials separated by one or several days in terms of its:

- Mean value
- Standard deviation
- 95^{th} percentiles distribution

These metrics are defined as follows:

- Let $\{\boldsymbol{p}^*_{i,j}\}_{\boldsymbol{i}\in[\mathbf{1},\boldsymbol{N}],j\in[\mathbf{1},\boldsymbol{M}]}$ be the position estimates collected over a specified time interval (N samples), along the j° trial among M trials made in the test.
- Let $\{\delta p_{ij}\}_{(i\in[1,N],j\in[2,M])}$ be the positioning difference (3D vector) between the trial n°j, (with $j \geq 2$) and the first trial, defined as

$$\boldsymbol{\delta p_{ij} = p^*_{i,j} - p^*_{i,1}}$$

- Consider now $\{\delta h_{ij}\}_{(i\in[1,N],j\in[2,M])}$ the Euclidian norm of the projection of δp_{ij} on the **local horizontal plane** (East/North (EN) reference frame) containing the location target true position

$$\delta h_{ij} = \sqrt{\delta p^{N\,2}_{ij} + \delta p^{E\,2}_{ij}}$$

- Note that δh_{ij} is a positive scalar, and that the test making M trials of N time stamps gives a set of $N.(M-1)$ positive scalars like δh_{ij}, which can be considered as a homogeneous statistic set of samples.
- The mean value, standard deviation, and percentile estimators are computed on this set:

$$\{\delta h_{ij}\}_{(i\in[1,N],j\in[2,M])}$$

- The mean value of the positioning differences $\boldsymbol{m_{\delta h}}$ is estimated as follow:

$$\widehat{m_{\delta h}} = \frac{1}{N.(M-1)}.\left(\sum_{i=1}^{N}\sum_{j=2}^{M}\delta h_{ij}\right)$$

- The standard deviation $\sigma_{\delta h}$ is estimated as follow:

$$\widehat{\sigma_{\delta h}} = \sqrt{\frac{1}{N.(M-1)}.\left(\sum_{i=1}^{N}\sum_{j=2}^{M}\left(\delta h_{ij} - \widehat{m_{\delta h}}\right)^2\right)}$$

The percentiles, noted $\sigma_{p^{th}}$ (i.e. respectively σ_{67} σ_{95}) are estimated using the nearest rank estimator for the p^{th} percentile. It is the solution of the following equation:

$$\frac{p}{100}.N.(M-1) = numberof\ element\left(\{\delta h_{ij}\}\middle|\ \delta h_{ij} \leq \sigma_{p^{th}}\right)$$

5.10.3 Performance requirements

5.10.3.1 Use case: Moving Location Target

5.10.3.1.1 Operational environment: Open area

The performance requirements are specified in table 42. The location target follows the trajectory defined in clause A.4.

Table 42: Performance requirements for day to day repeatability (Horizontal Plane), Moving location target, Open area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean error	0,015	0,15	0,50
Standard deviation	0,02	0,20	0,60
95th percentile	0,025	0,25	0,70

5.10.3.1.2 Operational environment: Urban area

The performance requirements are specified in table 43. The location target follows the trajectory defined in clause A.4.

Table 43: Performance requirements for day to day repeatability (Horizontal Plane), Moving location target, Urban area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,075	0,60	2,00
Standard deviation	0,10	0,80	2,40
95th percentile	0,125	1,00	2,80

5.10.3.1.3 Operational environment: Asymmetric area

The performance requirements are specified in table 44. The location target follows the trajectory defined in clause A.4.

Table 44: Performance requirements for day to day repeatability (Horizontal Plane), Moving location target, Asymmetric area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,075	0,60	2,00
Standard deviation	0,10	0,80	2,40
95th percentile	0,125	1,00	2,80

5.10.3.2 Use case: Static Location Target

5.10.3.2.1 Operational environment: Open area

The performance requirements are specified in table 45.

Table 45: Performance requirements for day to day repeatability (Horizontal Plane), Static location target, Open area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,015	0,15	0,50
Standard deviation	0,02	0,20	0,60
95th percentile	0,025	0,25	0,70

5.10.3.2.2 Operational environment: Urban area

The performance requirements are specified in table 46.

Table 46: Performance requirements for day to day repeatability (Horizontal Plane), Static location target, Urban area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,075	0,60	2,00
Standard deviation	0,10	0,80	2,40
95th percentile	0,125	1,00	2,80

5.10.3.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 47.

Table 47: Performance requirements for day to day repeatability (Horizontal Plane), Static location target, Asymmetric area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,075	0,60	2,00
Standard deviation	0,10	0,80	2,40
95th percentile	0,125	1,00	2,80

5.11 Position day-to-day repeatability in the Vertical Plane

5.11.1 Definition

The day-to-day repeatability of the position characterizes the ablility of the GBLS to provide an estimation of its position which is stable in time when the GBLS repeats the same trajectory.

The position day-to-day repeatability is measured by computing the maximum of the difference (error) between the vertical position of the location target reported by the GBLS at a given time and the position of the location target reported by the GBLS one day later, one month later, or even one year later, assuming the target is moving along the same trajectory.

The requirements for this feature can range from relaxed constraints for personal navigation applications, to more stringent ones for applications such as machine control and autosteering in construction or agriculture, dangerous cargo tracking, etc.

5.11.2 Metrics

The metric used to characterize the position day-to-day repeatability is the difference in horizontal Position estimations over *M* trials separated by one or several days in terms of its:

- Mean value
- Standard deviation
- 95th percentiles distribution

These metrics are defined as follows:

- Let $\left\{\boldsymbol{p}^{*}_{\boldsymbol{i},\boldsymbol{j}}\right\}_{\boldsymbol{i}\in[\mathbf{1},\boldsymbol{N}],\mathrm{j}\in[\mathbf{1},\boldsymbol{M}]}$ be the position estimates collected over a specified time interval (N samples), along the j° trial among M trials made in the test.
- Let $\left\{\delta \mathrm{p}_{\mathrm{ij}}\right\}_{(\mathrm{i}\in[1,\mathrm{N}],\mathrm{j}\in[2,\mathrm{M}])}$ be the positioning difference (3D vector) between the trials (from the second) and the first one, defined as:

$$\boldsymbol{\delta p_{ij}} = \boldsymbol{p}^{*}_{\boldsymbol{i},\boldsymbol{j}} - \boldsymbol{p}^{*}_{\boldsymbol{i},\mathbf{1}}$$

- Consider now $\left\{\delta \mathrm{v}_{\mathrm{ij}}\right\}_{(\mathrm{i}\in[1,\mathrm{N}],\mathrm{j}\in[2,\mathrm{M}])}$ the absolute value of the projection of $\delta \mathrm{p}_{\mathrm{ij}}$ on the vertical axis (local reference frame) containing the location target true position:

$$\delta \mathrm{v}_{\mathrm{ij}} = \left|\delta p^{V}_{ij}\right|$$

- Note that $\delta \mathrm{v}_{\mathrm{ij}}$ is a positive scalar, and that the test making M trials of N time stamps gives a set of $N.(M-1)$ positive scalars like $\delta \mathrm{v}_{\mathrm{ij}}$, which can be considered as a homogeneous statistic set of samples.
- The mean value, standard deviation, and percentile estimators are computed on this set:

$$\left\{\delta \mathrm{v}_{\mathrm{ij}}\right\}_{(\mathrm{i}\in[1,\mathrm{N}],\mathrm{j}\in[2,\mathrm{M}])}$$

- The mean value of the positioning differences $\boldsymbol{m_{\delta v}}$ is estimated as follow:

$$\widehat{m_{\delta v}} = \frac{1}{N.(M-1)}.\left(\sum_{i=1}^{N}\sum_{j=2}^{M}\delta v_{ij}\right)$$

- The standard deviation $\sigma_{\delta v}$ is estimated as follow:

$$\widehat{\sigma_{\delta v}} = \sqrt{\frac{1}{N.(M-1)}.\left(\sum_{i=1}^{N}\sum_{j=2}^{M}\left(\delta v_{ij} - \widehat{m_{\delta v}}\right)^{2}\right)}$$

The percentiles, noted $\sigma_{p^{th}}$ (i.e. respectively σ_{67} σ_{95}) are estimated using the nearest rank estimator for the p^{th} percentile. It is the solution of the following equation:

$$\frac{p}{100}.N.(M-1) = numberof\ element\left(\left\{\delta v_{ij}\right\}\middle|\ \delta v_{ij} \le \sigma_{p^{th}}\right)$$

5.11.3 Performance requirements

5.11.3.1 Use case: Moving Location Target

5.11.3.1.1 Operational environment: Open area

The performance requirements are specified in table 48. The location target follows the trajectory defined in clause A.4.

Table 48: Performance requirements for day to day repeatability (Vertical Plane), Moving location target, Open area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean error	0,025	0,25	0,75
Standard deviation	0,05	0,40	0,50
95th percentile	0,10	0,80	1,50

5.11.3.1.2 Operational environment: Urban area

The performance requirements are specified in table 49. The location target follows the trajectory defined in clause A.4.

Table 49: Performance requirements for day to day repeatability (Vertical Plane), Moving location target, Urban area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,15	1,20	4,00
Standard deviation	0,20	1,60	4,50
95th percentile	0,25	2,00	6,00

5.11.3.1.3 Operational environment: Asymmetric area

The performance requirements are specified in table 50. The location target follows the trajectory defined in clause A.4.

Table 50: Performance requirements for day to day repeatability (Vertical Plane), Moving location target, Asymmetric area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,15	1,20	4,00
Standard deviation	0,20	1,60	4,50
95th percentile	0,25	2,00	6,00

5.11.3.2 Use case: Static Location Target

5.11.3.2.1 Operational environment: Open area

The performance requirements are specified in table 51.

Table 51: Performance requirements for day to day repeatability (Vertical Plane), Static location target, Open area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,03	0,30	1,00
Standard deviation	0,04	0,40	1,20
95th percentile	0,08	0,50	2,00

5.11.3.2.2 Operational environment: Urban area

The performance requirements are specified in table 52.

Table 52: Performance requirements for day to day repeatability (Vertical Plane), Static location target, Urban area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,15	1,00	5,00
Standard deviation	0,20	1,50	5,00
95th percentile	0,30	2,00	10,00

5.11.3.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 53.

Table 53: Performance requirements for day to day repeatability (Vertical Plane), Static location target, Asymmetric area

Metric	Max position error [m]		
	Class A	Class B	Class C
Mean value	0,15	1,00	5,00
Standard deviation	0,20	1,50	5,00
95th percentile	0,30	2,00	10,00

5.12 Time-to-Fix-Ambiguity (TTFA)

5.12.1 Definition

TTFA is the time taken by the GBLS to provide location-related data with a completed resolution of the integer ambiguity for the carrier phase measurement, thus achieving the best accuracy for differential positioning.

The TTFA starts at the instant when one message of each required differential data has been received from at least one reference station.

The ambiguity resolution process starts as soon as the main part of the error budget is finalised, this consists of the orbito synchro error and the ionospheric error. This process is involved whenever differential GNSS techniques are used. The time to finalise this can be very dependant of the capabilities of the GNSS receiver. In particular dual frequency capability in order to reduce the ionospheric delaysand the assistance derived from the differential GNSS data.

It is expected that dual frequency receivers should achieve the class A performances, since they can internally reduce the ionospheric delay, while single frequency receivers are expected to achieve the class B or C performances.

The operational environment will impact the process, so that a receiver performance can be class A in an open sky environment while being class B in an urban or asymmetric environment.

In addition, the speed of ambiguity resolution can sometimes be traded against the possibility of incorrect ambiguity resolution. In order to avoid this case the performance feature will be validated only if the positioning error after ambiguity resolution is within the expected limits for a correct ambiguity resolution.

5.12.2 Metrics

The TTFA is the elapsed time between the instant when the process of the GBLS applying a differential model is started (i.e. the time when at least one message of each type in the differential protocol is received) and the instant when the expected highest accuracy output is achieved by the positioning output of the GBLS (e.g. final integer ambiguity resolution, convergence of PPP, etc.).

The TTFA starts from the instant when at least one message of each required differential data type has been received from at least one reference station. Considering that this time is largely dependant on the conditions of the differential service telecommunications, and that no information is generally displayed by the GBLS about the reception of these differential messages, fixed values will be applied during the tests:

- 60 s for RTK
- 150 s for NRTK
- 200 s for PPP

The performance is defined as a 95 % accuracy (horizontal and vertical) computed on a set of 1 000 consecutive samples of positioning GBLS outputs, and the output is considered stable if the 95 % accuracy estimated at a given instant, 50 s later, and 100s later all meeti the same requirement.

The highest accuracy achievable in differential mode is considered to be as follows:

- 0,03 m horizontal, 0,05 m vertical, if the environment is open area.
- 0,10 m horizontal and 0,15 m vertical if the environment is urban or asymmetric area.

5.12.3 Performance requirements

5.12.3.1 Use case: Moving Location Target

5.12.3.1.1 Operational environment: Open area

The performance requirements are specified in table 54. The location target follows the trajectory defined in clause A.4.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of better than 5 cm.

Table 54: Performance requirements for TTFA, Moving location target, Open area

Metric	TTFA [s]		
	Class A	Class B	Class C
Mean value	50	500	1 500
95th percentile	100	900	2 000

5.12.3.1.2 Operational environment: Urban area

The performance requirements are specified in tables 55. The location target follows the trajectory defined in clause A.4.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 15 cm.

Table 55: Performance requirements for TTFA , Moving location target, Urban area.

Metric	TTFA [s]		
	Class A	Class B	Class C
Mean value	50	500	1 500
95th percentile	100	900	2 000

5.12.3.1.3 Operational environment: Asymmetric area

The performance requirements are specified in tables 56. The location target follows the trajectory defined in clause A.4.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 15 cm.

Table 56: Performance requirements for TTFA, Moving location target, Asymmetric area

Metric	TTFF [s]		
	Class A	Class B	Class C
Mean value	50	500	n/a (see note)
95th percentile	100	900	n/a (see note)
NOTE: Class C receivers do not have a requirement to achieve a position fix in the asymmetric area scenario.			

5.12.3.2 Use case: Static Location Target

5.12.3.2.1 Operational environment: Open area

The performance requirements are specified in table 57.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 5 cm.

Table 57: Performance requirements for TTFA, Static location target, Open area

Metric	TTFF[s]		
	Class A	Class B	Class C
Mean value	40	400	100
95th percentile	80	800	1 500

5.12.3.2.2 Operational environment: Urban area

The performance requirements are specified in table 58.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 15 cm.

Table 58: Performance requirements for TTFA, Static location target, Urban area

Metric (as per clause 4.2)	TTFF[s]		
	Class A	Class B	Class C
Mean value	40	400	1 000
95th percentile	80	800	1 500

5.12.3.2.3 Operational environment: Asymmetric area

The performance requirements are specified in table 59.

In all cases the requirements are dependent on achieving a maximum 95th percentile horizontal and vertical (if applicable) positioning error of 15 cm.

Table 59: Performance requirements for TTFA, Static location target, Asymmetric area

Metric	TTFF[s]		
	Class A	Class B	Class C
Mean value	40	400	n/a (see note)
95th percentile	80	800	n/a (see note)
NOTE: Class C receivers do not have a requirement to achieve a position fix in the asymmetric area scenario.			

Annex A (normative): Applicable Conditions and Scenarios

A.1 General

This clause defines the conditions applicable to the definition of the performance requirements given in clause 5. These conditions concern:

- the external systems with which the GBLS interacts;
- the operational environments;
- the moving location target scenario;
- the interference scenarios.

A.2 External Location Systems Parameters

A.2.1 GNSS system parameters

GNSS systems applicable to the performance specifications are shown below including:

- the constellation geometry to be used;
- signal parameters to be used, in particular the signal modulation parameters, and the minimum received power on ground in nominal conditions.

Table A.1: GNSS Constellations parameters

GNSS system	System/User interface description	HDOP range
GALILEO OS	[1]	1,6 to 2,5
GPS L1C/A	[2]	1,6 to 2,5
GPS L5 (see note)	[3]	1,6 to 2,5
GPS L1C (see note)	[4]	1,6 to 2,5
GLONASS	[5]	1,6 to 2,5
Beidou	[6]	1,6 to 2,5
NOTE: Single frequency use only is considered at present.		

A.2.2 Wireless systems parameters

The GBLS may employ other telecommunications networks for positioning with the following interfaces:

- Wi-Fi: IEEE 802.11™ [i.2].
- Wireless Personal Area Network (short range wireless): IEEE 802.15™ [i.3].
    - Bluetooth: IEEE 802.15.1™ [i.4].
    - WPAN: IEEE 802.15.4a™ [i.5].
- Cellular:
    - GSM: ETSI TS 145 001 (3GPP TS 45.001) [i.6].
    - UTRA: ETSI TS 125 104 (3GPP TS 25.104) [i.7].

- E-UTRA: ETSI TS 136 171 (3GPP TS 36.171) [i.8].

A.3 Operational Environments

A.3.1 Operational Environments definition

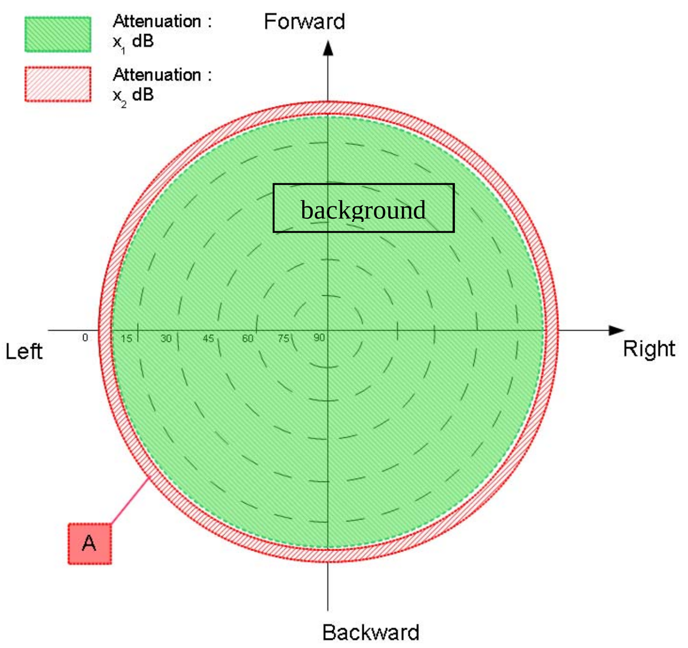
Each Operational Environment defined in table A.2 includes the associated conditions indicated, which are further defined in the clauses below.

Table A.2: Operational Environments and Associated Conditions

Operational environment type (see note 2)	Associated Conditions					
	Sky attenuation conditions (clause A.3.2)	**Track trajectory (see note 4) (clause A.4)**	**Multipath Level (clause A.3.3)**	**Interference Level (dBW/Hz) (see note 3)**	**Magnetic conditions (see note 1) (clause A.3.4)**	**Telecommunications beacon distribution (see note 1) (clause A.3.5)**
Open Area	Open sky	Outdoor	None	None	Nominal	Sparse outdoor
Urban Area	Urban Canyon	Outdoor	Yes	-195	Degraded	Dense outdoor
Asymmetric Area	Asymmetric visibility	Indoor	Yes	-195	Degraded	Dense indoor
NOTE 1: These conditions apply if the GBLS system implements the related sensor. NOTE 2: For all these environments, the antenna gain is assumed to be 0 dBi. NOTE 3: Interference is defined as the external noise power density at the antenna. NOTE 4: When the moving location target with the track trajectory scenario is used.						

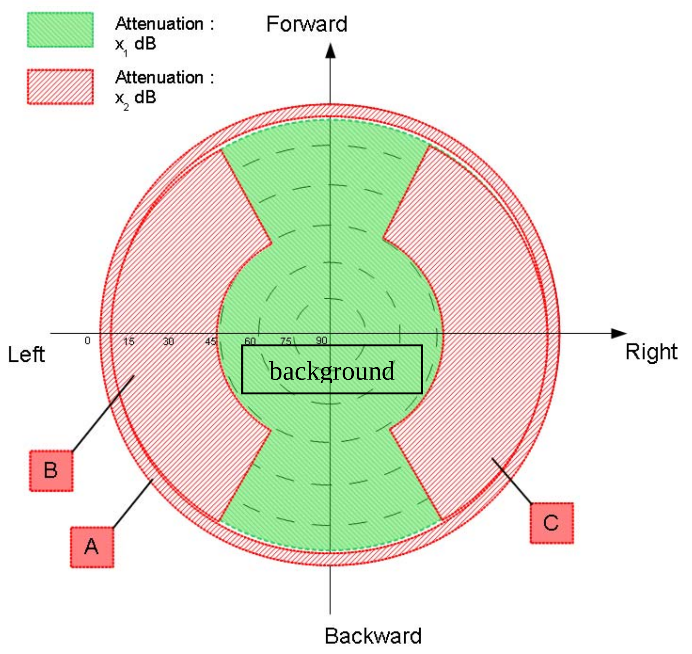
A.3.2 Sky Attenuation Conditions

The sky plots below define the solid angles (defined by elevation and azimuth angles) associated with a given attenuation in the hemisphere of the sky above the GNSS receiver.



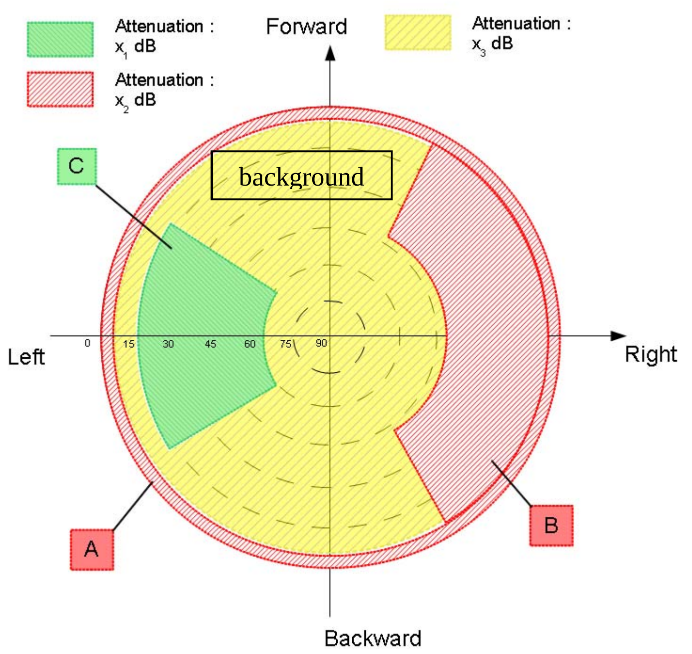
Zone	Elevation range (deg)	Azimuth range (deg)	Attenuation (dB)
A	0 to 5	0 to 360	$x_2 = 100$
Back-ground	Angles out of Zone A		$x_1 = 0$

Figure A.1: Open Sky plot



Zone	Elevation range (deg)	Azimuth range (deg)	Attenuation (dB)
A	0 to 5	0 to 360	$x_2 = 100$
B	5 to 60	210 to 330	$x_2 = 100$
C	5 to 60	30 to 150	$x_2 = 100$
Back-ground	Angles out of Zones A, B, C		$x_1 = 0$

Figure A.2: Urban canyon plot



Zone	Elevation range (deg)	Azimuth range (deg)	Attenuation (dB)
A	0 to 5	0 to 360	$x_2 = 100$
B	5 to 60	30 to 150	$x_2 = 100$
C	10 to 60	230 to 310	$x_1 = 0$
Back-ground	Angles out of Zones A, B, C		$X_3 = 15$

Figure A.3: Asymmetric visibility plot

A.3.3 Multipath Level

Multipath is applied to signals of satellites whose Line of Sight has an elevation lower than 30 °. A single tap reflection model is used. Characteristics of the reflected signal (or multi-path) with respect to the direct signal are given below.

The Carrier and Code Doppler frequencies of direct and multi-path for GNSS signal are defined in table A.3.

Table A.3: Multi-path model components

Initial relative Delay [m]	Carrier Doppler frequency of tap [Hz]	Code Doppler frequency of tap [Hz]	Relative mean Power [dB]
0	Fd	Fd / N	0
X	Fd - 0,1	(Fd - 0,1) /N	Y
NOTE 1: Discrete Doppler frequency is used for each tap. NOTE 2: The above model and values are based on those of ETSI TS 125 104 [i.7].			

X, Y and N depend on the GNSS signal type. In addition, Y depends on the intensity of multi-path faced in the operational environments. N is the ratio between the transmitted carrier frequency of the signals and the transmitted chip rate.

The initial carrier phase difference between taps shall be randomly selected between 0 and 2π. The initial value shall have uniform random distribution.

Table A.4 defines the parameters values.

Table A.4: Multi-path model parameters

System	Signals	X [m]	Y [dB]
Galileo	E1	125	-4,5
	E5a	15	-6
	E5b	15	-6
GPS/Modernized GPS	L1 C/A	150	-6
	L1C	125	-4,5
	L2C	150	-6
	L5	15	-6
GLONASS	G1	275	-12,5
	G2	275	-12,5

Table A.5: Ratio between Carrier Frequency and Chip Rate

System	Signals	N
Galileo	E1	1 540
	E5a	115
	E5b	118
GPS/Modernized GPS	L1 C/A	1 540
	L1C	1 540
	L2C	1 200
	L5	115
GLONASS	G1	3 135,03 + k · 1,10
	G2	2 438,36 + k · 0,86
NOTE: Parameter "k" above is the GLONASS frequency channel number.		

A.3.4 Magnetic Conditions

A.3.4.1 Output model

The heading output model of the sensor accounts for common magnetometers compass errors, and is given below.

$$\text{Heading}^{out} = (1 + SF) \times \text{Heading}^{true} + I_{mag} + b_{mag} + n_{mag}$$

Where:

- SF the scale factor;
- I_{mag} the EMI and magnetic materials interference term;
- b_{mag} the sensor offset; and
- n_{mag} a zero mean Gaussian noise term.

The bias is modelled by a Gauss Markov process:

$$b_{mag}(t+1) = b_{mag}(t) \times (1 - 1/T_{mag}) + w_{mag}$$

Where:

- T_{mag} being the bias correlation time; and
- w_{mag} the zero mean Gaussian bias noise term.

A.3.4.2 Perturbation level

Two perturbation levels are applied: nominal and degraded. Table A.6 shows the output model parameters values.

Table A.6: Magnetometers output model parameters

Parameters	Perturbation level	
	nominal	degraded
I_{mag}	0,1°	2°
n_{mag} (standard deviation)	0,05°	0,1°
SF	0,005	0,01
b_{mag} (offset)	0,1°	0,3°
T_{mag}	3 000 s	3 000 s
W_{mag} (standard deviation)	0,001°	0,001°

A.3.5 Telecommunications Beacons

Table A.7 defines the beacon density and type of telecommunications systems considered in the scenarios of table A.2.

Table A.7: Telecommunications beacon scenarios components

Type of telecommunications system	Sparse outdoor scenario	Dense outdoor scenario	Dense indoor scenario
Cellular	Yes (sparse distribution)	Yes (dense distribution)	Yes (dense distribution)
Wi-Fi	No	Yes	Yes
Bluetooth	No	No	Yes

The beacon distribution characteristics are provided for each type of beacon in table A.8.

NOTE: Skyplots defined for GNSS environments are not accounted for in Telecommunications beacon scenarios: attenuations considered are not applied to the beacon signals; the concept of elevation angle is ignored (all beacons are assumed to be seen at low elevation angles by the user), and signal attenuation (contribution to the Telecommunications range error) will be mainly driven by the distance from user to beacon and the associated RF losses.

Table A.8 provides the characteristics of the sparse and dense distributions applicable for the different telecommunications system type.

Table A.8: Telecommunications beacon distributions characteristics

Telecommunications Type	Distribution type	Density Number of beacon per km²
Cellular	sparse	9,37E-3
Cellular	dense	0,53
Wi-Fi®	dense	2 660
Bluetooth®	dense	2 660

A.4 Moving Location Target Scenario - Track trajectory

The definition below defines the reference trajectory for a Track moving scenario for the location target.

Figure A.4 defines the reference trajectory, and is in the horizontal plane with the reference point at the origin (0,0,0). The reference point may be anywhere on the Earth's surface. The track is traversed in clock-wise direction.

Two sets of parameters are defined, one for indoor and one for outdoor scenarios.

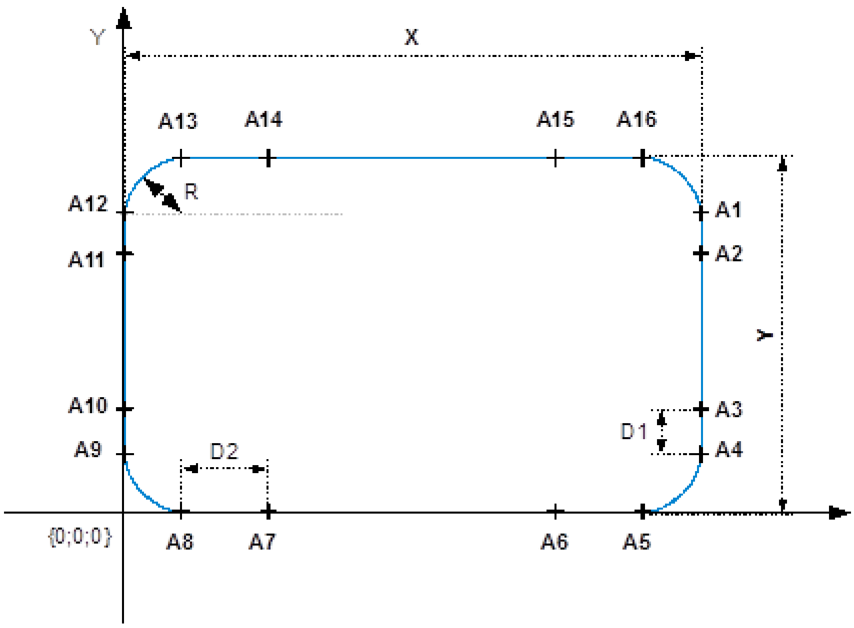


Figure A.4: Location target trajectory

Table A.9: Trajectory parameters

Parameter	Value (m) - outdoor	Value (m) - indoor
X	1 440	45,6
Y	940	37,6
R	20	1
NOTE: The above outdoor values are based on those of ETSI TS 125 104 [i.7].		

Figure A.5 provides the location target speed profile, when travelling along the trajectory above.

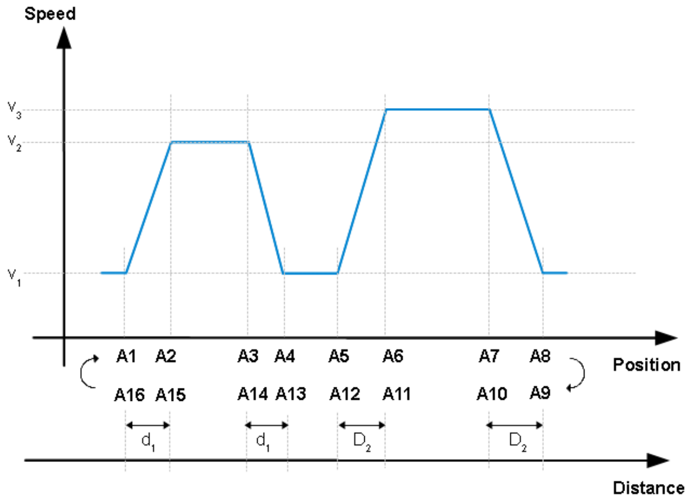


Figure A.5: Location target speed profile

The trajectory parameters for each Performance Feature are:

Table A.10: Location target trajectory parameters

Trajectory parameter	Value for outdoor trajectory	Value for indoor trajectory
v_1	25 km/h	1 km/h
v_2	100 km/h	4 km/h
v_3	100 km/h	4 km/h
d_1	250 m	10 m
D_2	250 m	10 m

A.5 Moving Location Target Scenario - Straight line trajectory

The definition below defines the reference trajectory for a Straight line moving scenario for the location target.

The trajectory is in the horizontal plane with the starting point anywhere on the Earth's surface. The location target moves on a straight trajectory at a uniform speed of 50 km/h.

A.6 Interference source definition

Table A.11 specifies the jamming signals used as interference sources scenarios in clause 5.7. The definition of the jammer is based on the interference models of some PPDs (Personal Privacy Devices) as described in literature.

Table A.11: Interference source definition

Class	Centre Frequency (MHz)	-3 dB Bandwidth (MHz)	Sweep time (µs)	Peak (dBm)
J#1: Chirp signal with one saw-tooth function	1 575,42	20	20	-9,6
J#2: Chirp signal with one saw-tooth function	1 575,42	10	20	-9,6

The jammer power accounts for the free space propagation losses defined in figure A.6 and the initial jammer power from table A.11. The relative Doppler is negligible compared to the frequency range of the jammer.

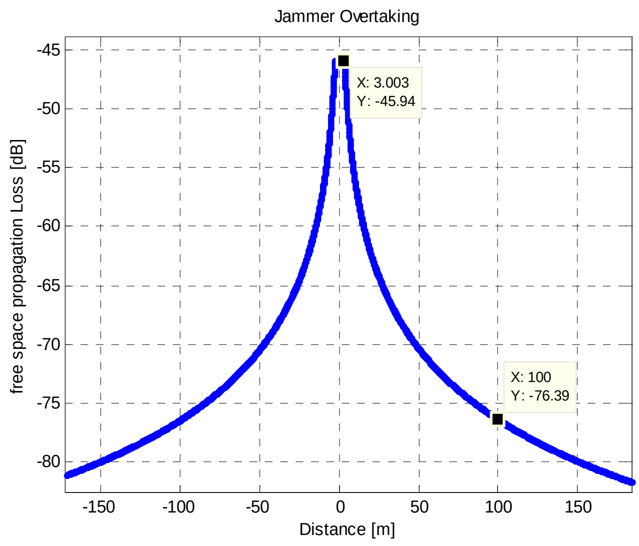


Figure A.6: Free space propagation loss with respect to the jammer distance

A.7 Authenticity Threat Scenarios

A.7.1 Scenarios description

Clause A.7 defines the threat scenarios for the definition of the Authenticity performance requirements.

All the threat scenarios define spoofing attempts to the GNSS sensor of the GBLS. Such spoofing attempts broadcast intentional RF interference, with a structure similar to authentic GNSS signals, in order to deceive the GNSS sensor into erroneously estimating pseudo-ranges and computing false PVT solutions.

The threat scenarios are defined below. The following pre-conditions apply to these scenarios:

- location-related data of the location target are available;
- all tracked GNSS signals are authentic.

A.7.2 Moving Location Targets

The error is modelled as a ramp function with slope equal to *b*. Such a ramp function starts at the same instant of the threat.

Table A.12: Threat scenario for moving location targets

Scenario identifier	Number of spoofed PRNs	Total Spoofing Power range (dBW)	Misleading information category	error slope b value range
M-1	All (see note 1)	-144,5 to -140,5	Estimated Time	2 to 20 ns/s (see note 2)
M-2	4	-148,5 to -144,5	Pseudorange measurement	3,5 to 6,5 m/s
M-3	4	-148,5 to -144,5	Estimated Position	1 to 7,5 m/s (see note 2)
NOTE 1: The number of spoofed PRNs is equal to the number of the satellites in view. NOTE 2: The model value ranges for the estimated time and position assume HDOP compliance with table A.1.				

A.7.3 Static Location Targets

The error is modelled as a ramp function with slope equal to *b*. Such a ramp function starts at the same instant of the threat.

Table A.13: Threat scenario for static location target

Scenario identifier	Number of spoofed PRNs	Total Spoofing Power range (dBW)	Misleading information category	error model b value range
S-1	All (see note 1)	-158,5 to -153,5	Estimated Time	2 to 20 ns/s (see note 2)
S-2	1	-158,5 to -153,5	Pseudorange measurement	3,5 to 6,5 m/s
S-3	1	-158,5 to -153,5	Estimated Position	1 to 7,5 m/s (see note 2)
NOTE 1: The number of spoofed PRNs is equal to the number of the satellites in view. NOTE 2: The model value ranges for the estimated time and position assume HDOP compliance with table A.1.				

A.7.4 Scenario parameters

A.7.4.1 Attack classification

Shadowed spoofing is defined for the GBLS. In this method, the counterfeit GNSS signals are generated and radiated towards the GNSS sensor in a way that the correlation peak associated to the counterfeit signal rises in the shadow of the correlation peak of real signal. Varying the relative delay between the authentic and counterfeit spreading codes and increasing the power of the counterfeit GNSS signals, the GNSS sensor is forced to lose the tracking of the authentic spreading code and synchronizes its local code with the counterfeit spreading code. Therefore, it means that GNSS constellation geometry, current GNSS time, and GNSS sensor position are known by the spoofing source in order to estimate the authentic code delay and Doppler frequency at the location target GNSS sensor. The counterfeit signal is a false copy of that actually in view at the moment of the attack.

Figure A.7 illustrates this concept on the correlation domain, where the correlation peaks associated to authentic signals are green, correlation peaks due to counterfeit signals are in purple and the composite correlation peaks are in blue.

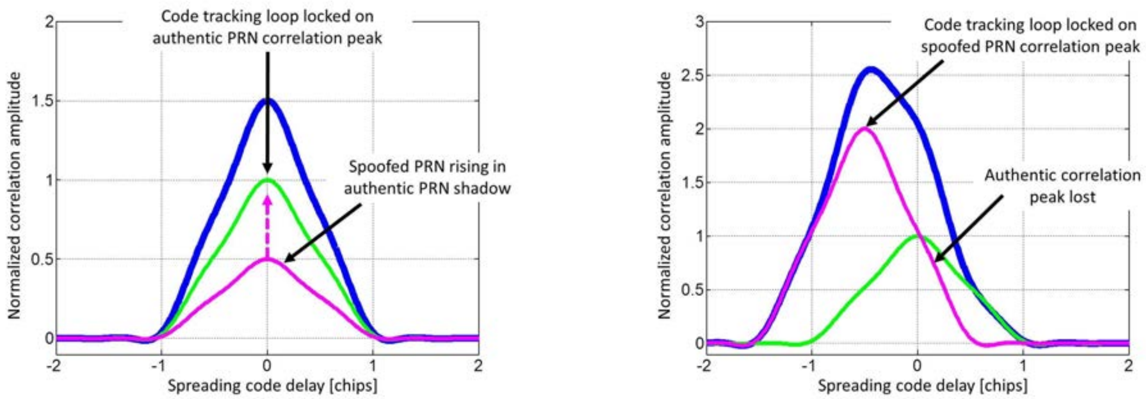


Figure A.7: Effects of shadowed spoofing on correlation functions

A.7.4.2 Total spoofing power

The total spoofing power (TSP) is the signal power of the sum of counterfeit GNSS signals received at the GNSS sensor antenna, which is assumed isotropic so that all signals are weighted equally.

It is defined as:

$$TSP = \sum_{i=1}^{N_{spoof}} p_i^s \quad \text{[dBW]}$$

where p_i^s is the power of the ith counterfeit signal generated by the spoofing device.

The TSP is variable for each scenario, and used to define the authenticity performance.

A.7.4.3 Misleading information categories

The spoofing attacks can cause the following types of misleading information at GNSS sensor:

- erroneous pseudorange measurement;
- erroneous time estimates;
- erroneous estimates of the position (for both static of moving scenario).

For each type of misleading information, the error is modelled as a ramp function with slope equal to *b*. Such a ramp function starts at the same instant of the threat. Table A.14 defines the units of the error and slope with respect to the type of misleading information.

Table A.14: Misleading information model parameters

Misleading information	Error unit	Slope b unit
pseudorange measurement	m	m/s
time estimates	s	s/s
position estimates (see note)	m	m/s
NOTE: The position error is measured on the across-track axis.		

The slope of the error model is variable for each scenario, and is used to define the GBLS authenticity performance.

A.8 Integrity Threat Scenarios

A.8.1 Integrity Threat definition

An Integrity Threat is the occurrence of a condition able to compromise the system integrity. Integrity is compromised under low observability conditions. Such conditions occur when the measurements errors are combined in such a way as to produce an appreciable error in the position and at the same time leave a small residual.

The integrity threat scenarios are defined as:

- Non-LoS (Line of Sight) tracking;
- Pseudo-range Ramp errors.

These threat scenarios are defined further below.

A.8.2 Non-LoS tracking

Non-LoS tracking events are modelled with an empirical statistical model that describes the Non-LoS effect on pseudo-ranges and Doppler errors when the GBLS is located in an urban environment. The effect and the duration of Non-LoS tracking are determined by:

- the selection of the satellites affected by Non-LoS (depending on the masking area of the urban environment and the conditional probability of the satellite being affected by Non-LoS conditions, given that the satellite is occulted);
- the duration of the Non-LoS condition (modelled as an exponential distribution);
- pseudo-range error and Doppler errors modelled as due to single reflections.

A.8.3 Pseudo-range Ramp errors

The threat is modelled through the generation of pseudo-range ramp errors per satellite with:

- 1 hour duration; and
- resulting in a horizontal position error growing by 5 m every 60 s.

This ramp error is generated every 4 hours for 1 hour (3 hours simulation nominal, and 1 hour simulating this threat conditions). The pseudo-range ramp error is generated by projecting a horizontal vector growing linearly from 0 to 300 m over 1 hour into the Line of Sight of the affected satellites, which may be just a subset of those being tracked. The resulting error is on top of the other errors due to the nominal conditions of the urban environment except for Non-LoS.

Annex B (informative): Differential GNSS: GBLS implementing differential GNSS and integrity performance through RTCM standards

B.1 Specific case of a GBLS implementing differential GNSS

D-GNSS/RTK are specific GBLS implementations involving one or more reference stations in the loop of the location determination process as well as a data link for receiving the differential GNSS data.

In this document the defined performances applies only to the location determination process of the target.

RTCM 10402.3 [9], RTCM 10401.2 [10] and RTCM 10403.2 [11] are widely used reference standards for differential GNSS applications. D-GNSS service and reference station/integrity monitor are primarily standardised by RTCM for marine navigation service (out of scope of this multi-part deliverable) in RTCM 10402.3 [9] and RTCM 10401.2 [10]. However these RTCM standards can apply to other non-maritime navigation services, so-called "multi use service" in [10].

RTK, NRTK and PPP service is also standardized by RTCM [11].

No end-to-end performance requirements are specified in these standards, which mostly focus on the differential GNSS data definition and exchange protocols.

End-to-end differential GNSS service performances are highly dependent on:

- The quality of GNSS reception and processing in the reference stations.
- The telecom link characteristics (which are out of scope of this multi-part deliverable).
- The distance between the reference receiver, or the network of reference stations, and the location target.

Although none of the RTCM standards provides end-to-end horizontal and vertical accuracy performance requirements for D-GNSS service, useful performance requirements are provided in RTCM 10401.2 [10] for the accuracy of the D-GNSS corrections applicable to multi-use service (i.e. non maritime navigation service) elaborated by the reference station. The following is recommended:

- A code phase measurement accuracy of better than 30 cm (RMS).
- A code range rate measurement accuracy of better than 4 cm/s (RMS).
- A pseudorange correction accuracy of better than 35 cm (RMS). A range rate correction accuracy of better than 5 cm/s (RMS).

In addition to the RTCM standards, [i.21] rovides guidelines and in-field experience for D-GNSS reference station installation and performance. Related to horizontal positioning error this document states that "a suitable accuracy indicator of DGNSS service usability is proven when, close to the reference station (e.g. within 50 m circumference), the horizontal position error is < 0,5 m (95 %) measured over a period of 24 hours, if DGNSS corrections are applied on independent GNSS measurements."

In this standard, the performances of the correction or other differential data are not specified but it is assumed that they meet the performances described above.

It is also assumed that during the performance evaluation process for a GBLS implementing differential GNSS, the data link functions as defined, allowing the reception of the differential GNSS data by any location target or central facility involved.

Finally, when testing a GBLS under differential mode, it is assumed that the differential GNSS data provided is correct, and that the following maximum distances between the closest reference station and the location target are met.

Table B.1

Type of differential system	Maximum distance
D-GNSS	4 kms
RTK	4 kms
NRTK	35 kms
PPP	500 kms

With these assumptions, a GBLS implementing differential GNSS should be tested for the following performances feature.

Table B.2

Performance Features (defined in clause 5)	In absolute mode	In differential GNSS mode
Horizontal Accuracy	√	√
Vertical Accuracy	√	√
GNSS Time Accuracy	√	√
Time-to-first-fix	√	
Position Authenticity	√	
Robustness to Interference	√	√
GNSS Sensitivity	√	
Position Integrity & Protection Level	√	
Day to day accuracy		√
TTFA		√

B.2 D-GNSS monitoring and integrity concept in RTCM standards

B.2.1 Overall concept and implementation

Integrity monitoring and alerting in a D-GNSS GBLS compliant with RTCM standards [9] and [10] do not rely on algorithms like RAIM and the associated computation of a Protection Level.

NOTE: no integrity monitoring and alerting functions for a GBLS implementing RTK methods is required by the RTCM standard [11].

The monitoring and integrity concept for D-GNSS systems in the RTCM standards aims at:

- Monitoring the quality and availability of GNSS satellites signals.
- Detecting satellites transmitting erroneous data.
- Checking the quality of D-GNSS correction data broadcast by the reference station through the telecommunication link and ensuring they are not corrupted or erroneous.

The implementation of this concept requires an independent check of the set of data from the reference station. This Integrity Monitoring involves monitoring the telecommunication link and decoding of GNSS signals with an independent receiver in order to check the quality and consistency of the correction data broadcast by the reference station and if necessary the sending of an alert to the reference station in case inconsistencies are detected.

Two modes are possible to implement this concept, with a third one combining these two modes also being possible:

- Post-broadcast mode: the simplest mode where the checks are performed after the corrections are broadcast.
- Pre-broadcast mode: the corrections are checked before they are broadcast. This is used for networked-based D-GNSS.

The implementation of Integrity Monitors may vary with the D-GNSS system:

- The simplest implementation is to co-locate the Integrity Monitor and the reference station.
- A more sophisticated installation is to implement several Integrity Monitors networked with the reference station, preferably distributed at the edge of the D-GNSS service area.

B.2.2 Monitoring and alerting

The main D-GNSS corrections generated and sent by the reference station are:

- Pseudorange corrections for each GNSS satellite in view at the reference station.
- Range rate correction: based on the Doppler shift of the satellite signal carrier, this parameter characterizes the satellite motion and provides to the location target the correction required for the pseudorange correction over the time.
- User Delta Range of Error: UDRE is a one-sigma estimate of the uncertainty in the pseudorange correction as estimated by the reference station, and combines the estimated effects of multipath, signal-to-noise ratio, and other effects.

Integrity monitoring consists of the check of usability of the GNSS data provided by the satellites for D-GNSS service provision. This assessment can be based on:

- Completeness of the GNSS range, phase, and navigation data per GNSS satellite in view.
- Integrity data or health status provided by the GNSS itself.
- Validity of navigation data.
- Plausibility, consistency and accuracy of distance measurements.

In case the data set is of too poor quality to be used in the D-GNSS service, the reference station may be excluded from the D-GNSS service provision.

For the D-GNSS signal, integrity checking is performed at Integrity Monitor level by assessing the quality of D-GNSS corrections applicable to the GNSS signals and the data received by the Integrity Monitor:

- Availability, plausibility and consistency of the correction terms broadcast by the Reference Station.
- Indicated validity and integrity of correction terms broadcast by the Reference Station.
- Availability of correction terms at Integrity Monitor level.
- Latency and validity of available correction terms at Integrity Monitor level.
- Residual ranging error after application of corrections at Integrity Monitor level.

In case the data set is too poor or if the qulity of D-GNSS corrections is of poor quality the Itegrity Monitor transmits an alert to the reference station indicating that the D-GNSS service should not be used for navigation purposes. As result the reference station can flag to "do not use" some or all the correction terms applicable to one or several satellites and as a result the target location receiver will exclude the faulty satellite(s) from its position solution.

B.2.3 D-GNSS integrity performance and system implementation

D-GNSS systems compliant to RTCM standards are designed to match the requirements set in IMO Recommendation A.1046 [i.21] for harbour entrances, harbour approaches and coastal waters:

- Alarm Limit: 25 m
- Time to Alarm: 10 s
- Integrity Risk: 10^{-5}

For design and implementation of D-GNSS reference stations and Integrity monitors, the IALA published updated recommendations [i.21], including proposed settings for the reference station and integrity monitor for the range of values of the D-GNSS correction terms with corresponding time intervals of observation when applicable.

In case the correction is out of this range, an alarm is triggered on the particular value. The choice of thresholds is a balance between a high false alarm rate, impacting the availability of the service, and limiting the inaccuracies experienced by the target location receiver.

Some values are given below, see [i.21] for a full list of settings:

- Applicable to the reference station:
    - Minimum number of satellites: 4 - No time interval.
    - Elevation mask angle: 7° - No time interval.
    - Pseudorange correction: 140 to 1 000 m - No time interval.
    - Range rate corrections: 4 m/s - No time interval.
- Applicable to the integrity monitor:
    - Minimum number of satellites: 4 - 60 to 65 s time interval.
    - Elevation mask angle: 7° - No time interval.
    - Correction age at IM reception: 10 to 30 s - 30 to 100 s time interval.
    - HDOP: 4 to 6 - 30 to 35 s time interval.
    - Horizontal Position accuracy: 10 m - Time interval 20 s.
    - Pseudorange residual: 100 to 150 m - Time interval 30 to 65 s.
    - Range rate residual: 2 to 5 m/s - Time interval 30 to 65 s.

Low UDRE: 100 to 101 m - Time interval 100 to 600 s.

Annex C (informative): Bibliography

IMO Resolution A.1046(27) adopted on 20 November 2011 - Worlwide Radionavigation System.

History

Document history		
V1.1.1	July 2015	Publication
V1.2.1	March 2017	Publication