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INTERNATIONAL STANDARD

colour inside

Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) –
Part 3: Galileo receiver equipment – Performance requirements, methods of testing and required test results

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International Standard IEC 61108-3 has been prepared by IEC technical committee 80: Maritime navigation and radiocommunication equipment and systems.

The text of this standard is based on the following documents:

FDIS	Report on voting
80/590/FDIS	80/595/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 61108 series, under the general title: *Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS)*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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MARITIME NAVIGATION AND RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS – GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS) –

Part 3: Galileo receiver equipment – Performance requirements, methods of testing and required test results

1 Scope

This part of IEC 61108 specifies the minimum performance standards, methods of testing and required test results for Galileo shipborne receiver equipment, based on IMO resolution MSC.233(82), which uses the signals from the Galileo Global Navigation Satellite System in order to determine position. It takes account of the general requirements given in IMO resolution A.694(17) and is associated with IEC 60945. When a requirement in this standard is different from IEC 60945, the requirement in this standard takes precedence. It also takes account, as appropriate, of requirements for the presentation of navigation-related information on shipborne navigational displays given in IMO resolution MSC.191(79) and is associated with IEC 62288.

A description of the Galileo Open Service and Safety of Life Service is given in the Galileo interface control documents (see Bibliography). This receiver standard applies to navigation in ocean waters for the open service and harbour entrances, harbour approaches and coastal waters for the Safety of Life service, as defined in IMO resolution A.953(23).

All text of this standard, whose meaning is identical to that in IMO resolution MSC.233(82), is printed in *italics* and the resolution and paragraph numbers are indicated in brackets i.e. (M.233/A1.2).

The requirements in Clause 4 are cross-referenced to the tests in Clause 5 and vice versa.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60721-3-6:1987, *Classification of environmental conditions – Part 3-6: Classification of groups of environmental parameters and their severities – Ship environment*

IEC 60945, *Maritime navigation and radiocommunication equipment and systems – General requirements – Methods of testing and required test results*

IEC 61108-1:2003, *Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) – Part 1: Global positioning system (GPS) – Receiver equipment – Performance standards, methods of testing and required test results*

IEC 61108-4, *Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) – Part 4: Shipborne DGPS and DGLONASS maritime radio beacon receiver equipment – Performance requirements, methods of testing and required test results*

IEC 61162 (all parts), *Maritime navigation and radiocommunication equipment and systems – Digital interfaces*

IEC 61162-1, *Maritime navigation and radiocommunication equipment and systems – Digital interfaces – Part 1: Single talker and multiple listeners*

IEC 62288, *Maritime navigation and radiocommunication equipment and systems – Presentation of navigation-related information on shipborne navigational displays – General requirements – Methods of testing and required test results*

IMO resolution A.694(17), *General requirements for shipborne radio equipment forming part of the Global maritime distress and safety system (GMDSS) and for electronic navigational aids*

IMO resolution A.915(22), *Revised maritime policy and requirements for a future Global Navigation Satellite System (GNSS)*

IMO resolution A.953(23), *World-wide radionavigation system*

IMO resolution MSC.233(82), *Adoption of the Performance Standards for Shipborne GALILEO Receiver Equipment*

ITU-R Recommendation M.823-3, *Technical characteristics of differential transmissions for Global Navigation Satellite Systems from maritime radio beacons in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Regions 2 and 3*

RTCM 10402 RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.4

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

NOTE All definitions and abbreviations used are the same as those used in the Galileo performance signal specification.

3.1 Terms and definitions

3.1.1
integrity
ability of the system to provide users with warnings within a specified time when the system should not be used for navigation

3.2 Abbreviations

Compass	Beidou-2 GNSS (China)
COG	Course Over Ground
CW	Continuous Wave
dGalileo, dGPS, dGLONASS	Differential Galileo, GPS, GLONASS
EUT	Equipment Under Test
FDE	Fault Detection and Exclusion
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GLONASS	GLObal Navigation Satellite System
GTRF	Galileo Terrestrial Reference Frame

ITRF	International Terrestrial Frame
HAL	Horizontal Alert Limit
HDOP	Horizontal Dilution Of Precision
HPL	Horizontal Protection Limit
HMI	Hazardous Misleading Information
MDE	Marginally Detectable Error
NB	Narrow Band
pdf	Probability distribution function
PDOP	Position Dilution Of Precision
P_{HMI}	Probability of hazardous misleading error
PVT	Position, Velocity, Time
RAIM	Receiver Autonomous Integrity Monitor
RF	Radio Frequency
RFCS	Radio Frequency Constellation Simulator
RFI	Radio Frequency Interference
SDME	Speed and Distance Measuring Equipment
SIS	Signal in space
SOG	Speed Over Ground
SV	Space Vehicle
TTA	Time-to-alarm
ULS	Up-Link Station
UTC	Universal Time Coordinated
VAL	Vertical Alert Limit
VPL	Vertical Protection Limit
WB	Wide Band

4 Minimum performances standards

4.1 Object

Galileo provides two different services of use for the maritime community.

(M.233/A1.3) *The Galileo Open Service provides positioning, navigation and timing services, free of direct user charges. The Open Service can be used on one (L1, E5a, E5b), two (L1 and E5a or L1 and E5b) or three (L1, E5a and E5b) frequencies.*

(M.233/A1.4) *The Galileo Safety of Life Service can be used on one (L1 or E5b) or two (L1 and E5b) frequencies. Each of the L1 and E5b frequencies carries a navigation data message that includes integrity information. The E5a frequency does not include integrity data.*

(M.233/A1.5) *Galileo receiver equipment intended for navigation purposes on ships of speeds not exceeding 70 knots, in addition to the general requirements specified in* IEC 60945, *shall comply with the following minimum performance requirements.*

(M.233/A1.6) *These standards cover the basic requirements of position fixing, determination of course over ground (COG), speed over ground (SOG) and timing, either for navigation purposes or as input to other functions. The standards do not cover the other computational facilities which may be in the equipment nor cover the requirements for any other systems that may take input from the Galileo receiver.* Other computational activity, input/output activity or extra display functions which may be provided shall not degrade the performance of the equipment below the minimum performance standards set out in this standard.

4.2 Galileo receiver equipment

(See 5.6.1)

4.2.1 Minimum facilities

(M.233/A2.1) The words "Galileo receiver equipment" as used in these performance standards include all the components and units necessary for the system properly to perform its intended functions. The Galileo receiver equipment shall *include the following minimum facilities:*

.1 antenna capable of receiving Galileo signals;

.2 Galileo receiver and processor;

.3 means of accessing the computed latitude/longitude position;

.4 data control and interface; and

.5 position display and, if required, other forms of output.

NOTE If Galileo forms part of an approved Integrated Navigation System (INS), requirements of .3, .4 and .5 may be provided within the INS.

4.2.2 Configuration

The Galileo receiver equipment may be supplied in one of several configurations to provide the necessary position information. Examples are as follows:

– stand-alone receiver with means of accessing computed position via a keyboard with the positional information suitably displayed;
– Galileo black box receiver fed with operational parameters from external devices/remote locations and feeding an integrated system with means of access to the computed position via an appropriate interface, and the positional information available to at least one remote location.

The above examples should not be implied as limiting the scope of future development.

4.2.3 Quality assurance

The equipment shall be designed, produced and documented by companies complying with approved quality systems as applicable.

4.3 Performance standards for Galileo receiver equipment

4.3.1 General

(See 5.6.2)

(M.233/A3.1) The Galileo receiver equipment shall *be capable of receiving and processing the Galileo positioning and velocity, and timing signals on:*

i) for a single frequency receiver, the L1 frequency alone. The receiver shall *use the ionospheric model broadcast to the receiver by the constellation to generate ionospheric corrections;*

ii) for a dual frequency receiver, ***either*** *the L1 and E5b frequencies* ***or*** *the L1 and E5a frequencies. The receiver* shall *use dual frequency processing to generate ionospheric corrections;*

A detailed description of the Galileo Navigation Signal Characteristics is given in Annex A.

(M.233/A3.2) The Galileo receiver equipment shall *provide position information in latitude and longitude in degrees, minutes and thousandths of minutes;*

NOTE Galileo uses Galileo Terrestrial Reference Frame System (GTRF) datum which is a realization of the International Terrestrial Reference Frame (ITRF) system and differs from WGS 84 by less than 5 cm worldwide.

(M.233/A3.3) The Galileo receiver equipment shall *provide time referenced to universal time coordinated UTC (Bureau International des Poids et Measures).*

4.3.2 Equipment output

(See 5.6.3)

(M.233/A3.4) The Galileo receiver equipment shall *be provided with at least two outputs from which position information, UTC, course over ground (COG), speed over ground (SOG) and alarms can be supplied to other equipment. The output of position information* shall *be based on the WGS84 datum and* shall *be in accordance with* IEC 61162*. The output of UTC, course over ground (COG), speed over ground (SOG) and alarms* shall *be consistent with the requirements of M.233/A3.16 and M.233/A3.18;*

(M.233/A3.17) The Galileo receiver equipment shall *have at least one normally closed contact which* shall indicate *failure of the Galileo receiver equipment;*

(M.233/A3.18) The Galileo receiver equipment shall *have a bidirectional interface to facilitate communication so that alarms can be transferred to external systems and so that audible alarms from the Galileo receiver can be acknowledged from external systems; the interface* shall *comply with* IEC 61162.

For reporting purposes the following sentences shall be available in any combination.

DTM – Datum reference (see IEC 61162-1)

GBS – GNSS Satellite fault detection (see IEC 61162-1)

GFA – GNSS Fix Accuracy and integrity (see IEC 61162-1)

GNS – GNSS fix data (see IEC 61162-1)

RMC – Recommended minimum specific GNSS data (see IEC 61162-1)

ZDA – Time and date (see IEC 61162-1)

If a sentence uses a datum other than WGS-84 then the DTM sentence shall be used in compliance with IEC 61162-1.

For alarm reporting purposes the following sentences shall be available.

ALR – Set Alarm State (see IEC 61162-1)

ACK – Acknowledge Alarm (see IEC 61162-1)

In addition, for integrating with other navigational aids, the following sentences may be available in any combination.

GRS – GNSS range residuals (see IEC 61162-1)

GSA – GNSS DOP and active satellites (see IEC 61162-1)

GST – GNSS pseudo-range error statistics (see IEC 61162-1)

GSV – GNSS satellites in view (see IEC 61162-1)

NOTE GBS, GRS, GSA, GST, GSV are required to support external integrity checking. They are to be synchronized with corresponding fix data (GNS).

4.3.3 Accuracy

(See 5.6.4)

4.3.3.1 Static position accuracy

(M.233/A3.5) The Galileo receiver equipment shall *have static accuracy such that the position of the antenna is determined to within:*

i) 15 m horizontal (95 %) and 35 m vertical (95 %) for single frequency operations on the L1 frequency;

ii) 10 m horizontal (95 %) and 10 m vertical (95 %) for dual frequency operations on L1 and E5a or L1 and E5b frequencies.

NOTE The minimum accuracy requirements specified for dual frequency processing are based on the performance requirements established in IMO resolution A.915(22) and IMO resolution A.953(23) for navigation in harbour entrances, harbour approaches and coastal waters. The Galileo Safety of Life service is expected be able to provide better accuracy (4 m horizontal 95 % and 8 m vertical 95 %).

4.3.3.2 Dynamic position accuracy

(M.233/A3.6) *The Galileo receiver equipment* shall have *dynamic accuracy equivalent to the static accuracy specified in* 4.3.3.1 *above under the sea states and motion experienced in ships* as described in IMO resolution A.694(17), IEC 60721-3-6 and IEC 60945.

4.3.4 Acquisition

(See 5.6.5)

(M.233/A3.9) The Galileo receiver equipment shall *be capable of selecting automatically the appropriate satellite-transmitted signals to determine the ship's position and velocity, and time with the required accuracy and update rate;*

(M.233/A3.12) The Galileo receiver equipment shall *be capable of acquiring position, velocity and time to the required accuracy within 5 min when there is no valid almanac data (cold start);*

(M.233/A3.13) The Galileo receiver equipment shall *be capable of acquiring position, velocity and time to the required accuracy within 1 min when there is valid almanac data (warm start);*

(M.233/A3.14) The Galileo receiver equipment shall *be capable of re-acquiring position, velocity and time to the required accuracy within 1 min when there has been a service interruption of 60 s or less;*

Acquisition is defined as the processing of Galileo satellite signals to obtain a position fix within the required accuracies.

Three conditions of the Galileo receiver equipment are set out under which the minimum performance standards shall be met.

Condition A

Initialization (cold start) – the equipment has

– been transported over large distances (>1 000 km to <10 000 km) without power or Galileo signals or by the deletion of the current almanac; or

– not been powered for >7 days.

Condition B

Warm start – the equipment has a valid almanac (Power outage and/or interruption of Galileo signal reception for at least 24 h).

Condition C

Brief interruption of power for 60 s.

No user action other than applying power and providing a clear view from the antenna for the Galileo signals shall be necessary, from any of the initial conditions above, in order to achieve the required acquisition time limits in Table 1.

Table 1 – Acquisition time limits

Equipment condition	A	B	C
Acquisition time limits (min)	5	1	1

4.3.5 Antenna and input/output connections

(See 5.6.6)

(M.233/A5) Precautions shall *be taken to ensure that no permanent damage can result from an accidental short circuit or grounding of the antenna or any of its input or output connections or any of the Galileo receiver equipment inputs or outputs for a duration of 5 min.*

4.3.6 Antenna design

(See 5.6.7)

(M.233/A2.2) The antenna design shall *be suitable for fitting at a position on the ship which ensures a clear view of the satellite constellation, taking into consideration any obstruction that might exist on the ship.*

4.3.7 Dynamic range

(See 5.6.8)

(M.233/A3.10) *The Galileo receiver equipment* shall *be capable of acquiring satellite signals with input signals having carrier levels in the range of –128 dBm to –118 dBm. Once the satellite signals have been acquired, the equipment* shall continue *to operate satisfactorily with satellite signals having carrier levels down to –131 dBm.*

4.3.8 Protection from specific interfering signals

(See 5.6.9)

The Galileo receiver equipment shall meet the following requirements:

a) in a normal operating mode, i.e. switched on and with antenna attached, it is subject to radiation of 3 W/m^2 at a frequency of 1636,5 MHz for 10 min. When the unwanted signal is removed and the Galileo receiver antenna is exposed to the normal Galileo satellite signals, the Galileo receiver equipment shall calculate valid position fixes within 5 min without further operator intervention;

NOTE 1 This is equivalent to exposing a Galileo antenna to radiation from an Inmarsat Fleet77 antenna at 10 m distance along the bore sight.

b) in a normal operating mode, i.e. switched on, and with antenna attached, it is subject to radiation consisting of a burst of 10 pulses, each 1,0 µs to 1,5 µs long on a duty cycle of 1 600:1 at a frequency lying between 2,9 GHz and 3,1 GHz at power density of about 7,5 kW/m^2. The condition shall be maintained for 10 min with the bursts of pulses repeated every 3 s. When the unwanted signal is removed and the Galileo receiver antenna is exposed to the normal Galileo satellite signals, the receiver shall calculate valid position fixes within 5 min without further operator intervention.

NOTE 2 This condition is approximately equivalent to exposing the antenna to radiation from a 60 kW "S" Band marine radar operating at a nominal 1,2 µs pulse width at 600 pulses/s using a 4 m slot antenna rotating at

20 r/min with the Galileo antenna placed in the plane of the bore site of the radar antenna at a distance of 10 m from the centre of rotation.

Advice shall be given in the manual for adequate installation of the antenna unit, to minimize interference with other radio equipment such as marine radars, Inmarsat ship earth stations, etc.

4.3.9 Position update

(See 5.6.10)

(M.233/A3.15) The Galileo receiver equipment shall *generate and output to a display and digital interface* (conforming to IEC 61162) *a new position solution at least once every 1 s for conventional craft and at least once every 0,5 s for high speed craft;*

NOTE For high speed craft purposes the equipment should provide an IEC 61162-2 interface with a position update rate of 2 Hz.

(M.233/A3.7) The Galileo receiver equipment shall *have position resolution equal or better than 0,001 minutes of latitude and longitude;*[1]

4.3.10 Differential Galileo input

(See 5.6.11)

(M.233/A3.19) The Galileo receiver equipment shall *have the facilities to process differential Galileo (dGalileo) data fed to it in accordance with the standards of* Recommendation ITU-R M.823 *and an appropriate RTCM standard, and provide indication of the reception of dGalileo signals and whether they are being applied to the ship's position.*

When a dual frequency Galileo receiver is equipped with a differential receiver, performance standards for static and dynamic accuracies (4.3.3.1 and 4.3.3.2) shall be 10 m (95 %) together with integrity monitoring.

When a single frequency Galileo receiver is equipped with a differential receiver, performance standards for static and dynamic accuracies (4.3.3.1 and 4.3.3.2) shall be 10 m (95 %).

An integrated dGalileo receiver shall have an ITU-R M.823 compliant asynchronous full duplex serial input/output port for testing in compliance with IEC 61108-4. The data input/output port shall be supplied for testing purposes only.

NOTE It is intended that the standard for the differential Galileo receiver will be contained in a future revision of IEC 61108-4.

4.3.11 Navigational warnings and status indications

(See 5.6.12)

4.3.11.1 Position

(M.233/A4.1) *The Galileo receiver equipment* shall *also indicate whether the performance of Galileo is outside the bounds of requirements for general navigation in the ocean, coastal, port approach and restricted waters, and inland waterway phases of the voyage as specified in either IMO resolution A.953(23) or Appendix 2 to IMO resolution A.915(22) and any subsequent amendments as appropriate.*

The Galileo receiver equipment shall as a minimum:

1 It should be noted that AIS receivers require 0,0001 minutes of latitude and longitude.

a) *(M.233/A4.1.1) provide a warning within 5 s of loss of position or if a new position based on the information provided by the Galileo constellation has not been calculated for more than 1 s for conventional craft and 0,5 s for high speed craft. Under such conditions the last known position and time of last valid fix, with the explicit indication of the state so that no ambiguity can exist,* shall *be output until normal operation is resumed;*

b) *(M.233/A3.19 provide differential Galileo status indication of:*

   1) *the receipt of dGalileo signals; and*

   2) *whether they are being applied to the indicated ship's position;*

c) display dGalileo text messages. The Galileo receiver either shall have as a minimum the capability of displaying appropriate dGalileo text messages or forwarding those messages for display on a remote system;

d) provide an indication of the navigational status.

(M.233/A4.2) For receivers having the capability to process the Galileo Safety of Life Service, integrity monitoring and alerting algorithms shall *be based on a suitable combination of the Galileo integrity message and receiver autonomous integrity monitoring (RAIM). The receiver* shall *provide an alarm within 10 s Time to Alarm (TTA) of the start of an event if an alert limit of 25 m Horizontal Alert Limit (HAL) is exceeded for a period of at least 3 s. The probability of detection of the event* shall *be better than 99,999 % over 3-hour period (integrity risk* $<=10^{-5}$ */3 h.*

The navigational status for different position accuracy levels shall be expressed in three navigational states

safe,

caution and

unsafe.

The conditions for a “Safe” navigational state are as follows:

a) the estimated error (95 % confidence) along the major axis of the error ellipse is less than the selected accuracy level corresponding to the actual navigation mode, and

b) integrity is available and within the requirements for the actual navigation mode, and

c) a new position has been calculated within 1 s for a conventional craft and 0,5 s for a high speed craft

The conditions for a “Caution” navigational state is that integrity has not been available for a period of at least 3 s.

The conditions for an “Unsafe” navigational state are as follows:

a) the estimated error (95 % confidence) along the major axis of the error ellipse is greater than the selected accuracy level corresponding to the actual navigation mode, and/or

b) integrity is available but exceeds the requirements for the actual navigation mode for a period of at least 3 s, and/or

c) a new valid position has not been calculated for more than 1 s for a conventional craft and 0,5 s for a high speed craft.

The navigational status shall be continuously displayed along with an indication of the accuracy level selected. The navigational status and the accuracy level selected shall be provided to other equipment in accordance with the equipment output requirements.

The manufacturers may use colours for navigational status indication and if so the following colours shall be used:

“Safe” shall be green,

“Caution” shall be yellow, and

“Unsafe” shall be red.

A change in the navigational status shall be indicated within 10 s.

For receiver equipment which does not provide information by a dedicated display, the provision of the navigational status indication and the selected accuracy level with an appropriate output interface is mandatory.

4.3.11.2 Integrity monitoring

The Galileo receiver equipment shall incorporate integrity monitoring to determine if the probability of an undetected position failure exceeds the integrity risk limit for the actual navigation mode and provide an integrity indication.

NOTE 1 The Galileo integrity concept is explained in Annex B.

Integrity calculations shall be expressed either in terms of the integrity risk (P_{HMI}) at HAL or the horizontal protection limit (HPL), which is the radius of a circle in the horizontal plane with its centre in the true position which is assured to contain the indicated horizontal position with a probability consistent with the integrity risk level.

NOTE 2 In the RAIM literature this is also referred to as the marginally detectable error (MDE). The protection level is equivalent to the maximum MDE for the satellites used in the position solution.

A receiver capable of receiving the Safety of Life service shall use the Galileo integrity message to determine the integrity status. The accuracy levels shall be user selectable for 10 m and 100 m for general navigation (see IMO resolution A.953(23)), and the corresponding protection levels are 25 m and 250 m respectively. Additional accuracy levels for user selection may be provided.

The integrity monitoring shall be based on the following sources:

a) Galileo Safety of Life integrity message when available, and

b) Receiver Autonomous Integrity Monitoring (RAIM).

An integrity indication shall be used to present the result of the integrity calculation with reference to the selected accuracy level appropriate for the vessel’s operational mode. The integrity indication refers to the “Safe”, “Caution” and “Unsafe” states of the navigational warning indicator.

As a minimum, the source of the integrity status indication, other than for the safe state, should be displayed.

4.3.11.3 Integrity monitoring using RAIM

4.3.11.3.1 General

(M.233/A4.1.2) The Galileo receiver equipment shall *as a minimum use receiver autonomous integrity monitoring (RAIM) to provide integrity performance appropriate to the operation being undertaken;*

RAIM calculations are undertaken through a combination of failure detection and integrity monitoring, and the RAIM algorithm employed shall be capable of detecting and excluding a faulty range signal from the position solution.

NOTE 1 RAIM is described in Annex C.

The decision thresholds used to detect and exclude a faulty range signal shall be consistent with the IMO integrity and continuity requirements as stated in IMO resolutions A.953(23) and A.915(22).

NOTE 2 dGalileo integrity information should be used to assist RAIM calculations when available.

4.3.11.3.2 Conditions for the safe integrity state

The result of integrity calculation (see Table 2) shall be stated as "safe", if the calculated horizontal protection level (HPL) is less than or equal to the horizontal alert limit (HAL).

This generally requires at least 5 "healthy" satellites available and in a robust geometry, i.e. the worst 4 satellite geometry is still suitable for navigation.

4.3.11.3.3 Conditions for the caution integrity state

The "caution" status indication shall be used when insufficient information is available to calculate HPL for more than 3 s.

Such conditions may occur if an insufficient number of satellites are available. Note that the resulting accuracy based on 4 satellites in use may be within the selected accuracy level, but the RAIM algorithm cannot verify it.

4.3.11.3.4 Conditions for the unsafe integrity state

The "unsafe" status indication shall be used when the calculated HPL exceeds the HAL for more than 3 s.

Table 2 – RAIM integrity states

Nav Status	No. of range signals	Protection level
Safe	≥5	and HPL ≤ HAL
Caution	<5	-
Unsafe	≥5	and HPL > HAL >

Note that Table 2 represents the theoretical results of RAIM calculations, but with certain satellite geometries and RAIM algorithms, the receiver may not be able to calculate a RAIM status with certainty.

4.3.11.4 Integrity monitoring using Galileo Safety of Life service

4.3.11.4.1 General

(M.233/A4.2) For receivers having the capability to process the Galileo Safety of Life Service, integrity monitoring and alerting algorithms shall *be based on a suitable combination of the Galileo integrity message and receiver autonomous integrity monitoring (RAIM)). The receiver* shall *provide an alarm within 10 s Time to Alarm (TTA) of the start of an event if an alert limit of 25 m Horizontal Alert Limit (HAL) is exceeded fo a period of at least 3 s. The probability of detection of the event* shall *be better that 99,999 % over a 3-h period (integrity risk* $\leq 10^{-5}$*/3 h).*

Galileo integrity does not assume the use of local failure detection by the user and the use of the integrity information does not protect against such local failures.

4.3.11.4.2 Conditions for the safe integrity state

The result of integrity calculation (see Table 3) shall be stated as "safe", if there is a minimum of one connected satellite, and the calculated horizontal protection level (HPL) is less than or equal to the horizontal alert limit (HAL) or the calculated P_{HMI} at the HAL is less than or equal to the integrity risk level.

NOTE Connected satellites are subsets of satellites which are connected to an up-link station (ULS) at any one time to provide real time integrity, see Annex B.

4.3.11.4.3 Conditions for the caution integrity state

The "caution" status indication shall be used when there are no connected satellites for more than 3 s.

4.3.11.4.4 Conditions for the unsafe integrity state

The "unsafe" status indication shall be used when there is a minimum of one connected satellites and the calculated horizontal protection level (HPL) exceeds the horizontal alert limit (HAL) or the calculated P_{HMI} at the HAL is greater than the integrity risk level for more than 3 s.

Table 3 – Integrity states corresponding to the Galileo integrity message

Navigational Status	No. of connected satellites	Protection level/ P_{HMI} calculation
Safe	≥1	and/or HPL ≤ HAL or and/or P_{HMI} *I* ≤ Integrity risk limit
Caution	0	
Unsafe	≥1	and/or HPL > HAL or and/or P_{HMI} *I* > Integrity risk limit

4.3.11.5 Self test

(M.233/A4.1.3) The Galileo receiver equipment shall *provide a self test function.*

4.3.12 Output of COG, SOG and UTC

(See 5.6.13)

4.3.12.1 Accuracy of COG

(M.233/A3.16) The COG, SOG and UTC outputs shall *have a validity mark aligned with that on the position output. The accuracy requirements for COG and SOG* shall *not be inferior to the relevant performance standards for heading* (IMO resolution A.424(XI) for convention craft and IMO resolution A.821(19) for high speed craft) *and speed and distance measuring equipment (SDME)* (IMO resolution A.824(19)) *and the accuracy* shall be *obtained under the various dynamic conditions that could be experienced onboard ships.*

The error in the COG (the path of the antenna position over ground) due to the actual ship's speed over ground shall not exceed the values in Table 4.

Table 4 – Accuracy of COG

Speed range (knots)	Accuracy of COG output to user
0 to ≤1 knot	Unreliable or not available
>1 to ≤17 knots	±3°
>17 knots	±1°

Due to the limitations of Galileo receivers to this standard, it is not appropriate to include requirements for COG errors attributed to high dynamic movement. Such limitations shall be stated in the manufacturer's operational manual.

4.3.12.2 Accuracy of SOG information

Errors in the SOG (velocity of the antenna position over ground) shall not exceed 2 % of the actual speed or 0,2 knots, whichever is greater.

4.3.12.3 Availability and validity of time information

The Galileo receiver equipment shall provide UTC with resolution of 0,01 s on the digital interface. The validity mark of the digital interface for position contained in GNS message shall be used for interpretation of validity of digital interface for UTC contained in the ZDA message.

4.3.13 Typical interference conditions

(See 5.7)

(M.233/A3.11) The Galileo receiver equipment shall *be capable of operating satisfactorily under normal interference conditions consistent with the requirements of resolution A.694(17).*

Operational situations include static accuracy and reacquisition within 30 s after satellite signals have been masked for 60 s or less by an obstruction, for example a bridge.

The typical Galileo RF interference environment can be characterized as being continuous wave (CW) in-band and near-band RFI, in-band CW/NB/WB RFI and in-band and near-band pulse interference.

NOTE Much work has been done in the aviation community to define interference levels in these three categories as reported in the Minimum Operational Performance Standards (MOPS) for Global Positioning System/Wide Area Augmentation System (GPS/WAAS) Airborne Equipment (RTCA/DO-229D December 13, 2006). The terminology and maximum RF interference levels defined in this subclause are based upon the terminology and RF interference masks developed within RTCA. These masks are also described in ITU-R Recommendation M.1477.

Except when explicitly stated, all the minimum performance requirements shall be achieved within the environment defined in Annex D.

5 Methods of testing and required test results

5.1 Test sites

The manufacturer shall, unless otherwise agreed, set up the Galileo receiver equipment to be tested and ensure that it is operating normally before testing commences.

During performance of all tests contained in the test clauses the following information shall be recorded for later evaluation:

- position;
- course over ground;

- speed over ground;
- time;
- indications and warnings.

Indications and warnings shall be appropriate to the conditions being experienced by the EUT at the time of their display.

5.2 Test sequence

The sequence of tests is not specified. Before commencement of testing, the sequence shall be agreed between the test laboratory and the supplier of the equipment.

Where appropriate, tests against different clauses of this standard may be carried out simultaneously. The manufacturer shall provide sufficient technical documentation to permit the Galileo receiver equipment to be operated correctly.

Additional data shall be provided by the manufacturer to cover specific tests which do not form part of the normal user operations, for example means to remove the almanac data, when applicable, for the purpose of testing according to 5.6.5.

5.3 Test signals

The static tests (5.6.4.1) shall be based upon using Galileo signals in compliance with the appropriate Galileo SIS-ICD, either the real Galileo signals or signals from a Galileo RF Constellation Simulator (RFCS).

The Galileo RFCS shall generate signals which have the same characteristics as the satellites, and produce signal delays due to normally occurring ionospheric and atmospheric conditions as well as multipath.

The Galileo RFCS shall operate in accordance with the Galileo signal specification, the Galileo Signal in Space (SIS) interface control document, as given for the E5a, E5b, and E1-BC signals (OS and SoL services).

The interference test generator shall be able to generate the broadband, CW and pulsed interference conditions typical for the marine environment as specified in 5.7.

A performance check is defined as a shortened version of the static accuracy test described in 5.6.4.1, that is a minimum of 100 position measurements shall be taken over a period of not <5 min and not >10 min, discarding any measurements with HDOP ≥ 2. The position of the antenna of the EUT shall not be in error compared with the known position >10 m (95 %) using WGS 84 as the reference datum.

The Galileo RFCS shall also be capable of generating differential corrections at a virtual reference station placed in any position using a geodetic class receiver and antenna.

The EUT shall have an ITU-R M.823 compliant asynchronous full duplex serial input/output port in compliance with IEC 61108-4 for input of differential correction signals. For integrated receivers the data input/output port may be supplied for testing purposes only.

Test signal A shall be a sequence of RTCM Version 2 messages for Galileo[2] type 41 or 42-3 (equivalent to ITU-R M.823 message 9 type 9-3 for GPS) and one message type 27 that form a continuous parity loop. The station ID of test signal A shall be an ID of a station that is stored in the almanac. The type 27 message shall give data for station B.

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2 RTCM 10402 RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.4.

Test signal B shall contain RTCM Version 2 messages type 41 or 42-3 for station B. The station ID of test signal B shall not be an ID of a station that is stored in the almanac.

5.4 Determination of accuracy

In the determination of the accuracy of position being calculated by the Galileo receiver equipment, note should be taken of the geometry of the satellites in use. The HDOP measurement is an indication of the suitability of the constellation in view for use in receiver equipment testing. If the HDOP is ≤2, the test conditions can be considered as suitable. For HDOP > 2, testing shall be delayed until better geometry is established. The aim of the accuracy tests is to establish that the measurement of position calculated by the EUT under static and dynamic conditions is as good as, or better than, the performance levels set out in this standard.

If a Galileo RFCS is used, the simulator scenario should be chosen such that HDOP ≤2 and PDOP ≤3,5 for the duration of the test.

5.5 General requirements and presentation requirements

5.5.1 Normal conditions

Normal environmental conditions shall be a convenient combination of +15 °C to + 30 °C temperature and 20 % to 75 % relative humidity.

When it is impractical to carry out the test under the conditions stated above, a note to this effect, stating the actual temperature and relative humidity during the tests, shall be added to the test report.

5.5.2 General requirements

All the general requirements of IEC 60945 appropriate to the category of the EUT, that is protected or exposed, shall be carried out. The manufacturer shall declare any preconditioning required before environmental checks. For the purposes of this standard, the following definitions for performance check and performance test, required by IEC 60945, shall apply.

Performance check – a shortened version of the static accuracy test described in 5.6.4.1, that is a minimum of 100 position measurements shall be taken over a period of not <5 min and not >10 min, discarding any measurements with HDOP ≥2. The position of the antenna of the EUT shall not be in error compared with the known position >10 m (95 %) using WGS 84 as the reference datum.

Performance test – the static accuracy test described in 5.6.4.1.

5.5.3 Presentation requirements

All the presentation requirements of IEC 62288 shall be carried out as appropriate to the facilities provided with the EUT.

5.6 Receiver tests

NOTE The number in brackets is the subclause of the relevant performance standard.

5.6.1 Galileo receiver equipment

(See 4.2.1)

The equipment under test (EUT) shall be checked for composition by inspection of the equipment and the manufacturer's documentation.

5.6.2 Position output

(See 4.3.1)

The EUT shall be checked for the form of the position output by inspection of the manufacturer's documentation.

5.6.3 Equipment output

(See 4.3.2)

The EUT shall be checked for conformity to IEC 61162 by inspection of the manufacturer's documentation and protocol tests.

5.6.4 Accuracy

5.6.4.1 General

(See 4.3.3)

The sampling interval will be two times the integration interval used for carrier phase smoothing of pseudoranges. For example, if the integration interval used for carrier phase smoothing of pseudoranges is 100 s, the sampling interval will be 200 s.

5.6.4.2 Static accuracy

(See 4.3.3.1)

5.6.4.2.1 Static test site

The antenna shall be mounted according to the manufacturer's instructions at a height of between 1 m and 1,5 m above the electrical ground in an area providing clear line of sight to the satellites from zenith through to an angle of +5° above horizontal. The position of the antenna shall be known, with reference to WGS 84 to an accuracy of better than 0,1 m in (x, y, z). Maximum cable lengths as specified by the manufacturer shall be used during testing.

If a Galileo RFCS is used, the simulator scenario shall be chosen such that clear line of sight views to all satellites above a +5° mask angle is ensured for the duration of the test.

5.6.4.2.2 Galileo

Position fix measurements shall be taken at the required sampling interval over a period of not <24 h. The absolute horizontal position accuracy shall be within 15 m (95 %) for a single frequency receiver and within 10 m (95 %) for a dual frequency receiver, having discarded measurements taken in conditions of HDOP ≥ 2 and PDOP ≥ 3,5. The horizontal position of the antenna shall be known to within 0,1 m in the datum used for position fixing.

5.6.4.2.3 Differential Galileo

Position fix measurements shall be taken at the required sampling interval over a period of not <24 h. The distribution of the horizontal error shall be within 10 m (95 %) for a single frequency receiver and within 10 m (95 %) for a dual frequency receiver, having discarded measurements taken in conditions of HDOP ≥ 2 and PDOP ≥ 3,5. The horizontal position of the antenna shall be known to within 0,1 m in the datum used for position fixing and for the generation of the corrections.

5.6.4.3 Angular movement of the antenna

The static tests specified in 5.6.4.2.1 and 5.6.4.2.3 shall be repeated with the antenna performing an angular displacement of ±22,5° (simulating roll) in a period of about 8 s (see IEC 60721-3-6) during the duration of the tests.

The results shall be as in 5.6.4.2.2 and 5.6.4.2.3.

5.6.4.4 Dynamic accuracy

(See 4.3.3.2)

5.6.4.4.1 Galileo

The tests for dynamic accuracy are a practical interpretation of the conditions set out in IEC 60721-3-6, Table V, item e), X – direction (surge) and Y – direction (sway). These are stated as surge 5 m/s^2 and sway 6 m/s^2 for all classes of environment.

The accuracy tests shall be performed using a Galileo RFCS and the simulator characteristics shall accurately represent the signals required.

The Galileo RFCS shall generate the correct signal in space associated with the following dynamic situations:

a) a fully locked and settled EUT travelling in a straight line at 48 knots ± 2 knots for a minimum of 1,2 min which is reduced to 0 knots in the same straight line in 5 s;

b) a fully locked and settled EUT travelling at least 100 m at 24 knots ± 1 knot in a straight line then subjected, for at least 2 min, to smooth deviations either side of the straight line of approximately 2 m at a period of 11 s to 12 s.

For both dynamic situations, the receiver shall remain in lock and the deviation from the programmed simulator positions shall be within the accuracies stated in 5.6.4.2.2.

5.6.4.4.2 Differential Galileo

The tests for dynamic accuracy are a practical interpretation of the conditions set out in IEC 60721-3-6, Table V, item e), X – direction (surge) and Y – direction (sway). These are stated as surge 5 m/s^2 and sway 6 m/s^2 for all classes of environment.

The accuracy tests shall be performed using a Galileo RF signal simulator and the RFCS characteristics shall accurately represent the dGalileo data signals broadcast in accordance with RTCM 10402 and ITU-R M.823.

The RFCS shall generate the correct signal in space associated with the following dynamic situations:

a) a fully locked and settled EUT travelling in a straight line at 48 knots ± 2 knots for a minimum of 1,2 min which is reduced to 0 knots in the same straight line in 5 s;

b) a fully locked and settled EUT travelling at least 100 m at 24 knots ± 1 knot in a straight line then subjected, for at least 2 min, to smooth deviations either side of the straight line of approximately 2 m at a period of 11 s to 12 s.

For both dynamic situations, the receiver shall remain in lock and the deviation from the programmed simulator positions shall be within the accuracies stated in 5.6.4.2.3.

5.6.5 Acquisition

(See 4.3.4)

5.6.5.1 Condition A – Initialization

The EUT shall be initialized by one of the following:

a) initialized to a false position at least 1 000 km from the test position, or alternatively, by deletion of the current almanac; or

b) isolated from a power source for >7 days; or

c) when using a Galileo RFCS, simulator scenario date and position should be changed by a large amount; the date by more than 7 days and position by more than 1 000 km.

A performance check shall be carried out after the time limit contained in Table 1.

5.6.5.2 Condition B – No valid almanac

a) The EUT shall be isolated from the power source for a period within 24 h to 25 h.

   At the end of the period, a performance check shall be carried out after the time limit contained in Table 1.

b) During normal operation of the EUT, the antenna shall be completely masked for a period between 24 h and 25 h.

   At the end of the period, a performance check shall be carried out after the time limit contained in Table 1.

5.6.5.3 Condition C – Brief interruption of power

During normal operation of the EUT, the power shall be removed for a period of 60 s. At the end of this period, the power shall be restored.

A performance check shall be carried out after the time limit contained in Table 1.

5.6.6 Antenna and input/output connections

(See 4.3.5)

The antenna input of the receiver, if provided, shall be connected to ground for 5 min. After completion of the test and reset of the EUT, if required, the antenna or input/output connections shall be connected normally, and a performance check shall be carried out to ensure that no permanent damage has resulted.

5.6.7 Antenna design

(See 4.3.6)

The antenna of the EUT shall be checked by inspection of the documentation provided by the manufacturer, to confirm that it is suitable for shipborne installation to ensure a clear view of the satellite constellation.

5.6.8 Sensitivity and dynamic range

(See 4.3.7)

5.6.8.1 Acquisition

This is tested by using a Galileo RFCS as follows:

a) transmit the simulator signal over a suitable antenna;

b) adjust the signal power by use of a calibrated test receiver to −123 dBm ± 5 dBm;

c) replace the antenna of the calibrated test receiver by the receiving unit of the EUT;

d) a performance check shall be carried out.

The EUT shall meet the requirements of this check, within this signal range.

5.6.8.2 Tracking

The received satellite signals shall be monitored by a suitable test receiver. These signals shall be attenuated down to −131 dBm. Under these conditions, the performance requirements shall be met.

This is tested by using a Galileo RFCS as follows:

a) transmit the simulator signal over a suitable antenna;

b) adjust the signal power by use of a calibrated test receiver to −123 dBm ± 5 dBm;

c) replace the antenna of the calibrated test receiver by the receiving unit of the EUT;

d) after the start of transmission and tracking with the nominal transmission level condition, gradually reduce transmission level down to −131 dBm.

The EUT shall continue tracking at least 4 satellites and provide a valid position solution.

5.6.9 Protection from other shipborne transmitters

(See 4.3.8)

5.6.9.1 L band interference

(See 4.3.8 a)

In a normal operating mode, using an appropriate signal source, the EUT shall be subjected to radiation of 3 W/m^2 at a frequency of 1636,5 MHz for 10 min.

The signal shall be removed and a successful performance check shall be carried out within 5 min.

5.6.9.2 S band interference

(See 4.3.8 b)

In a normal operating mode, using an appropriate signal source, the EUT shall be subjected to radiation consisting of a burst of 10 pulses, each 1,0 µs to 1,5 µs long on a duty cycle of 1 600:1 at a frequency in the range of 2,9 GHz to 3,1 GHz at power density of approximately 7,5 kW/m^2. This condition shall be maintained for 10 min with the bursts of pulses repeated every 3 s.

NOTE The peak power density is 7,5 kW/m^2 to be measured at the EUT; this is approximately 4,7 W/m^2 average power at a fixed transmitting antenna.

The signal shall be removed and a successful performance check shall be carried out within 5 min.

5.6.10 Position update

(See 4.3.9)

5.6.10.1 Slow speed update rate

The EUT shall be placed upon a platform, moving in approximately a straight line, at a speed of 5 knots ± 1 knot. The position output of the EUT shall be checked at intervals of 10 s, over a period of 10 min. The output position shall be observed to be updated on each occasion.

This test may be carried out by using a Galileo RFCS.

5.6.10.2 High speed update rate

The EUT shall be placed upon a platform, moving in approximately a straight line, at a speed of 50 knots ± 5 knots. The position output of the EUT shall be checked at intervals of 1 s, over a period of 10 min. The output position shall be observed to be updated on each occasion.

This test may be carried out by using a Galileo RFCS with a speed of 70 knots at intervals of 0,5 s.

The minimum resolution of position, that is latitude and longitude, shall be checked by observation during 5.6.10.1 and 5.6.10.2 above.

Record the output of the EUT during this test and confirm that received positions at the end of each interval are in compliance with the real or simulated reference position.

5.6.11 Differential Galileo input

(See 4.3.10)

The manufacturer's documentation shall be inspected to

a) verify that the EUT will correctly process the message protocol of
   1) the RTCM recommended standards for differential Galileo service, or
   2) in the case where maritime radiobeacons are used as the means of communication of the differential corrections, the standards contained in ITU-R M.823, and
b) confirm that
   1) receipt of dGalileo signals will be indicated,
   2) the application of dGalileo signals to the output ship's position is indicated.

5.6.12 Navigational warnings and status indications

(See 4.3.11)

5.6.12.1 General alarm tests

5.6.12.1.1 Position alarm test

This is tested using a Galileo RFCS as follows:

a) set up the EUT in a simulation environment with HDOP <2;
b) switch off transmission of simulated signals and observe that the EUT releases an appropriate indication within 5 s;
c) verify that the navigational warning indicator is set to Unsafe;
d) verify that the last known position and its time stamp are being displayed indicating the loss of position condition. Verify that this mode is provided constantly on display and output interface until removal of the error condition at the simulation environment;
e) switch on transmission of simulated signals and observe that the EUT resumes normal operation.

5.6.12.1.2 Differential Galileo status indication test

This is tested using a Galileo RFCS as follows:

a) set up the EUT in a simulation environment providing an HDOP <2. Observe that the status of EUT operation is Galileo without using dGalileo corrections;
b) set the EUT differential correction age mask to 30 s;
c) start transmission of test signal A (5.3). Observe that the indication for dGalileo status of EUT operation is given within 40 s;

d) stop transmission of test signal A (5.3). Observe that the status of EUT operation resumes to Galileo without using dGalileo corrections within 40 s.

5.6.12.1.3 Test of integrity monitoring using RAIM

(See 4.3.11)

NOTE For the purpose of testing of the RAIM functionality, it is recommended that means are provided for real-time display of the actual position error with reference to the simulated position. A description of this testing is given in Annex E.

5.6.12.1.3.1 Testing of "safe" and "caution" status

The EUT shall be set up under simulated conditions using a Galileo RFCS, providing 6 healthy satellites available, acquired and tracked, as follows.

a) Select an accuracy level of 100 m.

b) Observe that
   1) RAIM is indicated as in operation, and
   2) the safe status is indicated.

c) Reduce the number of healthy satellites to 4. Observe that
   1) RAIM is still indicated as in operation, and
   2) the status indication switches to caution within 10 s of the satellite change that caused it.

d) Increase the number of healthy satellites until the RAIM state returns to safe state. Observe that
   1) RAIM is still indicated as in operation, and
   2) the status indication switches to safe within 10 s of the satellite change that prompted it.

For each step of the above test sequence, observe if the appropriate interface output is provided.

Repeat the above test sequence for a selected accuracy level of 10 m and, if provided, for another accuracy level.

5.6.12.1.3.2 Testing of unsafe status

The EUT shall be set up under simulated conditions using a Galileo RFCS, providing 6 healthy satellites available, acquired and tracked.

a) Select an accuracy level of 100 m.

b) Observe that
   1) RAIM is indicated as in operation, and
   2) the safe status is indicated.

c) Reduce the number of healthy satellites to 5 and apply an unsafe simulated test constellation. This can be accomplished in a controlled manner by adding a suitable ramp to the pseudorange signal and/or adding a satellite clock error. Observe that
   1) RAIM is indicated as in operation, and
   2) the status indication switches to unsafe within 10 s of the time of the unsafe simulated test constellation.

d) Restore the pseudorange signals and/or remove the satellite clock error until the RAIM state returns to safe state. Observe that
   1) RAIM is still indicated as in operation, and

2) the status indication switches to safe within 10 s of the satellite change that prompted it.

e) Reduce the number of healthy satellites to 5 and apply a safe simulated test constellation. Change the behaviour of at least 1 satellite by varying the satellite clocks with the result that a satellite is detected as failed. Observe that
   1) RAIM is still indicated as in operation, and
   2) the status indication switches to unsafe within 10 s of the time of the satellite failure.
f) Change the behaviour of the satellites back to regular behaviour where no satellites are detected as failed. Observe that
   1) RAIM is still indicated as in operation, and
   2) the status indication switches to safe within 10 s.

For each step of the above test sequence, observe if the appropriate interface output is provided.

Repeat the above test sequence for a selected accuracy level of 10 m and, if provided, for another accuracy level.

5.6.12.1.4 Test of integrity monitoring using Galileo Integrity

5.6.12.1.4.1 General

(See 4.3.11)

For the purpose of testing of the Galileo integrity functionality, it is recommended that means are provided for real-time display of the actual position error with reference to the simulated position.

5.6.12.1.4.2 Testing of safe and caution status

The EUT shall be set up under simulated conditions using a Galileo RFCS, providing 6 healthy satellites available including 2 connected satellites that provide a valid integrity message with an independent connection status. The EUT shall acquire and track all satellites and use the connected satellite providing the better service as the source of integrity.

NOTE This can be done by retrieving and checking the connection status origin (COSo) parameters from the Galileo satellites navigation data. Satellites whose COSo value is set to 15 are not valid as the integrity source. The receiver should also check every second if the connection status counter (COSc) parameter is incremented by at least 1, which verifies that the satellite broadcasting the integrity information is actually connected.

Proceed as follows.

a) Select an accuracy level of 10 m.
b) Observe that
   1) Galileo integrity is indicated as in operation, and
   2) the safe status is indicated.
c) Consecutively reduce the number of connected satellites to 0. Observe that
   1) Galileo integrity is still indicated as in operation, and
   2) the status indication switches to caution within 10 s of the satellite change that caused it.
d) Increase the number of connected satellites to 1. Observe that
   1) Galileo integrity is still indicated as in operation, and
   2) the status indication switches to safe within 10 s of the satellite change that prompted it.

For each step of the above test sequence observe if the appropriate interface output is provided.

5.6.12.1.4.3 Testing of unsafe status

The EUT shall be set up under simulated conditions using a Galileo RFCS, providing 8 healthy satellites available including 2 connected satellites, acquired and tracked. Proceed as follows.

a) Select an accuracy level of 10 m.
b) Observe that
   1) Galileo Integrity is indicated as in operation, and
   2) the safe status is indicated.
c) Apply an unsafe simulated test constellation to the EUT such that the protection level is exceeding the HAL or the P_{HMI} is exceeding the integrity risk limit. Observe that
   1) Galileo integrity is still indicated as in operation, and
   2) the status indication switches to unsafe within 10 s of the satellite changes that caused it.
d) Remove the unsafe condition and restore the safe operation state. Observe that
   1) Galileo integrity is still indicated as in operation, and
   2) the status indication switches to safe within 10 s of the satellite change that prompted it.

For each step of the above test sequence observe if the appropriate interface output is provided.

5.6.12.2 Self test

The EUT shall be checked for provision of a self check function by inspection of the manufacturer's documentation.

5.6.13 Accuracy of COG and SOG

(See 4.3.12.1)

The EUT shall be set up on an appropriate mobile unit or use a Galileo RFCS, and all outputs indicating course over ground shall be monitored.

At a constant forward direction, the forward speed shall be within 0 knots to 1 knot. Ten seconds after being in the range, measurements shall be made for a duration of 2 min. This cycle shall be repeated for all speed ranges of the Table 4.

The test results shall be observed on the display and the approved interface.

For SOG tests, no reading of the speed indicator shall differ from the constant speed being applied at the time by more than 2 % of that speed or 0,2 knots, whichever is the greater.

For COG tests, the differences between the reference direction and measured course over ground in each test cycle shall not exceed the limits of Table 4.

5.6.14 Validity of COG and SOG information

NOTE The quality indicator of the GNS and VTG sentences should be used for interpretation of validity of COG and SOG.

With the EUT normally operating, preclude invalid position data by reducing the number of received satellites. Investigate the content of the resultant GNS and VTG sentences.

Observe that the quality indicators of GNS and VTG messages turn to invalid.

Observe that the COG and SOG information contained in VTG message is replaced by null fields.

5.6.15 Output of UTC

While the EUT is navigating, provoke an invalid position by reducing the number of received satellites to two. Investigate the content of the GNS and ZDA sentences provided.

Observe that the resolution of UTC information is contained in the ZDA sentence. Observe that the validity flag of GNS sentence turns to invalid. Observe that the ZDA sentence remains transmitted carrying complete UTC information.

5.7 Tests for typical RF interference conditions

(See 4.3.13)

5.7.1 Simulator conditions

The Galileo RFCS setup should be as follows:

- six Galileo satellites;
- one satellite at a maximum level of –118 dBm plus antenna gain at 90° elevation;
- one satellite at a minimum level of –128 dBm plus antenna gain at 5° elevation;
- four satellites at a level of –125 dBm plus antenna gain at 45° elevation.

5.7.2 Navigation solution accuracy test

Interference conditions, including narrow band and wide band RF noise, CW interference, and pulsed interference, centred at 1 575,42 MHz for E1 receivers, 1 176,45 MHz for E5a receivers and 1 207,14 MHz for E5b receivers shall be simulated using a RF noise generator. For the pulsed interference tests, a pulse-modulated carrier (CW) with peak carrier level of −20 dBm and duty factor of 10 % shall be used. The interference values are shown in Table 5.

Table 5 – RF interference values

Narrow band/Wide band interference (NBI/WBI) values		
Frequency MHz	**Noise bandwidth** MHz	**Total RMS power** dBm
1 176,45	1	–93,0
1 207,14	1	–93,0
1 575,42	1	−101,0

Pulsed interference values 10% duty factor		
Frequency MHz	**Pulse width** ms	**Peak carrier level** dBm
1 176,45	1	–20
1 207,14	1	–20
1 575,42	1	–20

Continuous wave interference (CWI) values	
Frequency MHz	**Power** dBm
1 176,45	–102,5
1 207,14	–102,5
1 575,42	–115,0 (−120,5 GPS)
1 605,0	–50,0

The method of test is as follows:

a) the equipment under test is subjected to one of the interference sources;

b) the simulator scenario shall be engaged and the satellite signals turned on;

c) the equipment under test shall be powered and initialized;

d) while the EUT is providing position solutions, the interference shall be applied to the equipment under test, and the level of the interference shall be adjusted to the required value;

e) when steady-state accuracy is reached, record a minimum of 20 position and HDOP values as reported by the EUT at a rate of one sample every 2 min;

f) repeat this cycle for any remaining interference source and receiver frequency.

If the EUT reports a position outside the given boundaries (at the 95 % confidence level) for the positioning service mode (see 4.3.3.1) in use, or fails to report a position in more than 5 % of the samples, a test failure is declared.

5.7.3 Re-acquisition test

The re-acquisition test is designed to simulate a temporary loss of signal, such as passing under a bridge. To determine the re-acquisition pass/fail criteria, consider a single trial where the EUT provides a valid position fix that is within required accuracy at 30 s from restoration of the satellite signals, and maintains a tracking status for at least the next 60 s. This unit is considered to have passed one trial.

The interference condition to be tested includes Narrow band and Wide band interference (NBI/WBI) as shown in Table 5.

The method of test is as follows:

a) the equipment under test is subjected to the Narrow band/Wide band interference source;
b) the simulator scenario shall be engaged and the satellite signals turned on;
c) the equipment under test shall be powered and initialized;
d) the EUT shall be allowed to reach steady-state accuracy before the satellites are to be switched off;
e) the simulator RF output shall be removed for 30 s;
f) the simulator RF output shall be restored to the EUT;
g) after 30 s record a position and HDOP value as reported by the EUT. If after 30 s, no position report has been sent from the receiver, record a trial failure and go to step i);
h) ensure that the receiver continues position reporting for the next 60 s;
i) go to Step d) and repeat as required. (Note that if the simulator scenario is reset, some receivers may require purging of all previous data to enable proper operation. This is due to the persistence of time data in the receiver and the inability of the receiver's software to deal with a backward transition in time);
j) repeat this cycle for any remaining receiver frequency.

A failure by the EUT to provide a position output after 30 s, reporting a position outside the given boundaries (at the 95 % confidence level) for the positioning service mode (see 4.3.3.1) in use or failing to continue position reporting for 60 s after sampling indicates a failure mode, will result in the trial being declared a failure.

Annex A
(informative)

Galileo navigation signals characteristics

Galileo provides 10 signals in three frequency ranges 1 164 – 1 215 MHz (E5), 1 215 – 1 300 MHz (E6) and 1 559 – 1 591 MHz (E1), in the Radio-Navigation Satellite Service (RNSS) allocated frequency bands. Table A.1 and Table A.2 show the main characteristics of the various signals and range codes as well as allocations with respect to the basic navigation services [3].

Table A.1 – General characteristics of the Galileo navigation signals

Signal No.	Signal	Carrier frequency M Hz	Channel designation	Symbol rate Navdata symbols/s)	Notes [a]
1	Data signal in E5a	1 176,450	E5a-I	50	OS; open, no encryption
2	Pilot signal in E5a	1 176,450	E5a-Q	–	No data
3	Data signal in E5b	1 207,140	E5b-I	250	OS, SoL; open, no encryption
4	Pilot signal in E5b	1 207,140	E5b-Q	–	No data
5	Data signal in E6	1 278,750	E6-A	Classified	PRS; encrypted code and data
6	Data signal in E6	1 278,750	E6-B	1 000	CS, encrypted code and data
7	Pilot signal in E6	1 278,750	E6-C	–	Encrypted code; No data
8	Data signal in E1 (L1 band)	1 575,420	E1-A	Classified	PRS; encrypted code and data
9	Data signal in E1 (L1 band)	1 575,420	E1-B	250	OS, SoL; open, no encryption
10	Pilot signal in E1 (L1 band)	1 575,420	E1-C	–	No data

[a] OS: Open Service, CS: Commercial service, SoL: Safety of Life service, PRS: Public Regulated service.

Out of the 10 Galileo signals, 4 are pilot signals which do not carry navigation data and which are intended to increase the tracking robustness at receiver level. This leaves 6 navigation signals, of which 3 are open (free of charge) for use in the Open and Safety of Life services. The two PRS signals and the commercial service have both code and navdata encrypted.

[3] Galileo Open Service Signal in Space Interface Control Document, OS SIS ICD, Draft 1, February 2008, ESA/GSA.

Table A.2 – General characteristics of Galileo observables

No.	Observable name	Carrier frequency MHz	Chipping rate Mchip/s	Notes
1	E5a	1 176,450	10,230	Open code and data
2	E5b	1 207,140	10,230	Open code and data
3	E5a+b (AltBOC)	1 191,795	10,230	High performance signal
4	E6-A	1 278,750	-	Classified
5	E6-BC	1 278,750	5,115	CS, code and data encrypted
6	E1-A	1 575,420	-	Classified
7	E1-BC	1 575,420	1,023	Open code and data

It should be noted that the E5a and E5b signals will be transmitted coherently as a wide-band Alternative (Alt) BOC(15,10) modulated signal having a side-band sub-carrier rate equal to 15,345 MHz (15 × 1,023 MHz) and code rate equal to 10,230 MHz (10 × 1,023 MHz). This signal is then amplified and transmitted at the 1 191,795 MHz carrier frequency.

The wide-band AltBOC signal allows the receivers to track the E5a and E5b bands in two modes:

– E5a and E5b separately, on their respective carriers,

– E5a+b together, as one single wide-band signal centred at 1191,795 MHz. Tracking the E5a+b signal coherently offers enhanced performances in terms of code tracking noise and multipath.

In practice, one could say that the introduction of AltBOC adds a fifth carrier frequency to the Galileo spectrum: a fully-featured Galileo receiver could produce code and carrier phase observables from the carriers given in Table A.2 (although most receivers will probably only support a subset of these carriers).

Galileo observables are user measurements provided by Galileo receivers. Each Galileo observable is a set of 4 measurements, which includes a code pseudorange, a carrier phase measurement, a Doppler (or range rate), and an SNR (signal-to-noise ratio). The difference between Table A.1 and Table A.2 is due to the fact that according to the design concept of the Galileo signals, the data and pilot components of each signal are tracked together and result in one measurement. Due to the AltBOC modulation scheme, the E5a and E5b signals can also be tracked co-operatively, which leads to a high performance AltBOC observable.

Annex B
(informative)

The Galileo integrity concept

B.1 General

B.1.1 Integrity concept

Integrity is a system quality metric which is related to the safe use of the system, and quantifies the probability of using erroneous data. For safety critical applications, such erroneous data are often termed Hazardous Misleading Information (HMI).

The error of the position determination using a GNSS is the combination of the following two factors [GIC05]:

- errors on individual satellite range measurements;
- deterministic geometry of the satellites as seen by a given user receiver.

The purpose of the integrity mechanism for Galileo is to ensure that each individual user receiver is provided with signals which are safe for its intended operation and is warned in due time if this condition cannot be met at any one point in time.

B.1.2 Definition of integrity

The definition of integrity varies in various standardisation organisations. IMO defines integrity as (IMO Res. A.915(22):2001):

The ability to provide users with warnings within a specified time when the system should not be used for navigation

A more complete definition is provided by the ICAO SARPs[4]:

A measure of trust which can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of the system to provide timely warnings to the user when the system should not be used for the intended operation.

B.1.3 Quantifying integrity

Position calculation using GNSS is typically performed at a fixed number of discrete samples per unit time (frequency). For each calculated position (fix) there is a small, but not always negligible, probability that the fix has an undetected error and that trusting such erroneous fixes may lead to hazardous situations.

Both IMO and ICAO use the word **risk** to indicate the probability of undesirable events (such as undetected errors) within a time interval. This unfortunately is not compliant with the general definition of risk which also includes the notion of the consequences (loss) related to the event.

So, when IMO and ICAO state their maximum integrity risk levels for various operational conditions, they refer to the probability of occurrence of an undetected position error in a given normalizing time interval, which for maritime is chosen to be 3 h (IMO Res.

[4] International Civil Aviation Organisation (ICAO) - Standards and Recommended Practises (SARPs).

A.915(22):2001) and for aviation is either 1 h or 150 s, depending on the mode of operation (ICAO SARPs).

B.2 Galileo integrity concept

B.2.1 Monitoring ground network

The Galileo ground segment includes a global network of Sensor Stations (GSS), collecting navigation data from the Galileo satellites and Up-link Stations (ULS) both for Tracking, Telemetry and Command (TT&C) and specific mission related up-links for dissemination of integrity related and other information.

B.2.2 Connected satellites

Real-time integrity information is provided by a subset of satellites, which are connected (to a ULS) at any one time, and a minimum of 2 connected satellites are in view at all possible user locations world-wide.

B.2.3 SISA, SISMA, IF threshold

Galileo will monitor the signal-in-space (SIS) within the ground segment using the measurements of the GSSs. With the known positions of the GSSs, the actual position of the SV and the error on the range (the signal-in-space-error, SISE) can be estimated.

Looking at the predicted SISE distribution for all different user receiver locations it is assumed that these distributions, which are not necessarily Gaussian, can be conservatively represented (overbounded) by a zero-mean Gaussian distribution of which the standard deviation is broadcast as the Signal-In-Space- Accuracy (SISA) as shown in Figure B.1.

NOTE Overbounding is a statistical technique whereby an unknown probability distribution (pdf, cdf) is represented by another (typically Gaussian) distribution in such a way that the real distribution does not exceed the overbounding distribution according to a given criteria.

The predictive distribution is determined using historical data. However, to detect situations in which the system does not meet the predicted performance, Galileo estimates the actual SISE in real time. This estimation will still contain some uncertainty due to measurement errors. The assumption made in this case is that the difference between the true and estimated SISE can be conservatively represented (overbounded) by a Gaussian distribution having a standard deviation which is called the Signal-In-Space-Monitoring-Accuracy (SISMA), see Figure B.1. The value of SISMA will depend on the geometry between the available GSSs and the SVs, the quality of the GSS observables and the quality of the propagation modelling.

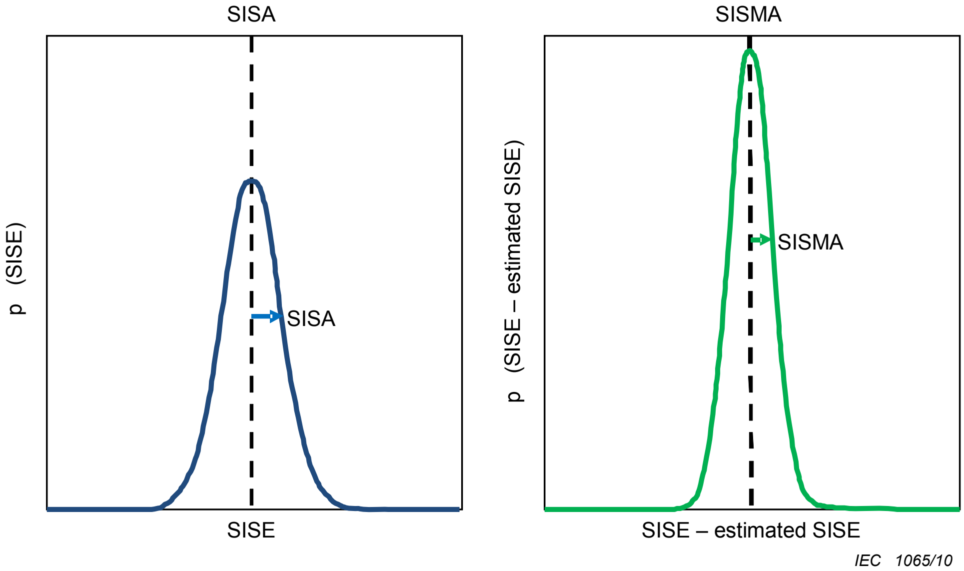


Figure B.1 – Graphical illustration of SISA and SISMA [GIC05]

When the estimated SISE exceeds a so-called integrity flag threshold TH, the satellite will be flagged "don't use". The user receiver uses the value of TH to conservatively represent the largest estimated SISE value that might have been measured by the ground segment.

B.2.4 Integrity dissemination

The integrity related information is disseminated via the I/NAV navigation message included in the Safety of Life service signals and two kinds of integrity data are supplied:

a) integrity tables that include flags to indicate the integrity status of each navigation data broadcast by each satellite, to be broadcast every 30 s, and

b) integrity alerts to be broadcast with an alert process that enables to update the integrity information in real-time (each 1 s).

The integrity flags (IF, 4 bits) associated with the integrity tables indicate the monitoring accuracy of the SIS, named SISMA, for the specific satellite, while the integrity alert indicator (IAI, 1 bit) associated with the integrity alerts only has two values: OK or Not OK.

The Galileo integrity concept also has provision for external regional integrity data in addition to the global data provided by the core ground segment. In this way, specific geographic regions may take responsibility for disseminating integrity data for their region.

B.2.5 IF table

The integrity flag inside the integrity table is used to indicate the integrity of any particular satellite, having the possible values as shown in Table B.1.

Table B.1 – Integrity flag values

Integrity flag value	Definition
0	Satellite NOT OK for use
1	Satellite OK with SISMA value = 0,30 m
2	Satellite OK with SISMA value = 0,40 m
3	Satellite OK with SISMA value = 0,50 m
4	Satellite OK with SISMA value = 0,60 m
5	Satellite OK with SISMA value = 0,70 m
6	Satellite OK with SISMA value = 0,85 m
7	Satellite OK with SISMA value = 1,00 m
8	Satellite OK with SISMA value = 1,15 m
9	Satellite OK with SISMA value = 1,30 m
10	Satellite OK with SISMA value = 1,60 m
11	Satellite OK with SISMA value = 1,90 m
12	Satellite OK with SISMA value = 2,50 m
13	Satellite OK with SISMA value = 3,80 m
14	Satellite OK with SISMA value = 5,20 m
15	Satellite not monitored

B.3 User integrity

B.3.1 General

The user receives direct information about the estimated performance of each satellite (SISA, SISMA, IF), where SISA is the Signal-in-Space Accuracy which is an estimate of the minimum standard deviation of a Gaussian distribution that overbounds the SIS error distribution for a fault free SIS.

B.3.2 Assumptions

For the user integrity concept every SV that is not excluded by a NOT-OK or not-monitored integrity flag, is considered to be in one of two states called fault-free and faulty mode. Since these SVs are considered available for positioning through the integrity flag (OK), every SV contributes in both of these states to the final integrity risk figure with the appropriate state probability. The probability that more than one satellite is in faulty mode is not allocated in the user receiver equation.

For the fault-free mode, the historical performance of the system is a good characterisation of the ranging errors, and the user receiver can assume that the SISE's distribution can be conservatively represented (overbounded) by a zero-mean Gaussian distribution with standard deviation equal to the broadcast Signal-In-Space-Accuracy (SISA).

For the faulty mode, the user receiver can use the value of TH to conservatively represent the largest estimated SISE value that might have been measured by the ground segment. As a result, the ranging error that the user might experience when satellites are in error can be represented conservatively by a Gaussian distribution with a mean value of TH (or –TH) and a standard deviation of SISMA.

With these assumptions the user receiver is able to determine the integrity risk of the position solution at any global location.

B.3.3 Integrity risk and protection level calculations

The information available at user receiver level to compute the integrity risk is the

- integrity flag,
- SISA value for each satellite and signal (included in both F/NAV and I/NAV),
- SISMA value for each satellite and signal, and
- IF threshold (TH) calculated using SISA, SISMA and the allowed false-alert probability.

With the assumptions in B.3.2, the distribution of the SISE is known for both the fault free and faulty modes, for each individual SIS. This allows the receiver to derive the position error distribution and the corresponding integrity risk. The total integrity risk is calculated as the weighted sum of the combination of all faulty and fault-free modes of all satellites. In this process combinations of modes that include more faulty modes are excluded, as they are not considered in the user receiver equation.

To ensure compliance to the specified combined integrity risk, the total integrity risk is directly calculated at the vertical and horizontal alert limit. The computations are rather complex, and the full mathematical expression of the so-called integrity equation can be found in [GIC05].

For Galileo, the preferred method of user integrity assessment [GIC05] is to calculate the integrity risk (P_{HMI}) at the alert limits (HAL, VAL) and compare this value with the integrity risk limit for the particular operation. If P_{HMI} is less than the integrity risk limit, we assume a normal situation. If not, the position solution will be flagged ”do not use”. Alternatively, Protection Levels (PL) may be used to characterise integrity. The protection level is the largest position error that can remain undetected with the allowable integrity risk. Use of the PLs requires more complicated, iterative algorithms than use of the integrity risk based on geometry and user range errors, and the horizontal and vertical components (HPL, VPL) should be within the alert levels (HAL, VAL) for integrity to be available.

P_{HMI} can be presented as sum of integrity risk probabilities in the horizontal and vertical planes:

$$P_{\text{HMI}} = P_{\text{HMI,H}} + P_{\text{HMI,V}}$$

HPL and VPL are given implicitly in the equation, however, since there are two unknowns and only one equation, a split must be assumed between the risks associated with HPL and VPL or it must be assumed that the risks associated with either HPL or VPL are negligible. In the maritime domain, normally only HPL is of interest, and the terms associated with VPL can be eliminated.

The split between the allocated horizontal and vertical contributions at (*HAL, VAL*) may be computed as a weighted contribution based on these integrity risks. The protection levels HPL and VPL can be defined as the horizontal and vertical spatial limits, where the HMI probability is exactly the allocated integrity risk ([GIC05], Annex E).

Thus, HPL and VPL are given implicitly in the equations (analytical expressions are given in ([GIC05], Annex E):

$$P_{\text{HMI,H,alloc}}(HAL,VAL) = f_{\text{H}}(HPL)$$

$$P_{\text{HMI,V,alloc}}(HAL,VAL) = f_{\text{V}}(VPL)$$

and can be described using the inverse functions:

$$HPL = f_{\mathrm{H}}^{-1}(P_{\mathrm{HMI,H,alloc}}(HAL, VAL))$$

$$VPL = f_{\mathrm{V}}^{-1}(P_{\mathrm{HMI,V,alloc}}(HAL, VAL))$$

Because it is not possible to resolve the inverse functions f_{H}^{-1} and f_{V}^{-1} analytically, an iterative method to compute HPL and VPL must be applied.

B.3.4 Critical satellites

A critical satellite is defined as a satellite in the user current geometry that is essential to keep the integrity risk below the allowed value. In other words, a satellite is critical for the user if its removal from the current geometry causes the HMI probability computation to exceed the HMI probability tolerated value. Notice that losing a satellite that is characterized as critical leads to a discontinuity event, whereas losing a non-critical satellite has no impact on continuity. A large number of critical satellites jeopardize the continuity. But on the other hand, allowing for a high number of allowed critical satellites increases the system availability. Hence, the determination of the maximum number of allowed critical satellites is a compromise between service availability and continuity allocation.

In order to declare the system available and thus to allow the start of a safety critical operation, the Galileo receivers can check at every epoch whether the following conditions are simultaneously met:

- HMI probability is not greater than a tolerated value;
- number of critical satellites is not greater than a determined threshold.

This might, however, not be operationally required.

Annex C
(informative)

Receiver autonomous integrity monitoring (RAIM)

C.1 Overview

C.1.1 Validate signal integrity

All certified marine GNSS receivers are required to validate signal integrity by either using an augmentation service, which for maritime include the IALA dGNSS service and SBAS(WAAS/EGNOS), the Galileo integrity service (see Annex B) or through Receiver Autonomous Integrity Monitoring (RAIM). The augmentation services are based on using a single- or a network of stationary receivers having the advantage of knowing the exact location of their receiving antennas so that the deviations in position and pseudoranges can be estimated more accurately. RAIM, on the other hand, only rely on redundant range observations in the receiver and do not have the benefit of a ground truth to estimate the position accuracy and to look for possible harmful biases in the observed pseudoranges.

C.1.2 Definition of RAIM

IMO defines RAIM as (IMO Res. A.915(22):2001):

A technique whereby the redundant information available at a GNSS receiver is autonomously processed to monitor the integrity of the navigation signals.

According to RTCA (RTCA/DO-229D) RAIM is defined as:

A technique whereby a civil GNSS receiver/processor determines the integrity of the GNSS navigation signals without reference to sensors or non-DoD integrity systems other than the receiver itself. This determination is achieved by a consistency check among redundant pseudorange measurements.

C.1.3 Concept evolution

The interest in integrity monitoring techniques was spurred on by efforts in the mid-1980's by FAA and RTCA special committee 159 to find ways of ensuring that aircraft could safely utilise the GPS system. In the marine offshore community, the first attempt to address the subject came with the UKOOA *Guidelines for the use of differential GPS in offshore surveying* in 1994 and a subsequent revision in 1997.

However, the general idea of using redundant observations for outlier detection using normalized least squares (LS) residuals as a test statistic was developed in the surveying community and dates back to the late 1960's [Baarda68].

Development of RAIM methodologies is an active field of research, especially in view of the large number of GNSS satellites being available in the near future with the replenishment of GLONASS and the new Galileo and Compass systems.

This Annex only describes the so-called snapshot LSR class of RAIM algorithms which use the Least Squares Residuals (LSR) of the position solution as observables and where all observables are referenced to the same epoch (snapshot). This is the classic form of RAIM algorithms which was developed in the selective availability (SA) era of GPS. Some basic snapshot LSR algorithms are given in the Bibliography, ([Sturza88], [Parkinson88], [Brenner90], [Kelly98], [UKOOA94]). It has been shown [Kelly98] that all these algorithms are in fact mathematically equivalent, and yield comparable performances.

The snapshot LSR class of RAIM algorithms has been adopted by RTCA for use in SBAS (WAAS, EGNOS) receivers for aviation and has gained a wide acceptance as a conservative and reliable method for integrity monitoring.

C.2 Integrity monitoring

C.2.1 General

The RAIM consistency check is based on the same pseudorange measurements that go into the positioning algorithm. When a failure is detected, attempts can be made to identify and exclude the source of failure and to continue providing a position using the remaining signals (failure detection and exclusion, FDE). When an unrecoverable failure is detected (no exclusion possible), a reliable position can no longer be provided (fault detection, FD).

The possible conditions associated with FDE are illustrated in Figure C.1 below, and the state of special concern in terms of integrity is the missed alert state which results from a missed detection or wrong exclusion of a failed satellite. This state implies that the calculated position is misleading and may lead to hazardous situations. Both loss of navigation and display of misleading information are considered to be major failure conditions.

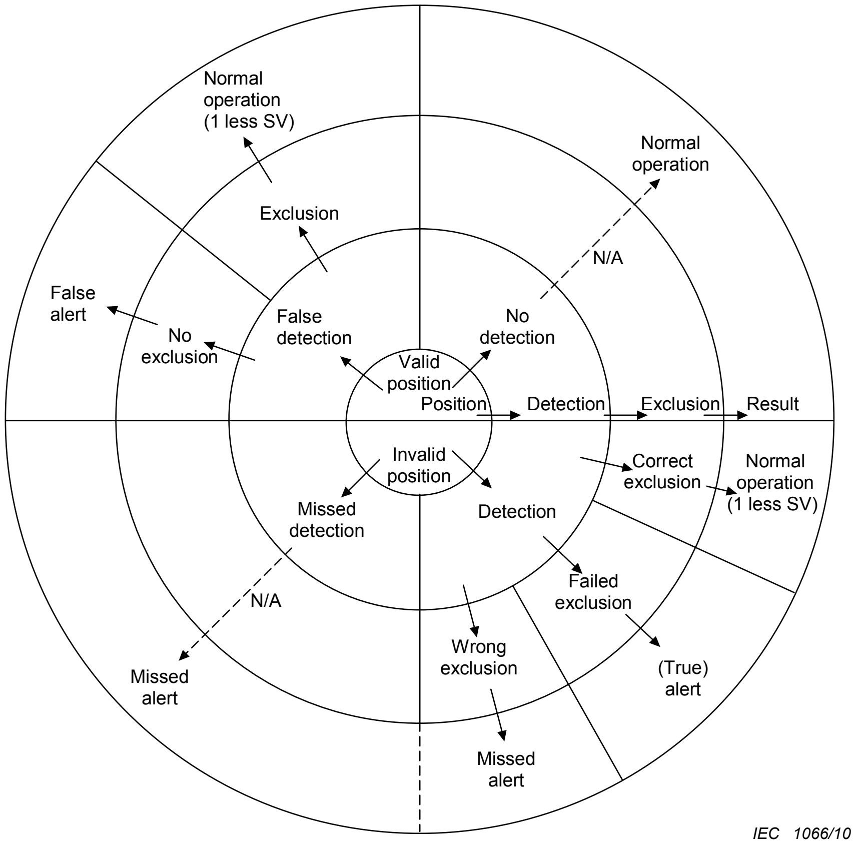


Figure C.1 – Navigation alerts and FDE events

As no navigation system is fault-free, IMO has issued a set of Required Navigation Parameters (RNP) for different phases of navigation which, in addition to accuracy requirements, also specifies tolerable probability levels for integrity and continuity (Figure C.2). The continuity requirement is related to the ability to perform a navigational operation without abruptions for a specified time interval. Both true and false alerts will give a loss of continuity.

The overall integrity and continuity requirements are further translated into a set of performance parameters for the integrity monitoring system, for example probability of missed (fault) detection and probability of false detection.

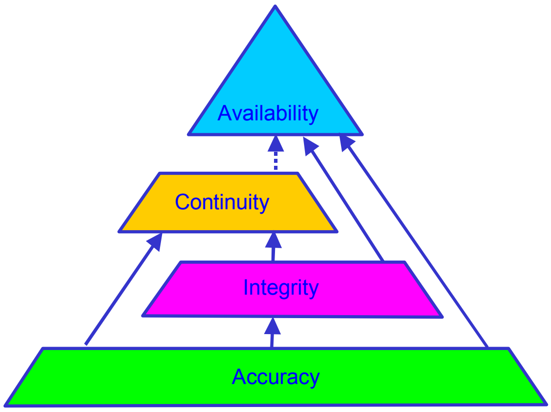


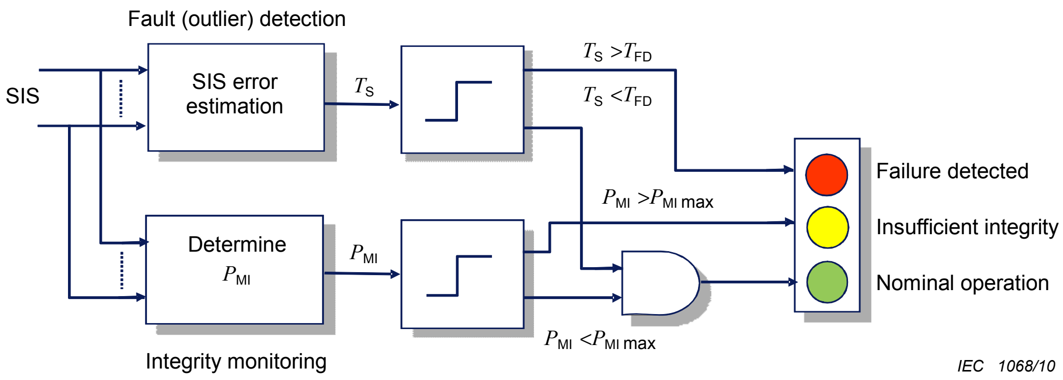
Figure C.2 – RNP parameters

C.2.2 Receiver autonomous integrity monitoring (RAIM)

When there is no available information on the actual position error, we have to resort to statistical methods for assessment of the quality of the calculated position. Basically, we have to perform a statistical test which examines (at least) two hypotheses; failure or no-failure. A hypothesis test is always based on a test statistics T_S which is computed from the measurement data, and a failure decision threshold T_{FD}.

RAIM is essentially based on two monitors: the failure detector, which determines whether the signal in space (SIS) contains failures and the actual integrity monitor which assesses the detection power of the failure detector and determines whether the probability of having an undetected failure P_{MI} (misleading information) is acceptable with respect to the RNP requirement represented by $P_{MI\ max}$.

The general architecture of a RAIM FD(E) is depicted in Figure C.3. The exclusion part is not shown, but would consist of the removal of a suspected faulty signal. After an exclusion, the reduced set of range measurements might lack sufficient failure detection power, which would result in an integrity warning (yellow light in Figure C.3).



NOTE See [Ober03].

Figure C.3 – Receiver autonomous integrity monitoring (RAIM)

C.3 Integrity risk and protection levels

C.3.1 General

The IMO RNP integrity requirements (IMO Res. A.915(22)) are stated in terms of

- an integrity risk limit of (maximum) 10^{-5} per 3 h, defined *as the probability that a user will experience a position error larger than the threshold value without an alarm being raised within the specified time to alarm at any instant of time at any location in the coverage area;*
- a horizontal alert limit (or threshold value) of 25 m or 2,5 m (harbour navigation), defined as *the maximum allowable error in the measured position – during integrity monitoring – before an alarm is triggered.*

The alert limit is determined from operational considerations for the actual navigation phase, and would normally include both a horizontal (HAL) and a vertical (VAL) component.

Thus, the integrity risk level P_{MI} may be calculated at the alert limits (HAL, VAL) using an appropriate error model, and the integrity of the calculated position will be decided by comparing it to the maximum integrity risk limit, $P_{MI\,max}$, given by the RNP requirement. This is the approach proposed for Galileo user integrity (see Clause B.2).

However, the more common (and intuitive) approach is to use the protection level concept developed by the aviation authorities [RTCA06], whereby the P_{MI} test statistic is replaced by a statistics defined in the position estimation domain, named the horizontal protection level (HPL). According to [RTCA06], *the Horizontal Protection Level (HPL) is the radius of a circle in the horizontal plane, with its centre being at the true position, which describes the region which is assured to contain the indicated horizontal position. It is a horizontal region for which the missed alert and false alert requirements are met for the chosen set of satellites when autonomous fault detection is used. It is a function of the satellite and user geometry and the expected error characteristics: it is not affected by actual measurements. Therefore, this value is predictable.*

The horizontal protection level (HPL) is defined in the position domain as shown in Figure C.4, and the test for integrity is a simple comparison of HPL against HAL. When HPL is greater or equal to HAL, integrity is not available (or insufficient), meaning that the calculated position may have an unacceptable error and can not be guaranteed within the RNP integrity requirements.

Figure C.4 illustrates the positioning errors in the horizontal plane which in addition to the position noise represented by the error ellipse, also includes a bias in the position.

The probability of a position failure P_f, which can be calculated by integrating the probability distribution function of the position distribution over the failure region outside the protection level, is equal to the integrity risk limit. Alternatively, as adopted for Galileo, integrity may be assessed by estimating P_f, at the alert limit.

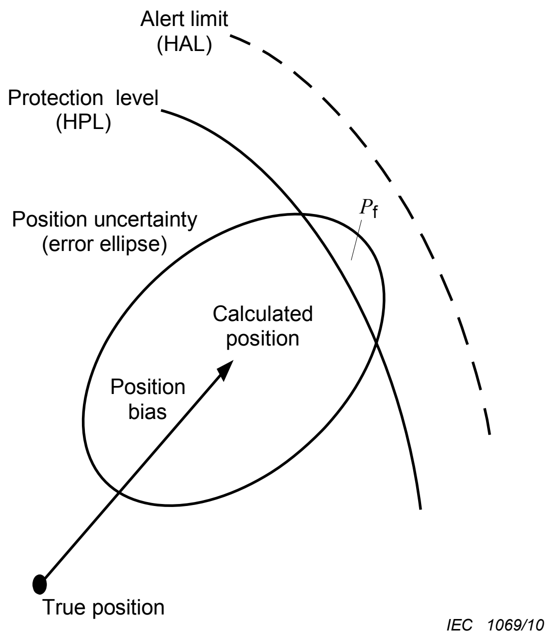


Figure C.4 – Position errors

It should be noted, however, that the position estimates are linear combinations of the pseudorange measurements, so that satellite exclusions are not possible in the position domain and that the protection levels will depend on the satellite geometry as well as the ranging errors.

C.3.2 Test statistics and decision thresholds

C.3.2.1 General

When computing a position from redundant pseudorange observables, a residual vector remains with components being the difference between the measured range and the calculated range to each of the satellites. From the residual vector, we can construct a test statistics to represent the measurement errors. Among the test statistics that can be used for detecting a failed satellite, two stand out because of their almost universal use.

a) (Weighted) sum of square residuals test statistic, *(W)SSE*. This statistic is typically assumed to be approximately Chi-square distributed [Brown96], and decision thresholds can be computed analytically.

b) Maximum Normalized Residual test statistic, $\hat{e}_{MAX.}$ The pdf of this statistic is, however, mathematically intractable [Kelly98], and only upper bounds may be estimated for the decision threshold.

C.3.2.2 (Weighted) sum of square residuals test statistic, (W)SSE

The pdf of the (W)SSE is given by a Chi-square distribution with parameters depending on which of the two assumptions (hypotheses) are made.

H0: Fault-free (FF) case; receiver noise given by (or bounded by) a zero mean Gaussian distribution.

H1: Fault mode (FM) case; one or more satellites have an unknown bias.

For H0 the pdf is a Central Chi-square distribution with f degrees of freedom, f being the redundancy of satellites (= N_S – 4). For H1 the pdf is a Non-central Chi-square (f, λ), where λ is the non-centrality (bias) parameter.

Knowing the pdf of the test statistic makes it possible to calculate the decision threshold T_D as a function of the number of redundant satellites (degrees of freedom, f) and the probability of false alert consistent with the continuity requirement.

Figure C.5 illustrates the classical hypothesis tests using the (W)SSE statistics. For the fault free case, the detection threshold, T_D, is given implicitly in an equation where the probability of false alert P_{FA}, should equal the integral of the tail of the pdf from T_D to infinity. Likewise, for the faulty case, the probability of missed detection, P_{MD}, should equal the integral of the tail of the pdf from 0 to T_D.

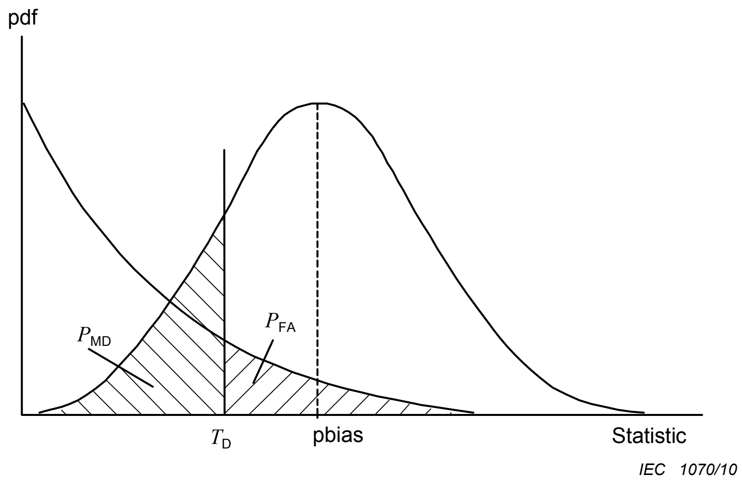


Figure C.5 – Decision threshold and minimum detectable bias for the (W)SSE statistic

Following the terminology used in the references (see Bibliography) the bias error which corresponds to the P_{MD} combined with a threshold fixed by the P_{FA} is called pbias. This is the maximum bias error which can exist without detection, and is also referred to as the marginal (or minimum) detectable bias (MDB).

For a given set of P_{FA} and P_{MD} values we may construct a simple table of normalised values for the detection threshold T_D and pbias for different numbers of satellites in view, using the standard deviation of the pseudorange errors as a normalisation constant [Kelly98].

C.3.2.3 Maximum normalized residual test statistic

The maximum normalised residual test algorithm has its roots in the surveying community as a method for eliminating outliers (blunders) in position observations. The method is conceptually very simple; choose the maximum residual which exceeds the decision threshold. Thus, both detection and identification of a faulty satellite is performed in one step. For the FDE algorithms using the (W)SSE statistics, identification of faulty satellites are normally conducted using a fault detection (FD) algorithm on subsets of $N_S - 1$ satellites, and searching for the subset without a fault detection condition.

The maximum normalized residual test is based on the assumption that the pseudorange observation which has the largest residual is most likely to be the failed satellite. However, one should bear in mind that, due to model error the maximum residual may not always correspond to the failed satellite [Kelly98].

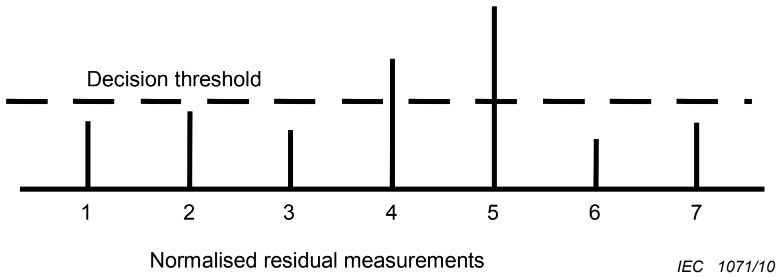


Figure C.6 – Maximum residual test statistic

As shown in Figure C.6, measurement No. 5 would be identified as a failed range signal.

The pdf for $\hat{e}_{MAX\,i}$ is, however, not readily available, so unlike the Chi-square test the decision threshold cannot directly be determined from the equation $P(|\hat{e}_{MAXi} > T_D) = P_{FA}$. An upper bound $T_D < T_D^*$ must be found such that the probability of $\hat{e}_{MAX}$ exceeding T_D is larger than $\hat{e}_{MAX}$ exceeding T_D^*.

T_D^* can, for example, be determined by using a Bonferroni-bound, and it is shown [Kelly98] that the maximum residual test is actually slightly more powerful than the methods based on the Chi-squared statistic.

C.3.3 Geometry screening – Calculation of protection levels

In order to calculate the protection levels as defined by RTCA and depicted in Figure C.4, we need to establish a connection between the residual domain and the position domain, that is mapping the test statistic into position estimation errors. In the surveying community the influence of ranging errors on the estimated positions is often referred to as external reliability while the detection of outliers is referred to as internal reliability [Baarda68], [UKOOA94].

Figure C.7 shows a plot of the position estimation error versus a test statistic (representing the range errors). The slope lines are the assumed relations between biases in each of the satellite ranges and the induced horizontal position errors. These slopes are a function of the geometry matrix used for (weighted) least squares position solutions, and will vary in time. A high value corresponds to a large angle of the slope and a high probability of misleading information, as a bias with a given level of detectability causes a large position estimation bias. It can thus be seen that the satellite with the largest slope is the satellite where a range error (bias) will be most difficult to detect [Brown97] as well as the satellite that will have the largest influence on the position error. This procedure is often referred to as geometry screening in the RAIM literature.

With reference to Figure C.7 the position error corresponding to the marginally detectable bias (pbias) for the maximum slope is often used as an approximation of the protection level. HPL does not guarantee the required P_{MD} under all dynamic conditions [Kelly98], however, when the time to alert is taken into account, that is a missed detection counts only when the position error is greater than HPL beyond the time to alert requirement (10 s), then HPL typically represents a conservative estimate of the maximum position error within the allowed P_{MD}.

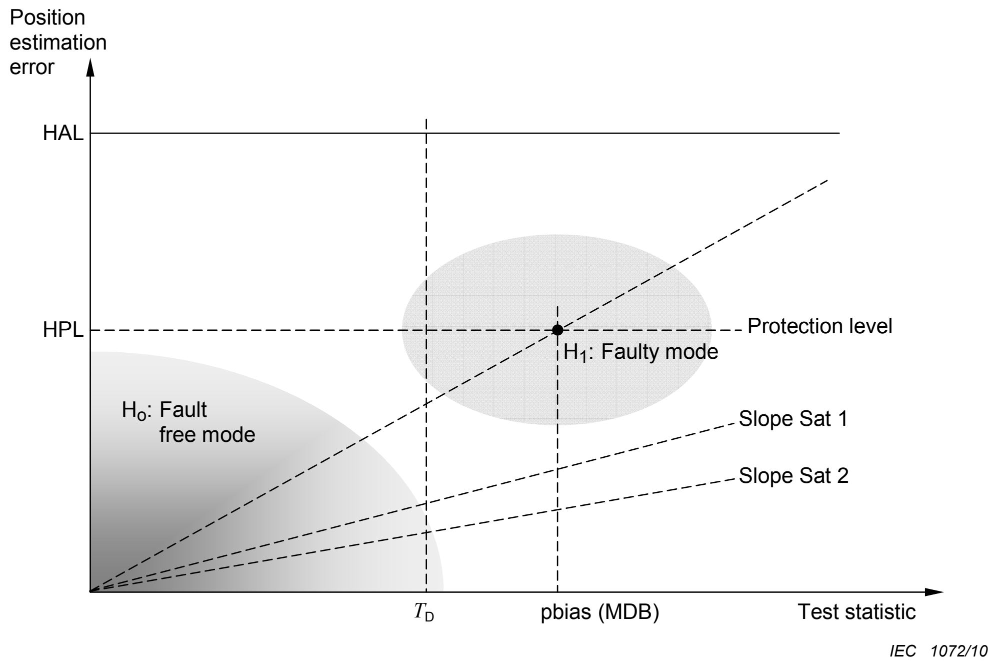


Figure C.7 – Geometry screening

C.3.4 RAIM availability

In addition to the primary function of providing an adequate integrity monitoring capability, the RAIM function must also be available to the user for an appreciable percentage of operational time. Basically, all RAIM FDE algorithms require a minimum of 6 satellites in view, and in addition RAIM may also be unavailable due to poor satellite geometries. The IMO RNP (A.915(22)) states that the availability of accuracy, integrity and continuity should be a minimum of 99,8 % when calculated over a 30 days period. A number of service volume simulations seem to indicate that such levels of availability may be difficult to meet for single constellations (GPS, GLONASS, Galileo) and that multiple constellations are required.

C.4 RAIM-FDE parameters

C.4.1 General

In summary the RAIM-FDE should resolve the following integrity related problems.

a) Detection and exclusion of satellite failures. This function uses the residuals of the fitted linear model obtained from N pseudorange observations. Faulty satellites are detected by forming a test statistic and compare it to a decision threshold. When a failure is detected, an attempt should be made to identify and exclude the faulty satellite using an algorithm which complies with a given set of criteria for
   - probability of false detection, P_{FA};
   - probability of missed detection, P_{MD};
   - probability of wrong exclusion, P_{WE}.

b) Screening out bad satellite constellation geometries for which there is an insufficient error detection power.

In order to arrive at a justified set of performance parameters for the RAIM algorithm we need to start with some basic assumption regarding the reliability of the satellite constellation.

C.4.2 Basic assumptions

Satellite failure

Table C.1 summarises the assumptions taken in order to estimate a proper set of FDE parameters [GIC05]. At the user level the fundamental property is the probability of failure in one or more satellites in view, where we will assume that a user will track 10 satellites on the average for the nominal Galileo constellation of 27 satellites.

Table C.1 – Galileo satellite failure [GIC05]

Parameter	Description	Value	Unit
P_{1sfail}	Probability of satellite constellation failure (one satellite out of 27)	$2{,}7 \cdot 10^{-6}$	Per sample
P_{usfail}	Probability of user-visible satellite failure (1 out of 10 visible satellites)	$1 \cdot 10^{-6}$	Per sample
R_{1sfail}	Failure rate of satellite constellation failure (one satellite out of 27)	$1 \cdot 10^{-4}$	Per hour of operation
R_{usfail}	Failure rate of user-visible satellite failure (1 out of 10 visible satellites)	$3{,}7 \cdot 10^{-5}$	Per hour of operation

The performance risk parameters are usually specified per operation and therefore a translation is required to convert the operational requirements to algorithmic requirements. The number of independent samples N_s in an operational period T_{op} is then equal to T_{op}/T_s and the integrity risk limit over the operational period is equally distributed among the independent samples. Thus, the per sample integrity risk limit is the operational integrity risk limit divided by N_s.

The probability of observing a failure in a particular sample is typically approximated as $P_{1sfail} = R_{1sfail} \bullet T_s$, where T_s is the sampling interval, which should be less than the correlation time for independent samples. This is normally equal to the smoothing time for carrier phase smoothed pseudoranges which is in the order of 100 s to 300 s. For the calculations to follow, we have assumed a sampling time of approximately 100 s.

Maritime RNP

The appropriate maritime RNP parameters are given in IMO Res. A.915(22). Integrity risk and continuity risk requirements are stated as 10^{-5} and $3 \cdot 10^{-4}$ per 3 h respectively. However, these figures are the navigational (GNSS) system requirements, which need to be translated into a per vessel requirement due to the fact that a satellite failure may affect many users at the same time. The GPS FDE requirements [Lee96] were derived assuming that a GNSS failure could affect 100 aircraft at the same time, that is tracking the same satellites. This also seems a reasonable figure for maritime navigation in areas with high traffic density. So the overall integrity and continuity risk requirements assumed for deriving the maritime FDE parameters are 10^{-7} and $3 \cdot 10^{-6}$ per 3 h per vessel, respectively. It should be noted that this only applies to failures external to the vessel, so that for internal receiver failures (e.g. false alerts), the original system requirements apply.

C.4.3 RAIM-FDE integrity

The source of this missed alert can be a missed detection or a wrong exclusion, and the required maximum level of missed alerts is set equal to the integrity risk limit. For a user tracking 10 satellites the probability of having an undetected failure is as follows:

$$P[\text{Undetected failure}] = P[\text{Missed detection|GNSS failure}] \bullet P[\text{GNSS 1 of 10 failure}]$$

With the assumed operational integrity risk limit of 10^{-7} per 3 h per vessel and the basic Galileo satellite failure assumption (see Table C.1), this gives $P_{MD} = P_{WE} \approx 0{,}001$ for a sampling interval of 100 s. This also means that when a failed satellite condition occurs (approximately once every 3 years), 1 out of every 1 000 vessels may have misleading navigational information world wide.

It should be noted that the IMO Res. A.915(22) refers to the integrity and continuity requirements as user requirements implying that the numbers pertain to each vessel. However, this would have as a consequence that 1 out of 10 vessels may have misleading information, which does not seem to be acceptable.

C.4.4 RAIM-FDE continuity

Both true and false alerts are continuity events, that is resulting in loss of navigation. The probability of having a true alert (loss of navigation) is generally given by

$$P[\text{true alert}] = P[\text{failed exclusion}] \bullet P[\text{GNSS 1 of 10 failure}]$$

With the assumed operational continuity risk limit of 10^{-6} per hour per vessel and the basic Galileo satellite failure assumption (see Table C.1) this gives $P_{FE} \approx 0,03$ for a sampling interval of 100 s. This also means that when a failed satellite condition occurs (approximately once every 3 years), 1 out of 30 vessels may lose their navigation capability world wide.

However, a failed exclusion will normally only occur when there are less than 6 satellites in view, which for Galileo can only occur when one or more satellite fails.

A false alert occurs when the FDE algorithm makes a false detection and cannot exclude the source of the false detection. This is an internal receiver effect, and the appropriate continuity risk requirement is 10^{-4}/h. Thus,

$$P[\text{false alert}] = P[\text{false detection}] = P_{FD} \approx 3 \bullet 10^{-6} \quad \text{for a sampling interval of 100 s}$$

C.4.5 RAIM-FDE parameters – Summary

In summary, the proposed FDE parameters for Galileo receivers are as given in Table C.2, last column. The parameters for aviation (non-Precision approach using GPS) and maritime use of GPS are shown for comparison.

Table C.2 – RAIM-FDE parameters

Para-meters	Description	RTCA NPA-GPS	IEC 61108-1:2003 GPS	IEC 61108-3 Galileo
R_{FD}	False alert rate	10^{-5}/h	10^{-4}/h	10^{-4}/h
P_{FD}	Probability of false detection	$3 \cdot 10^{-7}$	$5 \cdot 10^{-2}$	$3 \cdot 10^{-6}$
P_{MD}	Probability of missed detection	10^{-3}	$5 \cdot 10^{-2}$	$1 \cdot 10^{-3}$
P_{WE}	Probability of wrong exclusion	10^{-3}	-	$1 \cdot 10^{-3}$
P_{FE}	Probability of failed exclusion	10^{-3}	-	$3 \cdot 10^{-2}$
TTA	Time to alert	10 s	10 s	10 s

Annex D
(normative)

Galileo standard received signals and interference environment

D.1 Receiver power levels

D.1.1 Received power levels on the ground

The minimum and maximum receiver power levels on the surface of the earth, based on an ideally matched and isotropic 0 dBi receiver antenna is given in Table D.1 below (see Bibliography [ICD08], and [RTCA07]).

Table D.1 – Minimum and maximum receiver power levels on ground

	Minimum power dBm	**Maximum power** dBm
E5a, E5b	–126,2	–122,0
E1	–126,0	–122,5

D.1.2 Received signals at receiver input

The minimum and maximum power levels at the antenna port and at the receiver input is given in Table D.2 below based on the values in Table D.1 and Galileo signal link budget calculations from [RTCA07].

Table D.2 – Minimum and maximum levels at antenna port and receiver input

	E1	**E5a, E5b**
Minimum receiver input level	–117,0 dBm	–117,2 dBm
Minimum antenna port level	–130,5 dBm	–130,7 dBm
Minimum C/No	40,7 dBHz	40,7 dBHz
Maximum receiver input level	–88,0 dBm	–88,2 dBm
Maximum antenna port level	–117,5 dBm	–117,7 dBm
Maximum C/No	53,8 dBHz	53,8 dBHz

D.2 Galileo CW in-band and near-band interference environment

Continuous wave (CW) interference interacts with the individual range code's spectral lines found in the Galileo signal structure. Galileo receivers are typically more susceptible to CW than to any other type of interference. The minimum receiver performance defined in Clause 4 shall be achieved in the presence of in-band near-band CW interfering signals levels as high as the one defined by Figure D.1 and Table D.3 for the E5 band and Figure D.2 and Table D.4 for the E1 band.

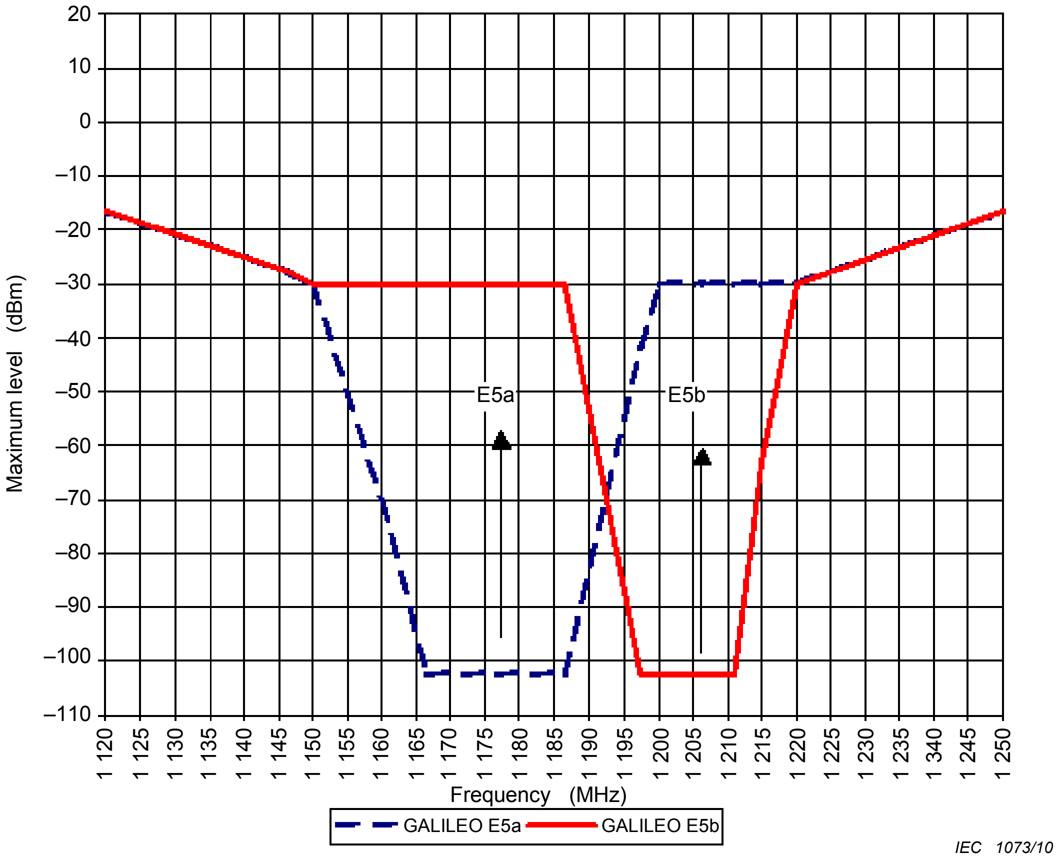


Figure D.1 – E5 in-band and near-band maximum CW RFI levels

Table D.3 – Table of main characteristics of Figure D.1 above

Frequency MHz	**Maximum RFI level E5a** dBm	**Maximum RFI level E5b** dBm
1 120,00	–16,5	–16,5
1 150,00	–30,0	–30,0
1 166,45 (E5a –10 MHz)	–102,5	–30,0
1 176,45 (E5a)	–102,5	–30,0
1 186,45 (E5a +10 MHz)	–102,5	–30,0
1 197,14 (E5b –10 MHz)	–38,0	–102,5
1 200,00	–30,0	–102,5
1 206,45 (E5a+20 MHz)	–30,0	–102,5
1207,14 (E5b)	–30,0	–102,5
1 211,14 (E5b +4 MHz)	–30,0	–102,5
1 215,00	–30,0	–60,0
1 220,00	–30,0	–30,0
1 250,00	–16,5	–16,5

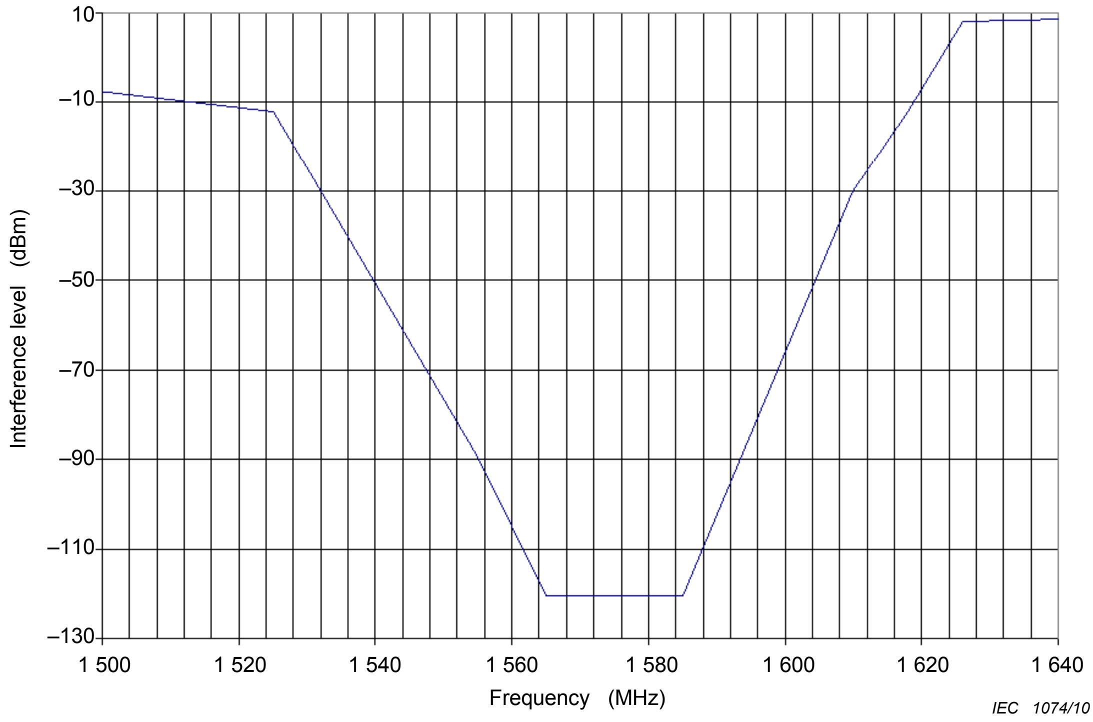


Figure D.2 – E1 in-band and near-band maximum CW RFI levels

Table D.4 – Table of main characteristics of Figure D.2

Frequency MHz	**Maximum RFI level E1** dBm
1 500 [a]	–8,5
1 525	–12,0
1 565,42 (E1–10 MHz)	–115,0 (–120,5 for GPS L1)
1 575,42 (E1, L1)	–115,0 (–120,5 for GPS L1)
1 585,42 (E1–10 MHz)	–115,0 (–120,5 for GPS L1)
1 610	–30,0
1 626,5	+8,0
1 640 [a]	+8,5

[a] The CW interference level below 1 500 MHz increases linearly to 25,5 dBm at 1 310 MHz. Above 1 640 MHz, the levels increase linearly to 21,5 dBm at 2 GHz, accounting for High Intensity Radiation Fields (HIRF).

D.3 Galileo in-band maximum RFI levels

The interference mask for narrow- and wideband noise-like interference varies as a function of the bandwidth of the interfering signal. This interference effect can be represented by RF noise centred at 1 575,42 MHz for E1, 1 176,45 MHz for E5a and 1 207,14 MHz for E5b.

The standardised receiver CW, narrow band (NB) and wide band (WB) RF noise susceptibility is defined through the set of curves plotted in Figure D.3 and Figure D.4 below and detailed in Table D.5 and Table D.6 that identify for different receiver's functions (acquisition, tracking and reacquisition) the maximum applicable RFI levels versus RFI bandwidth.

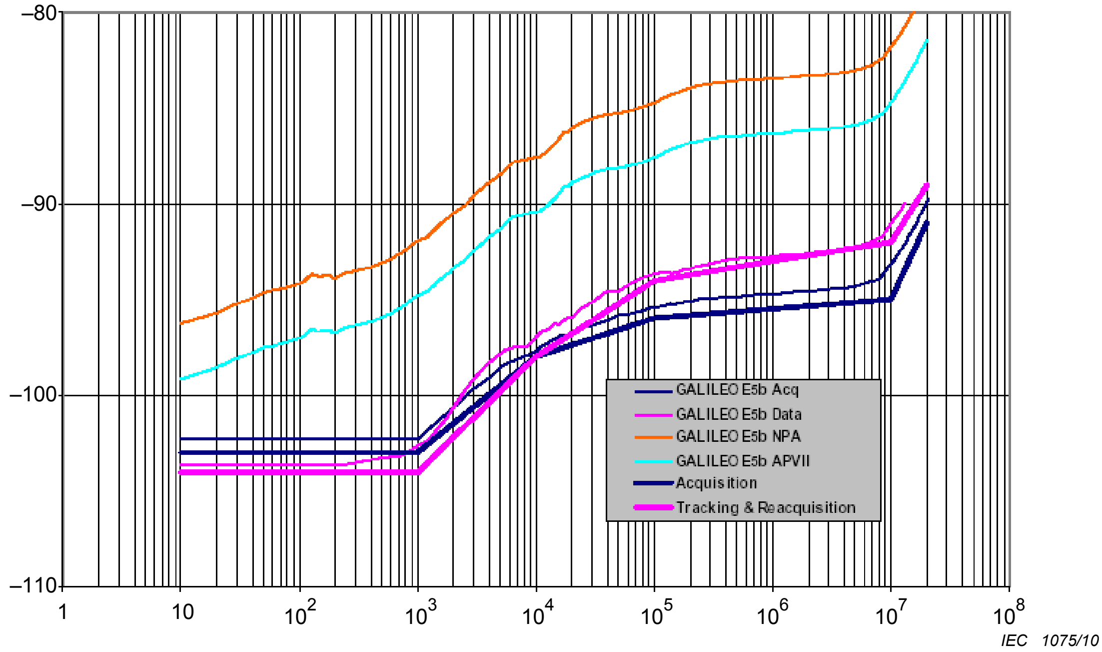


Figure D.3 – E5 Maximum in-band CW/NBI RFI levels

Table D.5 – E5 maximum in-band RFI levels versus bandwidth

Maximum RFI level dBm							
Bandwidth	10 Hz	1 kHz	10 kHz	100 kHz	1 MHz	10 MHz	20 MHz
Acquisition	–103	–103	–98	–96	–95,5	–95	–91
Tracking	–104	–104	–98	–94	–93	–93	–89

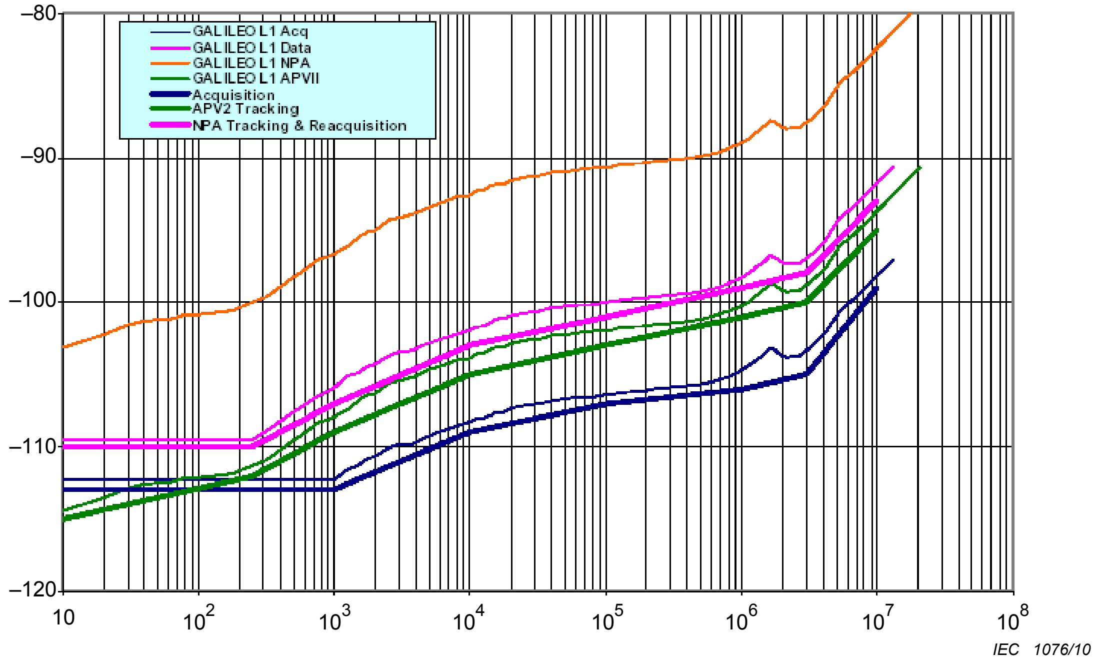


Figure D.4 – E1 Maximum in-band CW/NBI RFI levels

Table D.6 – E5 maximum in-band RFI levels versus bandwidth

Maximum allowable RFI level dBm								
Bandwidth	10 Hz	250 Hz	1 kHz	10 kHz	100 kHz	1 MHz	3 MHz	10 MHz
Acquisition	–113	–113	–113	–109	–107	–106	–105	–99
Tracking	–115	–112	–109	–105	–103	–101	–100	–95

D.4 Pulsed interference

Pulsed interference can occur due to proximity to radars or other RF devices operating in the same bands using pulsed waveforms. Galileo receivers typically are fairly robust when exposed to low duty cycle pulsed interference. The RF noise for pulsed interference tests consist of a pulse modulated carrier (CW) at 1 575,42 MHz for E1, 1 176,45 MHz for E5a and 1 207,14 MHz for E5b, with peak carrier level of –20 dBm and duty factor of 10 % while using a 1 ms pulse width.

Annex E
(informative)

Galileo RAIM testing

E.1 General

Receiver Autonomous Integrity Monitoring (RAIM) algorithms used in GNSS receivers have steadily developed and improved since the RAIM concept was introduced a few years ago. In the GPS system those algorithms are well established and widely accepted as improving the navigation reliability of any GNSS navigation system that has RAIM capability.

Since the testing of RAIM has to be carried out on Galileo receivers, it is important to establish a common procedure for these tests. This annex provides those responsible for developing a test environment with an aid to performing RAIM testing as it was intended by the description of 5.6.12.1.3.

E.2 Satellite signal alteration

The Galileo RFCS provides several methods for testing a receiver's RAIM algorithm. Two such methods are

a) applying an error to a satellite's clock, that is not declared in the navigation data message, which provokes a faulty position fix solution, or;
b) adding a pseudorange ramp to the satellite's RF signal which is not declared in the navigation data message.

Both methods result in an erroneous position solution being calculated by the GNSS receiver, which would be detectable by the RAIM algorithm.

In this example, the second method is used. The pseudorange ramp on a satellite's RF signal will result in an accordingly weighted position fix error if the faulty satellite is not excluded from position calculation, or the number of available satellites is less than 5.

E.3 RAIM testing scenario

To ensure a complete set of Galileo navigation data is received, the RFCS scenario used must allow 15 min of prerun, before any signal corruption or change is applied. This precaution is to be taken to ensure that the receiver under test is locked to all satellite, and producing a stable PVT solution.

The initial constellation should have at least 8 healthy satellites being tracked, to ensure stable RAIM functionality.

Theoretically, RAIM calculation is perfectly possible with 6 Galileo satellites being tracked, but for stability and RAIM algorithm integrity behaviour evaluation, the RAIM test should be started with at least 8 satellites, one modified by introducing a pseudorange ramp, then reducing the ramp to zero after a ramp hold duration of at least 1 min, to ensure enough time for the receiver to detect and exclude the affected satellite for the duration of the ramp. The ramp error should be at least a multiple of the entered HAL (also referred to as RAIM radius). After each ramp up and down cycle, allow at least 3 min of recovery time before reducing the number of satellites by one. (It has proven functional to switch off the satellite that was used for the introduction of the ramp, after the recovery time of 3 min).

Now, the cycle is repeated for one of the remaining satellites until a four-satellite-constellation is reached.

Observe that the calculated position fix is within HAL, or RAIM status is indicated accordingly.

For testing purposes, repeating the ramp cycle on one of the remaining four satellites is recommended. The RAIM status should stay at CAUTION as RAIM calculation is impossible with less than five satellites available. (See Table E.1 for details on RAIM scenario).

Table E.1 – Scenario overview

Pseudorange – Ramp: 500 m
4 min ramp up, 1 min hold, 4 min ramp down
Sat.- Ids: as appropriate by used almanac

Avail. SVs	8 Satellites					7 Satellites					6 Satellites					5 Satellites					4 Satellites					
Time into simulation run	**00:00:00**	00:15:00	00:19:00	00:20:00	00:24:00	**00:27:00**	00:28:00	00:32:00	00:33:00	00:37:00	**00:40:00**	00:41:00	00:45:00	00:46:00	00:50:00	**00:53:00**	00:54:00	00:58:00	00:59:00	01:03:00	**01:06:00**	01:07:00	01:11:00	01:12:00	01:16:00	**01:19:00**
Ramp status		Ramp up	Ramp hold	Ramp down	Ramp end	**Sat. Off**	Ramp up	Ramp hold	Ramp down	Ramp end	**Sat. Off**	Ramp up	Ramp hold	Ramp down	Ramp end	**Sat. Off**	Ramp up	Ramp hold	Ramp down	Ramp end	**Sat. Off**	Ramp up	Ramp hold	Ramp down	Ramp end	
ID of altered SV		as appropriate for used almanac*					as appropriate for used almanac*					as appropriate for used almanac*					as appropriate for used almanac*					as appropriate for used almanac*				

*Satellites may rise and set below elevation mask of 10° (horizon) during scenario runtime - Precautions have to be taken to avoid rising and setting of active and healthy SVs during RAIM scenario.

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