**IALA Recommendation R-121**

**On**

**the Performance and Monitoring of**

**DGNSS Services in the Frequency Band**

**283.5 – 325 kHz**

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International Association of Marine Aids to

Navigation and Lighthouse Authorities

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| **Date** | **Page / Section Revised** | **Requirement for Revision** |
| Sept. 2004 | 5. Integrity,  11. Validation,  New Appendix 1 "DGNSS Broadcast Site Settings | Provide better guidance on these important areas to administrations setting up and operating DGNSS services. |
| Oct. 2014 | New structure  Renewing of content | Options for DGNSS reengineering  Service based architecture  Improved explanation of requirements |
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**IALA Recommendation on the Performance and Monitoring of a DGNSS Service in the frequency band 283.5 - 325 kHz**

**THE COUNCIL**

**NOTING t**he function of the IALA with respect to Safety of Navigation, the efficiency of maritime transport and the protection of the environment,

**NOTING ALSO** IMO resolutions A.915(22) on Maritime Policy for the Future Global Navigation Satellite System (GNSS), and A.1046 (27) on World Wide Radionavigation System,

**NOTING FURTHER** ITU-R Recommendation M.823-3 on the Technical characteristics of differential transmissions for Global Navigation Satellite Systems (GNSS) from maritime radio DGNSS sites in the frequency band 285-325 kHz (283.5-315 kHz in Region 1),

**RECOGNISING** the need to ensure that Differential GNSS (DGNSS) services in the frequency band 283.5 kHz – 325 kHz are operated in accordance with certain minimum standards that take into account relevant ITU-R Recommendations and IMO Resolutions,

**RECOGNISING ALSO** that the minimum standards should include the signal format, reference datum, availability, continuity, integrity, accuracy, signal monitoring, range and coverage, status reporting, validation, and the publication of information about the system,

**HAVING CONSIDERED** the proposals made by the e-Navigation Committee:

**ADOPTS** the Minimum Standards for the Performance and Monitoring of DGNSS Services in the frequency band 283.5 – 325 kHz set out in the annex of this recommendation; and

**RECOMMENDS** National Members and other appropriate Authorities providing, or intending to provide, DGNSS services in the frequency band 283.5 – 325 kHz, to use the Minimum Standards set out in the annex to this recommendation.

Annex

Minimum Standards for the Performance and Monitoring of DGNSS Services in the frequency band 283.5 – 325 kHz

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# Introduction

## Scope of document

A Global Navigation Satellite System (GNSS) is a space-based positioning, navigation and time distribution system designed for world-wide use. GPS and GLONASS are first generation GNSS and were developed in the 1990’s. . The second generation cover modernised GPS and GLONAS along with new systems such as Galileo and BeiDou.

Differential GNSS (DGNSS) is a means of improving the accuracy of GNSS and providing integrity monitoring to the user. DGNSS involves having reference stations, at precisely known locations, that provide real-time corrections and integrity information to GNSS signals.

This Recommendation considers the generation and broadcast of code based corrections with a focus on the maritime domain. It describes the use of transmitters in the 285 – 325 kHz / 283.5 – 315 kHz LF/MF marine frequency band to provide DGNSS signals, but acknowledges that other means of transmitting corrections are available, for example via AIS. It must be noted that DGNSS is an augmentation of GNSS and is not a stand-alone radio navigation system. DGNSS systems provide shore-to-ship services.

GNSS does not inherently provide integrity information and therefore the position may contain significant errors for extended periods of time, without notifying the user. Augmentation will provide the user with integrity information A successful response on board the ship will depend on the navigator’s correct perception of the meaning of the integrity information and that he takes the proper cause of action. Such information could indicate that the GNSS system is no longer reliable and the proper action should include a reversion to alternative navigation systems or to a reliance on visual and radar means of position fixing. The service provider may wish to emphasize this in its publications informing mariners about the DGNSS system.

The service provider is recommended to publish that they follow IMO and IALA Recommendations for the provision of DGNSS, giving emphasis to the provision of integrity information.

System performance is based on the assumptions that the system provider conforms to these Recommendations and that the user equipment meets the design and installation standards as specified in Ref x.

This document covers existing methods of providing marine beacon DGNSS. Other related recommendations from IALA are:

* Future DGNSS options are captured in R-135 [1]
* Vulnerability of GNSS systems is discussed in R-129 [2]
* Recommendation to National Members to provide DGNSS is captured in R-115 [3]

## Structure of document

Chapter 2 defines and details the overall performance parameters and requirements for the broadcast of the corrections. The performance parameters are absolute accuracy, integrity, continuity, availability and coverage. Each parameter has an associated requirement for ocean and harbour entrances, harbour approach and coastal waters.

Chapter 3 provides technical aspects for a service provider on how to develop, implement and maintain a DGNSS service. It gives a guideline on which parts are needed to acquire, generate and broadcast the corrections and how to facilitate fulfilment of the requirements of the performance parameters: accuracy, integrity, continuity, availability and coverage.

This recommendation gives details on two different types of implementation. One is the classical approach by generating the corrections and the integrity checks at the beacon site. The other is the Virtual Reference Station (VRS) approach which utilizes surrounding reference stations to calculate corrections for each beacon site.

Chapter 4 gives the service provider an understanding on how to operate and validate the DGNSS system during its lifetime with respect to the performance parameters. An overview is given to how a DGNSS system should contain different levels of self-monitoring, such as short-baseline monitors and far-field monitors. A DGNSS service provider should inform the user about the DGNSS system, and this chapter deals with which data to publicise.

Chapter 5 details the cross-references made in this document.

Annexes includes examples on calculations, technical implementations and other relevant data. The following annexes are included:

* Annex A: Abbreviations
* Annex B: Example of DGNSS broadcast settings
* Annex C: Example of validation of availability and continuity.
* Annex D: Typical link budget of a DGNSS beacon service
* Annex E: System Availability
* Annex F: MF Antenna Performance

# Performance Requirements

## Definitions

System performance is characterised by a number of different aspects, including Accuracy, Integrity, Continuity, Availability and Coverage[[1]](#footnote-1), as:

Absolute accuracy (Geodetic or Geographic accuracy). The accuracy of a position estimate with respect to the geographic or geodetic co-ordinates of the Earth.

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

Continuity: The probability that, assuming a fault-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area.

Availability: The percentage of time that an aid, or system of aids, is performing a required function under stated conditions (i.e. when it provides the required integrity for the given accuracy level). Non-availability can be caused by scheduled and/or unscheduled interruptions.

Coverage: The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of performance.

## Positioning Performance Requirements

IMO Resolution A.1046 (27) details the requirements on worldwide radio navigation systems considering vessels operating in ocean and harbour entrances, harbour approaches and coastal waters. The requirements are described by accuracy, integrity, availability, and continuity for positioning. **Table 1** summarizes the requirements specified in A.1046 (27), augmented by those described for comparable performance levels in A.915(22).

**Table 1** **Maritime requirements based on IMO Recommendations [IMO A.915(22) & A.1046 (27)]**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | System Level | | | | Service Level | |
|  | Absolute Horizontal Accuracy (95%) | Integrity | | | Availability  (2 years) | Continuity  (over 15 minutes) |
|  | Alarm Limit | Time to Alarm1 | Integrity Risk |
| Area | m | m | s | % | % | % |
| Ocean | < 100 | N/A | N/A | N/A | > 99.8 | N/A |
| Harbour entrances, harbour approaches and coastal waters | < 10 | 25 | 10 | 10-5 | > 99.8 | 99.97 |
| 1 *Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities;* | | | | | | |

Neither IMO Recommendation detail how these requirements should be met. GNSS alone can meet the requirements for ocean phase; however, augmentation services are needed to meet the accuracy, integrity and continuity requirements for harbour entrances, harbour approaches and coastal waters. It is assumed that the DGNSS service shall consist of areas of overlapping coverage, where each individual reference station availability is >99.5% and continuity is >99.95%. IMO Recommendation A.1046 (27) removed the duration over which availability should be calculated; however the 2 year duration has been retained in this Recommendation in order to allow for comparison with previous performance statistics.

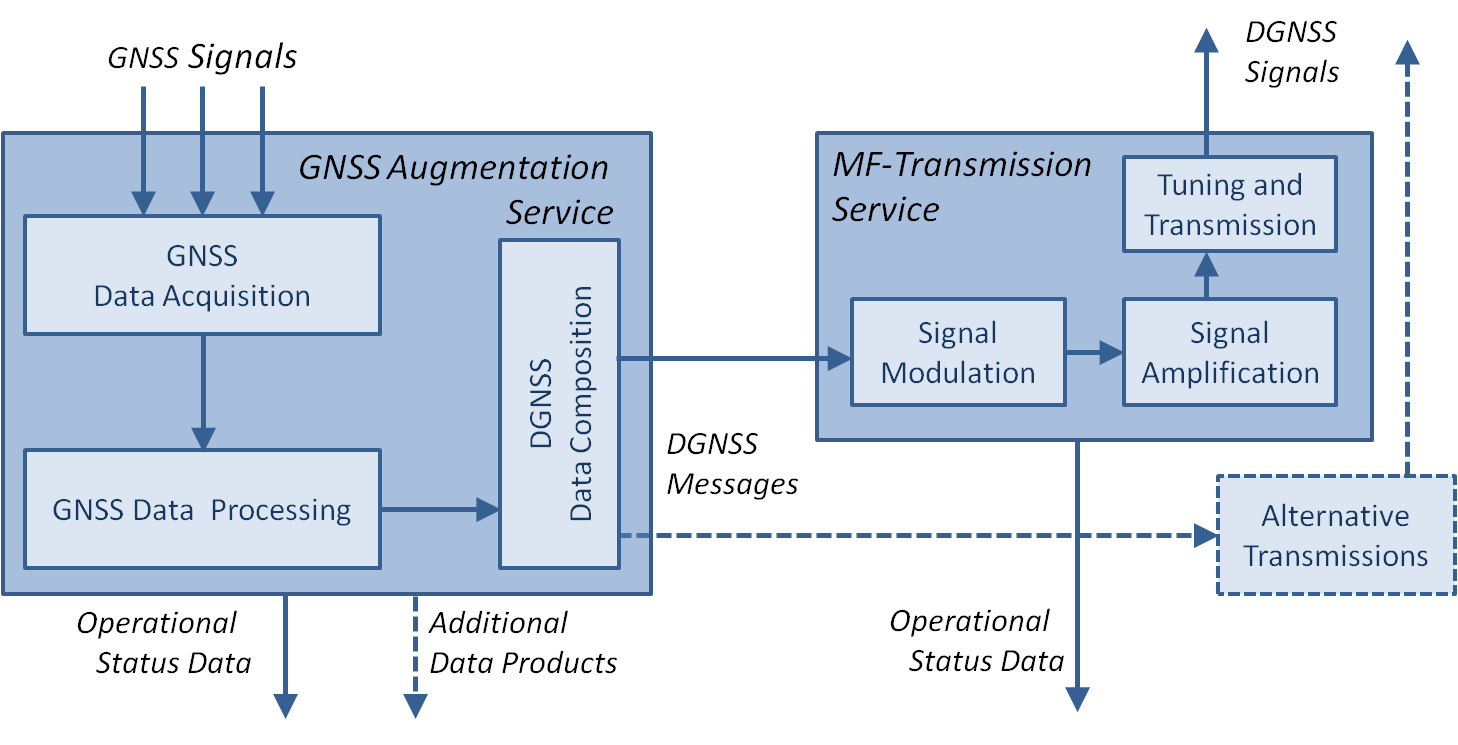
Typically, DGNSS services achieve an accuracy in the order of <5m (95%). Should deci-metre accuracy be required, alternative augmentation approaches such as Real Time Kinematic (RTK) or Precise Point Positioning (PPP) should be considered, but these are not considered in this recommendation.

Service providers should consider the appropriate number, and location, of reference stations to achieve sufficient coverage to ensure these requirements are met.

# Shore Site Architecture

This chapter deals with the shore site architecture of a maritime DGNSS service in the frequency band 283.5 - 325 kHz, whose use enables the fulfilment of performance requirements given in Chapter 2. The purpose of a DGNSS service can be described by 2 general functionalities realised by 2 complementary services:

* The GNSS augmentation service is responsible for the generation of GNSS correction and integrity data. DGNSS messages are formed using the derived GNSS augmentation data.
* The MF transmission service generates and broadcasts MF signals in the radio beacon band, which are used as carrier of DGNSS messages. The opportunity to broadcast DGNSS messages on alternative transmissions is suggested by the dashed line.



**Figure 1 Generalised architecture of DGNSS Service**

The generalised functional architecture of a system providing a DGNSS Service is shown in Figure 1 and reflects both the functionalities and assigned services. The functional separation of the DGNSS service is in compliance with the principles of a modular architecture design.

## GNSS Augmentation Service

The primary aim of the GNSS Augmentation Service is the provision of DGNSS messages. For this purpose a suitable output data interface to the DGNSS Transmission Service is necessary. The generation of DGNSS messages requires the realization of the following 3 tasks:

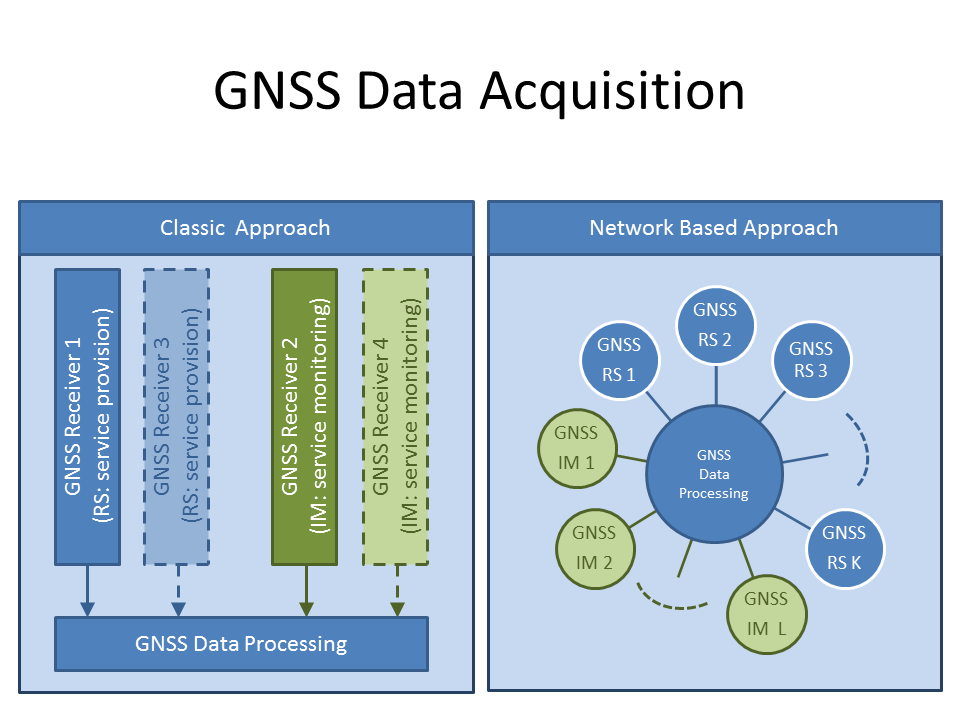
1. Task “GNSS Data Acquisition” to collect the required data for DGNSS service provision.
2. Task “GNSS Data Processing” to derive the GNSS augmentation data from available GNSS data.
3. Task “DGNSS Data Composition” to arrange the GNSS augmentation data in DGNSS messages.

Composed DGNSS messages are delivered to the DGNSS Transmission Service to enable the generation of DGNSS signals. At present DGNSS signals are mostly provided in the MF band, but a dashed line outlines the opportunity to broadcast alternative transmissions such as AIS, eLoran, mobile Internet (GSM), etc. The GNSS Augmentation Service should be equipped with an additional interface, which enables the monitoring of DGNSS service by the stakeholder based on provided status data. The opportunity to use DGNSS services as data source for PNT relevant safety information is suggested by the second output data interface “Additional Data Products” of the GNSS Augmentation Service.

### GNSS Data Acquisition

The task “GNSS Data Acquisition” deals with the provision of GNSS ranging and navigation data, which are commonly used for the determination of position, velocity, and time data (PVT). The GNSS Augmentation Service needs GNSS receivers to acquire the GNSS data from the GNSS signals. The type of GNSS receiver used determineswhich GNSS signals the service can generate DGNSS messages for.

Due to GNSS modernization and the establishment of further satellite based navigation systems the number of GNSS signals with civil access will increase in the future. An improvement of GNSS based PVT determination can be expected if all available GNSS signals are used.. Therefore service providers are encouraged to review IALA R-135, which considers the future use and role of DGNSS services. At present it is expected that the role of GNSS augmentation services focuses more and more on the improvement of integrity in the context of safety-critical GNSS applications. Consequently, service providers are also encouraged to extend the service provision on new GNSS signals.



**Figure 2 Opportunities of GNSS data acquisition for DGNSS service provision (RS: reference station, IM: integrity monitoring station)**

GNSS data acquisition can be realised with a single GNSS receiver, a set of GNSS receivers or a network of receiver (Figure 2). The number of GNSS receivers used for data acquisition determines the achievable level of redundancy in the GNSS data basis. An increased level of redundancy in the GNSS data basis enables that the provision of DGNSS services and therefore the DGNSS based PVT determination can be improved.

**Classic Approach:**

In minimum a DGNSS service provision can be realised with GNSS data collected by a single GNSS receiver at the reference station (RS). Assuming, that integrity monitoring of DGNSS service provision is part of the classic approach, at least one otherGNSS receiver is necessary. A fixed receiver operates as an integrity monitoring station (IM) and assesses the achievable PVT performance by applying GNSS augmentation data to its own GNSS measurements .

**Network based Approach:**

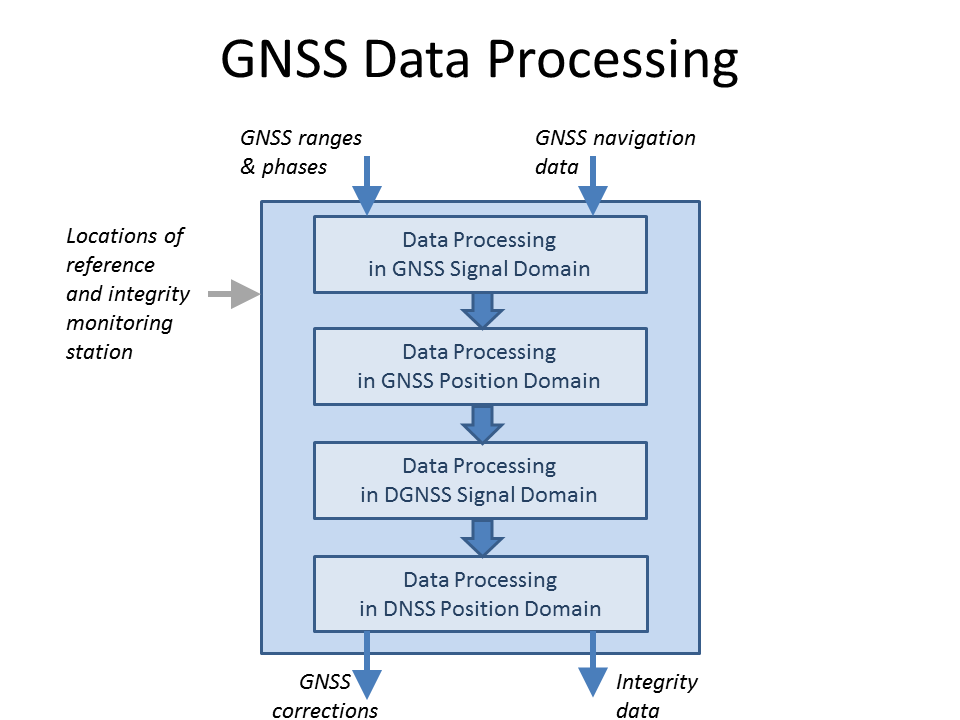
A network based approach can be established by using a suitable number of GNSS receivers distributed over the intended coverage area. Best results could be achieved when the service area is enclosed by the GNSS receiver network. The data of a single GNSS receiver within the network should be used either for service generation or for service monitoring to avoid correlation effects between service provision and monitoring.

The classic and the network based approach of data acquisition are shown in Figure 2. As shown, the network based acquisition of GNSS data is realized with multiple GNSS receivers (from 1 – K), whereby additional GNSS receivers are used for integrity monitoring (from 1-L).

### GNSS Data Processing

The task “GNSS Data Processing” is responsible for the generation of DGNSS augmentation data. The results of GNSS data processing are referenced in RTCM broadcast standard version 2.3, as described in ITU-R M823-3. In this case correction data provided by the GNSS augmentation service covers pseudo range and range rate corrections for GNSS signals (currently only GPS and GLONASS) in the upper L-band as described in IMO Resolution MSC.114(73). Additionally, integrity data describes the operational status of GNSS augmentation service and characterizes the usability of single GNSS signals as well as provided corrections.

Figure 3 shows a generic presentation of GNSS data processing, whereby the processing is divided into 4 stages, principally. The data basis for GNSS data processing covers GNSS range and phase measurements as well as navigation data provided by GNSS itself. The antenna position of GNSS receivers used in reference and integrity monitoring stations should be determined accurately in a common geographic reference system (see chapter 3.1.4 performance aspects).



**Figure 3 Stages of GNSS data processing during service provision**

The first 2 processing stages deal with the assessment of GNSS as data base for DGNSS service provision and with the determination of the desired correction parameters:

* The usability of single GNSS signals for positioning as well as service provision stands in the focus of the first processing stage. For this purpose range and range rate corrections to each satellite are determined using the known antenna position of the measuring point. These correction parameters can also be used as indicators to decide about the quality of single GNSS signals and assigned corrections. Both - the number of GNSS satellites in view as well as the number of usable GNSS signals – can be used to indicate, if the data base is sufficient for GNSS position determination as well as DGNSS service provision.
* The second processing stage accounts the capability of GNSS taking into account the current usable GNSS signals and their spatial arrangement. In this context the Dilution of Precision (DOP) is a suitable indicator to estimate the expected performance of GNSS based positioning. Additionally, the achieved GNSS position accuracy with or without application of receiver autonomous integrity monitoring techniques (RAIM) could improve the assessment of GNSS database.

An intermediate result of the first 2 processing stages is the provision of GNSS correction data as well as integrity data characterising the usability of GNSS and its signals. The next processing stages deal with the self-assessment of the provided DGNSS services realised in DGNSS signal and position domain:

* In the DGNSS signal domain the independent acquired GNSS range measurements are corrected with the provided GNSS correction data. The residual error determined range and range rate at integrity monitoring site can be applied as indicator in the signal domain to assess the quality of provided corrections. It should be expected that the residuals of corrected range and range rates should be appreciable below the real error.
* In the DGNSS position domain the position is calculated using own but corrected GNSS measurements. The deviation between true and calculated position is a proper indicator to describe the achievable performance of DGNSS positioning at monitoring site.

Results of the GNSS data processing cover differential GNSS corrections as well as integrity data characterising the used GNSS, the operated DGNSS service, and the provided GNSS augmentation data.

### DGNSS Data Composition

The data composition follows the rules given in ITU-R Recommendation M.823-3 (Ref. 1). The following message types should be used to provide augmentation data for the first generation GNSS (GPS and GLONASS) based on RTCM SC 104 V2.3 (Ref. X):

* Type 1 (GPS Full Correction Set) or 31 (GLONASS Full Correction Set)
* Type 9 (GPS Partial Correction Set) or 34 (GLONASS Partial Correction Set)
* Type 3 (GPS Reference Station Parameters) or Type 32 (GLONASS Reference Station Parameters)
* Type 7 (DGPS Radiobeacon Almanac) or Type 35 (GLONASS Radiobeacon Almanac)
* Type 6 (Null frame, used as transmission fill).

*Further recommendations should be taken into account:*

* *Partial Correction Sets messages are preferred because of better performance in impulse noise conditions.*
* *Message Types 3/32, and 7/35 should be broadcast at the minimum time intervals specified in ITU-R Recommendation M.823.*
* *Message Type 5, which deals with GPS constellation health, is included in ITU-R Recommendation M.823, but is not normally used.*
* *Message Type 16/36 may be used to broadcast special messages in text form, but should not normally be used for integrity warnings, which are included in message headers.*
* *Type 16/36 messages may be used for status information, or for navigation related information such as hydrographic or meteorological data.*
* *Type 16/36 messages should never be broadcast consecutively as this will cause excessive receiver alarms, receiver memory overloads, and/or data link loading.*
* *Type 16 /36 messages should not be broadcast for a period of at least ninety seconds preceding or following a Type 3/32, 5, or 7/35 message and the interval between*
* *successive Type 16/36 messages should be no less than three minutes.*
* *Proposed Message Type 27 (DGPS extended radio beacon almanac) may be required in the future to be broadcast in conjunction with Message Type 7 to fulfil IMO [MSC 114 (73)] automatic radio beacon selection mode.*

### Performance Aspects

Aim of DGNSS augmentation services is the improvement of GNSS based position, velocity and time determination by provision of GNSS correction parameters and GNSS/DGNSS related integrity information. The performance of provided correction and integrity data depends on usable GNSS data basis and applied data processing techniques. Likewise the final settings of assessment and decision thresholds (ANNEX 1) influence the achievable DGNSS service performance. Otherwise differences in the technical design and service realisation contribute to the achievable performance level of GNSS augmentation services. Therefore service providers are encouraged to inform users about their specific service implementation and to publish the achieved service performance.

**Accuracy Aspects:**

The accuracy of service provision depends on a number of factors. Invariant, installation specific factors result from architecture design, implemented functions and sensors of established GNSS augmentation service. Such factors cover for example:

* the quality of used GNSS sensors determining the accuracy and availability of range measurements and navigation data for service provision;
* the number of GNSS sensors used and their spatial arrangement (system architecture for GNSS data acquisition) determining the amount of data and included redundancy, which can be exploited for service provision and monitoring;
* the geographical latitude of measuring points determining number and geometry of GNSS satellites in view;
* the accuracy of antenna phase centres determined by initial measurement (e.g. 3D accuracy should be better than 5 centimetre);
* the chosen location of GNSS sensors (antennas) in relation to environmental conditions (shadowing, multipath) and occurrence of radio interferences; and
* the applied measures and methods to indicate and reduce propagation effects and system failures (e.g. carrier smoothing techniques, fault detection and exclusion techniques).

Variant factors come from the system in use taking into account the current occurrence of signal disturbances, increased latencies, malfunction or failures within GNSS and DGNSS components. A decreased number of measurements or a reduced quality of derived distances can result in temporary downgrading or loss of service provision. Increased latencies can result into the provision of GNSS corrections with higher age. Then temporal decorrelation results in an increase of residual errors in the corrected distance measurements.

A suitable accuracy indicator of DGNSS service usability is the proof, that within a 50 m circumscribed circle of the reference station the horizontal position error is <0.5m (95%), if DGNSS corrections are applied on independent GNSS measurements.

Service providers are requested to publish the level of accuracy. Furthermore service providers are encouraged to monitor the achieved accuracy in the service area by service monitors or routine service evaluation. Furthermore the service provider should ensure that service generation and provision is realised in a common reference datum. The user should be informed about the reference datum used, to allow them to transform the datum if necessary.

GNSS augmentation systems have the ability to estimate the current accuracy in the service area based on position accuracies determined at selected points (monitors). If the monitor is nearby the reference station, the estimated accuracy neglects the spatial decorrelation of several error sources and offers accuracies in the sub-meter level. Investigations[[2]](#footnote-2) in Portugal have shown, that the DGPS position error coming from spatial error decorrelation could be modelled by

95% DGPS error [m] = 0,41 + 0,0038 . S[NM],

whereby S is the distance between reference station and user given in nautical miles. It should be noted that such estimations depends on the geographical region and the quality of the user receiver At present various opportunities exist, which could be used to reduce the influence of spatial error decorrelation. If several integrity monitors are located at service boundaries, the opportunity exists, to achieve a user position related refinement of correction terms e.g. by interpolation. Otherwise, with a network of reference station the correction data can be determined for a virtual reference station, which will be placed in the vicinity of a single user.

Considering the current maritime DGNSS implementations, a user should expect that the real achievable position accuracy differs from the position accuracy estimated by the service provider. Main causes for this are local signal disturbances (multipath, interferences) besides spatial decorrelation effects and quality of used receivers.

**Integrity Aspects:**

Integrity monitoring within the GNSS Augmentation Service serves the quality control of used GNSS and provided DGNSS data. Tests performed in the GNSS signal domain and GNSS positions domain clarifies the current usability of GNSS for PVT determination as well as DGNSS service provision. The results of assessment can induce alarms indicating single satellite signals as “do not use” or complete DGNSS stations as “unhealthy”. Additional tests in the DGNSS signal domain and DGNSS position domain can only be performed by one or more integrity monitoring stations. In combination with integrity checks of the MF Transmission Service they evaluate the fulfillment of requirements on DGNSS service provision. In dependence on intra-system situations single GNSS/DGNSS signals or the complete service can be signed as “unusable” or “unmonitored”.

* ***GNSS signal domain (GNSS SD)***

Integrity monitoring in the GNSS signal domain checks the availability and quality of GNSS data regarding their usability for DGNSS service provision as well as monitoring. The usability of single GNSS satellites and its signals for service provision can be assessed e.g. based on:

* completeness of GNSS range, phase, and navigation data per GNSS satellite in view;
* integrity data or health status provided by GNSS itself;
* validity of navigation data;
* plausibility, consistency and accuracy of distance measurements;

Incompleteness or insufficient quality of GNSS range and phase measurements as well as GNSS navigation data can result in the decision that specific GNSS satellite signals shall not be used for DGNSS service provision.

* ***GNSS position domain (GNSS PD)***

Integrity monitoring in the GNSS position domain checks to see if the current availability of usable GNSS signals is sufficient for GNSS as well as DGNSS based positioning. In addition to RSIM standard the opportunity is seen to use the current achieved GNSS position accuracy as an additional quality indicator for DGNSS service provision. Integrity monitoring in the GNSS position domain shall be realized for each measuring points used for service provision and can cover e.g.:

* number of usable GNSS satellites for positioning;
* spatial arrangement of usable GNSS satellites given by Dilution of Precision (DOP);
* accuracy of GNSS positioning;

Therefore a poor data set or insufficient quality of GNSS data as well as worse GNSS position performance can result in the decision to exclude single stations from service provision. In extreme cases, where a multiple satellites are affected, a DGNSS service provision can be impossible.

* ***DGNSS signal domain (DGNSS SD)***

Integrity monitoring in the DGNSS signal domain can be realized at the reference station and integrity monitoring sites, alternatively or complementary. Checks at reference sites can prove if the generation of GNSS correction data is either successful or not. Only at integrity monitoring sites the quality of provided GNSS corrections can be assessed considering residual errors by mixing own GNSS measurements with received correction terms.

* accessibility of generated correction terms at RS;
* plausibility of generated correction terms at RS;
* consistency of generated correction terms at RS;
* indicated validity and integrity of correction terms provided by RS;
* accessibility of correction terms at IM;
* latency and validity of available correction terms at IM;
* residual ranging error after application of RS corrections at IM;

Incompleteness or insufficient quality of own GNSS measurements as well as received GNSS corrections can result int the decision at the IM that data assigned to specific GNSS satellite signals shall not be used for DGNSS based positioning.

* ***DGNSS position domain (DGNSS PD)***

Integrity monitoring in the DGNSS position domain checks to see if the current availability and quality of corrected GNSS signals is sufficient for DGNSS based positioning at integrity monitoring sites. In this case the IM is considered as an artificial user of the GNSS augmentation system. The evaluation can base e.g. on:

* number of GNSS satellites links, for which at IM own measurements and correction data are available – both classified as usable for positioning;
* spatial arrangement of usable GNSS satellites at IM given by DOP’s;
* accuracy of DGNSS positioning at IM;

Therefore a poor data set or an insufficient quality of corrected GNSS measurements at IM as well as unacceptable positioning errors can result in the recommendation that the provided GNSS augmentation service should not be used for navigation purposes.

The service provider is encouraged to implement, as a minimum, the integrity monitoring functionalities described in RTCM 10401.2 (RSIM Standard). As outlined, the data basis usable for DGNSS service provision and monitoring differs in dependence of applied GNSS data acquisition (see **Figure 2**) and the placement of reference and integrity monitoring stations.

In the classic approach the on-site integrity monitoring is performed by applying either the Local Integrity Monitoring concept (LIM), the Far Field Integrity Monitoring concept (FFIM), or a combination both:

* A Local Integrity Monitoring concept (LIM) can be applied, if the integrity monitoring station is located in the vicinity of the reference station. In such cases it is impossible to estimate the influence of error decorrelation effects on achievable position performance at user site.
* The Far Field Integrity Monitoring concept (FFIM) can be applied, if one or more integrity monitoring stations operate at the boundary of the service area, where error decorrelation effects can be estimated. When the user operates in the vicinity of the integrity monitor, the monitored position error can be considered as representative for user’s position error. Therefore, where possible, far field monitors should be located at the boundaries of the service area.

If a network based data acquisition is used, the opportunity exists to consider error decorrelation effects during generation and monitoring of GNSS corrections. Within a network based concept it should be clarified, whether a single station operates as reference or monitoring station, so to avoid as far as possible any correlation between service generation and monitoring processes. However, the integrity of a network based provision of GNSS augmentation data should consider the integrity of communication systems ensuring the data exchange between spatial distributed measuring and processing components.

The service provider is encouraged to meet a suitable choice of integrity monitoring functionalities taking into account the available data basis and the desired level of integrity. Monitoring functionalities can be based e.g. on availability, plausibility, consistency, validity, latency, and accuracy tests. In principle, integrity statements are more meaningful, if they are derived from evaluated position accuracies in the service area. However, a comprehensive assessment of position accuracies in the service area increases the dependency of service integrity on communication integrity. Service providers are requested to publish the applied monitoring functionalities including decision rules deciding about the usability of components and data. On the one hand this enables an improved understanding of usability information and allows on the other hand the exploitation of GNSS/DGNSS related integrity data within shipside alarm management.

**Availability Aspects:**

The availability describes the usability of a the DGNSS service. User’s access on the DGNSS signal as carrier of correction and integrity data is a precondition of DGNSS service usability. In line with definitions in IMO A.915(22) DGNSS signal availability is given, if the radio reception of the DGNSS signal is ensured in the specified coverage area (see chapter 2) and if the DGNSS signal is provided according to its specification (see chapter 3.1.3 signal structure, data format and content). Due to its independence from GNSS availability the DGNSS signal availability is suitable to measure the performance of provided DGNSS services. A lost access on GNSS signals at service sites or a complete outage of GNSS implicates that the DGNSS service cannot provide GNSS correction data. The self-monitoring of the DGNSS service ensures the detection of GNSS data absence. In such cases it can be expected that the DGNSS signal provides integrity data informing about the absence of DGNSS correction data and the resulting impossibility of DGNSS based position determination. The DGNSS signal availability will be measured by the service provider at one or more monitoring sites. Due to spatial decorrelation effects the signal availability estimated by the provider at a single monitor sites can be different to the signal availability observed at distant users.



If 2 or more monitoring sites are used for service evaluation, the influence of decorrelation effects on the reliability of availability statements can be reduced.

System availability is an additional performance term defined in IMO A.915(22) as the availability of a system to a user, covering the signal availability and the performance of user’s receiver. Before the DGNSS system availabilitycan be evaluated, a clarification is necessary against which user requirements the performance of user’s receiver should be assessed. The system availability is further described in Annex X

**Continuity Aspects**

Continuity in the coverage area can be measured (1) at broadcast site(s), (2) by the use of far-field monitor(s) or a combination of both. Chapter 4 will provide information how to measure and calculate continuity in this respect.

## MF Transmission Service

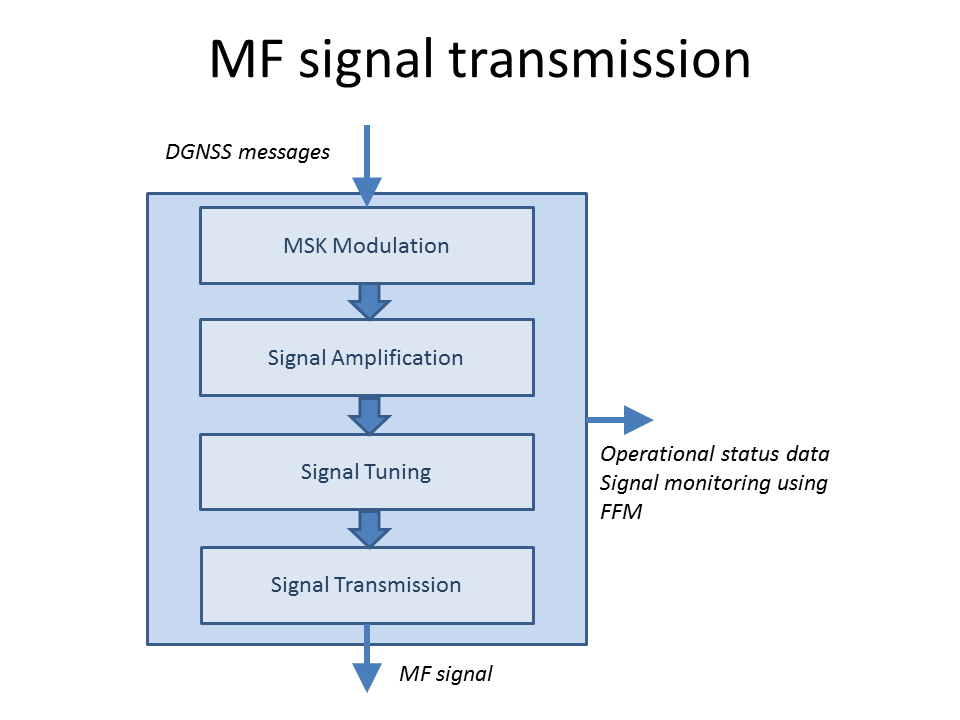
As shown in figure 1 the main task of the MF transmission service is the provision of DGNSS messages by signals in the frequency band 283.5 to 325 kHz. For this purpose following 3 tasks are realised:

1. Task “Signal modulation” to modulate the MF carrier signal with the DGNSS messages composed by the GNSS augmentation service;
2. Task “Signal amplification” to amplify the signal on the specified signal power level to fulfil the range requirements;
3. Task “Signal tuning” and “Signal transmission” to emit the DGNSS signal with a suitable antenna system.

The MF transmission service should also provide status data describing the current progress of MF transmission service covering radio signal generation and distribution.

As described in the IALA Recommendation R-135 in the future the MF transmission service could also provide additional ranging signals as a redundant position-fixing system, complementary to, but independent of GNSS.

Figure **4** shows the different functional elements of the MF transmission service.



**Figure 4 Main tasks of a MF transmission service**

### Signal Modulation (MSK Modulator)

The modulation technique applied for DGNSS signal generation is Minimum Shift Keying (MSK) (class of emission G1D) as defined in ITU-R Rec. M.823-3. The MSK modulated signals should have carrier frequencies in the MF beacon band between 283.5 to 325 kHz, which are separated in 500 Hz from each other. The DGNSS messages used as modulating signal shall be selectable to data rates of 25 (GLONASS only), 50, 100 or 200 bps. It should be noted that higher data rates enable a faster update and provision of DGNSS corrections but limit the coverage area of the DGNSS service due to lower signal to noise ratio. Service providers should publish the frequency and data rate used for DGNSS service provision.

### Signal Amplification (MF Transmitter)

The MF Transmitter amplifies the modulated input signal on the required signal power level and provides the amplified DGNSS signal to the connected MF Antenna System.

### Signal Tuning (Automatic Tuning Unit)

The ATU (Automatic Tuning Unit) matches the antenna system resistive component to the impedance of the feeding cable of the MF transmitter (typically 50 Ω). Further the ATU bring the MF antenna in resonance with the operational frequency of the DGNSS site. It is recommended that the ATU should provide means to detect and correct a detuning of the antenna system, which can result from weather or seasonal conditions. Further the ATU should provide measurements of antenna current to the MF-transmitter to enable meter readings from transmitter site or from connected remote control facilities. The use of an electronic impedance meter may be helpful to support the coarse and fine tuning of the used MF antenna system and to provide additional information regarding the quality of the tuning process. Readings of the proportion of transmitted and reflected power at the MF transmitter are foreseen status data informing about the achieved tuning and matching quality.

### Signal transmission (MF Antenna System)

The MF antenna system, consisting of MF antenna and grounding system, is a one of the most critical elements within the DGNSS service because the antenna can be affected by severe weather conditions and is typically not realized as a fully redundant antenna system. Therefore the requirements regarding a reliable performance of the MF antenna as well as the ATU are very high. If no standby antenna is available at the DGNSS site, the required down time for regular and planned maintenance should be low. The required DGNSS coverage range is mainly dependent on the performance of the antenna system and the transmitted power. Annex F provides detailed information how to calculate the performance of the MF antenna system.

### Performance Aspects

**Range/Coverage Aspects**

Nominal ranges of stations over seawater paths should be published at stated field strengths (for example 50, 75 or 100 µV/m) (Ref. 5). Published coverage diagrams are normally based on software modelling predictions and should be verified by measurements. The modelling process can be quite complex and difficult, especially over mixed land/sea paths. Advice regarding modelling can be sought through IALA. In predicting coverage, each service provider should establish the required field strength considering following factors:

* Radiated power,
* Antenna system configuration, including horizontal and vertical polar diagrams,
* Antenna efficiency (η),
* Ground wave propagation curves for frequencies between 10kHz and 30MHz as applicable at 300 kHz as given in ITU-R P.368-7, (Refs. X)
* Ground conductivity along the propagation path as provided in ITU-R P.832-2 “World atlas of ground conductivities” (ref),
* Fading due to skywave propagation of the station’s signal: At night the field strength at every point in the coverage should be not less than that specified at the nominal range for at least 95% of the time. Night-time field strengths may be calculated in accordance with references 8, 9 & 10,
* Atmospheric noise: Assumed levels of atmospheric noise should be in accordance with current ITU-R data and practice applicable at 300 kHz. It is recommended that the noise level be that which is not exceeded more than 95% of the time on average throughout the year (Refs. 11 & 12).

**Signal Monitoring**

Signal monitoring of the MF Transmission Service serves to prove that the functionalities of the transmission service have been fulfilled. A successful provision of DGNSS augmentation signals via MF radio channel is basic condition for the applicability of DGNSS service. The signal monitoring of MF transmission service can be done considering following performance parameters of received MF signals:

* signal strength (SS),
* signal to noise ratio (SNR),
* RTCM message throughput (WER), and
* Temporal validity of message content.

The results of MF signal monitoring can induce alerts to service providers and may cause a switch to standby equipment of the MF Transmission Service.

**Availability Aspects**

The availability of MF transmission services contributes to the availability of the DGNSS service which is based on the integrated use of GNSS augmentation service and MF transmission service. User’s access on the DGNSS signal as carrier of correction and integrity data is a precondition of DGNSS service usability. In line with definitions in IMO A.915(22) DGNSS signal availability is given, if the radio reception of the DGNSS signal is ensured in the specified coverage area (see chapter 2) and if the DGNSS signal is provided according to its specification (see chapter 3.1.3 signal structure, data format and content). Following this definition the signal availability depends on the availability of both services

,

whereby

 - availability of MF transmission service,

 - availability of component composing the DGNSS message content,

 - availability of subsystem realising GNSS data acquisition and processing as well as DGNSS data generation.

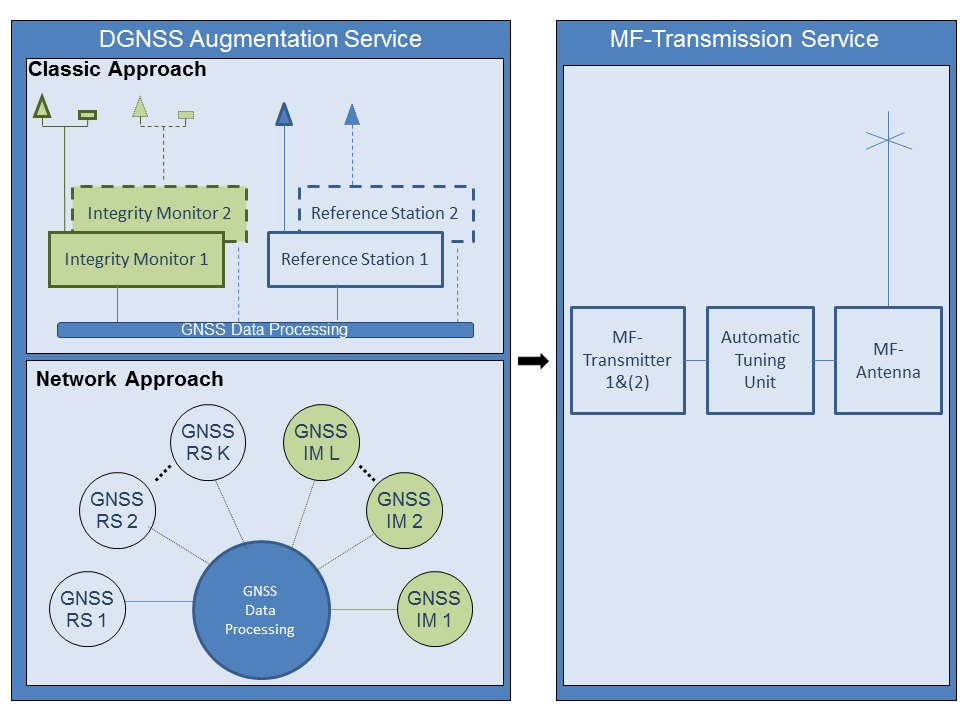
The self-monitoring of the MF transmission services ensures the detection of failures, malfunctions and breakdowns during DGNSS signal generation and transmission.

**Continuity Aspects**

Continuity in the coverage area can be measured (1) at broadcast site(s), (2) by the use of far-field monitor(s), or a combination of both. Similar to the availability the continuity of the MF transmission services contributes to the continuity of the DGNSS service which is based on the integrated use of GNSS augmentation service and MF transmission service.

## Technical Implementation

This chapter provides recommendations how a radio beacon DGNSS site could be implemented based on the DGNSS augmentation- and the MF transmission service. The implementation for the DGNSS augmentation service can be performed following the classical approach with local reference and monitoring receiver or the network approach based on virtual reference stations. The realization of the MF transmission is following a straight forward design which is typically identical for both methods. Figure 5 illustrates the implementation concept for a DGNSS service in the radio beacon band.

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**Figure 5 Implementation of a DGNSS service in the radio beacon band**

The functional details of the components of a DGNSS augmentation service are already described in chapter 3.1 and 3.2. The following sections are mainly focused on technical system components, which are required to establish a maritime DGNSS service in the MF radio beacon band.

### Components of the classic approach

An implementation of the DGNSS augmentation service based on local reference and integrity receiver should provide at least the following system elements:

* **Reference Station:** Within the classic approach the reference station consist of a minimum of a single GNSS reference receiver and a MSK modulator. Furthermore the GNSS data processing is usually part of the reference station. In Figure 5 the MSK modulator and GNSS data processing is considered as part of the reference station. To fulfil the availability requirements it is recommended to provide a backup reference station for redundancy.
* **Integrity Monitor:** The Integrity monitor uses a minimum of a single MF receiver/MSK demodulator and a single GNSS/DGNSS reference receiver to receive and assess the transmitted DGNSS corrections. In Figure 5 the MF receiver and MSK demodulator is considered as part of the integrity monitor. To fulfil the availability requirements it is recommended to provide a backup integrity monitor for redundancy. Typically the integrity monitoring on the DGNSS position domain is performed as post-broadcast integrity, where transmitted GNSS corrections from a DGNSS site are received with a local integrity monitor (LIM), however some equipment providers allow the use of pre-broadcast integrity monitoring where DGNSS data checked before transmission
* **Communication:** The reference and monitor receiver exchange information on the basis of the RTCM recommended standards for differential GPS reference stations and integrity monitors (RSIM ref). It should be noted that the currently RSIM messages (version 1.2) only support the GPS component in the context of DGNSS integrity monitoring. With the introduction of RSIM version 1.3 it can be expected that integrity monitoring for full DGNSS range will be possible. Typically a site PC is used for site control and data logging. External communication and remote control is typically performed using a TCP/IP router.

### Components of the network approach

An implementation of the DGNSS augmentation service can be performed by a network approach , asshown in Figure 5. A network of GNSS sensor stations distributed within a defined area is used for GNSS data acquisition. The network approach should provide at least the following system elements:

* **Network of GNSS sensors:** A sufficient number of GNSS sensor sites are necessary to enable the provision of augmentation data (correction data and integrity information) in the aimed service area. For example, in Germany it was demonstrated that a number of 10 to 15 GNSS sensor sites are sufficient (ref. X). The sensor stations transmit their measured GNSS raw data to a central server for processing (GNSS data processing).
* **GNSS data processing at the VRS server:** Based on the received raw data streams, the Virtual Reference Station (VRS) server (GNSS data processor) calculates DGNSS correction data for multiple predefined positions. It is recommended that virtual reference stations should be located within the coverage range of the specific DGNSS site and in areas with highest demands concerning position accuracy and integrity(Ref.x). Another important task of GNSS data processing by VRS server is the implementation of the integrity monitoring functionality. For the network approach the integrity monitoring is based on the Pre-Broadcast Monitoring (PBM) algorithm, which ensures that all relevant checks have been performed before DGNSS data are transmitted. For network based integrity monitoring it is important that independent GNSS raw data streams are used for generation and monitoring of DGNSS augmentation data.
* **Communication:** In difference to the classic approach there is no need for internal radio communication using hardware equipment based on RSIM standard recommendations. However the network approach results in high requirements concerning the availability and quality of the communication links to the connected MF transmission service at the remote DGNSS sites. Typically a software module installed on the VRS server is used for network control and data logging.

### Components of the MF transmission service

The MF transmission service should provide at least the following system elements:

* **MSK modulator:** The MSK modulator modulates the generated RTCM messages on a signal carrier in the radio beacon band. The MSK modulator may be more or less regarded as the interface between the GNSS augmentation and the MF transmission service. In the classic approach the MSK modulator is typically an intrinsic part of a reference station and belongs to the DGNSS augmentation service. In the network approach the MSK modulator is usually a separated device and part of the MF transmission service. To achieve the required level of DGNSS signal availability the MSK modulator should consist of two identical but redundant modulator parts.
* **MF transmitter:** The MF transmitter amplifies the modulated input signal to the required signal power level. To achieve the required level of DGNSS signal availability the MF transmitter should consist of two identical but redundant transmitter parts.
* **Automatic Tuning Unit:** The Automatic Tuning Unit (ATU) matches the antenna system resistive component to the impedance of the feeding cable of the MF transmitter. A redundant ATU would only be necessary in the case of a redundant MF antenna system.
* **MF Antenna:** The MF antenna transmits the amplified DGNSS signal and provides the required coverage. It is up to the service provider whether this is duplicated for redundancy, however if it is not the requirements regarding the reliable performance of the MF antenna and the ATU are very high.

### Remote Control and Far Field Monitoring

The concept in Figure 5 does not show additional installations like control facilities or the difference between local and far field monitors. Independent tothe applied service concept, DGNSS service provision is based on more or less spatial distributed components realising the functionalities of GNSS data acquisition and processing, as well as DGNSS service provision and assessment. Therefore the service providers need one or more control stations for remote control of distant facilities.

As outlined in Figure 5, integrity monitors can be used to evaluate the GNSS augmentation service. Additionally, approaches are mentioned to monitor the MF transmission service.

Integrity monitoring is usually based on local integrity monitors (LIM) as well as far field monitors (FFM), which provides signal monitoring in remote areas. Future improvement could be realised by far field integrity monitoring (FFIM) which enables a more enhanced analysis of service performance by measuring the influence of spatial error decorrelation and feedback this information to the reference site.

# Operational Aspects

The set of signals radiated from the DGNSS beacons operated by a coastal or maritime administration is considered a DGNSS service and the administration is considered a DGNSS service provider. The operation of the service is considered as the set of tasks performed by the DGNSS service provider in the following domains:

* **Operation and Maintenance:** The DGNSS service provider should continuously monitor the DGNSS transmissions detect service disruptions and anomalies.
* **Performance Verification:** The DGNSS service provider should verify that the service is performing according to specifications.
* **Publication of information:** The DGPS service provider should provide a description of the DGNNS service and provide up to date information of scheduled maintenance activities.

## Operation and Maintenance

The DGNSS service provider is responsible for the operation and maintenance of the DGNSS service. To monitor the quality of the service the DGNSS service provider should provide means to:

* ,
* to monitor the service using local or remote integrity monitors (LIM, FFM) to detect service disruptions and anomalies,
* inform users in the case of navigational warnings regarding service disruptions or scheduled interruptions,
* manage any service disruptions, and
* manage maintenance work or changes to the service in such a way where service disruption is minimized and the users is provided with advanced warning.

The service provider may wish to consider remote control options for all system components at their DGNSS sites as this will aid the swap of system components.

## Performance verification

The DGNSS services provider should verify that accuracy and integrity requirements given in Table 1 are achieved. For this purpose it is necessary that GNSS availability is given and that these performance quantities are measured with appropriate monitoring facilities. The assessment of availability and continuity can be related either on fulfilment of accuracy and integrity (DGNSS system availability and continuity) or the provision of DGNSS signals (DGNSS signal availability and continuity). This allows that performance verification of DGNSS services can be performed taking into account that either GNSS availability is given or not. The service provider is recommended to provide as a minimum the performance verifications given below.

### DGNSS signal availability

The service provider should designate a geographical area where they operate their service within the required performance. The service area may be limited by beacon signal strengths or may be a specific geographical area as designated by the operator. The service provider is recommended to analyse service performance and include information about the extent of the service area in its publications.

In cases where coverage from DGNSS beacons belonging to separate service providers partially overlap, it is recommended also to take this into account as these provide a contribution to performance in the overlapping area. In order to maximize the combined performance such service providers should:

* coordinate the scheduling of maintenance work that may affect the service performance in overlapping areas,
* exchange information about service disruptions affecting overlapping areas,
* exchange information about achieved performance for the beacons in the overlapping areas.

Availability requirements are stated in chapter 2.

The service provider is recommended to take the degree of coverage from multiple beacons into account when validating the service availability. The service provider is recommended to consider implementing signal far field monitors in order to monitor signal strength.

Availability of the signal from a single beacon can be written as:

Availability (A1) = UP TIME/TOTAL TIME

Where:

UP TIME = the time where the beacon provide a signal with signal strength and SNR within

stated bounds and provide accuracy and integrity warnings within requirement

TOTAL TIME should be an extended period of time up to 2 years

In case of loss of signal from one DGNSS beacon DGNSS receivers are capable of automatically re-acquiring signal from other beacons that normally provide sufficient signal strength at the user’s location. In such areas of overlapping coverage service availability is defined as the probability that a signal from at least one beacon (which meets the accuracy and integrity requirements) is present.

Mathematically this can be written as:

Aservice = 1 – (1 – A1)n

Where:

n = number of beacons that meet the performance requirements at the receiver location

A1 = signal availability from a single beacon

The average availability over the service area as a whole may be estimated from the above and from the proportions of the service area covered from different numbers of beacons. See Calculation example in ANNEX C.

### DGNSS signal continuity

Continuity requirements are stated in chapter 2. For a DGNSS beacon the continuity can be calculated as the probability that a signal failure incident will start during the Continuity Time Interval (CTI). Normally the CTI will be very small compared to the typical interval between failures (MTBF) and thus the continuity can be mathematically this written as:

Continuity (C) = 1-CTI/MTBF

Where:

CTI = Continuity Time Interval, 15 minutes as stated in A.1046(27)

MTBF = the Mean Time Between Failures, as measured by the service provider over 2 years

There is no need to include the availability at the beginning of the time period of the operation because if there is no service, then the operation will not commence. If the beacon used during the CTI suffers a disruption there may, depending on the receiver design, be a delay of several minutes while the DGNSS receiver re-acquire signal from another beacon. This delay may be unacceptable for a particular operation and it is recommended that continuity should not take into account the presence of DGNSS signals from multiple beacons.

The average continuity for the service area as a whole may be estimated from the proportions of the service area covered from different beacons or, if beacons are experiencing similar MTBFs, as the average beacon continuity. See calculated example in ANNEX C.

### Verification of integrity monitoring

Integrity requirements are stated in chapter 2.

It is recommended that as a minimum the service provider monitor the transmission of integrity warnings from the beacons and identify instances where the time interval between the occurrence of a breach of integrity and the transmission of the integrity warning to the user does not meet the required Time To Alarm (TTA).

Performance verification of integrity monitoring could be completed if the fulfilment of integrity risk and alert limit will be considered. For this purpose additional measures are needed.

The recommended thresholds for detecting failures suggested appropriate action is provided in ANNEX B.

### Verification of DGNSS Accuracy

Accuracy requirements are stated in chapter 3. The service provider should measure the accuracy of the GNSS position as corrected by DGNSS inside the coverage area of each beacon. Such measurements can be done either by use of far field monitor or by periodic measurement campaigns. The formula below may be utilized to estimate the accuracy at the edge of the beacon coverage area.

A = C + S \* distance , where

A is the 95% DGPS error

C is the constant error due to beacon antenna survey error and multipath and interference at the receiver

S is the spatial decorrelation that increases as distance between the beacon and DGNSS receiver increase.

Different research provides estimates for both of these variables: C = 0,41and S = 0,0038 meters per nm after measurement in western European area (ref)

The USCG NDGPS Recap estimate C = 0.2839 and S = 0.0025 meters per km after measurement in the California. (Ref)

The service provider may estimate C and S by appropriate measurements within their DGNSS service area.

### Further performance verifications?

## Publication of information

The DGNSS service provider is recommended to consider the DGNSS service to be a maritime aid to navigation and should accordingly publish sufficient information about the service to enable users to use the service safely at all times and to utilize it fully. It is recommended to employ information channels appropriate to the intended users and to the nature of the information. This includes Notices-to-mariners, broadcasting of maritime safety information (MSI) (chapter 4.1) in the GMDSS, radio beacon almanacs in DGNSS type 7, type 27 and type 35 messages (chapter 3.1.3) and the world wide web including the IALA LISTS OF RADIONAVIGATION SERVICES.

Relevant information should, as a minimum, include:

* description of the service [for example which GNSS is supported], and its intended purpose, identification of the service provider, identification of where information relating to the service can be found and references to the relevant standards and specifications the service comply to (Ref.x)
* advice for safe use of the service and cautionary notes taking into account user receiving equipment. [For example receiver configuration regarding automatic beacon acquisition, activation of receiver integrity monitoring, audio alarm for integrity warning, receiver priority of augmentation systems, service performance in areas outside the declared service area, use of satellites not in view from beacons], (Ref x)
* technical parameters for each DGNSS beacon at the IALA LISTS OF RADIONAVIGATION SERVICES
* Achieved service performance for criteria explained in chapter 4.2
* the geographical service area where the performance criteria apply
* contact information for the service provider
* navigational warnings regarding service disruptions or scheduled interruptions

Individual Administrations are encouraged to publish service descriptions, including coverage predictions and system performance statistics.

IALA maintains the master list of radio beacon DGNSS stations on the Internet (http://www.iala-aism.org). Administrations are responsible for updating their own sections of the IALA master list.

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More info about ref. papers ?????.

## ANNXES

## ANNEX A Abbreviations

|  |  |  |
| --- | --- | --- |
| DGNSS | - | Differential GNSS |
| DOP | - | Dilution of Precision |
| GLONASS | - | Глоба́льная навигацио́нная спу́тниковая систе́ма |
| GNSS | - | Global Navigation Satellite System |
| GPS | - | Global Positioning System |
| HF | - | High Frequency (3 – 30 MHz) |
| IALA | - | International Association of Marine Aids to Navigation and Lighthouse Authorities |
| IEC | - | International Electrical Commission |
| IMO | - | International Maritime Organisation |
| IS | - | Integrity Monitoring Station |
| ITU | - | International Telecommunication Union |
| MF | - | Medium Frequency (0.3 – 3 MHz) |
| MSC | - | Maritime Safety Committee |
| MSI | - | Maritime Safety Information |
| PNT | - | Position, Navigation, and Timing |
| PVT | - | Position, Velocity, and Timing |
| RAIM | - | Receiver Autonomous Integrity Monitoring |
| RS | - | Reference Station |
| RTCM | - | Radio Technical Commission for Maritime Services |
| VRS | - | Virtual Reference Station Technique |

# ANNEX B DGNSS Broadcast Settings

It is recognised that certain reference station and integrity monitor threshold settings are vital to the proper performance of the DGNSS station. This Appendix (Table 3) lists some parameters that affect the DGNSS service and/or the service provider with the suggested range of settings..

The parameters are related to the classic approach of DGNSS technical implementation (ref.3.3.1) and should be seen as an example and starting point when defining settings of an individual DGNSS Broadcast Site. In order to gain further insight into the functions of the reference station and integrity monitor, service providers should consult the RTCM 10401.2, "*Standard for Differential Navstar GPS Reference Stations and Integrity Monitors (RSIM)*".

**Table 3 – DGNSS Broadcast Site Settings**

| Parameter | Recommended setting/ threshold | Interval | System Impact | |
| --- | --- | --- | --- | --- |
| To system provider | To user |
| **REFERENCE STATION** | | | | |
| Minimum number of satellites  Pseudorange corrections for three satellites are sufficient to generate a 2D horizontal position solution and correct the clock bias, assuming that the height is fixed and known. Generating the pseudorange corrections for four satellites will allow a user to also solve for the height and derive a 3D position. Since the user does not always know the correct input height, a 3D position solution using four satellites is preferred.  Accordingly, the RS minimum satellite setting should be four. | 4  (FI: 4) | n/a | * Causes an alarm * Possibly automatic switch to standby RS receiver/antenna | * Degration in position accuracy due to too few corrected SV  (poor HDOP) |
| Pseudorange Correction  Pseudorange corrections are generated by the RS to compensate for the delay that signals encounter as they pass through the ionosphere and troposphere, as well as clock and satellite ephemeris errors observed by the RS. The RS computes a pseudorange to the satellite and compares it with an absolute range based on its known surveyed antenna position. The RS measures the difference between the pseudorange and the absolute range and generates differential correction. Pseudorange corrections do not compensate for local errors in the user side like errors caused by multipath or receiver noise.  According to the experience gathered from service providers this alarm threshold value should be set for 100-600m. If the pseudorange correction exceeds this value, it may indicate a satellite problem. Too small threshold value may cause the RS to halt corrections for a satellite unnecessarily. Larger threshold values may result in slightly greater system inaccuracies reaching the user. | 100 – 600m  (FI: 140-1000m) | n/a | * Causes an alarm * Will set PRC and RRC values for a specific SV to "do not use" as described within RTCM SC104 | * Will drop "do not use" marked SV from position solution |
| Range rate correction  Range rate is determined by measuring the Doppler shift of the satellite signal carrier. The Reference Station calculates the rate of change for the pseudorange of all the satellites it is tracking. Range Rate correction was earlier a very effective way of mitigating Selective Availability (SA) dither.  This alarm threshold value is set for 0.5-10m/s. If the pseudorange correction exceeds this value, it may indicate that the satellite is actually moving erratically or has a clock problem. Smaller threshold values may result in the Reference Station halting satellite corrections unnecessarily. Larger threshold values may result in slightly greater system inaccuracies transmitted to the user.  Now when the SA is no longer used range rate corrections may be set to zero to eliminate the effects of random noise error generation as long as DGPS corrections are broadcasted within 30 to 60 seconds. | 0.5 – 10 m/s  (FI: 4 m/s) | n/a | same as above | same as above |
| Integrity Monitor feedback  IM feedback provides the RS with information on the accuracy of the DGPS broadcast. The threshold setting determines the maximum amount of time the RS will continue to transmit corrections after it received the last feedback from the IM. The feedback is done by sending a pre-set periodic "heartbeat" message (RSIM#20).  The IM ensures the accuracy of the broadcast by determining its own position with its internal GPS receiver and monitoring the MSK broadcast from the DGPS transmitter. The IM applies corrections to the raw GPS data and determines the computed position of its receiving antenna. If the computed position drifts outside of an allowable window based on the surveyed antenna position, the IM informs RS (via the heartbeat message) about the situation and the RS will set the header of all RTCM messages to "not working". If the heartbeat message is not received within the Threshold Value, then the RS will set the header of all messages to "unmonitored."  This alarm threshold value is set for 3s-12s. Smaller threshold values may result in excessive unavailability times at the site. Larger threshold values may result in unmonitored or poor quality corrections transmitted to the user. | 3 – 12 s  (FI: 12 s) | n/a | * Causes station health (header) to be set "unmonitored" * Possibly automatic switch to standby IM receiver | * Quality of corrections are unknown * Station should be used with caution and switch to another DGNSS site if available |
| Elevation angle (mask angle)  The purpose of the mask angle is to screen all satellites below a predetermined angle above the horizon. The RS will not use satellites below this level in its position and/or clock solutions. Most RS do track satellites below the mask angle if an open channel is available and can pass observables via an open communication port.  The mask angle is set at between 5 to 10 degrees. Operating at the lower end of the range will benefit the service provider as more useable satellites will improve availability, especially when some satellite(s) are unavailable. However, multipath, tropospheric and satellite observables errors tend to become more significant in degrading the user position solution as the mask angle is lowered (i.e. low elevation angle satellites are included in the solution). | 5 – 10 degs.  (FI: 7 deg) | n/a | - Improved availability at lower elevation angle setting | - Slight degradation of user position accuracy when operating at lower elevation angle setting |
| **INTEGRITY MONITOR** | | | | |
| RTCM correction age  RTCM correction age (measured in seconds) is the time difference between the time when a set of corrections is computed at the reference receiver and the time when the corrections are received within the IM’s DGPS receiver.  The correction age is directly related to the data rate used at the reference station. In normal operation the correction age is as follows:  (using a set of 9 SV and Message type 9-3)  - 50 Bit/s: this baud rate is not typically used  - 100 Bit/s: 6-7 sec  - 200 Bit/s: 3-4 sec.  Since S/A was set to zero, the resulting position accuracy at a user GPS receiver is no longer affected by correction ages less than a few minutes. The remaining errors within the GPS signal like ionosphere and troposphere change slowly in time.  Thus in an environment where S/A is set to zero, correction ages above the given threshold will primarily have an impact on the integrity functionality of a reference station. Taking into account the integrity requirement with a TTA of 10 seconds to inform the user, the correction age should not exceed this value significantly. Due to the method used to calculate the correction age, high settings (>10s) may need to be used in some applications to avoid frequent alarms.  Correction age interval is a time period over which correction ages are observed and averaged. The IM is continuously monitoring the correction age interval so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 1–30 seconds. Longer intervals result in slower detection of excessive pseudorange correction age. Shorter intervals add processing overhead to the IM. | 10 - 30 s  (FI: 10-30 s) | 1 – 30 s  (FI: 60-100) | * Causes warning or alarm * Possibly automatic switch to standby RS receiver or transmitter | * If correction age is higher than 10 sec it will affect TTA performance * Switch to another DGNSS site if available |
| Message error ratio  During data link reception, message error ratio is calculated as the number of bad bits divided by the total number of bits.  The value is set at 0.1. A higher ratio is an indication that there may be a problem with the data link. Lower threshold values hold the transmitter to a higher standard of modulation. When one of the 30-bit words in a message frame fails the parity test the bits for the entire message are considered bad.  Message error ratio interval is a time period over which data is observed to use for calculating the message error ratio. There should be little or no extra processing overhead in the IM based on this interval because the MSK receiver is continuously monitoring the message error ratio. If the value is out of tolerance an alarm is generated.  This value is set at between 10–60 seconds. Longer intervals result in slower detection of data link problems. Shorter intervals add processing overhead to the IM.\* | 0.1 (10%)  (FI: 1-15) | 10 - 60 s  (FI: 60-100 s) | * Causes warning or alarm * Possibly automatic switch to standby RS receiver or transmitter | * Switch to another DGNSS site if available |
| Beacon SNR  The signal-to-noise ratio (SNR) is the minimum acceptable ratio of the amplitude of the data link signal to the amplitude of the ambient noise expressed in dB.  This value is set at >7 dB. If the near-field SNR falls below this value, the data link signal may not be of sufficient quality that the user’s receiver can properly decode the broadcast.  Beacon SNR interval is a time period over which data is observed. The Integrity Monitor is continuously monitoring the SNR so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–30 seconds. Longer intervals result in slower detection of data link problems. Shorter intervals add processing overhead to the Integrity Monitor.\* | > 7 dB  (FI: 1-17 dB) | 10-30 s  (FI: 60-65 s) | * Causes warning or alarm * Possibly automatic switch to standby RS receiver or transmitter | * Will reduce coverage area |
| Beacon signal strength  The beacon signal strength is a measure of the near field signal strength expressed in dB (µV/m).  This alarm threshold value is set 4dB-7dB bellow the n0minal value. If beacon signal strength falls below the threshold, the data link signal may not be at a level sufficient for the user’s receiver to properly decode the broadcast.  Threshold value is set by the service provider according to site specific measurements.  Beacon signal strength interval is a time period over which data is observed. The Integrity Monitor is continuously monitoring the Beacon signal strength so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–60 seconds. Longer intervals result in slower detection of data link problems. Shorter intervals add processing overhead to the Integrity Monitor.\* | 4 to 7dB bellow nominal  (FI: 1-100 dB) | 10 – 60 s  (FI: 60-65 s) | * Causes warning or alarm * Possibly automatic switch to standby RS receiver or transmitter | * Will reduce coverage area |
| Minimum satellites  This setting specifies the minimum number of satellites with accompanying pseudorange corrections required to generate a valid 3D differential position solution. The integrity monitor should be set to detect the PRCs of at least 4 satellites. When the visible satellite constellation goes below this threshold, an internal alarm may be sent to the service provider.  This value is set to alarm when less than 4 satellites are visible. | 4  (FI: 3-4) | (FI: 30-65) | * Causes an alarm * Causes station health (header) to be set "unmonitored" only if no position fix can be performed due to low number of SV | * Station should be used with caution and switch to another DGNSS site if available |
| SV Interval (Difference of used satellites)  This parameter is not described in REF (3). Some manufacturers, however, have implemented this setting. This interval is basically a time period over which data is observed, specifying the maximum time delta between correctors for use in a solution computation. The Integrity Monitor is continuously monitoring the SV interval so there should be little or no change in processing overhead. If the value is out of tolerance an alarm is generated.  Service providers that employ this parameter typically set this value from 0-10s |  | 0 to 10 s | * Causes an alarm * Causes station health (header) to be set "unmonitored" * Possibly automatic switch to standby IM receiver * Possibly automatic switch to standby RS receiver | * Station should be used with caution and switch to another DGNSS site if available |
| HDOP  The IM uses horizontal dilution of precision (HDOP) to measure the current quality of the constellation geometry as it relates to triangulation of the pseudoranges.  This value is set at <7.5. Low HDOP numbers indicate good constellation geometry. High HDOP values indicate poor constellation geometry. If the HDOP is higher than the threshold, the validity of the corrections becomes uncertain and the site’s pseudorange generation must be suspended.  HDOP interval is a time period over which data is observed. The IM is continuously monitoring the HDOP so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–30 seconds. Longer intervals result in slower detection of HDOP data problems. Shorter intervals add processing overhead to the Integrity Monitor. | < 7.5  (FI: 4-6) | 10 – 30 s  (FI: 30-35 s) | * Causes an alarm * Causes station health (header) to be set "unmonitored" * Possibly automatic switch to standby IM receiver | * Station should be used with caution and switch to another DGNSS site if available |
| Absolute Horizontal Position  Also referred to as Horizontal Position Error. The IM applies pseudorange corrections received over the data link to the pseudoranges generated by its internal GPS receiver. It uses these corrected pseudo ranges to generate a DGPS corrected position. The radial error in that position in relation to the surveyed position is the 2D position Error.  This value is set at between 5-10 meters. Smaller threshold values may result in greater site unavailability time – more time out of tolerance. Larger threshold values may result in greater system inaccuracies transmitted to the user.  2D position interval is a time period over which data is observed. The IM is continuously monitoring the 2D position interval so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–30 seconds. Longer intervals result in slower detection of system position accuracy problems that may originate from a variety of sources. Shorter intervals add processing overhead to the IM. | 5 – 10m  (FI: 10 m) | 10 – 30 s  (FI: 20 s) | * Causes an alarm * Causes station health (header) to be set "unmonitored" * Possibly automatic switch to standby IM/RS receiver | * Station should not be used * Switch to another DGNSS site if available |
| Pseudorange residual (PRR)  The IM applies pseudorange corrections received over the data link to individual pseudoranges generated by its internal GPS receiver, and then compares them to the known surveyed position of its own antenna. The resulting value is the Pseudorange residual.  This value is set at <12 meters. Smaller threshold values may result in the IM telling the RS to stop correcting satellites unnecessarily. Larger threshold values may result in greater system inaccuracies transmitted to the user.  Pseudorange residual interval is a time period over which data is observed. The IM is continuously monitoring the Pseudorange residual interval so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–30 seconds. Longer intervals result in slower detection of pseudorange accuracy problems. Shorter intervals add processing overhead to the Integrity Monitor. | < 12m  (FI: 100-150 m) | 10 – 30 s  (FI: 30-65 s) | * Causes an alarm * Will set PRC and RRC values for a specific SV to "do not use" as described | * Will drop "do not use" marked SV from position solution |
| Range rate residual  The difference between the most recent range rate correction received and the current pseudorange rate measured at the IM.  This value is set at <10m/s. Motion faster than the threshold value may indicate a problem with the satellite actually moving erratically or may indicate a satellite clock problem. Smaller threshold values may result in the IM telling the RS to stop correcting satellites unnecessarily. Larger threshold values may result in greater system inaccuracies transmitted to the user.  Range rate residual interval is a time period over which data is observed. The IM is continuously monitoring the Range rate residual interval so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–60 seconds. Longer intervals result in slower detection of excessive Reference Station Range Rate correction values. Shorter intervals add processing overhead to the Integrity Monitor. | < 10 m/s  (2-5 m/s) | 10 – 60 s  (FI: 30-65) | * Causes an alarm * Will set PRC and RRC values for a specific SV to "do not use" as described | * Will drop "do not use" marked SV from position solution |
| Low UDRE  UDRE is a one-sigma estimate of the pseudorange correction error due to ambient noise and residual multipath. Basically, every PRC generated by the RS has a "reported" UDRE value in it and when the IM uses the PRC it tries to determine if the "reported" UDRE is correct. If the IM determines that the reported UDRE is set to a value "LOWER" than it should be, then we have a "Low UDRE" condition.  This value is set at 1m-100m. Using higher UDRE threshold values may allow multipath and receiver noise errors to impact the user. Lower values may result in excessive site unavailable time.  Low UDRE interval is a time period over which data is observed. The IM is continuously monitoring the UDRE so there should be little or no processing overhead change. If the value is out of tolerance an alarm is generated.  This value is set at between 10–30 seconds. Longer intervals result in slower detection of problems. Shorter intervals add processing overhead to the Integrity Monitor. | 1 – 100m  (FI: 100-101m) | Please consult manufacturer for settings  (FI: 100-600 s) | * Causes an alarm * Cause station health (header) to be set "unmonitored" * Possibly automatic switch to standby IM/RS receiver | * Switch to another DGNSS site if available |
| Elevation angle (Mask Angle)  The mask angle screens all satellites below a predetermined angle above the horizon. The IM will not use satellites below this level in its position and/or clock solutions.  The mask angle is set at between 5 to 10 degrees. Operating at the lower end of the range will benefit the service provider as more useable satellites will improve availability, especially when some satellite(s) are unavailable. However, multipath, tropospheric and satellite observables errors tend to become more significant in degrading the user position solution as the mask angle is lowered (i.e. low elevation angle satellites are included in the solution). | 0 – 10 deg.  (FI: 7 deg.) | n/a | - Optimal monitoring of the broadcast when setting is identical to the RS’s | - Optimal broadcast service |

\* Note: The Message Error Ratio, Beacon SNR and Signal Strength intervals are similar to moving window averages - you are making calculations every second no matter what the Interval is, but if during, or for an entire Interval the value goes beyond the Threshold, an alarm is generated. Shorter Intervals show changes more quickly, and Longer Intervals show changes more slowly (because it takes a greater number of changes to raise the "average").

## ANNEX C Calculation example for DGNSS signal availability and continuity in areas with multiple DGNSS signal reception

For this example , the service area is designated to include the area within 100nm outside the coastal baseline and the sea area inside the baseline to a distance of 20nm from the baseline. The minimum required signal field strength is found to be 20uV/m. There are 12 beacons providing signals in such a way that:

* 25% of the service area receive sufficiently strong signals from only one beacon
* 50% of the service area receive sufficiently strong signals from two beacons
* 25% of the service area receive sufficiently strong signals from three or more beacons

Signal availability is measured by far field monitor and by means of recording outages on individual beacons from the centralized beacon alarm-and-management system. The average MTBF for the 12 beacons was 2 failures/year = 4380 hours. Instances where accuracy and correction age was not within specifications were considered failures. The average time to restore for the 12 beacons was 2 days = 48 hours.

Using these figures and the availability equation for a single transmitter, the average signal availability for each of the 12 beacons is 1 - 2\*48/4380 = 97,81%.

As such the average service availability within the service area is 0,25\*(1-(1-0,9781)) + 0,5\*(1-(1-0, 9781)2) + 0,25\*(1-(1-0, 9781)3) = 99,42%, which is slightly below requirement.

The average continuity is C = 1-CTI/MTBF =1-0,25/4380 = 99,994%, which is well above requirement.

## ANNEX D Example link budget

|  |  |  |
| --- | --- | --- |
|  | Signal | Noise |
| Transmitter RF power |  |  |
| Antenna combiner, tuner and feeder losses |  |  |
| Antenna gain |  |  |
| Propagation loss (ITU-R P.369-9) |  |  |
| Skywave fading margin |  |  |
|  |  |  |
| Atmospheric noise (ITU-R P.372-10) |  |  |
| Precipitation static noise |  |  |
| Man-made noise |  |  |
| Interference |  |  |
|  |  |  |
| Receiver antenna gain and feeder loss |  |  |
| Receiver sensitivity |  |  |
| Minimum SNR |  |  |
|  |  |  |
|  |  |  |

## ANNEX E System Availability

During the navigation in harbour entrances, harbour approaches and coastal water (see IMO A.1046(27)) the performance of user’s receiver should be measured against integrity for a given accuracy level. That means that the performance of user’s receiver is measured against realized positioning, achieved position accuracy, and assessed position accuracy (integrity). In consequence, the system availability of DGNSS depends on DGNSS signal availability as well as GNSS signal and system availability in equal measure.

* A precondition for position determination is an ensured GNSS signal availability at user site. The GNSS system availability considers the ability of the receiver to determine the position in case of ensured GNSS signal availability. Due to receiver malfunctions covering hardware errors and effects coming from disturbed GNSS signals it should be expected that the GNSS system availability is smaller than the GNSS signal availability:

 with

.

The decrease of availability induced by GNSS equipment is modelled by .

* Assuming that only a DGNSS based positioning can meet the desired accuracy level and ensures the required integrity monitoring, the DGNSS system availability can only be achieved if in case of GNSS and DGNSS signal availability the GNSS/DGNSS sensor is able to determine and assess the position.

 with

.

The decrease of availability induced by combined GNSS/DGNSS equipment is modelled by .

Due to occurrence of spatial decorrelation effects and performance differences in applied GNSS/DGNSS receivers it should be expected that the DGNSS system availability estimated at a monitor site differs from user’s DGNSS system availability.

.

The reliability of GNSS and DGNSS related availability statements can be improved, if more than one monitoring site is used for the evaluation of GNSS as well as DGNSS signal and system availability. This would allow the application of enhanced error detection and separation methods and reduces the influence of single sensor failures on the evaluation results. For instance, the missing of GNSS measurements at a services site can be caused by a complete outage of GNSS, by local disturbances of signal propagation (e.g. interferences) or by malfunction of the GNSS sensor used for data acquisition. Using several GNSS sensors for service provision and monitoring the outage of single sensors can be over bridged to reduce the influence of single sensors on system availability.

If the availability is related to a single measuring location and time point, the availability describes the momentary status of DGNSS service usability for positioning. Analysing the availability over an operation period at one or more locations is more an operational task of service providers to characterize the DGNSS service availability by experimental evaluated probability statements (see chapter 4). Due to dependencies between GNSS and DGNSS system availability a GNSS system availability of exactly 99.8% results in the fact that a DGNSS system availability of 99.8% will be impossible. Therefore service providers are requested to prove the fulfilment of the DGNSS signal availability (99.8%) in minimum. Furthermore, the ability of a DGNSS service to generate warnings within 10 s in cases of malfunctions, non-availability and discontinuity should be experimental evaluated by the service provider. Additionally, service providers are encouraged to publish the measurement and analysis procedures applied for monitoring and evaluation of DGNSS signal and system availability. In safety-critical areas with high risk level a monitoring and evaluation of DGNSS system availability is considered as suitable approach to enhance the safety of DGNSS based positioning.

## ANNEX F MF Antenna Performance

The overall performance of a transmitting antenna in the MF band is characterized by following technical items:

* effective antenna height and radiation resistance depending from antenna type and size (height, width, guy wires, if used, etc.);
* antenna efficiency, total antenna resistance and earth resistance;
* service range of the station as a function of transmitter output power;
* insulation resistance; and
* influence of salt spray, dirt, ice and wind load .

To plan a DGNSS site with a planned range at a given field strength level (typically 50, 75 or 100 µV/m) it is essential to have a useful combination of transmitter output power and an MF antenna which ensures an adequate antenna efficiency. The antenna efficiency depends mainly on two factors:

* the radiation resistance which depends on the shape and height of the antenna (expressed by the efficient electrical height of an antenna (Heff); and
* the total series resistance at the antenna input which is a sum of losses within the loading and tuning coil as well as the losses in the earth.

The following part will provide short background information about the interrelation of the physical antenna height, effective antenna height, the radiation resistance (Rrad), and the antenna efficiency η. The antenna (or power) efficiency η is given by



and

 - input power

 - radiated power

 - antenna current at antenna input

 - total series resistance of the antenna resonant circuit

 - radiation resistance

 - resistance of ATU and loading coil, (RL  typically between 2 and 7 Ω)

 - earth resistance (RE typically between 3 and 9 Ω)

**Error! Reference source not found.** presents the antenna efficiency for some typical values of the total resistance.

**Table 2** **Antenna efficiency for some typical values of total resistance**

|  |  |  |
| --- | --- | --- |
| RE [Ω] | earth resistance and  ground conductivity | η [%]  for an antenna with a radiation resistance of 1 Ω and RL=7 Ω |
| 3  5  7  9  11  13 | good (low)  good  acceptable (medium)  acceptable  poor (high)  poor | 9.0  7.7  6.6  5.8  5.3  4.7 |

Rrad (Heff) is an inherent property of the antenna, whereas η also depends on earthnet and ground conductivity. An impedance meter allows to measure the total resistance Rtot and to determine the antenna efficiency η for a real installation.

1. As defined in IMO 915 (22) & IMO 1046 (27) [↑](#footnote-ref-1)
2. The Journal of Navigation (2005), 58, p. 207-225 [↑](#footnote-ref-2)