|  |
| --- |
| IALA Guideline |

1???

Future of Radiobeacon DGPS/DGNSS

Edition 1.0

Document date

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

|  |  |  |
| --- | --- | --- |
| Date | Page / Section Revised | Requirement for Revision |
| month/year approved by Council | aaaaa | aaaaaa |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

1 INTRODUCTION 5

1.1 History of Marine Radiobeacon DGPS/DGNSS 5

1.2 Maritime requirements and standardisation 5

2 Sources of position integrity 6

2.1 Conventional non-satellite based navigation 6

2.1.1 How does conventional navigations assist with identifying a GNSS Integrity issue 6

2.1.2 New and emerging bridge equipment. 6

2.1.3 Advantages of conventional navigational practice 6

2.1.4 Disadvantages 6

2.1.5 Differences in equipment 7

2.2 MSI 7

2.3 Sbas 7

2.4 RTK and PPP 8

2.5 Radiobeacon 9

2.6 RAIM 9

2.6.1 Main RAIM features 10

2.6.2 RAIM in maritime regulation 11

2.7 Commercial Services 13

3 Future options 13

3.1 Maintain GPS L1 corrections 13

3.2 Provide corrections to multiple GNSS and/or GNSS frequencies 14

3.3 Discontinue services 15

4 Future development 15

4.1 Ranging Mode 15

5 Key points to consider 17

List of Tables

Table 1 Example of a table with the significant information in the first column **Fel! Bokmärket är inte definierat.**

Table 2 Example of a table with the significant information in the first row **Fel! Bokmärket är inte definierat.**

Table 3 Example of a table with coloured rows **Fel! Bokmärket är inte definierat.**

Table 4 Example table 19

List of Figures

Figure 1 Example figure caption **Fel! Bokmärket är inte definierat.**

Figure 2 Another example figure caption **Fel! Bokmärket är inte definierat.**

List of Equations

Equation 1 Geographical range **Fel! Bokmärket är inte definierat.**

Equation 2 Theory of Special Relativity **Fel! Bokmärket är inte definierat.**

# INTRODUCTION

IALA radiobeacon services have been operating for many years, providing a harmonised service in many parts of the World. However, many administrations are now considering the on-going requirement for the service and as such whether to update ageing equipment. Changes in technology mean administrations [have to] face choices on the way forward which include retaining the same functionality [or recapitalisation], introducing new technology or discontinuing the service [discontinuing the radiobeacon service].

This document aims to provide guidance to national administrations on which aspects and questions to consider when assessing the future of the service. It provides an overview of available options and other aspects which may assist in the decision process.

## History of Marine Radiobeacon DGPS/DGNSS

The IALA DGNSS beacon system was developed in the 1990s and systems were installed in many countries over the period 1991-2000. The system was adopted as the international maritime standard for providing differential corrections for Global Navigation Satellite Systems (GNSS).

Marine radiobeacon DGPS was first developed to counter Selective Availability (SA), a deliberate error added to the civilian GPS service to degrade accuracy for civilian users, but which the United States discontinued in May 2000. As such, the original driver was accuracy improvement, however since SA’s removal in most locations the main issue to be addressed is integrity however the accuracy improvement remains important for some users.

While IALA supports the use of radiobeacon DGNSS where considered appropriate by the national competent authority under SOLASand as such it is not provided everywhere.

## Maritime requirements and standardisation

IMO Resolutions A.915 (22) [ref] and A.1046(27) [ref] provide maritime performance requirements, albeit it is recognised that A.915 is in need of review and update. Maritime beacon requirements are consolidated in IALA Guideline No. 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz [ref].

It is recognised that today’s stand-alone [un-augmented] GNSS are often sufficient to meet all but the most stringent accuracy requirements listed in Resolution A.915 and A.1046, the open services provided by the constellation GNSS service do not provide integrity information to the user. However they are not able to meet the integrity requirement taking into account the risk within these resolutions.

IMO receiver performance standards and the IEC receiver test specifications make provision for the use of marine radiobeacon DGNSS and Receiver Autonomous Integrity Monitoring (RAIM). While mentioned in the IMO receiver performance standards, marine radiobeacon DGNSS is not a carriage requirement. However, some classification societies require a DGPS receiver for certain classes.

IALA recognises the important need to inform the mariner, in a clear and timely manner, if GNSS become unreliable. This guideline considers different options that can support this by providing integrity at system level or user level. The differences between these integrity levels can often confuse and to aid understanding further information on integrity is captured in Annex X.

Most shipbourne receivers fitted today are radiobeacon DGPS enabled with many also capable of using SBAS information. There is, however, no SBAS type approval currently in place and therefore mariners should exert caution on the use of SBAS with non-approved receivers.

When assessing vessel operations the age of navigation equipment onboard a vessel must be a considered. It is recognised that bridge equipment will only be updated to the latest IEC standard when the ship owner considers it necessary and as such, the equipment may not be providing the latest functionality.

# Sources of position integrity

New text here that explains integrity

## Conventional non-satellite based navigation

SOLAS Chapter V Chapter 19 specifies carriage requirements for shipborne navigation systems and equipment. The requirements are based on tonnage and build date and therefore apply to existing vessels, with each item being associated with the relevant IMO performance standards.

This includes: gyro/magnetic compass, speed log, echo sounder & radar. In this context, we can consider the use of these systems as conventional navigation.

All vessels should be navigated by using all available means, which includes the use of both conventional and additional equipment (where specified) such as ECDIS and GNSS. All these systems have potential errors and tolerances and should be cross checked with other equipment. STCW ECDIS training requires cross checking of position with additional manual position fixes such as by visual bearings or radar. Other methods of verifying position include parallel index on radar and visual situation awareness from observing navigation marks adjacent to the vessel, such as a buoyed channel, lighthouse, sector lights or significant navigational features.

### How does conventional navigations assist with identifying a GNSS Integrity issue

In accordance with best practice, integrity monitoring of all systems is an intrinsic element of the process of navigation. A fault could emerge in the gyro compass as readily as the ECDIS or GNSS system.

A GNSS integrity issue would be highlighted by a difference in position obtained by conventional means when compared with a position obtained by GNSS. A fix could be obtained by visual compass bearings, radar ranges and bearings, parallel index techniques, visual observations, depth from echo sounder, DR and EP. Traffic flow, buoyage, ferry routing, fishing vessel concentrations, windfarm locations, oil rigs and offshore structures are all factors to be taken into account under the heading of good seamanship and situational awareness.

### New and emerging bridge equipment.

Multi-constellation receivers: In addition to GPS, further GNSS constellations have been established which are in some cases, being integrated within a single receiver unit. This has advantages and disadvantages for the mariner. In one respect, the mariner now has even more information to process and manage, while from a different perspective, there is now a greater opportunity to verify position integrity by comparing positions obtained from different constellations , recognising that such comparison will identify single constellation failures and not external influences such as jamming. The origin of the position data and the output position provided to the user needs to be very clear.

### Advantages of conventional navigational practice

For SOLAS vessels, the equipment is mandated and type approved and therefore guaranteed to be available to the mariner with a specified performance standard.

Training is mandated through STCW and therefore all bridge personnel are comprehensively trained in the operation of these core systems and techniques. Training in GNSS denial techniques is recommended.

These onboard tools are independent of external networks or radio signals. They are therefore less susceptible to interference, jamming or cyber attack.

### Disadvantages

Skills and Training: The skills required to navigate by conventional means are built up over time and through formal STCW qualifications. There is evidence to suggest that bridge teams can become over reliant on GNSS, particularly when coupled with ECDIS, leading to skill fade and a lack of opportunity to practice conventional navigation techniques. Despite cross referencing being formally mandated within ECDIS training, failure to consistently follow procedures will mean that an error in GNSS will not be immediately identified.

Not all vessels will be fitted with ECDIS, but virtually all will have GNSS and many will have ECS, with various levels of training, standardisation and charting. The need for a thorough approach to navigation remains in all cases, including cross referencing position fixing systems, particularly where GNSS is used as the primary means.

### Differences in equipment

Many mariners frequently change from ship to ship and company to company. Manufacturers present information in different ways and unfamiliarity with the equipment may mean that the mariner may not recognise an alarm or indication when it occurs even when a GNSS unit itself is advising of an integrity issue. This could be a RAIM indication or some other failure and applies similarly to ECDIS and other navigation equipment.

Note: ECDIS is not mandated for existing cargo ships of less than 10,000 grt, though many vessels will have ECS. Fishing vessels and small leisure craft will have a variety of often non-type approved equipment.

## MSI

All ships are required to use type approved equipment necessary to receive navigational warnings and Notices to Mariners issued by authorities. Whenever disturbances to GNSS occur, have not been warned through NtoM, and are significant, users will report (required to report? SOLAS?) this to VTS or coastal radio stations, assessed by the MSI-authority and navigational warnings is issued. The delay between the occurrence of disturbances and the issuance of a navigational warning is unpredictable. In most cases such warnings will be delayed several hours and only disturbances that have major impact on ships navigation can be expected to be reported. Warnings are useful only if the disturbances are still occurring after the warning has been received. Additional systems used by authorities to monitor GNSS performance in the sea area may be utilized to detect disturbances and issue more precise navigational warnings with shorter delay. Navigational warnings include all ships and coverage is not limited. It is expected that delays in provision of navigational warnings will be reduced in the future as this service is part of the IMO E-navigation concept. Exact timelines for this is however uncertain.

NtoM provide advance warning of loss of integrity of GPS signals occurring from pre-planned activities such as military exercises.

## Sbas

The performance of GNSSs can be improved by regional Satellite-based Augmentation Systems (SBAS). SBAS improves the accuracy and reliability of GNSS information by monitoring GNSS signals, computing and providing corrections. SBAS enabled receivers are able to receive these differential corrections and integrity messages, and include these as an input to the position calculation. SBAS information is typically broadcasted over the covered area using geostationary satellites that serve as an augmentation, or overlay to the original GNSS signal, as identified in IALA Guideline 1152, on which an SBAS Maritime Service based on signal in space (SiS) is introduced. However, SBAS corrections and integrity messages can be also transmitted by different by different channels, such as the internet , or specific infrastructures (MF-radiobeacon and AIS) as explained in IALA Guideline G1129.

Originally SBAS was developed for aviation users; their use in the maritime domain is increasing enhancing the marine safety for harbour approaches and coastal navigation. IMO recognize GNSS as part of WWRNS only for ocean areas where required performance levels can be achieved without using augmentation systems [e.g. IMO Circular SN.1/Circ.329]. In order to achieve the levels of performance required in IMO Resolution A.1046(27) for coastal areas and harbour approaches, augmentation of GNSS is needed.

It is important to mention that the introduction of SBAS corrections and integrity information could follow a short and medium time strategy for it deployment in the maritime ecosystem. It was studied how the SBAS data can be used via existent maritime service provider’ AtoN. Thus, a feasible strategy, to bring the benefits of SBAS into the maritime ecosystem, may be:

* In the short term, SBAS corrections can complement DGNSS network. As it is introduced in IALA G1129 “The retransmission of SBAS corrections using MF-radiobeacons and AIS”, SBAS messages can be used for the generation of local area corrections in RTCM format, which brings a solution compatible with the user equipment already deployed.
* Then, the medium term solution would be focus in the developing of a maritime service, based in the SBAS Signal in Space (SiS), according to IMO Res.1046 operational requirements. In fact, at the time of writing this Guideline the European GNSS Agency (GSA) is working on the development of an EGNOS maritime service that will be declared in a near future.
* In the long term, an SBAS maritime service aligned with the operational requirements of IMO Res.915, based on SiS and GNSS multi-frequency and multi-constellation, could be foreseen. Such a service will bring substantial benefits in the accuracy, integrity and coverage of the augmented GNSS signals.

IMO Resolution A.1046(27) requires that governments or organizations owning and operating the recognized radionavigation systems should state formally that the system is operational and available for use by merchant shipping. Some Governments owning SBAS as the European Commission, Australia or recently the Republic of Korea are supporting the operational use of SBAS in the maritime areas. IALA is developing an approach that will allow augmentation service providers to recognise a maritime user and encourage Governments in this recognition.

The development of the tailored SBAS service SiS for the maritime community shall include:

* The definition of a Service Provision Scheme , a document that identifies the involved stakeholders, its roles and responsibilities. But also it identifies the communication channels, and the information that shall be transmitted between actors, and how it is consumed by the users.
* The development and deploy of the Service Provision , which includes the set-up of the infrastructure that support the service provision. Then, the provision of SBAS safety related information can be integrated in MSI services, and GNSS corrections can be used by the mariners.
* The elaboration of SBAS guidelines for GNSS receivers manufacturers, and then The development of the SBAS type-approved receiver which considers SBAS satellite selection criteria.

SBAS are local augmentation systems, so the maritime services based on SBAS will have a limited coverage area. Then,The SBAS service coverage area for the maritime user should be notify by the SBAS competent government or organisation.

## RTK and PPP

Real-Time Kinematic (RTK) and Precise Point Positioning (PPP) are ground-based high accuracy GNSS augmentation systems that have been used in surveying applications for many years.

RTK is a short-range relative positioning technique providing centimetre-level accuracy based on the common processing of code and carrier phase measurements collected at reference station and user site. National surveying and mapping authorities and private companies operate RTK networks in many countries around the world. RTK correction information is usually distributed to users via VHF/UHF radio modems or through mobile Internet.

PPP is a global positioning technique that requires real-time precise satellite orbit and clock corrections derived from a globally distributed geodetic network of GNSS reference stations. PPP provides absolute positioning at centimetre to decimetre accuracy level without local reference station as used in RTK. PPP service providers broadcast corrections to subscribed users via geostationary communication satellites or the Internet.

RTK and PPP were originally developed without integrity focus. However, maritime applications such as dredging, docking, harbor maneuvers or port approach requiring high accuracy can now rely on RTK and PPP to also provide them with integrity in two ways.

One way is by providing redundant measurements, where the user’s position can be simultaneously determined based on independent correction sources. Thus the correctness of the trusted vessel position can be validated.

The other way is through additional dedicated integrity messages derived from the RTK or PPP ground infrastructure. Satellite and position integrity flags can be transferred to the users along with the corrections.

For example, AIS/VDES Application Specific Messages incorporating RTK/PPP integrity information have already been defined and used in research projects. Standardisation of such novel messages is underway.

References

RD-01 RTCM 10402.3 RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.3 with Amendment 1 (May 21, 2010)

RD-02 RTCM 10403.3, Differential GNSS (Global Navigation Satellite Systems) Services - Version 3 (October 7, 2016)

RD-03 NAVGUIDE 2018 Marine Aids to Navigation Manual

RD-04 IALA Guideline 1127 Systems and services for high accuracy positioning and ranging

## Radiobeacon

o The Integrity Monitor part of the system monitors the health status of satellites and MBDGPS broadcast signals as well as signal content (the accuracy of DGPS Reference Station-generated corrections). When monitored parameters exceed specified thresholds, the Integrity Monitor will generate appropriate alarms.

o The digital correction signal (containing differential corrections and integrity data) is broadcast locally over ground-based transmitters of, typically up to a 200 NM range. These transmitters operate at long/medium wave radio frequencies between 283.5 kHz and 325 kHz.

\*Radiobeacons provide a signal that is used to modify the position output of the navigation receiver in ships in the beacons coverage area. The DGNSS system and signal format was developed in the early 1990s and have limited ability to ensure the signal source, the radiobeacon, is authentic or that is has not been manipulated. Examples of risks are false beacons, GNSS spoofing local to a DGNSS beacon may cause the beacon to transmit erroneous corrections or false integrity alarms to all ships using DGNSS in the coverage area.

o MBDGPS services have been implemented and in existence for over 20 years and continue to provide position corrections to the mariner in some of the busiest and most used waterways in the World; however, since selective availability was set to zero in 2000, in most regions single frequency GPS can now provide sufficient position accuracy to meet all but the most stringent IMO accuracy requirements ref. Resolutions A.1046 and A.915. GNSS do not however, provide integrity in their own right: this is where MBDGPS is still a good source of real time system level integrity for maritime users.

Implementation details are available in Guideline 1112 and 1129.

The beacon service is supported by the IMO as a harmonised solution with an agreed spectrum. See Recommendation 121.

## RAIM

The origin of RAIM algorithms lies on the fact GNSS do not broadcast any information about the integrity of their signals. It is possible for a GNSS satellite to broadcast incorrect information that will cause errors on the users position, but there is no way for the receiver to determine this using standard techniques. Every RAIM algorithm family use redundant information to produce several GNSS position fixes and compare them, and a statistical function determines whether a fault can be associated with any of the signals. That is, when more satellites are available than needed to produce a position fix, the extra pseudoranges should all be consistent with the computed position. A pseudorange that differs significantly from the expected value may indicate a fault of the associated satellite or another signal integrity problem (e.g., Ionospheric interference).

RAIM as a term does not refer to a single algorithm or type of algorithm, there are several RAIM implementations based in different hypotheses.

There are nominally two types of classical RAIM, namely:

 Measurement Rejection Approach (MRA): MRA use Fault Detection and Exclusion (FDE) techniques to ensure that only valid measurements are used in the navigation solution and the respective protection levels computation.

 Error Characterisation Approach (ECA): It consists on computing Protection Levels (PLs) based on the characterization of the measurement errors; these techniques do not necessarily require FDE techniques.

However, RAIM algorithms ware developed for aviation GNSS receivers and although RAIM algorithms are implemented almost universally in maritime GNSS receivers, there is currently no IMO or IEC specifications or standards which say how RAIM should operate in the maritime environment (see section 2.6.2 for further information about RAIM in maritime regulation). There is therefore a need for the development of maritime specific RAIM algorithms, as RAIM algorithms developed for aviation are not suitable for the maritime environment.

Open questions on RAIM:

• There was general consensus that the RAIM standards are currently not adequate and should be developed in IMO. It would require an IMO request for a defined algorithm before the IEC is able to develop one, therefore there maybe a role for IALA to provide a suitable request.

• There was a discussion regarding the differences between maritime and aeronautical RAIM which concluded that the RAIM algorithms are generally similar, therefore the operational environment is already defined for aviation, but there is significant work required to understand the maritime operational environment (noise, multipath etc) which would need to be considered in the definition of a suitable algorithm.

• It was further noted that the evolution of maritime user requirements could lead to changed in the algorithm used. Currently algorithms are designed to identify single failed satellites, however with the move to multi-constellation receivers, a new algorithm may be needed to ensure efficient use of all available satellites and frequencies. Advanced RAIM and maritime M-RAIM were mentioned as future developments.

### Main RAIM features

The term Classical RAIM refers to fully autonomous algorithms which can implement only one, a combination or all the following capabilities: Fault detection, Fault exclusion and Protection Level computation. Depending on the selected algorithm, its capabilities and assumptions it has different advantages and drawback. Currently the majority of RAIM algorithm implemented in maritime receivers are based on the classical aviation approach, which are bases in some hypothesis that may be not suitable for maritime domain. The following list summarises the main advantages and drawbacks that classical RAIM algorithms have:

* **Advantages**
* It provides integrity worldwide. Since the algorithm is implemented in the user receiver and does not need (most of them) any external information they could provide integrity information to the user anywhere, if the algorithm hypothesis are met.
* It does not necessarily require external infrastructure.
* It provides integrity at user level if environment is well characterised. Both main RAIM families requires a correct characterization of the error components or detection thresholds to really provide integrity.
* **Drawbacks**
* The Classical RAIM algorithms do not handle several simultaneous faulty measurements. The use of more than a single constellation will have a positive impact on positioning performance. However, with an increased number of satellites, the number of faults that need to be considered increases as well to ensure the same integrity level. Therefore, as RAIM considers nominal conditions, the probability of multiple simultaneous failures might be not neglected in the case of using two or more constellations and it needs to be reflected in the integrity risk allocation.
* RAIM algorithms provides generally poor performances. They are based in a priori information about the error components or the environment. They must be conservative in order to provide the integrity required for any user under any condition, which imply poor performances for very conservative estimations or a safety risk if the characterisation is deficient. Moreover, this values are fixed in conventional RAIM so cannot be updated. A classic example of conservative fixed parameter is the ionospheric estimation which is provided in Classical GPS RAIM implementations by the Klobuchar ionospheric model. Although this model works very well under normal ionosphere conditions, it is not really accurate under severe ones.
* Error overbounding models shall be well characterized for maritime environment to provide the integrity required. Almost every RAIM algorithm are based in overbounding error models for their calculations, if these models are not well characterised it may imply a safety risk.
* The Classical RAIM algorithms do not handle constellation failures. Oldest RAIM algorithms does not consider this issue since they assumes that only one constellation is used. However, this limitation is overcame by several RAIMs nowadays.
* The Classical RAIM algorithms do not handle nominal error biases. It is assumed that fault-free measurements are Gaussian-distributed and their mean is zero except the faulty measurement. Nevertheless, this limitation is also overcame by several new RAIM algorithms nowadays.
* **Future evolutions**
* Ad-hoc RAIM algorithm may be designed for maritime.
* Future maritime RAIM algorithms shall be robust against hazardous local events and shall handle multiple and constellation failures.
* RAIM algorithms requirements and validation tests shall be standarised.
* The limitations of single failure assumption and the poor performances may be overcame with some new RAIM algorithms or the use of augmentation systems (SBAS, DGNSS, etc.)

### RAIM in maritime regulation

The use of RAIM in maritime is contemplated in the regulation since, for example, the performance standards for shipborne GPS receiver equipment claims that the GPS receiver equipment shall provide “*an indication if the position calculated is likely to be outside of the requirements of these performance standards”* [M.112/A5.1]. Very similar statements could be found for GLONASS, Galileo and BeiDou IMO performance standards.

The standard IEC 61108 specifies the minimum performance standards, methods of testing and required test results for each GNSS core constellation shipborne receiver equipment, based on their correspondent IMO Resolutions. In order to provide the indication about the reliability of positioning estimation, IEC standards indicates that a GNSS receiver shall incorporate integrity monitoring using at least fault detection algorithms, for example RAIM, or similar means to determine if accuracy is within the performance standards and provide an integrity indication. This RAIM definition does not constrain the specific RAIM algorithm implementation deliberately in order to let the manufactures implement the most suitable one for their applications. According to this IEC standard, every approved receiver shall incorporate any kind of at least fault detection algorithms, but capabilities of these algorithms may differs a lot from one manufacture to other.

The integrity indication for different position accuracy levels shall be expressed in three states:

* SAFE (green indicator): It indicates the ability of computing reliably the integrity information for the selected accuracy and the estimated performances are inside the requirements.
* CAUTION (yellow indicator): It indicates that there are not enough information con compute reliably the integrity information for the selected accuracy.
* UNSAFE (red indicator): It indicates the ability of computing reliably the integrity information for the selected accuracy and the estimated performances are outside the requirements.

It is important to remark that the concept of RAIM algorithm and also the integrity requirements differs significantly in each GNSS constellation.

* GPS standard:
  + Based in classical FD RAIM concept, requirements provided for the probability of false alarm and probability of miss detection.
  + Relaxed integrity requirements for GPS. The probability of miss detection and false alarm are of ≤ 5%. Furthermore, the probability of GPS false alarms (≤5%) is very high in order to comply with the continuity requirements stated in IMO Recommendation A.915(22) or IMO A.1046(27), which are of 99.97%.
* Galileo standard:
  + Based in PL computation RAIM. The receiver shall provide an alarm within 10s of the starts of an event if a Horizontal Alert Limit (HAL) is exceeded for a period of at least 3s while AL and PLs concept are not contemplated for GPS
  + Integrity requirements for Galileo are much more stringent. The integrity risk shall be ≤ 10-5/3h for the computed Protection Level

Because all of that it is recognised that the integrity requirements for every GNSS constellation shall be revised in order to provide a coherent and harmonised set of parameters that could be easily assessed.

In order to prove that a receiver is compliant with the requirements specified in this standard, two simple tests are proposed. The first one intends to test the performance of the receiver under safe and caution states, and the other one tests the unsafe state. Both test only check the allowed elapsed time since something causes a change in the integrity status (by a change in the number of satellites or their behaviour) until it is displayed in the integrity monitoring.

The “safe” and “caution” test reduces the number of satellites available from 8 until the integrity algorithm has not enough information to compute the estimation of the accuracy and then provides a “caution”. This procedure is ambiguous because, for example, it does not indicate any minimum number of satellites.

The lack of some test parameters definition is more observable in the “unsafe” test. It claims that in nominal conditions the user shall “change the behaviour of at least 1 satellite by varying the satellite clocks with the result that the position accuracy gradually degrades until it will no longer be inside the selected accuracy level with 95% confidence level”. This test is clearly deficient in terms of safety because the magnitude of the change in the satellite clock is not defined, so any user may implement RAIM algorithms that detects only too large or too small errors. The error introduced in the test should be quantified or at least limited. In addition, there are not any procedure to check if the probability of miss detection and false alarm are being correctly considered by the implemented RAIM.

Considering the simplicity of the aforementioned tests, which do not even assess the probabilities of miss-detection or false alarm, there is no assurance that the RAIM algorithm implemented in the receiver correctly provides system-level integrity. To ensure this, it would be necessary to improve the test method in order to characterize the value of the introduced error, add new tests to evaluate the complete set of requirements to the implemented integrity algorithm.

It shall be remarked that these tests only consider a single satellite failure at a time. However, some algorithms are able to detect multi-failure or even the failure of the entire constellation. They are allowed by this regulation but these capabilities are not tested and therefore it shall be not assumed that they are safe under these conditions.

## Commercial Services

Several companies provide high accuracy augmentation data for maritime use on a commercial basis. This information may be provided via satellite or via an internet link to the bridge equipment and is largely aimed at the high accuracy user.

Such systems may provide accuracies in the region of <10cm (PPP type service) or <2cm (RTK type service) with different usable ranges and time to convergence. It is anticipated that most services will also offer integrity but this would need to be confirmed.

The cost of commercial services could be significant both in terms of hardware and annual data subscription rates. This combined with the higher accuracies, which are likely to be more precise than many mariners require, may mean that such services are not suitable for most maritime users.

* Radiobeacon
  + Point to services offered today and potentially in the future.
  + Already in use, located along most navigable channels etc.
* SBAS
  + Some SBAS may not recognise a maritime user
  + Guidance on which SBAS to use.
  + Use at high latitudes
* RAIM
  + Standards and the need for development.
* National RTK/PPP
* Visual and Radar – use of physical AtoN
* Other ranging information – inc. R-mode
* MSI
* What do you do with more than one augmentation source? (beacon and SBAS and between different SBAS.
* Timeline for sources.

# Future options

Provide guidance on the potential options for the future, recognising the choice is down to the national authority.

## Maintain GPS L1 corrections

* Ability to get the equipment – encourage manufacturers to support with new hardware
* Reusing equipment from nations that have discontinued
* Introduction of SBAS 3rd party corrections
* Availability of the technology and knowledge – transmission and reception equipment
* Concentrate only on ‘critical’ stations dependent upon the requirement to meet SOLAS obligations i.e. the degree of risk for shipping
* Recommend that Development of a timeline to reflect the ‘S’ curves of technology becoming operational
* Cooperate with national surveying organizations

It is recognized that DGNSS beacon receivers are in wide use today and is a very reliable and well known and harmonized service world wide. Some countries has ceased transmission while others are planning to discontinue, but the number of beacons are still high.

It is important to recognise that DGNSS is providing integrity information to the mariner. The integrity provided by the DGNSS service supports safe navigation.

Today, some NSPs are facing operational and technical concerns to keep the quality of service due to aging equipment and reduced number of equipment manufacturers. It is still possible to buy such equipment though, including reference and integrity monitor equipment, amplifiers, automatic tuning units and antennas. It has also been shown that it is possible to use SDR to modulate the DGNSS signal. It is further recommended that NSPs cooperate across boundary’s to solve obsolesces or long delivery time by sharing spares.

The DGNSS is based on open and available interface description including the RTCM 2.4 + RSIM.

IALA provide guidance on how to provide the DGNSS service in the recommendation R-121 and its corresponding Guideline 1112. An NSP that selects to start providing or to continue to provide the DGNSS service is recommended to read these two documents. The guideline G-1112 includes two options for generating corrections: locally produced by equipment specially developed for this purpose or with corrections received from an external source (called network based or Virtual Reference Station).

IALA also provide guidance for NSP seeking the opportunity to retransmit SBAS corrections. The guideline G1129 was released 2019 and gives details on how to use existing SBAS systems to create the correction.

Providing the DGNSS service is not mandatory and therefore an NSP can choose to provide it or not. Because it is not mandatory it is also possible to select to what service level should be given. The R-121 suggests that the IMO 1046 requirements are used, but this does not have to be the case. Providing the DGNSS service at a lower service level will of course give the mariner more integrity compared to not providing the service at all.

Other equipment, antennas etc…is that explained in G-1112?

Two different version for integrity monitoring: pre-broadcast and post-broadcast.

A station can be set up with a combination of the above mentioned three variants.

Two types of upgrades: full recapitalisation or partial upgrade.

### Case studies

#### Using SDR modulators

#### “Swedish approach”

Partial upgrade e.g. upgrade of transmitters only or reference equipment or IT equipment (off-the-shelf HW, e.g. PC, server, DB both central and on-site) (an example continue use legacy reference units with new IT equipment via RSIM).

#### “French approach”

#### “German approach” etc

## Provide corrections to multiple GNSS and/or GNSS frequencies

* Software based infrastructure to do it
* GNSS GLONAS available today for constellations / new frequencies in the future re. RTCM v.2.4 timeline
* Shipborne equipment timeline / guestimate
* Software update for shipborne equipment that is already multi-constellational – but with RTCM v.2.3
* Today the current dual frequencies are E1 and E5. In the future there may be other frequencies providing other services
* The capability to add phase corrections.

As multiple GNSS are available in the near future, maritime navigation equipment is expected to use these GNSS as well. IMO has already established performance standards (IMO Resolution MSC.401(95)) as a solution for GNSS Jamming, and has defined that multiple GNSS corrects should be able to be processed if provided. Therefore, the radiobeacon service, which is currently provided with GPS L1 correction, should be expanded to MC (Multi-Constellation) augmentation service, which should ensure integrity in the ocean as well as improved positioning accuracy for multiple GNSS. In order for the radiobeacon service to be extended to the MC augmentation service, the broadcast standards must be revised, and RTCM has completed the broadcasting standard draft (RTCM SC-104 v.2.4) for MC augmentation. Therefore, when the RTCM broadcasting standard for MC augmentation is announced, the corrections to multiple GNSS and/or GNSS frequencies shall be provided accordingly.

## Discontinue services

If an authority decides to discontinue Radiobeacon DGNSS services, the following issues should be taken into consideration:

* Any such decision should be based on a risk assessment of the volume of traffic and degree of risk to marine navigation within that authority’s area;
* Any such decision should incorporate an assessment of how future Position, Navigation and Timing integrity will be assured for marine traffic within that authority’s area;
* Any such decision should incorporate a public consultation process with users and other stakeholders, including any neighbouring national authorities (ref. IALA Guideline G 1079);
* Any such decision should be communicated to all stakeholders concerned (e.g. via national stakeholder meetings, user groups and through maritime safety information), and only effected after timely and adequate notice has been promulgated; (12 months is a recommended minimum). Its recommended for authorities to remain operational until other alternative options are fully operational, standardised and ready for ship equipage.
* It should be noted that DGNSS signals provided by neighbouring service providers may still be available in the waters of a country that has discontinued its marine radiobeacon DGNSS service, and that the frequency allocation needs to be maintainedIALA recommends maintaining the existing infrastructure (for a period to be defined by the national competent authority) to support other alternative purposes i.e. to support R-mode, as sites and assets such as transmission antennae and frequency allocations have value and may not be easily replaced.

# Future development

* What are the potential future systems and when are they likely to be available
* Add the future development in an annex including a timeline for the infrastructure

## Ranging Mode

Studies are being conducted on the benefit of expanding the functionality of existing maritime radio systems by providing a timing signal from which the user may then calculate their position independently from GNSS. This is known as Ranging Mode (R-Mode).

At present, the marine medium frequency (MF) radio-beacon system and the very high frequency (VHF) data exchange system (VDES) services are being considered as candidates for modification to add R-Mode functionality. By providing timing information over their normal MF or VHF transmissions, a shipboard receiver may then calculate a distance (range) to the transmitter. By calculating the range to several stations, the user is able to calculate the ship’s position.

Coverage, geometry and interference issues are investigated. Several R-Mode testbeds are being established which provide MF or VHF but also MF and VHF signals. First prototypes for R-Mode transmitters and receivers are being developed.

The provision of R-Mode services would require the availability of an accurate non-GNSS timing source at the transmitter. High stability clocks could be an expensive option and it is more likely that time would be sourced from a low frequency radio time clock or eLoran – *Further details will be added ! Reference to Guideline from IALA R-Mode Workshop !*

The provision of R-Mode services requires an accurate timing source at the transmitter. This source is synchronized regularly with the R-Mode reference time which is used by all R-Mode transmitters in the area. Furthermore, a hold-over capability ensures ns accurate timing when synchronization is not possible. Depending on the classification of R-Mode as a backup or contingency the following systems or technologies can be used for synchronization of transmitters: GNSS, eLoran, R-Mode self-synchronization, fibre optics to national realization UTC or other.

Current challenges of the R-Mode implementation on marine radiobeacons are the sky-wave interference and the ambiguity resolution for the range estimation. Simulations with R-Mode signals, which make use of the entire radio beacon band, show that widening the signals would help to mitigate the sky-wave and solve the ambiguity issue.

The R-Mode system development is driven by members of the IALA. Figure . shows the IALA R-Mode roadmap.

IALA – R-Mode roadmap – Reference IALA ENG10



* GNSS evolution – changes in the GNSS constellations and services
  + Objectives of the evolution:
    - Improve performances and coverage
    - Provide additional added-value services
    - Improve resilience to GNSS vulnerabilities.
  + GNSS evolutions at different levels:
    - GNSS core constellations *reference EMRF/ERNP*
      * GPS L1 and future L2 and L5 signals
      * Galileo E1 and E5ab
      * GLONASS G1 and future G2
      * Beidou B1
    - GNSS services
      * OS Positioning
      * Medium-accuracy
      * High Accuracy
      * Search and Rescue
      * Other Services: Authentication, Timing, SAR Return Link
    - Regional Satellite Navigation Systems
      * QZSS
      * IRNSS
    - Space-Based augmentations:
      * QZSS
      * SBAS single frequency and SBAS DFMC
      * Beidou
    - GNSS user evolutions
      * Hybridization
      * Integrity monitoring and assurance
      * High accuracy - PPP

Most part of the GNSS system are currently under evolution (different stages from the Regions). Roadmap for the evolutions:

* + Galileo
  + GLONASS
  + Beidou
* Augmentation
* System level security issues / Cyber security
  + Identification & authentification schemes for broadcasted information 🡪 future RTCM messages should reflect
  + Network based systems should be hardened against cyber attacks
  + Tamper safe equipment 🡪 IEC 63154 standard in development (connectivity, internet, USB..)

## Other use for the MF maritime band

The IALA DGNSS frequency allocation is recognised as a significant asset in global harmonisation. R-Mode is one potential use of the band but there might be other services to be explored. The frequency band could be used as a general data communication channel to support future e-Navigation services. Possible data rates could be XX kBit/s depending on the selected modulation. The data rate can never be high, but the stations has potential to reach further than e.g. VDES.

* Communications – sending MSI for real-time integrity failures. How should this be conveyed to the user?

# Key points to consider

* Standards – where are we? The timeframe for modification / creation of technical standards
* L1/G1/E1 B1 corrections as minimum requirement
  + Available as standard output of IALA Beaconsystem– Only source of Integrity for SPS-Mode receivers
  + Availability of SBAS for maritime users, partially including integrity, but same weaknesses as L1 signal itself !
  + End of life of the equipment is reached today – Upgrade options and technologies ?
    - Corrections for L2 & L5/E5
    - R-Mode compatibility
    - Guideline for DGNSS shore-based equipment upgrades is missing, reference from IALA Guideline 1060 section 2 (Need to update). Replacement options refers to R135 which is under maintenance by this document !
    - Budgets – Needed investments – Reference to GSA SC24 Project
* Multi–Constellation Receiversin use today
  + GPS & GLONASS good availability
  + GPS & GLONASS & Galileo & Beidou one approved receive
* Multi-Frequency Receivers
  + IMO PS & IEC Test Standard for Galileo E1 & E5a/b
  + IMO PS for MSR (MSC.401) & Msc.1 Circ.1575 PNT Guidelines
    - Support Multi-System & Multi-Signal resilient navigation receivers.
* **ToDo**: Development of IEC/RTCM Test Standards for Wheelmark approvals
* Ana – if the DGPS service is discontinued the equipment on vessels will still remain in place and currently there is no mechanism to force vessels/ owners to update their equipment unless there is a need through mandatory carriage requirements etc.
* 3 different time periods
* Regional considerations should be taken into account - Iono

Cyber-security considerations

# Encourage Competent Authorities to develop/implement/amend a national radionavigation plan taking into consideration these guidelines

1. EXAMPLE OF AN ANNEX - LANDSCAPE

Body text

1. example of ANNEX heading level 1

Body text

* 1. example of annex heading level 2

Body text

* + 1. Example of annex heading level 3

Body text

* + - 1. Example of Annex heading level 4

Body text

1. Example table caption

| No | Title/Topic | IMO References | Requirements | Possible Audit Questions | Remarks |
| --- | --- | --- | --- | --- | --- |
| 1 | Table text | Table text | Table text | Table text | Table text |
| Table text | Table text |
| Table text | Table text |

1. EXAMPLE OF AN APPENDIX TITLE
2. APPENDIX HEADING 1

Body text

* 1. APPENDIX HEADING 2

Body text

* + 1. APPENDIX HEADING 3

Body text

* + - 1. Appendix Heading 4

Body text

1. (EXAMPLE ANNEX TITLE)
2. Introduction (Example Annex Heading 1)

Body text.

* 1. Example of ANNEX HEADING Level 2

Body text

* + 1. Example of annex heading level 3

Body text

* + - 1. Example of Annex heading level 4

Body text

1. PERMITTED COLOUR PALETTE

The IALA colour palette is divided in 3 palettes of different level of hierarchy that has to be respected.

Corporate colours (Not shown)

IALA’s corporate colour palette is directly inspired from the colours in our logotype:

* dark blue
* white
* yellow
* gradient blue

Primary & secondary colours

The primary colours are to be applied in complement with the corporate colours.

This second level of colours gives rhythm and helps to segment our publications.

The secondary colours are used to highlight information, titles in a minor proportion only.

These colours can’t be replaced by other tints.

**PANTONE PROCESS CYAN C CMYK :** C 100

**RGB :** R 0 - G 159 - B 223

**CMYK : 50 % OF THE TONE RGB :** R 131 - G 208 - B 245

**CMYK : 50 % OF THE TONE RGB :** R 148 - G 217 - B 213

**CMYK : 50 % OF THE TONE RGB :** R171 - G 219 - B 233

**CMYK : 50 % OF THE TONE RGB :** R 178 - G 193 - B 237

**PANTONE 326C CMYK :** C 81 - Y 39

**RGB :** R 0 - G 175 - B 170

**PANTONE 7703 C**

**CMYK :** C 79 - M 2 - Y 10 - K 11

**RGB :** R 0 - G 181 - B 208

**PANTONE 660 C CMYK :** C 88 - M 50

**RGB :** R 64 - G 126 - B 201

**CMYK : 20 % OF THE TONE RGB :** R 212 - G 237 - B 252

**CMYK : 20 % OF THE TONE RGB :** R 213 - G 240 - B 237

**CMYK : 20 % OF THE TONE RGB :** R 216 - G238 - B 245

**CMYK : 20 % OF THE TONE RGB :** R 218 - G 223 - B 246

**PANTONE 258 C CMYK :** C 51 - M 79

**RGB :** R 153 - G 80 - B 159

**CMYK : 50 % OF THE TONE RGB :** R 201 - G 169 - B 208

**CMYK : 50 % OF THE TONE RGB :** R 183 - G214 - B 155

**CMYK : 50 % OF THE TONE RGB :** R 246 - G 174- B 135

**CMYK : 50 % OF THE TONE RGB :** R 157 - G 157 - B 156

**PANTONE 739 C**

**CMYK :** C 78- Y 95- K 5

**RGB :** R82 - G 174 - B 50

**PANTONE 2347 C**

**CMYK :**M 88 - Y 100

**RGB :** R 230 - G 56 - B 17

**PANTONE COOL GRAY 11 C CMYK :** K 100

**RGB :** R 87 - G 87 - B 86

**CMYK : 20 % OF THE TONE RGB :** R 232 - G 221 - B 288

**CMYK : 20 % OF THE TONE RGB :** R226 - G 238 - B 217

**CMYK : 20 % OF THE TONE RGB :** R 253 - G 224- B 208

**CMYK : 20 % OF THE TONE RGB :** R218 - G 218 - B 218

**CMYK : 10 % OF THE TONE RGB :** R 237 - G 237 - B 237

Guideline

Recommendation

Model Course

PRIMARY COLOURS

SECONDARY COLOURS