**WG3 updates to the NAVGUIDE**

**Introduction**

The following pages contain our input to the NAVGUIDE. I’ve extracted the radio navigation aspects from the main document in an effort to check the formatting and also the structure.

Highlighted text is to be updated. The other text should be as amended at the last meeting, but I would welcome your review and comments.

**Structure**

The following pages contain the text within the following structure (this will become Chapter 5 in due course)

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# Positioning, Navigation and Timing

Positioning, Navigation and Timing (PNT) information is widely used across the maritime sector. It supports vessel navigation, e-Navigation services and provides timing and positioning information for maritime Aids to Navigation.

Over the past decade it’s become clear that reliance on PNT has grown dramatically while at the same time the threat of signal disruption or corruption has grown. There is a clear need for resilience in the provision of PNT information as it underpins so many aspects of maritime navigation, communications and maritime AtoN operations.

Resilience may look like and mean different things depending on the operation at hand, the threat faced and available local options. It is widely recognised that one solution cannot mitigates all threats in all locations, and what is needed are a scalable, configurable solutions through what is often referred to as a system-of-systems approach.

Global Navigation Satellite Systems (GNSS) are widely used as the primary means of navigation today and that is expected to remain so into the future. Resilience is achieved when GNSS PNT information is supported by data from other, independent, PNT sources and combined in such a way that the integrity of the data is maintained and the mariner or AtoN service provider can retain their PNT solution, should any of the PNT sources fail.

There are many different systems, which can provide PNT information, and this chapter introduces the most prominent.

Refer to IALA publication:

• Recommendation R1017 – Resilient Positioning, Navigation and Timing

## Satellite Positioning and timing

Global Navigation Satellite System (GNSS) is the generic term for satellite navigation systems that provide timing signals that enable the users’ receiver to calculate its position, velocity and time.

GNSS consist of three segments – a satellite constellation, a ground segment and the user’s receiver. The satellites continuously transmit coded signals in one or more frequency bands. A user’s receiver, positioned anywhere on the earth’s surface, can use these signals to determine their position and velocity in real time, based on ranging measurements.

If a GNSS is recognised by the IMO as a component of its World Wide Radio Navigation System (WWRNS), as set out in IMO Resolution A.1046 (27), the receivers of that GNSS are deemed to satisfy the IMO carriage requirements for position fixing equipment referred to in Chapter V of the SOLAS Convention.

GNSS receivers, in combination with other equipment, can be used to obtain:

• absolute positioning;

• relative positioning (this can be further processed to derive speed over ground (SOG), course over ground (COG), etc.); and

• timing

This information may refer to a stationary observer (static positioning) or to a moving observer (kinematic positioning).

There are several GNSS available today, with GPS, GLONASS, BeiDou and Galileo recognised as components of the IMO’s WWRNS. It is planned that regional GNSS components like QZSS and NAVIC will become operational in the next few years. GPS, GLONASS, Galileo, BeiDou, QZSS and NAVIC operate interoperable services under the framework of the International Telecommunication Union (ITU).

### Global Positioning System (GPS)

The Global Positioning System (GPS) became fully operational in 1995. The system is operated by the United States Air Force on behalf of the United States Government.

GPS provides two levels of service. The Standard Positioning Service (SPS) provides accurate positioning to all users since it is available for peaceful civil, commercial, and scientific use. Otherwise, the Precise Positioning Service (PPS) provides full system accuracy to those designated and authorised users among U.S. and allied national security systems.

The GPS Space Segment consists of a nominal constellation of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) high orbits at an inclination angle of 55 degrees and with a 12-hour period.

The GPS SPS is available on a non-discriminatory basis, free of direct user fees, to all users with an appropriate receiver. The service satisfies the requirements for general navigation and harbour approach with a horizontal position accuracy of 9 metres (95% probability) [2]

A modernisation program aims to improve the accuracy and availability for all users and involves new ground stations, new satellites and four additional navigation signals: three new civilian signals known as L2C, L5 and L1C and a new military code termed M-Code.

Further information on GPS can be found at the USCG NAVCEN website (www.navcen.uscg.gov). The website also has a link to the latest United States Federal Radionavigation Plan that provides a comprehensive account of current and future developments for GPS.

### Global Navigation Satellite System (GLONASS)

GLONASS is a three-dimensional positioning, velocity and time system managed by the Russian Space Agency on behalf of the Russian Federation.

It is available on a non-discriminatory basis and free of direct user fees to all users with an appropriate receiver. With a full complement of 24 satellites, the service satisfies the requirements for general navigation and gives an average User Range Error of 1-6m (95%).

Recent satellites have introduced a second civil signal, with future satellites expected to provide a third civilian signal on the L3 frequency.

GLONASS satellites use Frequency Division Multiple Access (FDMA). However new satellites will provide additional signals using code division multiple access (CDMA) to become interoperable with other GNSS.

Equivalent to the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS) of GPS, GLONASS provides a standard precision (SP) navigation signal and a high precision (HP) navigation signal, namely the Channel of Standard Accuracy (CSA) and Channel of High Accuracy (CHA), respectively. The Open Service (OS) provides positioning and timing service with the open access provided by way of the aggregate ranging FDMA signals generated by the GLONASS OC, broadcast at L1 and L2, and whose performance is associated with that of CSA (Chanel of Standard Accuracy) in the GLONASS service volume. The OS with the associated CSA performance is available to any user globally and continuously.

GLONASS High Precision signal is broadcast in phase quadrature with the SP signal providing full system accuracy to those authorised users by the Russian Armed Forces.

Further information on GLONASS and future developments, is available on the Information and Analysis Centre’s website (https://www.glonass-iac.ru/en/).

### BeiDou

BeiDou Navigation Satellite System (BDS) is China’s independently constructed and operated GNSS system. It can be compatible with other GNSS in the world. BDS can provide all-time, all-weather PNT services with high accuracy and high reliability for all kinds of users.

BDS consists of three major components: the space constellation, the ground control segment and the user segment. The global constellation consists of 3 GEO satellites, 3 IGSO satellites and 24 MEO satellites. BDS now can provide the following services:

The Open Service (OS)

With positioning accurate to 10 meters globally and to 5 meters in Asia-Pacific region free of user charge. The OS can be used on one (B1C or B1I) frequency and the better performed B1C is priority recommended. It is also recommended to use two (B1C and B2a ) frequencies.

The Message Service.

As for message services in China and surrounding areas, the service capacity will be increased to 10 million times per hour and the receiver transmission power will be reduced to 1-3W, capable of transmitting 1,000 Chinese characters per message (14,000 bits). As for global message services, the service capability is 40 Chinese characters per message (560 bits).

The Search and Rescue (SAR) service is a contribution of BDS to the Cospas-Sarsat MEOSAR program through the provision of a Forward Link Alert Service (FLS). In addition, Return Link Service (RLS)/BDS is provided through B2b signal.

BDS Precise Point Positioning (PPP) Service Signal PPP-B2b is transmitted by BDS GEO satellites. The PPP-B2b signal serves as the data broadcasting channel for correction parameters, such as satellite precise orbit and clock offset parameters of BDS and other GNSS, and provides PPP services for users in China and surrounding areas, with the dynamic precise position service accuracy at decimeter level and static precise potion service at centimeter level.

Further information on BDS can be found via website (www.beidou.gov.cn).

### Galileo

Galileo is the European GNSS designed to be interoperable with other GNSS, managed and operated under civil control. Galileo uses a constellation of 24 satellites to achieve its positioning performance targets but aims to have a constellation of 30 satellites when fully operational (including in-orbit spares).[5]

Galileo Initial services were declared in 2016 together with the recognition of IMO as part of the World Wide Radionavigation System. Galileo is offering today the following services:

1. An Open Service (OS): With horizontal position accuracy of 2 metres (95%), free of user charges and providing positioning, time and synchronisation information.

2. Search and Rescue Services (SAR): EU contribution to the MEOSAR system of COSPAS-SARSAT. Galileo search-and-rescue service forwards since 2017 distress signals to Cospas-Sarsat Mission Control Centres by detecting emergency signals from beacons and relaying messages to them in near real time that are then sent to the Rescue Coordination Centres (Forward Link Service). Galileo also delivers since 2020 an acknowledgment message to beacons with the return link capability to inform the user that the alarm has been received (Return Link Service).

3. High Accuracy Service (HAS): A free access service complementing the OS by delivering high accuracy data and providing better ranging accuracy, enabling users to achieve sub-meter level positioning accuracy. With HAS, Galileo will be the first constellation able to provide a high-accuracy PPP service globally directly through the Signal in Space. High-accuracy data will be transmitted using an open format in the Galileo E6-B signal and via the internet for Galileo and GPS (single and multi-frequency) to achieve real-time improved user positioning performances (positioning error of less than two decimetres in nominal conditions).

4. Public Regulated Service (PRS): Encrypted navigation service restricted to government-authorised users, for sensitive applications that require a high level of service continuity. PRS is primarily intended for use by EU Member State government authorised military or civil users, e.g. emergency services and police.

### Regional systems

#### Quasi-Zenith Satellite System

Japan is developing a Quasi-Zenith Satellite System (QZSS). QZSS is based on three satellites in highly elliptical, inclined orbits and one geo-stationary satellite. The final constellation is expected to consist of 7 satellites, with each transmitting 6 signals in the L‑band: 3 in L1, 1 in E6, 1 in L2 and 1 in L5. The signal in E6 (L6) aims to support a commercial service with high data rate (2 kbps). Full implementation will also provide augmentation services to GPS and QZSS.

Further information is available at http://QZSS.go.jp/en/.

#### Indian Regional Navigational Satellite System

The Indian Regional Navigational Satellite System (IRNSS) with an operational name of NAVIC (Navigation with Indian Constellation) will be an independent navigation system covering the Indian region through a space segment of 3 GEO satellites and 4 IGSO satellites. The inclination of the orbital plane of the IGSO satellites is low, so that all the satellites can be seen simultaneously over India.

Three NAVIC services are:

• Open Service using signals in the L5 and S bands;

• Precise Positioning Service using signals in the L5 and S bands; and

• Restricted Access Service using signals in the L5 band only.

The Open and Precise services target dual frequency users, but it is also intended to compute and broadcast ionosphere-corrections to support single frequency users. Owing to the limited coverage of the NAVIC network of reference stations, the satellites will, apart from the navigation payload, also include a dedicated C-band uplink/down-link ranging payload to support precise satellite orbit determination.

## Terrestrial positioning and timing

Within this section, we consider different terrestrial navigation and timing systems, noting that the use of Radar for absolute positioning is captured in Section x.

### Loran-C

Loran–C is a hyperbolic radionavigation system that was developed during the 1960’s to meet U.S. Department of Defense requirements. The Russian Federation operates a similar radionavigation system called CHAYKA.

Loran-C chains comprise between three to five stations that have a spacing of 600 to 1000 nautical miles. The signal format is a structured sequence of specially designed radio pulses on a carrier wave frequency centred on 100 kHz. One of the stations is designated as the ‘master’ and transmits groups of 9 pulses. The other stations are called ‘secondaries’ and these transmit groups of 8 pulses. The spacing between groups of ‘master’ pulses from a single chain is a characteristic unique to that chain and is referred to as the Group Repetition Interval (GRI).

The 100 kHz carrier wave frequency favours the propagation of a stable ground wave over long distances. Careful signal design allows Loran receivers to determine positions using the ground wave and reject the delayed sky wave that would potentially distort the received signal.

The transmissions from each chain are monitored and controlled continuously. System abnormality indicators are built into the signal format and can be identified by the receiver providing inherent integrity warnings.

### eLoran

Enhanced Loran (eLoran) is a terrestrial navigation system developed from Loran-C. It is a Positioning, Velocity, and Timing (PVT) service for use by land, sea and air navigation, as well as other applications reliant on timing data.

eLoran is independent of, and has dissimilar failure modes to GNSS, and therefore complements GNSS in support of resilient PNT. eLoran provides positional accuracy in the region of 8 - 20 metres and time and frequency performance (to stratum-1 level) similar to current GNSS.

eLoran differs from Loran-C as it uses an all-in-view method of operation, calculating the distance to all eLoran stations in view. eLoran stations are synchronised with, but independently of, GNSS time. Synchronising to a common time source allows receivers to employ a mixture of eLoran and other systems, such as GNSS.

eLoran receivers calculate the distance from each station by firstly assuming that the entire earth’s surface is covered in sea-water. By knowing the speed of the signal over sea-water, along with the times of transmission and reception, a pseudorange can be calculated. This pseudorange is then adjusted to take into account the propagation delays due to the signal passing over land. These delays are called Additional Secondary Factor delays (ASFs). ASFs are measured by the service provider and supplied to users as a database built into their receivers. ASFs may change slightly due to weather or seasonal effects, reducing the efficiency of the correction and affecting accuracy. However, this is resolved by installing a differential Loran reference station nearby, which is able to measure the difference and calculate a correction. The correction information is then passed to the eLoran station for dissemination to the user over the eLoran data channel.

The inclusion of a data channel as part of the main transmission is one of the inherent features of eLoran. It can be used to provide other data services in addition to differential corrections.

The eLoran signal is standardised by SAE within its Transmitted Enhanced Loran (eLoran) Signal standard (SAE9990).

Refer to IALA publication:

• Recommendation R011- The performance and monitoring of eLoran services in the frequency band 90-110 kHz.

• Guideline G1125 – The technical approach to establishing a maritime eLoran Service

### Ranging mode

Ranging mode (R-Mode) is a terrestrial positioning system under development. It uses the frequency bands of existing maritime radio infrastructure for the provision of timing signals that enables GNSS independent position and time estimation. At present, the MF band of the IALA radio beacon system and the VHF bands AIS, ASM and VDE-TER of the VDES are being used in R-Mode testbeds in Europe, Asia and North America.

Three transmitters must be received to perform R-Mode based positioning at sea. Due to the different range of the transmitter of about 250 km for MF and several tens of km for VHF, which strongly depends on the antenna tower height, the coverage of MF and VHF R-Mode service can differ noticeably. Both signals are subject to different effects of signal attenuation, interference and distortion which decreases the performance. The combination of MF and VHF R-Mode signals can noticeably increase the R-Mode positioning performance.

All R-Mode transmitters are synchronized to an R-Mode system time. Depending on the synchronization source and technology to perform synchronization, the system time refers to a time scale which is traceable to UTC. Usually GNSS is used for synchronisation today within the testbeds. To reduce the dependence or to be completely independent from GNSS, R-Mode stations would need to have atomic clocks or another means for synchronization.

Refer to IALA publication:

• Guideline 1158 – VDES R-Mode

## Augmentation Services

The aim of GNSS augmentation services such as Differential Global Navigational Satellite Systems (DGNSS) is the improvement of GNSS-based positioning in a given area. In this context, various methods can be applied to increase the accuracy of GNSS-based positioning, and to verify the integrity of applied components (systems, services) and provided data. An essential basis for the provision of DGNSS service is own GNSS measurements gathered in real time at single reference stations or a network of stations.

There are two main approaches, ground based differential services such as the IALA radio beacon DGNSS system and space-based services, such as Satellite Based Augmentation Systems (SBAS). The following sections introduce each system in more detail, however they work in similar manners – they both compare the performance of high-grade GNSS receivers to the known location of the antenna in order to observe position errors introduced by the earth’s atmosphere and other such sources.

In safety-critical applications, DGNSS services should also include integrity monitoring functions to ensure signals are valid and fit for use. Such monitoring can be realised by plausibility and consistency tests, as well as methods estimating error behaviour and budgets, to provide integrity warnings in real time to the end user, informing them is satellite or system should not be used.

The DGNSS service provision is realised by radio signals carrying augmentation, correction and integrity data. Users operating in service areas and equipped with appropriate receivers can use this augmentation data to:

• enhance accuracy of GNSS based positioning;

• notify of faulty satellites or GNSS failure;

• detect satellite signals with increased propagation errors;

• exclude disturbed signals from positioning; and

• be informed about the usability of services or other information.

Currently, DGNSS services are provided for operational satellite navigation systems such as GPS and GLONASS. In principle, similar DGNSS services can be provided for developing GNSS such as GALILEO, BeiDou and QZSS.

Each DGNSS service can be separated into two parts - generating and distributing the augmentation data. The generation of DGNSS augmentation data requires own GNSS measurements gathered at a single reference station or a network of stations. Different DGNSS messages and services may use different generation methods and means of dissemination. At present, certain communication channels used for the provision of DGNSS augmentation data are assigned to specific DGNSS services. For example, the provision of DGNSS augmentation data is realised by SBAS.

Refer to IALA publication:

• Recommendation R1022 Provision of GNSS augmentation services for maritime navigation

### Terrestrial augmentation systems

#### IALA Beacon DGNSS

IALA beacon DGNSS provide differential corrections, as well as integrity information, to nearby maritime users to improve accuracy and integrity of GNSS based determination of position, velocity and time data (PVT).

The method of differential positioning was developed in the 1990s, is internationally accepted and supported in most coastal waters, especially in areas of high traffic density. By placing high grade GNSS receivers at know surveyed locations, it’s possible to calculate the difference between the estimated GNSS position and the true surveyed location. The difference for each satellite’s pseudorange are observed from which corrections are determined and shared with nearby users, enabling their receiver to improve their estimated position.

Additionally, integrity monitoring functionalities assess the usability of GNSS signals, ensuring mariners employing such marine radio beacon DGNSS service use valid and healthy satellite signals.

The radio link used for the provision of DGNSS correction and integrity data defined by ITU (Recommendation ITU-R M.823-3). For such services, the DGNSS signal transmission is realized in the maritime radionavigational band (283.5 to 325 kHz)[6]. At user sites, type-approved DGNSS radio beacon receivers (meeting IEC 61108-4 test and performance standards) are necessary to enable the ship-side use of DGNSS services for an improved PVT data determination.

The full list of radio beacon based DGNSS stations (as notified to IALA by aids to navigation authorities) is at the IALA website (www.iala-aism.org).

Refer to IALA publication:

• Recommendation R-1115 (Provision of maritime radionavigation services in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Region 2 and 3);

• Recommendation R-121 (Performance and Monitoring of DGNSS Services In The Frequency Band 283.5-325khz); and

• Guideline 1112: (Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325kHz).

#### AIS for DGNSS Transmissions

Automatic Identification System (AIS) is a ship to ship and ship to shore data exchange and broadcast system, operating in the VHF maritime band. It is described in more detail in Section 7.

AIS has the capability of providing DGNSS corrections to onboard equipment using standardised transmissions (Message No 17) as described in IALA Recommendation A-124.

#### The BeiDou Ground Augmentation System.

BDS utilizes mobile communication networks or the Internet to provide users within the coverage area of reference station network, with high-precision positioning services at meter, decimeter, centimeter and millimeter levels.

#### Maritime Phase-Based GBAS (MGBAS)

In the past few decades, the development of phase-based measurement techniques was driven by surveying needs, to achieve position accuracies with GNSS in the centimetre level. In IALA Recommendation on the Future of DGNSS (R-135), the RTK technique is mentioned as an approach to meet maritime requirements on high-precision positioning in port areas and for docking. Several manufacturers of maritime GNSS/DGNSS equipment provide solutions supporting RTK-based positioning.

#### RTK over AIS

In survey applications, the RTK correction information is usually distributed to users via VHF/UHF radio modems or via commercial broadband internet. However, when used in hydrographic measurements further away from the shoreline, these communication options might not be always available. The communication options in these areas would then be via satellite or via AIS (the latter is also available only within coastal VHF coverage, usually up to 50 - 70 kms from the coastline).

RTK over AIS is in operational use for selected user groups in some countries and it has been reported to function without major problems and deliver the required positioning accuracy.

When using RTK over AIS, it should be noted that it puts a high demand on the VHF Data Link. Other limitations of this technique are that only one mobile user can be served by one AIS base station at a time, there is reduced understanding of accuracy due to rapid atmospheric fluctuations and that it may not be applicable in areas of high channel loading. The channel loading problem may be addressed in the future by using the additional channels allocated for VDES.

It is noted that RTK is a short-range system, and that there is a need to introduce monitoring and assessment of the integrity of RTK services and RTK based positioning in the context of safety-critical applications.

### Satellite Based Augmentation Systems (SBAS)

SBAS support wide-area or regional augmentation through the collection of data from reference stations located across a region, with differential data provided to the user via satellite-broadcast messages. The basic arrangement is to use a set of monitoring stations (at precisely known positions) to receive GNSS signals. Data from these stations are processed in order to obtain estimations of the errors that are also applicable to the users (i.e. ionospheric errors, satellite position/clock errors, etc.). Once these estimations have been computed, they are transmitted to the users by means of a GEO satellite.

There are many SBAS current in operation or planned, as shown in Figure 1.



Figure 1: Existing and under definition SBAS systems (Source: GSA User Technology Report 2018)

Some SBAS providers are working to provide specific maritime services, noting that the open service signals can be used by most maritime receivers. To aid consistency of operation, the International Electrotechnical Commissions (IEC) is working on a maritime SBAS test specification.

Refer to IALA publication:

• Guideline 1129 – The retransmission of SBAS corrections using MF radio beacon and AIS

• Guideline 1152 – SBAS maritime service

#### Wide Area Augmentation System (WAAS)

WAAS has been implemented by the US Federal Aviation Authority (FAA) to support the use of GPS for general and commercial aviation over continental United States. It was recently extended to cover parts of Mexico and Canada. At present, the WAAS architecture includes 38 reference stations, 3 master stations, 4 up-link stations, 2 geostationary satellite links and 2 operational control centres. Further information on WAAS can be found on the USCG Navigation Centre website (www.navcen.uscg.gov).

#### European Geo-stationary Navigation Overlay Service (EGNOS)

EGNOS is the European satellite-based augmentation system that provides safety critical navigation services to aviation, maritime and land-based users over most of Europe. EGNOS augments the GPS L1 Coarse/Acquisition (C/A) civilian signal by providing corrections and integrity information.

EGNOS provides three services:

• Open Service (OS), freely available to any user. The main objective of the EGNOS OS is achievable positioning accuracy by correcting several error sources affecting GPS signals (EGNOS-SDD)

• Safety of Life (SoL) Service, provides the most stringent level of signal-in-space performance developed primarily to support aviation (EGNOS-SDD); A service in the maritime sector is under development with a specific service provision layer including performance monitoring and the promulgation of Maritime Safety Information (MSI). The publication of the IEC Standard for SBAS receiver tests is needed (PNW 80-996 ED1).

• EGNOS Data Access Service (EDAS) is the EGNOS terrestrial data service which offers ground-based access to EGNOS data in real time and also in a historical FTP archive to authorised users (e.g. added-value application providers) (EGNOS-SDD). The EGNOS Space Segment comprises 3 geostationary (GEO) satellites. The EGNOS Ground Segment comprises a network of Ranging Integrity Monitoring Stations (RIMS), two Mission Control Centres (MCC), six Navigation Land Earth Stations (NLES), and the EGNOS Wide Area Network (EWAN) which provides the communication network for all the components of the ground segment.

Further information on EGNOS can be found at www.egnos-portal.eu.

#### BeiDou Satellite Based Augmentation System (BDSBAS)

BDSBAS is an important part of BDS. The constellation of BDSBAS includes 3 GEO satellites operating at an altitude of 35,786 km and are located at 80°E, 110.5°E, and 140°E. These satellites use Pseudo Random Noise (PRN) code 144, 143 and 130, respectively. The coordinate system of BDSBAS is WGS-84.

The deviation of BDSBAS service network time to GPS Time is within 50 nanoseconds. BDSBAS provide the Single Frequency (SF) service through BDSBAS-B1C signal and the Dual-Frequency Multi-Constellation (DFMC) service through BDSBAS-B2a signal for users in China and surrounding areas.

Further information on BDSBAS can be found via website (www.beidou.gov.cn).

#### Multi-Satellite Augmentation System (MSAS)

In Japan, the Multi-Satellite Augmentation System (MSAS) is a SBAS similar to EGNOS and WAAS. MSAS has been commissioned for aviation use, with two GEO-links using the L1 band via dedicated satellites, shared with communications and meteorological missions. The system has been operational since 2007 and there are plans to add additional services in the future.

Further information on MSAS can be found via the website: (https://www.mlit.go.jp/koku/15\_hf\_000105.html).

#### GPS-Aided Geo Augmented Navigation System (GAGAN)

India has developed its own SBAS called GPS-Aided Geo Augmented Navigation system (GAGAN). The system provides signals primarily for aviation users over the Indian landmass and is the first to cover the equatorial region. As the system conforms to ICAO standards it is interoperable with other SBAS and provides a link between EGNOS and MSAS.

Further information on GAGAN may be found at [www.isro.org](http://www.isro.org).

#### System for Differential Corrections and Monitoring

Russia is developing an augmentation to provide corrections for GLONASS and GPS called the System for Differential Corrections and Monitoring (SDCM). This system will consist of 3 geostationary satellites, assigned PRN codes 125,140 and 141.

#### Korea Augmentation Satellite System (KASS)

Republic of Korea is developing a Korea Augmentation Satellite System (KASS), which is an SBAS similar to others, such as WAAS and EGNOS. KASS includes 2 geostationary satellites, 7 reference stations, 2 master stations, 2 up-link stations, and 2 operational control centres. Upon completion of system development and establishment, scheduled in 2022, KASS will begin to provide its open service in 2023. It will then undergo a series of system certification processes in the next several years before its provision of safety of life (SoL) service in the aviation sector. Further information on KASS can be found via website (www.kass.re.kr).

### Integrity options

Augmentation systems check the data provided by each satellite and constellations, to ensure they are valid and operating within normal ranges. Any satellite or constellation found to be working outside of the norm, is marked as unhealthy and not used in the user’s position estimate.

This test is known as integrity. There are two different approaches, system level and user level integrity. System level integrity checks the operation of the system at a set, normally static, location – such as the reference stations used within marine radio beacon DGNSS and SBAS solutions. Such systems are able to identify system level failures, aspects such as erroneous satellite position data, clock errors or atmospheric effects. System level tests are unable to determine or capture any integrity errors at the users’ location.

User level integrity is the name given to integrity checks that take place within the user’s receiver as these can include not just system level failure effects, but also local effects such as interference and multipath near to the user receiver. It is anticipated that user level integrity and system level integrity will be required in the future as the reliance on PNT information grows.

#### Receiver Autonomous Integrity Monitoring

Receiver Autonomous Integrity Monitoring (RAIM) is a technology developed to assess the integrity of GNSS signals, and therefore the user level integrity of GNSS-based positioning. This kind of integrity monitoring is autonomously realized within the user’s receiver with special importance for safety critical applications, such as aviation and maritime.

Range measurements are required from at least four GNSS satellites to enable the determination of position, velocity and time data. However, the application of RAIM in a navigation receiver requires redundancy in the range measurements.

Safety-critical RAIM algorithms might use only “Fault Detection” (FD) or “Fault Detection and Exclusion” (FDE), which enables the continuation of operation in the presence of a single GNSS satellite and signal failures. To detect a faulty satellite, at least five range measurements are required, whereas to isolate and exclude a faulty satellite, at least six range measurements are required. While RAIM can detect many failure modes, it cannot detect some failures affecting multiple satellites.

The upcoming availability of various GNSS will increase the usable number of navigation signals for RAIM-based positioning. New and modernized GNSS supports the provision of GNSS signals in two or more frequency bands and therefore improves the capability of GNSS based ranging.

Future advancement in RAIM algorithms should improve the availability and continuity of RAIM based positioning.

Such enhanced RAIM techniques - called Advanced RAIM (ARAIM) - may become available to maritime users (https://gssc.esa.int/navipedia/index.php/ARAIM ).

## Radar Aids to Navigation

Radar aids to navigation are devices that provide returns to a ship’s radar that help to locate and/or identify a navigation mark. The IMO carriage requirements contained in Chapter V, Regulation 19 of the SOLAS Convention 1974 (as amended), states all ships of:

• 300 gross tonnage and upwards are to carry a 9 GHz radar;

• 3,000 gross tonnage and upwards are to be fitted with a 3 GHz radar or, where considered appropriate by the Administration, a second 9 GHz radar.

Some administrations may impose other carriage requirements.

IMO Resolution MSC.192 (79) Adoption of the Revised Performance Standards for Radar Equipment (December 2004) states that 9 GHz radars should be capable of detecting radar beacons, SARTs and radar target enhancers. By omission, 3GHz radars are not required to detect radar beacons and SARTS. With the removal of the 3GHz radar racon detection requirement, ship-owners are free to use higher performing solid-state radars (previously known as New Technology (NT) radars), discussed below.

9 GHz radars are also extensively carried by vessels not covered by SOLAS or local regulation. Due to this high rate of carriage, radar aids to navigation in the 9 GHz band are especially useful.

### Radar Reflectors

A radar reflector is a passive device designed to return the incident radar pulses of electromagnetic energy back towards the source and thereby enhance the response on the radar display. By design, a radar reflector attempts to minimise absorption and random scattering effects. A radar reflector is generally installed as a supplementary device at sites that would also be marked with a light. The main objectives are to enhance:

• target detection at long ranges (for example, for landfall navigation);

• target detection in areas of sea or rain clutter; and

• radar conspicuity of aids to navigation to reduce the risk of collision damage.

The performance of a radar reflector can be defined in terms of its effective radar cross section (RCS). This is a value determined by comparing the strength of radar signals returned by the radar reflector with the equivalent return from a radar reflective sphere of 1m2 reflecting area.

The range at which a radar reflector target can be detected is dependent on the heights of the radar antenna, the reflector and the output power of the radar. There are analogies to the geographical range of visual marks. The radar performance of corner cluster reflectors may vary considerably from one make to another.

Use of small radar reflectors can also be subject to multipath fading effects. Please see IALA Guideline No.1010 on Racon Range Performance for a discussion on multipath fading.

Most radar reflectors are designed for use by 9 GHz radars. The reflectors can also be used with 3 GHz radars; however, the effective radar cross section is about an order of magnitude less.

### Radar Target Enhancers

A Radar Target Enhancer (RTE) is a device that amplifies and returns the pulse from a ship’s radar to give an enhanced image on the radar screen. The returned signal from an RTE is not coded. The RTE was designed primarily for buoys and small vessels that might normally carry a passive radar reflector. RTE testing has shown RTEs to have provided an effective radar cross section (RCS) of about 100 m2, compared with an RCS of 20 to 30 m2 for passive radar reflectors typically fitted to buoys.

To date, commercially available RTEs only operate in the 9 GHz band. RTE use is subject to multipath fading effects (please see Guideline 1010 on Racon Range Performance).

### Radar Beacons

Radar beacons (racons) are receiver/transmitter devices operating in the maritime radar frequency bands (9 and 3 GHz) that enhance the detection and identification of certain radar targets. Please note that IMO MSC.192 (79) has done away with the requirement for 3 GHz radar to detect racons.

A racon responds to the presence of a ship’s radar by sending a characteristic pulse train. The response appears as a coded mark (or “paint”) on the ship’s radar display (refer Figure 29) that highlights the range and bearing of the racon. The display paint can be fixed to a specified length or can be dependent on the radar range setting. It uses a Morse Code letter character for identification.



Figure 29: A Racon (left) and a Radar Display (right) with and without the Racon character

#### Racon Applications

A racon is generally considered to be a supplementary aid to navigation installed at sites that would also be marked with a light. The number of vessels capable of making use of a racon is effectively unlimited.

A racon can be used for:

• ranging and identification of positions in ice conditions or on inconspicuous or featureless coastlines;

• identification of aids to navigation, both sea-based and land-based;

• landfall identification;

• indicating centre and turning points in precautionary areas or Traffic Separation Scheme (TSS);

• marking hazards;

• indicating navigable spans under bridges; and

• identifying leading lines.

#### Frequency-Agile Racon

A frequency-agile racon responds on the frequency on which it is interrogated, and the response can be re-painted on each radar sweep. The purpose of frequency agility is to provide a signal to the radar that is within the receiver bandwidth of the radar.

Racons operate in the 9 GHz band with horizontal polarisation, and/or in the 3 GHz band, with horizontal and optional vertical polarisation.

|  |  |  |  |
| --- | --- | --- | --- |
| **Preferred Terminology** | **Alternatives** | | |
| 9 GHZ | 9300 9500 MHZ | X-BAND | 3 CM |
| 3 GHZ | 2900 3100 MHZ | S-BAND | 10 CM |

Table 32: Preferred terminology for the description of Racon Operating Frequencies

#### Racon Performance Criteria

The availability of a racon is the principal measure of performance determined by IALA. In the absence of any specific considerations, IALA recommends that the availability of a racon should be at least 99.8%.

#### Racon Technical Considerations

There are a number of technical considerations in the use of racons to assist with the navigation of a ship:

* To avoid masking other features on the radar display, the racon response is usually switched on and off on a pre-set cycle;
* The angular accuracy of the bearing between the ship and racon depends entirely on the interrogating radar, while the accuracy of the range measurement depends on both the radar and racon;
* When racons are used in leading line applications, an alignment accuracy of about 0.3 degrees can be expected; and
* When a ship is very close to a racon, side-lobes from the radar antenna can trigger the racon. The resulting multiple responses on the radar display may be a distraction and can mask other targets. Side-lobe suppression techniques are standard features of frequency agile racons.

#### Use with solid-state Radars

All currently available and installed racons are designed for use with high power pulse (magnetron) radars. In comparison, solid-state radars (previously referred to as New Technology radar) use low power transmissions with long pulses. Due to the low received peak signal strength, long pulse at the racon and modulation technique, current racons may not detect solid-state radars and may not transmit a response usable by such radars. Studies have shown that pulsed solid-state radars are able to reliably trigger racons at shorter ranges than would have been achieved with a magnetron pulsed radar. The IMO regulations regarding 9 GHz radars and racons remain unchanged and although detection and triggering range might be reduced, it is the responsibility of manufacturers of 9 GHz solid-state radars meant to satisfy SOLAS carriage requirements to retain racon functionality.

Despite changes to the IMO regulations relating to 3 GHz racons, existing racons with 3 GHz capability will continue to be useful to 3 GHz pulse radars of both magnetron and pulsed solid-state variants. Advanced techniques of solid-state radars do not automatically mean that racons are no longer useable. Some manufacturers are continuing to provide racon compatibility in their solid-state 3 GHz radars.

Please refer to Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability for more information on solid-state radars.

### Radar Referenced Positioning

Algorithms may be developed to allow the radar display to be overlaid upon the electronic chart using detectable recognised navigational features (racons, passive radar beacons or land edge patterns etc.). This technique, although unlikely to challenge the accuracy of a GNSS based position fix, might be adopted as part of a PNT integrity assessment and/or as a back-up in the event of GNSS service or equipment failure or corruption.

### Enhance Radar Positioning System

A new system known as Enhanced Radar Positioning System (ERPS) has been under trial for many years and results have been presented at IALA conferences in 2014 and 2018. ERPS uses enhanced racons (eRacons) that announce their location by encoding their identity and surveyed position into the response signals returned to radars. Enhanced radars (eRadars) then use the encoded data to calculate position solutions. Dynamic position accuracies of better than 28 meters with availability better than 87% have been measured during trials. ERPS is independent of GNSS and can be used as a back-up system in support of resilient PNT.

Refer to IALA publication:

• Guideline 1010 on Racon Range Performance

• Recommendation R-101 on Maritime Radar Beacons (Racons)

• Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability

• Recommendation O-113 for the Marking of Fixed Bridges over Navigable Waters

## Non-radio Positioning Systems

### Inertial systems

Many studies have been carried out on the integration of GNSS with Inertial Measurement Units (IMU) for maritime navigation. There exist various grades of IMU, from the very expensive navigation grade, through to tactical grade and low-cost units based on the Micro Electro Mechanics System (MEMS). The IMU grade characterizes the achievable performance of data provision covering velocities and orientations. A small IMU grade is associated with higher drift rates. Depending on the different drift rates, an IMU can provide contingency for various lengths of GNSS outages and support resilient PNT.

In combination with a GNSS compass, an IMU can provide accurate and stable heading data for longer GNSS outages. None of the currently available inertial systems is capable of maintaining all levels of navigation accuracy during a lengthy outage of GNSS. For ocean areas, both navigation and tactical-grade IMUs will give protection for appreciable outages over 15 minutes and navigation grade IMUs approximately 1 hour. For coastal areas, the required accuracy of 10 meter could be obtained for 3.5 minutes with a navigation-grade IMU and 1.5 minutes with a tactical grade IMU.

### ePelorus

An electronic pelorus (ePelorus) is a device for taking bearings of visual marks and converting them to an electronic format for input to an electronic chart system. Such a device would enable the integration of visual AtoN with e-Navigation.

The feasibility of constructing a low-cost ePelorus from commercial off-the-shelf components is being investigated to demonstrate its effectiveness as a backup, and to evaluate the potential for integrating visual AtoN with e-Navigation.

References

[1] A registry is simply a bookkeeping device where definitions/specifications are kept in organised locations known as registers. the registry eases the tasks of development of new things, by providing a centralised source for finding definitions/ specifications

[2] GPS Performance Standards, 2008

[3] United Nations Office for Outer Space Affairs, “Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentations Systems”, 2011

[4] At the time of writing, further information on BeiDou may be found on the internet hhttp://www.en.beidou.gov.cn/csnclist.html

[5] Further information on Galileo can be found at the following website: http:/ / ec. europa. eu/ growth/ sectors/ space/ galileo/

[6] A 1kW transmitter will generally allow position fixing to better than 10 metres over a radius of about 200 nautical miles

[7] United Nation Office of Outer Space Affairs