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| IALA Guideline |

1147

the USE of enhanced RADAR POSITIONING SYSTEMS

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.

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

Radar has always been used as a resilient relative positioning system. When used with fixed, known absolute position targets, a fair absolute position solution for a vessel can be manually calculated. But identifying targets can be difficult and published (navigation chart) positions may be approximate. A system known as Enhanced Radar Positioning System (ERPS) uses specially modified racons (radar beacons, or eRacons) with specially modified radars (eRadars) to allow radars to automatically calculate absolute position. In this system, eRacons provide their absolute position encoded on their response signals to eRadars, which use these signals to calculate their own vessels’ positions. The system is independent from Global Navigation Satellite System (GNSS).

ERPS trials using three eRacons demonstrated dynamic absolute position differences of better than 27 meters (95%) compared to Real Time Kinetic position solutions, and accuracies of 2.5 meters (95%) with the vessel berthed.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | One eRacon | | Two eRacons | | Best Available | |
| Trial Phase | Horizontal Error (meters) | Availability (%) | Horizontal Error (meters) | Availability (%) | Horizontal Error (meters) | Availability (%) |
| Static | 37.5 | 86.7 | 11.9 | 61.9 | 16.5 | 86 |
| Dynamic | 30.3 | 87.4 | 26.2 | 64 | 25.3 | 87.9 |
| Berthing | 38.6 | 87.3 | 2.5 | 62.7 | 12 | 93.7 |

This Guideline supports resilient PNT as recommended in the IALA Recommendation R-1017 by introducing ERPS, detailing the system to aid interoperability, outlining practical issues and defining the next steps in the process to adopt ERPS use.



## International Activity

One of the aims of this Guideline is to inform mariners and manufacturers alike. Trials to date have been conducted by a limited set of participants and it is recognized that a standard approach is required to ensure interoperability between eRacon and eRadars developed by different manufacturers. This Guideline sets out the signal specification and design to aid this interoperability by setting a common approach.

In some combination with this text:

There have been a number of ERPS sea trials in Denmark, UK and Singapore, sponsored by the EU EfficienSea (Danish Maritime Authority) project, the EU ACCSEAS (General Lighthouse Authorities of the United Kingdom and Ireland) project and by the Maritime and Port Authority of Singapore. ERPS is an open system in the public domain. ERPS has been the subject of a number of IALA input papers, two IALA Conference presentations and e-Navigation Underway conference presentations.

Please see Annex B for more information on the various sea trials.

Information on ERPS trials can also be found at the IALA Testbeds web site: <https://www.iala-aism.org/technical/e-nav-testbeds/>

## RESILIENT PNT AND BACKUP SYSTEMS

GNSS has been widely recognised as the primary Position Navigation Timing (PNT) data source. However, its vulnerabilities have been identified, which could lead to GNSS outage or providing erroneous position information. This makes GNSS-dependent navigation systems unable to provide the expected performance. IMO, in its e-Navigation Strategy Implementation Plan (MSC.1/Circ.1595) identifies and captured the risk as one of the Risk Control Options (RCO 5) “Improved reliability and resilience of on-board PNT systems”. In order to achieve resilience in PNT service provision, it is necessary to put in place a back-up or fall-back arrangements utilising the techniques that do not share the failure modes of GNSS. In the case of GNSS outage or malfunction, the backup system can provide PNT services.

IALA defines three categories of resilience, Redundant, Backup, and Contingency. The options are defined by the level of performance provided by the alternative system and the time for which that performance is maintained.

The majority of PNT solutions can be scaled to meet the requirements of all three categories, depending on the system design and available budget.

The word backup is used in this guideline for simplification but ERPS could be designed as a redundant or contingent system, depending on the specifics of each location. Each administration will need to consider which category is right for its needs and the degree of risk in the waters served.

“This may need some wordsmithing but I’d like to get across that the three categories are there and that calling a system any one option at this stage doesn’t mean it can’t be designed to work as one of the others. Noting that ERPS is going to be location dependent so designing it as a redundant system is likely to be very expensive and need significant infrastructure. “

“I’m also questioning in my mind whether the redundant system definition includes the worldwide nature of GNSS, in which case ERPS couldn’t do that – of whether it doesn’t and then ERPS could possibly provide the level of performance in a smaller location with enough infrastructure. Am I just confusing matters here by trying to add this?”

Further information on the need for resilience is provided by IALA Recommendation on Resilient Position, Navigation and Timing, R1017, Edition 1, 2018.” and subsequent guidelines

## INTRODUCTION TO ENHANCED RADAR POSITIONING

ERPS is a simple concept in which the eRacon provides absolute position information encoded in its response signal to the eRadar. The concept is similar to what navigators would do by hand, using radar target azimuth and distance to triangulate a vessel’s position. eRacons are essentially normal racons modified to encode their identification and position into the signal response to the radars that interrogate them.

The eRacon position (latitude, longitude and elevation) is surveyed and entered as static parameters in the eRacon configuration, therefore eRacons must be located at fixed sites and not placed on buoys. The eRacon identification and surveyed position data is encoded by the eRacon using modulation in the leading dash of the racon Morse code response.

The Morse code response is received by eRadar and is demodulated to extract the identification and position data from the eRacon. In order to calculate the position, it is necessary either to have:

* A single eRacon signal together with own ship heading; or
* Signals from two or more eRacons.

The calculated position is transmitted to the connected navigation systems, such as ECDIS, through a standard NMEA sentence (perhaps RAGGA).

Knowing the azimuth, range and location of the eRacon targets, eRadars calculate and report positions for their own vessels. If available, multiple eRacons are used simultaneously to improve position accuracy.

There is no dependency on GNSS. The vessels’ own position can be calculated with no previous knowledge of the positions of the vessels. No other external data is needed

# AIMS AND OBJECTIVES

ERPS technology seeks to add a layer of resiliency to ports and waterways by diversifying position information inputs to the navigation system with accurate, reliable, and real-time positioning systems independent of GNSS.

Establishing guidelines for eRacon and eRadar interoperability provides a framework for utilisation of ERPS and is a stepping stone to international standardization of ERPS.

ERPS, as a backup system, adds resilience to position fixing for harbour entrance, harbour approach and coastal waters navigation areas. Due to the need to have at least one eRacon in view, WRPS is unsuitable for use in Ocean waters.

|  |  | **Harbour entrance, harbour approach and coastal waters** |
| --- | --- | --- |
| Accuracy  (95% Horizontal Navigation System Error (HNSE)) |  | 10 m |
| System Integrity\* |  | Within 10s |
| Signal Availability |  | 99.8% |
| Continuity |  | 99.97% (over 15 min) |

\*Integrity warning of system malfunction, non-availability or discontinuity should be provided to users within 10s.

IMO Resolution A.1046 operational Requirements

• Navigation in harbour entrances, harbour approaches and coastal waters: positional information with an error not greater than 10 m with a probability of 95%. Signal availability should exceed 99.8%. When the system is available, the service continuity should be ≥99.97% over a period of 15 minutes. An integrity warning of system malfunction, non-availability or discontinuity should be provided to users within 10s.

Accuracy (complex, 1, 2, 3 or more racons)

Availability (complex, 1, 2, 3 or more racons)

Continuity (complex, 1, 2, 3 or more racons)

It would also be worth noting that due to the limitations of the operation of an eRacon some of the functionality is unachievable (please correct me if I’m wrong as I’m assuming that the “System Integrity” can’t be updated within 10 seconds??).

# TECHNOLOGY

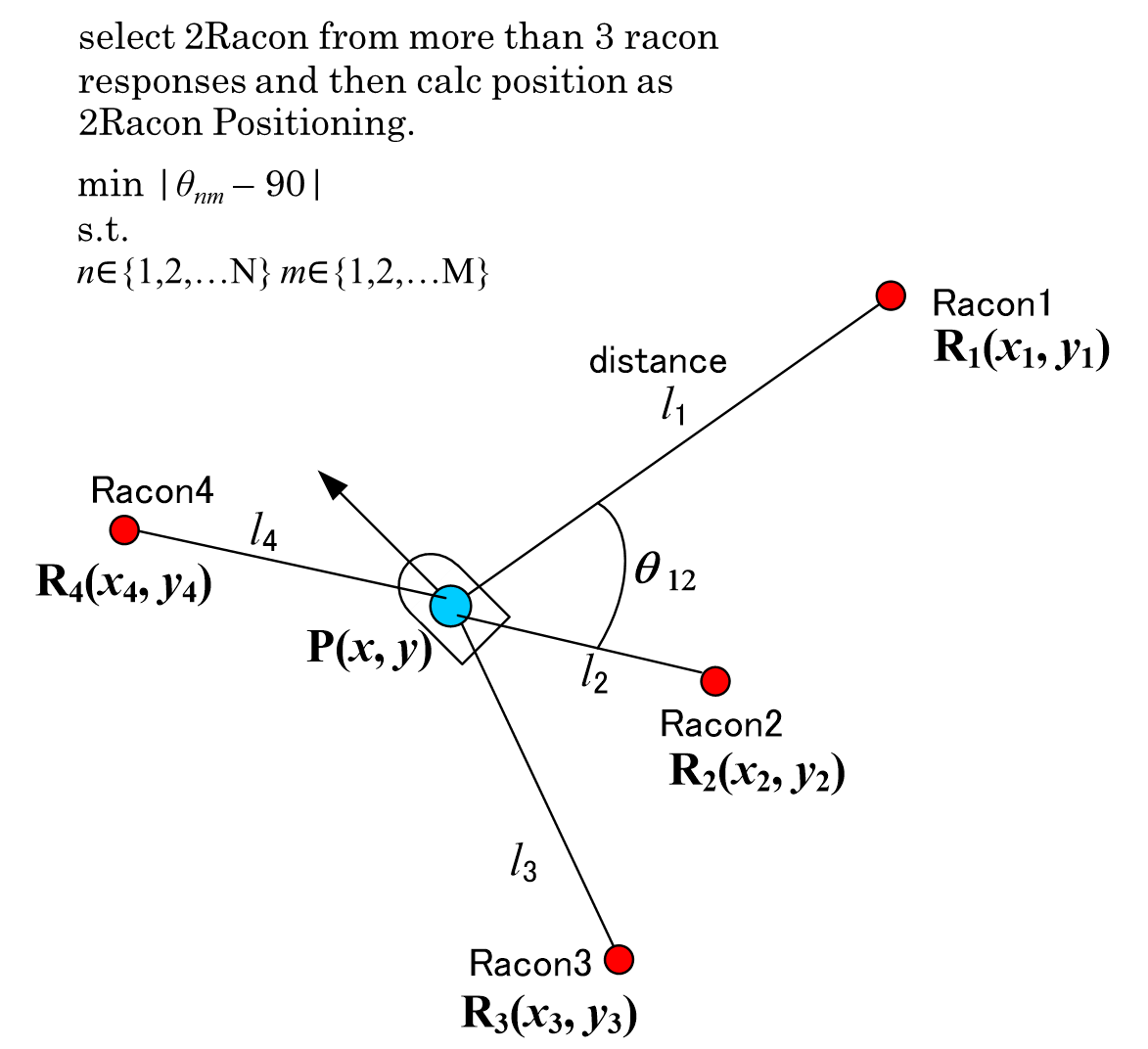
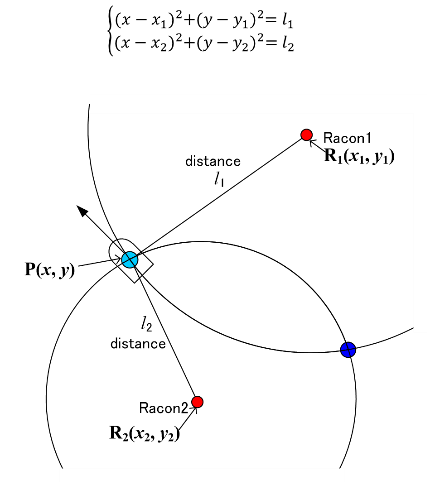
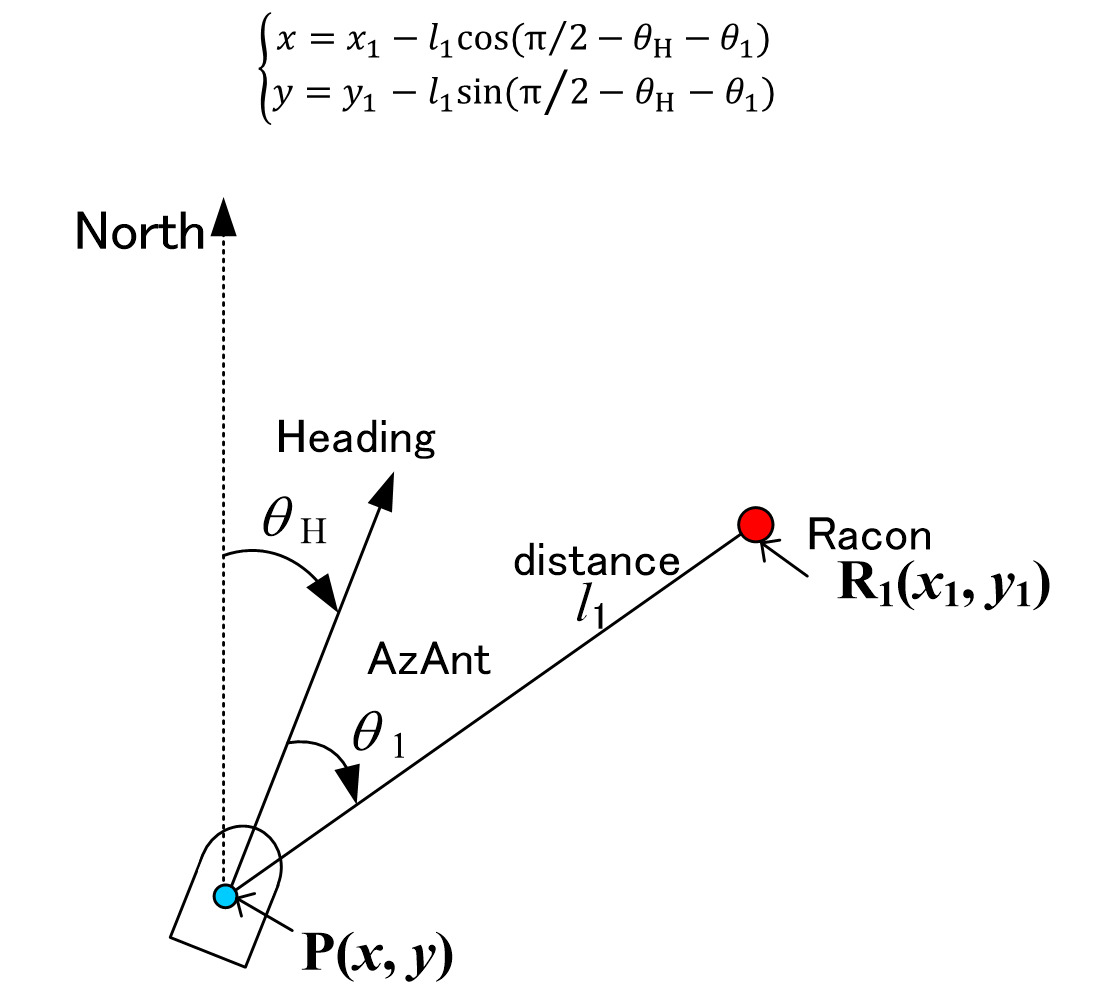
Task: Describe accuracy, availability, continuity goals; both bands

Task: Describe integrity; what it means in context of ERPS

ERPS can be very cost effective in that radars (with digital receivers) and racons (with digital transmitters) can be fitted with needed software at very low per unit cost.

Knowing the azimuth, range and location of the eRacon targets, the speed and heading of their own vessels and their own antenna elevation and rotation characteristics, eRadars calculate and report positions for their own vessels.

Illustrations (I have retrieved better copies!):



Each illustration needs description.

# LIMITATIONS

Lack of standardization.

Are we allowed to use the bands for this purpose (ITU)?

Interaction with IMO, ITU, IEC, CIRM, IHO, others?

Mathematics describing operational envelope and expected performance have not been done. Who knows how to do this? We need to recruit them!

Which band(s)

Describe how concept works

Describe benefits

Describe difficulties (busy harbors, blocking, geometry)

“Fuzzy” radar display images

Refer to other IALA documents for use and installation of racons in general

1. **DEFINITIONS**

The definitions of terms used in this IALA Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at <http://www.iala-aism.org/wiki/dictionary> and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

1. **ACRONYMS**

IMO International Maritime Organization (Acronym style)

ECDIS Electronic Chart Display and Information System

ERPS Enhanced Radar Positioning System

GNSS Global Navigation Satellite System

PNT Position Navigation and Timing

EU European Union

NMEA National Marine Electronics Association

GGA NMEA standard time, position and fix related data message from a GNSS receiver or alternative position fixing device

GPGGA GGA message from a GNSS receiver

RAGGA GGA message from a radar

1. **REFERENCES**
2. IALA Conference 2018, Enhanced Radar Positions Systems for Resilient Positioning
3. ENAV20-13.11 On Racons in Busy Harbors
4. ENAV21-13.10 Singapore eeRadar and eRacon Sea Trials August 2017
5. IALA R1017 Resilient Position, Navigation and Timing (PNT)
6. Other IALA documents? R-101, G-1010, e-Nav-145
7. ERPS Signal specification

This annex describes the ad-hoc IALA/Furuno/Tideland ERPS Packet Format Revision 2.0. It is recognised that the format chosen for work done to date may not be ideal or optimal. The format was chosen because it was easy to do given the constraint of working with an existing commercial racon. It is expected that ERPS will be used in the 9.4 GHz (X-Band) maritime radar band.

1. Data Format Description

The eRacon transmits identification and position data to the eRadar. The eRacon does this by embedding a data packet in the leading dash of a standard racon Morse code response. The eRadar normally receives a number of responses from each eRacon for each sweep of its antenna.

Two data packet formats are defined: alternating and non-alternating.

The alternating format provides position latitude then longitude in alternate messages. An advantage of this format is that the data packet is smaller and allows a shorter Morse code dash.

The non-alternating format provides both position latitude and longitude in the same message.

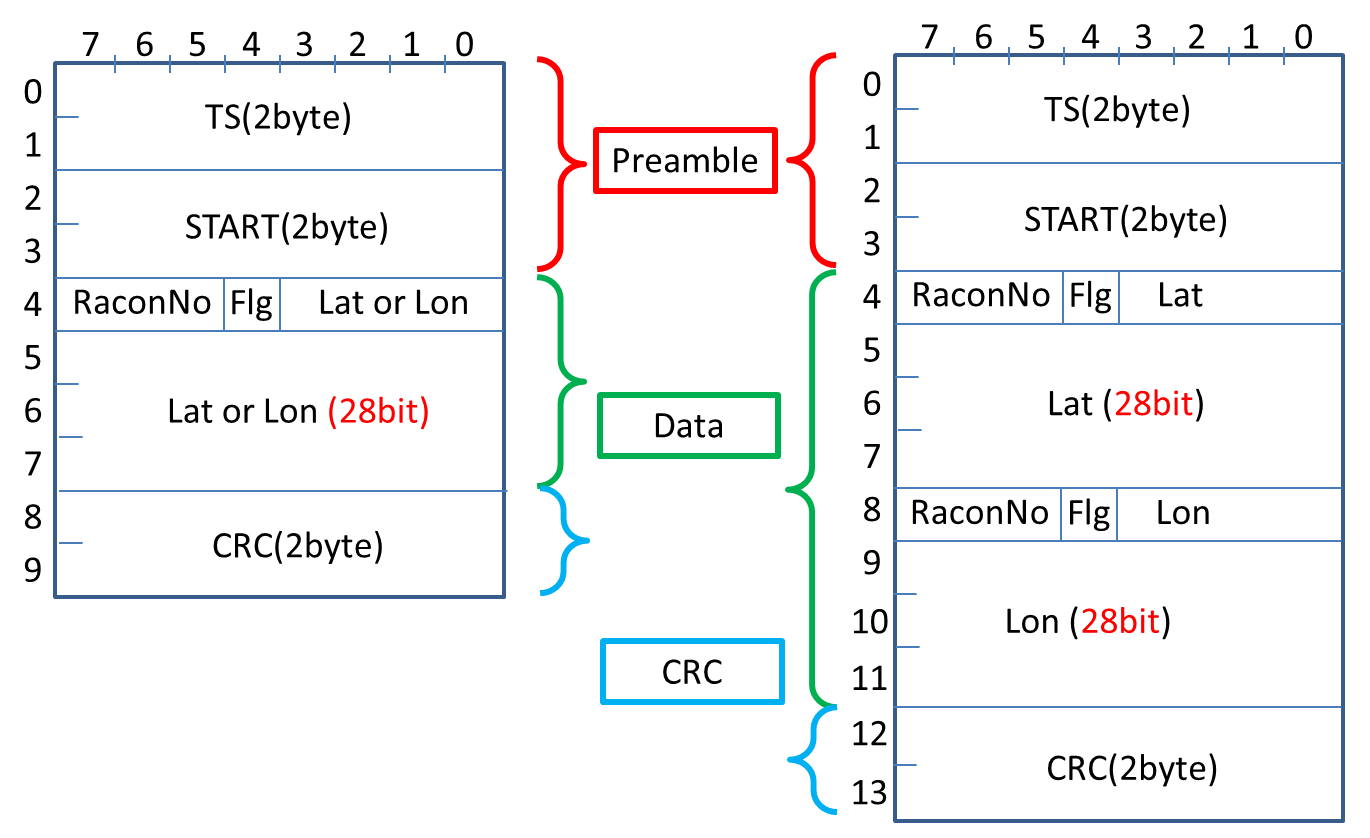
Data packets use FSK modulation. Transmission at the carrier frequency indicates no data.

Each format has Preamble, Data and CRC fields.

1. Format Fields

The following figure shows the data format. Data is “Big Endian” with the MSB shifted out first. The Preamble includes 16 training bits and a 16-bit start word. RaconNO is a 3-bit id code for the eRacon and runs from 0 to 7. Flg is 1-bit and indicates latitude with 0 and longitude with 1. The position is represented in a 28-bit signed word, scaled as minutes times 10000; North and East are positive, South and West are negative. The non-alternating format holds two data fields. A 16-bit CRC checks the Data only.

When transmitted, the Data and CRC fields are 4B5B encoded, and the entire packet is NRZI(Mark) encoded. 0 bits are indicated by the carrier frequency minus the frequency deviation and 1 bits are indicated by the carrier frequency plus the frequency deviation.



1. Specifications

|  |  |  |
| --- | --- | --- |
| Name | Value | Descripiton |
| ID Code | 0 - 7 | Code that identifies which eRacon transmitted the packet |
| Symbol Length | 200 nsec | Length of one bit |
| Frequency Deviation | 15 MHz | Zero is carrier minus deviation; One is carrier plus deviation |
| Training Bits | 0xFFFF |  |
| Start Bits | One of 0x7591, 0x9EB2, 0x47AC, 0xC8F5, 0xD9E1, 0x5647 | Start bits have no data significance |
| Position (Latitude or Longitude) | 28-bit signed number | Position in units of minutes \* 10000; North and East are positive, South and West are negative |
| CRC | CRC-16/IBM-3740 | Also known as CCITT-FALSE per <http://reveng.sourceforge.net/crc-catalogue> |
| Data Encoding | 4B5C | Per IEEE 802.3-2008 Section 24.2.2.1.1 Data Code Groups |
| Packet Encoding | NRZI(Mark) | Per IEEE 802.3-2008 Section 1.4.235 |

1. ERPS TRials

***We will add earlier trials during next session.***

During the ERPS trial in Singapore in 2015, conducted by the Maritime and Port Authority of Singapore (MPA), Furuno and Tideland, and the first in a busy harbour, the use of the eRacon in frequency agile mode (the normal racon mode, compared to fixed frequency mode) failed. This seemed similar to other reports of racons performing poorly in busy harbours, where limited to no response due to vessel position was an issue. To quantify this issue, an experiment to survey radar traffic was designed. A test eRacon was made available to capture the survey data. It was observed that radar frequencies seemed to be clumped around a small number of frequencies and there may be many radars on the same frequency.

This could be due to a limitation of magnetron production capabilities, which can be mitigated with the movement towards solid state radars. To enhance eRacon, two suggestions for solid state radar manufacturers would be to: a) use more of the frequencies within the band, and b) avoid repeatedly using the same frequency on a large number of radar units.

The trial also found that modulation of the eRacon signal can be visible on radar displays (e.g. “fuzzy” traces). Characteristics such as modulation frequency, modulation depth and data bit rate affected the display. Further study is needed to minimize display effects due to modulation.

Also observed was a geometric error similar to the Horizontal Dilution of Precision (HDOP) for GNSS. This is caused by overlapping azimuthal measurement errors. In many waterways, there will be a need to carefully plan the deployment (number and placement) of eRacons in order to minimize errors of this type.

As vessels approach eRacons, the elevations of the eRacon and eRadar antennas may need to be included in the calculation for a more accurate position. For instance, with a relative elevation difference of sixty meters, at one nautical mile separation, position error could be about one meter. Further study is also needed to determine if, and how, antenna elevation correction is needed.

From the 1st trial using a single eRacon, achieving a dynamic accuracy of 55m to the most recent trial using five eRacons – utilising three eRacons for the calculation of location at any one time – and achieving a dynamic accuracy of 26m, the project team is encouraged by the results of the successful trials. Interested parties are encouraged to work together to promote the development of a standardized independent complementary electronic positioning system to the GNSS to enhance navigation safety in confined waters.

Reference IALA test beds….

Body text (To assist in the use of this guideline, the following acronyms and definitions have been used: GNSS IMO PNT)

Body text (left justified)

Body text (left justified)

1. List 1.
2. List1.

List 1 text (for subsequent text at the same level).

1. List 1:
   1. List a.
   2. List a.

List a text (for subsequent text at the same level).

* 1. List a:
     1. List i.

List I text (for subsequent text at the same level).

* Bullet 1;

Bullet 1 text (for subsequent text for the same bullet).

* Bullet 1:
* Bullet 2;

Bullet 2 text (for subsequent text for the same level).

* Bullet 2:
* Bullet 3;

Bullet 3 text (for subsequent text for the same level)

* Bullet 3.

# Example Heading level 1

Body text

## (Example Heading level 2)

Body text

1. Geographical range

Where:

*Rg* is the geographical range (nautical miles) (alternatively NM)

*ho* is the elevation of observer’s eye (metres) (alternatively m)

*Hm* is the elevation of the mark (metres) (alternatively m)

### (Example heading level 3)

Body text.

1. Theory of Special Relativity

Where:

*E* is the kinetic energy (Joules) (alternatively J)

*m* is the mass (kilograms) (alternatively Kg)

*c* is the speed of light (metres/second) (alternatively m/s)

#### (Example heading level 4)

Body text.

# Example Heading level 1[[1]](#footnote-1)

Body text. Bullets have only one sentence. Anything further needs to appear in the relevant 'bullet text' style.

* Bullet 1:
* Bullet 1:
* Bullet 1.

## TABLES

Body text

1. Example of a table caption; table with the significant information in the first column

|  |  |
| --- | --- |
| Table heading | Table text |
| Table heading | Table text |
| Table heading | Table text |
| Table heading | Table text |
| Table heading | Table text |
| Table heading | Table text |

1. Example of a table caption; table with the significant information in the first row[[2]](#footnote-2)

|  |  |  |
| --- | --- | --- |
| **Table heading** | Table heading | Table heading |
| Table text | 1. Table List 11    1. Table list a   Table list i | Table text |
| Table text | Table text | Table text |
| Table text | Table text | Table text |
| Table text | Table text | Table text |

Example of ‘normal text’ following a Table

1. Example of a table caption; table with coloured rows

|  |  |  |
| --- | --- | --- |
| Table heading | Table heading | Table heading |
| Table text | Table text | Table text |
| Table text | Table text | Table text |
| Table text | Table text | Table text |
| Table text | Table text | Table text |
| Table text | Table text | Table text |
| Table text | Table text | Table text |

**Note:** Colours for text and cell shading need to be selected from the permitted palette (see ANNEX C)

# FIGURES



1. Example figure caption



1. Another example figure caption

# DEFINITIONS

*Suggested text:* The definitions of terms used in this IALA Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at <http://www.iala-aism.org/wiki/dictionary> and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

# ACRONYMS

IMO International Maritime Organization (Acronym style)

# REFERENCES

1. Abcd
2. Efgh
4. 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

1. Example footnote [↑](#footnote-ref-1)
2. Example of footnote [↑](#footnote-ref-2)