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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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# 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.

1. Results of August 2017 Sea Trials

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | One eRacon | | Two eRacons or Best Two of Three | | 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 the provision of resilient PNT services 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.

1. Typical ERPS System

## INTERNATIONAL ACTIVITY

There have been a number of ERPS sea trials in Denmark, UK and Singapore, sponsored by the EU EfficienSea project, the EU ACCSEAS project and by the Maritime and Port Authority of Singapore. ERPS has also been the subject of a number of IALA input papers, two IALA Conference presentations and e-Navigation Underway conference presentations. More Information on the various sea trials can be found in Annex B and at the IALA Testbeds web site: <https://www.iala-aism.org/technical/e-nav-testbeds/>.

One of the aims of this Guideline is to further inform mariners and manufacturers alike about ERPS Technology. 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.

To aid the standardisation, the signal specification that was developed during the tests has been included as Annex A. The draft signal specification is offered as a starting point for further developments and standardisation.

## RESILIENT PNT AND BACKUP SYSTEMS

GNSS has been widely recognised as the primary Position, Navigation and Timing (PNT) data source. However, its vulnerabilities, which could lead to GNSS outage or provision of erroneous PNT information and make GNSS-dependent navigation systems unable to provide the expected performance, have been identified. . IMO, in its e-Navigation Strategy Implementation Plan (MSC.1/Circ.1595) identified 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 alternative techniques that do not share the failure modes of GNSS. In the case of GNSS outage or malfunction, the alternative system can provide PNT services.

IALA defines [reference to be added] three categories of alternative PNT systems, redundant, backup, and contingency systems. These categories are defined by the level of performance provided by the alternative system and the time for which that performance is maintained. Based on this categorization, ERPS is not capable of providing a redundant service for GNSS, because it would not provide timing, but it could be designed to provide a backup or contingency positioning service, 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.

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 SYSTEM

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 the 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.

Knowing the measured azimuth and range (distance) of the eRacon targets, and the received position (latitude, longitude and elevation) of the eRacons, 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 vessel. No other external data is needed.

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ERPS uses WGS84 datum.

# 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.

ERPS for use in harbour entrance, harbour approach and coastal waters navigation areas. Due to the need to have at least one eRacon in view, ERPS is unsuitable for use in Ocean waters. ERPS can be useful for navigation around or across windfarms and oil fields.

1. PNT System Performance Requirements

|  | 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

The ability of ERPS to provide performance to these requirements has not been evaluated.

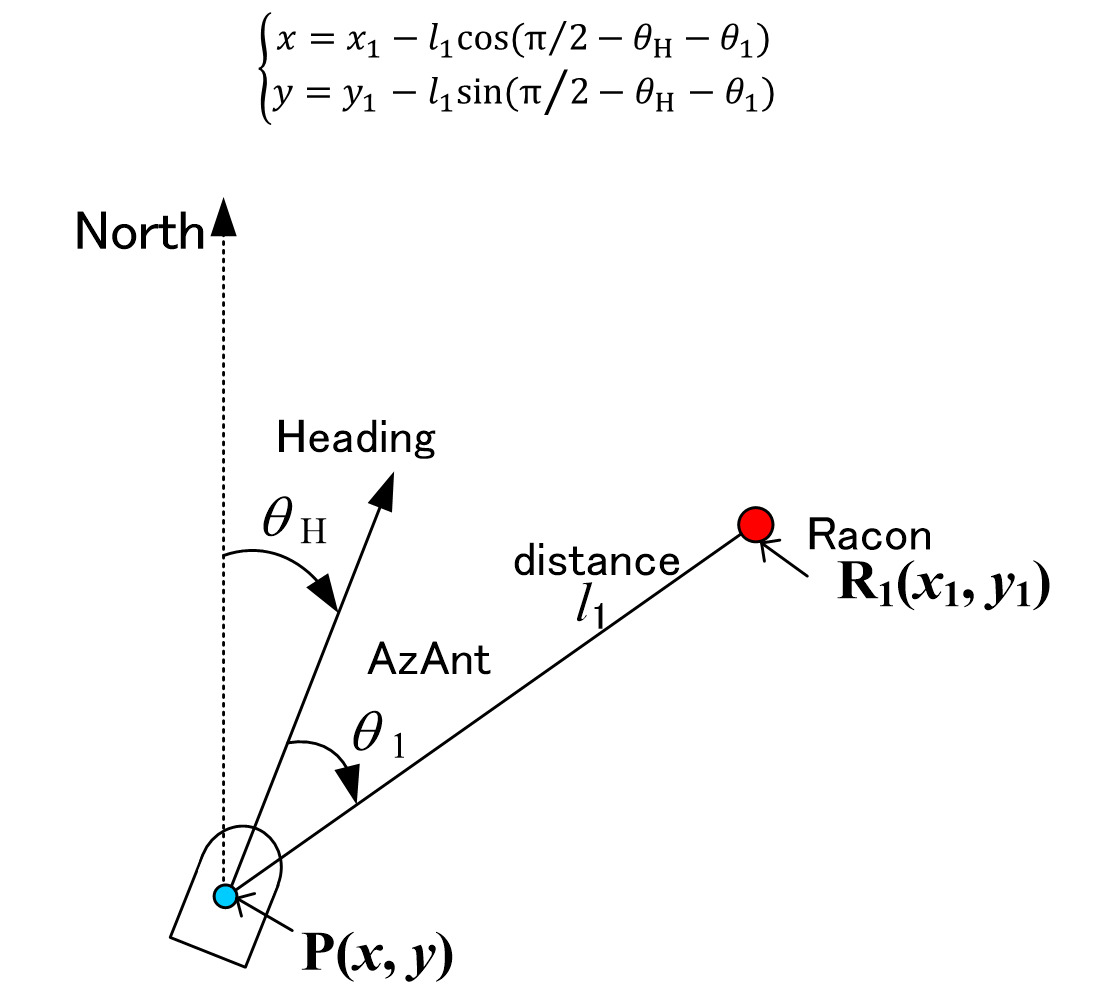
Establishment of guidelines for eRacon and eRadar interoperability will provide a framework for utilisation of ERPS and is a steppingstone to international standardization of ERPS.

# TECHNOLOGY

Knowing the measured azimuth and range of the eRacon targets, the speed and heading of their own vessels. their own antenna elevation and rotation characteristics, along with the received positions (latitude, longitude and elevation) of the eRacons, eRadars calculate and report positions for their own vessels.

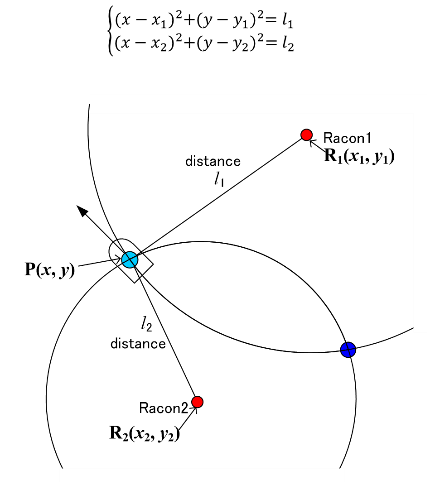
## SOLUTION CALCULATIONS

### One eRacon Solution



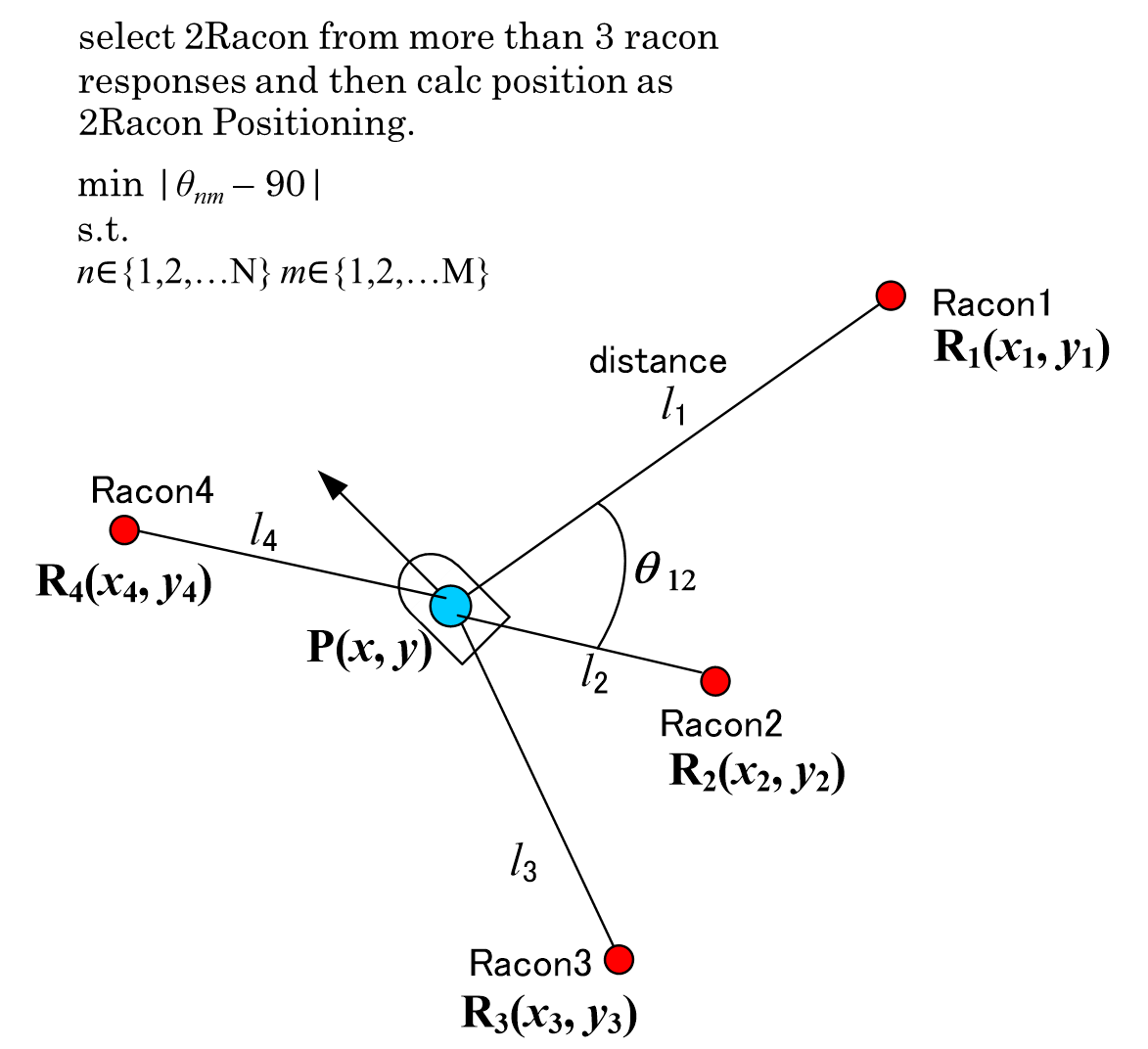
1. One eRacon Solution

### Two eRacon Solution



1. Two eRacon Solution

### Two of Three eRacon Solution



1. Two of Three eRacon Solution

Each illustration needs description.

# INSTALLATION

eRacons can be installed at any location that would normally be chosen for a racon. eRacons will appear as normal racons when interrogated by non-ERPS radars. Sites should be chosen per existing racon recommendations and guidelines.

Position solutions are dependent on geometry among the eRadar and eRacons. The problem is similar to Horizontal Dilution of Precision (HDOP) for GNSS systems. Wikipedia gives this definition:

“Dilution of precision (DOP), or geometric dilution of precision (GDOP), is a term used in satellite navigation and geomatics engineering to specify the Error propagation as a mathematical effect of navigation satellite geometry on positional measurement precision.”HDOP is specific to the horizontal position solution.

To improve geometry, additional eRacon sites may be needed to give good geometry to a high number of likely eRadar positions.

The following figures illustrate good and bad geometries:

Need illustrations for good and bad geometry.

# LIMITATIONS

Lack of standardization.

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

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

Length of time for recapitalisation

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

Is authentication of eRacon signal required? How are keys distributed?

Is globally unique AtoN ID needed (reference recent work by ARM). Will be required for authentication.

Which band(s)

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.

Add these terms to dictionary:

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

HDOP Horizontal Dilution of Precision

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 eRadar and eRacon Sea Trials August 2017
5. IALA R1017 Resilient Position, Navigation and Timing (PNT)
6. IALA R-101 Marine Radar Beacons (Racons)
7. IALA G1010 Racon Range Performance
8. IALA e-NAV-146 Strategy for Maintaining Racon Service Capability
9. ENAV17-13.16 Singapore eRadar/ eRacon Trials\
10. ENAV18-6.9 Trial results of Radar Positioning in Singapore for resilient positioning
11. ENAV19-13.12 Singapore eRadar and eRacon Sea Trials October 2015
12. IALA R-129 GNSS Vulnerability and Mitigation Measures
13. 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. To date, sea trials have included a pulse-type radar. Other approaches utilising swept frequency capabilities for pulse compression (is this aka FMCW?) are also being tested by eRacon and eRadar manufacturers.

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 several 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.

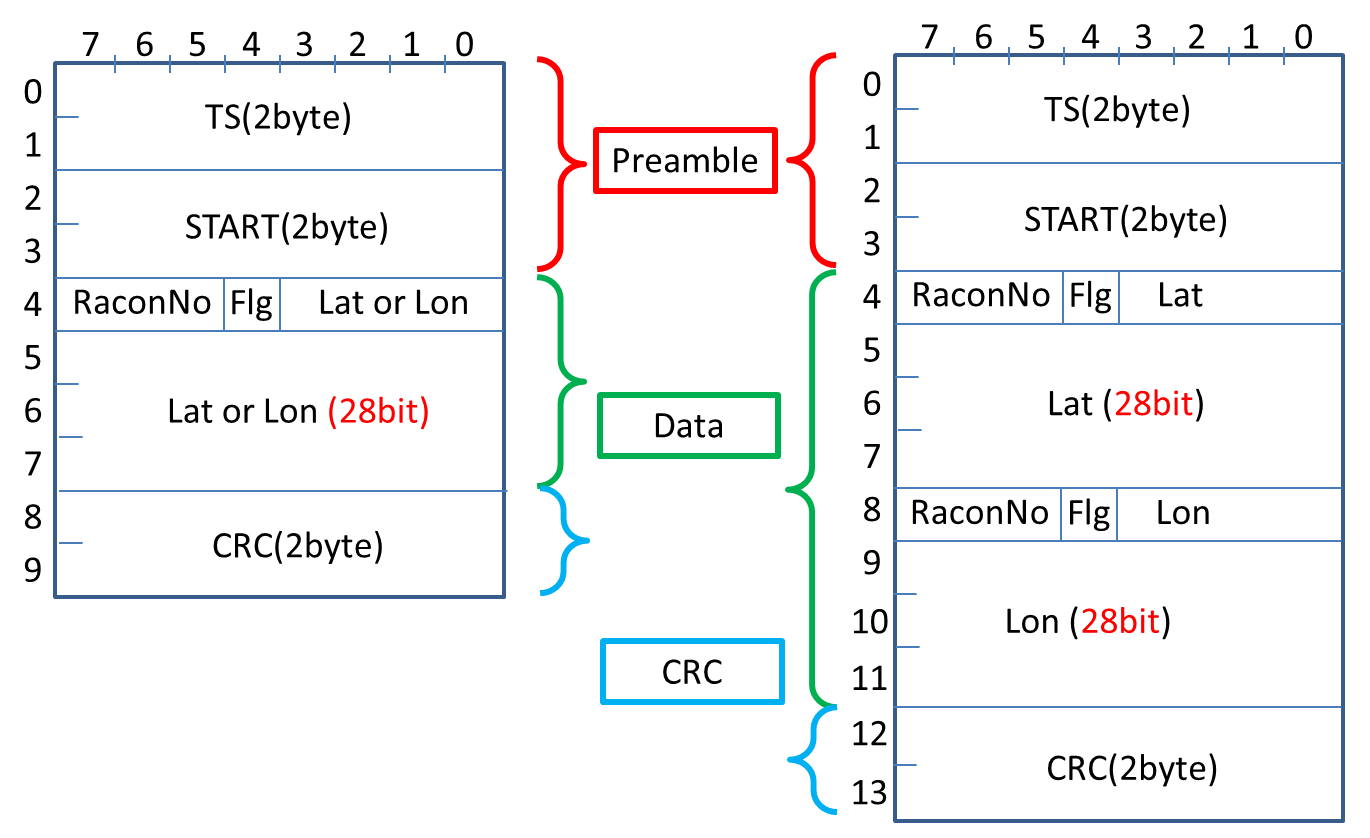
Data packets use FSK modulation. Transmission at the carrier frequency indicates no data.

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. Zero is indicated by the carrier frequency minus the frequency deviation and one is indicated by the carrier frequency plus the frequency deviation.



1. Specifications

|  |  |  |
| --- | --- | --- |
| Name | Value | Description |
| 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….