



IALA GUIDELINE

GNNNN THE USE OF ENHANCED RADAR POSITIONING SYSTEMS

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1. INTRODUCTION

Radar has traditionally 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 [1] using three eRacons demonstrated dynamic absolute position differences of better than 27 metres compared to Real Time Kinetic position solutions, and accuracies of 2.5 metres with the vessel berthed.

Table 1 Results of August 2017 Sea Trials

Trial Phase	One eRacon		Two eRacons or Best Two of Three		Best Available	
	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 R1017 [2], by introducing ERPS, detailing the system to aid interoperability, outlining practical issues, and defining the next steps in the process to adopt ERPS use.

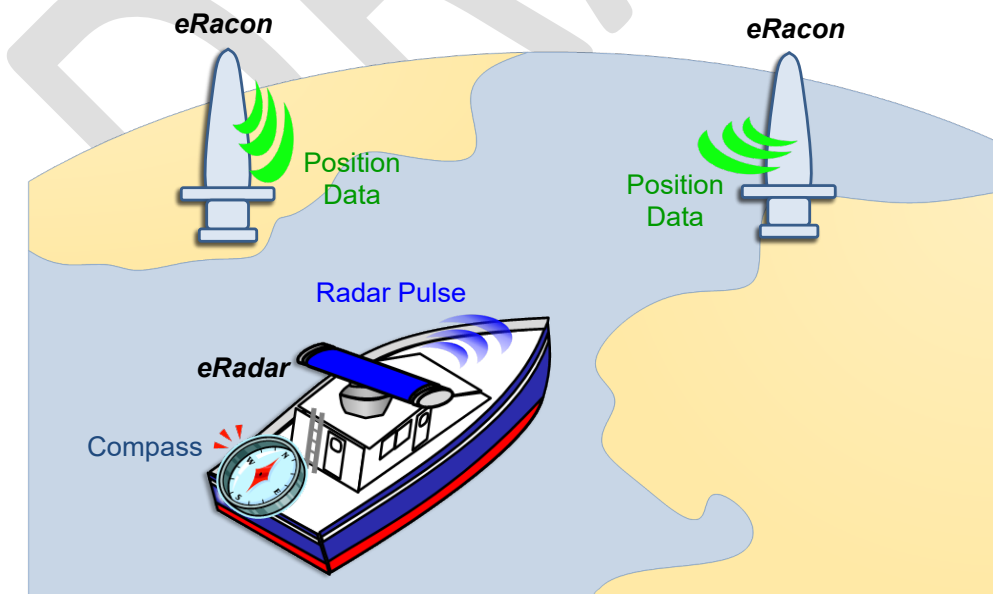


Figure 1 Typical ERPS System

1.1. 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 papers [1][2][3][4][5][6], two IALA Conference presentations [7][8] and e-Navigation Underway conference presentations.

The aim of this Guideline is to further inform the international community, mariners, and manufacturers alike, about ERPS Technology. Trials to date have been conducted by a limited set of participants and it is recognized that international standards are required to ensure interoperability between eRacon and eRadars developed by different manufacturers.

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

1.2. 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”. 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 [9] 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 local backup 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 *R1017 Resilient Position, Navigation and Timing*, Edition 1, 2018 [4] and subsequent guidelines.

1.3. 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. 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 eRacon, 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 positions can be calculated with no previous knowledge of the positions of the vessel. No external data other than from the eRacons are needed.

Calculated positions can be transmitted to the connected navigation systems, such as ECDIS, through standard NMEA sentences.

ERPS uses WGS84 datum (World Geodetic System 1984, describing the coordinate system used by GNSS).

2. 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 is suitable for use in harbour entrance, harbour approach and coastal waters navigation areas (please see reference [2] for guidance on use in busy harbours). 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.

Table 2 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 comply with all the IMO performance 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.

3. 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.

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

The sections that follow illustrate solution calculations.

3.1. ONE ERACON SOLUTION

$$\begin{cases} x = x_1 - l_1 \cos(\pi/2 - \theta_H - \theta_1) \\ y = y_1 - l_1 \sin(\pi/2 - \theta_H - \theta_1) \end{cases}$$

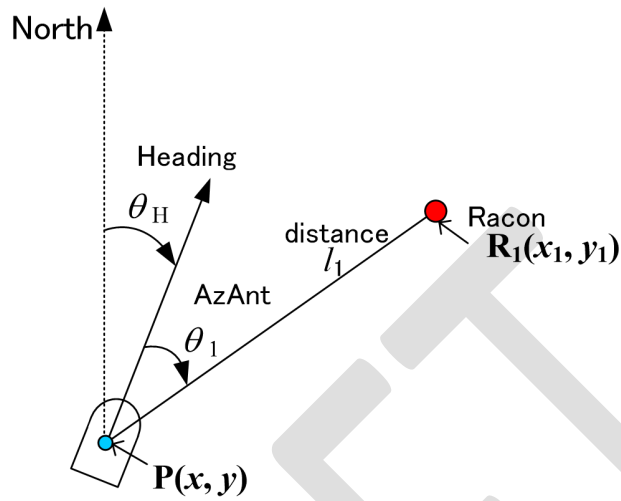


Figure 2 One eRacon Solution

In this case, the eRadar sees only one eRacon, but can use its own true heading to calculate a position solution.

3.2. TWO ERACON SOLUTION

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = l_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = l_2^2 \end{cases}$$

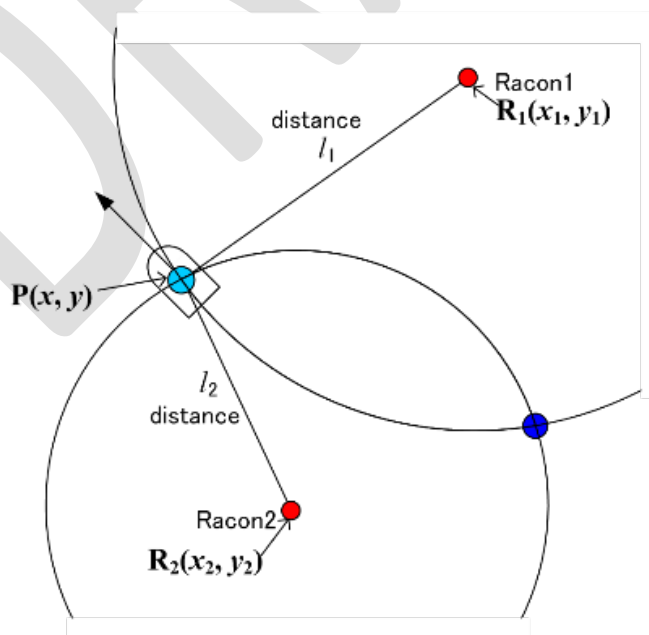


Figure 3 Two eRacon Solution

With two eRacons, the radar calculates a position solution that is independent of the heading of the vessel. To note, this example shows the use of Pythagoras' Theorem with target ranges to calculate two possible solutions. Target azimuths are used to discriminate between the two solutions.

3.3. TWO OF THREE OR MORE ERACON SOLUTION

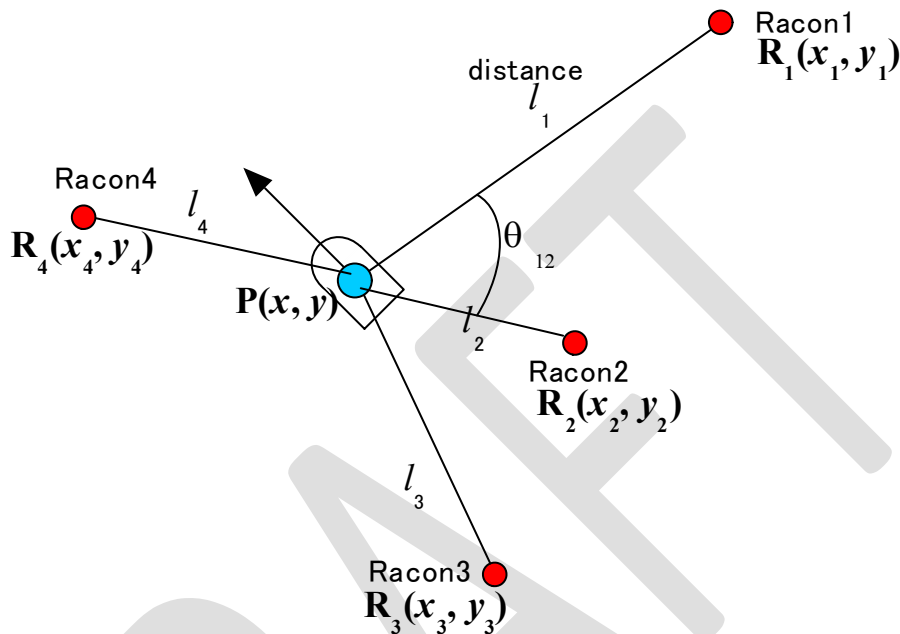


Figure 4 Two of Three eRacon Solution

With more than two eRacons, the eRadar choose the two that provide the best solution (please refer to geometry discussion in Section 4). Once the two best are selected, then a position solution can be calculated similarly to the two-eRacon example. In this example, possible good solutions might use Racon 1 and Racon 4, Racon 4 and Racon 3, Racon 1 and Racon 2, Racon 2 and Racon 3, or Racon 1 and Racon3. Using Racon 4 and Racon 2 shows worst case geometry.

4. INSTALLATION

eRacons can be installed at any fixed 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 [10][11].

Position solutions are dependent on geometry among the eRadar and eRacons. The geometric limitation of Horizontal Dilution of Precision (HDOP) will apply.

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

5. CHALLENGES

There are two categories for challenges in the realization of ERPS: Acceptance and Standardisation.

IALA hosted the Workshop on Enhanced Radar Positioning System (ERPS) Standardization in December 2021. The report of this workshop [13] discusses many of the challenges in realizing ERPS.

5.1. ACCEPTANCE CHALLENGES

This category includes regulatory and economic issues that may affect the acceptance of EPRS as not only a useful system in and of itself, but also as a resilient PNT solution. This category includes the need for international agreement to standardisation.

- International bodies, users and service providers need to accept ERPS as a viable PNT solution and as a resilient PNT solution.
- It needs to be confirmed that current world-wide radio regulations allow the use of EPRS in the maritime radar bands. The introduction of new modulation and additional transmitted data may indicate a change of use (positioning vs. data communication).
- Usage in each maritime radar band (9.4 GHz – X-Band and/or 3.0 GHz – S-band) needs to be confirmed.
- ERPS shall comply with all the IMO performance requirements.
- A lengthy recapitalization (twenty years or more) will delay initial availability of the system. Users and service providers need to be prepared for this.
- There is a lack of standardization on how radars and racons work together. With no standardisation (formal or ad-hoc), there can be no interoperability. Items that need standardisation include radar and racon modulation, over-the-air protocol, timing, etc.
- Interaction with relevant international organisations needs to be initiated. Organisations may include IMO, ITU, CIRM, IEC, RTCM, NMEA, IHO, etc.

5.2. STANDARDIZATION CHALLENGES

This category includes standardisation issues that need to be solved.

- Mathematics describing operational envelope and expected performance need to be finalised. Motions of the radar antenna and the vessel and other error terms need to be identified and compensated for.
- Requirement for authentication of eRacon signal needs to be decided. Key distribution needs to be solved. Options could be open signal and an authenticated signal.
- Globally unique AtoN ID is preferred [12]. Unique ID will be required for authentication.
- Difficulties in busy harbours are from the same sources as for regular racons - e.g., blocking by vessels and structures, poor geometry, reflections from vessels and structures, radar frequency issues, large number of radars, etc. [6]. Refer to other IALA documents for use and installation of racons in general [10][11].
- “Fuzzy” radar display images – because of interactions between the modulation of the racon returns and radar input filters, pulse radars can show the racon return lines as fuzzy or striped. There may be modulations schemes that can minimize the effect on pulse radars.
- Requirement to capture and distribute integrity information needs to be decided. Methods for doing so need to be finalized.
- Interoperability with marine radars transmitting using traditional pulse, FMCW (frequency modulation continuous wave) and pulse compression modulations must be assured.

6. 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.

7. ABBREVIATIONS

CIRM	Comité International Radio-Maritime
ECDIS	Electronic Chart Display and Information System
ERPS	Enhanced Radar Positioning System
EU	European Union
GNSS	Global Navigation Satellite System
HDOP	Horizontal Dilution of Precision
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organization
IMO	International Maritime Organization
NMEA	National Marine Electronics Association
PNT	Position Navigation and Timing
NMEA	National Marine Electronics Association
RTCM	Radio Technical Commission for Maritime Services
WGS84	World Geodetic System 1984

8. REFERENCES

- [1] ENAV21-13.10 Singapore eRadar and eRacon Sea Trials August 2017
- [2] IALA R1017 Resilient Position, Navigation and Timing (PNT)
- [3] ENAV17-13.16 Singapore eRadar/ eRacon Trials
- [4] ENAV18-6.9 Trial results of Radar Positioning in Singapore for resilient positioning
- [5] ENAV19-13.12 Singapore eRadar and eRacon Sea Trials October 2015
- [6] ENAV20-13.11 On Racons in Busy Harbours
- [7] IALA Conference 2014, Advances in Radar Aids to Navigation
- [8] IALA Conference 2018, Enhanced Radar Positions Systems for Resilient Positioning
- [9] IALA R0129 GNSS Vulnerability and Mitigation Measures
- [10] IALA R0101 Marine Radar Beacons (Racons)
- [11] IALA G1010 Racon Range Performance
- [12] IALA G1143 Unique Identifiers for Maritime Resources
- [13] ENG15-3.2.8 Final Report on the IALA Workshop on Enhanced Radar Positioning System Standardization

9. FURTHER READING

IALA Recommendation *R0146 Strategy for Maintaining Racon Service Capability.*

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ANNEX A 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 solid-state radar operated using unmodulated pulses emulating a magnetron radar.

A.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.

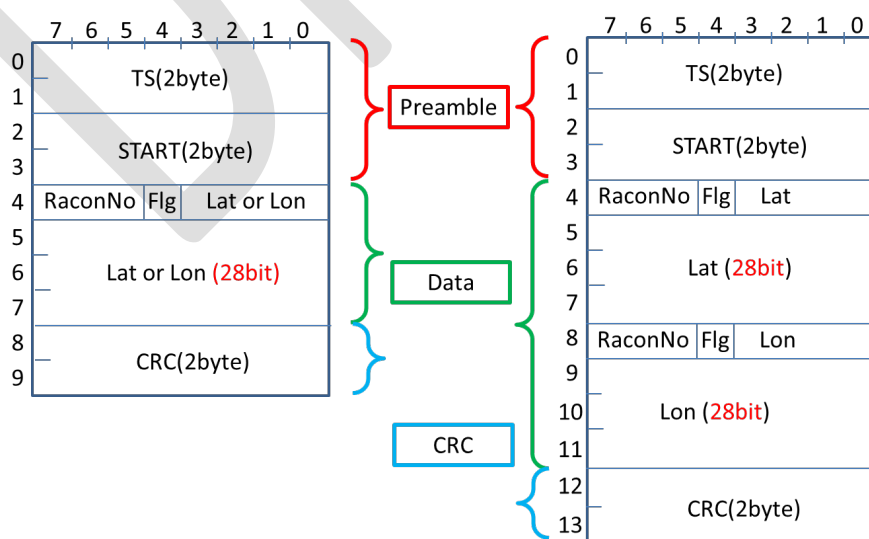
Data packets use FSK modulation. Transmission at the carrier frequency indicates no data.

Each format has Preamble, Data and CRC fields.

A.2. 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.



A.3. 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