Modern Racons for Modern Radars

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ABSTRACT

Modern solid-state radars use modulation techniques that can confuse existing racons, especially in busy areas. There is a need for the development of modern racons that can work with modern solid-state radars and improve performance in busy areas.

In addition, the reliance of on Global Navigation Satellite Systems (GNSS) and their vulnerabilities are well known. The need for GNSS independent positioning capability is also widely recognized and there is an opportunity to use modernized radar and racons in this regard.

A system known as Enhanced Radar Positioning System (ERPS) uses specially designed racons (eRacons) with specially designed radars (eRadars) to allow radars to automatically calculate their absolute position. In this system, eRacons provide their surveyed absolute position encoded on their response signals to eRadars, which use these signals, along with measured range and bearing, to calculate their own vessels' absolute positions. The system is independent from GNSS. This system is simple to implement on modern radars and racons and should be included in any modern racon discussion.

This paper discusses the need for standardization of racon and radar features that are needed to allow the further development of ERPS and modern racons. Standardization is needed to assure the future use of racons.

KEYWORDS: racon, radar, ERPS, resilient PNT

ABSTRACT (FRENCH)

ABSTRACT (SPANISH)

1 INTRODUCTION

At some point in time, the type of racons installed today will no longer be usable. Eventually, modern marine radars will replace the traditional magnetron radars in common use today. This paper focuses on radars and racons in the 9400 MHz band, as they are most useful for close-in, port, harbour, berthing and inland waterway operations. Radars and racons in the 3000 MHz band have similar issues and solutions but are not discussed specifically. A modern radar is one that uses a solid-state transmitter, modulated to give best performance[1]. The purpose of this paper is to offer a way forward for continued use of racons.

[1] Compare to traditional radar with magnetron vacuum tube transmitter and pulse modulation.

Every evolution and change in technology has the potential to introduce new challenges and issues, over and above those it resolves. Some technical challenges are introduced in Section 2, while

Section 3 discusses regulatory issues, including the International Maritime Organization (IMO) call for more resilience in Positioning, Navigation and Timing (PNT) systems and how radars and racons contribute to higher resilience.

Section 4 discusses using radar for automatic absolute positioning. Two systems are introduced, Enhanced Racon Positioning System (ERPS) and radar terrain matching.

2 TECHNICAL CHALLENGES

This section illustrates technical challenges in three areas:

- racon side lobe suppression – this is an important racon feature to help prevent false triggering of the racon and confusing radar displays; racons are useless without this feature
- range limitations using solid-state radars – such transmitters operate at lower transmitted power than traditional magnetron transmitters which reduces the detection range of the racon
- modulation used by modern radars – current racons expect pulse modulation and there are no set standards for the modulation employed

2.1 Racon Side Lobe Suppression

Side Lobe Suppression (SLS) is a required feature for racons. The term “side lobe” refers to any signal lobe of a non-ideal radar antenna that is not the “main lobe”. The main lobe signal is used by the radar for ranging. The purpose of SLS is to prevent the racon from transmitting to any signal but the main lobe from the radar antenna. The reason it is needed is the combination of powerful radar transmitter, non-ideal radar antenna and sensitive racon receiver can result in a signal that the racon can respond to when the radar antenna is pointing away from the racon. In some cases of close-in operation, a racon without SLS can respond to nearly every pulse of the radar[2].

SLS works by measuring the signal strength of the transmission from a radar and only responding to the most powerful received signals from that radar. Individual radars are identified by various methods, including frequency, pulse width and radar antenna sweep period.

Figure 1 shows radar signals captured during an interval of time. There appear to be three radars operating here. The more obvious is the radar with an antenna period of about 2.6 seconds and peak amplitude about -34 dBm. There also appears to be two other radars – one at a period of about 2 seconds with amplitude of about -30 dBm, the other at about 4.5 seconds period and -23 dBm amplitude. In this case, SLS would block the 2.6 and 2 second period radars because the 4.5 second period radar has a higher amplitude.

[2] A racon without SLS is more of a radar jammer than a useful aid to navigation.

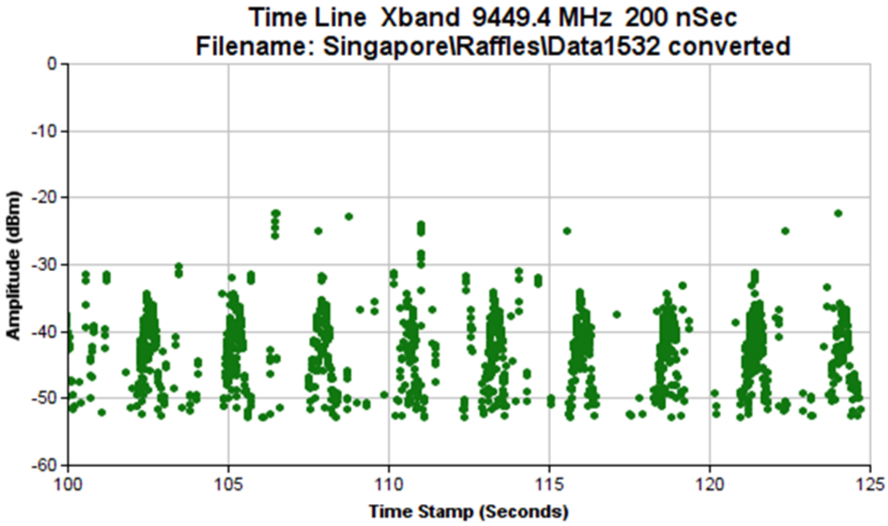

Figure 1 Radar Signals over an Interval of Time

2.1.1 Radars in Busy Harbours

There has been anecdotal evidence of poor performance of racons in busy harbours. Some radars see racons intermittently or not at all. This was studied in the port of Singapore in 2017. Please see "On Racons in Busy Harbours" [1]. Radar traffic was monitored by measuring radar pulse frequency and pulse width along with a time stamp. Figures 1, 2 and 3 are taken from the Singapore study report. The study showed that most problems are related to SLS and are caused by many radars transmitting at the same frequency. This was not unexpected, knowing that many radar magnetron devices are manufactured to the same frequency. Figure 2 shows a map of radar frequencies and pulse widths over for an interval of time. The clumping of radar frequencies is apparent.

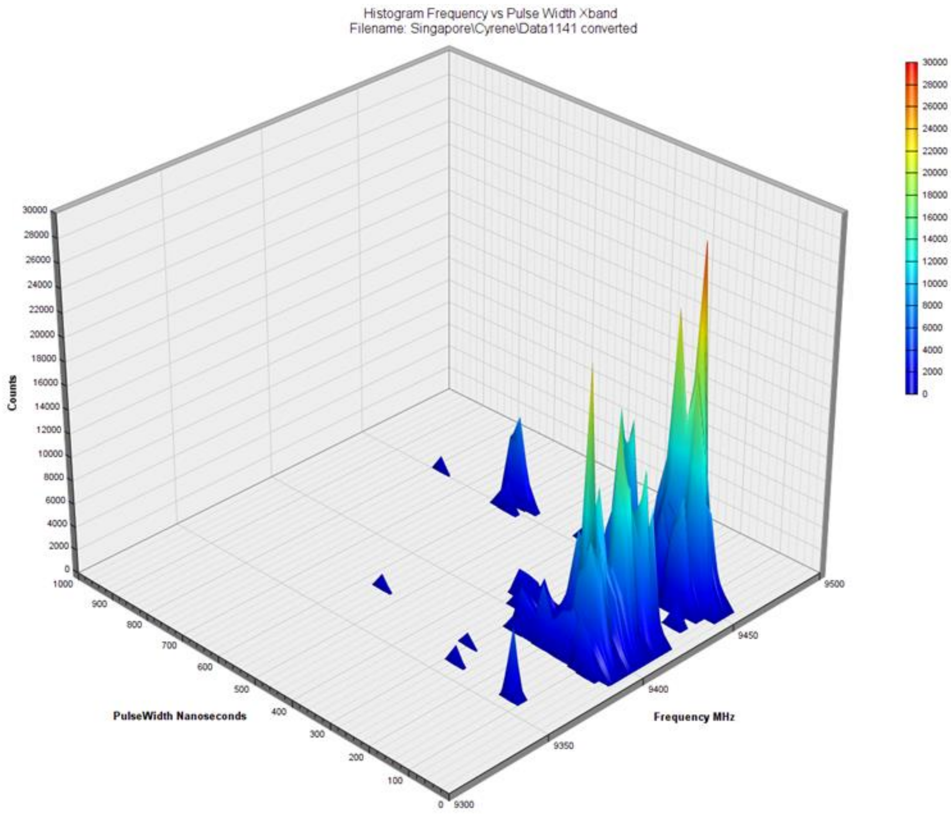

Figure 2 3-D Histogram of Radar Frequencies

Figure 3 shows a slice through Figure 2 at one pulse width.

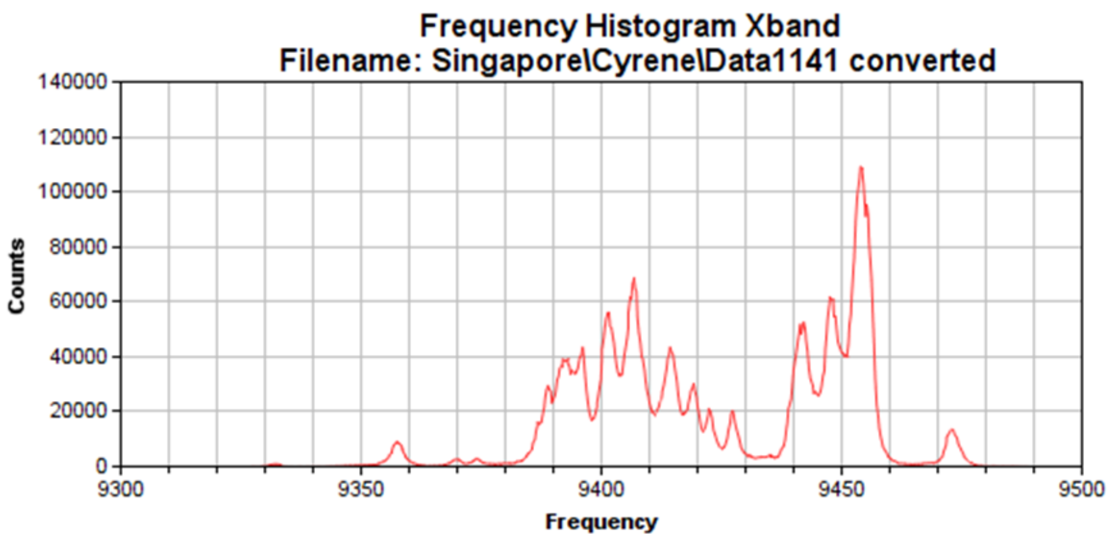

Figure 3 Frequency Histogram at One Pulse Width

These figures show that many racons are broadcasting on the same frequency, which means that while one vessel's radar may trigger the racon, other vessels with a radar that looks similar in the radio frequency domain, do not trigger the racon, and therefore do not get the use of that AtoN.

2.1.2 Gets Worse with Solid-State Radars

Most magnetrons are delivered to a radar manufacturer at a specified nominal frequency, with many using the same design. The manufacturer may have bought tens of thousands at the same nominal frequency which are installed in radars all over the world. The frequency peak shown in the figure above has been verified by Furuno to be the frequency they specify. SLS works, though poorly, because manufacturing tolerances spreads the actual frequency of the magnetron so that they are not all on the exact same frequency.

Consider that solid-state transmitters can be set to an exact frequency. The worst case is all radars, from all manufacturers, are set to the same frequency. In a busy harbour (or anywhere there are multiple radars operating) only one radar will be serviced by the racon due to SLS. The solution is for the manufacturers to set each radar transmitter to a different frequency.

2.1.3 The 9400 MHz Band

IMO "*Resolution MC/192(79) Adoption of the Revised Performance Standards for Radars*" [2] and International Telecommunication Union (ITU) "*Recommendation ITU-R M.824-4*" [3] recognize the full marine radar band to range from 9200 to 9500MHz. The addition to the band of 9200 to 9300 MHz was made many years ago. To the authors' knowledge, there are no marine radars operating in 9200 MHz part of the band. Likewise, the authors know of no racon servicing the 9200 MHz part of the band. Radar and racon manufacturers need to agree on whether to use the full band, or not.

2.2 Range Limitations Using Solid-State Radars

Solid-state radars transmit at lower power than magnetron radars. This reduces the signal strength at the racon antenna, which reduces the detection range of the racon. The actual reduction can be quite a large value, but the practical result may not be that bad.

In 2009 the General Lighthouse Authorities of UK and Ireland (GLA) conducted a trial onboard the Irish Lights vessel Granuaile comparing the performance of a solid-state radar to a magnetron radar. The trial report, "*Second Racon Trials with NT Radar*" [4] concluded that the solid-state radar did have a reduced range, as expected. The GLA data indicate that:

- Range reduction severely limits the usability of racons for land fall; range is reduced to less than radio horizon
- In port and harbour operation, radio horizon is quite close, especially when racons are mounted to buoys; detection range for racons with lower receiver sensitivity may be less than radio horizon; detection range for racons with higher receiver sensitivity may be as far as radio horizon

One conclusion is that racons with higher receiver sensitivity can perform adequately with solid-state radars in port and harbour operations.

2.3 Radar Modulation

There are no standards for the modulation that radars can use. Each manufacturer may choose the modulation they think best and have no desire to publish details of their intellectual property. This is a difficult environment for racon manufacturers.

One racon manufacturer appears to have reverse engineered the modulation from at least one radar and claims to respond to that and similar radars. There was a trial sponsored by China Maritime Safety Administration [5] with a different manufacturer that showed a racon working with a modern radar.

However, these solutions are in precarious positions, dependent on the whims of the radar manufacturers. What works today, may not work tomorrow. Clearly, some form of standardisation is required to ensure interoperability between the different racon and radar manufacturers.

2.4 The Way Forward – Standardisation

The move to solid-state radar technology has the potential to limit the performance of racons. There needs to be a coordinated approach to future radar operating conditions. The authors suggest radar and racon manufacturers initially take a voluntary approach to managing the spectrum. Contact between IALA and Comité International Radio-Maritime (CIRM) levels has been initiated. To recap, the following are basic issues to address:

- Frequency usage – at what frequencies within the band will radars operate; what diversity in transmission frequency can be provided
- How to signal racon – what modulations should racons expect
- How racons should respond – what modulations should racons use

3 REGULATORY ISSUES

3.1 Resilient PNT

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 "MSC.1/Circ.1595 *eNavigation Strategy Implementation Plan"* [6] 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.

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. The use of racons can aid the radar operator in the identification of fixed targets.

IALA "*Recommendation R1017 Resilient Position Navigation and Timing (PNT)*" [7] and "*Recommendation R0129 GNSS Vulnerability and Mitigation Measures*" [8] discuss resilient PNT.

3.2 IMO Carriage Requirements

IMO "*Resolution MSC.192(79) Revised Recommendation on Performance Standards for Radar Equipment*" require 9400 MHz radars to trigger and display racons, search and rescue transponders (SART) and radar target enhancers (RTE)[3]. With currently installed racons, modern radars might be unusable to satisfy this requirement because of modulation incompatibilities.

3.3 Radar and Racon Standards

There are no existing radar and racon interoperability standards. IMO "*Resolution A.615(15) Radar Beacons and Transponders*" [9] and *ITU-R M.824-4* are recommendations on what should happen, not how it should be done. The path to modern racons will require radar and racon standards to ensure interoperability. Modulation standards are needed to *allow* and *enable* interoperability.

3.4 Where to Start?

In 2021 IALA held a workshop to discuss Enhanced Radar Positioning Systems (ERPS is discussed in Chapter 4). Please see "*Workshop Report IALA Workshop on Enhanced Radar Positioning System Standardization*" [10]; many of the suggestions from the workshop regarding standardisation apply directly to the problems of modern racons.

4 AUTOMATIC RADAR ABSOLUTE POSITIONING SYSTEMS

As stated earlier in section 3.1, radar data can be used by a navigator to manually calculate the absolute position of the vessel. This is not a difficult calculation, but tedious and error prone to do manually. And the solution may be out of date before it can be used. Having the radar do the calculation automatically is an attractive and somewhat obvious solution. But a radar lacks absolute position references, which must be provided by some other party.

A system known as Enhanced Radar Positioning System (ERPS) uses specially designed racons (eRacons) with specially designed radars (eRadars) to allow radars to automatically calculate their absolute position. The system is independent from GNSS and can be considered as a resilient PNT solution per IMO. ERPS is a backup to GNSS. Please see IALA "*Guideline G1147 The Use of Enhanced Radar Positioning Systems*" [11]. This system is simple to implement on modern radars and racons and should be included in any modern racon discussion.

ERPS has been developed over many years and through several collaborative projects, including EU EfficienSea and ACCSEAS programs. These projects, along with additional development sponsored by the Maritime and Port Authority of Singapore, have demonstrated the concept works and that performance with accuracies of 27 meters can be achieved, recognising that this is affected by geometry and the number of eRacons in view.

It is interesting to note that ERPS does not require a modern radar as defined above. Any radar with digital or software defined receiver can be modified to use EPRS.

4.1 Description

ERPS is rather simple in concept and execution. eRacons provide their surveyed absolute position encoded on their response signals to eRadar interrogations,

eRadars use these signals, along with their own measured range and bearing, to calculate their own vessels' absolute positions. At least two eRacons are needed to get position solution.

If the eRadar can also use the vessel's heading (compass), position solutions can be calculated using only one eRacon. Figure 4 illustrates ERPS:

[3] SARTs and RTEs may have similar issues as racons. They are not discussed in this paper.

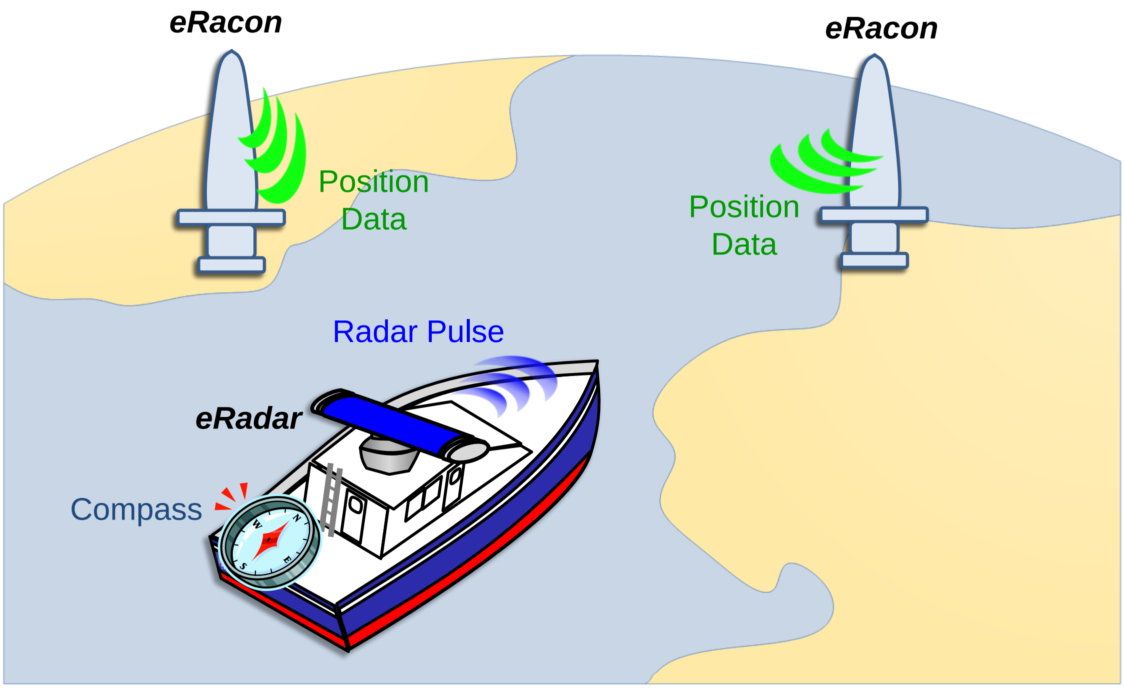

Figure 4 Enhanced Radar Positioning System

4.2 Map Matching

Terrain Matching is an alternative approach to absolute position determination using radar data. There are a number of potential approaches as discussed in [12], but the general concept is that the radar matches measured terrain features to a database of features and calculates absolute positions. This technique is a candidate for resilient positioning.

Although the technique does not necessarily require racons, racons can be included in terrain features databases and may be required where there are insufficient radar returns, for example in areas of low-lying coastline.

The two approaches are compatible and could be considered within the same standardisation process.

4.3 Regulatory Issues – Resilient PNT

The IMO, during the development of its e-Navigation SIP, recognised the need for resilient Positioning, Navigation and Timing. Vessels generally obtain their absolute positions from Global Navigation Satellite Systems (GNSS) which have known common vulnerabilities, and as such, the IMO support the use of multiple, dissimilar systems.

At the same time, radar is mandatory carriage on larger vessels and is typically fitted to most craft. Therefore, making use of this evolving technology is advantageous to the overall business case and supports its introduction.

Recognising that the ERPS concept may evolve further and has the potential to include the use of computational advances such as terrain database matching, the use of radar to support resilient PNT at sea is a beneficial and optimistic development.

4.4 Adoption

Adoption requires support from the radar and racon manufacturers.

Much standardization work needs to be done. IMO MSC.192(79) specifically allows radars to use other signals from racons. ITU radar performance M.824-4 may need to be updated. Other ITU radio regulations and documents may need to change to allow racons to transmit location information.

The IALA Workshop on ERPS mentioned in Section 3.4 was a good start at identifying the work to do.

5 CONCLUSIONS

The vessel's radar is a significant navigation aid, its evolution path to solid-state technology brings potential benefits through reduced power and the ability to provide data encoding to support resilient PNT, but there's a need to standardize the approach, to aid system interoperability and performance, and to support efficient management of the spectrum.

Automatic position determination is very attractive and seems to be easily added to radars and racons.

The authors invite IALA to hold a second ERPS workshop to further the work on modern racons. Attendance of radar and racon manufacturers would be extremely beneficial.

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