# 'Radar Transponders and Radar Target Enhancers'

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1. INTRODUCTION. The useful paper by Richard Trim in the September issue of the *Journal*[1] discusses the fixed frequency racon and its potentially clutter-free display, precluded from use by differential squint loss in slotted-array marine radar scanners. The fixed offset frequency mode of operation solved that problem fifteen years ago. Other forms of selectable racon not mentioned in the paper are also available, but none has yet been widely used. Radar designers wish to avoid the compromises forced by a need to receive racons on the main echo channel. Introduction of shipboard GPS (Global Positioning System) is altering the use made of racons. Now radar target enhancers (RTES) offer an alternative electronic detectability improvement method for buoys and weak targets generally. Their international technical specification is in draft form. The time is therefore ripe for integrated consideration of the future roles and specifications of racons and RTES.

2. FIXED OFFSET FREQUENCY RACONS. About 1980, frequency-agile racons (Fig. 5 of the Trim paper) were being introduced. Insertion of a bias in their frequency-control signal readily offsets the response. Instead of radar frequency or band edge, each reply is then made at a fixed offset from its interrogating radar's individual transmitter, sufficient to de-tune echoes and clutter.[2] This gives acceptable squint loss on all radars (as can be inferred from Fig. 5 of the paper), might not cause insuperable frequency allocation problems, and requires less bandwidth in the radar than the fixed-frequency mode. Brief details are included in reference 3.

With the ready co-operation of the Northern Lighthouse Board (NLB), the new mode was trialled for the International Association of Lighthouse Authorities (IALA). The X-band racon, of Marconi's 'Sea-Watch Accord' type, had relatively high antenna gain (10 dB), receiver sensitivity ($-78$ dBW) and response power (1 W). The Racal-Decca radar of NLB's lighthouse tender *Pharos* was adapted by re-tuning its existing 9310 MHz experimental band-edge racon channel to 50 MHz below the 9420 MHz magnetron frequency. Scanner aperture was 9 ft. Radars then had the traditional long-persistence cursive raw radar display without pulse–pulse or scan–scan correlation for clutter or interference rejection.

A 3-position switch at the display permitted:

(a) *Alternate pulse mode*. Within each scan, echoes and then racon were displayed alternately. Paints from the normal echoes and clutter were permanently added to the racon trace (the racon had no muting feature). Using only half the normal number of pulses per scan per channel, there was a slight loss of picture quality. Pulse–pulse correlation would probably have rejected all these alternate-pulse signals.

(b) *Alternate scan mode*. The display switched between channels when bearing astern after each scan. First echoes were displayed at full quality, then racon over fading echoes, then echoes over fading racon, and so on.

(c) *Racon-only mode*. Echoes were suppressed. For safety, spring bias prevented permanent engagement of this mode.

In trials off the Firth of Forth, Scotland, range exceeded 30 miles. Experienced participating navigators thought the system useful. Racon-only mode (c) was good for code-reading a newly detected racon. Alternate scan mode (b) was preferred to alternate pulse mode (a). It effectively aligned the racon relative to echoes, clearly revealed it in

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severe clutter, did not appreciably degrade radar use for collision-avoidance or manoeuvre tasks, and did not prove too distracting to the observer. In service, an *echoes-only mode* would have enabled racon responses to be dropped when not needed, for example deep-sea.

3. THE ITOFAR COMMANDABLE RACON. Meanwhile Ericsson and the Swedish Board of Navigation developed an alternative system, hosted on the Ericon racon. Called ITOFAR (interrogated time offset frequency agile racon[4]), changes in radar pulse repetition frequency command the racon to delay its response into the inter-pulse period. A display sweep delay switch selects the racon either clear of, or superimposed on, echoes and clutter, generally as for frequency offset mode.

Despite the success of the fixed offset frequency trials, radar manufacturers at the time preferred ITOFAR because it required no microwave radar modification.

4. THE POSITION TODAY. ITOFAR is used at selected sites in Scandinavia, mainly Sweden, on bridges and to combat the effects of sea ice on displays. Elsewhere, despite extensive publicity and discussion within IALA, none of the selectable systems has entered general service. To this day most navigators have to put up with racon responses mixed with echoes and clutter, without control of display mode. The radar design has to accommodate racons within a receiver channel primarily intended for echoes having a steeper signal strength/range law, clutter and shorter pulselength.

Modern radars have narrower and better-defined receiver channels, probably rejecting all echoes and clutter when de-tuned only 25 MHz. Such small offset would make squint loss negligible. A USIFAR (user-selectable included frequency agile racon), using 25 MHz modulation on the response carrier frequency and a dedicated radar receive channel, has a specification in reference 4 but has not yet become popular. The old 9300–9320 MHz fixed-frequency racon channel, now used for ground-based aeronautical beacons, will be added to the 9320–9500 MHz X-band marine radar allocation from 2001. The equivalent 2900–2920 MHz channel has already been absorbed in the S-band radar allocation, which incidentally is 2900–3100 MHz, not as stated in the Trim paper.

Richard Trim fears that too many transponders may congest the display, making the picture unusable and risking loss of navigationally important echoes. In practice, frequency, scanner bearing and pulse repetition frequency variations among radars minimize congestion. Racon muting timers repeatedly clear responses and sidelobes from the screen, revealing masked echoes. Any residual problem would be further alleviated by user-selectable racons.

Most slow-sweep racons, although still permitted by reference 4, have been replaced by more powerful S/X-band agile types, many with sidelobe suppression. These are easy to use, reliable and cheap to run, but complex and necessarily expensive. First cost (around £20 000) has severely constrained introduction in the Third World, where other aids are sparse and racons would be particularly effective.

5. RTES AND PASSIVE REFLECTORS ON BOATS AND BUOYS. RTES are a promising new tool, but disappointing improvement of detectability is sometimes reported when RTES or passive (e.g. corner) reflectors are installed on small targets. The reason may be as follows.

Coming as they do from point sources, RTE and passive reflector responses are subject to severe multipath interference from sea-surface reflections in calm water. The structure echo of the boat or buoy may be of the same order of magnitude but, being a distributed target, is subject to less multipath. Random movements, however, cause strength fluctuations[5]. Signals from each source reach the radar at identical frequency but randomly differing phases, so signal strengths do not necessarily add. On this hypothesis, and this needs confirmation by trials, the resultant may fluctuate more than either component, reducing the probability of detection. In radar engineers' terms, fluctuation characteristics may change from an approximation to Swerling[6] Case 5 (needing, say, 5 dB signal to noise ratio for 90 percent probability of detection in one scan) to Case 3 (10 dB) or even Case 1 (14 dB). Racons, with their long response pulses, are immune from this effect. Vertically separating RTE antennas, or RTE and reflector, by a metre or more to split go and return multipath patterns might give some improvement.

6. THE FUTURE – RACONS. Recent microwave component cost reductions may be causing the radar manufacturers at last to reconsider the merits of a separate racon receiver channel, to facilitate otherwise incompatible improvements in reception of echoes with less clutter. This would open the door to a user-selectable racon service.

Soon all ships must carry GPS or an equivalent, giving navigators their positions to high accuracy. No longer will terrestrial aids be needed for landfall. One wonders whether the current expensive, long-range dual-band racons, with their need for sidelobe suppression, will then be seen as overkill. Just as weaker lighthouse lights are now found effective, smaller and cheaper racons might suffice. Their tasks would be to mark buoys and other aids to navigation at short (5 to 10 miles?) range and to provide back-up for GPS receiver failure. Perhaps now is the time to rethink the racon strategy, leading to a better service with lower cost and wider field of use. Possibilities include:

(a) User-selectable or commandable racons, chosen from ITOFAR, Fixed Offset Frequency or USIFAR. The latter two have similar radar receiver and bandwidth requirements. All offer a 'racon on demand' service plus the possibility of more effective display of both echoes and racon traces, especially in clutter.

(b) All ships have to carry X-band radar; indeed Search and Rescue Transponders (SART) and current RTES are X-band only. Removal of the landfall role may justify dropping the S-band racon service. This of course begs the delicate question of whether radar observers know which band they are using.

(c) Will high (1 W) power still be needed? Selectable racons do not have to punch through clutter. The old swept-frequency racons got by on 0·2 W in clutter. Lower power would cheapen the racon and permit operation from smaller solar panels.

(d) Lower power would also reduce the necessity for sidelobe suppression; fewer components, lower cost, higher reliability.

(e) Cheap swept-frequency racons, not themselves selectable, appear as 'echoes' on most radar modes. They display for a few scans each 60–120 seconds and might suffice for many tasks. Perhaps these old workhorses should be revived.

7. THE FUTURE – RADAR TARGET ENHANCERS. Before finalizing the ITU specifications[7] for these relatively new devices of great potential, their characteristics merit deep consideration by the marine community.

RTES were primarily conceived as active reflectors to enhance the radar cross section (RCS) of small vessels. Radar designers might argue that, consistent with cost and power consumption, the bigger the RCS the better, and that the current 40 $m^2$ (at long range, less when saturated at short range) offered by devices as instanced in the Trim paper is too low to defeat clutter. They would prefer 80 $m^2$ or more at X-band. Big RTES on small yachts would disconcert navigators of deep-sea ships who judge target size by echo strength – in effect RCS – acting earlier for perceived bigger vessels. The draft ITU specification requires only 8·2 $m^2$ at X-band.

Ships have never had to ascertain their own effective RCS or to meet any minimum figure. Historically this was justified by typically large size, tall and reflective silhouette and low speed; reasons all invalid for high speed craft (HSC). These low and streamlined

– 'stealthed' to a radar engineer – vulnerable passenger vessels may need powerful RTES to be seen at safe detection range.

Lighthouse and Harbour Authorities can make buoys radar-distinctive by fitting passive reflectors, RTES or racons, with an ascending cost scale. Only racons currently work well at S-band. Although unable to match the long response of a racon, which alone proclaims the navaid among the plethora of echoes in a busy harbour, RTES are now being installed of 40 $m^2$ RCS. Rather more seems desirable where significant sea or rain clutter is likely. The relative merits of RTES and racons for navaid applications need careful balancing.

From the above, it seems that a family of RTE sizes is needed for differing tasks. Richard Trim's suggested combination passive reflector and RTE is a possible way forward, but mutual interference between these fluctuating sources merits careful thought and trial before going into service. Other developments are possible. Although RTE responses cannot be offset in frequency or use ITOFAR methods, it should be possible to apply the USIFAR principle to give a user-selectable service.

This brings us back to a basic question which only mariners can answer – are user-selectable navaids wanted?

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KEY WORDS

1. Radar. 2. Transponders. 3. Echo enhancers.