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Civil Marine Radar – A Fresh Look at Transmitter Spectral Control and Diversity Operation

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This year marks a watershed in the design, production and operational use of Civil Marine Radar (CMR) as we know it. Tighter regulations for in-band spectral purity and out-of-band transmission, when coupled to a possible loss of S-band frequencies for both CMR and Air Traffic Control (ATC) radars, will seriously restrict the synergistic advantage of dual-band systems, as well as the form of new RF heads. There is a conflict of IMO requirements to still retain simple pulse radars to activate Racons and SARTS while also meeting these new stringent spectral regulations. Options are given for serious discussion amongst all concerned before it is too late.

KEY WORDS

1. Radar. 2. Marine. 3. Commercial. 4. R&D.

1. INTRODUCTION. The primary aim of this paper is to alert designers, producers and users to the broader ramifications of the impending changes of regulations for Civil Marine Radars (CMR) regarding both a tighter spectral purity of each transmission, and the possible loss of detection of many kinds of targets if the use of S-band is withdrawn.

Further aims include:

(a) to present some alternative options to the existing designs of simple pulse radar to assist the development of a new generation of CMR.
(b) to provide a review of the benefits of true diversity of operation using both S and X-Bands.
(c) to consider the use of within band diversity operation.
(d) to propose a means of reducing target fading by using the normally wasted or discarded orthogonal target returns.
(e) to suggest that the reception of both co-polar and cross-polar returns as in (c) above will lead to a reduction of some forms of unwanted clutter when used in conjunction with individual Constant False Alarm Rate (CFAR) processors for each receiver channel.

The position is more complex than it appears at first. To help those wishing to probe further, a comprehensive set of references combined with a bibliography are provided. For example, Morchin (1993) has some 460 pages packed with radar equations and notes on these to guide marine radar designers to methods and techniques used in other kinds of both military and commercial radar. It is appreciated that at first sight these techniques may appear inordinately expensive, but without the front ends for 'Sky Television' the very cheap but effective Low Noise Amplifiers (LNAs) found in almost all CMRs would never have been in place.

The major advantages to users of today's CMR are much greater performance and reliability, lower weight and power consumption of the antenna turning gear, transmitter and receiver or transceiver, all comprising the RF head. Other significant improvements for the user are in 'displays' with the introduction in the 1970s of digital scan converters (DSC), which have improved brightness and user control of target afterglow. From the earliest types of PPI presentation (e.g. North Up, True Motion (Wylie, 1960)), we now have ARPA displays with integrated computers (Boles, 1990) and much stronger on board sensors, navaids, and external inputs from GPS and comprehensive radio systems.

New requirements for spectral purity of transmission, and possible loss of the small but only marine allocation in S-Band, creates a vital loss of operational effectiveness through the withdrawal of an essential diversity feature in use for over 50 years (Williams, 1975 and 1981).

2. THE SPECTRAL PURITY PROBLEM AND NEW SPECIFICATIONS FOR CMR.

The mobile phone industry is hungry for more channel space, and some are still active in attempts to take over all the marine S-Band (3·0–3·1 GHz) and also place very stringent 'in and out-of-band' spectral purity specifications on new transmitters and even perhaps making these changes retrospective. Some magnetrons are well driven and isolated from poor and also variable voltage standing wave ratios (VSWRs) by the use of four-port ferrite circulators from their antennas; however, if these are remote, microwave feeders can produce unwanted long line effects. Other magnetrons are both badly driven and matched, resulting in both poor spectrums and reliability; these effects were described by the author after witnessing laboratory tests a couple of years ago at EEV (Williams, 2000). So perhaps unfairly, the magnetron has a bad name. Unfortunately, the drive to produce very cheap RF heads for CMRs results in only three port circulators being provided by some manufacturers.

Diversity of operation has been well known by CMR users over 40 years, but a straightforward study was carried out (Williams, 1975) illustrating clearly that there was no single choice of either S or X-Band. That study demonstrated a need for both frequencies in order to cope with the wide range of target characteristics, antenna heights, required range bands, angular discrimination, sea and rain clutter. Precipitation alone (in both rate, form, temperature and spatial density) needs a carefully specified set of parameters to compare the two radars apart from the vagaries of anaprop due to surface and higher ducts due to variations of moisture as a function of height.

2.1. *Options for current and future CMR design.*

2.1.1. *Short-term.* Waveguide filters could be fitted with the penalty of extra cost, room, weight and loss. They are probably easy to fit between antenna and transceiver and carry the small extra two-way loss of a dB at most. In addition to fitting a $\mu\lambda$ filter, some attention to the modulator regarding the magnetron rate of rise of the voltage pulse, together with the dynamic source impedance of the modulator during the onset of current and oscillation, may help to reduce a poor spectrum (see Williams, 2000 and manufacturer's data sheets). So really short-term measures are under way. However, a word of warning on a topic already written about elsewhere; although a $\mu\lambda$ filter may be purchased and fitted, the match presented by the waveguide run and antenna may be poor (i.e. a VSWR worse than 1·3). Even 30 year-old text books assume magnetrons are decoupled from dodgy and variable loads with ferrite components, and loads able to absorb returned power; but the commercial pressure to reduce price means that some CMR sets will, under certain conditions, have a dirtier spectrum than before the filter was fitted. This may sound trivial, but there is no use jumping from the frying pan into a hot fire.

2.1.2. *Early medium-term.* For an early solution, an existing Frequency Modulated Continuous Wave (FMCW) radar could be used, as described in Barrett (1987), whose paper gives both design aspects and performance; sufficient went to sea to validate the low signature design, so answering present critics regarding compatibility with other CMRs.

There are problems of triggering Racons from FMCW sets, and this issue is addressed later. There is no doubt that there may be many design features to be tackled by some CMR manufacturers to achieve decent clutter reduction. For instance, swept gain may not be fitted in the traditional sense, just a tilted frequency response, but there is now a new growing area of expertise in providing collision avoidance for cars 'nose to tail' on motorways in conjunction with cruise control (Tullsson, 1997), (Eriksson, 1997), (Mende, 1997) also for short range airport surveillance (Bethke, 1997).

2.1.3. *Medium-term.* Another possibility is to use a simpler solid-state coherent radar with better transmitter spectral control using longer pulses on 48 and 24 nm range (Williams, 2000). This is a novel concept laying between a traditional CMR and a 100% duty cycle transmitter as used in FMCW. The major problem is to drop from CMR magnetron peak powers of 100 kW (a special C-band set used for spotting tuna fish) through 30 kW, 25 kW 10 kW, 5 kW and even lower to 10 W peak power from solid-state amplifiers not impossibly expensive at the time of writing. The possible answer is to squeeze every bit of performance one can and use 2 m or even 3 or 4 m antenna apertures at least as a short-term measure. Other possibilities are to reduce the antenna vertical beam width and in some way stabilise the antenna platform against ship roll and pitch perhaps electronically or quasi mechanically/electronically.

Reits (1992) has reviewed the boundary conditions beyond normal CMR pulse radars with low duty cycles of 0·0005 maximum, compression radars with a transmission duty cycle of say 0·05 as used in defence air, ground and naval equipment for 30 or 40 years (see Barton, 1997 and Skolnik, 1990) and flying in space on the Canadian Radarsat and ERS 1 and chopped FMCW with a duty cycle of 0·5, and finally true FMCW with a duty cycle of 100%.

The true FMCW ideally needs twin antenna to minimize unwanted transmitter spill over to the receiver, but Beasley (1981) describes a more modern clutter canceller than those used on the big 2 kW CW trackers in the 1960s as described in Janes weapon systems. The Controlled Spectrum Solid State Radar (CSSSR) concept has only been published recently (Williams, 2000), so a further description is given later with more detail.

2.1.4. *Late medium-term.* A later prospect would be to take up more recent designs of FMCW such as perhaps some variation of the Elta sets EL/M-2238 or EL/M-2129 (see also current brochures some on web sites Elta Israel 2002). It has proved difficult to find other examples of FMCW CMRs, but there are many devoted to military projects and instrumental use; for example, one designed and built for measuring oil depth in ocean tankers by Sabre (1996). See also Monod (Radar 1997) and Lighart (1990 Proc. IEE 137.F 6) and Stove (IEE F 139 5). Although in the wrong band and designed for operation of a km at most, an RF head is available in quantity production for future consideration, although it is not suitable in its present form.

2.1.5. *Later medium-term.* Another later option could be to consider a pulse-coded transmission and pulse compression receiver. For an introduction to the significant literature, refer first to Farnet (1970 as chapter 20 in Skolnik (ed.) 1970), Curlander (1971), Cook (1967), Skolnik (1982), and Barton (1997). Pulse compression was introduced in the 1960s (Skolnik, 1980) and Barton (1975, vol. 3) contains 11 selected specialist papers from Cook (1960) and Bernfield (1965) to Haggarty (1968). Barton completes his collection of papers with one by Caputi (1973). There are other possibilities described in commercial brochures, but these are still very expensive and complicated and not at all what CMR people are used to; for example, how would users react to range side lobes suddenly appearing on their Visual Display Units (VDUs)?

Pulse compression was brought into service to allow more mean power to be radiated without transmitters having to put out enormous peak power on very short pulses with problems of flash over etc. The big travelling wave tubes (TWTs) could handle only a few kW of mean power and some 10s of kW peak, but of course, being part of a coherent drive an amplifier could receive both analogue chirp and/or digital phase modulation within the pulse; a situation not dissimilar from solid-state if some 30 dB up. We now note that analogue expansion and compression filters have in general changed to digital ones to obtain superior linearity.

2.1.6. *Long-term 'daydream' or horror scenario.* A ban might be made on all CMRs (hard to police on open oceans) and force the use of various forms of narrow-band radio information systems as has been discussed for many years and is now becoming a reality as the Automatic Information System (AIS), rather like a marine form of TCAS and its low cost cousin TPAS for light aircraft (Allan, 2002). Such schemes will always endanger all craft from super tankers and VLCCs down to ocean and small pleasure yachts and indeed single folk on ocean crossings, all vulnerable to each other and non-cooperating objects like water logged floating containers and ice in polar regions (see Tabata, 1975 to Stefani, 1997). Criminals will always find a way to impersonate ships electronically to both security forces and customs. This leaves the far less efficient passive, optical, IR, EM sensors and sonar detection systems for collision avoidance from flotsam and jetsam (Ryan, 1992 and Haykin, 1994 and 1997). Insurgent 'stealth' boats and frogmen will remain immune using both stealth and false identities when replying to radio surveillance systems. So SSR methods help identify objects with Racons fitted but never true flotsam and jetsam as big and dangerous as ice chunks and lost containers.

None of these options are 'off the shelf' from manufacturers or marine chandlers or boat yards; therefore, capital, resources and design effort are needed for the usual development of stage A and stage B models, then pre-production for customer acceptance and finally full production batches when the chosen design has been proven.

3. THE NEED TO TRIGGER MARINE FORMS OF SSR.

As already stated, until the requirement to trigger marine radar beacons is removed, most unlikely in the short term, this problem will remain. Bermojo Díaz (2002) provides an up-to-date paper on the general topic of maritime Secondary Surveillance Radar (SSR). After a comprehensive introduction, Diaz describes Search and Rescue Transponders (SARTs), which are a form of 'in band' SSR and goes on to describe 'non-radar in band' equipment such as GMDSS, EPIRBS, and the INMARSAT A, B, and C satellite communications service.

Diaz then addresses the 50-year old RACONs. For early history, see Wylie (1960) and Richardson Radar (1977). Racons need some form of pulse trigger as provided by standard pulse CMRs. A sweeping FMCW carrier will produce a pulse, albeit with a slow rise and fall time as it goes in and out of a standard CMR I.F. filter, but sufficient gain may correct this. Diaz and his co-authors provide a timely paper with relevant and modern references including discussion of 'Active' Radar Target Enhancers (RTEs). It has to be noted that the aircraft anti-collision device TCAS was in R&D for many years, and a similar timescale can be expected for the marine system AIS.

This paper does not attempt to go through all the permutations and combinations of 'in-band', 'out-of-band' and cross-band transponders (such as the historic IFF in all its ramifications of marks) but merely seeks to establish the need for any CMR to trigger unmodified Racons.

4. AN INTERIM TEST BED FOR AN IMPROVED PERFORMANCE AND CLEAN SPECTRUM SOLID STATE RADAR (CSSSR).

Some of the much bigger Vessel Traffic Management System (VTMS) coastal radars have antennas of the reflector and horn feed type (Brown, 1992) with facilities for both frequency and polarisation diversity at the same time affording the following advantages:

(a) Mirror apertures of dimensions 7·5 m by some 3 m yield gains of 35 and 45 dB with beamwidths of 1·1 degrees on S and 0·32 degrees on X-Band. The vertical beam width and shape chosen at each site sets the final vertical dimension.
(b) S-Band operation over 2·9 to 3·1 GHz covering the CMR band without squint and having the normal co-polar channel and also a cross-polar one for the extra receiving channel for polarisation diversity, i.e. 2 channels.
(c) X-Band operation over full marine band (9·2 to 9·5 GHz) without squint and having the normal co-polar channel and also a cross-polar one for the extra receiving channel for polarisation diversity, i.e. 2 further channels.
(d) The ability on both channels to operate on a pulse-by-pulse basis with frequency hopping without the need to correct for antenna squint as the big reflector and two sets of microwave feeds are non-dispersive.
(e) Large antenna gains to examine the effects as would be provided with a 10 kW transmitter and a smaller and lower gain CMR antenna.

These systems, perhaps with some EU help, could provide an ideal working test bed to demonstrate properly the real advantages in spectral purity and many other means of improving small non-responder fitted target detection in difficult clutter conditions with the CSSSR now described.

5. NOVEL CLEAN SPECTRUM SOLID STATE RADAR (CSSSR).

5.1. Today one speaks of total systems, and CMR is no different. So a modern ship carries at least 3 CMRs as subsystems of the total package. Typically S and X-

Table 1. Performance comparison between a traditional and novel Controlled/clean Spectrum Solid State Radar (CSSSR) for consideration.

Parameter	Old CMR	CSSSR	Pre-detector change, old to new dB	Post-detector change, old to new dB	Notes
Peak Power	10 kW	10 W	−30 miss out	0	1
Pulse length	1 μs	4 μs	+6 miss out	2·5	2
PRF	500 pps	1500 pps	+5 miss out	2·5	3
Tx duty cycle	0·0005	0·01	+13 miss out		4
Mean power	5 W	0·1 W	−17	0	5
Rx Bandwidth	4 MHz	0·3 MHz	+11·2	0	6
Microwave two-way losses	4	3	+1	0	7
Expected change, see notes 1 to 8			−17+11·2+1 = −4·8 dB	+5 dB	8

band RFUs are on the forrard mast with one aft for docking. In addition, another is often fitted further forrard but at a lower height on the bow. In these situations, all may contribute to a higher synergistic performance than individual CMRs. So proper video integration is needed that, if required, would make the right decision to meld or overlap the separate pictures to form an adaptive, on line, PPI picture. This of course means any SSR responder can be interrogated by a single RF head and, in principle, the others may use Vertically polarised transmission with Vertically polarised reception or VV operation as it carries advantages in reduction of spiky sea clutter. Another feature is frequency diversity and, apart from the interswitching in present CMR systems, this has not been clearly identified (as far as can be seen) as a reason to preserve S-band as a coherent part and indeed a major plank in any fully integrated CMR system even though it has been fitted aboard ships for some 50 years (Wylie, 1952 and Beattie, 2000). Numerous papers are available based on a large series of trials on the complementary role of dual-band operation and synergistic combination of twin RF heads (Clarke, (ed.) 1985 and Williams, 1980, 1981 and 1982).

One of the major advantages of the CSSSR is the ability to change both the transmitted carrier frequency (within any one of the bands viz. S or C or X-band) and PRF and also the pulse length for each pulse, due to the adoption of a coherent synthesiser digital PRF generator and solid-state power amplifier with enough dynamic bandwidth to go from 9·320 to 9·500 GHz or as required. At present, mean and peak powers are some 10 W and 3 W (Baker, 2000). With the reduced size of these new heads they, when developed, may be located in the actual antenna(s) to reduce RF losses.

5.2. Some comparison is needed of the long-range performance of a present day middle of the range pulse CMR with that being proposed. It is assumed that the same antenna is used in principle, although the dispersion of a SWG antenna will need some thought; but later this may be of benefit to facilitate a look back facility as has been used in military radars for many years to provide a second look at small fading targets in each rotation of the antenna. Other common parameters such as front-end noise factor, turning rate etc. (not given in Table 1) have not been changed to allow an unbiased comparison to be arrived at.

5.3. Points that should be highlighted from Table 1 are listed in the following notes.

5.3.1. *Note 1*. There is a drop of 30 dB but, using the matched concept, then only the receiver bandwidth and mean power need be considered up to the video detector on a single pulse at this stage. So 30 dB is not taken into account here on this row.

5.3.2. *Note 2*. The pulse length that affects the mean transmitter power is taken care of lower in the table under receiver bandwidth, but its footprint also affects the observer's detectability so we also allow the square root, say 5 dB extra in the penultimate column.

5.3.3. *Note 3*. With the same antenna rotating at the same speed, the higher PRF yields three times the pulses per beam width but the processing gain is not linear, so we can only claim 2·5 dB for a full M/N integrator; this is not implemented in most CMRs being used for interference suppressions only (i.e. a 2/2 to validate the single pulse).

5.3.4. *Note 4*. Most CMRs only run their magnetrons at a duty cycle of 1/2000; solid-state amplifiers are rated for CW operation, so on the longer ranges we allow only a nm of blanking by using a longer transmitter pulse and fully integrate the maximum number of pulses used on all the longer ranges whilst dropping the pulse length to minimize precipitation clutter.

5.3.5. *Note 5*. The reduction of mean power in this new CMR offset has to be recovered by the use of a matched narrow-band and properly tuned receiver coupled by the transmission of a clean spectrum on each pulse length used. So this new receiver, with full power matching for all pulse lengths used, is made possible by the Xtal controlled type of CMR ensuring very accurate alignment of receiver and transmitter frequencies.

The difficulty of designing receivers for the older rectangular or 'crude' pulse transmitters has meant that the old receiver bandwidths were often 3 or 4 times as wide as a matched filter one. Ranging accuracy may suffer a little, but that is a penalty to pay for an environmentally friendly transmitter. However, the use of a parallel wider band receiver IF amplifier is not precluded to allow strong target signals to be above the higher noise floor and suffer less leading edge excessive delay (Ward C., private communication, 2001).

5.3.6. *Note 6*. It is appreciated that current pulse radars are operating with a modest Automatic Frequency Control (AFC) and with the transmitter power spectrum often being wider than it needs to be (as being generated by a near rectangular-shaped pulse). This means a much broader receiver pass band than optimum, so these older sets can have significant extra receiver loss. The new transmitter and receiver system may be always kept accurately on tune and power matched, but pulse stretch will occur so there is less system gain than calculated, but this is always a judgment.

5.3.7. *Note 7*. For the proposed new CMR, there is no reason why the whole RF head should not be mounted adjacent to the actual radiating antenna thus removing the two-way microwave loss including the microwave rotating joint and thus reducing the allowance made for the wave-guide or other microwave feeder loss. However, during the R&D phases, a conventional microwave rotating joint may be used to allow design work and design adjustments to be carried out without the designer being rotated at 20 rpm.

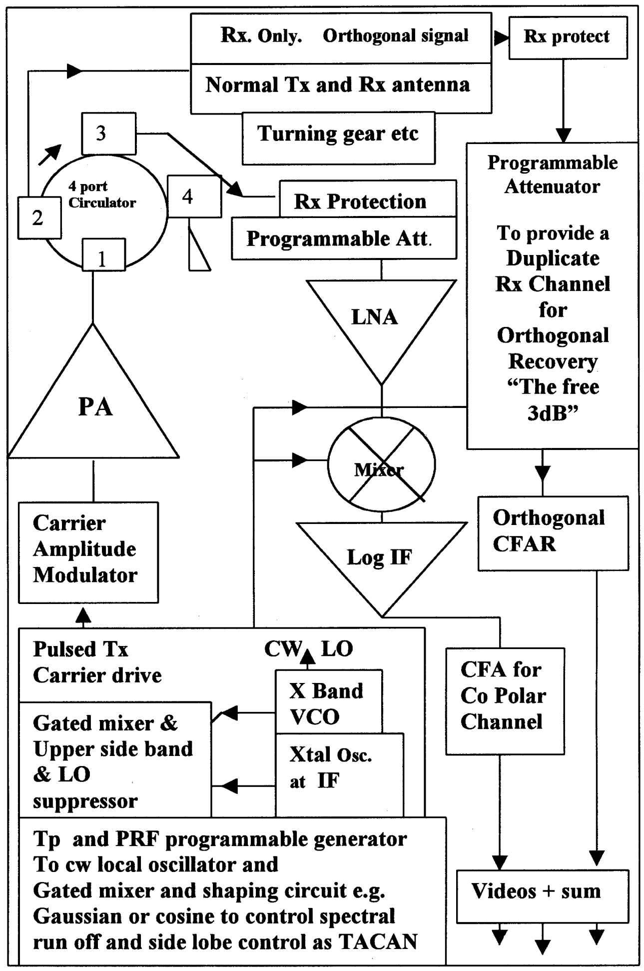

Figure 1. Essential modules of proposed CSSSR.

5.3.8. *Note 8*. In Table 1, only the entries from the relevant rows have been totalled to show how the receiver match or pre-detector part leaves the proposed CMR 4·8 dB poorer, but with full use of modern DSP, the CMR achieves parity.

6. REALISATION OF THE CSSSR.

6.1. Figure 1 shows the primary programmable PRF, pulse length and individual Local Oscillator (LO) frequency generators. A novel feature is the generation of the transmitter drive from a side step mixer only during transmission to avoid receiver saturation from unwanted breakthrough, and the spectral control by shaping the amplitude of transmitter pulses. The choice of the shape is the analogue of the power taper across the antenna (i.e. for uniformity the first sidelobe is only 13 dB down), but one is free to go cosine, cosine^2 or Taylor or even gaussian as first used on a TACAN transmitter (Skolnik, (ed.) 1970, Chapter 7 on Transmitters by Weil).

Other components are self evident except that the additional receiver antenna and receiver channel enable a 'free' reception of the orthogonal vector (Raney, 1995) to provide extra reception and some rain rejection and SSR reception if using VV. Trials show that a degree of polarisation rotation occurs all the time (if only a few degrees) to couple the CMR and local Racons. The third entirely new feature is full pulse-to-pulse frequency agility.

6.2. These features will offer a further decade of operational improvement and a real chance to evaluate the anti-clutter features of frequency hopping to suit each pulse in use and also polarisation diversity, and the possibility of triggering a responder. While this is at the expense of a much reduced peak power being transmitted, using a higher gain antenna will help. So this proposed CSSSR equipment offers the basis for some preliminary design work and, while it is a simpler solution than a full pulse compression radar, it is all solid-state. Certainly there have been small TWTs around for many years with very good reliability, but they need reasonable high voltage, although less than the drive pulse required for the much higher peak power magnetron.

There is plenty of experience with the above techniques in both military and civil radars used for remote sensing. The space sector offers one example that is unique with years of expensive R&D resulting in only one or two sets being made, so the R&D overhead or non-recurring cost is enormous. On the other hand, as mentioned earlier, the millimetric radars being built for anti-collision and Automatic Cruise Control are a similar situation to CMRs, both have volume production. So CMR has come to its crossroad.

7. DIVERSITY.

7.1. *Types of Diversity*. There are as many forms of diversity as one can arrange for, leaving aside cost at first, so some of these are listed below together with a note of the benefit gained:

(a) Within band frequency agility or frequency hopping, see below.
(b) Dual operation on both the CMR bands, good in precipitation – see Table 2.
(c) Frequency hopping in a band to decorrelate clutter. The criteria may be initially set up as some function of the pulse in use at one time (Nathanson, 1969 after Pidgeon, 1967 – figures and text pages 252 and 253).
(d) Choice of polarisation on transmission and reception (e.g. VV or HH or VH or HV or circular polarisation with dual-reception channels) that is both co-polar and cross-polar – the venerable rain rejection mode. Trials have shown that, if the co-polar return has a deep fade, the cross-polar channel is often fade free sometimes recovering a deep 30 dB fade.

To compound the complexity, the inter-pulse period may also be random within desired range considerations. In fact, for the first time a CMR of this form may (with perhaps some loss in long range performance) have bursts of long and short pulses intermingled to allow the display to select a pulse length to suit the range scale in use. This would be a new freedom on the bridge.

7.2. *Rain Attenuation*. Shaw (private communication) brought up the topic of really serious tropical rain in the region of 16 to 40 mm/hour. Whilst in Europe, 16 mm/hr is considered very heavy, the design has to provide for decent long-range performance in the tropics, even though the time of radar use in these areas may be not more than a few percent of the total; ships still wish to make good and safe progress worldwide. So if a radar of the future carries say an S-band 12 ft antenna,

Table 2. An illustration of the radar attenuation in tropical rain over 20 nm.

Frequency Band	2-way coefficient (dB)	Attenuation for 20 nm 1 mm/hour	Attenuation including 40 mm/hour
S	0·01	0·2	8·0
X	0·13	2·6	104·0
Difference in attenuation X to S-Band in dB			**96**

as is required to meet the 2 degree antenna resolution, then perhaps two antennas can be fitted in a common housing either in piggy back or, to reduce windage and turning motor power consumption, fitted back-to-back as DSCs have no trouble in overlaying the time separated videos. Then the S-Band gives good performance whilst the X-Band radar, in what is now a composite CMR system, gives superb azimuth resolution of 0·6 degrees.

Table 2 shows a simple summary of likely attenuation in heavy tropical rain of 40 mm/hour for the two marine bands. So there is no doubt that S-band has to remain to give any sort of performance in the tropics when it is throwing it down. Because of the radar fourth-power law, 104 dB implies a reduction in operational range of 104/4 or 26 dB in range or more than 100 times. No amount of modern signal processing will alter this; despite removal from the display screen of the high rain clutter, this strength of clutter will cause an enormous penalty in target loss.

7.3. *Track before Detection.* In some situations, instead of a composite video to feed the ARPA display, each radar channel (for example S and X-band) feeds its own track formation modules. Fresh targets will then be reported (somewhat later in time) with high confidence against false alarms. This is an illustration of the different ways in which various forms of diversity can be operated. In today's competitive world markets, little detail of this nature is published as, if either software or hardware fails, then circuit boards and complete modules are exchanged; on the other hand, like PCs, it may be considered best to exchange a complete display.

8. CONCLUSIONS.

8.1. The first conclusion is that there is no total solution to replacing many thousands of existing CMRs at sea with a new design that will have a satisfactory transmitter spectrum and also trigger Racons. The second is that there has to be extensive trials of any new design, not only with regard to the above requirements, but also because there has to be complete compatibility as regards mutual interference when some 100 or more systems can be operating in radar line-of-sight of each other. Today, even though extensive modelling is used with varying degrees of success, papers such as Tullsson (1997) are investigating mutual interference aspects as revealed from practical trials. So the marine fraternity, whilst not being able to use this kind of millimetric wave equipment, should benefit from the problems and experience of its growing use in cars and other vehicles.

8.2. The solution must rest with the pressure groups, manufacturers, mariners, other interested bodies and the funds available to undertake the R&D either by using the options discussed in this paper, or others as might be suggested, coupled with the wise drafting of new regulations.

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