REPORT ITU-R M.2050

Test results illustrating the susceptibility of maritime radionavigation radars to emissions from digital communication and pulsed systems in the bands 2 900-3 100 and 9 200-9 500 MHz

(2004)

1 Introduction

Tests have been performed to assess the effects that emissions from digital communication systems have on three maritime radionavigation radars that operate with a primary allocation in the 2 900-3 100 MHz band and two radars that operate with primary allocation in the 9 200-9 500 MHz band. The radars were International Maritime Organization (IMO) SOLAS[1] compulsory carriage category maritime radionavigation radars that employ scan rates, pulse widths, PRFs, IF bandwidth, noise figure, and antenna beamwidths typical of those identified in Recommendation ITU-R M.1313. These radars are representative of the types being used by the United States Coast Guard for shipboard navigation, by the commercial shipping industry, and recreational boaters as well. The radars operating in the 2 900-3 100 MHz band are identified as Radars A, B and C in this Report and the 9 200-9 500 MHz radars are identified as Radars D and E.

Radars identified in Recommendation ITU-R M.1313 typically employ interference mitigation techniques/processing methods identified in Recommendation ITU-R M.1372 to allow them to operate in the presence of other radionavigation and radiolocation radars. Techniques of that kind are very effective in reducing or eliminating low duty-cycle asynchronous pulsed interference between radars. All of the radars that were tested have some type of interference rejection circuitry/processing, which by default was enabled. Recommendation ITU-R M.1461 contains protection criteria for radars operating in the radiodetermination service.

These tests investigated the effectiveness of each of the radar's interference suppression circuitry/software to reduce or eliminate interference due to the emissions from a communication system employing a digital modulation scheme. Additional tests were also performed using low duty-cycle pulsed emissions as an interference source.

The tests were performed with the assistance of the radar manufactures and experienced mariners. Their guidance was used to properly set up and to operate the radars.

The tests were performed with non-fluctuating targets generation which were inserted into the radar receivers.

This Report describes the conduct of the findings to date.

2 Objectives

The objectives of the testing were:

– to quantify the capability of each of the five maritime radionavigation radar's interference-rejection processing to mitigate unwanted emissions from digital communication systems as a function of their power level;

---

[1] International Convention for Safety of Life at Sea.

- to develop *I*/*N* protection criteria that would mitigate the unwanted digital communication systems emissions in maritime radionavigation radars;
- to observe and quantify the effectiveness of each of the maritime radionavigation radar's interference rejection techniques to reduce the number of false targets, radial streaks (strobes), and background noise or "speckle".

3 Radars under test

3.1 Radar A

Maritime radionavigation Radar A, which was introduced circa 2000 and is still being refined, is designed for commercial applications and is an IMO category radar that operates in the 2 900-3 100 MHz band. Nominal values for the principal parameters of this radar were obtained from regulatory type-approval documents, sales brochures and technical manuals. These are presented in Table 1.

TABLE 1

Radar A transmitter and receiver parameters

Parameter	Value			
Frequency (MHz)	3 050 ± 30			
Pulse power (kW)	30			
Range (nmi) (km)	0.375-1.5 0.7-2.8	3-6 5.6-11.1	12 22.2	24-96 44.5-177.8
Pulse width (μs)	0.08	0.30	0.60	1.2
PRF (Hz)	2 200		1 028	600
IF bandwidth (MHz)	28	3	3	3
Spurious response rejection (dB)	60			
System noise figure (dB)	4			
RF bandwidth (MHz)	Unknown			
Antenna scan rate (rpm)	26			
Antenna scan time (s)	2.31			
Antenna horizontal beamwidth (degrees)	1.9			
Antenna vertical beamwidth (degrees)	22			
Polarization	Horizontal			

The radar uses a multistage logarithmic IF amplifier/detector. This type of receiver design is very common in marine radionavigation radars since they have to detect targets that have very small and large returns. A logarithmic amplifier increases the range of target returns that can be handled by the radar receiver without it becoming saturated.

The noise figure of the radar was measured and was found to be 5.3 dB, which was consistent with the nominal value of 4 dB. The 3 dB IF bandwidth is about 3 MHz for the range scale used for the tests. Using those parameters the noise power of the radar receiver is calculated to be about –104 dBm.

Radar A has extensive signal processing and target tracking capabilities, including an adaptive local constant-false-alarm-rate (CFAR) feature and a scan-to-scan correlation feature. The local CFAR (acting within a small fraction of one range sweep) is known as an ordered-statistic CFAR, which is a type that permits the desensitizing effect of interfering pulses to be lessened or avoided. This is done by discarding a selectable number of background signal samples that would otherwise be used in establishing the detection threshold. The process discards the samples having the greatest amplitude. As more samples are discarded which contain the higher amplitude interfering pulses, the less influence they are likely to have on the sensitivity of valid target detection.

Radar B can also perform a scan-to-scan correlation process that provides an additional means for discriminating between signals that are present consistently, such as a valid target, and signals that appear at random times, such as asynchronous pulsed interference.

3.2 Radars B and D

Radars B and D are maritime radionavigation IMO category type of radars produced by the same manufacturer and are designed for commercial applications. Radar B operates in the 2 900-3 100 MHz band while Radar D operates in the 9 200-9 500 MHz band. Radars B and D locate their transmitter/receiver below deck and use waveguide to send/receive signals from the antenna. They use different antennas and receiver front-ends, but have a common display along with common receiver elements including the interference rejection processing and IF circuitry. The radars use a multistage logarithmic IF amplifier and a separate video detector. Radars B and D also use pulse jitter. The transmitted pulse PRF can be jittered to prevent second time around echoes and also to reduce the interference from other transmitters in the vicinity. This function is automatically set in the transceiver and provides up to ±25μs jitter about the nominal value.

Nominal values for the principal parameters of these radars were obtained from regulatory type-approval documents, sales brochures and technical manuals. They are presented in Table 2.

TABLE 2

Radars B and D transmitter and receiver parameters

Parameter	Value			
Frequency (MHz)	3 050 ± 10		9 410 ± 30	
Pulse power (kW)	30			
Range (nmi)	0.125-1.5	3-24	48	96
Pulse width (μs)	0.070	0.175	0.85	1.0
PRF (Hz)	3 100	1 550	775	390
IF bandwidth (MHz)	22	22	6	6
Spurious response rejection (dB)	Unknown			
System noise figure (dB)	5.5			
RF bandwidth (MHz)	Unknown			
Antenna scan rate (rpm)	24/48			
Antenna horizontal beamwidth (degrees)	2.8		1.2	
Antenna vertical beamwidth (degrees)	28		25	
Polarization	Horizontal			

The values of pulse width and PRF in Table 2 are the default settings for that particular range. The operator can, for some ranges, select other pulse widths and PRFs that are under or over the default values.

Pulse-to-pulse and scan-to-scan correlators are used by Radars B and D to mitigate interference which may be caused from other radars operating nearby. For the pulse-to-pulse correlator, returns are compared on a pulse-to-pulse basis to reduce interference. A signal is only displayed if it is present on two consecutive pulses. This interference rejection function is most effective if the transceiver has been set to provide PRF jitter. For the scan-to-scan correlator, a target is only displayed if it is present on two consecutive scans. These radars do not have CFAR processing. A complete discussion of these radar interference mitigation techniques can be found in Recommendation ITU-R M.1372.

3.3 Radars C and E

Radars C and E are maritime radionavigation IMO category type of radars produced by the same manufacturer and are designed for commercial applications. Radar C operates in the 2 900-3 100 MHz band while Radar E operates in the 9 200-9 500 MHz band. Radars C and E are a topmast design. The receiver/transmitter (R/T) is encapsulated in a metal housing located directly below the rotating antenna. The video from the R/T unit is sent to the ppi located below deck via cables. They use different antennas and receiver front-ends, but have a common display along with common receiver elements including the interference rejection processing and IF circuitry. Both of the radars use an eight-stage successive approximation logarithmic IF amplifier/detector.

Nominal values for the principal parameters of these radars were obtained from regulatory type-approval documents, sales brochures and technical manuals. They are presented in Table 3.

TABLE 3

Radars C and E transmitter and receiver parameters

<table>
<tr><th>Parameter</th><th colspan="6">Value</th></tr>
<tr><td>Frequency (MHz)</td><td colspan="3">3 050 ± 10</td><td colspan="3">9 410 ± 30</td></tr>
<tr><td>Pulse power (kW)</td><td colspan="6">30</td></tr>
<tr><td>Range (nmi)</td><td colspan="2">0.125-3</td><td colspan="2">6-24</td><td colspan="2">48-96</td></tr>
<tr><td>Pulse width (μs)</td><td colspan="2">0.050</td><td colspan="2">0.25</td><td colspan="2">0.80</td></tr>
<tr><td>PRF (Hz)</td><td colspan="4">1 800</td><td colspan="2">785</td></tr>
<tr><td>IF bandwidth (MHz)</td><td colspan="2">20</td><td colspan="2">20</td><td colspan="2">3</td></tr>
<tr><td>Spurious response rejection (dB)</td><td colspan="6">Unknown</td></tr>
<tr><td>System noise figure (dB)</td><td colspan="6">4</td></tr>
<tr><td>RF bandwidth (MHz)</td><td colspan="6">Unknown</td></tr>
<tr><td>Antenna scan rate (rpm)</td><td colspan="6">25/48</td></tr>
<tr><td>Antenna scan time (s)</td><td colspan="6">2.31</td></tr>
<tr><td>Antenna horizontal beamwidth (degrees)</td><td colspan="3">2.0</td><td colspan="3"></td></tr>
<tr><td>Antenna vertical beamwidth (degrees)</td><td colspan="3">30</td><td colspan="3"></td></tr>
<tr><td>Polarization</td><td colspan="6">Horizontal</td></tr>
</table>

The values of pulse width and PRF in Table 3 are the default settings for that particular range. The operator can, for some ranges, select other pulse widths and PRFs that are under or over the default values.

Radars C and E use pulse-to-pulse and scan-to-scan correlators to mitigate interference from other radars. A description of these techniques is provided in § 3.2. These radars do not have CFAR processing.

3.4 Radar video displays

Radar A, due to its enhanced signal processing capabilities, has the ability to display various types of targets in different combinations. The radar is able to display amorphous raw-video "blips" (known as the image display), synthetic targets that appear as an "o", and/or tracked targets that appear as an "x". The brightness of the video image targets corresponds to the level of the target return. Targets that have a brighter "blip" have a greater return echo. The synthetic targets required about 2-3 dB of additional desired power compared to the raw-video targets to obtain the same probability of detection, Pd, when operating at minimum detectable signal (MDS) level but do not change their brightness in correspondence to the reflected signal strength.

Radars B and D (from the same manufacturer) use a colour CRT to display targets and radar information to the user such as PRF, pulsewidth, and range rings among other parameters. These radars do not show synthetic targets and only display raw-video "blips". Likewise, Radars C and E (from another manufacturer) only display raw-video "blips". However, the display used with radars C and E is monochromatic raster scan type. Besides targets, this display also indicates various radar parameters. Like Radar A, for these radars the raw-video "blip" is brighter for targets that have a greater return echo.

4 Unwanted signals

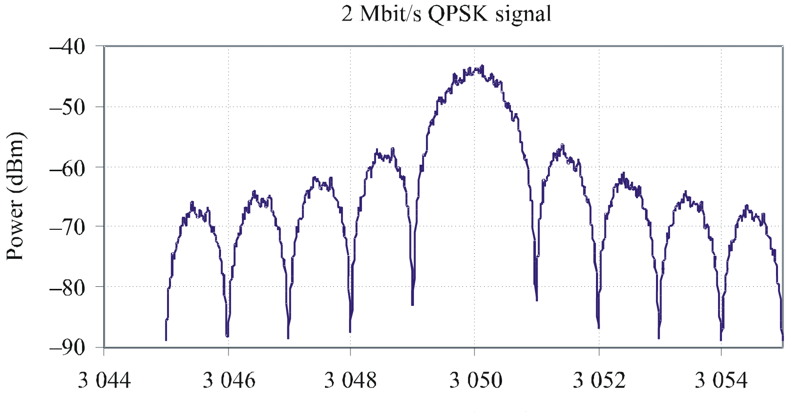
Radar A was tested with a 2 Mbit/s quadrature phase shift keyed (QPSK) waveform as an interference source. Radars B and C were tested with 64 quadrature amplitude modulation (QAM), 16-QAM, code division multiple access2000 (cdma2000), and wideband CDMA (WCDMA) signals as interference sources. Radars D and E were only tested with the cdma2000 and WCDMA signals. All interfering signals were on-tune with the radars. The QPSK signal injected into Radar A was continuous, occurring for a full 360°.

The unwanted CDMA signals that were injected into Radars B, C, D and E were gated to occur at the same time of the target generation within the same azimuth. The gate time was equal to the length of time that a stationary interference source would be within the radar's antenna 3 dB horizontal beamwidth as it rotates. The QAM signals were not gated.

The measured emission spectrum of the continuous QPSK signal is shown in Fig. 1.

FIGURE 1

Emission spectra of QPSK waveform



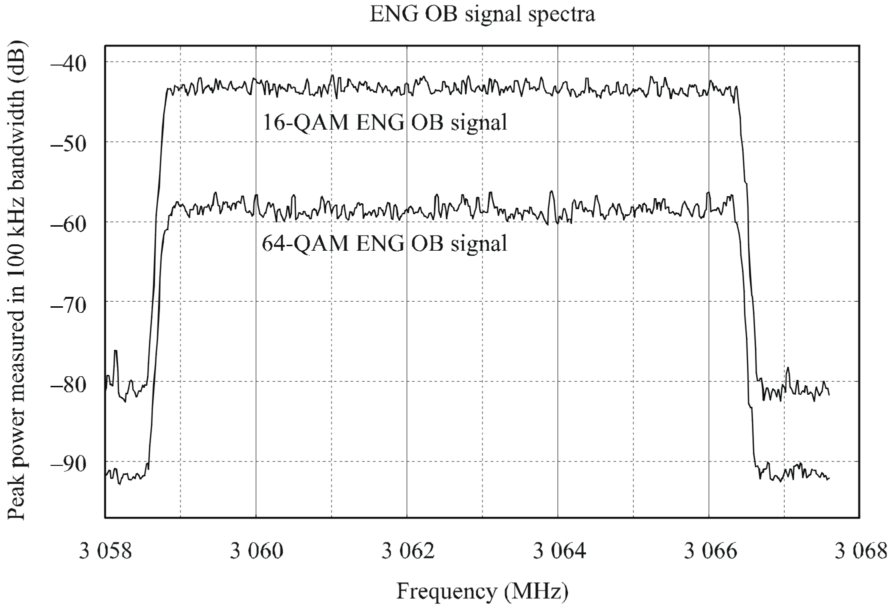
Rap 2050-01

Communication test sets were used to generate the DVB-T 16-QAM, DVB-T 64-QAM, cdma2000 and WCDMA signals. Spectrum shots of each of the unwanted signals are shown in Figs. 2 and 3. The cdma2000 signal was for the reverse link (mobile-to-base) standard according to the IS-95 format for cellular mobile telephones. The WCDMA signal was for the uplink standard according to the 3GPP 3.5 format.

The 16 and 64 DVB-T QAM signals in Fig. 2 represent the type of modulation scheme that is used by digital cameras for electronic news gathering (ENG OB) purposes.

FIGURE 2

QAM signal used in ENG OB



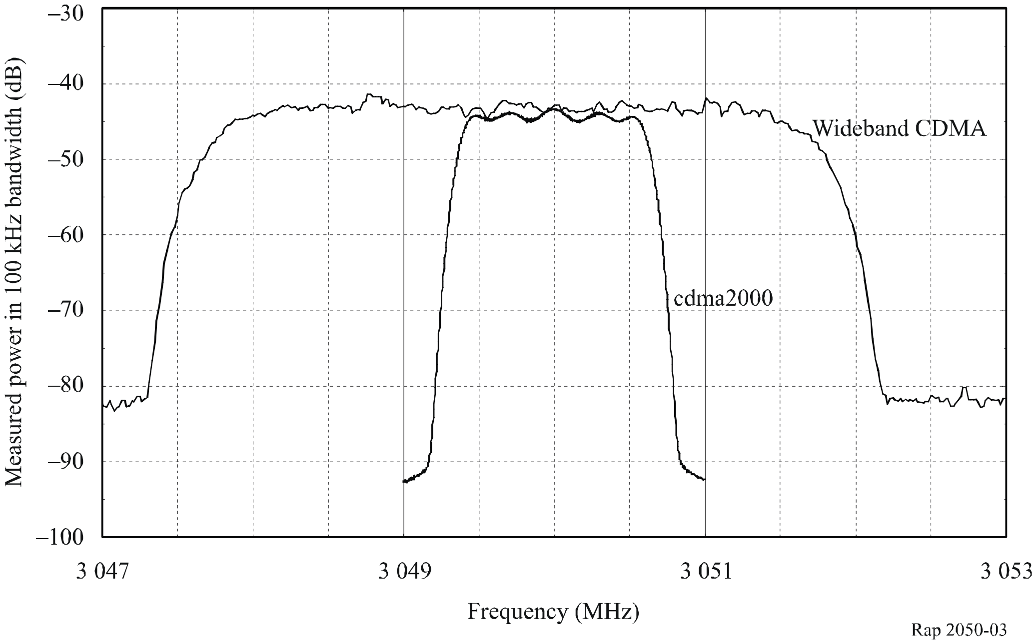
Note 1 – The spectrum curves are offset in amplitude for graphical clarity.

Rap 2050-02

FIGURE 3

CDMA signals

Wideband CDMA and cdma2000 signal spectra

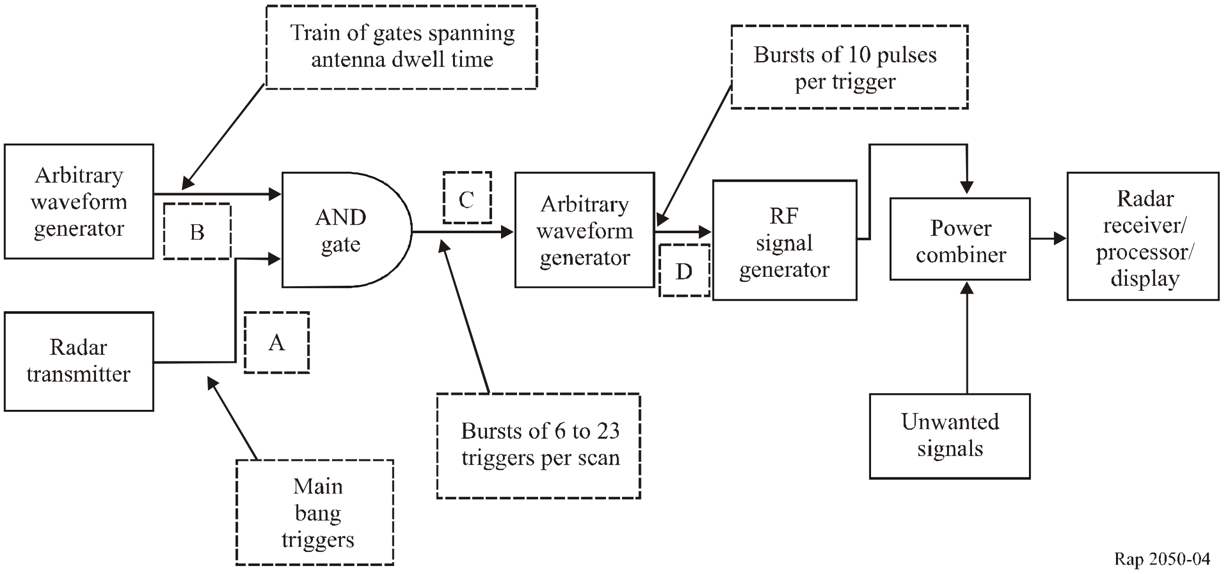


5 Non-fluctuating target generation

Ten simulated equally-spaced, equi-amplitude targets were generated along a radial using RF signal generators, arbitrary waveform generators, and other miscellaneous RF equipment (combiners, cabling, attenuators, etc.) for each of the radars operating at a 3-nmi (5.6 km) range. The target generation system provided groups of RF pulses that were of the correct pulse width and timing such that when they injected into the radar receiver, the pulses appeared as ten individual targets on the radar's ppi display. The ten targets were equally spaced along a radial that was 3-nmi long. The targets at each distance within that 3-nmi radial had the same signal power into the radar receiver. This simulates the targets having a larger RCS as the distance increases. The number of pulses that were used to generate each individual target was dependent upon the radar's PRF, antenna rotation rate, and antenna horizontal beamwidth. The instrumentation used to generate the targets is shown in Fig. 4. The target generation system provides non-fluctuating targets: at each distance the RCS is constant.

FIGURE 4

Target generator instrumentation



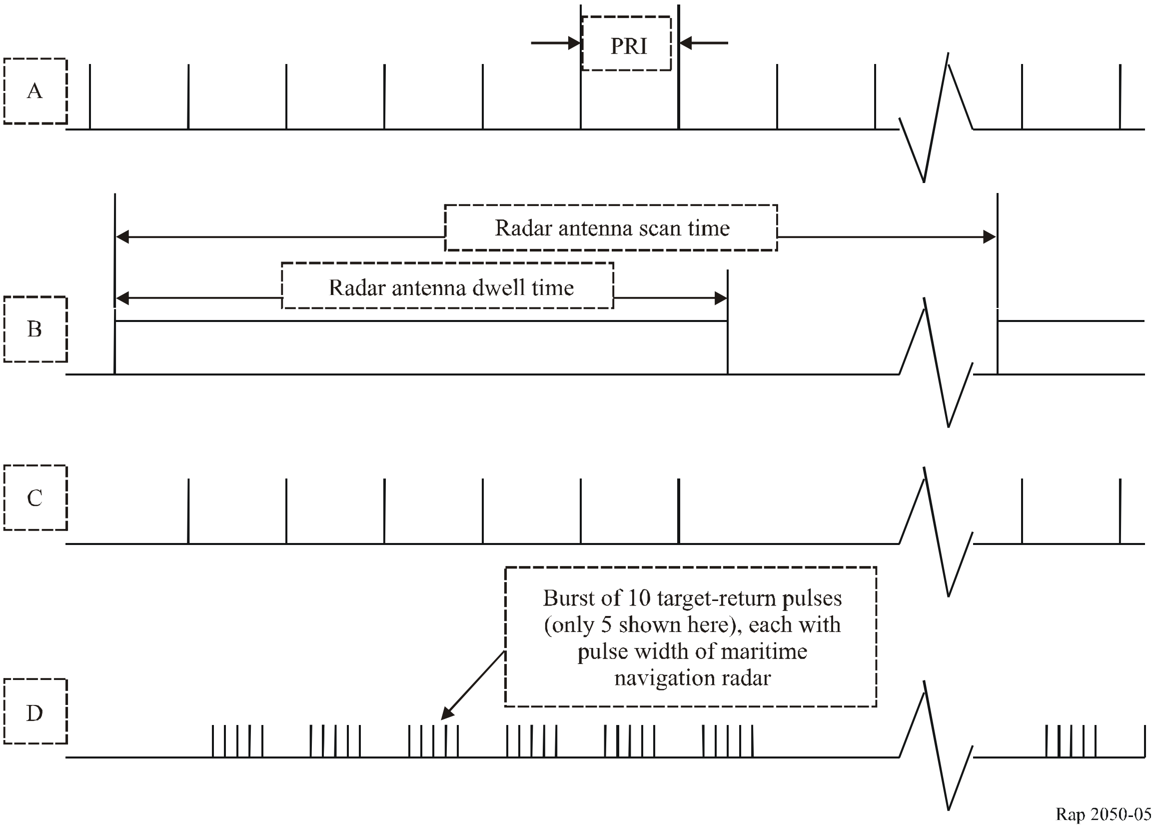
The train of transmitter trigger pulses (A) was used to trigger the simulated-target generator. A free-running pulse generator was used to produce gate pulses (B) representing the amplitude modulating effect on target return due to the antenna beam. Those pulses gated the train of transmitter triggers in an AND gate circuit, producing bursts (C) of trigger pulses containing from 6 to 23 pulses each. Each trigger pulse was applied to an arbitrary waveform generator, which delayed the trigger appropriately and generated a burst of ten pulses (D), each having the width of one of the radar's short pulses. All ten of these occurred within one "sweep" of the radar; i.e. within the displayed fraction of one pulse repetition interval or PRI. Each of those pulses in turn modulated an RF signal generator set to a frequency near 3 050 or 9 410 MHz to produce a simulated-target-return pulse train. The specific RF signal generator frequency was adjusted to maximize the radar's response.

The ten target pulses triggered by each radar trigger all occur within the return time of one of the radar's short range scales i.e. one "sweep". Consequently, the pulses simulate ten targets along a radial; i.e. a single bearing. For adjustment of the display settings, the RF power of the target generator was set to a level so that all ten targets were visible along the radial on the ppi display with the radar's video controls set to positions representative of normal operation.

The pulse repetition rate of the target generator (waveform B) was adjusted so the targets would appear at the same azimuth on consecutive scans of the ppi. The timing diagram of the target generator is shown in Fig. 5.

FIGURE 5

Target generator timing diagram



For the tests, the signal levels of all targets were adjusted to produce stationary target detections consistent with a fixed Pd of about 90%. The Pd of 90% was chosen to reflect the case that the Pd can never be 100% due to propagation effects, interference and other factors. The IMO, at this time, has not specified a minimum Pd for marine radionavigation radars. The IMO performance standard[2] does specify target types, the radar target cross-section, and the minimum range to detect them. The IMO is developing a minimum Pd for these types of radars which they may publish in the near future.

6 Test conditions

The tests were performed with the following parameters set on the maritime radionavigation radars as shown in Table 4.

---

[2] Extracts from IMO Resolutions A222(VII), A278(VIII), A477(XII) for radar equipment required by Regulation 12, Chapter 5 of the IMO-SOLAS Convention.

TABLE 4

Radar control settings

Parameter	Setting
Sensitivity time control (STC)	Disabled
Fast time constant (FTC)	Disabled (default)
Interference rejection (IR)	On (default)
Automatic gain control	On (default)
Radar a image selected	Raw video ("image") and/or synthetic targets
Radar B, C, D, E	Raw video
Range scale	3 nmi (5.6 km)

For all of the radars, the sensitivity-time-control (STC) and fast-time-constant (FTC) can be activated at the operator's discretion. STC is a technique for suppressing sea-clutter return by attenuating received signal strongly at short range and by amounts that decrease with increasing range, with no attenuation at long ranges. FTC is a technique for suppressing rain clutter return by differentiating the received signal after envelope detection.

For each of the radars that were tested, baseline values for the software functions that controlled the target and background brilliance, hue, and contrast settings were found through experimentation by test personnel and with the assistance of the manufactures and with professional mariners that were experienced with operating these types of radars on ships of various sizes. Once these values were determined, they were used throughout the test program for that radar.

7 Test procedures

For each radar that was tested, the RF power output of the target generator system was adjusted so that the target ("blips") Pd was about 90% without unwanted signals being present, with the baseline ppi target and background display settings. Table 5 lists the target power at each radar's RF input that was required to obtain a Pd of 90%. Once these values were determined, they were used throughout the tests.

TABLE 5

Target power levels

Radar under test	Target power at RF input (before mixer) for a Pd of 0.90 (dBm)
A	–90
B	–89
C	–77
D	–89
E	–86

For Radars A, C and E, the appropriate levels of unwanted signal powers that were required to produce the *I*/*N* levels within the radar receivers was determined using the calculated receiver noise power calibrated to the receiver's waveguide input. The receiver noise power was calculated using the IF bandwidth and noise figure. Any differences in bandwidths between the radar receiver and the test signals were accounted for in setting the *I*/*N* levels.

The appropriate levels of unwanted signal powers that were required to produce the *I*/*N* levels within radar receivers B and D were determined by monitoring the output of the IF circuitry at a test point located at the detector input with the spectrum analyser. The spectrum analyser was set to zero-span mode and the value of the radar receiver noise power at the IF test point, without any unwanted signal being present, was measured and recorded. The unwanted signal was then injected into the radar RF front-end and the noise power at the IF test point was monitored for a 3 dB increase as the power level of the unwanted signal was also increased. A 3 dB increase in the receiver noise power is equal to an *I*/*N* of 0 dB. Once the value of the unwanted signal that generated the *I*/*N* of 0 dB was found, the unwanted signal power levels that generated the other *I*/*N* values were easily determined. The power levels of the unwanted signals were controlled using step attenuators or the test set panel display.

For Radars B and D, the number of targets on each radial was counted for 50 simulated rotations of the antenna for each *I*/*N* level for each type of unwanted signal. The Pd was calculated by dividing the number of counted targets by the total number of targets that were generated.

For Radars A, C and E, observations of the relative strength or brightness of the targets displayed on the ppi were performed and documented at the various *I*/*N* levels. The nature of the effect of the interference on Radars A, C, and E target displays prevented performing an actual "count" of the targets because all of the targets tended to "fade" at the same rate. These effects included a "dimming" of the targets, an increase in the number of false targets, radial streaks ("strobes"), and an increase in background "speckle" or noise.

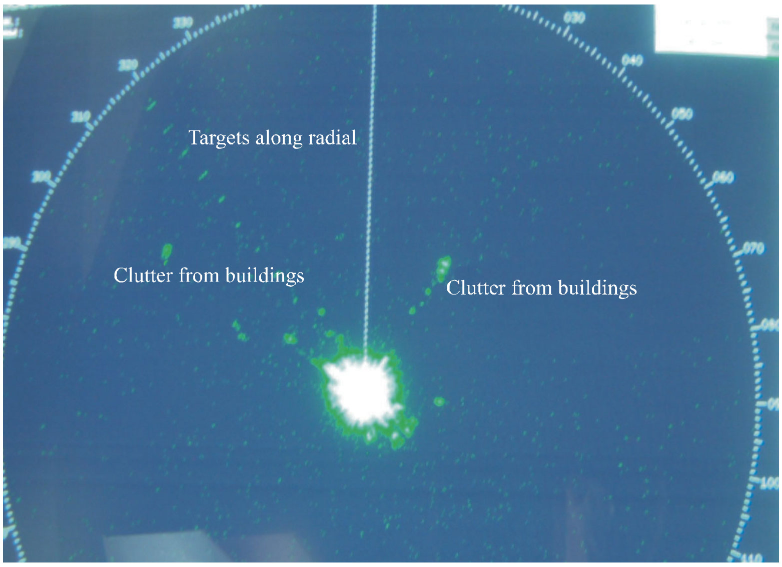
8 Test results

8.1 Radar A (3 GHz)

Figure 6 shows a digital photograph of Radar A's plan-position-indicator (ppi) baseline operating state (no interference injected). Note that the raw-video targets appear along a radial at about 320°. Local clutter returns from buildings and slight speckling are also visible on the radar display.

FIGURE 6

Radar A baseline state with video targets



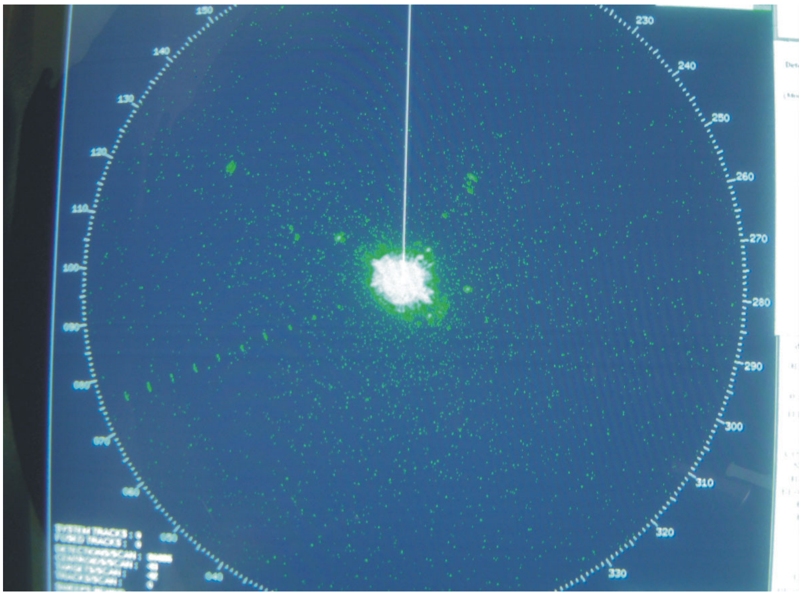
Rap 2050-06

Observations of video image targets on the radar's ppi display were made with emissions from the QPSK generator applied to its receiver. The power level of the QPSK emission was adjusted until the appearance of the radar's ppi was in a baseline condition.

The power level of the QPSK waveform was adjusted within a range of values to find the level where the QPSK emissions did not adversely affect the performance of the radar in displaying video targets. Figures 7 and 8 are photographs of the radar's ppi that show the effects of the QPSK waveform at power levels of –112 and –102 dBm, (measured within a 3 MHz bandwidth) respectively. The radar's receiver noise power is about –104 dBm. The resulting *I*/*N* ratios are –8 and +2 dB.

FIGURE 7

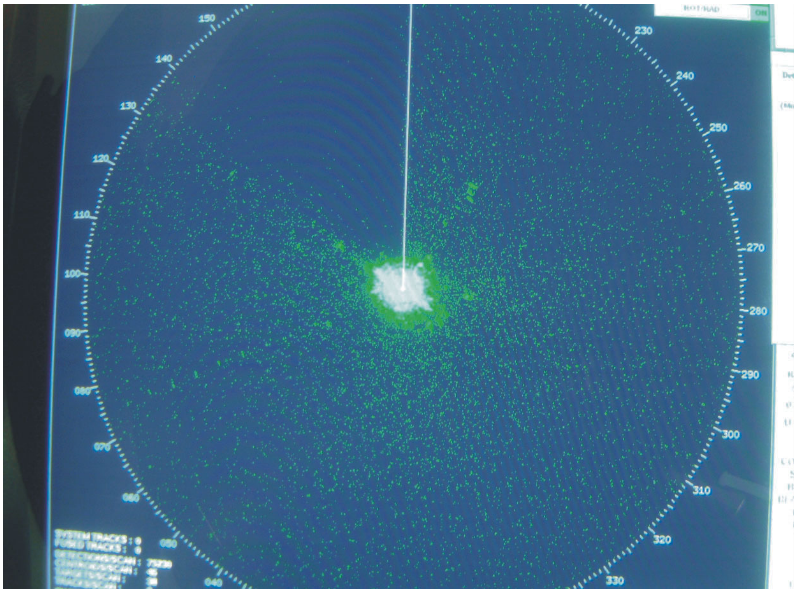
QPSK interference for *I*/*N* = –8 dB



Rap 2050-07

FIGURE 8

QPSK interference for *I*/*N* = +2 dB



Rap 2050-08

The photographs show that the QPSK emissions caused an increase in the background noise or speckle. In comparing Fig. 6, which is the radar baseline state without interference, to Fig. 7 (which has an *I*/*N* of –8 dB) the background speckle has increased but the targets are still detected and displayed. In Fig. 8 the *I*/*N* is +2 dB and the QPSK emissions have increased the background noise to the extent that some of the targets are indistinguishable from the speckle.

The power level of the QPSK emissions was adjusted to find the point where the video targets were still clearly visible and the background "speckle" was similar to the baseline level. That power level was found to be about –111 dBm at the receiver input, for an *I*/*N* ratio of about –7 dB.

It is important to note that the test targets on the radial are more visible than "real world" targets that would be distributed anywhere on the radar's ppi. Therefore, care needs to be taken in interpreting radar presentations in the presence of noise.

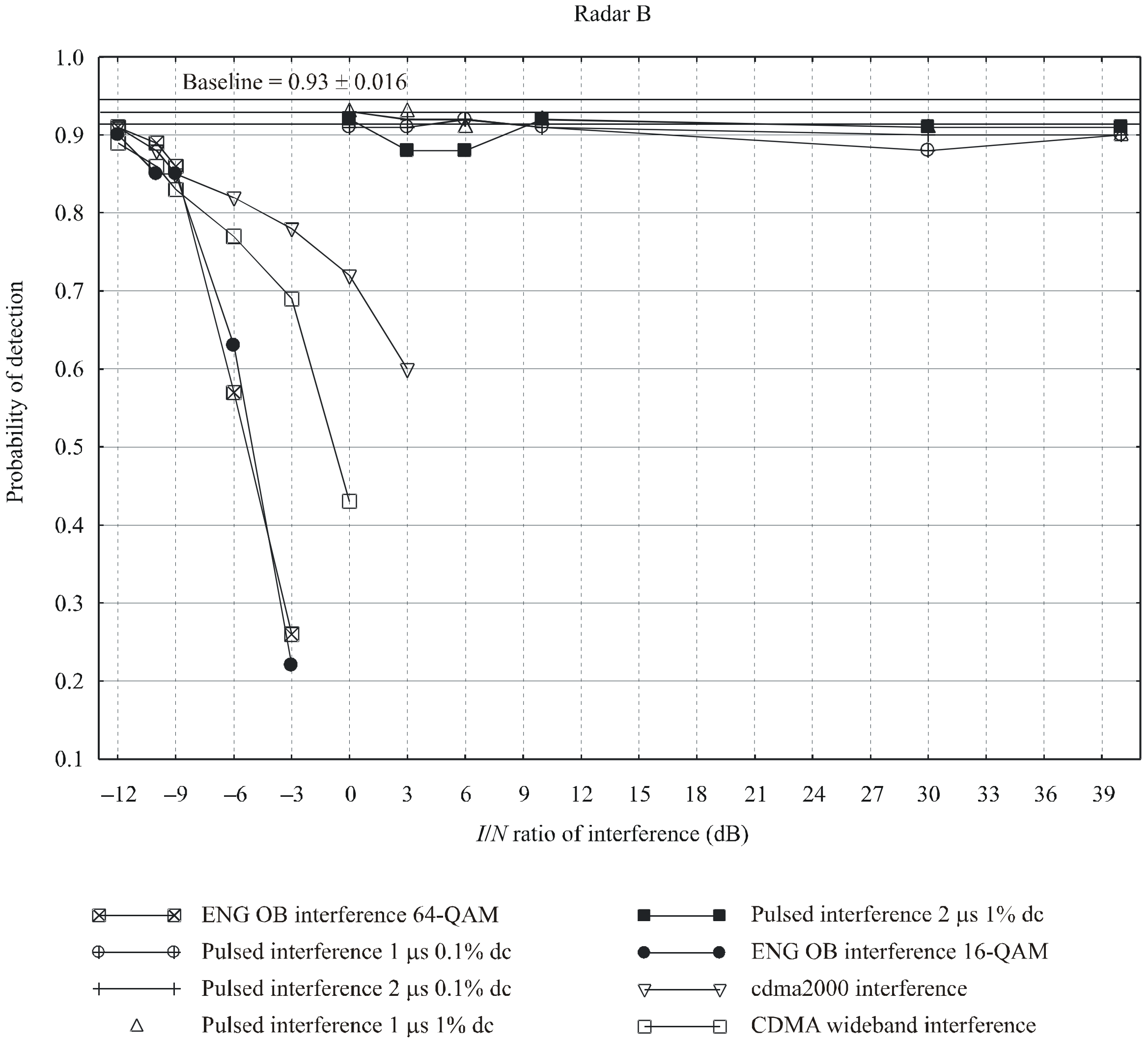
The *I*/*N* values were not based on one specific photograph *per se*. The photographs in this Report are representative of the interference condition. Some of the radar's scans might show a worse state (denser speckle/false targets) while others might show a better state (clearer ppi) at the same *I*/*N* level. Approximately 20 scans were observed at each *I*/*N* level in choosing the *I*/*N* values represented in Figs. 6 through 8.

8.2 Radar B (3 GHz)

For Radar B it was possible to observe the effect that the unwanted signals had on individual targets. For each unwanted signal, it was possible to count the decrease in the number of targets that were visible on the ppi as the *I*/*N* level was increased. Target counts were made at each *I*/*N* level for each type of interference. A baseline target Pd count was performed before the beginning of each test. The results of the tests on Radar C are shown below in Fig. 9, which shows the target Pd versus the *I*/*N* level for each type of interference. The baseline Pd in Fig. 9 is 0.93 with the 1-sigma error bars 0.016 above and below that value. Note that each point in Fig. 9 represents a total of 500 desired targets.

FIGURE 9

Radar B Pd curves



Rap 2050-09

Figure 9 shows that, except for the case of the pulsed interference, the target Pd was reduced below the baseline Pd used in these tests minus the standard deviation for *I*/*N* values above –12 dB for all of the unwanted signals that used a digital modulation. The QAM interference caused the quickest drop in the Pd as the *I*/*N* was increased. Data was not taken for higher *I*/*N* values above of –3 dB for QAM because all of the targets were gone on the ppi above that level. The cdma2000 had the least effect on the target Pd, but it was still causing a drop in the target Pd at *I*/*N* values above –12 dB.

8.3 Radar C (3 GHz)

For Radar C it was difficult to count the decrease in target Pd as the interference was injected into the radar's receiver. The interference caused all of the targets to fade at the same rate no matter where they were located in the string of targets. It was not possible to make individual targets "disappear" as the interference power was increased, and count the number of lost targets in order to calculate the Pd. Therefore, the data taken for Radar C reflects whether or not the appearance of all the targets was affected at each *I*/*N* level for each type of interference. The data for Radar C is summarized in Tables 6 and 7.

TABLE 6

Radar C with continuous ENG OB interference

***I/N* ratio (dB)**	**64-QAM**	**16-QAM**
–12	No effect	No effect
–10	No effect	No effect
–9	Targets slightly dimmed	Targets slightly dimmed
–6	Targets dimmed	Targets dimmed
–3	Targets not visible	Targets not visible
0	Targets not visible	Targets not visible
3	Targets not visible	Targets not visible
6	Targets not visible	Targets not visible

The data in Table 7 shows that the unwanted QAM signals affected the visibility of the targets for Radar E on its ppi at an *I/N* level of –9 dB. At that level the brightness of the targets on the ppi was slightly dimmed from their baseline state. At *I/N* levels of –6 dB they were dimmed more and for *I/N* levels above –3 dB the targets had dimmed so much that they were no longer visible on the ppi.

TABLE 7

Radar C with gated CDMA interference

***I/N* ratio (dB)**	**WBCDMA**	**cdma2000**
–12	No effect	No effect
–10	No effect	No effect
–9	No effect	No effect
–6	Targets dimmed	Targets dimmed
–3	Targets not visible	Targets not visible
0	Targets not visible	Targets not visible
3	Targets not visible	Targets not visible
6	Targets not visible	Targets not visible

The data in Table 6 shows that the unwanted CDMA signals affected the visibility of the targets for Radar C on its ppi at an *I/N* level of –6 dB. At that level the brightness of the targets on the ppi was noticeably dimmed from their baseline state. At *I/N* levels of –3 dB and above, the targets had dimmed so much that they were no longer visible on the ppi.

For Radar C, the gated 2.0 and 1.0 μs pulsed interference with duty cycles of 0.1% and 1.0% did not affect the visibility of the targets on the ppi at the highest *I/N* level, which was 40 dB.

8.4 Radar D (9 GHz)

For Radar D it was possible to observe the effect that the unwanted signals had on individual targets. For each unwanted signal, it was possible to count the decrease in the number of targets as the *I/N* level was increased. Target counts were made at each *I/N* level for each type of interference. A baseline target Pd count was performed before the beginning of each test. The results of the tests on Radar D are shown in Fig. 10. Figure 10 shows the target Pd versus the *I*/*N* level for each type of interference. The baseline is shown at a Pd of 0.92 with the 1-sigma error bars 0.016 above and below. Note that each point in Fig. 10 represents a total of 500 desired targets.

FIGURE 10

Radar D Pd curves

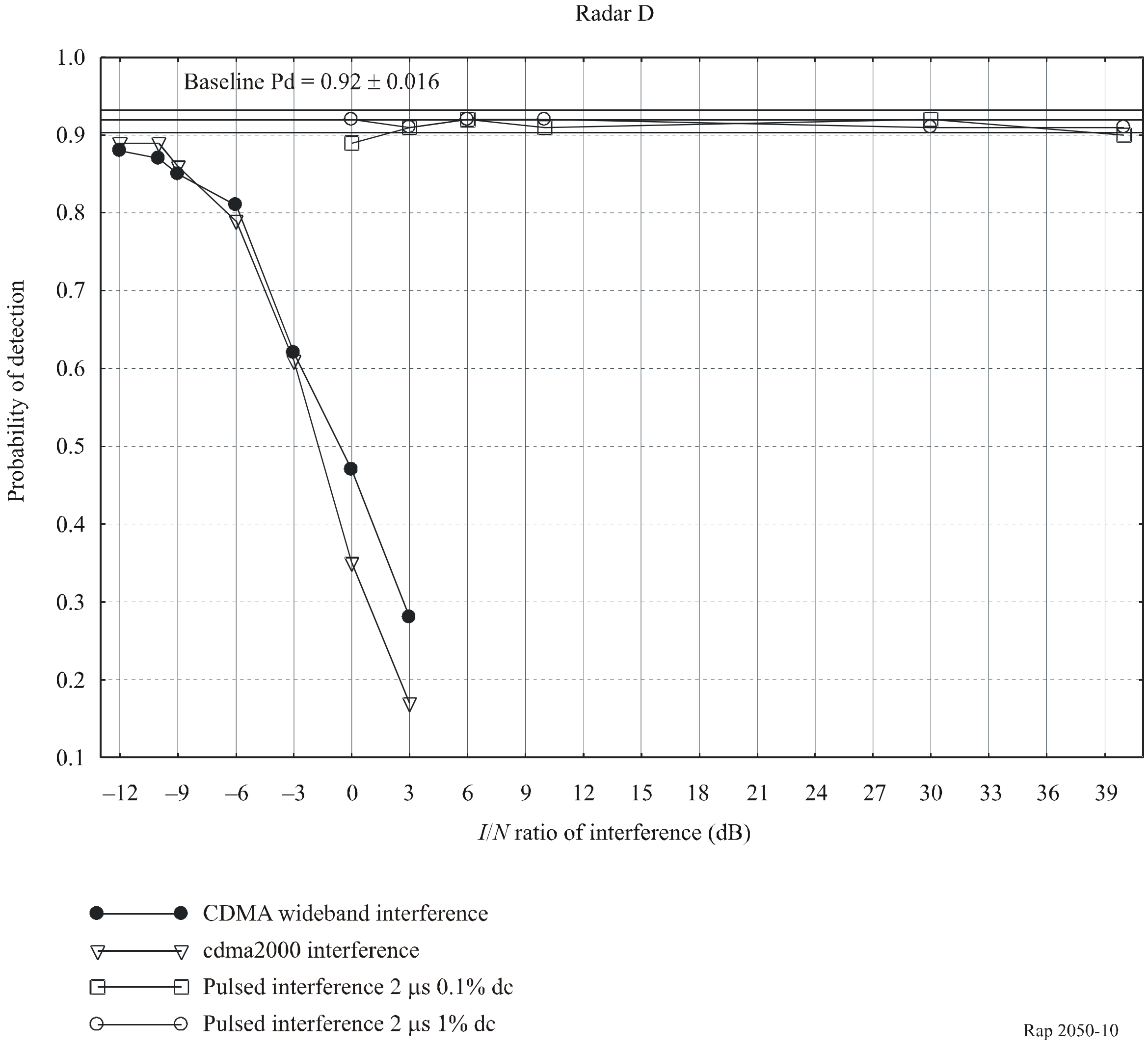


Figure 10 shows that, except for the case of the pulsed interference, the target Pd was reduced below the baseline Pd used in these tests minus the standard deviation for *I*/*N* values above –12 dB for the unwanted CDMA signal.

8.5 Radar E (9 GHz)

As in the case of Radar C, for Radar E it was difficult to count the decrease in target Pd as the interference was injected into the radar's receiver. The interference caused all of the targets to fade at the same rate no matter where they were in the string of targets. It was not possible to make individual targets "disappear" as the interference power was increased. Therefore, the data taken for Radar C reflects whether or not the appearance of all the targets was affected or not at each *I*/*N* level. The data for Radar E is summarized in Table 8.

TABLE 8

Radar E with gated CDMA interference

I/*N* ratio (dB)	WBCDMA	cdma2000
–12	No effect	No effect
–10	No effect	No effect
–9	No effect	No effect
–6	Targets dimmed	Targets dimmed
–3	Targets dimmed	Targets dimmed
0	Targets not visible	Targets not visible
3	Targets not visible	Targets not visible
6	Targets not visible	Targets not visible

The data in Table 8 shows that the unwanted CDMA signals affected the visibility of the targets for Radar E on its ppi at an *I*/*N* level of –6 dB. At that level the brightness of the targets on the ppi was noticeably dimmed from their baseline state. At *I*/*N* levels of 0 dB and above, the targets had dimmed so much that they were no longer visible on the ppi.

For Radar E, the gated 2.0 and 1.0 µs pulsed interference with duty cycles of 0.1% and 1.0% did not affect the visibility of the targets on the ppi at the highest *I*/*N* level, which was 40 dB.

9 Conclusions

The results of these tests show that when the emissions of devices using digital modulations are directed towards a radar of the type tested herein exceed an *I*/*N* ratio of –6 dB, some of the radars started to have dimmed targets, lost targets, or generate false targets. For other radars at this *I*/*N* level, these effects had already manifested. When using radars with a logarithmic IF amplifier/detector (Radars A, C and E), the targets, as indicated in Tables 6, 7 and 8, were either not visible or dimmed at the *I*/*N* levels of –3 dB and –6 dB. Depending on the type of interference coupled into Radars A, C and E, the effects of the interference were maximized (i.e. the targets had disappeared from the ppi and no other effects were visible) at *I*/*N* levels between 0 and –10 dB. For Radars B and D (which use a logarithmic amplifier and separate video detector), at the *I*/*N* level of –6 dB, the target Pds dropped below the baseline 1-sigma error. These test results show that at an *I*/*N* of –10 dB, for Radars A, C and E, the targets are no longer dimmed and for Radars B and D, the target Pds are slightly below the baseline 1-sigmas error. However, note from § 3.4 (*supra*), for Radar A that the synthetic targets required about 2 to 3 dB of additional desired signal power compared to the raw-video targets to obtain the same probability of detection, Pd, when operating at a minimum detectable signal level, but the appearance of the targets were not brighter on the ppi.

The tests show that the radars can withstand low-duty cycle pulsed-interference at high *I*/*N* levels due to the inclusion of radar-to-radar interference mitigating circuitry and/or signal processing. The radar-to-radar interference mitigation techniques of scan-to-scan and pulse-to-pulse correlators and CFAR processing, described in Recommendation ITU-R M.1372, have been shown to work quite well. However, the same techniques do not work for mitigating continuous emissions that appear noise-like or CW like within the radar receiver.

As most marine radars in the 2 900-3 100 and 9 200-9 500 MHz bands are very similar in design and operation, one does not expect a great variation from the protection criteria that was derived from the radars that were used for these tests. Therefore, these test results should apply to other similar radars that operate in the 2 900-3 100 and 9 200-9 500 MHz bands as well.

Determining the acceptable amount of interference for these types of radars can be somewhat subjective due to the eyesight and experience of the radar operator looking at the ppi counting targets and grading the brightness of the targets themselves. However, due to the radar's design, there is no other way for these tests to be performed other than for the operator/tester to observe the targets on the radar's ppi.

The amount of experience they have in operating radars is a factor in looking at the ppi and determining exactly what defines a target and how much degradation they can withstand. An experienced and/or a formally trained radar operator will be better able to discern real targets from false targets, interference and/or clutter than an inexperienced one. To witness and participate in these tests, the manufacturers provided radar design engineers and the United Kingdom Maritime Coast Guard Agency (MCA) provided experienced radar operators and instructors. The results and conclusions of these tests were verified by them.

The above conclusions were based upon tests using non-fluctuating targets. Other tests, such as those which might include fluctuating targets, could yield different results and therefore different conclusions.