RECOMMENDATION ITU-R M.1644

Technical and operational characteristics, and criteria for protecting the mission of radars in the radiolocation and radionavigation service operating in the frequency band 13.75-14 GHz

(Question ITU-R 226/8)

(2003)

Summary

This Recommendation provides the technical and operational characteristics, and criteria for protecting the radiolocation and radionavigation radars operating in the 13.75-14 GHz band. It contains a detailed description of the predominant shipborne radiolocation radar in the band, plus a tabular set of characteristics of all the known shipborne, airborne and ground-based radars operating in the band.

The ITU Radiocommunication Assembly,

considering

a) that the antenna, signal propagation, target detection, and large necessary bandwidth characteristics of radars needed to achieve their functions are optimum in certain frequency bands;

b) that the technical characteristics and protection criteria of radiolocation and radionavigation radars are determined by the mission of the system and vary widely even within a band;

c) that considerable radiolocation and radionavigation spectrum allocations (amounting to about 1 GHz) have been removed or downgraded since WARC-79;

d) that some ITU-R technical groups are considering the potential for the introduction of new types of services (e.g. fixed satellite, wireless access, and high-density fixed and mobile) in bands between 420 MHz and 34 GHz used by radionavigation and radiolocation radars;

e) that representative technical and operational characteristics of radiolocation and radionavigation radars are required to determine the feasibility of introducing new types of systems into frequency bands in which the radars are operated;

f) that criteria for protection of the radars' missions are also needed for that same purpose;

g) that some radiolocation and radionavigation radars operate in both the 13.75-14 GHz band and the 13.4-13.75 GHz band;

h) that radiolocation and radionavigation radars operate in both airborne and shipborne platforms, by many administrations in all regions of the globe, and on land by at least one administration, *recommends*

1 that the technical and operational characteristics of the radars described in Annex 1 be considered representative of radars operating in the frequency band 13.75-14 GHz;

2 that the appropriate criteria for protecting the operational performance of those radars presented in Annex 1;

3 that those criteria be used in analysing compatibility between those radars and systems in other services;

4 that in the presence of any modulated continuous wawe (CW) interfering signals with most or all of its 3 dB emission bandwidth spanned by the radar receiver passband in the main beam direction, the ratio of interfering signal power to radar receiver noise power level, I/N, of –6 dB be used as the interference protection criteria for the radars described in Annex 1, consistent with the guidance contained in Recommendation ITU-R M.1461.

This protection criterion represents the net protection level if multiple interferers are present. This threshold value is to be used in conjunction with the overall mission-protection criteria presented in Annex 1.

Annex 1

Characteristics of radiolocation and radionavigation radars and criteria for protection of their mission

1 Introduction

The band 13.75-14 GHz is allocated on a primary basis to the radiolocation service, the FSS (Earth-to-space), and certain functions of the space research service. It is also allocated for the radionavigation service by some administrations. The standard frequency and time signal-satellite service (Earth-to-space) operates in this band on a secondary basis.

2 Mission

The radars described in § 2 through 5 of this Annex are used worldwide, primarily aboard ships operated by many administrations. They operate in sea and coastal areas, and there are a few land-based sites. They are used to detect and track discrete approaching airborne and surface objects (conventionally referred to in radar literature as targets). Many ships are equipped with several of these radars, and radars of this type aboard one ship cannot serve the needs of other ships even if they are nearby. Since some of the targets of interest are airborne at very low altitude, the 13.75-14 GHz band offers an ideal compromise between multipath phenomena and atmospheric attenuation for performance of this mission. Similarly, many airborne and land-based radars perform the same function as the shipborne radar systems.

3 Technical characteristics

The radiolocation system characteristics contained herein represent the predominant type of shipborne radar operating in the 13.75-14 GHz band. Table 4 in Appendix 1 to this Annex provide characteristics for other airborne, shipborne, and land-based radar systems operating in the band 13.75-14 GHz. The characteristics in § 2 through 5 of this Annex should be used in studies of sharing with these shipborne radars, and the characteristics in Appendix 1 should be used with the other types of radars.

3.1.1 Transmitter power/radiated power

The transmitter is a klystron with peak output power of 30 kW (45 dBW). Search loss from transmitter to antenna is –5 dB; track loss from transmitter to antenna is –4 dB.

3.1.2 Search

Search peak equivalent isotropically radiated power (dBW) = transmitter peak power (dBW) – transmission line loss (dB) + antenna gain (dBi):

Beam 1 peak e.i.r.p. = 45 – 5 + 31.5 = 71.5 dBW;
Average e.i.r.p. = 57.2 to 54.9 dBW[1];

Beams 2, 3, and 4 peak e.i.r.p. = 45 – 5 + 28.5 = 68.5 dBW;
Average e.i.r.p. = 54.2 to 51.9 dBW[1].

3.1.2.1 Search waveforms

The search system uses a coherent transmitter/receiver for digital moving target indicator processing.

3.1.2.1.1 Low pulse repetition frequency mode

Pulse width (PW):	2.2 μs phase coded with 0.2 μs segments
Pulse repetition interval (PRI):	minimum = 60 μs; maximum = 100 μs
Duty factor:	maximum = 3.7% (–14.3 dB); minimum = 2.2% (–16.6 dB).

3.1.2.1.2 High pulse repetition frequency (clutter) mode

Pulse width:	0.2 μs
Pulse repetition interval:	between 10 and 14 μs.

3.1.3 Track

Track peak e.i.r.p. (dBW) = transmitter peak power (dBW) – transmission line loss (dB) + antenna gain (dBi):

Track peak e.i.r.p. = 45 – 4 + 38.5 = 79.5 dBW;

Average acquisition e.i.r.p. = 62.5 to 61.0 dBW[1];

Average track e.i.r.p. = 59.5 to 58.0 dBW[1].

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[1] The average powers given here are for periods of time equal to a fraction of a second, and should not be compared to the e.i.r.p. limit in No. 5.502 of the Radio Regulations, which applies for a period of time equal to one second.

3.1.3.1 Track waveform

The track system uses a coherent transmitter/receiver for pulse-Doppler processing.

Pulse width:	0.2 µs in acquisition; 0.1 µs in track
Pulse repetition interval:	between 10 and 14 µs
Duty factor:	acquisition 2% (–17 dB) to 1.4% (–18.5 dB); track 1% (–20 dB) to 0.7% (–21.5 dB).

3.2 Radar receiver noise level and losses

N = Radar receiver thermal noise = –134 dBW in a 10 MHz bandwidth.

This is the noise level of the terrestrial environment in a 10 MHz reference bandwidth without any receiver-added noise.

NF = Radar noise figure = 5 dB.

Receiver noise level = –129 dBW (10 MHz bandwidth).

This is the level with the receiver-added noise included.

L_{RF} = RF transmission line loss between the radar antenna and preamplifier = 2 dB.

The overall receiving-system noise level referred to the antenna port and expressed in a 10 MHz reference bandwidth is therefore:

$$-129 + 2 = -127 \text{ dBW}$$

3.3 Antenna characteristics

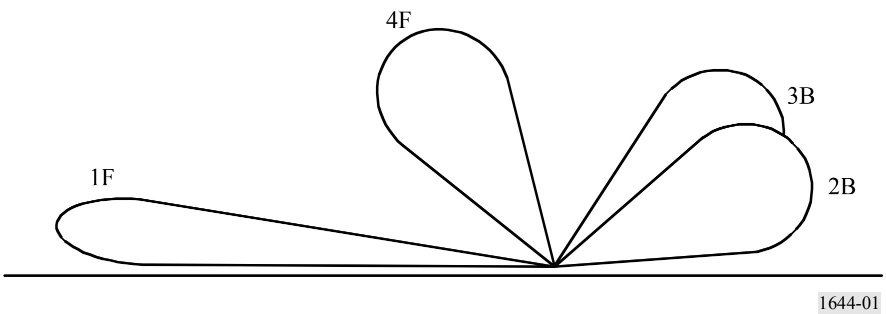
Each of these radars contains two separate antenna assemblies. One set of antennas is used for the search function, and another antenna is used for the acquisition and track functions.

3.3.1 Search antennas

Configuration 1 elevation coverage is accomplished using one 10° antenna centred at 4.5° (1F) and one 20° antenna (4F) centred at 60°, both facing forward, and two 20° antennas centred at 20° (2B) and 40° (3B), both facing backward. Figure 1 presents the composite elevation coverage pattern with all antennas superimposed. Table 1 lists parameters of the search antennas.

FIGURE 1

Configuration 1 search main beam patterns



Azimuth rotation rate is 540°/s. On ships with two systems, each radar covers 310° of azimuth.

TABLE 1

Search antenna parameters – Configuration 1

Antenna position	Elevation beamwidth (degrees)	Elevation beam centre (degrees)	Gain (dBi)	Azimuth beamwidth (degrees)
1F	10	4.5	31.5	2.2
2B	20	20	28.5	2.2
3B	20	40	28.5	2.2
4F	20	60	28.5	2.2

Configuration 2 elevation coverage is accomplished using two 2.5° antennas centred at 0° (1F and 2B) and two 10° antennas (3B and 4F) centred at 6.25 and 16.25 respectively. Figure 2 presents the composite elevation coverage pattern with all antennas superimposed. Table 2 lists parameters of the search antennas.

Azimuth rotation rate is 540°/s. On ships with two systems, each radar covers 310° of azimuth.

FIGURE 2

Configuration 2 search main beam patterns

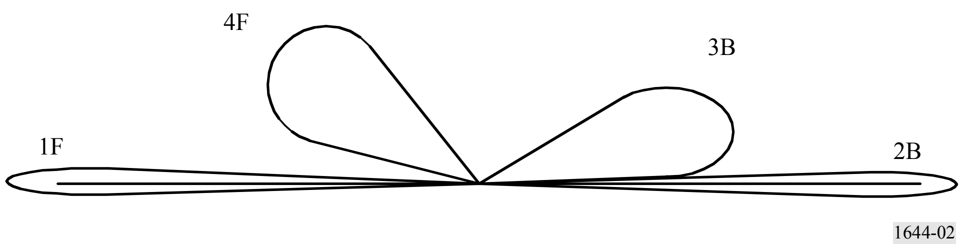


TABLE 2

Search antenna parameters – Configuration 2

Antenna position	Elevation beamwidth (degrees)	Elevation beam centre (degrees)	Gain (dBi)	Azimuth beamwidth (degrees)
1F	2.5	0	37.5	2.2
2B	2.5	0	37.5	2.2
3B	10	6.25	31.5	2.2
4F	10	16.25	31.5	2.2

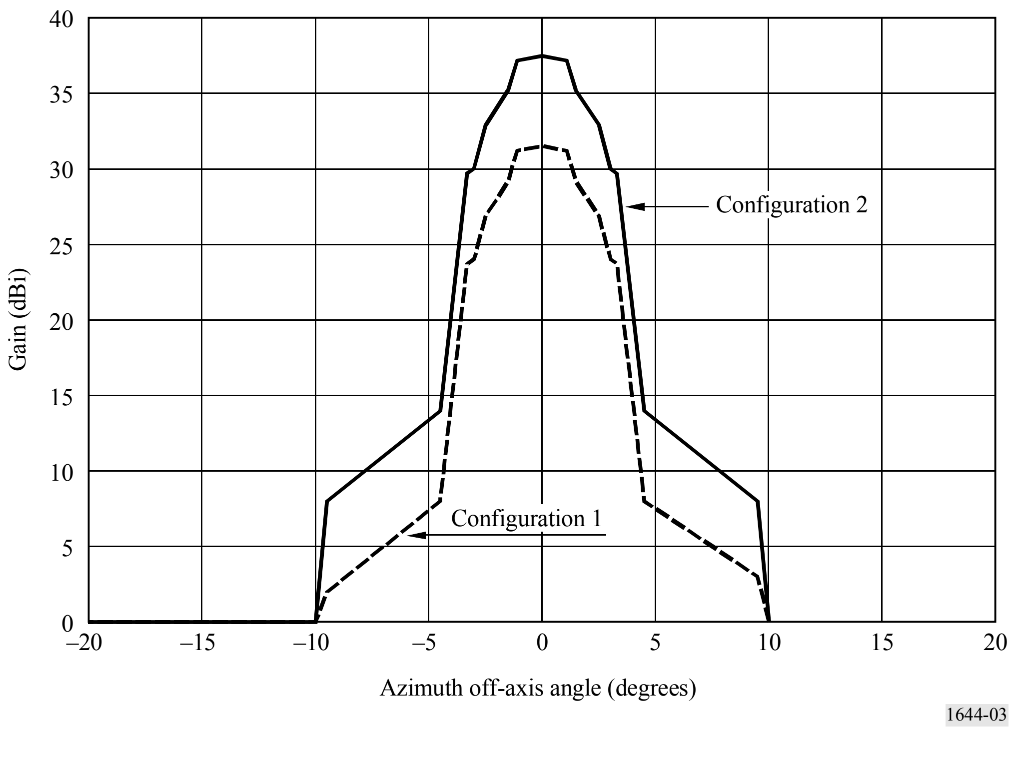
TABLE 3

Radar antenna off-axis gain in azimuth

Off-axis angle (degrees)	Configuration 1 gain (dBi)	Configuration 2 gain (dBi)
–180	0	0
–10	0	0
–9.5	2	8
–4.5	8	14
–3.3	23.7	29.7
–3	24	30
–2.5	26.9	32.9
–1.5	29.2	35.2
–1.1	31.2	37.2
0	31.5	37.5
1.1	31.2	37.2
1.5	29.2	35.2
2.5	26.9	32.9
3	24	30
3.3	23.7	29.7
4.5	8	14
9.5	3	8
10	0	0
180	0	0

FIGURE 3

Search radar antenna beam 1F gain patterns



3.3.2 Track antenna

The track antenna is a monopulse four-horn fed parabolic dish segment with elevation beamwidth of 1.2° and azimuth beamwidth of 2.4°; gain is 38.5 dBi and side lobe levels are more than 20 dB below the main lobe. When designated to acquire a target, the antenna executes a limited size raster pattern and goes into track when the target is detected.

3.4 Planned radiolocation system modifications

Radar detection of objects at low-elevation angles is being improved by increasing antenna gain on the horizon using existing search waveforms. Increased e.i.r.p. levels will be transmitted with the scan beam centred on the horizon as follows:

Peak e.i.r.p. < 2° elevation = 79 dBW: average e.i.r.p. = 64 dBW (search mode)

Peak e.i.r.p. > 2° elevation = 79 dBW: average e.i.r.p. = 59 dBW (track mode).

The modified search antenna aperture is identical to the existing track antenna aperture. The modified search antenna is only used below 2° elevation. In today's system, the track antenna is the source of the maximum peak and average e.i.r.p. (79 dBW and 59 dBW respectively). In the modified radar, the peak e.i.r.p. will remain at 79 dBW since the track and low-elevation search apertures will be the same, but the average e.i.r.p. below 2° (search) will increase due to the greater pulse widths used in search than in track.

4 Operational characteristics

4.1 System radiation time

For deployed ships/systems, when the ships are in potentially hazardous areas, the systems must radiate continuously.

4.2 Radiolocation system geographic distribution

Approximately 800 of these radars are in use. Insofar as interactions with geostationary satellites are concerned, it can be assumed that the radars are uniformly distributed on the Earth's sea surface and that one-third of them are visible to a geostationary satellite. However, locally up to 70 of these radars could be operating within a 200 km^2 area and located from 1 km offshore to the radar horizon.

The number of radars operating in the 13.75-14 GHz band is approximately 333.

The probability, P_c, that a single FSS transmitter would operate co-frequency with a given radar operating in the 13.75-14 GHz band is approximately:

$$P_c = BW / 250$$

where BW is the interferer's bandwidth (MHz).

The probability that an interferer's emission spectrum would overlap the passband of one or more radars aboard a cluster of ships can be much higher than that.

4.3 Range of radiolocation antenna heights

The system mount deck height varies from 3 to 36 m above the waterline. The search antenna is approximately 5 m above the deck and the track antenna is approximately 4 m above the deck.

5 Criteria for protection of the radars' mission

5.1 Surveillance requirements

This radiolocation device is not a traditional surveillance type radiolocation device, but rather an integrated part of a larger weapon system provided to protect a ship from incoming threats. Its use is driven by the threat environment. The demand for use is 100% when operating close to shorelines.

5.2 Interference threshold

Recommendation ITU-R M.1461 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services, contains information on the interference threshold power level to be used in calculations of the potential for interference into radars.

Interfering signals of the noise-like continuous-carrier type that is characteristic of all conventional communications services exert a virtually unalterable desensitizing effect on radiolocation radars, regardless of the radars' waveform and signal processing. Consequently, the desensitization is predictably related to the intensity of the interference. In any azimuth sector in which such interference arrives, its power-spectral density simply adds to the power spectral density of the radar receiving system thermal noise, to within a reasonable approximation. If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply $I_0 + N_0$.

An increase of $I_0 + N_0$, relative to N_0, of about 1 dB would constitute significant degradation for the radiolocation service, even if it occurs only when the interference couples via the radar main beam. Such an increase corresponds to an $(I + N)/N$ ratio of 1.26, or an I/N ratio of about –6 dB.

This applies to the aggregate effect of multiple interferers, when present; the tolerable I/N ratio for an individual interferer depends on the number of simultaneous interferers and their geometry, and needs to be assessed in the context of a given scenario.

Because the –6 dB I/N ratio desensitization threshold applies when the strongest coupling condition occurs, including coupling via the radar's main beam, as well as when coupling is weaker (as via radar-antenna side-lobes) it can be expressed for any particular radar as a pfd limit. If the antenna main beam capture area is 0.5 m^2, the desensitization threshold for interference from communications transmitters will then be –164 dB(W/(m$^2 \cdot$ 4 kHz)) for coupling via the main beam.

For coupling via side-lobes or a combination of main beam and side-lobes from multiple sources, the impinged pfd's must be weighted according to the pertinent side-lobe suppression factors and aggregated before comparing them with this pfd limit. If that limit is exceeded for any radar beam-pointing direction, it will unacceptably degrade radar coverage.

The effect of pulsed interference is more difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. Several different forms of performance degradation, notably including false target generation, can be inflicted by such unwanted pulsed signals. In general, numerous features of radiodetermination radars can be expected to help suppress low-duty cycle pulsed interference, especially from a few isolated sources. Techniques for suppression of low-duty cycle pulsed interference are contained in Recommendation ITU-R M.1372 – Efficient use of the radio spectrum by radar stations in the radiodetermination service.

5.3 Overall protection criteria

In order that the radar might be able to effectively locate and discriminate targets in the presence of noise-like continuous interference, the above aggregate interference threshold level of -164 dB(W/(m$^2 \cdot$ 4 kHz)) must not be exceeded at the radars described in § 2 through 5. The corresponding *I*/*N* ratio of –6 dB would correlate to a 1 dB loss in range or radar-cross-section sensitivity. This is equivalent to a 6% loss in range coverage for a given radar-cross-section target) or a 26% increase in minimum detectable radar-cross section at a given range, and is the maximum interference level that can be tolerated from any direction in the surveillance volume.

6 Tabular summary of characteristics

The characteristics of the shipborne radars described in § 2 through 5 are summarized in Appendix 1, separately for the search and track functions, as "Radar A" and "Radar B". These radars operate in all ITU-R regions.

The characteristics of other radars of various types are included in Appendix 1 as radars C, D, E, F and G, and include shipborne/land-based, and airborne radars. The data on radars C, D, E, F and G are very limited, but the existence of these radar types can be important. As with the radars described in § 2 through 5 of this Annex, the protection criteria for these other radars in the presence of noise-like communication signals consists of an *I*/*N* ratio of –6 dB, which can be expressed as pfd levels per Table 4 of Appendix 1 to this Annex. As with radars A and B, interference received via side-lobes and/or from multiple sources must be weighted according to side-lobe suppression factors and aggregated as appropriate before comparison with those pfd levels.

Appendix 1
to Annex 1

TABLE 4

Characteristics	Radar A Track	Radar B Search	Radar C	Radar D	Radar E	Radar F	Radar G Track
Platform type (airborne, shipborne, ground)	Shipborne	Shipborne	Shipborne	Airborne	Airborne	Airborne	Ground
Type of service Radiolocation: RL Radionavigation: RN	RL	RL	RL	RL(1)	RL(1)	RL	RL
Tuning range (GHz)	13.75-14	13.75-14	Within 13.75-14	Within 13.75-14	Within 13.75-14	Within 13.75-14	Within 13.75-14
Modulation (unmodulated pulses, chirp, phase-code)	Unmodulated	Unmodulated and phase code	Pulsed	Not given	Not given	Not given	Unmodulated pulses
Transmitter peak power into antenna (dBW)	41	40	Not given	Not given	Not given	40	46 (nominal)
Average e.i.r.p. (dBW)	59.5 (62.5 in acquisition)	63 (currently ≤ 58.2)	Approx. 59	Not given	Not given	41.4 (nominal)	44.6-48.4
Peak e.i.r.p. (dBW)	79.5	79	>60	>40	>50	71 (nominal)	81
Pulse width minimum (μs)	0.1	0.2	Not given	Not given	Not given	0.6	0.085
Pulse width maximum (μs)	0.2	2.2	Not given	Not given	Not given	Not given	0.11
Pulse repetition rate minimum (pps)	71 400	10 000 (2.2 μs pulse width) 60 000 (2 μs pulse width)	Not given	Not given	Not given	1 800	2 700

TABLE 4 (*continued*)

Characteristics	Radar A Track	Radar B Search	Radar C	Radar D	Radar E	Radar F	Radar G Track
Pulse repetition rate maximum (pps)	100 000	14 000 (2.2 µs pulse width) 100 000 (2 µs pulse width)	Not given	Not given	Not given	Not given	3 300
Transmit duty cycle, minimum (%)	0.7	2.2	Not given	Not given	Not given	0.11(2)	2.295×10^{-2}
Transmit duty cycle, maximum (%)	2.0	3.7	Not given	Not given	Not given	Not given	3.795×10^{-2}
Chirp bandwidth (MHz)	Not applicable	Not applicable	Not applicable or not given	Not applicable or not given	Not applicable or not given	Not applicable or not given	Not applicable
Phase-coded sub-pulse width (µs)	Not applicable	0.2	Not applicable or not given	Not applicable or not given	Not applicable or not given	Not applicable or not given	Not applicable
Compression ratio	Not applicable	11:1	Not applicable or not given	Not applicable or not given	Not applicable or not given	Not applicable or not given	Not applicable
RF emission bandwidth (MHz): –3 dB –20 dB	 10 Not given	 5 Not given	 Not given Not given	 Not given Not given	 Not given Not given	 Not given Not given	 Not given
Output device (klystron, …)	Klystron	Klystron	Not given	Not given	Not given	Not given	Magnetron
Antenna pattern type (pencil, fan, cosecant-quared, etc.)	Pencil beam	Fan beam	Not given	Not given	Not given	Not given	Pencil beam
Antenna type (reflector, phased array, slotted array, ...)	Parabolic reflector	Slotted array	Not given	Not given	Not given	Not given	Slotted array

TABLE 4 (*continued*)

Characteristics	**Radar A Track**	**Radar B Search**	**Radar C**	**Radar D**	**Radar E**	**Radar F**	**Radar G Track**
Antenna mainbeam gain(s) (dBi): Search Track	 – 38.5	 37.5 (currently ≤31.5) –	 >20 >20	 >20 >20	 >20 >20	 < 31 search or track	 36
Antenna elevation beamwidth (degrees)	1.2	2.5 and 10 (currently 10 and 20. See p. 5 and 6)	Not given	Not given	Not given	Not given	15
Antenna traverse or azimuthal beamwidth (degrees)	2.4	2.2	Not given	Not given	Not given	Not given	0.25
Beam motion(s)	Tracking	Programmed search scan	Programmed search scan Tracking	Programmed search scan Tracking	Programmed search scan Tracking	Not given	Tracking
Antenna horizontal scan rate (degrees/s)	Follows target	540	Search: not given Track: follows target	Search: not given Track: follows target	Search: not given Track: follows target	Not given	60
Antenna horizontal scan type (continuous, random, 360°, sector, etc.) (degrees)	Follows target	Continuous over 180	Track: follows target	Search: not given Track: follows target	Search: not given Track: not applicable	Not given	360
Antenna vertical scan rate (degrees/s)	Not applicable	Not applicable	Search: not given Track: not applicable	Search: not given Track: not applicable	Search: not given Track: not applicable	Not given	Not applicable

TABLE 4 (*end*)

Characteristics	Radar A Track	Radar B Search	Radar C	Radar D	Radar E	Radar F	Radar G Track
Antenna vertical scan type (continuous, random, 360º, sector, etc.) (degrees)	Not applicable	Step scan	Search: not given Track: not applicable	Search: not given Track: not applicable	Search: not given Track: not applicable	Not given	Not applicable
Antenna side-lobe (SL) levels (1st SLs and remote SLs)	–18.5 dB	–15.5 dB	Not given	Not given	Not given	Not given	–23 dB or less
Antenna height (m)	41	41	5-20	≤ 12 000	≤ 12 000	Not given	34.5 to 280
Receiver IF 3 dB bandwidth (MHz)	10	10	Not given	Not given	Not given	Not given	14 (nominal)
Desensitization threshold pfd (dB(W/($m^2 \cdot 4$ kHz))	–164	–164	–165	–145	–155	–156[(3)]	–164.7
Number of systems Geographical area	800 Worldwide	800 Worldwide	Not given	Not given	Not given	Not given	18 (Region 3)
Receiver noise level (10 MHz bandwidth)	–129 dBW	–129 dBW	Not given	Not given	Not given	Not given	Estimated –124.7 dBW

(1) Radars restricted to maritime environment.

(2) Duty cycle was calculated from the pulse width and pulse repetition rate provided.

(3) This is an estimate calculated from, Interference sensibility of radar = –143 dBW and assuming, Receiver bandwidth = 1/(0.6 μs) = 1.666 MHz. The correct value could differ significantly from this value if intra-pulse modulation were used, but such modulation is seldom used on pulses as narrow as 0.6 μs.