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Electromagnetic exposure assessment of Italian Coast Guard workers exposed to RADAR sources

Giancarlo Burriesci (1), Moreno Comelli* (2), Nicola Zoppetti (2), Simona D'Agostino (1,3) and Marco Valentini (1)
(1) Department of Occupational and Environmental Medicine, Epidemiology and Hygiene, Italian National Institute for Insurance against Accidents at Work, Rome, Italy
(2) Institute of Applied Physics "Nello Carrara" of the National Research Council, Sesto Fiorentino, Italy;
(3) DIET, Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome, Italy

Abstract

The study evaluates exposure to electromagnetic fields generated by radar systems on Italian Coast Guard vessels. The Furuno DRS4D-NXT and Lorenz MDS-9 radars (X-band, 9.4 GHz) were analyzed in the ports of Rome and Vibo Valentia (Italy), following the European Directive 2013/35/EU. The measurements conducted with advanced instruments indicate that maximum exposure remains within safety limits, although the Lorenz radar recorded higher values due to its greater peak power. Although the results comply with the occupational limits, the increasing use of radar on small vessels also raises concerns about the exposure of the general population, highlighting the need for further studies and more accessible measurement tools.

1. Introduction

The present work is the result of a measurement campaign aimed at assessing the exposure to electromagnetic fields (EMF) generated by radar equipment, present on some vessels in use by the Italian Harbor Master's Office. Specifically, the radars were mounted in the G.C. B120 boats of the Rome harbormaster's office and the C.P. 2096 boat of the Vibo Valentia harbormaster's office. Radars (RAdio Detection And Ranging) are instruments used to locate objects even at great distances. They work in the microwave frequency range, generally in the X-band, and their operation is based on the emission of a train of short-duration pulses. Between one pulse and the next, the transmitter/receiver system listens to return echoes. Targets are located by directional radiation of high electromagnetic energy and by observing return echoes, which provide their distance and position relative to a given direction. Specifically, EMF generated by Furuno DRS4D-NXT radar equipment and a Lorentz radar Plotter antenna type mod. MDS-9 emitting in X-band were examined for this project. The complexity of the emitted signals required the use of very sophisticated equipment with narrowband evaluations. Equally complex was the measurement protocol followed, which had to consider several parameters. The procedure described in this paper is intended to serve as a practical example for measurements in the field.

2. Regulatory references

Health and safety requirements for workers exposed to EMF are established in Dir 2013/35/EU [1]. Among other prominent features, this directive sets exposure limits (ELVs) and, above all, action levels (ALs). Specifically, annexes II and III list all the values of ALs for exposure to electric fields from 1 Hz to 10 MHz and from 100 kHz to 300 GHz that are required as reference levels for measurements, to show compliance with the relevant ELVs, during experimental testing. ELVs are determined on the basis of biophysical and biological considerations, which cannot be measured in the exposure environment, established for the protection of scientifically established acute effects, i.e., thermal effects and electrical stimulation of nerve or muscle tissue. Consequently, compliance with ELVs, the direct determination of which, especially in the case of time-varying fields, would require complex assessments using dedicated software, is ensured by compliance with the relevant VAs.

It should be remembered that the rationale of the Directive bases many of its indications on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [2]. Only the ALs used for the evaluation of EMF emissions produced by the investigated radars are shown in Table 1, where:

1. $[ALs(E)]^2$ and $[ALs(B)]^2$ are to be averaged over a six-minute period. For RF pulses, the peak power density averaged over the pulse width shall not exceed 1,000 times the respective ALs(S) value. For multi-frequency fields, the analysis shall be based on summation, as explained in the practical guides referred to in Article 14.
2. ALs(E) and ALs(B) represent the maximum calculated or measured values at the workers' body position. This results in a conservative exposure assessment and automatic compliance with ELVs in all non-uniform exposure conditions. In order to simplify the assessment of compliance with ELVs, carried out in accordance with Article 4, under specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14. In the case of a very localized source within a distance of a few centimeters from the body, compliance with ELVs shall be figured out dosimetrically, case by case.

3. The power density shall be averaged over any 20 cm^2 of exposed area. Spatial maximum power densities averaged over 1 cm^2 should not exceed 20 times the value of 50 Wm^{-2}. Power densities from 6 to 10 GHz are to be averaged over any six-minute period. Above 10 GHz, the power density shall be averaged over any $68/f^{1.05}$ - minute period (f is the frequency expressed in GHz) to compensate for progressively shorter penetration depth as the frequency increases.

Table 1 - ALs for exposure to electric and magnetic fields from 100 kHz to 300 GHz.

Frequency range	ALs(E) (RMS, V/m)	ALs(B) (RMS, μT)	ALs(S) (Wm^{-2})
100 kHz ≤ f < 1 MHz	6.1×10^2	$2.0 \times 10^6/f$	—
1 MHz ≤ f < 10 MHz	$6.1 \times 10^8/f$	$2.0 \times 10^6/f$	—
10 MHz ≤ f < 400 MHz	61	0.2	—
400 MHz ≤ f < 2 GHz	$3 \times 10^{-3} f^{½}$	$1.0 \times 10^{-5} f^{½}$	—
2 GHz ≤ f < 6 GHz	1.4×10^2	4.5×10^{-1}	—
6 GHz ≤ f ≤ 300 GHz	1.4×10^2	4.5×10^{-1}	50

The emissions of the radars examined are of the X-band impulse type at frequencies of around 9.4 GHz for both devices. Therefore, the evaluation of the fields must include both the calculation of the average electric field ($V_{average}$) and the calculation of the peak electric field (E_{peak}), whose action values, based on Note 2 to Table 1, are respectively 140 V/m and 4480 V/m.

3. Methods

For the evaluation of the radars examined, we used many of the operational indications found in CEI 211-7/B (2016-05) Appendix B [3] and in [4, 5].
Two devices were examined: a Radar Furuno DRS4D-NXT (9.41 GHz ± 30 MHz, peak power output 25W) and a Lorentz radar Plotter antenna type mod. MDS-9 (9.41 GHz ± 30 MHz, peak power output 4 kW).
The exposure assessment was carried out using:

- f is the frequency expressed in hertz
- Measuring chain 1: Rohde & Schwarz mod. FSL 18 (9 kHz – 18 GHz) spectrum analyzer, antenna Horn double-ridged guide EMCO mod. 3115 (1 GHz ÷ 18 GHz), coaxial cable.
- Measuring chain 2: Agilent ESA 7704 B (1 GHz ÷ 18 GHz) spectrum analyzer, antenna Schwarzbeck mod. BHA 9120 D (6 GHz – 18 GHz), coaxial cable.

The choice of spectrum analyzers had to take into account the specific parameters and especially the resolution bandwidth (RBW).
An optimal RBW allows both to evaluate the time width of the radar pulse and to determine its peak emission power. In fact, measuring in the mode generally referred to as *pulse spectrum* and choosing a sufficiently small RBW provides an accurate measurement of the pulse duration. Conversely, by having a rather large RBW, an accurate measurement of the peak power emitted by the radar is obtained. The evaluations were carried out using two narrowband instrumental chains, each consisting of the spectrum analyzer coupled via coaxial cable to the antenna. The latter was placed at the locations occupied by the crew at such a distance that the far-field condition is verified. The physical quantity under evaluation was the electric field E (RMS value, and peak value in the case of radar signals).
For this type of measurement, the power values expressed in dBm and evaluated by means of the spectrum analyzer, in order to be compared with the respective action limits, must be converted by means of the following equation into electric field values (V/m):

$$\text{ALs}\left(\frac{V}{m}\right) = 10^{\frac{Epeak(dBm)+\text{AF}+\text{AC}-13}{20}} \quad (1)$$

where AF and AC are the values in dB related to antenna factor and cable attenuation. Respectively 38.8 and 7.3 for while Rohde & Schwarz spectrum analyzer and Antennas EMCO, and for Agilent spectrum analyzer and Antenna Schwarzbeck are 38.1 and 6.21. The conversion coefficient is 13.
A 10% error is associated with the measurements, assigned on the basis of evaluations of the repeatability of the measured signal.

4. Results and Discussion

To characterize radar emission, the positions intercepting the radiation beam were identified so that the measurement represents the worst case and therefore returns a precautionary value. Figure 1 shows a general radar radiation emission beam.

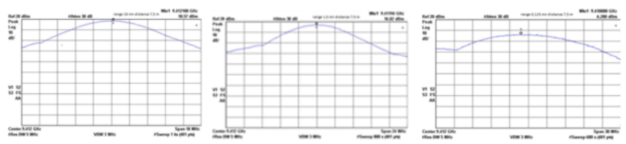

Figure 1. Radar emission peaks at same distance and different range setting. The higher the range, the higher the peak

The Furuno radar, emitting at a frequency of 9.41 GHz ± 30 MHz, was set during the measurements in the range of 12 nautical miles and with an antenna rotation speed of 24 rotations per minute (rpm). The antenna of the measurement chain was positioned (Figure 2a) close to the bridge at a height of 1.8 m and at 2.5 m, which, although difficult for a person to occupy, better intercepts the beam emitted by the radar (worst case).

Figure 2. Boat G.C. B120 (a) - Boat CP. 2096 (b).

Measurements aboard the CP2096 boat were conducted at two different distances towards the prow, two meters and four meters, whereas towards the stern only at the distance of 5.7 m (Figure 2b). The latter choice is due to the circumstance that towards the stern there is the wide roof of the cockpit that shields from the electromagnetic waves. For all measurements, the radar was set to the range of sixteen nautical miles because previous measurements showed that the maximum range available on the instrument corresponds with the highest electromagnetic field emitted, as shown in Figure 1. Even in this case, the antenna rotation speed of the emitter was 24 rpm, and the positioning of the antenna receiver represents the worst case of exposure.
The results of the measurements are shown in Tables 2 and 3. Figures 3a and 3b show the peak power and average power measurements in channel power mode for the Furuno radar. In the latter mode, the RMS value of the field produced by the radar at the measurement point is measured directly, considering antenna rotation and duty cycle. In fact, with an RBW small enough to discriminate the frequency components of the signal, the signal power within the frequency band (Integration Bandwidth) is calculated by evaluating it in such a way that it contains at least three or four secondary lobes to the right and left of the main scan lobe (Figure 3a).

Table 2 - EMF exposure values emitted by the Furuno DRS4D-NXT radar (narrowband electric field measurements - Measuring chain 1)

	Stern
ALs average (dBm)	-43.81
ALs average (V/m)	0.29
Limits ALs average (V/m) Dir 2013/35/EU	140
ALs peak (dBm)	-6.70
ALs peak (V/m)	20.9
Limit ALs peak (V/m) Dir 2013/35/EU	4480

Table 3 - EMF exposure values emitted by the Lorenz radar (narrowband electric field measurements - Measuring chain 2) as a function of different measuring points

	Stern	Prow 2m	Prow 4m
ALs average (dBm)	----	----	-25.97
ALs average (V/m)	----	----	1.84
Limit ALs average (V/m) Dir 2013/35/EU	140	140	140
Als peak (dBm)	24.45	29.89	25.32
ALs peak (V/m)	613.7	1148.15	678.422
Limit ALs peak (V/m) Dir 2013/35/EU	4480	4480	4480

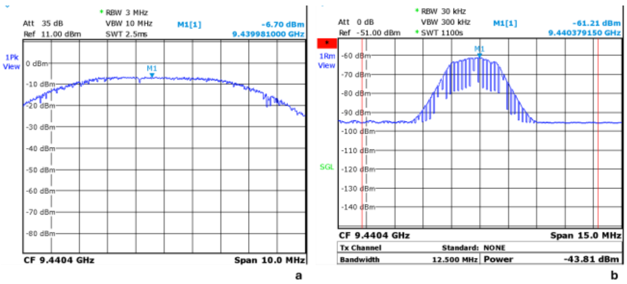

Figure 3. Peak Power Measurement (a) and Average Power-Channel Power Mode (b)

As far as the peak power measurement is concerned, the envelope height increases as the RBW increases, but this effect lasts until the width of the main lobe is exceeded. Once this condition is reached and an RBW is set that also includes the two secondary lobes, the amplitude of the signal peak is equal to approximately 95% of the energy emitted by the source. In this case, in order to obtain an accurate measurement of the peak power, the measurements must be extended, in MaxHold or Average mode, for a sufficiently long scan time so that each video point is illuminated at least once by the rotating radar beam. As can be seen, the results show that the peak value of ALs is at least an order of magnitude higher than the mean value of ALs. This circumstance led to the choice of measuring ALs peak values rather than average values also because such measurements require long sampling times, at least 45 minutes.

6. Conclusions

The surveys carried out on both boats G.C. B120 and CP. 2096 to assess, respectively, the emission of the Furuno DRS4D-NXT and the Lorentz MDS-9 radars, showed electromagnetic field values lower than the action levels envisaged by the directive 2013/35/EU for the evaluation

of the electromagnetic occupational exposure, considering both the peak electric field and the mean field.
It should be noted that although the Lorenz radar's emissions are compliant, they are much higher than those emitted by Furuno radar; this could be due to the different peak power outputs, as reported in Devices Examined.
The study is in progress: in fact, according to what is stated in the 211-7/b standard for the protection of the public, radar emissions can also be evaluated with broadband instruments. For the future, it is planned to compare the results obtained with the two methods (broadband/narrowband) to check their reliability also for the protection of workers. In view of the results, a simplified procedure for evaluation will be studied, to be implemented on the WEB-NIR portal [6]. Also, considering that radar equipment is increasingly widespread, with different technical characteristics, and installed even in small vessels, this evaluation can only be considered as a first step in the study of such emissions. In fact, these devices emit complex signals that require sophisticated instruments and highly qualified personnel for their correct evaluation. Although the purpose of this work was to assess workers' exposure, it is worth noting that the installation of radars could also be a source of exposure for the members of the general population using these means of transport. Currently, some manufacturers are placing small instruments on the market with specially designed probes to evaluate these types of signals. For these reasons, the evaluation of these types of sources requires further targeted studies both to assess the impact of these emissions and to develop more effective measuring instruments, as well as to assess the possible exposure of non-boat personnel (i.e., the members of the population).

6. Acknowledgements

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