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NATALIA JÓŹWIK-MICHAŁOWSKA[1], ANDRZEJ FELSKI[2]
1) Maritime Institute in Gdańsk, 2) Polish Naval Academy, Poland

THE ELECTROMAGNETIC FIELD IN THE VICINITY OF RADIO-NAVIGATION SYSTEMS

ABSTRACT

Today, electromagnetic waves are the basic medium for all communication tasks. This applies also to navigation, where the most commonly waves have lengths measured in centimetres (radar, GPS) and longer, such as the waves used in the AIS or DGPS technologies. Navigators are mostly interested in the communication functionality of the used systems, i.e. such factors as range of the system and signal-to-noise ratio. This leads directly to increasing the transmitters' power. However, it is important to bear in mind that the electromagnetic field can endanger human health, therefore, establishing the level of radiation both on vessels and near the shore transmitters is crucial in this context. The experience of authors shows that the knowledge of the most of navigators hereupon is not large. From this result extremely irresponsible behaviors of one persons, as well as inexplicable phobias others.
This article presents the subject using the example of the electromagnetic field present near a lighthouse emitting AIS and DGPS signals. Relevant measurements were made at the Rozewie lighthouse by certified laboratory of Maritime Institute in Gdansk according the polish standards and internal, certified procedures. Results of the measurements were related to the national and European standards for electromagnetic field measurements in the context of occupational health and safety.

Keywords: electromagnetic field, risk, DGPS, AIS

1. CHARACTERISTICS OF THE ELECTROMAGNETIC FIELD

The 19th century is called the age of steel, yet, it was in the middle of that century, when James Clerk Maxwell generalized the available knowledge on the electrical and magnetic phenomena, combined it with the knowledge on waves and proposed a general description of the said phenomena, thus providing theoretical grounds for the modern use of radio waves, which today are fundamental to information exchange on Earth and in space. But also it is present in our everyday life, e.g. the widely used wireless transmission and the omnipresent remote controls.

Maxwell's findings, described in terms of hermetic mathematical formalism, initially did not make a significant impression on the world of science, however, when Oliver Heaviside simplified them in 1885 and proposed to express them using vector calculus, they were universally recognised. The following year, Heinrich Hertz accomplished the first intentional transmission and reception of electromagnetic waves in the spectral range other than light, which is considered a confirmation of Maxwell's concepts and an actual beginning of the age of radio.

Electromagnetic waves are combined disturbances of the electric and magnetic fields, propagated in space with a finite speed. They are transverse waves, which means that at each point of the field, the electric field vector (E) and the magnetic induction vector (H) are perpendicular to the direction of propagation of these waves and to each other. Today, it seems a common knowledge that the propagation range of radio waves depends on the transmitter's power, however, this correlation is more complex, as it depends to a large extent also on their frequency and the direction of polarization. For example, the specific nature of the propagation of radio waves over saltwater definitely favoured the use of vertical polarization. All these factors must be taken into account when considering efficiency of a radio system.

Until recently, a full range of frequencies had been used in maritime navigation applications: from 10 kHz (OMEGA radio navigation system) to 10 GHz (navigation radar). Nowadays, the spectrum of the waves used is considerably limited and is dominated by frequencies measured in MHz and GHz (DGPS is the exception in this rule), while the universal use of satellite technology prompts the application of circle polarization, although the still used vertical polarization.

When speaking about electromagnetic waves, we are aware that they generate an electromagnetic field in a certain area around the transmitting antenna. We are usually interested in increasing the range of transmitting devices, which means increasing the generated power. At the same time, it has long been known that this field, especially if powerful, may have a negative influence on human health. When describing the electromagnetic field, it is common to use a description of electrical components, i.e. electric field strength (E). It is a vector quantity that corresponds to the force exerted by the electric field on a charged particle (unit load), regardless of its motion in space. It should be noted that this phenomena applies also to the particles of a human body!

The electromagnetic field is also a partly magnetic phenomena, which cannot be overlooked when considering risks to human health, as strong magnetic fields occur not only in the air. Depending on the magnetic permeability, it is induced in other objects, including human tissues.

Thus the crew aboard, whence are generated electromagnetic signals for navigational purposes, ought to have the consciousness regarding, potentially negative influence on the persons in vicinity.

2. EUROPEAN AND NATIONAL REGULATIONS RELATED TO THE ELECTROMAGNETIC FIELD

Devices generating electrical fields are now widely used, not only in the form of radio devices. Average citizens associate the sources of potential risks with radio transmitters and more recently also with base stations of cellular networks, yet they are unaware that the electromagnetic field (although on a much smaller scale) is also generated by mobile phones, Wi-Fi routers or even all types of remote controls. The electromagnetic field is also generated by many everyday devices, which most people do not regard as dangerous, such as microwave ovens, induction ovens and various medical devices – not only those based on x-rays, but also those used e.g. in physical therapy. The most common source of electromagnetic fields is energy network.

Mindful of risks to human health caused by electromagnetic fields, authorities have long been enforcing regulations to manage this issue. Since Poland's accession to the European Union, the Polish laws are in fact consistent with the European standards [13]. This issue is regulated by the European Parliament and Council Directive 2013/35/EC of 26 June 2013 *on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents* [3], [8]. It defines minimum requirements in the work environment in order to guarantee a better level of protection of health and safety of workers.

Regarding the exposure of general public to the electromagnetic field, the European Parliament issued a resolution 519/1999, regulating the rules of exposure of the general public to electromagnetic fields in the frequency range from 0 Hz to 300 GHz. Based on the resolution, many countries have issued relevant laws, often supplemented with recommendations for additional reduction of exposure in residential areas, adopting the "precautionary principle". The Polish regulations for occupational health and safety and environmental protection describe in details how to identify and define the generated fields and how to assess their impact on the health of the population.

This issue should be considered in two aspects:

- the population using electrical equipment generating the electromagnetic field;
- personnel operating/maintaining electrical installations.

This article discusses the issue of the safety of the personnel operating selected marine devices. Each vessel uses devices generating the electromagnetic field, mostly radio-communication, radio-navigation (positioning) and radars. However, similar devices are also located on land. The following section presents this issue using the example of the Rozewie lighthouse as a typical location of this kind. Several radio-communication devices are placed at the lighthouse or in its vicinity. They include radiotelephones, a transmitter for the DGPS reference station and a base station transmitter for the AIS system.

The obligation to recognize and assess the electromagnetic field has been established for the proximity of the devices and radio-communication systems. Although radio-communication systems are often automatic, they require periodic inspections, adjustments and maintenance, therefore it is possible to define a working space. Conditions of exposure to the electromagnetic field affecting people working during operation of radio-communication systems require periodical inspections carried out according to the recommended and verified methods, in order to recognize electromagnetic risks and take appropriate protective measures [5], [11]. The Polish recommended in-situ measurement method of the field parameters in the working space during operation of the transmitting devices of radio-communication systems is specified in a journal Principles and Methods of Assessing the Working Environment 2017, no. 2(92), pp. 89–131. There are also several other national documents regulating this issue [15].

In the Regulation of the Minister of Family, Labour and Social Affairs [12] on maximum permissible concentration and intensity of harmful factors in the work environment, Intervention Exposure Levels (IPN) are defined, which determine the levels of the electromagnetic field used as the upper and the lower limits of the protection zones: intermediate, hazardous and dangerous [11]. In the Regulation of the Minister of Family, Labour and Social Policy of 29 June 2016 on occupational health and safety at work related to exposure to electromagnetic field, among the typical sources of this field, “broadcasting tele- and radio-communication systems” and “base stations of mobile telecommunications systems” are also listed [12].

Measurements of the levels of electromagnetic fields (EMF) in the environment, in the vicinity of installations generating such fields, are carried out according to the requirements defined in [14] on limit values of electromagnetic fields in the environment and the ways to comply with those levels. Monitoring of MF field levels is performed on the basis of the Regulation of the Minister of the Environment of 12 November 2007 on the scope and procedure for carrying out periodical measurements of EMF levels in the environment [3], whereas the Regulation of the Minister of Environment of 30 October 2003 [9] specifies the permissible levels of electromagnetic fields in the environment, differentiated for residential plots and areas accessible to people. The regulation specifies the frequency ranges of electromagnetic fields and their physical parameters characterizing the impact on environment and methods of checking compliance with the permissible levels. Measurements of electromagnetic fields are carried out in the proximity of installations producing such fields and the results obtained are compared with the limit values. Measurements should be carried out in fine weather, at a temperature of not less than 0˚C and a relative humidity below 75%, in the absence of precipitation.

Measurements of electromagnetic field levels in the vicinity of radio communication, radio navigation and transponder installations are carried out in a way that enables determining the distribution of electromagnetic fields with acceptable levels and defining the boundaries of the areas of limited use. The presence of a field produced by several devices which do not operate at the same time sets a permissible level for the installation or a group of installations. Such measurements are performed during operation of all equipment producing the MF field in a given frequency range. In the case of a possible multi-purpose use, measurements are made during operation with the highest measured levels of the field. Measurements can be made in sampling points at a height of 0.3 m to 2 m above the ground or other surfaces accessible to people and in vertical sections, along a vertical line of movement of the probe to find maximum or permissible levels of electromagnetic fields.

The said measurements should be performed in accordance with the methods set out in the Polish Standards, in particular PN-EN 50413. In Poland, as part of the establishment of a uniform legal system for the protection of people from excessive exposure to electromagnetic fields from 0 Hz to 300 GHz, a revision of national metrological standards has been developed [1], [2] as an integral supplement to the revised regulation of the Minister of Labour and Social Policy. In 2002, the Chairman of the Polish Committee for Standardization established a standard PN-T-06580:2002, "Labour protection in electromagnetic fields and radiation of the frequency range from 0 Hz up to 300 GHz". Part 1 contains terminology (PN-T-06580-1), part 3 specifies methods of measuring and evaluating the field in the workplace (PN-T-06580-3), principles for the assessment of occupational exposure to electromagnetic fields and radiation of the entire range of frequencies covered by the regulations, giving e.g. detailed definitions and rules for determining the actual doses and exposure rate for all cases when exposure may occur in actual working conditions [1], [2], [4], [7], [15].

The standards also include detailed descriptions of the conditions under which it is possible to use simplified rules of measurement and evaluation of occupational exposure. Moreover, they cover exposure measurement methods within the range of the electrical and magnetic fields or electromagnetic radiation with a frequency from 0 Hz to 300 GHz, the measured values used to assess the exposure of workers and the recommended working conditions for the sources of such fields during testing.

3. ROZEWIE LIGHTHOUSE

The Rozewie lighthouse is an important element of the navigation infrastructure on the Polish coast. It is a characteristic tower with a height of 32.7 m, located at geographical coordinates: 54° 49’ 49.35” N and 018° 20’ 10.64” E. The building was constructed in 1822, and was subject to two significant upgrades in 1910 and 1978.

Figure 1. The Rozewie lighthouse. Photo: N. Jóźwik-Michałowska.

The appearance of the lighthouse changed the most during the second renovation, when its height was increased by 8 m, by inserting a metal cylinder. The reason for that modification were nearby trees growing in the "Rozewie Cape" Nature Reserve, which had obstructed the light. Also a different light source was installed. In accordance with the contemporary trends, the lighthouse is equipped with several devices generating electromagnetic waves. They are traditional radio-communication devices, but also radio-navigation ones.

3.1. SOURCES OF THE ELECTROMAGNETIC FIELD INSTALLED IN THE ROZEWIE LIGHTHOUSE

Six transmitting devices operate at the lighthouse in the VHF band (five radiotelephones and an AIS base station), a DGPS transmitter and microwave transmission.
Sources of the field in the VHF range are:

- UKF 1 radiotelephone type RT2048 (Sailor), frequency range 154.4÷163.75 MHz, antenna located 22 m above terrain;
- UKF 2 radiotelephone type TP929M (TP Radio), frequency range 156÷162 MHz, antenna located 22 m above terrain;
- UKF 3 radiotelephone type TP929M (TP Radio), frequency range 156÷162 MHz, antenna located 33 m above terrain;
- UKF 4 and UKF 5 radiotelephones type MS800 (Spectra), frequency range 148÷174 MHz, antennas located 31 m above terrain on an additional mast;
- AIS base station – SAAB AIS R40 operating at frequency 161.975 MHz (channel 87B) and 162.025 (channel 88B). Output power 12.5 W (actual), GMSK/FM modulation, GP 160 (Procom) antenna with omnidirectional radiation pattern, vertical polarization, located 33 m above terrain, fed through coaxial cable.

All radiotelephones have an output power of 25 W (actual), operate with G3E modulation and a load of a half-wave dipole with omnidirectional radiation pattern and vertical polarization, fed through coaxial cable. Within one working day on the worksite consisting of the service of radionavigation devices the real residence time compose of 4 hour per 24 tour of duty.

The DGPS reference station transmitter (by Nautel, installed in 2011), working at 301 kHz, is located in the radio beacon room, has a rated power of 200 W (actual 130 W) and operates with G1D modulation by 24h per day V33070 antenna, Valcom Limited (Canada), omnidirectional (antenna gain 17 dBi) vertical polarization, fed by coaxial cable.

Figure 2. Antenna of the DGPS transmitter with the Rozewie lighthouse in the background (photo S. Szewczak, available at https://popiasku.pl/?s=nadmorskie-poi&id_kat=15&id_m=165&id=3769) (access on 29.01.2018)

The lighthouse includes also ALCATEL LUCENT 9500MR radio link equipment with operating frequency of 23 GHz, a parabolic directional antenna installed at 27 m above terrain, azimuth 124°, channel width 3.5 MHz. Due to the specific characteristics of the antenna, it was not taken into account in the subsequent part of the article, assuming that its impact on people present in its proximity is irrelevant.

3.2. DESCRIPTION OF MEASURED RESULTS

The presented measurements were carried out for the purposes of occupational health and safety. These are routine activities of the Department of Electronics on the basis of Certificate no AB848 given by Polish Centre for Accreditation.

The measurements were made for stationary and non-stationary fields in workplaces of personnel performing maintenance and supervision of the broadcasting equipment, in locations frequented by persons employed in the lighthouse (in the operating area). Outdoor environmental conditions during the measurements: absence of precipitation, temperature 15°C, relative humidity 55%. Indoor environmental conditions: temperature 20°C, relative humidity 38%. The results of the measurements were recorded each time a maximum measured value was achieved.

The highest value of the field generated by the UKF 1 Sailor RT 2048 device located in the lighthouse keeper's room was 4.5 V/m, which constitutes a secure zone.

The area around the antenna mast is also in the safe zone. The remaining UKF radiotelephones installed in the technical room also do not pose a threat. However, in the lighthouse gallery and in the room under the dome, the value of 10V/m was recorded, which constitutes an intermediate zone. This is due to the fact that antennas of these radiotelephones are arranged at the height of gallery windows, creating a partial threat to people staying in the gallery while using a given radiotelephone.

The location of the SAAB AIS R-40 base station and its antenna means that despite the fact that it works 24 hours a day, no EM field values were detected that would cause exposure risk for people present in the room.

The situation is different around the DGPS transmitter. The measurement results of the field strength in auxiliary vertical measurement sections on open grounds around the antenna during operation of the DGPS Nautel beacons demonstrated that limit values were significantly exceeded. The maximum value is 700 V/m for the sampling point at a distance of 0.5 m from the source, which indicates a hazardous zone. Approx. 18 m from the antenna, measurements indicate the lower limit of the hazardous zone, and 30 m from the antenna: the lower limit of the intermediate zone.

Tab. 1. Applied gauges.

Lp.	Device	Measurand	Producer
1	EMR-300 C No 2244/31 AI-0011	Electric and magnetic components	Wandel & Goltermann GmbH&Co
1a	Sonde 11.2	Electric component: - frequency: 10 MHz - 60 GHz - intensity: 0,8-250 V/m	Wandel & Goltermann GmbH&Co
1a	Sonde 10.2	Magnetic component: - frequency: 27 MHz-1 GHz - intensity: 0,01-12 A/m	Wandel & Goltermann GmbH&Co
2	NBM-520 No D-1233	Electric and magnetic components	Narda
2a	Sonde EF-0392	Electric component: - frequency: 0,1 MHz - 3 GHz - intensity 0,5-1000 V/m	Narda
2b	Sonde EF-1891	-Electric component: - frequency: 3 MHz - 18 GHz - intensity: 0,8-1000 V/m	Narda
2c	Sonde HF-3061	Magnetic component: - frequency: 300 kHz - 30 MHz - intensity 0,01-16 A/m	Narda

Source: Authors.

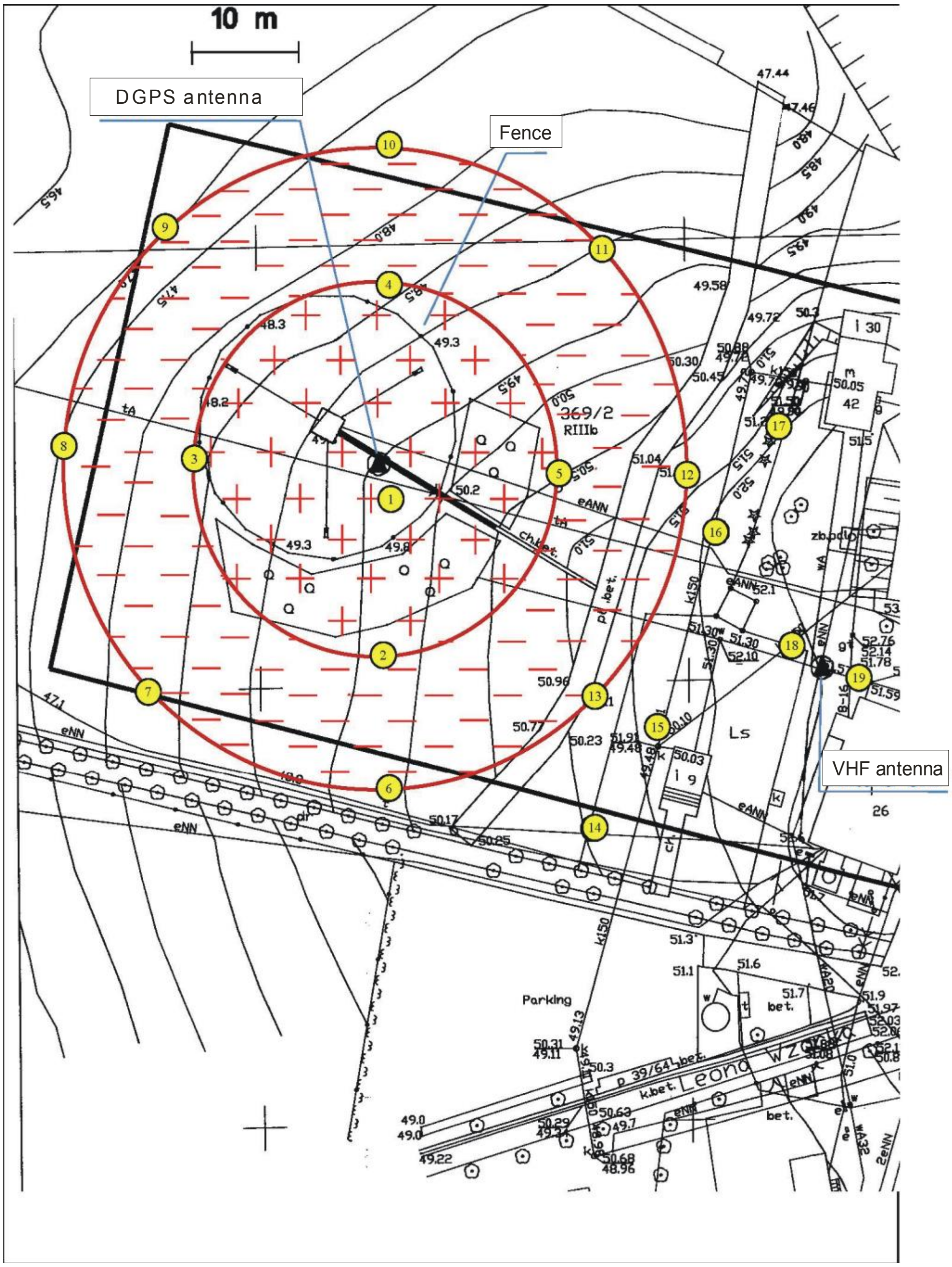

Figure. 3. Layout of vertical measurement sections around the antennas of the lighthouse. Source: Maritime Institute in Gdansk.

Tab. 2. Results of measurements in specific points.

No of pint	Distance to source [m]	Values of components			Zone of threat
		High	Walue		
		[m]	E_{max} [V/m]	H_{max} [A/m]	
1	2	3	4	5	6
1	0,5	2,0	700,0	< 0,01	Unsafety (head)
1	0,5	1,2	650,0	< 0,01	Unsafety (trunk)
1	0,5	0,2	500,0	< 0,01	Unsafety (legs)
2	18,0	2,0	66,7	< 0,01	Intermediate
3	18,0	2,0	66,7	< 0,01	Intermediate
4	18,0	2,0	66,7	< 0,01	Intermediate
5	18,0	2,0	66,7	< 0,01	Intermediate
6	30,0	2,0	20,0	< 0,01	Safe
7	30,0	2,0	20,0	< 0,01	Safe
8	30,0	2,0	20,0	< 0,01	Safe
9	30,0	2,0	20,0	< 0,01	Safe
10	30,0	2,0	20,0	< 0,01	Safe
11	30,0	2,0	20,0	< 0,01	Safe
12	30,0	2,0	20,0	< 0,01	Safe
13	30,0	2,0	20,0	< 0,01	Safe
14	See fig. 3	2,0	< 0,5	< 0,01	Safe
15	See fig. 3	2,0	< 0,5	< 0,01	Safe
16	See fig. 3	2,0	< 0,5	< 0,01	Safe
17	See fig. 3	2,0	< 0,5	< 0,01	Safe
18	See fig. 3	2,0	< 0,5	< 0,01	Safe
19	See fig. 3	2,0	< 0,5	< 0,01	Safe

Source: Authors.

3.3. EM FIELD ASSESSMENT IN THE WORKPLACE

Summarizing the above results, it can be concluded that electromagnetic fields at frequencies from 301 kHz to 23 GHz are present at the Rozewie Lighthouse. The sources of these fields are transmitters, feeders and antennas of radio devices described above.

Presence of people is allowed at permanent and flexible work stations of operators of individual devices, because the occurring exposure is negligible (safe zone), coming from sources operating in the VHF range, i.e. radiotelephones and the AIS base station.

Low risk (general exposure) occurs as a result of the operation of the DGPS radio beacon on the gallery, in the designated hazardous zones. This is a typical situation near devices generating the electromagnetic field. In such cases, sources of radiation and boundaries of the protected zones listed above must be clearly marked. A vivid example of this situation is the area around the antenna of the DGPS radio beacon, with an intermediate zone in the 30 m radius, because limit values are exceeded. Therefore, the presence of people in this area is subject to restrictions. In the remaining areas available to the public (i.e. buildings, access roads and the open ground around the lighthouse), there was no occurrence of radiation exceeding the acceptable values.

CONCLUSIONS

The electromagnetic field exists around all electric-powered devices. Generated as a carrier of signals, it is virtually ubiquitous. In their daily activities, users of systems based on radio waves, e.g. users of radio navigation systems, are interested in generating signals of sufficient power in order to obtain larger range. In most cases, they also expect an adequate signal-to-noise ratio. However, this also causes a threat to the life and health of people present in the vicinity, both the personnel and the general public. Frequency range of the electromagnetic field is also important in such cases, because different frequency ranges have different effects on living organisms. This makes employers obliged to identify the sources of the electromagnetic field and its characteristics, as well as designate and adequately mark potentially hazardous zones. Employees operating such devices should also be aware of this risk. Of course the metal-construction of the ship and many corridors can create other circumstances than these which are round the lighthouse. However presented results can give the opinion on the similar situation aboard.

The article discusses the case of AIS, and DGPS installations commonly used in modern navigation systems, generating the VHF and MF electromagnetic field. They were presented as sample values, to raise awareness of the scale of the risk. In standard situation of crew members on commercial vessel the picture is very similar. Of course aboard vessel only DGPS receiver is exploited, so it does not radiate the energy as transponder on the examined lighthouse. Differences stay in details.

Each commercial vessel has obligation to use AIS transponder, which is working in very similar manner to VHF which has been examined on Rozewie Lighthouse. Question can be how its antenna is situated on the vessel ? Also, similar danger zones will appear aboard from the work of the navigational radar which does not exist on the lighthouse.

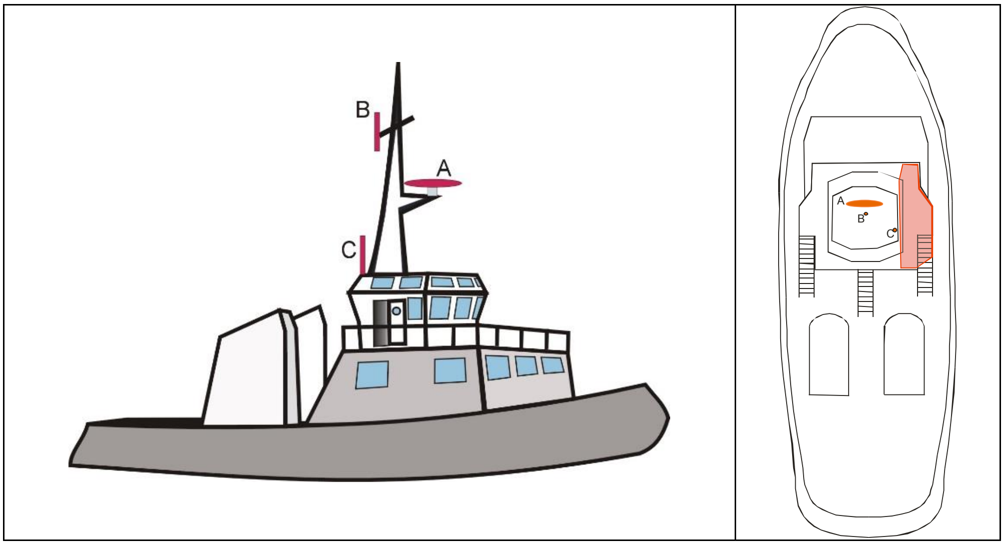

Figure 4. Generalized example of distribution of antennae on small vessel. Source: Authors.

Even on smallest vessel radar and VHF transponder are in use (see fig. 4). Many measurement campaigns done by authors give us basis to generalize, that when antennas are situated as this is shown and noted as A and B, even on such small ships, as a rule, there is not threats for personnel. On standard vessel the distance between antennas and work places is bigger, so this is more safety situation. However on long vessel on forecastle or on poop deck, intermediate zone can exist, so residence time in such zone should be limited. For comparison, in fig. 4 VHF antenna (as C) is shown in the place, where sometimes is installed. Such solution can cause the rising of the indirect zone, what it is presented as the red area.

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NATALIA JÓŹWIK-MICHAŁOWSKA
Maritime Institute in Gdańsk
Abrahama 1, 80-307 Gdańsk, Poland
e-mail: njozwik@im.gda.pl

ANDRZEJ FELSKI
Polish Naval Academy
Śmidowicza 69, 81-127 Gdynia, Poland
e-mail: a.felski@amw.gdynia.pl

STRESZCZENIE

Obecnie fale elektromagnetyczne stanowią podstawowe medium komunikacyjne. Stosowane są również w nawigacji, przy czym najczęściej dotyczy to fal centymetrowych (radar i GPS) i dłuższych, na przykład stosowanych w systemach AIS i DGPS. W przypadku nawigacji zwracamy szczególną uwagę na funkcje komunikacyjne, czyli na takie czynniki jak zasięg systemu i stosunek sygnału do szumu. To prowadzi wprost do zwiększania mocy nadajników. Jednakże nie można zapomina o tym, że pole elektromagnetyczne może negatywnie wpływać na ludzkie zdrowie, a więc ustalenie poziomu tego pola, tak na statku jak i w pobliżu instalacji lądowych ma istotne znaczenie. Doświadczenie autorów wskazuje, że wiedza o tych aspektach jest wśród nawigatorów niewielka, co skutkuje niejednokrotnie zachowaniami ryzykownymi jak i nieuzasadnionymi fobiami.
W artykule opisano charakterystykę pola elektromagnetycznego występującego na latarni morskiej emitującej sygnały AIS oraz DGPS na podstawie pomiarów wykonanych przez

certyfikowane laboratorium Instytutu Morskiego w Gdańsku, z odniesieniem do przepisów oraz norm krajowych i unijnych.