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A review of electromagnetic field sources on ships

Przegląd źródeł pola elektromagnetycznego na statkach

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Abstract: Electromagnetic radiation is one of the possible harmful factors present in the work environment. The subject matter dealing with exposure of people working on ships to electromagnetic fields has so far mainly focused on the sources located on military units [18, 22, 23, 24]. On the basis of many years of experience related to operation in the Maritime Institute in Gdansk of a laboratory performing measurements of electromagnetic radiation for the purposes of occupational health and safety, this study briefly characterized sources of electromagnetic radiation that may occur on vessels.

Keywords: EMF, radiocommunication, marine radars, radio hazard, work environment, occupational safety and health.

Streszczenie: Promieniowanie elektromagnetyczne jest jednym z potencjalnie szkodliwych czynników dla zdrowia, które występują w środowisku pracy. Tematyka poruszająca zagadnienie narażenia osób pracujących na statkach na pole elektromagnetyczne dotychczas skupiała się głównie na źródłach znajdujących się na jednostkach wojskowych [18, 22, 23, 24]. Na podstawie wieloletnich doświadczeń związanych z funkcjonowaniem w Instytucie Morskim w Gdańsku laboratorium wykonującego pomiary promieniowania elektromagnetycznego dla celów bezpieczeństwa i higieny pracy w niniejszym opracowaniu krótko scharakteryzowano źródła promieniowania elektromagnetycznego, które mogą występować na jednostkach pływających.

Słowa kluczowe: radiokomunikacja, radary morskie, środowisko pracy, bezpieczeństwo i higiena pracy

INTRODUCTION

To guarantee safety and the best use of vessels, they are equipped with a wide range of electronic devices, especially for radiocommunication and radiolocation that generate electromagnetic field (EMF) from a wide scope of frequencies.

The aim of the study was to characterize potential sources of electromagnetic radiation on ships. Devices referred to in this work have been listed among typical EM field sources as "Broadcasting tele- and radiocommunication systems (radio television, etc.)" and "Radar systems" in the Regulation of the Minister of Family, Labor and Social Policy of 29 June on health and safety at work related to exposure to electromagnetic fields (Journal of Laws of 2016, item 950, amended item 1276, attachment No. 1, item 5, 20, Consolidation 2018 item 331). In connection with the above, exposure of radiocommunication and radar devices operating in the environment requires periodic inspection in accordance with the requirements of the Regulation of the Minister of Health of February 2, 2011 on testing and measurements of harmful factors in the work environment (Journal of Laws No. 33, item. 166), which read that it should be performed according to methods described in the Polish Standards and in the absence of them "by recommended and validated methods".

The method of electromagnetic field measurements in radiocommunication devices was published in 2017 [2], but it does not include devices located on mobile objects such as ships and vehicles.

MATERIALS & METHODS

1. Standards

Implementation of Directive 2013/35/EU [20] in Poland by regulation [15] introduced changes in the existing ranges of protection zones and introduced, among others, the concept of Action Levels (ALs).

Tab. I. Electric field ALs at frequencies from 1 MHz to 10GHz* [14].

ACTION LEVELS (ALS)	ELECTRIC FIELD STRENGTH, E [V/M] AT FREQUENCY:				
	2500÷3X10^6 Hz	3X10^6÷10^7 Hz	10^7÷10^{8}Hz	10^8÷ 3X10^9 Hz	3X10^9÷ 10^{10} Hz
1	2	3	4	5	6
Safe zone E < ALs(p)-E	E < 20	E < 7		E < 7	
Intermediate zone ALs(p)-E ≤ E < ALs(Low)-E	20 ≤ E < 66.7	7 ≤ E < 2 x 10^8/f		7 ≤ E < 20	
Danger zone ALs(Low)-E ≤ E < ALs(High)-E	66.7 ≤ E < 800	2 x 10^8/f ≤ E < 2.4 x 10^9/f		20 ≤ E < 240	
Hazard zone E ≥ ALs(High)-E	800 ≤ E	2.4 x 10^9/f ≤ E		240 ≤ E	
Base limit ALs(ob)-E	200	6 x 10^8/f		60	
Peak limt ALs(m)-E	-	-	-	4500	(3.2+4.3xf/10^{10})x10^3
Minimum sensitivity of E-field measurement	20	7		7	
Minimum range of E-field measurement	20÷800	7÷2.4 x 10^9/f		7÷240	

* for f > 10^{10} Hz: peak limit 7500 V/m, other parameters look column 6. f – frequency in Hz; ALs(p) – Action Level (primary); ALs(Low) – Low Action Level; ALs(High) – High Action Level; ALs(ob) – Base Action Level; ALs(m) – modulated field Action Level

Tab. II. Magnetic field ALs at frequencies from 1 MHz to 10 GHz* [14].

ACTION LEVELS (ALS)	MAGNETIC FIELD STRENGTH, H [A/M] AT FREQUENCY:		
	20000÷3X10^6 Hz	3X10^6÷10^7 Hz	>10^7 Hz
Safe zone H < ALs(p)-H	H < 6 x 10^4/f	H < 0.02	H < 0.02
Intermediate zone ALs(p)-H ≤ H < ALs(Low)-H	6 x 10^4/f ≤ H < 1.6 x 10^6/(3 x f)	0.02 ≤ H < 1.6 x 10^6/(3 x f)	0.02 ≤ H < 0.05
Danger zone ALs(Low)-H ≤ H < ALs(High)-H	1.6 x 10^6/(3 x f)≤ H < 3.2 x 10^6/f	1.6 x 10^6/(3 x f)≤ H < 3.2 x 10^6/f	0.05 ≤ H < 0.32
Hazard zone H ≥ ALs(High)-H	3.2 x 10^6/f ≤ H	3.2 x 10^6/f ≤ H	0.32 ≤ H
Base limit ALs(ob)-H	1.6 x 10^6/f	1.6 x 10^6/f	0.16
Limbs limit ALs(k)-H	8 x 10^6/f	8 x 10^6/f	-
Peak limt ALs(m)-H	80	80	-
Minimum sensitivity of H-field measurement	6 x 10^4/f	0.02	0.02
Minimum range of H-field measurement	6 x 10^4/f ÷3.2 x 10^6/f	0.02 ÷3.2 x 10^6/f	0.02÷0.32

*For f >8x10^8 Hz H-field is calculated from H = E/377; f – frequency in Hz.

New limits of protection zones (ALs) are shown in the regulation [14]; for radio and radar devices, they are shown in table I and table II.

Because the limits of protection zones, as compared to previous regulations, have not changed significantly, it can be assumed that the measurement results carried out before the change of regulations also constitute valuable information.

Information presented in this article was collected on the basis of measurements made by the Laboratory of the Department of the Marine Electronics on 172 vessels in 2016–2017 and the results of measurements included in the unpublished works [4, 5, 6, 7, 8, 9, 10] of the Department.

2. Sources of electromagnetic fields on ships

The presence of radiocommunication devices and marine radars on ships results from the requirements of classificatory regulations which adapt regulations resolved by the International Maritime Organization (IMO). These devices, whicih are electromagnetic fields sources include:

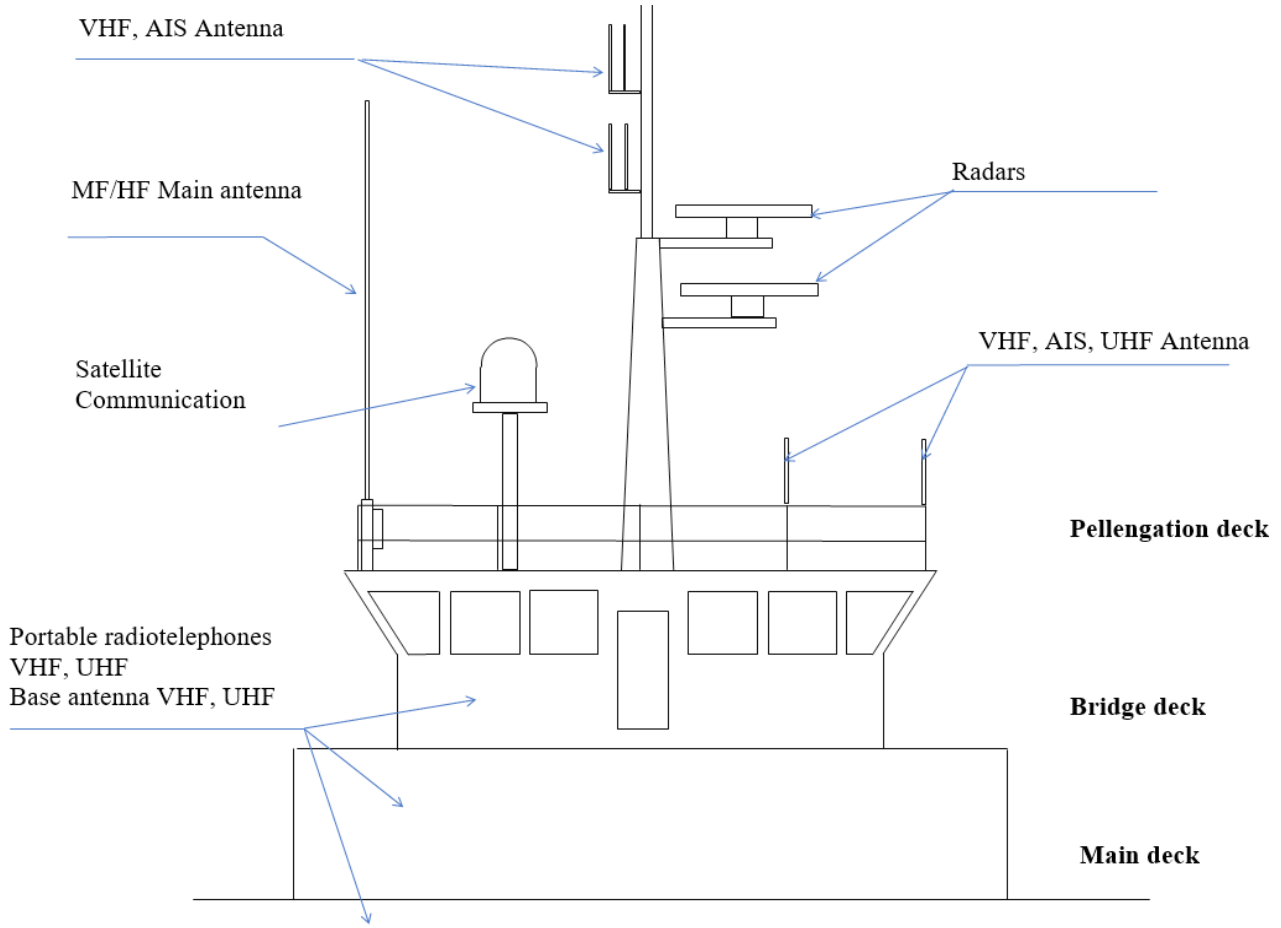

Fig. 1. An example of a scheme for the placement of antennas on a ship.

- MF/HF radio (band 1.6 MHz - 30 MHz)
- VHF radiotelephone (band 156-162 MHz)
- AIS transponder (161.975 MHz {channel A} and 162.025 MHz {channel B})
- INMARSAT (L-band 1.6 GHz)
- marine radars (S-band 3 GHz, X-band 9.4 GHz)

Equipping the unit in the above-mentioned devices depends, among other things, from its type and size, which is subject to relevant regulations [11]. The above list does not finish the subject of all devices which can constitute sources of the electromagnetic filed in the given unit. Requirements imposed on the shipowner may include additional devices such as internal radiocommunication (VHF/UHF), maritime radionavigation system[1], systems of mobile phone networks (base transceiver station antennas, microwave antennas used to point-to-point communication systems), Wi Fi networks, Bluetooth devices.

3. Sources of electromagnetic radiation on ships – characteristics.

3.1 Maritime radionavigation system

These are transmitting stations or transceiving systems designed for radio-navigation. These devices are situated mostly on shore on the Coast Radio Stations, but can also constitute equipment of greater specialized sea units (like oil rig). The maritime radionavigation system works automatically and the operator's only task is switching it on/off.

The device usually includes a transmitter, antenna coupler and antenna. Its frequency ranges from 283.5 kHz to 325 kHz in compliance with recommendation ITU-R M.823-2 (03/2006).

The main source of radiation is the antenna. The small quantity of such devices on ships does not allow for a description which would take into account the possible threats. It is understandable, however, that the location of the antenna will have essential influence on the range of protective zones, e.g., its distribution under the helideck, 2–3 m from platforms accessible for the crew can efficiently counteract to the exposure of protective zones to the electromagnetic field.

3.2 MF/HF radios

The main radios [20] usually consist of the manipulator, transmitter, antenna coupler and antenna itself. In smaller radios, the transmitter can take the form of one casing with a manipulator. The frequency ranges from 1.6 MHz to 30 MHz (transmis-

[1] Maritime radionavigation systems are located mainly on land, but may also occur in some specialist units, e.g., oil rigs.

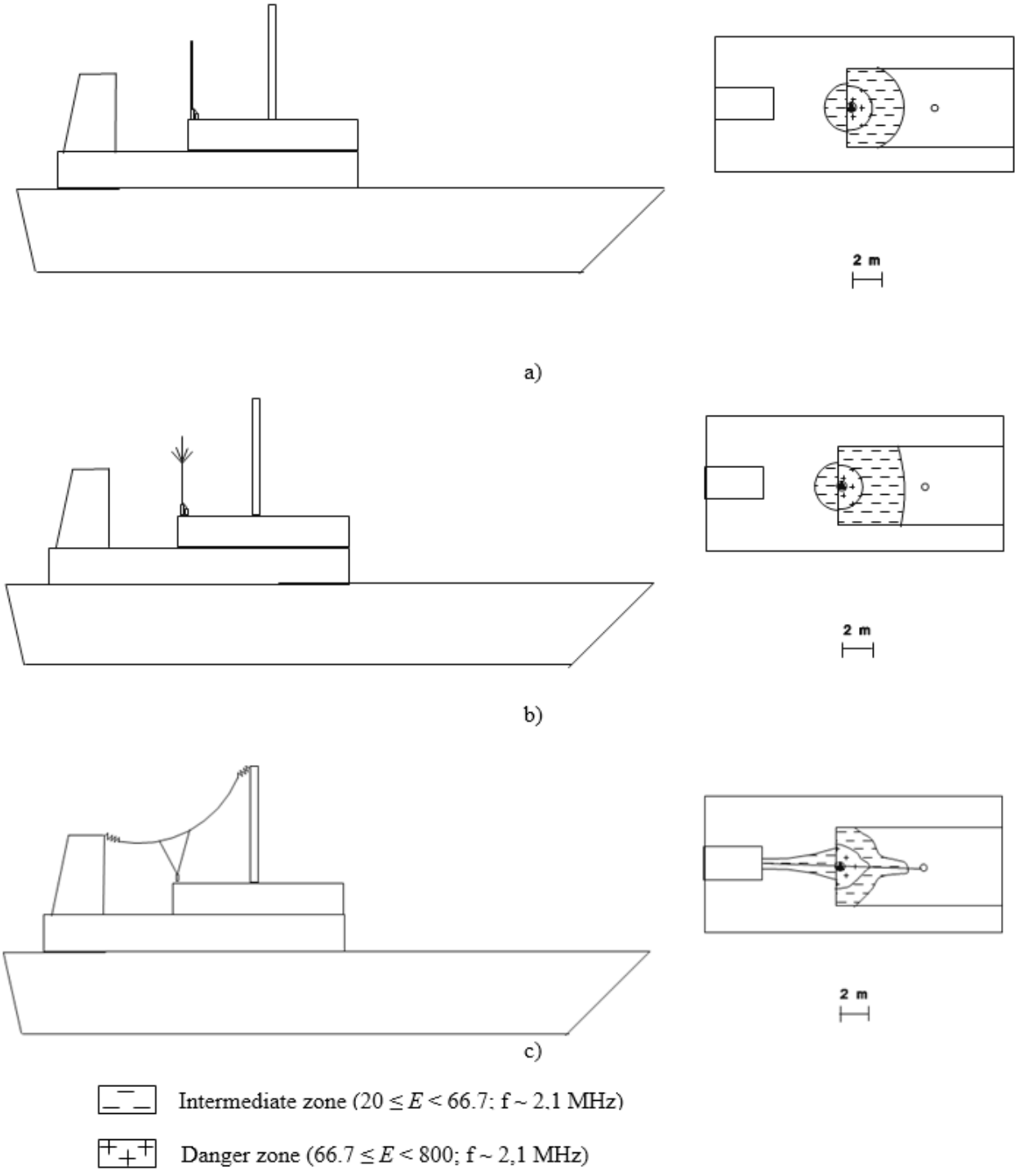

Fig. 2. Ranges of protective zones (E-field) depending on the type of transmitting antenna of the MF / HF radio (a – rod antenna, b – whip antenna, c- wire).

sion). Embracing bands MF (1606.5 kHz-4000 kHz), and HF (4 MHz – 27.5 MHz) meet the specifications of the ITU recommendation . of the power of MF/HF radio transmitters are usually situated within 150W to 600W. The emission of signals in the MF/HF radio station uses SSB modulation, which is a type of amplitude modulation. The types of SSB modulation used in MF/HF radio stations are: J3E (Single Sideband Suppressed Carrier), R3E (Single Sideband Reduced Carrier), H3E (Single Sideband Full Carrier). The last element of the set and at the same time the main source of electromagnetic radiation is the antenna: wire or monopole/rod with a length of several to a dozen or so meters. Thanks to measurements performed by the Laboratory of Marine Electronics staff, it can be concluded that the main source of electromagnetic radiation is the antenna and feeder. The range of protective zones is dependent from the following factors:

- height of antenna assembly over deck level,
- type of antenna,

- presence of metal elements close to the antenna can constitute secondary electromagnetic field sources,
- localization of antenna coupler.

Because the transmitting antenna usually is assembled at a height from 0 to 3 m over the deck level, the occurrence of protective zones cannot be avoided. Additionally, if the antenna is located below 1m over the level of the deck, then protective zones can also appear on lower decks. The antenna located on the wall of the ship's superstructure can cause occurrence of a protective (usually indirect) zone in the room vicinal to the antenna.

The type of transmitting antenna is also significant for the range of protective zones (Fig. 2. a, b, c). In the surrounding of the bar antenna, which is most often used on vessels, protective zones spread regularly in the shape of a circle, or an ellipse (look Fig. 2. a). In the more less frequently met whip (rod antenna with four branches at the head of the working antenna - see Fig. 2.b), the range of the zone can be a lot greater than for the bar antenna and is dependent from the characteristics, and the technical state of branches at the antenna top. The range of protective zones will be greater for directions of the antenna's individual branches, as for the smaller deck, the border of the indirect zone will have a shape of a nearly straight line.

In the case of a thin line antenna (look Fig. 2. c), the schedule of protective zones will mainly depended from the place in which the antenna's thin line is unclasped and the height of its placement over the deck. The shape of protective zones will be irregular to circular at the place of vertical connection with the antenna coupler.

Another factor which influences the dispersion of protective zones is the presence of secondary radiation sources such as steel-thin lines and mast pull-offs, as well as other antennas in the environment of the transmitting antenna. Secondary sources of radiation are most often surrounded by an indirect zone within 2-3 meters from the given element. Secondary sources of electromagnetic radiation can also be feeders left after disassembled antenna installations, an indirect zone can occur in the rectrix at the end of the feeder .

The antenna coupler, and in principle the feeder which connects it with the antenna is a source of the electromagnetic field of protective zones (even the dangerous zone). Usually, it is assembled at a close distance from the antenna on board. The nearer it is to the antenna (shorter feeder), the lower its impact on the dispersion of protective zones. The antenna coupler can also be installed close to the transmitter in the room and the feeder led out by the insulator outside to the antenna, in such case a room surrounded by the above-mentioned exit will have protective zones to about 2.5 m depending on the size of the room and applied covers of the antenna coupler and feeders. Main MF/HF radios, due to their construction and high power of up to approximately 600 W are a source of extreme value for electromagnetic radiation on vessels. Because their utilization systematically grows smaller (usage of other communication devices), the exposure of the crew to radiation emitted by the above-mentioned devices can be considered as controlled and temporary.

3.3 VHF and UHF devices

The following are most common devices from the VHF and UHF range, which can be found on the vessels:

– **radiotelephones** VHF [21] on vessels depending on their application can use different frequencies bands. The most common devices are those which operate in the marine band: 156-162 MHz which serve ship-to ship and ship-to shore[2] ocommunication at short distances, and are the most common sources of electromagnetic radiation on ships. These devices can occur in stationary form – installed in rooms in stationary mode (e.g., in the wheelhouse) or in mobile version as portable VHF radiotelephones. The device can choose the channel from the served band (i.e., channels from 1 to 28 and from 60 to 88). One ought to pay attention that many channels have a special destination (channel 16 – called in danger) or is used by services and institutions supervising the given reservoir or littoral zone. That is why during measurement, such channels should not be disturbed and if there is no other possibility, the operator of the given channel should be communicated with (e.g., with the proper Maritime Offices). Frequencies of each channels and their destination are given in recommendation ITU-R M.1084-5 (03/2012).

VHF radiotelephones can regulate the power of 25W/1W (stationary devices) and 6W/5W/1W (mobile devices), therefore during measurement, it should be verified whether the device is transmitting at maximum power (Hi/Lo on the display or in older devices, highlighted 1W).

In the case of basic radiotelephones used in costal stations, the power of transmission can be greater depending on the permissions held.

In the case of VHF radiotelephones, the main source of electromagnetic radiation is the antenna which as a rule is found on the mast or in another "high" spot in the unit (for the purpose of achieving the sufficient range of communication). Radiation above the ALS(p) level (border of indirect zone) may also occur at the antenna's exit from the device (in this case, it is advisable to make sure that the feeder is not loose and possibly screwing it tight). Ships are also equipped with devices that work in a wider range of 134–174 MHz to also embrace the sea frequency band. Parameters of transmitting devices do not diverge considerably from those described above. Radiotelephones which work within the aviation frequency band (i.e., 118–138 MHz), have a lower power (approx. 10 W) and modulation A3E.

– **radiotelephones UHF** that work within the range 450–470 MHz are used mostly as auxiliary devices for internal communication. This system of communication consist of stationary

[2] ship-shore – communication between the ship and eg port, etc.

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radiotelephones in chosen rooms, portable (worn by crew members) radiotelephones and base antennas assigned to the vessel's decks. The device has similar parameters as VHF radiotelephones, with FSK modulation. An important aspect that should be considered are antennas, one unit can have several types of antennas with different radiation characteristics. The technical parameters have been described in recommendation ITU-R M.1174-3 (03/2015). Devices operating in the PMR[3] band (446 MHz) with a power of 0.5 W are also used for internal communication.

– **AIS transponder** [39] is used for automatic exchange of information between ships, as well as between ships and Coast Radio Stations supervising ship traffic. The device works on frequencies of 161.975 MHz (the channel A) and 162.025 MHz (channel B). Powers of transmission: 12.5W; 5W; 1W. Type of modulation: GMSK/FM. To avoid disturbances, transmission remains in the SOTDMA system (Self-Organized Time-Division Multiple Access). Information is sent at time intervals dependent from the vessel's movement. For ships moving(quickly) - every 10 s, for others which are not in movement, about 1 minute to 3 minutes. Technical details have been described in recommendation ITU-R M.1371-5 (02/2014). Similarly to VHF radiotelephones, the antenna is another source of electromagnetic radiation. The AIS transponder is a non-standard equipment of every vessel, regulated by suitable laws (5th chapter of the SOLAS convention).

The ranges of protective zones from devices working in the VHF and UHF bands are mostly dependent on the antenna installation height as well as the power of transmission. For antennas assembled on the reeling approx. 1m over the deck, there occur danger and intermediate zones (in the case of AIS, only the intermediate zone of approx. 1-2 V/m below the lower limit of the danger zone ALS(Low). Ranges of protective zones differ significantly depending on many factors and can reach from 0.5-1 m to 4-5 m (for a maximum range of the intermediate zone). Similarly as in the case of the MF/HF radio, secondary sources of radiation may appear, but on a smaller scale.

3.4 Satellite communication

Devices which ensure provision of many services (among other things, telephony, data transmission etc.) to ships through earth-synchronous satellites found on the geostationary orbit.

The systems used consist of two basic elements - the overdeck part (antenna and transmitter) and the subdeck part (terminal –interface) Devices of satellite communication work on several frequencies.

The INMARSAT system uses the L-band at frequencies of 1626.5–1660.5 MHz (transmission). The equivalent power of isotropic radiation (EIRP): 7–33 dBW. It uses a directional aerial with circular right-handed polarization.

Other satellite communication systems use frequencies from the Ku-band (13.75 GHz – 14.5 GHz), as well as the Ka-band (29.0 GHz – 30.0 GHz) and a transmitter power of8W to 16W.

The main electromagnetic field source – the antenna, is usually assembled in a such place which will not disturb the path of the beam to the nearest satellite of the system.

3.5 Marine radars

The present shipping demands usage of many devices creating electromagnetic fields in a wide range of frequencies. One such device is the marine radar [21]. They operate in X-band (3 cm) and S-band (10 cm) frequencies, usually 9410±30 MHz and 3050±10 MHz. The power of marine impulse transmitters falls in the range from 2 kW to 30 kW (where the source of microwave radiation is the magnetron) and from 100mW to 250W for radars working on the FMCW[4] technology, which slowly supersedes impulse radars from use, mainly on small units. The width of sounding impulses lies within the range from about several dozen nanoseconds to several microseconds. The frequency of repetition of impulses (PRF) ranges from several hundred Hz to several kHz. The average powers of radars are situated within several to several dozen watts. The antenna beam width is situated within a fraction of a degree to several degrees. Usually, bunches for radars with a closed antenna are larger (from 3˚ to 6˚) than for devices with an open antenna which usually adapt values from 0.5˚ to 2.5˚ and for radars from the S-band, about 1.0˚.

The vertical beam width (elevation) is usually situated within 20˚ to 30˚.

Research conducted by the Laboratory of Marine Electronics, showed that microwave radiation hazard on ships mostly derives from the radar's antenna. Due to placement of the transmitter by the antenna, in most currently used radars, the problem of tightness of waveguides or transmitters (in rooms) can be ignored. Based on the experience from many years of research conducted on ships in Poland since the 1960s, it can be concluded, that:

- Radars installed on ships are a potential source of electromagnetic radiation.
- The type and range of occurrent protective zones are relative to the transmitter's power and assembly method of the transmitting antenna on the specific ship.
- Low placement of antennas (common practice on small ships) over the deck or a roof of the wheelhouse is the most frequent reason fore occurrence of protective zones.
- Withdrawal of radars with a transmitter situated in the room allowed to the elimination of threats occuring in rooms.

The ranges of protective zones are determined with reference to ALS limits in line with the regulation [14]. Tables 1 and 2 show limits for the electric field and magnetic-field, respectively. The-

[3] Private Mobile Radio.

[4] Frequency-modulated continuous-wave radar

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Tab. III. Parameters characterizing the average power of the transmitter depending on the radar range.

RANGE [NM]	PULSE REPETITION RATE PRR (Hz)	IMPULSE WIDTH [µS]	AVERAGE PULSE POWER X* [W]	AVERAGE PULSE POWER S** [W]
0,125; 0,25; 0,5	3000	0,07	5,25	6,3
0,75; 1,5	1500	0,15	5,625	6,75
3	1500	0,3	11,25	13,5
6	1000	0,5	12,5	15,0
12; 24	1000	0,7	17,5	21,0
48; 96	600	1,2	18,0	21,6

* transmitter 25 kW, ** transmitter 30 kW

se concern the frequency range used by radio and radar devices. The frequency range recommended for measurements done to obtain approximate limits of protective zone ranges for the described electromagnetic radiation sources is marked in bold.

RESULTS

On the basis of many years of experience in measuring practice of the Laboratory of Marine Electronics and the realization of thousands of measurements of the intensity of the electromagnetic field on vessels, a range of devices that are sources of non-ionizing radiation has been recognized.

The implementation of new regulations in June 2016 has imposed a range of new duties on users of electromagnetic radiation sources and introduced new guidelines concerning measurement.

Further research should be conducted to assess exceedance of the newly introduced limits.

Until now, however, no uniform requirements have been developed for assessing the exposure of seafarers to electromagnetic fields in international regulations. Working under different flags (having different requirements) does not allow to estimate the number of workers in exposure to electromagnetic fields. It should be noted that seafarers outside the electromagnetic field are exposed to a number of other harmful or burdensome factors, such as noise, vibration, microclimate and others.

Further studies on the exposure of seafarers to the electromagnetic field are necessary to assess the new equipment in which vessels are equipped. It is also necessary to ensure greater access to information for people responsible for health and safety at work which this publication is intended to use.

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