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Electromagnetic Compatibility Testing of Military Ships

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Abstract. Electromagnetic compatibility (EMC) testing of military ships is an essential process for ensuring the correct and safe operation of electrical and electronic systems under complex operational conditions. This paper presents a methodology for assessing electromagnetic compatibility at the ship level, considering the vessel as an integrated system. The objectives include determining overall electromagnetic susceptibility, optimizing operations by reducing interference, and verifying the self-compatibility of installed equipment. The testing process is structured into two main stages: (i) assessing the impact of unintentional emissions on radio-frequency (RF) sensors and analysing their susceptibility to portable emission sources, and (ii) determining the overall electromagnetic compatibility of onboard systems under real operational conditions. The paper also details the conditions for conducting these stages, as well as the test scenarios based on emitter - susceptor combinations.
Keywords: electromagnetic compatibility; electromagnetic interference; EMCON.

1. Introduction

The development and integration of modern electrical and electronic systems on board military ships have led to increased complexity of the shipboard electromagnetic environment, generating new challenges in ensuring electromagnetic compatibility (EMC). The simultaneous operation of a large number of equipment items, often across wide frequency ranges and in varying operating modes, leads to unwanted interactions that may affect system performance and the operational safety of the ship.

In this context, electromagnetic compatibility must be addressed as an emergent property of the entire platform, resulting from the interaction between equipment, the electromagnetic environment, and operating conditions. The integration of equipment on board involves not only verifying compliance with applicable standards, but also assessing its impact on the existing electromagnetic environment and on other systems.

This paper addresses these challenges and proposes a coherent approach to the analysis and management of electromagnetic compatibility at ship level, taking into account both operational requirements and the need to mitigate risks associated with electromagnetic interference.

2. Shipboard integration of equipment and systems

The integration/installation of equipment and systems onboard a ship involves [2, 6]:
(i) meeting the following objectives:

- the equipment/system shall not cause unacceptable interference to other equipment, systems, apparatus, or devices installed onboard the ship;

- the equipment/system shall maintain its internal electromagnetic compatibility (intra-equipment, intra-system) after onboard installation;
- the equipment/system installed onboard shall not be subjected to unacceptable interference from other onboard equipment or systems, natural disturbances, or crew actions, including during storage;
- the equipment/system shall not pose a potential hazard to personnel, ammunition, or fuel onboard during operation.

and

(ii) completion of the following steps :

1. Pre-installation phase of equipment and system integration on board the ship:

- definition of the electromagnetic environment class at the installation location;
- modeling and simulation of electromagnetic compatibility assurance for the equipment/system onboard the ship (at the installation location);
- analysis of equipment/system test standards and compliance documentation in order to:
  - determine compliance with applicable standards for installation in that environment and with the requirements of the electromagnetic environment class onboard the ship (at the installation location);
  - assess the risk associated with installing the equipment/system onboard as a result of the compliance analysis;
- assessment of risks to ship safety or mission, depending on the importance of the electromagnetic environment at the installation location and the importance of the equipment/system - assessment followed by the determination of acceptable and unacceptable risks (Figure 1, Figure 2) [2]:
  I. if the equipment/system and the electromagnetic environment have a determining role in ensuring the safety/mission of the ship, then the emissions of the assessed equipment/system may pose a threat to the ship or the electromagnetic environment in which it is installed and, therefore, must be controlled at a non-existent to low risk level, and the susceptibility of the equipment/system must be controlled at a non-existent to low risk level;
  II. if the equipment/system has a determining role in ensuring the safety/mission of the ship and the electromagnetic environment has a non-determining role, then the emissions of the assessed equipment/system do not pose a threat to the ship or the electromagnetic environment in which it is installed and, therefore, must be controlled at a low to medium risk level, and the susceptibility of the equipment/system must be controlled at a non-existent to low risk level;
  III. if the electromagnetic environment has a determining role in ensuring the safety/mission of the ship and the equipment/system has a non-determining role, then the emissions of the assessed equipment/system may represent a threat to the ship or the electromagnetic environment in which it is installed and, therefore, must be controlled at a non-existent to low risk level, and the susceptibility of the equipment/system must be controlled at a low to medium risk level;
  IV. if the equipment/system and the electromagnetic environment have a non-determining role in ensuring the safety/mission of the ship, then the emissions and susceptibility of the assessed equipment/system must be controlled at a low to medium risk level.
- establishing:
  - measures to reduce unacceptable risks (additional tests, modification of installation requirements, installation of protective ,,barriers" to reduce radiofrequency emissions (conducted and radiated) and susceptibility to radiofrequency emissions (conducted and radiated), etc.;

- additional requirements to ensure the electromagnetic compatibility of the equipment/system on board the ship.

Note: All additional changes regarding the on-board installation of the equipment/system are followed by the analysis and verification of the intra-system compatibility of the equipment/system.

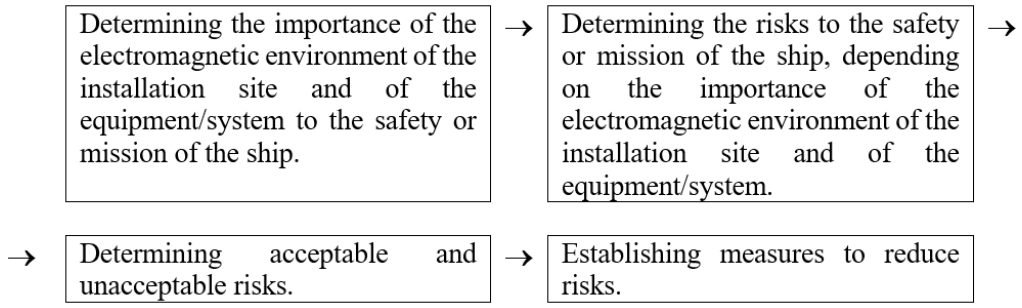

Figure 1. Risk assessment based on the impact of the electromagnetic environment and the equipment/system on the safety/mission of the ship

		Electromagnetic environment	
		Determined (critical) for ship safety / mission	*Non-determining (non-critical) for the safety / mission of the ship*
Equipment / system	*Determined (critical) for ship safety / mission*	Emission level = *low* **I** Susceptibility level = *low*	Emission level = *low to medium* **II** Susceptibility level = *low*
	Non-determining (non-critical) for the safety / mission of the ship	Emission level = *low* **III** Susceptibility level = *low to medium*	Emission level = low to medium **IV** Susceptibility level = *low to medium*

Figure 2. Risk assessment [2]

2. Installation of equipment and systems on board the ship:

- installing equipment and systems in line with the manufacturer's guidelines, while adhering to standards that ensure electromagnetic compatibility of onboard ship equipment (for example, AECTP-500, IEC 60533, etc.);
- visual verification of the correct installation of the equipment and systems on board the ship (for example, grounding, shielding, installation of filters, connection of appliances and devices, connection of cable shields to the ship's hull, separation of cables, etc.).

3. Operational verification of equipment and systems on board the ship:

- verification of the operation of the equipment and systems in all working modes, so that it operates at nominal parameters after installation on board;
- verification of compliance with the requirements of intra-equipment/system compatibility.

4. Evaluation of the electromagnetic compatibility between onboard equipment and systems:

- evaluation of the electromagnetic compatibility between onboard equipment and systems under representative operational scenarios;

- evaluation of the electromagnetic compatibility of shipboard equipment and systems under representative mission scenarios, taking into account the shipboard electromagnetic environment.

5. Evaluation of inter-platform (inter-ship) electromagnetic compatibility:

- evaluation of the electromagnetic compatibility of equipment and systems on board the ship in scenarios representative of the ship's missions, taking into account the operational environment.

3. The components of ensuring the electromagnetic compatibility of a military ship

Ensuring the electromagnetic compatibility of a ship involves considering / analysing the elements presented in Table 1 [1, 3, 6-10]:

Table 1. Elements required for the analysis and testing of shipboard electromagnetic compatibility.

Element / Requirement	Description / References

Interconnection/interfacing requirements	• the mission and operational requirements of the ship;
	• establishing the operational characteristics of the equipment/system required to be installed on board the ship in accordance with the mission and operational requirements of the ship;
	• determining the class of the electromagnetic environment at the installation site:
	  • determining the characteristics of the on-board network and analyzing compatibility with the requirements for connecting the equipment/system required to be installed on board the ship to the on-board network;
	  • determining the electromagnetic field level at the installation site;
	• requirements for frequency management.

Sources that determine the electromagnetic environment on board	• natural sources / God-made noise (atmospheric electrical discharges, cosmic noise, electrostatic discharges, etc.);
	• functional sources (man-made noise) external to the ship:
	  • unintentional (radio, TV, industrial noise, nearby ship transmitters, etc.);
	  • intentional (electronic jamming, nuclear electromagnetic pulse, electromagnetic pulse due to electromagnetic pulse weapons, etc.);
	• functional sources on board (ship's own) – relating to disturbances transmitted through the power supply network and those transmitted by radiation (radiocommunication equipment, satellite communications, radionavigation, radars, sonars, submarine acoustic channel communications equipment, active jamming equipment, radar recognition equipment, etc.).

Analysis, simulation and testing	• creation of a database with operational characteristics and technical parameters of on-board equipment; • analysis of the certificate of conformity of the equipment/system and the test standards provided therein in order to establish compliance with the requirements of the electromagnetic environment on board the ship (of the installation site);

Element / Requirement	Description / References
	• modeling and simulation of scenarios for verifying the electromagnetic compatibility of on-board equipment/systems; • determination of interference margins; • analysis and establishment of acceptable and unacceptable risks; • establishment of measures to reduce risks – establishment of requirements for ensuring the electromagnetic compatibility of the equipment/system on board the ship; • installation of the equipment/system in accordance with the manufacturer′s installation manual and standards for ensuring the electromagnetic compatibility of equipment on board ships, and implementation of risk reduction measures (in the event that installation on board is decided); • checking the operation of the equipment/system in all working modes, so that it operates at nominal parameters after installation on board; • checking the electromagnetic compatibility of the equipment/system with the other equipment/systems in the electromagnetic environment in which it is installed, in different scenarios; • checking the electromagnetic compatibility of the equipment/systems on board the ship in different scenarios, depending on the ship′s missions, considering the ship's own electromagnetic environment.
Analysis and determination of susceptors on board the ship	• electrical and electronic equipment on board; • fuel on board; • ammunition on board; • ship's personnel.
Ensuring the necessary documentation	• equipment/system installation manuals; • standards, manuals/technical specifications, guides, etc. used; • ship electromagnetic compatibility testing program plan; • preparation of final document templates (electromagnetic interference control plan, electromagnetic compatibility test plan, electromagnetic compatibility testing report, reports with special requirements resulting from the application of tests, plan/report with new technologies to be applied, reports on the condition of the platform/ship, etc.).
Program Manager Documents	• the main plan for testing, evaluation, and analysis of the electromagnetic compatibility of the ship (MPTEA-EMC); • specific MPTEA-EMC procedures; • analyses relating to logistical support (maintaining the equipment/system in working order), results of other testing and evaluation of the equipment/system by certain testing laboratories, reliability and maintainability of the equipment/system, effects of the electromagnetic environment on the equipment/system (forecasted), spectrum supportability (fitting the frequency bands of the

Element / Requirement	Description / References
	equipment/system into the frequency bands allocated to the military domain), operational safety regarding the protection of personnel, etc.; • the mission and operational requirements of the ship and the need to install the equipment/system in accordance with them; • analysis of the compliance of the test procedures (standards) in the equipment/system test document, issued by the EMC testing laboratory/manufacturer, with the requirements of the electromagnetic environment on board the ship (of the installation site); • reviewing the risk assessment related to installing the equipment or system on board after completing the compliance evaluation; • evaluating potential risks to ship safety and mission performance, taking into account the significance of the electromagnetic environment of the installation site and the importance of the equipment/system – assessment followed by the establishment of acceptable and unacceptable risks; • application and adaptation of standards, specifications, guides, and installation manuals, following risk analysis; • review and approval of contractual documents (in the case of installation of new equipment/systems), following risk analysis; • configuration control and management of equipment/systems; • frequency management; • database with operational characteristics and technical parameters of equipment/systems on board; • personnel training program on ensuring and maintaining electromagnetic compatibility; • analysis/results of modeling and simulation of scenarios for verifying the electromagnetic compatibility of equipment/systems on board; • solving electromagnetic compatibility problems arising during the installation and testing of electromagnetic compatibility of new equipment/systems and during the testing of the electromagnetic compatibility of the ship as a whole; • maintaining coordination with all stakeholders involved in testing, evaluation, and analysis of the ship's electromagnetic compatibility; • preparation of the final documentation covering the testing, evaluation, and analysis of the ship's electromagnetic compatibility.

Figure 3 shows the diagram on how to integrate an equipment/system on board.

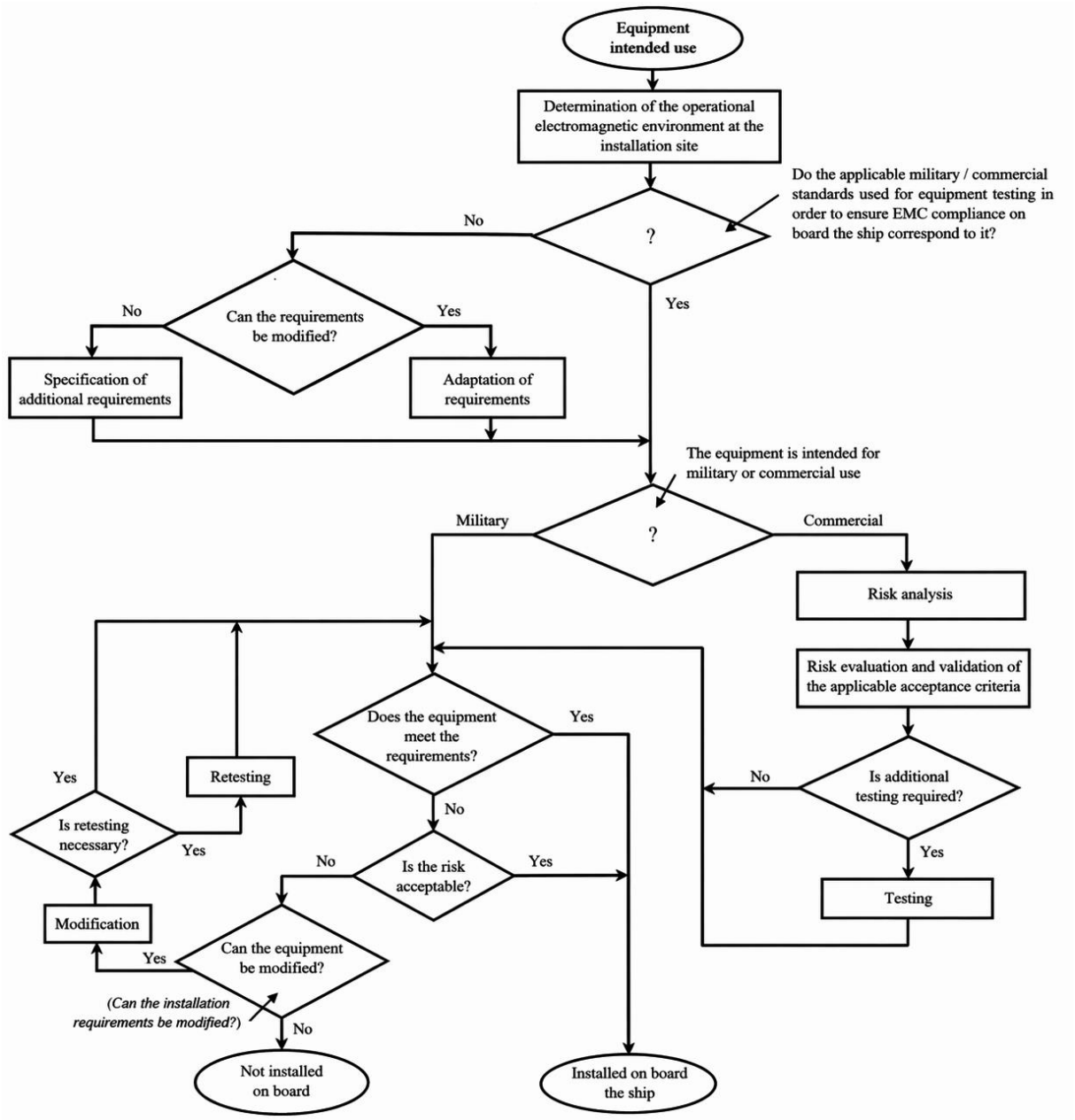

Figure 3. Diagram of how to integrate an equipment/system on board the ship [2]

Intra-platform and inter-platform testing of the electromagnetic compatibility of the military ship is carried out for [1, 2, 5]:

- determining the electromagnetic susceptibility of the ship, considered as a whole system, to establish whether the ship is operational when all on-board equipment and systems operate at nominal parameters (radio communication equipment, GMDSS, GPS, radars, weapon systems, sensors/transducers, etc.);
- optimizing military operations by minimizing electromagnetic interference between ships;
- ensuring that all installed electrical/electronic equipment and systems, including newly installed ones, are self-compatible, as well as compatible with the expected electromagnetic environment.

During the *intra-platform and inter-platform testing of the electromagnetic compatibility of the military ship,* the following will be taken into account [2, 5, 6]:

- identification and evaluation of the ,,source - victim" pairs, including ,,multiple sources - victim", depending on the operating modes/regimes, frequency, and period of operation (requires the establishment of scenarios);
- establishment of a frequency management plan for all transmitters and receivers connected to the antennas, a plan that must include:
  - predictable interactions between transmitters and receivers (analysis, simulation) - analysis of co-channel interference (co-channel interference), adjacent-channel interference (adjacent-channel interference), and out-of-band interference (out-of-band interference);
  - analysis/determination by simulation of interference margins for equipment/systems, including ammunition;
- testing must be carried out in an area where the level of the ambient electromagnetic field does not affect the validity of the results;
- testing must include absolutely all equipment, systems, appliances, and devices on board;
- on-board power supplies (on-board network) and external power supplies must comply with applicable standards for the quality of electrical energy (disturbances transmitted on the power lines must not degrade the operation of equipment/systems, etc.);
- the on-board network must allow the simultaneous operation of all equipment, systems, appliances, and devices on board.

Intra-platform electromagnetic compatibility testing of the military ship is performed in two stages:

- Stage I - aims to determine [1, 2, 5]:
  - the impact of unintentional electromagnetic emissions of electrical/electronic equipment/systems and cables on board the ship on radio-frequency sensors (receivers, wireless sensors);
  - the susceptibility of sensors and electrical/electronic equipment/systems to emissions from portable radiocommunication transmitters on board, by using them at a distance of 46 cm (18 inches [20]);
- Stage II - aims to determine the electromagnetic compatibility of the electrical/electronic equipment/systems on the ship.

Radio-frequency sensors are any devices that detect or receive electromagnetic waves in the 2 MHz–460 MHz band for the ,,above deck" area and in the 2 MHz–6 GHz band for the ,,below deck" area, including wireless data links [1, 2, 5].

In the event of ship modernization, only those sensors that may be affected by the changes occurring on board will be tested [5].

When testing / analysing the electromagnetic susceptibility of the ship, the following shall be taken into account [1, 2, 5]:

- background (ambient) noise level;
- electric / magnetic field intensity radiated by equipment and cables and their frequency (excluding antenna radiation), both in the ,,above deck" and ,,below deck" areas;
- electric field intensity radiated by the antennas of on-board transmitters (radio communication equipment and radars), the frequency bands of these radiations (including out-of-band and non-essential radiations/emissions), and the directivity characteristics of the antennas;
- levels and frequencies of electromagnetic disturbances transmitted by conduction by the equipment (primarily the quality of the electrical voltage supply - d.c./a.c.);
- levels and frequencies of electromagnetic disturbances transmitted by conduction on the cables connecting the ,,above deck" and ,,below deck" areas;
- secondary radiators in the ,,above deck" area;
- hull-induced intermodulation interference levels;
- hull attenuation;

- shipboard RADHAZ (Radiation Hazards) areas.

Preparation of the test stages:

1. Preparation of the documentation required for the execution of Stage I, including the following:

- name of the ship, boarding number, location during the test, and the condition of the ship (repair, modernization, etc.);
- how to conduct the test;
- applicable personnel safety requirements, including the identification of potential hazards;
- list of electrical and electronic equipment and systems (including cabling) that produce unintended emissions, along with their operational characteristics;
- list of tested (monitored) radio-frequency receivers, together with their operational parameters, including frequency bands, sensitivity, and receiver noise characteristics;
- list of tested (monitored) wireless sensors, including their operational characteristics such as frequency bands and sensitivity;
- list of electrical and electronic equipment and systems and wireless sensors for testing susceptibility to emissions from portable radiocommunication transmitters;
- description of the testing procedures for equipment/systems and sensors;
- list of test equipment (date of calibration) and software used;
- name, number, and operational characteristics of portable radiocommunication transmitters (power, frequency bands) used for susceptibility tests;
- location of test points;
- calculation relationships, conversions of measured quantity levels, etc., according to the test procedures.

2. Preparation of the documentation required for the execution of Stage II, including the following:

- procedure for measuring intermodulation interference generated by the ship's hull;
- test matrix with all equipment/systems that generate radiation and monitored equipment (susceptors), Table 2 (Table 4 gives examples of active equipment – radiation generators and monitored equipment);
- the test procedure will contain:
  - possible scenarios (Table 4), startup sequences of active equipment, and monitoring of susceptor equipment depending on the scenario;
  - operating modes of equipment depending on the scenarios for determining the most unfavorable frequencies and working modes, also taking into account the previous analysis of the operational characteristics of the disturbing and susceptor equipment/systems;
  - operator records to identify electromagnetic interference or the degree of variation/modification of technical parameters or operational characteristics of monitoring equipment/systems (degradation of operating status);
  - procedure for establishing on-board communications so that tests are not influenced;
  - a list of auxiliary installations required to operate continuously on board the ship (during test procedures) in order to ensure the safety of the ship.

Table 2. Equipment matrix.

Active equipment (disturbing) / Monitored equipment (susceptors)	X-band radar transmitter	S-band radar transmitter	VHF radio transmitter	HF radio transmitter	...	…	…	…
VHF radio receiver			*					
HF radio receiver				*				
X-band radar receiver	*							
…								

* Equipment operating in the same band or adjacent bands.

Conducting tests corresponding to Stage I [1, 2, 5]:

- a location is selected for the test so that the ambient electromagnetic field level in the 2MHz - 460MHz band does not exceed the level specified in Figure 4;
- at that location [1, 2]:
  - there must be no cranes within 50 meters;
  - all cranes/booms in the immediate vicinity (50 - 75 meters) must have their arms retracted;
  - there are no large metal structures near the ship, such as scaffolding;
  - there are no ships moored near or next to the ship under test;
- emission control measures (EMCON) are active;
- the use of radio transmitters for communications during the tests must be controlled in such a way that the tests are not influenced;
- check (deficiencies discovered are corrected before the start of phase I of testing):
  - connections between equipment, equipment grounding and the existence of devices that have been installed to ensure the electromagnetic compatibility of the equipment and systems on board (shields, Surge Protective Device, filters, etc.);
  - installation and operation of antenna couplers and network filters;
  - that there is no missing electronic equipment, defective equipment, broken or missing transmission lines, damaged antennas, improperly installed antennas, improper antenna connections, etc.;
- measure and classify unintentional electromagnetic emissions from all electrical / electronic equipment (radio frequency transmitters will operate without emission into space, radar antennas will be in „antenna rotation" mode), Table 3 [5];
- locate and note in the test report the radio-frequency sources that have a medium/severe influence on monitored equipment/sensors;
- in the event that a sensor cannot be monitored, the field level at its installation point will be determined (the equipment containing the respective sensor will be turned off, and the test equipment will have the same sensitivity as the sensor);
- testing the susceptibility of sensors and electrical/electronic equipment/systems to emissions from portable radiocommunication transmitters on board:
  - identify and note in the test report the non-operational equipment;
  - the portable radiocommunication transmitter (used in the test) will emit at maximum power and will be placed at a distance of 30 cm from the monitored equipment/sensor (the equipment/sensor is operating normally before the start of the test procedure);
  - the portable transmitter is placed at a distance of 30 cm on all sides of the tested equipment and will be rotated so that the equipment is irradiated with both horizontally and vertically polarized waves;
  - in the event of susceptibility of the monitored equipment/sensor, the portable transmitter will be distanced from the equipment/sensor until the disturbance state disappears (the distance and maximum power of the transmitter are recorded), or the distance of 30 cm will be maintained and the power of the portable transmitter will be gradually reduced until the disturbance state of the equipment/sensor disappears (the power of the transmitter is recorded).

Table 3. Classification of the influence of unintentional electromagnetic emissions of electrical/electronic equipment [5]

Unintentional emission level (detected noise level)	Classification of the influence of unintentional electromagnetic emissions	Category
< 10 dB	Low[1]	III
10 – 20 dB	Medium[2]	II
> 20 dB	Severe	I

Notes:
1. Unintentional emissions should not affect more than 10% of the channels or the frequency band of the selected equipment (otherwise, they are considered to have a medium influence).
2. Unintentional emissions should not affect more than 50% of the channels or the frequency band of the selected equipment. In this case, they are considered serious.

Conducting tests corresponding to Stage II [1, 2, 5]:

- a location is selected so that the operational environment on board the ship is determined only by the equipment on board (MIL-STD-1605 requires that the ship be at least 50 Mm from the shore – AECTP-500, 90 km);
- it is checked (the deficiencies discovered are corrected before the start of the second phase of testing):
  - the connections between the equipment, the equipment grounding, and the existence of devices that have been installed to ensure the electromagnetic compatibility of the equipment and systems on board (shields, Surge Protective Device, filters, etc.);
  - the installation and operation of the antenna couplers and network filters;
  - that there is no missing electronic equipment, defective equipment, broken or missing transmission lines, damaged antennas, improperly installed antennas, improper antenna connections, etc.;
- all loose metal objects on the outer decks (exposed) that are not part of the ship's normal equipment are removed;
- a diagram is identified and made showing the arrangement of the antennas on board, also noting the vertical and horizontal distances between them (allows an analysis in terms of directivity characteristics);
- an inventory of the transmitters and receivers on board is made, establishing the frequency bands, transmitter power, intermediate frequencies, and receiver passbands, and whether this equipment is operational (in the case of non-operational equipment, testing will end only after all the equipment is operational and all test scenarios have been carried out);
- test scenarios are established (before the start of the tests) in order to determine the potential disruptor → susceptor combinations (the transmitters will operate at maximum nominal power, and testing will be done in all their working modes), Table 4.
- before executing the test scenarios, they will be executed in the following order:
  - intersystem interference testing – the transmitters will operate in turn with emission into space, at maximum nominal power and in all operating modes, starting from the highest frequencies; one transmitter will operate with emission into space and, at the end of the test, it will remain on but without emitting into space; another transmitter will operate, and all on-board equipment will be monitored in order to determine radiated or conducted interference;
  - intersystem interference testing – the transmitters in the test will operate with emission into space, at maximum nominal power and in all operating modes, starting from the highest frequencies; one transmitter will operate with emission into space and, at the end of the test, it will remain switched on with emission into space, following which another

transmitter in the scenario will operate with emission into space, and all on-board equipment will be monitored in order to determine radiated or conducted interference;

- within a scenario, in the event that electromagnetic interference is observed in equipment or a sensor, the emission into space of the transmitter being tested at that time will be stopped in order to observe whether the interference disappears;
- within a scenario, emphasis will be placed on potential source–victim combinations identified during scenario planning.

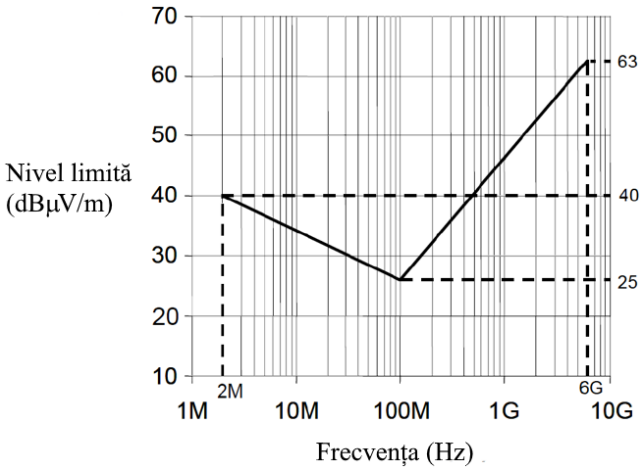

Figure 4. Ambient electromagnetic field level [2]

In the analysis of the electromagnetic compatibility of the military ship, the intermodulation interference generated by the ship's hull is also taken into account. The requirement for ensuring intra-system electromagnetic compatibility on board is considered to be met if the intermodulation interference generated by the ship's hull, of an order greater than the 19th, which have as their primary source of radiation the high-frequency transmitters on board, is not detectable by the receivers on board the ship [4].

The measurement of the ship's unintentional emissions (the transmitters on board are not working) is carried out under EMCON (EMission CONtrol). The MIL-STD-464D standard provides for an electric field intensity level measured at a distance of one nautical mile from the ship of 5.8 dBμV/m, or 10.8 dBμV/m at one kilometer, in the frequency band 500 kHz – 40 GHz.

Table 4. Possible scenarios in phase II of testing [2]

Scenario	Active Equipment	Monitored Equipment
1.	Electrical equipment that exceeded the permissible limits of Phase I	Receivers – HF (3 MHz–30 MHz) and VHF (30 MHz–300 MHz)
2.	Transmitters – HF and VHF	Receivers – HF and VHF
3.	All transmitters starting with VHF (except radar)	All receivers starting with VHF
4.	Radar transmitters	All receivers starting with HF. Closed-circuit TV system
5.	Sonar transmitters Demagnetization system	Receivers – sonar, LF (30 kHz–300 kHz), underwater communication equipment
6.	Other transmitters (active radiation-generating equipment) that were not used in Scenarios 1–5	Receivers according to the active equipment bands

7.	All transmitters (active radiation-generating equipment) used in Scenarios 1–6	All monitoring equipment in Scenarios 1-6

4. Conclusions

The electromagnetic compatibility (EMC) of equipment and systems on board a military ship is an essential condition for ensuring its safe and efficient operation within the specific operational environment. The paper highlights that the integration of equipment on board cannot be achieved without a rigorous analysis of the electromagnetic environment, the interactions between equipment, and the associated risks.

The results presented emphasize the importance of applying a systematic approach based on well-defined stages: compliance assessment with applicable standards, risk analysis, implementation of interference mitigation measures, and validation through testing in relevant scenarios. It has also been demonstrated that intra-platform and inter-platform testing are indispensable for identifying source–victim pairs and for optimizing the simultaneous operation of equipment.

In conclusion, ensuring electromagnetic compatibility directly contributes to enhancing ship safety, protecting personnel, and enabling mission accomplishment under optimal conditions, constituting a fundamental element in the design, integration, and operation of modern naval systems.

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