IOSUD – UNIVERSITATEA „DUNĂREA DE JOS” DIN GALAȚI

Școala doctorală de Științe Fundamentale și Inginerești

DOCTORAL THESIS

Summary

Contributions to anti-disturbance protection of communications systems on board military ships

Doctorand,

Vasile Solcanu

Conducător științific,

Prof. univ. dr. habil. ing. Marian GĂICEANU

Seria I 3: Inginerie electrică nr. 7

GALAŢI

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Domeniul fundamental ȘTIINȚE BIOMEDICALE

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I. Timeliness of the theme

The particularly high concentration of technical means in a limited space such as that on board a military ship, inevitably leads to the oversaturation of the electromagnetic spectrum and the appearance of disruptive electromagnetic interference (EMI). Under these conditions, part of the equipment installed on board these ships is at the same time both the source and the victim of IEM [1], [2], [3], [4], [5].

Due to the increasing rate of emergence and implementation of new generations of military and civil technology, we meet in the equipment of military fleets ships that have not yet completed their life span but which are already equipped with equipment and systems of sensors and weapons that are outdated in terms of technological. Moreover, during the lifetime of a ship, several generations of technology appear, frequently requiring the introduction of these ships into modernization programs. Thus, we meet on the same ship systems from different generations, from different manufacturers and from different countries that must work coherently without affecting each other. These ships are forced to participate in combat, rescue and peacekeeping missions with ships of the latest generation, missions whose success depends on the lives of many people. In this sense, the military ships of the EU and NATO countries, including those of the Romanian Naval Forces (FNR) carry out joint military deterrence activities in the "hot" areas of the eastern Mediterranean Sea and the Black Sea. In order to combat the smuggling of emigrants but also to save their lives if their boats sink, the EU has several operations carried out in the Mediterranean Sea: the Themis operation for the Central Mediterranean, the Poseidon operation for the Eastern Mediterranean, the Indalo operation for the Mediterranean Sea from the West. Thanks to these efforts, more than 528,653 lives have been saved since 2015 [6], [7].

The costs required for the production, maintenance and modernization of military ships raise problems for all countries with such fleets, regardless of their political and economic power, including the USA, the country with the most developed economy and the largest military maritime fleet. Thus, on 31.10.2024, the head of US Naval Operations, Admiral Lisa Franchetti, announced that, due to budget constraints, the decision was made to extend the life of 12 Arleigh Burke-class destroyers under the conditions that in 2023 the decision was made to extend the life of five other destroyers of the same class for the same economic reasons [8], [9].

More recently, in the recent armed conflict between Ukraine and the Russian Federation, the loss of a ship fresh from a modernization process shows once again the great importance of having the entire apparatus operating at optimal parameters. To achieve this, it is imperative that the principles, measures and norms of electromagnetic compatibility (EMC) are known and respected by all the factors involved in this process [8].

The EMF problem of the communication systems on board military ships (SCBNM) is an extremely vast, complex and topical one, all the more so since the current technological evolution is unprecedented in the history of mankind. These systems are also characterized by a great diversity of the technical equipment used and the ways of making communications both by wire, optical fiber, hydroacoustic, direct wave radio, with the ionosphere or by satellite. The listed characteristics make it particularly difficult to achieve compatibility both between the physical equipment used, their interconnection and between the organizational and command structures. However, the unitary leadership of the naval forces as well as their collaboration with other structures and forces cannot be achieved without ensuring secure and quality communications.

It becomes obvious the special importance of studying and understanding EMC, issuing standards and procedures that regulate this field as clearly as possible, as well as the importance of training the personnel who serve the equipment on the ship as well as that of the companies and shipyards that maintain, repair or modernize these ships.

Taking into account the previously presented as well as the particularities of the ships from the FNR equipment, old ships that periodically enter repair - modernization programs, one of the main objectives of the thesis is to identify appropriate solutions to make the communication system on board the ship compatible with costs minimal, under the conditions of the coexistence in the same limited place of a very large number of electrical and electronic systems from different generations, manufactured according to different military / civil standards, a good part of which have already been replaced / updated. From this main objective result the other objectives with the help of which the main objective can be achieved, namely: the identification of the main sources of disturbances / threats on board the ship, their analysis and modeling, the type of signals they generate, the methods of coupling and their effects on SCBNM / constructive floors of radio transmitters (RE) and radio receivers (RE). Another objective of the thesis is to identify communication systems that are more resistant to perturbations through the analog and digital modulations they use.

II. The content of the work

In the chapter 1 we conducted a research on the military and civil EMF standards in force and presented their evolution. The standards presented are those adopted by the structures of which Romania is a part: NATO and the EU as well as Great Britain because the FNR has four ships purchased from this country. Also, based on the studied documentation, I presented the problems generated by the cost in the construction, equipping and modernization of military ships, a problem faced by the FNR as well. In order to emphasize the importance of adopting appropriate EMF measures on board ships and aircraft, from the studied bibliography I also presented some accidents/disasters generated precisely by the non-adoption and non-compliance of these measures.

In the first part of chapter 2, I made a presentation/definition of EMF terms taken both from the specialized literature and from the normative acts in force. Moreover, throughout the content of the thesis, the terms used are also presented through their definition and the imposition of limits in the normative acts and standards in force. Also in this chapter we presented the basic EMC relationship, the foundation of electromagnetic interference coupling mechanisms, and made a detailed analysis of shipboard EMF sources and coupling mechanisms. I also presented the principles of the organization of distress and military communications and the composition of the systems that serve them.

Chapter 3 presents a detailed analysis of the main signals encountered in the shipboard electromagnetic environment (EME) using series and the Fourier transform as a mathematical apparatus. Also, both the signals used in analog and digital communications are presented. The mathematical relationships are accompanied by figures in both the time domain and the frequency domain obtained in Mathcad and Matlab-Simulink. I also presented the schemes that I personally designed in Matlab-Simulink to obtain these figures.

In chapter 4 we analyzed and modeled the dispersion magnetic fields created by alternating current rotating electric machines, single-phase transformers and the magnetic and electromagnetic fields generated by current-carrying conductors. The field values obtained by calculation, based on the proposed calculation relations, are validated by the results of some field measurements. We also proposed an algorithm for the global modeling of the perturbing magnetic field of dispersion in a compartment arranged on a ship and an algorithm for drawing a map of the intensity of the magnetic dispersion fields. The results presented by the calculations are obtained starting from the field values obtained from the measurements. Also in this chapter we analyzed the threats represented by intentionally produced electromagnetic interference (IEMI) of which the nuclear electromagnetic pulse is also a part. The simulation of their effects on a coaxial cable is performed using the Ansys HFSS simulation program.

In chapter 5 we presented the IEM coupling methods as well as the main anti-disturbance measures. We have paid more attention to IEMs transmitted through conductors as well as the effects that their shielding has on IEM transmission.

Chapter 6 includes the description of the main EMC characteristics of RE and RR both based on the descriptions in the specialized literature and on the basis of the regulations in force. Also in this chapter I presented the distortions introduced by the communication channel.

Chapter 7 is a particularly extensive one in which, with the help of graphs drawn in Mathcad, based on mathematical relationships as well as with the help of simulations carried out in Matlab–Simulinck, we performed the study and analysis of the effects of co-channel and adjacent channel IEM on the input stages in a RR, the analysis of the effects of nonlinearities of the characteristics of electronic devices on the processed signals, the study of co-channel interference and the stability of local oscillators on the quality of the processing of received signals, the study of the resistance to disturbances of the main types of communication systems on board military ships used during missions maritime search and rescue and disturbance stability analysis of digital (digitally modulated) communication systems. Also in this chapter, an algorithm for calculating the interference margins for radio communication systems on board military ships is presented.

Chapter 8 presents the results of the electromagnetic field measurements carried out on a military sea vessel in which we proposed the introduction of a new criterion / quantities for determining the efficiency of a screen.

Chapter 9 presents the main contributions and development directions.

Chapter 10 includes the list of works presented and published by the author of the thesis.