Risk-based EMC Approach for the Ship's Semi-enclosed Reverberant Indoor Environment to evaluate EMI generated by Wireless Devices

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***Abstract*— Ships are one of the most complex semi-reverberant electromagnetic environments. To lower the cost and weight of the cabling in ships, wired devices are being replaced by wireless ones. This increment, with the presence of the multipath reflective environment, will increase the chance of electromagnetic interference. Although the electronic devices placed within satisfy various electromagnetic compatibility standards, the risk of interference still exists because of the complexity of the environment. A full risk-based electromagnetic compatibility approach can significantly help to mitigate the interference risks. In this paper, we discussed how a semi-enclosed reverberant environment increases the field strength below the deck of the ship and can cause electromagnetic interference within. We also discussed the risk-based electromagnetic compatibility approach using the Accessibility, Susceptibility, and Consequence cube to overcome electromagnetic interference risks.**

Keywords*— *electromagnetic compatibility, ship, rule-based EMC, risk-based EMC, wireless devices

I. Introduction

Replacing wired interconnections with wireless devices in a ship provides several benefits in terms of cost, space, and weight [1]. The usage of wireless devices is on the rise, and the complete replacement of wired devices is closer than anticipated [2]. Contrary to the aforementioned benefits, the usage of wireless devices leads to electromagnetic interference (EMI) concerns. For example, one such accident happened due to interaction between a very high frequency (VHF) radio and the joystick control, leading to a sudden power surge in the supply vessel which was servicing a semi-submersible offshore oil and gas installation [3]. This led the joystick to perform unauthorized orders, resulting in contact between the vessel and the installation, causing damage. In another example, the ship's steering was hindered by a walkie-talkie, resulting in a minor accident [4]. Even though accidents were minor, but if the inclusion of one or two wireless devices on a ship can have such an impact, replacing major wired devices with wireless devices possesses bigger risks. The effect of EMI depends on the ship environment where wireless devices are kept [5]. In a ship, the outdoor environment is completely different from the indoor environment. This makes the ship a complex environment that needs to be studied to overcome the EMI issue. The ship's electromagnetic environment, both indoors and outdoors, is extremely complicated. Indoors, the 'protected' or 'below deck' environment is meant, while outdoors is the 'exposed' or 'above deck' environment.

The outdoor environment is a free/open space environment [6], but the indoor environment is semi-reverberant [7]. A free/open space environment is an environment with a low quality (Q) factor, whereas a reverberant environment is defined as an enclosed environment with a very high Q factor. A semi reverberant environment covers the gap and can have a Q factor greater than free space but less than a reverberant environment. The difference in the ship's indoor and outdoor electromagnetic environments is a consequence of the difference in the amount of reflections, also termed as the reverberation index [8], present. Due to less reflection in the ship's outdoor environment, the electrical field strength of wireless devices declines with increasing distance, causing less severe EMI issues. However, due to multipath reflection in the ship's indoor environment, the electrical field strength is independent of the distance between source and victim, causing significant EMI issues [9].

The following parameters need to be considered while studying the outdoor EM environment of a ship: frequency bands, the maximum allowable noise level of receivers, transmitted signal power levels, and field strength, antenna characteristics (polarization, directivity, and gain), spatial effects (like antenna positions and areas of exposure), the temporal behavior of systems (pulsed, CW), modulation, signal processing, coding, construction materials, etc. The aforementioned parameters create the solution space of frequency, spatial, temporal, coding, and material diversity for the outdoor environment and are part of the EM Coexistence or Topside Design. The risk of EMI is more detrimental indoors due to the complexity of the electromagnetic field propagation, and the main focus of this work is thus related to that semi-enclosed ship's indoor environment. Possible sources and victims present indoors of ships are: a) wireless sensor network (WSN), b) wireless local area network and its repeaters (WLAN), c) Zigbee-based sensor networks, d) mobile communication (GSM, UMTS, 4G, 5G), e) wireless broadband communication (WiMAX), etc.

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This paper describes the ship's indoor environment and will act as a tutorial, describing how the chance of EMI will increase in such an environment, together with the increasing usage of wireless devices. One of the possible options is the risk-based EMC approach for evaluating the ship's complex environment. Lloyds, the ship certifying organization, recently authorized and accepted the risk-based EMC approach as an alternative to the conventional rule-based approach [10]. The risk-based approach can ensure that commonly available commercial off-the-shelf (COTS) technology can be securely integrated onboard ships, which can also result in lowering the total marine vessel installation costs.

II. Ship's Indoor Environment

The electric field strength in the indoor environment increases locally and does not decrease steadily with distance, as expected generally in a ship's outdoor environment. In the extreme scenario, if the ship's indoor environment is as reflective as a well-operated reverberation chamber, the electric field strength can grow up to 20 dB [11]. In this extreme instance, the resonant scattered components grow stronger than the directly linked component, making spatial separation less effective, and the exponential decay does not apply. Apart from that, numerous reflections and the possibility of signal absorption in the indoor environment might cause variations in the power output of various wireless devices, which are otherwise equally distributed in the outdoor environment. This can also cause EMI of the functional radio signal, resulting in loss of data, i.e., an increase in the Bit Error Rate.

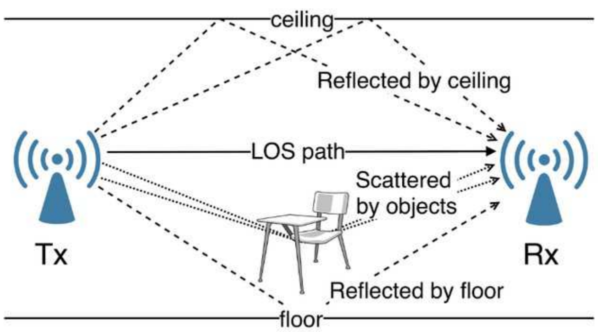


Fig.1. Indoor environment signal propagation (Figure adopted from [12])

The ship's indoor environment can be regarded as a semi-reverberant environment where the following factors have an influence on the electromagnetic field distribution [9]: a) frequency, b) material, like steel, c) size, i.e., volume, d) lossy objects, e) openings like windows and poorly shielded doors.

Several studies have been performed on a naval vessel, to estimate the field strength and the electromagnetic field distribution [13] due to the use of wireless devices:

A) Ship's hallway: The hallway in indoors of a ship is one of the primary examples of a reverberant environment where the impact of a highly reflecting environment on-field strength can be observed and simulated. The hallway, as shown in Figure 2, can be regarded as a lengthy metal corridor. In order to understand the effect of a reflective metal corridor on wireless LAN (WLAN) and Bluetooth wireless devices (both operating in the 2.4 GHz band), such a hallway was modeled and simulated. The transmitter was put at 2.85 m height with various receivers lined up across the whole corridor at a height of 1 m. The power for the WLAN transmitter was adjusted to 50 mW and operated with an external antenna. As the antennas were simple monopoles, for simplicity both the transmitter and receiver antennas were regarded as isotropic sources and receivers.

Figure 3 shows the variation of the electrical field strength across the entire hallway, on the receiving antenna, with increasing distance between the source and the victim. Figure 4 shows the electrical field strength grid of the hallway, representing the area where the chance of electromagnetic interference was highest.

Fig.2. Ship's Hallway (Figure adopted from [14])

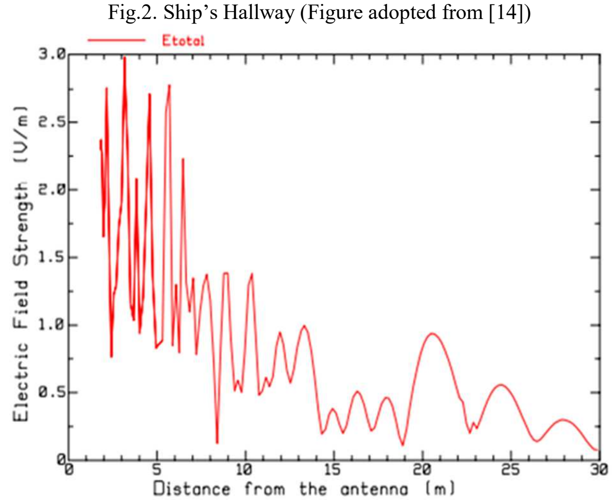


Fig. 3. Electrical field strength as a function of the distance to the antenna across the entire hallway (Figure adopted from [13]).

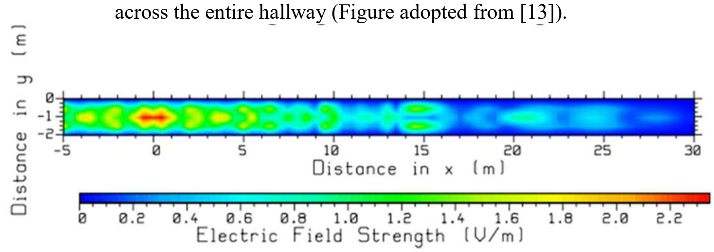
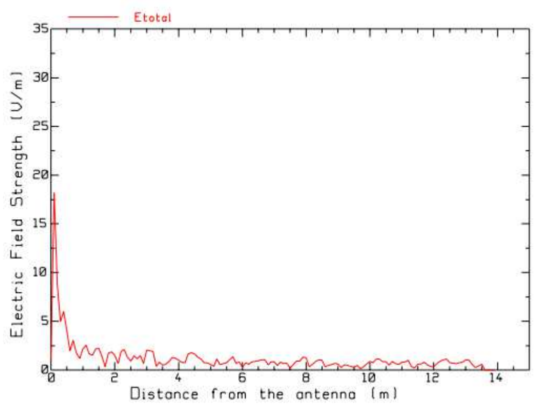


Fig. 4. Electrical field strength grid of the hallway (Figure adopted from[13]).

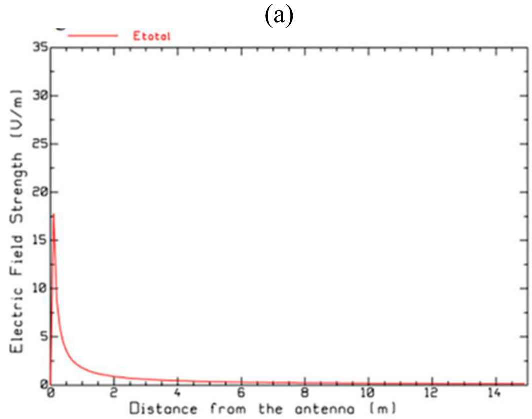
Although the hallway is nearly reflective, the effect of multiple reflections is observable.

B) Navy control room: An example of a highly reflective or reverberant environment in the indoor of a ship is a naval control room such as shown in Figure 5. A receiver was located in a straight line across the room. Figure 6a shows that the electric field strength as a function of the distance from a WLAN 35 mW antenna in a typical naval command and control room. It can be compared with the theoretical field strength in a free/open space propagation model (Figure 6b).

Fig. 5. A typical naval ship's command and control room (Figure adopted from [15])



(a)



(b)

Fig.6 (a) shows that the electric field strength as function of the distance from a WLAN 35 mW antenna in a typical naval command and control room, (b) the theoretical field strength in a free/open space propagation model (Figure adopted from [13])

Figure 7 shows the simulated field strength distribution for the command-and-control room of the ship, wherein the transmitter and receiver were placed at 2 m and 1.6 m heights with 50 mW of transmitted power. It is apparent that the metal walls and other structures inside the room lead to multiple reflections, resulting in both cold and hot spots inside the room. Due to these reverberant effects, the electric field strength in the indoor environment is generally higher than in the free/open space environment, which could create EMI issues. These effects are not included in the international standards which are the foundation of the rule-based approach.

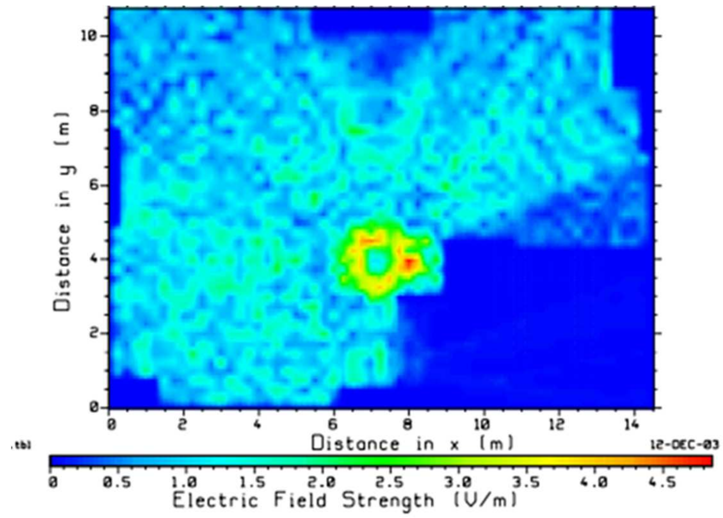


Fig.7. field strength grid for the command-and-control room of the ship (Figure adopted from [13])

Hence, a risk-based EMC approach is proposed to estimate the risk of interference caused by wireless devices inside the semi-reverberant indoor environment of ships.

III. Risk-Based EMC Approach

The rule-based EMC approach is based on the assumption that if a piece of equipment meets the criteria of a standard, no interference will occur [16]. According to the rule-based EMC approach, any marine electrical device; including bridge-mounted equipment, radio communication, and navigation equipment; must comply with either the IEC 60945 [17] or the IEC 60533 [18] standard. These fundamental standards describe emission and immunity testing and do not take into account every single feature and change in the given environment, such as aging, repairs, and so on. They also fail to accommodate technological advancement. In contrast, the risk-based EMC approach considers the operating electromagnetic field environment. Therefore, this technique has already been utilized by several companies in the marine industry, such as Lloyd's Register. Such a technique can lead to a cost-effective ship installation with a defined environment that can be developed by stating technical criteria and having the tests performed, verified, and validated. The four major steps [16] included in the risk-based EMC approach are:

1) EMC management plan
2) EMC control plan

3) EMC implementation plan
4) EMC verification and validation plan

The first step in the risk-based EMC approach is the EMC management plan, which identifies the EM environment of the ships as well as the inherent EM hazards. It also identifies and categorizes the sources and victims in the environment. The second step is the EMC control plan, wherein it provides the optimal solution for risk mitigation as well as documents them as a prerequisite during the implementation of any electrical devices on a ship. A Source-victim matrix tool or any other risk management tool can be used in an EMC control plan to categorize all the electrical devices present on a ship into high-risk or low-risk devices. Such a tool can also be used to understand the associated risks and threats further providing preventive measures for the abatement of the possible risks by mitigating the interference. The ASC cube [19] (Figure 8) is one such tool known as a multidimensional risk matrix that can be used to understand the EM environment and associated EMI risk. The ASC cube tool is composed of the following parameters: 1) *Accessibility*, 2) *Susceptibility,* and 3) *Consequence.* Accessibility relates "to the presence and suitability of points that can be used for delivering disturbances (injected or radiated)", such as doors or fences, accessible ports for injecting a transient, surveillance system, and proximity to public roads [20]. Consequence, on the other hand, is related to the adverse effect of dis-functioning electrical apparatus whose quantification can be done on the basis of its severity and is the consequences are instantaneous or delayed [20]. Susceptibility is basically the inability of the electrical devices/equipment/system to operate without deterioration in electromagnetic disturbance [21].

Using these parameters, a cube can be formed as shown in Figure 8. Systems close to the origin are considered to have good hardness (low-risk), whereas systems farthest from the origin have the least hardness (high-risk) against EMI. This cube tool also states that a system should be considered sensitive even if the consequence is less effective while the accessibility and susceptibility criteria are high. The method for finding the EMI risk could follow the outline given in the flowchart in Figure 9.

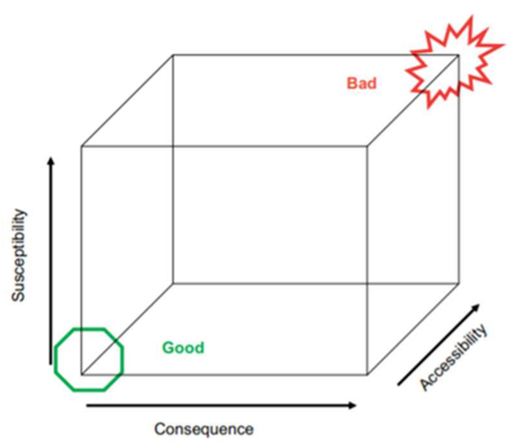


Fig.8. ASC cube (Figure adopted from [18])

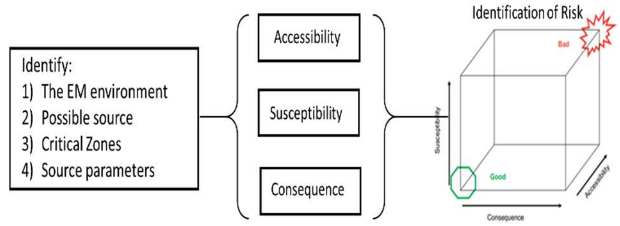


Fig.9. Flowchart to identify risk for the risk management process

After the identification of the risk using an ASC cube, an EMI risk control plan can be processed. Such a control plan can be executed in the third step and hence named as the EMC implementation plan. Various methods, such as using filters, shielding, etc., are used to control the risk of EMI. The last step is the EMC verification and validation plan, wherein a ship's environmental system is validated for EMC using various measuring techniques in which voltages and currents, as well as field strengths, frequency ranges, measurement distances, and so on, are involved. Verification tests are carried out during the construction phase, whilst validation testing is carried out during the harbor acceptance and sea acceptance trials. Thus, the risk-based EMC plan assists in evaluating the environment and the impact of wireless electrical devices that potentially could cause EMI.

IV. Conclusion

Due to the cost and weight-related benefits, the implementation of wireless devices on ships is increasing. However, the inclusion of wireless devices on ships tends to create EMI-related issues. This work defines the different ship environments and categories into outdoor and indoor. Issues related to EMI depend on the environment where electrical systems are kept in. On a ship, the outdoor environment behaves as a free/open space environment, whereas the indoor environment can be qualified as a semi-reverberant environment. We discussed the impact of EMI on the ship's indoor environment. We initially overview the ship's indoor environment using two examples wherein we observed that the field strength varies because of multiple reflections. This can lead to EMI issues in the ship environment as the resulting higher field strengths have not been included in conventional international standards. A risk-based EMC approach was utilized to evaluate the risk of EMI issues on a ship. This paper discussed the disadvantages of the traditional rule-based approach, which relies on device standards and describes the risk-based approach, which is a more efficient approach to mitigating the chances of EMI. To understand the EM environment and also to notice the sources and victims, an ASC cube has been discussed. In the future, complete risk-based EMC approach steps are required to mitigate these EMI issues created by the wireless devices in a ship's semi-enclosed reverberant environment.

V. ACKNOWLEDGMENT

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