Appling TRIZ Theory in Ship Overall EMC Design

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Abstract. Same frequency interference between electronic equipment still cannot be wiped out, which leads electromagnetic compatibility (EMC) system engineers to the one and only way by making an EMC rule to manage and control all the equipment onboard. However, while the sensors are following the EMC rule in battle, the weapons’ maximal combat capability is usually not able to be attained. Therefore, EMC management and control widely used in today’s ship engineering design is actually a compromise. This paper presents an unconventional design method combining the TRIZ methodology into traditional EMC design methods. The proposed method used TRIZ tools such as function analysis, causal analysis, ideal solution analysis and resources analysis to make deep analysis of the same frequency interference problem on ship. The final solution is obtained through contradiction resolution theory, Su-Field analysis and 76 standard solutions in this paper. At the end, a few enlightening ideas are harvested for the engineering innovative design problem.

1. Background
The mission of ship overall electromagnetic compatibility (EMC) system is to ensure that equipment can work well compatibly on board under the ship electromagnetic environment (EME), which is the combined results of both wanted signals and unwanted emissions, containing a wide range of waveforms with differing characteristics of frequency, time, amplitude and energy that can disturb the normal functioning of a ship platform and its associated systems. Major electromagnetic interference (EMI) problems and considerable additional costs are likely to arise if EMC requirements and ideas are not taken into account at all stages of projects for the design and development of equipment and systems. It is therefore essential and important to implement suitable EMC designs and measures from the beginning and during ship’s whole life cycle.

Experience has shown that the ideal EMC status is unrealistic for a ship, especially for those with a big mass of antennas. In practical engineering, ship overall EMC always compromises with other performances of the ship. In order to achieve good EMC status for a ship, that is workable condition of a set of systems and equipment on board simultaneously when their components do not generate degradation in performance, overall EMC design must be carried out by a series of measures and technological process [1–2], including antenna arrangement and optimization, shielding, filtering, ground connection, cable classification and optimized distribution, etc., which are all simple, economical and well-effective. Besides, EMC management and control is a significant step in ship overall EMC system, which is designed based on the optimization of the whole ship EMC status, for example, antenna arrangement is totally confirmed, but causing operational effectiveness loss to the confined equipment in frequency, time, space and energy domain, that directly impact on the general combat performance of the whole ship.
2. Problem Description
Electromagnetic degradation of ship platform systems and weapon systems is a complex and often misunderstood area of ship overall EMC design. Electro technical systems and equipment are commonly selected on their individual merit with little or no thought of the problems of integration into the complex electromagnetic environment of a modern ship platform. With the rapidly growth of electrical and electronic equipment and systems on platforms, the number of EMI sources has increased rapidly. In ship overall EMC management and control strategy, many equipment are specifically fitted to generate electromagnetic radiation or receive electromagnetic signals under controlled and limited conditions because transmitters produce unintended and unwanted emissions that are harmful to susceptive receivers. The majority of EMI problems encountered on ships are self-generated mutual interference with both the source and victim working on the same frequency, which is also the most difficult to deal with for the reason that EMI is usually exaggerated when the equipment are operating at the same time and on the same frequency.

When the same frequency interference problem on ship cannot be settled by means of conventional EMI control methods, such as, overall antenna optimized arrangement, construction technological process, and so on, they can only turn to EMC management and control for help, in which way the combat equipment are forced to lower their combat capabilities, due to the restrictions on their operational frequency, time, space and energy. As almost every design engineer encounters, system incompatibility and design conflict are the two most common problems, which seems more prominent in ship overall EMC design.

Under the situation, this paper introduces a method named TRIZ (Theory of inventive problem solving, in Russian), which has been widely used in mechanical engineering but rarely in EMC design. The TRIZ method was developed in the former Soviet Union by Altshuller, who had analysed over 400,000 patents in designing 40 inventive principles and developed a contradiction matrix to improve innovative design method [3]. In the innovative design problem solving process, the TRIZ method [3–7] is a tool for the designer to handle these design contradictions just as what we are facing.

The ultimate goal is a well-designed ship with good electromagnetic compatibility, which can get rid of EMC manage and control measures, or at least making them invisible, that is the EMC manage and control measures will not bring evident loss to the whole combat ability of a warship. In this paper, we are attempting to incorporate the TRIZ method into our traditionally overall EMC design, in order to get some new ideals and constructive enlightenment.

3. Problem Analysis
3.1. Function Analysis
The function model for a ship overall electromagnetic compatibility (EMC) system is illustrated in figure 1, which shows clearly the output product of ship overall EMC system is a function that can be described as ensuring equipment working well compatibly on board under the condition of all possible EMI. The components of ship overall EMC system are electrical and electronic equipment, including those with transmitters and receivers and EMC management and control equipment, which are unnecessary to decompose further since every equipment onboard should meet its own self-EMC requirement. Supra-system contains ship surface environment, people on board, and ocean environment, which also affect with components of ship overall EMC system like they do to each other. F_{EM} is the most typical effect in EMC system, we call harmful F_{EM} EMI which is denoted by wavy arrow line; another effect is electrical signal control F_{E}, imaginary lines mean not effective.
3.2. Causal Analysis

Figure 2 shows root cause analysis searching for root causes, if the root cause is controllable then it can be the right direction to solution. In the first causal link path, all three root causes are uncontrollable, so this causal link path is out of the discussion of this paper.

Analysis of the second causal link path is based on the interference equation as follow:

$$\frac{I}{N} = P_t + G_t - L_p + G_r - R_s - \phi(\beta) - \phi(\Delta f')$$

where the only factor that can be controlled is transmission path loss $L_p$, which is expressed as:

$$L_p = 20 \log d + 20 \log f' - 26.8 + k$$

Therefore, short distance between two antennas $d$ is determined as a root cause in the second causal link path, while the other is low isolation degree between same frequency antennas. As indicated in figure 2, these two root causes are both controllable, but the first one is not in the range of this paper since antenna arrangement is already established, which only left the second root cause to be a investigation direction.

For the third causal link path, although only three uncontrollable root causes are obtained, but analysis process guides us a way, which is, in order to minimize the operational effectiveness loss, working principle and style involving electromagnetic wave emission and reception of related
equipments must be intensively studied during the process of working out the EMC management and control strategy.

**Figure 2.** Root cause analysis figure of electromagnetic interference (EMI) between same frequency antennas on ship.

### 3.3. Contradiction Zone Determination

According to root cause analysis result, this paper determines its research scope on the following two contradiction zones:

- How to increase the isolation degree of same frequency antennas whose location is fixed on a ship.

The model figure of this problem is shown in figure 3, where the problem areas are coupling paths between antenna.

a) Key point 1: the distance between same frequency antennas is short due to limited space resource on ship.
b) Key point 2: same frequency antennas can look straight to each other without obstacles on transmitting path.
   - How to design and optimize EMC management and control strategy for each same frequency interference pairs.
   
a) Key point 3: space resource contradiction.
   b) Key point 4: frequency resource contradiction.
   c) Key point 5: time resource contradiction.

3.4. Ideal Solution Analysis
Ideal solution can be divided into two types as final ideal solution and ideal solution. As the final ideal solution is usually hard to achieve, we need to define ideal solution to indicate direction following these steps:
1) What is the final goal? All electrical and electronic equipments on ship realize EMC.
2) What is the ideal solution? Causing no operational effectiveness loss.
3) What is the obstacle to achieve ideal solution? There exits EMI on ship between same frequency antennas.
4) What is the results when this obstacle occurs? Equipments are forced to lower their combat capabilities due to EMC management and control.
5) What is the condition of avoiding this obstacle? No EMI between same frequency antennas, or EMC management causing no operational effectiveness loss.
6) What are the available resources of creating this condition? Electromagnetic characteristic, working principle and style of related equipments are different from each other, in other words, equipments themselves are available resources. More detailed available resources are listed follow on.

3.5. Available Resources Analysis
System internal resources contains matter resource, field resource, space resource, time resource, function resource, frequency resource, information resource, which are all belong to direct application resources, while function resource and information resource are belong to differential resources at the same time. Information resource can be equipments’ electromagnetic characteristic including pulse (pulse width, pulse repetition frequency, pulse compression ratio, etc.), frequency agility, frequency hopping, and so on, which are also export resources for ship overall EMC system. System external resources contains matter resource (e.g., air, metal, composite material), field resource, etc.

4. Problem Solving

4.1. Contradiction Resolution Theory
When using the TRIZ method in innovative design problem solving, the designer needs to first find the corresponding contradictions for the problem at hand, as we have done in section III.C. Next, the designer matches the meaning of each contradiction with two appropriate parameters from 39 engineering parameters that have been defined in the TRIZ contradiction matrix [3–7], that is what we will do in the following part. Using this contradiction matrix, the designer then can locate 3–4 suitable principles for solving that particular engineering innovative design problem.

4.1.1. Describe key point.
   a) Key point 1: Ship EMC sacrifices for the good of ship overall performance, which results in the fact that the distance between same frequency antennas can not be increased.
   b) Key points 2: The reason why there is no obstacle on EM wave transmitting path is because the obstacle is usually metal, which would bring negative influence to ship’s Radar Cross-Section (RCS), aesthetic property, and practicabilities.
   c) Key point 3: If space resource contradiction happens, look angle of certain antenna is limited, whose detecting and tracking range would shrink, leading to space operational effectiveness loss.
   d) Key point 4: If frequency resource contradiction happens, filters must be added to susceptive receiver, which would narrow down the detecting frequency range of the receiver, leading to frequency operational effectiveness loss.
   e) Key point 5: If time resource contradiction happens, certain receiver must shut down to avoid the same frequency signal on board, whose detecting time would reduce, leading to time operational effectiveness loss.

4.1.2. Turn key point contradiction into TRIZ standard contradiction pair [3–6] as listed in table 1.

4.1.3. Find inventive principle in the contradiction matrix for each contradiction pair as listed in table 1.

4.1.4. Get the solution to problem on the basis of applicable inventive principle.
a) Scheme 1: According to Principle 35. Parameter Changes, ship overall EMC system can require equipments to make appropriate changes on their working style or electromagnetic property, in order to adapt to ship’s particularity.

b) Scheme 2: According to Principle 31. Porous Materials, wave-absorbing material or EM composite material can be put into use.

c) Scheme 3: Combining Principle 22. “Blessing in Disguise” with Principle 10. Preliminary Action guided us to the way of how to making refined EMC management and control strategy, using harmful factors to achieve positive effects, which is management combination of time management, space management, frequency management, etc.

Table 1. Contradiction Pair and Inventive Principle Table

| No. | Improving Feature          | Worsening Feature       | Inventive principle                |
|-----|----------------------------|-------------------------|-----------------------------------|
| 1   | Length of stationary object| Reliability             | No.15 Dynamics                    |
|     |                            |                         | No.28 Mechanics Substitution      |
|     |                            |                         | No.29 Pneumatics and Hydraulics    |
| 2   | Length of stationary object| Object-affected harmful factors | No.1 Segmentation                 |
|     |                            |                         | No.18 Mechanical Vibration        |
| 3   | Length of stationary object| Adaptability or versatility | No.1 Segmentation                 |
|     |                            |                         | No.35 Parameter Changes           |
| 4   | Object-affected harmful factors | Adaptability or versatility | No.11 Beforehand Cushioning      |
|     |                            |                         | No.22 “Blessing in Disguise”      |
| 5   | Object-affected harmful factors | Loss of information     | No.10 Preliminary Action          |
|     |                            |                         | No.11 Beforehand Cushioning      |
| 6   | Reliability                | Loss of information     | No.10 Preliminary Action          |
| 7   | Reliability                | Loss of time            | No.30 Flexible Shells and Thin Films |
|     |                            |                         | No.4 Asymmetry                    |

4.2. Su-Field Analysis and 76 Standard Solution

4.2.1. Build Su-Field model as shown in figure 4.

![Su-Field model figure of electromagnetic interference (EMI) between same frequency antennas.](image-url)
4.2.2. Apply resolution process of Standard Solution [3–6] to determine the general solution.

- Because same frequency interference FEM in figure 4 belongs to totally harmful function, follow Standard Solution 1.2.1 (NO.9) in 1.2 Class, introduce S3 to eliminate harmful function, as shown in figure 5.
- Another Standard Solution 1.2.2 (NO.10) in 1.2 Class it to change S1 or S2 to eliminate harmful function.
- For insufficiency of function FE, in figure 4, Standard Solution 2.2.2 (NO.17) can be chosen, which tells major trends of the evolution, enlightening us to increasing the degree of fragmentation of time, space, and frequency for the propose of operational effectiveness loss reduction.

4.2.3. Get the solution to problem on the basis of obtained Standard Solution.
- Scheme 1: According to No.9 Standard Solution, as shown in figure 5, the solution is to introduce new substance (S3) on the path where unwanted EM waves transmit.
- Scheme 2: According to No.10 Standard Solution, the solution is to design constraints for S1 and S2 in ship EMC system, by modifying the parameters of whose working system or antenna’s electromagnetic properties.
- Scheme 3: According to No.17 And No.42 Standard Solution, the solution is to subdivide the time, space and frequency resources, for the purpose of a delicacy EMC management rules.

5. Final Solution
Summarizing the above schemes solved with different inventive principles of TRIZ tools, we identify the final solution as listed in Table 2.

**Table 2.** Final Solution and Usability Evaluation Table

| No. | Scheme                                           | Used inventive principles                                                                 | Usability evaluation                                                                 |
|-----|--------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 1   | Demand equipment to modify parameter             | Principle 35 (Parameter Changes) in contradiction matrix; Principle 10 (change S1 or S2 to eliminate harmful function) in 76 Standard Solution. | Ship overall EMC design system has certain ability to restrain equipments onboard, which requires a lot of coordination and communication. |
| 2   | Add wave-absorbing material between antennas     | Principle 31 (Porous Materials) in contradiction matrix; Principle 9 (introduce S3 to eliminate harmful function) in 76 Standard Solution. | This solution can reduce energy transfer between antenna with the same working frequency, which has no influences on ship’s stealth and aesthetic. But the effect depends heavily on the electromagnetic property of used composite EM materials or coatings. |
| 3   | Combine several kinds of EMC managing means and pick the optional | Principle 22 (Blessing in Disguise) and Principle 10 (Preliminary Action) in contradiction matrix. | Based on in-depth study into operating principle and working manner of relevant electric equipments and combined with operational flow of a warship, customized EMC managing and controlling stratage can be worked out for each EMI pair, by applying TRIZ methodology, which aims at different EMI pairs and makes use of work characteristics and operating feature of both the interference source and the victim. |
| 4   | Subdivide the time, space and frequency resources for delicacy manage | Principle 17 (turn S2 from macroscopic to microscopic) and Principle 42 (system transform(d): to microscopic level) in 76 Standard Solution. |                                                                                       |

6. Conclusion

Based on the TRIZ theory, this paper developed a complete set of ship EMC design method for a specific problem known as the same frequency interference on ship. The frameworks of this method are illustrated that integrate with selected TRIZ tools and corresponding inventive principles. This new method provides the designer with a supporting tool to develop new design inspiration with less limitation. More concrete EMC engineering problems are to be solved by further research of the method discussed in the paper.

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