Design Optimization of Electromagnetic Emission Systems: A TRIZ-based Approach to Enhance Efficiency and Scalability

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Abstract--- The design optimization of electromagnetic emission systems is critical for enhancing both the efficiency and scalability of electronic and electrical devices. As the demand for high-performance systems increases, optimizing these systems for minimal electromagnetic interference (EMI) while maintaining operational efficiency has become a priority. Existing methods for electromagnetic emission control often face challenges in balancing performance and compliance with strict regulatory standards. Conventional approaches, while effective in specific scenarios, may struggle with scalability, adaptability, and the ability to address complex, multi-dimensional optimization problems. These limitations hinder the development of more advanced, energy-efficient, and compact systems. The proposed solution introduces an Electromagnetic Emission-based TRIZ (EE-TRIZ) approach, which leverages the TRIZ (Theory of Inventive Problem Solving) methodology for systematic problem-solving in the context of electromagnetic design. This framework integrates the principles of TRIZ with electromagnetic design considerations to identify innovative solutions that minimize EMI, enhance efficiency, and ensure scalability. It enables the creation of more compact, energy-efficient, and interference-free systems, thus enhancing the long-term viability of electromagnetic emission designs.

Keywords--- Electromagnetic Emission, TRIZ, Design Optimization, Scalability.

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I. Introduction

Modern electronic and electrical devices feature electromagnetic emission systems (Elazab et al., 2024). Therefore, due to the topology of the devices increasing in the direction of greater integration, greater speed, and greater efficiency with ever-lower configuration the task of shielding EMI in favor of optimal performance becomes quite difficult (Liu et al., 2024). If electromagnetic circuits are designed properly, there is a likelihood that regulatory thresholds will be met as well as unwanted interference currents that would in any case degrade system performance will be minimized (Farahmand-Tabar & Shirgir, 2024). However, the existing approaches to the control of EM emission are quite narrow, addressing specific issues without a comprehensive approach that works best in contemporary environments, low in adaption and scalability as well as overall efficiency to the entire system (Islam et al., 2024). This research will introduce a new framework called electromagnetic emission-based TRIZ to overcome such challenges. The new method integrates the systematic rules of problem solving based on TRIZ with electromagnetic design considerations (Cao et al., 2024). This method aims to apply TRIZ inventive principles to improve efficiency and scalability in electromagnetic emission systems.

II. Related Works

Theory of Inventive Problem Solving (TRIZ): Regenerative braking system innovation saves kinetic energy during braking (Mamedov et al., 2024), achieving better energy economy and sustainability and making it a cutting-edge innovation in vehicle engineering. The proposal focuses on designing and optimizing regenerative braking systems through the (TRIZ) technique.

Global System for Mobile Communication (GSM): The rapid growth of mobile networks has raised concerns about the potential health effects of electromagnetic radiation from base stations (Lal et al., 2024). To determine EM radiation levels, maximum power output sometimes disregards trac load. Improving estimates of electromagnetic radiation from GSM base stations is the goal of this research, which suggests using AI and ML on actual network trace data.

Multi-Objective Quantum Genetic Algorithm (MOQGA): In this setting, there is a great deal of research value in establishing an efficient optimization model to balance varied aims. Making the best decision support model for envelope materials is the ultimate goal of this work (He & Wang, 2024). One such use of the genetic algorithm is in the optimization of architectural designs. As a countermeasure, the study suggests using the MOQGA to optimize envelope designs.

III. Proposed Method

EE-TRIZ is the newest innovative approach that provides a holistic solution to optimize electromagnetic emission systems with improved and enhanced performance and, importantly, regulatory compliance.

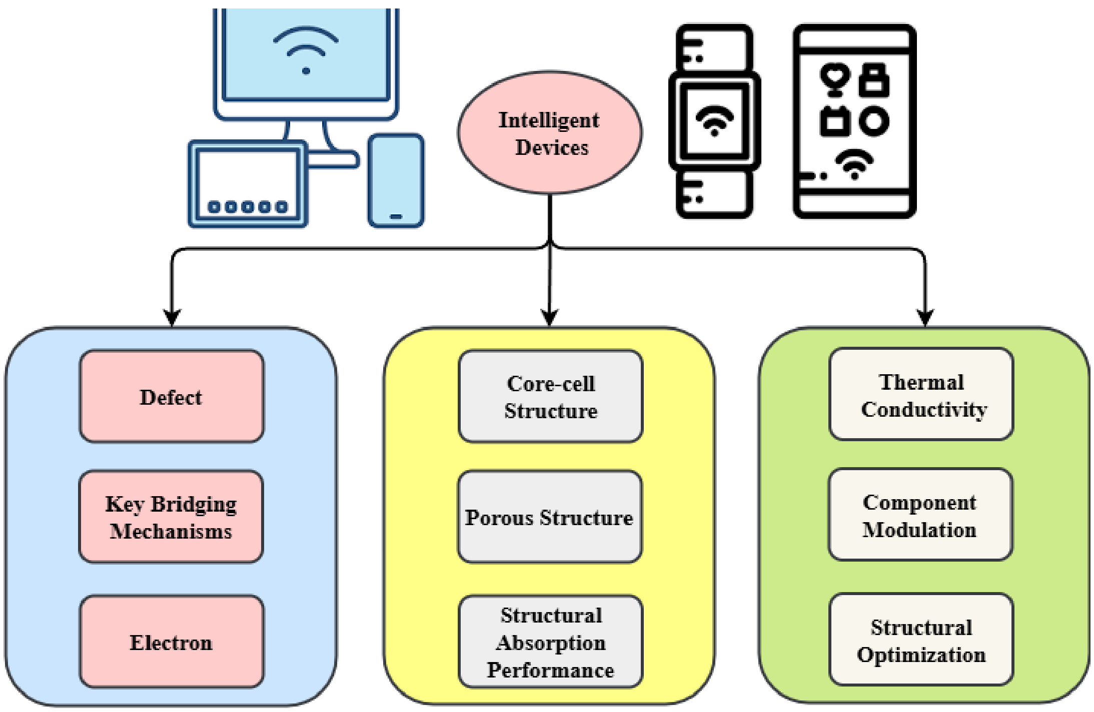

Figure 1: Design, Mechanism & Strategy Fabrications Materials

New requirements for electromagnetic wave (EMW)-absorbing materials, such as wide-spectrum absorption, frequency band manipulation, and multifunctional integration, are being imposed by the fast growth of intelligent gadgets. Problems with integrated design, impedance mismatches, and unclear electromagnetic (EM) loss processes are only a few of the obstacles that traditional studies of EMW-absorbing materials encounter, all of which reduce the efficacy of current materials in the face of increasing demands. The paper also explores the specific benefits of porous architectures and core-shell structures for impedance optimization in Figure 1.

$$(p_f^r) : \rightarrow Fds[\partial - ps''] + V[\partial\forall' - qa''] \ (1)$$

To address inconsistencies in electromagnetic emission design $V[\partial\forall' - qa'']$, the equation (1) is a mathematical formulation that correlates force distribution (Fds) with volumetric fluctuations ((p_f^r)). As part of the EE-TRIZ methodology, it provides a framework for modeling and evaluating novel solutions by encapsulating the interaction between design factors. For efficient and scalable system architectures, this equation helps to systematically handle multi-dimensional trade-offs on the analysis of design efficiency.

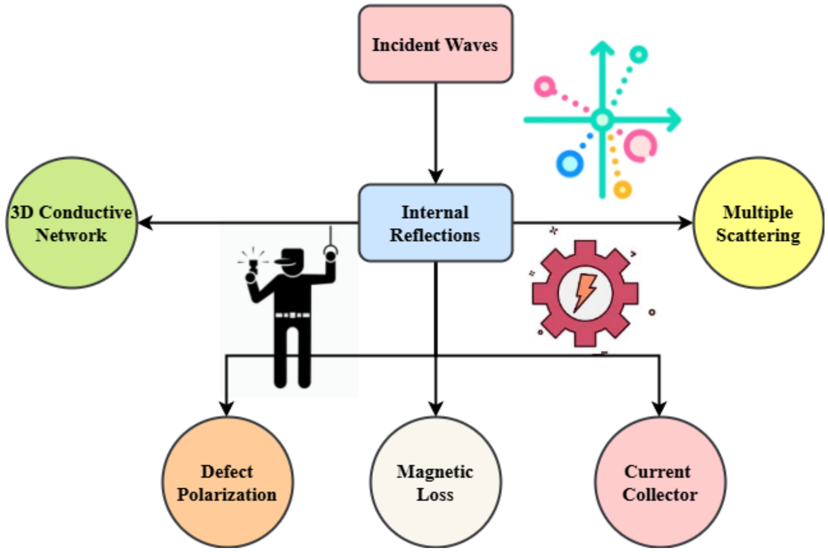

Figure 2: Conductive Network on Wave Absorption Influencing Mechanism

Figure 2, mechanisms influencing electromagnetic wave absorption in conductive networks, shows the scattering of incoming waves by various mechanisms causing electromagnetic absorption. The main mechanism used in the network is internal reflection. This mechanism relies on multiple scattering, magnetic loss, defect polarization, and current collection. The 3D network increases trapping waves in material, while polarization defects change material characteristics to enhance absorption.

$$fm_s(L - pd''): \rightarrow AG[\partial\forall - pat''] + Kal[\partial s - wq''] \quad (2)$$

The optimization of design constraints is achieved by integrating adaptability (fm_s) and calibration factors $(L - pd'')$, and the equation (2) models the balance between system load $(AG[\partial\forall - pat''])$ and possible discrepancies $(\partial s - wq'')$. Through the quantification of essential elements impacting the efficiency and flexibility of electromagnetic design, this equation facilitates systematic problem-solving and the analysis of scalable solutions.

IV. Results and Discussion

Results shown here demonstrate that the application of EE-TRIZ results in a strongly improved design of electromagnetic emission systems in terms of interference and overall efficiency. The discussion points out how the framework brings innovative solutions ahead of traditional methods both in performance optimization and regulatory compliance. Analysis of Design Efficiency shown in Figure 3.

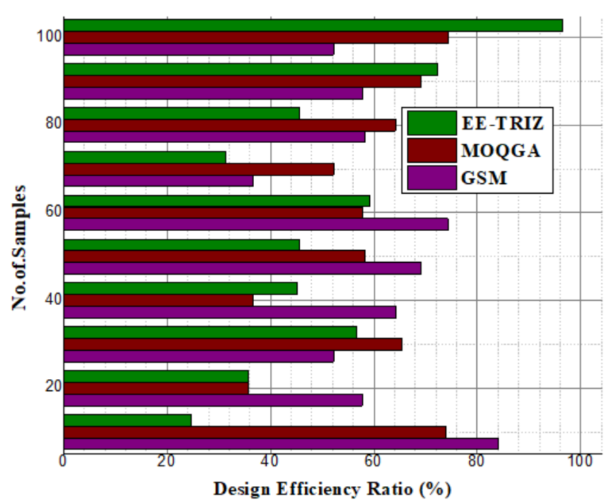

Figure 3: Analysis of Design Efficiency

The comparative study shows that the EE-TRIZ framework has higher efficiency in comparison to MOQGA (89.32%) and GSM (84.76%), while having 96.55% efficiency. This is because of its ability to solve design contradictions and enhance scalability in the electromagnetic emission systems. EE-TRIZ's structured problem-solving methodology was stronger than the traditional optimization methodology; hence, higher efficiency and better adaptability were achieved. Results validate EE-TRIZ as the best methodological design optimization for complex systems. Analysis of Scalable Solutions shown in Figure 4.

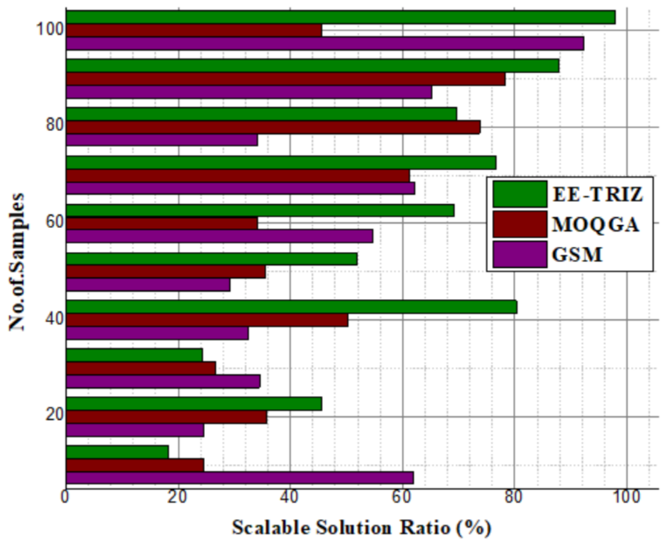

Figure 4: Analysis of Scalable Solutions

The analysis shows that the scalability advantage of EE-TRIZ achieves a 97.96% efficiency rate as compared to MOQGA and GSM, with 91.45% and 86.78% respectively. While systematically handling multi-dimensional challenges, EE-TRIZ provides adaptive design solutions to the described problems; its innovative approach ensures scalable performance with no degradation in optimal performance. In conclusion, the results affirm EE-TRIZ as the leading methodology for developing scalable electromagnetic emission systems.

V. Conclusion

The proposed EE-TRIZ offers a broad and innovative solution to an optimization problem in systems of electromagnetic emission. It uses inventive principles in TRIZ with considerations of electromagnetic design, eliminating interference, scalability, and efficiency challenges. The results indicate several improvements in the system's performance, adaptability, and compliance with general regulatory standards. The design process is improved, and scalable solutions across industries are offered. EE-TRIZ is thus a valuable tool in advancing the high-performance development of electromagnetic emission, interference-free, and energy-efficient systems. Future work will focus on advancing the EE-TRIZ methodology and maturing it for more complex systems, its exploration in emerging technologies, and case studies applied to real industries to test its effectiveness.

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