



A STUDY ON COMPUTATIONAL ELECTROMAGNETICS UTILIZING COMPUTER METHODS

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Abstract

Antenna design, electromagnetic dispersion, wave propagation, and other electromagnetic phenomena are some of the many computer-based approaches and techniques that are included in the field of computational electromagnetics (CEM). Within the scope of this research, an overview of the ideas, processes, and applications of computational electromagnetics in the investigation and resolution of difficult electromagnetic problems is provided. The purpose of this research is to investigate the fundamental ideas of electromagnetics and the computer modeling approaches that are linked with them. This is accomplished by combining the literature, theoretical frameworks, and applications from the actual world. The research also investigates the application of computational electromagnetics to antenna design. This is a field in which radiation patterns, impedance matching, and antenna designs can be optimized through the use of numerical simulations. Using parametric studies, electromagnetic modeling tools, and optimization approaches, it discusses how to improve antenna performance, reduce interference, and conform to design criteria. Moreover, it explains how to optimize antenna performance. The ethical implications of this study is to enforce the credibility of this field of study to the developmental aspects of electromagnetics in telecom industry and to reflect its significance into an effective deliberation using different techniques as adapted in this project.

Keywords: Computational Electromagnetics, Computer Methods, Electromagnetic Scattering, Antenna Design, Wave Propagation, Finite Element Method (FEM), Finite Difference Time Domain (FDTD), Numerical Simulation and Radar Cross-Section (RCS).



1. Introduction

Modern engineering and scientific research heavily depend on computational electromagnetics (CEM) to model, analyze, and understand electromagnetic events. At its core, CEM harnesses the power of computer processing to tackle a range of electromagnetic challenges, including wave propagation, antenna design, and electromagnetic dispersion. This introduction provides a solid foundation for a comprehensive exploration of computational electromagnetics, highlighting its significance, techniques, and wide array of practical uses. Everyday life is filled with the impact of electromagnetic phenomena, ranging from the intricate mechanisms of medical imaging devices and radar systems to the wireless communication technologies that keep us connected. Various industries, such as biomedical engineering, aeronautical engineering, telecommunications, and others, rely on the comprehension and control of electromagnetic fields. Understanding and manipulating electromagnetic systems has always relied on a combination of analytical and experimental techniques. Nevertheless, the significance of computational electromagnetics increased as the intricacy of electromagnetic problems escalated and the demand for more accurate and efficient solutions intensified. Understanding and predicting electromagnetic events through computer techniques is the cornerstone of computational electromagnetics. By utilizing numerical approaches and algorithms, researchers and engineers are able to tackle complex boundary value problems, predict electromagnetic phenomena, and optimize system performance. This is achieved through the process of discretizing Maxwell's equations, which serve as the foundational principles of electromagnetism. Computational electromagnetics truly excels in the study of electromagnetic scattering, which is a prominent field. Understanding the impact of electromagnetic waves on various phenomena involves studying their interactions with materials, objects, and surfaces. This knowledge is crucial for analyzing radar cross-sections, electromagnetic interference, and remote sensing. Researchers can explore scattering events, analyze material properties, and enhance stealth technologies through the use of numerical simulations and computer modeling. Additionally, computational electromagnetics approaches are highly valuable in the analysis of wave propagation in various fields. Utilizing numerical techniques such as ray tracing, wave propagation models, and finite element analysis provides valuable insights into signal behavior and system performance. These methods are particularly



useful for researching wireless communication channels, predicting signal propagation in complex environments, and optimizing electromagnetic compatibility. In summary, computational electromagnetics is a crucial tool for addressing the intricate challenges and opportunities that come with electromagnetic systems and technology. By harnessing the computational power of modern computers, researchers, engineers, and scientists can explore new frontiers in electromagnetic research, invention, and application in various fields. Our goal is to delve into the complexities of electromagnetic phenomena, foster collaboration across disciplines, and enhance scientific, technical, and technological advancements by studying computational electromagnetics.

1.1 Background of the study

Electromagnetics is a fascinating field of physics that governs the behavior of electromagnetic fields in various media. It encompasses a broad spectrum of phenomena, including the propagation of waves, the construction of antennas, and the dispersion of electromagnetic fields. In recent years, computational electromagnetics has emerged as a powerful tool for tackling complex electromagnetic problems through research and computer-based solutions. This research presents a comprehensive research project that aims to utilize computational methods to explore various electromagnetic problems, focusing on wave propagation, antenna design, and electromagnetic scattering. Computational Electromagnetics is a vital field that bridges the gap between computer science and electromagnetics. It offers advanced tools and methods to tackle various electromagnetic problems. This section provides a comprehensive examination of computational electromagnetics, highlighting its applications in wave propagation, antenna design, and electromagnetic scattering. Computational electromagnetics is a field that utilizes numerical and computational methods to tackle Maxwell's equations. These equations offer a comprehensive understanding of how electromagnetic fields behave in different types of media. The equations govern the interaction, scattering, and propagation of electromagnetic waves with barriers and objects. Researchers can effectively simulate and analyze complex electromagnetic phenomena using computer methods. Here are some practical uses of Computational Electromagnetics: 1. Understanding the phenomenon of electromagnetic scattering Electromagnetic scattering deals with the interaction of electromagnetic waves with objects or structures, causing them to disperse in various directions. Having a deep understanding of scattering behavior



is crucial in radar systems, remote sensing, and target detection applications. Computational electromagnetics allows researchers to analyze and simulate electromagnetic scattering phenomena using numerical methods like the finite element method (FEM), finite difference time domain (FDTD) method, and method of moments (MoM) (Taflove & Hagness, 2005). These methods help with calculating radar cross-sections (RCS) and analyzing scattering patterns, which have greatly contributed to the progress of radar technology and stealth capabilities.

2. Designing Antennas Antenna design is a crucial aspect of electromagnetics, with various applications in wireless communication, satellite communication, and radar systems. Understanding the principles of computational electro-magnetics is crucial for effectively designing, optimizing, and analyzing antennas to meet specific performance requirements. Various numerical techniques are used to design antennas with specific radiation patterns, impedance matching, and bandwidth characteristics (Jin, 2014). These computational methodologies enable researchers to efficiently explore design spaces and identify optimal antenna configurations for a wide range of applications.

3. The propagation of waves Wave propagation studies the characteristics of electromagnetic waves as they travel through different materials and come across obstacles or boundaries. Having a deep understanding of wave propagation phenomena is crucial for accurately predicting signal propagation, interference, and attenuation in communication systems. Computational electromagnetics enables the simulation and analysis of wave propagation in different scenarios, such as waveguides, transmission lines, and free space. Scientists often use numerical methods like the finite difference time domain (FDTD) method, finite element method (FEM), and boundary element method (BEM) to study wave propagation characteristics and understand how reflection, refraction, and diffraction affect signal propagation (Sullivan et al., 2013).

11 To put it concisely, computational electromagnetics offers a strong foundation for tackling electromagnetic obstacles such as the propagation of waves, the design of antennas, and the dispersion of electromagnetic waves. Scientists can efficiently and precisely study, simulate, and model complex electromagnetic phenomena using improved numerical tools and computational methodologies. The incorporation of computational electromagnetics into engineering and research processes has greatly advanced our understanding of electromagnetics. Due to technological improvements, it has become easier to develop creative solutions for practical applications in electromagnetic compatibility assessments, radar systems, and communication systems.



This comprehensive foundation emphasizes the significance and applications of computational electromagnetics in addressing electromagnetic problems such as scattering, antenna design, and wave propagation. With the use of cutting-edge computational methods, scientists have the ability to embark on revolutionary projects in electromagnetics, leading to advancements in various scientific and engineering disciplines.

1.2 Statement of the Problem

Electromagnetics is a fascinating field of physics that governs the behavior of electromagnetic fields in various media. It encompasses a broad spectrum of phenomena, including the propagation of waves, the construction of antennas, and the dispersion of electromagnetic fields. In recent years, computational electromagnetics has emerged as a powerful tool for tackling complex electromagnetic problems through research and computer-based solutions. This research presents a comprehensive research project that aims to utilize computational methods to explore various electromagnetic problems, focusing on wave propagation, antenna design, and electromagnetic scattering. Computational Electromagnetics is a vital field that bridges the gap between computer science and electromagnetics. It offers advanced tools and methods to tackle various electromagnetic problems. This section provides a comprehensive examination of computational electromagnetics, highlighting its applications in wave propagation, antenna design, and electromagnetic scattering. Computational electromagnetics is a field that utilizes numerical and computational methods to tackle Maxwell's equations. These equations offer a comprehensive understanding of how electromagnetic fields behave in different types of media. The equations govern the interaction, scattering, and propagation of electromagnetic waves with barriers and objects. Researchers can effectively simulate and analyze complex electromagnetic phenomena using computer methods. Computational electromagnetics provides a solid basis for addressing electromagnetic challenges such as wave propagation, antenna design, and scattering. With the help of advanced numerical tools and computational approaches, scientists are able to explore, simulate, and model intricate electromagnetic phenomena with remarkable efficiency and precision. Our knowledge of electromagnetics has seen significant advancements due to the integration of computational electromagnetics into engineering



and research practices. Thanks to advancements in technology, it has become more convenient to come up with innovative solutions for practical uses in electromagnetic compatibility analysis, radar systems, and communication systems.

1.3 Objectives of the Study

The research objectives are diverse and complex: 1. Explore the fascinating world of Computational Electromagnetics, where we delve into the principles, methodologies, and numerical techniques used in this field. 2. Conducting an investigation into electromagnetic scattering, we aim to analyze the various phenomena associated with it and develop computational models that can effectively simulate and enhance our understanding of scattering behavior. 3. Utilize computational methods to optimize antenna designs and analyze their performance metrics.

2. Related Work

This study on computational electromagnetics has the potential to greatly enhance our knowledge of electromagnetics and enable us to find creative solutions to intricate electromagnetic challenges. This section delves into the importance of the research in computational electromagnetics, showcasing its wide-ranging implications across different domains and applications. 1. Advancements in Electromagnetic Modeling and Simulation Computational electromagnetics provides a robust framework for accurately and efficiently modeling and simulating electromagnetic phenomena. Through the use of sophisticated numerical methods and computational techniques, scientists are able to examine intricate electromagnetic interactions, make predictions about system performance, and enhance designs. This study seeks to push the boundaries of electromagnetic modeling and simulation, allowing researchers to address practical issues in fields like radar systems, communication systems, and electromagnetic compatibility analysis (Taflove & Hagness, 2005). 2. Advancements in Antenna Design and Optimization Antennas play a vital role in wireless communication, satellite systems, and radar technology. Understanding the principles of computational electromagnetics allows for creative methods in designing and optimizing antennas. Through the use of



sophisticated computational techniques and optimization algorithms, scientists can delve into design spaces, fine-tune antenna parameters, and improve performance metrics like gain, bandwidth, and directivity. This study makes a valuable contribution to the field of antenna design, which in turn leads to advancements in wireless technology and communication systems (Balain, 2016). 14 3. Deepening our grasp on the intricacies of wave propagation phenomena Understanding wave propagation phenomena is crucial in various fields such as communication systems, electromagnetic sensing, and signal processing. Understanding wave propagation characteristics with high precision is made possible through computational electromagnetics. Through the simulation of electromagnetic wave propagation in various mediums and environments, scientists are able to investigate a range of phenomena including attenuation, dispersion, diffraction, and scattering. This study contributes to our knowledge of wave propagation phenomena, which has practical applications in designing reliable communication systems and creating new sensing technologies (Sullivan et al., 2013). 4. The influence on Engineering and Technology The study of computational electromagnetics has far-reaching implications for engineering and technology in a wide range of industries. Through the use of computational models and simulation tools, researchers are able to streamline the design process, enhance system performance, and minimize development expenses. This study greatly enhances engineering practices in areas including aerospace, telecommunications, defense, and medical imaging. In addition, the knowledge obtained from computational electromagnetics research opens up opportunities for the advancement of cutting-edge technologies and the exploration of uncharted territories in the field of electromagnetics (Jin, 2014).

3. Scope of the Study

Exploring computational electromagnetics, which involves using computer methods to tackle electromagnetic challenges like electromagnetic scattering, antenna design, and wave propagation The subject of "A Study On Computational Electromagnetics; Utilizing Computer Methods To Address Electromagnetic Issues Such As Electromagnetic Scattering, Antenna Design, And Wave Propagation" covers a wide range of computational techniques, numerical methods, and applications used to tackle electromagnetic challenges.



This section outlines the specific areas, approaches, and uses that are covered by the research, offering a clear understanding of the scope and goals of the study.

1. Computational Techniques and Numerical Methods The study involves a thorough examination of different computational techniques and numerical methods used in computational electromagnetics. Some of the methods used in this field are finite element methods (FEM), finite difference time domain (FDTD) methods, method of moments (MoM), and finite element-boundary integral (FE-BI) methods. These techniques are essential for accurately and efficiently modeling, simulating, and analyzing electromagnetic phenomena (Jin, 2014).

2. Analysis of Electromagnetic Scattering One of the main areas of study is the analysis of electromagnetic scattering phenomena. The study explores the use of computational electromagnetics to model and simulate scattering from intricate objects and structures. This involves calculating radar cross-sections (RCS), studying scattering patterns, and analyzing scattering mechanisms using numerical methods like MoM and FDTD (Taflove & Hagness, 2005).

3. Antenna Design and Optimization Antenna design and optimization are important areas of research that deserve attention. This study delves into computational methods and optimization algorithms used in the design of antennas. These methods aim to achieve specific performance metrics, including radiation patterns, impedance matching, and bandwidth characteristics. Optimization techniques, such as genetic algorithms and particle swarm optimization, are utilized to enhance antenna designs for specific applications (Balain, 2016).

4. Analysis of Wave Propagation Understanding wave propagation analysis is essential for comprehending signal propagation, interference, and attenuation in communication systems. The study explores computational methods for analyzing wave propagation phenomena in different mediums and environments. This involves simulating wave propagation in waveguides, transmission lines, and free space, as well as analyzing reflection, refraction, and diffraction effects using numerical methods like FDTD and FEM (Sullivan et al., 2013).

5. Practical Applications and Engineering Solutions The research explores practical applications and engineering solutions made possible by computational electromagnetics. This involves creating cutting-edge solutions for radar systems, communication systems, electromagnetic compatibility analysis, and various engineering fields. The study seeks to connect theoretical insights with practical



applications, making valuable contributions to engineering practices and technology (Chew, 1995).

4. Areas of further Research

There are numerous areas that warrant further investigation arising from the study on computational electromagnetics. These areas hold great potential for enhancing our comprehension and practical use of electromagnetics. These areas explore different aspects of electromagnetic phenomena and computational methods, with the goal of tackling unresolved challenges, investigating emerging technologies, and pushing the boundaries of knowledge in the field.

Here are some specific areas that could be explored in more depth:

1. **Cutting-Edge Simulation Techniques** Explore innovative computational methods and algorithms to improve the precision, speed, and scalability of electromagnetics simulations. This involves the development of hybrid simulation techniques, such as the combination of FEM with boundary element methods (BEM) or the integration of FDTD with ray tracing methods, in order to accurately model electromagnetic interactions in complex and heterogeneous environments.
2. **Metamaterials and Metasurfaces** Delve into the intricate world of designing, fabricating, and characterizing metamaterials and metasurfaces with electromagnetic properties that are carefully customized. Efforts in research should prioritize the development of metasurfaces that can manipulate wavefronts, control polarization, and shape beams. This will allow for the advancement of imaging, sensing, and communication systems with enhanced functionalities.
3. **Quantum Electromagnetics** Explore the use of quantum computing and quantum electromagnetics to tackle both theoretical and practical obstacles in the field of electromagnetics research. This involves investigating quantum-inspired algorithms for solving electromagnetic scattering problems, optimizing antenna designs, and simulating complex electromagnetic systems beyond the capabilities of classical computing.
4. **Terahertz Technology** Discover the fascinating possibilities and practical uses of terahertz (THz) technology in the field of electromagnetics research and engineering. Research areas may involve THz imaging, spectroscopy, communication, and sensing,



utilizing computational methods to simulate THz wave propagation, scattering, and material interaction.

5. **Electromagnetic Compatibility (EMC)** Examine the intricacies of electromagnetic compatibility (EMC) concerns in intricate electronic systems, encompassing electromagnetic interference (EMI), electromagnetic susceptibility (EMS), and signal integrity. Efforts in research should prioritize the development of models and tools for predicting outcomes and simulating scenarios to evaluate EMC compliance, address EMI/EMS issues, and enhance the overall EMC performance of systems.

6. **Bio electromagnetic** Investigate the relationship between electromagnetic fields and biological systems in the field of bio electromagnetic research. Studying the effects of electromagnetic radiation on human health, cellular physiology, and medical therapies is a crucial aspect of this field. Additionally, developing computational models to assess exposure levels and predict biological responses to electromagnetic fields is an important focus.

7. **5G and Beyond** Explore the effects of cutting-edge communication technologies, including 5G and beyond, on the way electromagnetic waves travel, how antennas are designed, and the performance of wireless networks. Research areas may involve millimeter-wave communication, massive MIMO systems, and beamforming techniques, utilizing computational methods to enhance network deployment and coverage.

8. **Electromagnetic Imaging and Sensing** Discover computational techniques for electromagnetic imaging and sensing applications in medical imaging, non-destructive testing, and environmental monitoring. Efforts in research should prioritize the development of algorithms for inverse scattering, methods for tomographic reconstruction, and designs for sensor arrays. These advancements will greatly enhance the resolution, sensitivity, and accuracy of imaging.

9. **Understanding Electromagnetic Wave Absorption** Explore new materials and structures for applications involving the absorption and shielding of electromagnetic waves. Areas of research could involve studying electromagnetic metamaterials, carbon-based nanomaterials, and composite materials that have specific electromagnetic properties to absorb and reduce electromagnetic radiation across a broad range of frequencies.



10. Collaborations across different disciplines Promote collaborations between researchers in electromagnetics and experts from various fields including materials science, physics, chemistry, biology, and computer science. Collaborative research efforts can result in creative solutions, the exchange of ideas, and significant advancements in tackling intricate problems at the convergence of electromagnetics and other fields.

11. Electromagnetic Energy Harvesting Explore computational methods for enhancing the efficiency of electromagnetic energy harvesting systems, such as radio frequency (RF) energy harvesting and electromagnetic induction. Efforts in research should prioritize the design of antenna structures, impedance matching networks, and energy conversion mechanisms. This will help to extract the maximum amount of energy from ambient electromagnetic fields. The goal is to power low-power electronic devices and sensors in the most efficient way possible.

12. Understanding the Propagation of Electromagnetic Waves in Complex Media Investigate the characteristics of electromagnetic waves in intricate substances, like metamaterials, photonic crystals, and plasmonic structures. Research areas may involve studying wave propagation phenomena, such as negative refraction, superlensing, and cloaking, and creating computational models to anticipate and manipulate electromagnetic wave propagation properties for advanced photonics and optical devices.

13. Electromagnetic Heating and Thermal Effects Explore computational methods for analyzing the heating and thermal effects in materials and biological tissues. Research areas can involve electromagnetic hyperthermia for cancer treatment, microwave-assisted material processing, and thermal management in electronic devices. Computational electromagnetics simulations are used to optimize heating profiles, control temperature distributions, and improve efficiency and safety.

14. Nonlinear Electromagnetics Delve into the fascinating world of nonlinear electromagnetics phenomena, which encompass a wide range of intriguing phenomena such as harmonic generation, frequency mixing, and nonlinear optical effects. Efforts in research should prioritize the development of computational models and simulation techniques. These will enable the study of interactions between waves that are not linear, the characterization of materials that exhibit nonlinearity, and the design



of photonic devices that also possess nonlinearity. These advancements will have significant applications in telecommunications, sensing, and imaging.

15. High-Frequency Electromagnetics Explore computational methods for analyzing electromagnetic wave propagation and scattering at high frequencies, such as millimeter-wave and terahertz frequencies. Areas of research could involve the design of high-frequency antennas, waveguides, and components for emerging communication systems, imaging technologies, and sensing applications. Additionally, there is a focus on developing efficient numerical techniques to address challenges related to high-frequency simulations.

16. Cybersecurity and Electromagnetic Threats Delve into the fascinating world where cybersecurity and electromagnetics meet, tackling the ever evolving challenges posed by electromagnetic interference (EMI), eavesdropping, and EMP attacks. Efforts in research should prioritize the development of computational models and simulation tools. These tools will help assess vulnerabilities, analyze risks to electromagnetic security, and design electronic systems and infrastructure that can withstand electromagnetic threats.

17. Space and Satellite Communications Explore computational methods for analyzing electromagnetic wave propagation and communication in space environments, such as satellite communication systems, deep space missions, and interplanetary exploration. Areas of research could involve studying ionospheric effects, space weather phenomena, and satellite constellations to enhance satellite communication links, minimize signal degradation, and enhance the reliability and coverage of space-based communication networks.

18. Education and Outreach Initiatives Create educational materials, training programs, and outreach efforts to raise awareness and foster curiosity in computational electromagnetics among students, educators, and the wider community. This involves coordinating workshops, summer schools, and online courses on computational electromagnetics basics, software tools, and applications. Additionally, I participate in science communication activities to share research findings and motivate future electromagnetics researchers 100 and engineers. Ultimately, these avenues for additional investigation present thrilling prospects for pushing the boundaries of computational electromagnetics and tackling urgent obstacles in electromagnetics research and engineering. Through the exploration of these avenues, researchers have



the opportunity to expand the limits of knowledge, foster technological advancements, and make meaningful contributions to solving practical problems in various fields. 5.5

5. Conclusion

Ultimately, the research titled "A Study On Computational Electromagnetics; Utilizing Computer Methods To Address Electromagnetic Issues Such As Electromagnetic Scattering, Antenna Design, And Wave Propagation" has offered significant knowledge regarding the intricate and diverse realm of electromagnetics. Using sophisticated computational methods, this study has explored different electromagnetic phenomena such as scattering, antenna design, and wave propagation. Its goal is to tackle fundamental challenges and push the boundaries of electromagnetics research and engineering. This study has shown how computational electromagnetics approaches can effectively and flexibly address various electromagnetic problems. Through the use of advanced simulation techniques and numerical algorithms, scientists have made significant progress in understanding electromagnetic interactions, improving device performance, and discovering new applications in various fields. By delving into the intricacies of electromagnetic scattering patterns, developing cutting-edge antenna structures, and studying wave propagation in complex media, computational electromagnetics has become an invaluable tool for comprehending and utilizing electromagnetic phenomena in real-world applications. The study's recommendations and proposals, like a physicist's, guide computational electromagnetics research and technology. Scientists can push electromagnetics research and open new channels for innovation and inquiry by exploring cutting-edge technologies, cultivating cross-disciplinary relationships, and solving important societal concerns. 101 In conclusion, "A Study On Computational Electromagnetics" shows how computational approaches advance electromagnetic phenomena knowledge and technology. Researchers can solve complex problems, develop innovative technologies, and advance science and engineering for society by exploring and innovating in this ever-changing field.

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