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SHIELDING PROPERTIES OF A NANOCOMPOSITE BASED ON MAGNETICALLY FUNCTIONALIZED CARBON NANOTUBES

Master degree thesis

Specialty 7-06-0611-02 Information Security

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GENERAL DESCRIPTION OF WORK

Research aim and objectives

This study aims to investigate the use of a nanocomposite based on magnetically functionalized carbon nanotubes (MFCNTs) for reducing electromagnetic leakage in the sub-terahertz range. It examines how electromagnetic waves (EMWs) interact with this material, develops RLC circuit-based models to describe the interaction, and evaluates the shielding performance through calculation and analysis, with the goal of supporting future applications in electromagnetic protection and information security.

Connection of the work with priority areas of scientific research

This work relates to priority research areas in electromagnetic compatibility, information security, and advanced functional materials. By studying the shielding behavior of a nanocomposite in the sub-terahertz range and modeling its interaction with EMWs, the research supports the development of new materials and methods for protecting electronic systems, living organisms, and sensitive information from unwanted electromagnetic radiation (EMR), which is important for modern radio engineering, environmental safety, and defense technologies.

Presentation of thesis results

The main results of the dissertation were reported and discussed at the 23rd and 24th International Scientific and Technical Conferences “Technical Means of Information Protection” (Minsk, April 08, 2025; Minsk, April 08, 2026).

INTRODUCTION

The work focuses on protecting information in the sub-terahertz frequency range from leakage through electromagnetic channels by using nanocomposite materials for electromagnetic shielding.

The material studied is a nanocomposite based on MFCNTs.

A review of electromagnetic shielding mechanisms has been carried out, together with an overview of the main approaches used to describe composite materials. In addition, the interaction between an EMW and the nanocomposite based on MFCNTs has been examined.

The study includes the following stages:

– an RLC circuit-based radio-engineering approach was developed to characterize the interaction between EMWs and nanocomposites based on MFCNT;

– the shielding performance of the selected material was calculated;

– the obtained results were analyzed and processed.

The findings can be applied in further research on electromagnetic shielding in the sub-terahertz range. They are also useful for the development of efficient electromagnetic shields used in environmental protection of living organisms from harmful EMR, information security, radio engineering, and military applications.

MAIN PART

The first chapter introduces three different shielding mechanisms. Electric field shielding requires a grounded material with good conductivity. Low-frequency magnetic field shielding requires materials with high-permeability. High-frequency magnetic field shielding requires good conductors. This chapter also introduces the main parameters, such as permittivity and permeability. Based on the advantages and disadvantages of several classical EMTs, a new model is proposed.

The second chapter introduces the chirality of carbon nanotubes, the common structures of single-walled carbon nanotubes and multi-walled carbon nanotubes, and the common methods used for synthesis of carbon nanotubes. The transmission coefficient and reflection coefficient of the proposed model are calculated. The resulting equations are very complex, so the system is represented as an equivalent RLC circuit in the following chapter to simplify the calculations.

The third chapter presents the laboratory data and figures, demonstrating that resonance occurs in the system at specific frequencies. The circuit parameters influence the response characteristics of the reflection and transmission coefficients (smooth or sharp resonance peaks). For certain values of the circuit parameters, the permeability, transmission coefficient, and reflection coefficient all exhibit pronounced step-like behavior. Within the investigated parameter range, only the inductance causes noticeable changes in the permeability. The series circuit model corresponds to structurally oriented materials and enables tunable microwave absorption in the 5G/6G frequency bands. The parallel circuit model corresponds to highly dense conductive networks and provides ultra-high electromagnetic shielding performance over a broad frequency range for military applications.

The fourth chapter presents the application range and advantages of the material. Although traditional materials are effective, they are costly and have limited functionality. In contrast, MFCNT nanocomposites utilize the synergistic effects of conduction loss, dielectric loss, and magnetic loss to achieve improved broadband electromagnetic absorption and shielding performance, while also being lighter and more cost-effective. Therefore, they are suitable for applications in information protection, electronic device shielding, and electromagnetic compatibility across various fields.

CONCLUSION

The effective mitigation of EMI and radiation remains a critical challenge in modern electronics. Uncontrolled electromagnetic emissions not only form channels for sensitive information leakage but also pose potential risks to human health. Consequently, the research and development of highly efficient, broadband, cost-effective, and user-friendly shielding materials is essential, which is driven by both biological safety concerns and the growing demands of secure information systems and advanced electronic design.

The objective of this thesis was to develop a radio-engineering approach for describing the interaction between EMWs and a magnetic nanocomposite based on MFCNTs using RLC circuit models, as well as to calculate the shielding characteristics of the investigated nanocomposite. This objective was achieved through the successful completion of all tasks set in the study.

The obtained results are important for further research in the field of electromagnetic shielding in the sub-terahertz frequency range. In addition, they can be applied in the fabrication of shielding materials used in various areas, including:

– information security for suppressing electromagnetic leakage channels;
– protection of information processing devices from EMI;
– military applications for reducing the radar visibility of objects;
– environmental protection of living organisms from harmful electromagnetic radiation through the development of protective clothing and personal shielding equipment;
– other areas of science and engineering.