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**Frequency Response Investigation of Open Metallic Surfaces by The
Method of Auxiliary Sources**

SPECIALITY 01.04.03 - RADIOPHYSICS

**ABSTRACT
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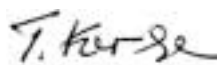
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Actuality.

One of the directions in applied electrodynamics, that studies interactions and undesirable influences between electronic devices is EMC (Electro Magnetic Compatibility). Modern vehicles, such as airplanes, cars etc. consist of many sensitive electromagnetic devices. Those devices are as well sensitive to outside (external) Electromagnetic field at the same time. This effect is especially significant for bodies with cavities. It is well known, that the open cavities serve as good resonators for external incident electromagnetic waves that may lead to high local electromagnetic fields inside the car at the resonance frequencies. These fields may negatively affect not only the normal operation of the on-board sensitive electronic equipment, but also human, and must not exceed established safety limits. For this reason use of electronic devices is prohibited in certain environment, for example in airplanes. EMC has become the number one problem in design of modern vehicles. As a rule, large amount of electromagnetic sources inside the car create electric field of 20-30v/m. In case of resonance, his field increases, that due to the car frame. Field inside the car can become 300% more than the field outside, it such increase is caused resonant properties of the car case. In this case electromagnetic properties of devices placed inside the car should be protected from the influence of this field. To received signals existence of high intensity electromagnetic background field nearby may cause unpredictable reaction of electric device. There was a case, when passenger used cellular phone in the car, while the onboard computer malfunctioned on received signals and made inappropriate decisions, namely, opened airbags.

Study of electromagnetic properties of the vehicles in terms of EMC becomes as important as studying their mechanical and/or aero dynamical properties. In order to solve EMC problem for a car, it is necessary to study field distribution in it and find to places where EM field increases and overcomes established limits.

To comply with those limits, it is necessary to investigate the electrodynamic properties of semi-open objects with cavities made of thin metallic walls, partitions and enclosed dielectric objects. Experimental measurements for such investigations are expensive and time consuming. On the other hand, computer simulation is expected to be the efficient way to solve this problem. The problem of diffraction on presented 3-D structure can be solved using variety of methods, but all of them,

according to their ideology, require huge computational resources and are very time consuming.

It is important to develop effective methodology for solving EM problems for open 3D structures. Problems presented in this dissertation are solved using the Method of Auxiliary Sources, further enhanced by the author.

Most of the methods need approximately 10-12 sample points per wavelength to obtain acceptable accuracy. In case of 3D surfaces, this parameter on squared wavelength should be no less than 100-150. Taking into account size and complexity of modern cars, number of unknowns greatly increases, requiring large computer resources and simulation time. This is the reason why conventional computational methods are inconvenient for interactive real-time investigations. Unlike them, MAS allows the scattered field description using considerably smaller number of unknowns. Considering the scattered field singularities (SFS), it is possible to qualitatively describe the scattered field using just few Auxiliary Sources (AS) [1]. For the same reason, MAS is very efficient in solving diffraction problems on dielectric bodies. Consequently, it provides the fast algorithm that allows solution of the problem even on the conventional workstation. Also the important advantage of the MAS in contrast with other methods is that it allows evaluating the current induced on the surface both from inner and outer sides.

The aim of the dissertation:

1. Further development of the Method of Auxiliary sources for solving EM diffraction problems on open enclosures.
2. Investigation of car case as an example of such structure. Study behavior of resonance frequencies changing as result of geometry of the model; Studying EM diffraction on a car with the passenger model.
3. Development of software package for engineering applications to investigate 3D diffraction problems on dielectric and open metallic enclosures.

Problem solving methodology is based on the method of auxiliary sources, which was developed for studying wide range of EM diffraction problems by Georgian mathematicians V.Kupradze and I.Vekua. This method is very effective for closed surfaces. We've enhanced this method for open metallic surfaces in this dissertation. To solve the problem, we've developed approach, where we close open metallic surface by an imaginary one. Then we use M.A.S. for a resulting

closed surface, where we require validity of the boundary conditions on both real and imaginary boundaries.

Validity of the calculation results.

We examine adequacy of results by: 1. Validity of satisfaction of boundary conditions. 2. Energy conservation law; 3. the analyzing of obtained results. 4. Comparing analytical and numerical results for simple geometries, for which analytical solution is known.

Novation of dissertation.

1. Method of Auxiliary Sources is developed for EM diffraction problems on open metallic enclosures. New approach is introduced, where we close open metallic surface by adding the imaginary one. After this step we build the set of auxiliary sources inside and outside of the resulting extended surface. This approach allows one to optimally solve the diffraction problems using M.A.S. for thin open metallic surfaces. After this we apply M.A.S. to the resulting closed surface, and require satisfaction of the boundary conditions on both real and imaginary surface.

2. The software package for engineering application has been developed to carry out the numerical experiments .Using this software the electro-dynamical features of the open metallic enclosures have been investigated in the frame of Electromagnetic Compatibility (EMC) and its qualitative response have been found.

3. Using developed approach, frequency response of the sliced sphere was investigated. Obtained results are in good agreement with those calculated by using Method of Moments (MoM) approach. Using the same developed approach, frequency response and behavior of EM field at the resonance frequencies of car model were also investigated for two different geometries.

4. Frequency response of the car model with partitions (partially separating the interior of the cavity into several sub domains) is investigated.

5. Case of diffraction problem of the external incident field on the car body, when lossy dielectric material (human model) is located inside, was investigated.

Newly developed approach allows to find at electric current distribution on thin metallic surfaces on both sides.

The main results of the dissertation.

The special software package has been developed, that allows numeric investigation of resonance frequency response of the following types of objects: 1) metallic and dielectric objects with closed boundaries. 2) Open metallic surfaces. 3) System that consist of open metallic surface and dielectric bodies.

Using this package the following problems have been solved:

1. Problem of finding resonance frequencies for closed metallic surfaces. To solve this problem, we have used the simplified method of A.S. Using this method we reduce our problem to that of solving system of inhomogeneous linear algebraic equations. For a given frequency band, when system is irradiated, resonance frequencies and eigenfields are determined by field's rapid increase conditions inside the body. Numerical results are in good agreement with theoretical data. Automobile like closed metallic body is also investigated including resonance frequencies and eigenfields.

2. Electromagnetic response of open conducting surface using EM diffraction problem using new, proposed approach has been investigated. Diffraction problem on a sliced sphere is solved as a testing task. Obtained results agree with those calculated using the MoM. Despite the fact that MAS needs auxiliary sources located on both sides of conducting and imaginary surfaces, MAS approach is more efficient in wide range of frequencies than MoM. Two different car models with relative wavelength ka (3.7–30 range) were also investigated in different polarization cases. Using the same approach, frequency response and behavior of EM field at the resonance frequencies of car model were also investigated for two different geometries.

3. EM diffraction problem is solved on conducting metal system. Car case with partitions is considered as a model. Its EM property has been investigated. Resonance frequencies of this model have been found and analyzed along with that for sliced sphere.

4. EM diffraction problem on open conducting surfaces enclosing high permittivity dielectric system has been solved. This is a simplified "user is in the car" case model. As a model we have chosen a ellipsoid with dielectric permittivity of human. Influence of a human body on EM properties of the car and frequency response has been investigated on same parameters.

EM response of those systems is studied using a diffraction problem. New approach is tested. Obtained results are compared with those obtained by other methods. Research showed that developed method of MAS enables to solve diffraction problems on complicated systems with conducting surfaces in wide frequency band with small use of PC resources and computation time.

Contribution of the author: The main results presented in the dissertation are obtained by the author. In the publications made together with co-authors author made the computer and theoretical simulations of the problem, developed the efficient algorithm, along with the computer code and took part in computer simulation as well as in interpretation of physical results.

Publication and approbation of the main results of the dissertation. The main results are published in 6 referred proceedings of international conferences and symposiums. Results also presented at the following international conferences:

1. 2001 IEEE AP-S International Symposium, Boston, Massachusetts, July 8-13, 2001.
2. VI th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2001), Lviv, Ukraine, September 18-20, 2001.
3. 2002 IEEE AP-S International Symposium, San Antonio, Texas, June 16-21, 2002.
4. VII-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2002), Tbilisi, Georgia, October 11-13, 2002.

Author himself presented results at DIPED-2002, and received the diploma.

Short overview of dissertation:

Presented dissertation is a natural development of a long research conducted at the LAE of TSU. For solution of EM problems the following methods are used: Integral equations, MAS, MoM and others. LAE has had large experience of solving EM problems using MAS for many years. Class of solved problems using MAS has been also enlarged during this period. Prior to his work main 2D-3D diffraction problems for rotated bodies with symmetric wave sources were solved.

The main goal of this dissertation is the study of frequency response and other EM properties of complicated 3D objects considering changing geometries.

We used MAS to solve this problem. New approach is developed, which lets solve EM diffraction problems on open conducting materials.

Section I. Full overview of MAS for solving 3D diffraction problems in frequency domain is given. Representation of Electric and Magnetic fields in dipole fields is discussed. Using collocation method, problem is reduced to the solution of the system of linear equations. EM diffraction problem for open surfaces using MAS is considered and different approach for solution is developed. Using the new approach, testing task is solved and obtained results are compared with those obtained from MoM.

Section II. Eigenvalues and Eigen field calculation method based on MAS for a Dirichle problem on closed perfect conducting surface is considered. Eigenvalues and Eigen field for ideal conducting sphere are numerically calculated and compared to analytical results for testing purposes. Same problem is solved for body with different geometries.

Section III. EM solution of diffraction problem for open conducting complicated surfaces using MAS is presented. Two car cases are chose as models and their frequency response are obtained for a given EM field polarization. Behavior of frequency response for 2 slightly different geometries is compared. Pictures of resonance field distributions are given.

Car case-like geometry with partitions is considered. A new algorithm is developed using MAS for this complicated geometry. Frequency response for this model are obtained and compared to the results from previous section. Pictures of resonance field distributions are given.

EM diffraction problem on the car enclosing high permittivity dielectric body is solved. This is simplified “user is in the car” case model. Frequency response and resonance field distributions for this model are calculated and presented.

Conclusion.

Software package for solving EM diffraction problems on open conducting surfaces in order to study its resonance frequencies using MAS has been developed. Using this package resonance frequencies has been studied for following cases:

- 1) Conducting bodies having simple and complicated closed geometries.
- 2) Sliced conducting sphere.
- 3) Simplified car model for two similar geometries. Differences in frequency response due to different geometries are analyzed.
- 4) Simplified car model with partitions.
- 5) Perfectly conducting open surface and absorbing dielectric material system.

This is a “human in the car” simplified model. Influence of a human, located in or nearby the car on frequency response and resonance fields of the car is studied.

Results are validated by checking the satisfaction of boundary conditions, theoretical analysis of the obtained results, the comparison of results obtained by the other method, comparisons of analytical and numerical results for simple geometries, when analytical solution is known.

Publications of the Author:

1. R. Zaridze, G. Bit-Babik, K. Tavzarashvili, A. Bijamov, **D. Kakulia**, G. Ghvedashvili. “The Method of Auxiliary Sources in Scattering and Diffraction Problems” is presented on 2001 IEEE AP-S International Symposium, Boston, Massachusetts, July 8-13, 2001. pp.738-741.
2. R. Zaridze, **D. Kakulia**, K. Tavzarashvili, A. Bijamov, G. Ghvedashvili, G. Chelidze, “Electrodynamic Properties of Semi-open Objects with Cavities and Partitions”, Proceedings of VI-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2001), Lviv, Ukraine, September 18-20, 2001, pp. 54-59.
3. R. Zaridze, **D. Kakulia**, K. Tavzarashvili, A. Bijamov, G. Ghvedashvili, G. Chelidze, “Determination of Eigenvalues of The Object Using The Method Of Auxiliary Sources (MAS)”. Proceedings of VI-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2001), Lviv, Ukraine, September 18-20, 2001, pp. 183-190.
4. R. Zaridze, **D. Kakulia**, K. Tavzarashvili, A. Bijamov, G. Ghvedashvili, G. Chelidze. “Method of Auxiliary Sources Implementation for Diffraction Problem Solution on Semi-Open Metallic Surface with Partitions and Enclosed Dielectric Objects”. Presented to 2002 IEEE AP-S International Symposium, San Antonio, Texas, June 16-21, 2002. pp.172-175.

5. R. Zaridze, **D. Kakulia**, G. Chelidze, G. Ghvedashvili. "Investigation of The Resonance Characteristics of The Car Case". Proceedings of VII-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2002), Tbilisi, Georgia, October 10-13, 2002, pp. 102-105.
6. R. Zaridze, K. Tavzarashvili, G. Ghvedashvili, **D. Kakulia**, G. Saparishvili, A. Bijamov. "The MAS For Numerical Modeling of EMC/EMI in Vehicles and SAR Problems". 15th International Zurich Symposium & Technical Exhibition on EMC 2003. February 18-20. (accepted for publication).