The Method of Auxiliary Sources as an Efficient Numerical Technique for Large 3D Semi Open Structures

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Abstract — The Method of Auxiliary Sources (MAS) has been demonstrated as a suitable for solution of diffraction and inverse problems in complex 2-D large objects [1]. Based on MAS numerical study of 3D RCS, EMC/EMI and SAR problems, related to the EM field resonance enhancement inside vehicles and the interaction of the cellular phone radiation with the user's head are given in [2-4]. Objective of this paper is to present details of MAS application to the wide 3D Electrodynamic problems. The area of its efficient application, some features and advantages to achieving efficient solutions, are discussed. The extension of the MAS for semi-open structures with partitions is also presented.

Introduction. Despite the rapid development of computer technology, the solution of modern EMC/EMI, RCS and SAR problems are still restricted by the limited computational resources, especially for radiation and diffraction problems on electrically large and complex structures with cavities. For solving a diffraction problem with widely used codes, it is required to divide the scatterer's surface into at least 10-12 parts per wavelength. For 3-D surface problems this leads at least to 100 unknowns per wavelength square. For larger scatterers, the number of unknowns increases drastically. The Increasing complexity and especially electrical dimensions require the development of the efficient and accurate numerical methods. New ideas and approaches are needed to overcome the limitations of traditional methods. Modern numerical electromagnetic codes, such as FDTD, MOM, TLM and others are user-friendly, simple and straightforward for application. The complexity of the problems that can be solved is limited by the available computational resources. The MAS technique uses less computational resources and increases the efficiency. However, this is done at the expense of some knowledge and skills demanded from a user. That is the reason, why MAS is rarely applied in practical problems by other researchers.

The Method of Auxiliary Sources. The key idea of the MAS is to represent the unknown scattered field by a sum of fundamental solutions of appropriate wave equations – Auxiliary Sources (AS), whose radiating centers are located on some auxiliary surfaces shifted outwards from the boundary of the domain where the scattered field is to be found [1,5]. Experience of using MAS for 2-D problems revealed [1] that a good understanding of the physical properties of the scattered field is necessary for solving the problem in the most efficient way. The proper use of the Scattered Field's Singularities (SFS) is very important. For 2D objects having rounded corners, it was shown that SFS are typically located on caustic surfaces. These surfaces can be understood as distorted mirror images of an incident field source. In contrast to geometric optics, it cannot be assumed that the wavelength is zero and continuous caustic surfaces are formed [6]; for a finite wavelength the SFS are distributed at discrete locations on the caustic surface. One can

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imagine them being bright spots on the caustic surface distributed at distances depending on a wavelength [1]. When the SFS locations are properly recognized as locations of the AS, the computational efficiency will be greatly improved. Special attention should be paid to the frontal surface, i.e., the parts of the scatterers, which first encounter the incident field. It is especially important, when an incident field source is located close to the scatterer. So, for solving the 3-D EM diffraction problems efficiently, the requirement to have at least a general idea of the physical properties of the scattered field is together with proper treatment of the object's surface geometry is also very important. There are several advantages to use MAS.

First advantage. If AS are taken on the surface, the MAS approach will turn to the Integral Equations Method. Advantage of the MAS is evident, when the AS move away from the physical surface. The required number of AS to achieve a specific accuracy decreases sharply, and consequently, the required CPU-time also decreases. This can be explained by the fact that shifting of AS inside the scatterer makes the scattered field's function more smooth on the surface of the body. The compensation of incident field at the collocation points with the scattered field is elaborated. The fulfillment of the boundary conditions between collocation points is improved.

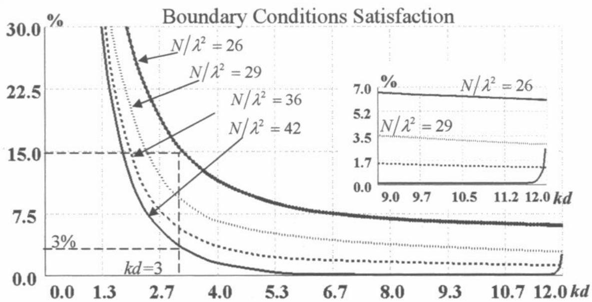

Fig. 1. Dependence of the accuracy of the fulfillment of the boundary conditions on the normalized distance *kd* for different numbers of collocation points on the squared wavelength

Advantage becomes quickly visible if we analyze the number of unknown we need to solve for a given accuracy as a function of the distance between the surface of the body and the auxiliary sources. Let us illustrate this in a very simple example. In the Fig.1, we can see how necessary numbers of AS to achieve fixed accuracy depends on shifting distance. Farther AS position, less numbers we need. However, care must be taken since further deepening of AS could lead to a divergent solution. This occurs due to following reasons: 1) If the sources are too close together, the numerical representation of the matrix will lead to instabilities in the matrix solution. 2) If the SFS appears outside of the auxiliary contour and the fields generated by AS cannot describe these singularities. The SF must be analytical everywhere outside of the sources. So, test of divergence would indicate on the presence of SFS.

Second advantage is – proper consideration of SFS. It was proved [7], that every scattered field, which is propagates to infinity and carrying energy, must have singularity inside, or at list, on the surface the scatterer. Other wise scattered field could be zero everywhere up to infinity. These singularities uniquely determines scattered field and, opposite, every scattered field have his unique, special SFS distribution [1]. From physical point of view it is understandable, as these singularities must be wave energy source and connected with caustic surface and distorted mirror image of the incident wave source. Now consider a simple case such that the source can be perfectly mirrored in object surface. Consequently, the scattered field can be either represented by the induced surface currents, or by the mirror image of the source. Both methods lead to the same fields, but the one using the mirror image is numerically much more efficient. The high numerical advantage of MAS is based on this principle. Ideally, one will place the auxiliary sources where the mirror images are located. The solution is obtained in a two-step procedure. First, the optimal, or at least good locations of the auxiliary sources need to be determined. Farther, the magnitude and phase of the sources needs to be calculated by applying boundary conditions. In electrodynamics it is high interest to handle high frequencies, close to optics one. It means that our interest will be to follow if it is possible to determine SFS for more complicated geometries. It would be shown, that for any position of the incident wave source and curve surface there is the best position of the auxiliary source to present frontal reflected field. This point is the center of the mirror image. Generally, in the Geometric Optics it names Caustic Surface (CS) which presents distorted image of the source. There exist general rule to determine CS and, as soon as in GO they suppose wave land is zero, CS is continues. In case of finite wavelength SFS are distributed along CS [1].

Some features, which must be considered in general case. In order to represent scattered field's every polarizations, two orthogonal dipoles are placed for each collocation point, and their orientation vectors must be chosen parallel to tangential plane that is to the actual body's surface at the appropriate collocation point location. For the MAS efficiency, following guidelines needs:
1. Choose the proper mesh of the surface of the object – The mesh should adapt to the principal cross-sections and main curvatures of the surface in collocation points, i.e., the minimal and the maximal radius of curvature can be determined. 2. Tangential unit vectors should be oriented parallel to the main cross-sectional plane in collocation point. For a curved surface, the AS cannot be shifted from the surface at a distance, greater than the length of the curvature radius along the negative direction of the normal vector in convex areas. Otherwise, the AS will go beyond the SFS, which may cause non-convergence of the solution.
3. The orientation of the AS should be parallel to the tangential unit vectors on the surface of the object. When the minimal and the maximal curvatures differ at a collocation point on the physical surface, the optimal locations of the two related orthogonal AS should have different distances from the surface. The AS that represents the current in the direction of the maximal curvature needs to be placed closer than the one that represents the current in the direction of the minimal one. Therefore, for 3D cases, in general, AS can be located on different surfaces having bifurcation points or lines, similar to caustic surfaces in optics. Special attention needs to be given to the AS located at the bifurcation areas. In these points, the incident field source's distorted image is found [16]. In order to minimize the total number of sources required achieving the desired accuracy of the boundary problem solution, it is important to carefully place the sources that contribute significantly to the scattered field. The selection of AS from a variety, such as an elementary electric dipole, a magnetic dipole, etc, is another way for optimizing MAS's efficiency.

Extension to the objects with apertures and cavities. Another case that needs special treatment is the semi-open geometries. Imagine a metallic hollow sphere cut on the top. It is excited by an elementary dipole. To solve this problem, first the incomplete sphere is completed with an imaginary surface. Next, two sets of AS are placed on the auxiliary surfaces, inside and outside. The inner AS represents the field outside the sphere and on the boundary, and the outer AS represents the field inside the sphere and on the imaginary surface. The boundary condition $E_{tan} = 0$ is enforced on the metallic surface; the field's continuation is enforced on this newly added imaginary surface. The shape of an imaginary surface cannot be set arbitrarily, as it influences the efficiency of the solution. It is good to avoid sharp corners in MAS. The algorithm is similar to that of the dielectric body, and, therefore, MAS can be applied for solving problems where dielectrics are partially covered with conductive patches.

More details of priori determination of field singularities in particular problems, effective placement of the AS for efficient MAS application and new results of investigations will be discussed during presentation of this paper.

Conclusion. This paper summarizes the acquisition of the knowledge within the main principles and features of the MAS numerical technique in application to 3D RCS, EMC/EMI, SAR and antenna problems. The MAS is extended to the simulation of the semi-open structures.

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