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EFFICIENCY OF METHOD OF AUXILIARY SOURCES FOR MATHEMATICAL MODELING AND SIMULATION OF APPLIED PROBLEMS

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ABSTRACT. *This article contains review of the application of the Method of Auxiliary Sources (MAS) in modern electrodynamic problems, regarding to evaluation of the field's distribution nearby of base stations and different obstacles. In case of problems with the electrically large objects, for reducing the required computational and time resources, based on the MAS, new approach is proposed. This approach is tested on the open structure as the perfectly conducting plate with electrically large and finite dimensions.*

INTRODACTION. Despite the rapid development of computer technology, the solution of the modern problems of scattering electromagnetic waves, RCS, EMC and EMI are still restricted by the limited computational resources, especially for problems of radiation and diffraction of electrically large and complex structures with cavities. The increasing complexity and electrically large dimensions require the development of the efficient and accurate numerical methods.

Modern numerical electromagnetic methods, such as FDTD, MOM, TLM are user-friendly, simple, straightforward for application. The complexity of the problems that can be solved is limited by the available computational resources. For solving diffraction problems, it is required to divide the scatterer's surface into at least 10-12 parts per wavelength. This is the result of describing the variation of electric and/or magnetic current on the surface directly as the unknowns in the mathematical formulation. For 3-D surface problems this leads at least to 100 unknowns per wavelength square. In order to consider every polarization of the current on the surface of the object, the number of unknowns increases at least in two times. Consequently, for the larger scatterer, the number of unknowns increases drastically. In contrast, MAS allows representing of the scattered field everywhere, including on the scatter's surface by a smaller number of unknowns or Auxiliary Sources (AS). In series of problems, proposed numerical technique (MAS) uses less computational resources and increases computation efficiency. The main idea is placing them into locations of the Scattered Field Singularities (SFS), which are located on caustic surfaces of the Scattered Field (SF). Thus, every AS represents the SF of larger parts of the surface as mirror image of incident field's source. Compared with MOM, which allows a straightforward computational solution after division of the surface, the proper placement of auxiliary sources in MAS needs some additional skill. It requires some prerequisite knowledge of Geometric Optics (GO) [1], so that the codes will work efficiently, especially in 3D cases. After the division of the surface, the AS and distribution of the AS must be properly chosen. The optimal locations are determined by the geometry of the objects and also by the incident field's source, which is the significant difference with the MOM.

The rigorous theoretical foundation of MAS was provided by V. Kupradze in 1967. A number of researchers probably independently, used the basic idea of the MAS for scattered field calculation by the shifting AS inside the object to solve just some simple scattering problems. However, MAS is rarely applied in practical problems by other researchers, mainly because of the difficulties in selection of the AS positions [2]. Poor convergence in calculations is the result of improper selection and distribution of the AS. There are many main features, which could be considered in order to use the MAS efficiently.

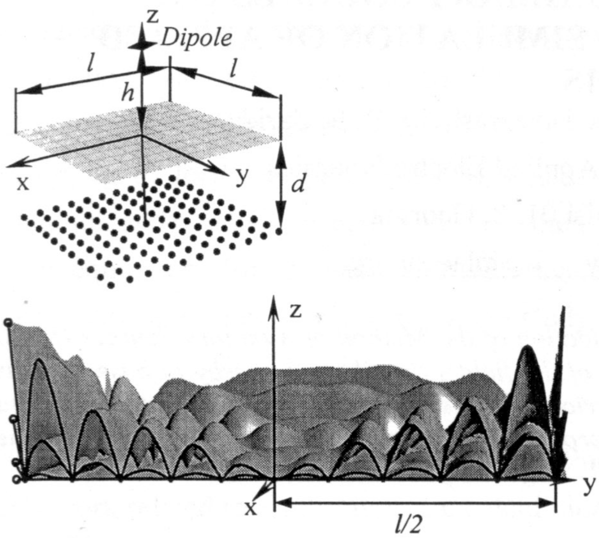


Figure.1 Geometry of example and Typical distributions of the residual for different auxiliary distance *d*.

- *d/λ=3.33, Residual=2.00%*
- *d/λ=4.00, Residual=0.60%*
- *d/λ=6.67, Residual=0.00%*
- *d/λ=13.3, Residual=0.08%*

FEATURES OF THE MAS. Main idea of the MAS is the representing of scattered or penetrative fields by fields of some auxiliary sources which are placed outside of the field's determination area. Main difference between MAS and the Method of Moments (MOM) or MAS and Integral Equation Method (IEM) is that MAS uses auxiliary non-real currents, shifted on so called auxiliary surface. Auxiliary currents create same scattered field as real ones. During the realization, efficiency of the MAS greatly depends on selection of auxiliary surface. The more auxiliary surface is remote away from real one the better is satisfaction of boundary conditions. This property of MAS gives free play to find optimal auxiliary surfaces and presents special topic for investigation.

First significant advantage of the MAS is evident, when the Auxiliary Sources (AS) are shifted from the physical boundary surface divided into two different mediums. Below there is considered an example for analyze how behaves satisfaction of the boundary conditions by shifting AS. In this case, just 3 collocation points come on every one wavelength square. In Figure.1 geometry of the problem is given. Flat, finite square area, with l=6.67λ side sizes (surface area 42.25 λ^2), located in point of origin,

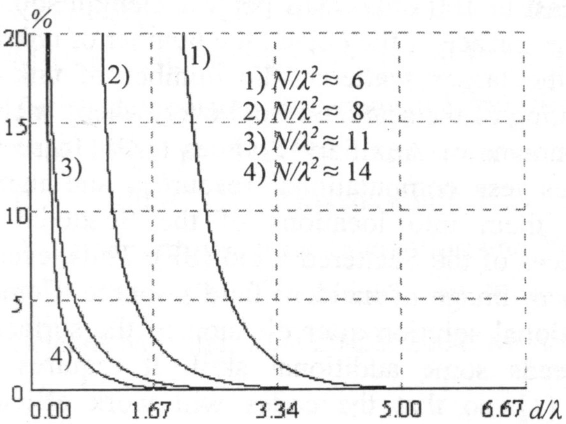


Figure.3 Dependence of the boundary conditions satisfaction per relative auxiliary distance *d/λ* for different relative densities of collocation points

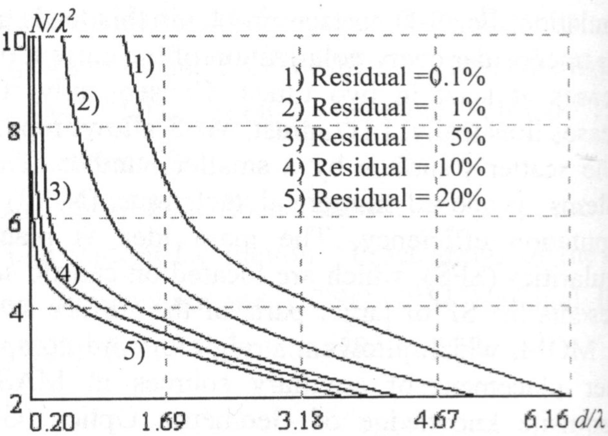


Figure.3 Dependences N/λ^2 to *d/λ* for fixed values of boundary condition satisfaction

illuminated by dipole field on h=6.67λ distance along Z and polarized along Y. Auxiliary surface is shifted on d distance along –Z. In Figure.1 is shown typically dependence character of satisfaction of the boundary conditions ($E_{tau}=0$) by shifting AS away from main one for 4 different distances mentioned in the Figure.1. There is the tangent component of the total E field distribution. The satisfaction of the boundary conditions is demanded in 11x11 uniformly distributed collocation points; the deviation is distributed in area between them. Step by step moving AS away the deviation becomes less and less. For obviousness, in Figure.1 just half of the plate is presented, cut in YOZ section. The total field is determined by same number (11x11=121 multiplied on 2, considering two orthogonal directions) of AS distributed with the same size of plate.

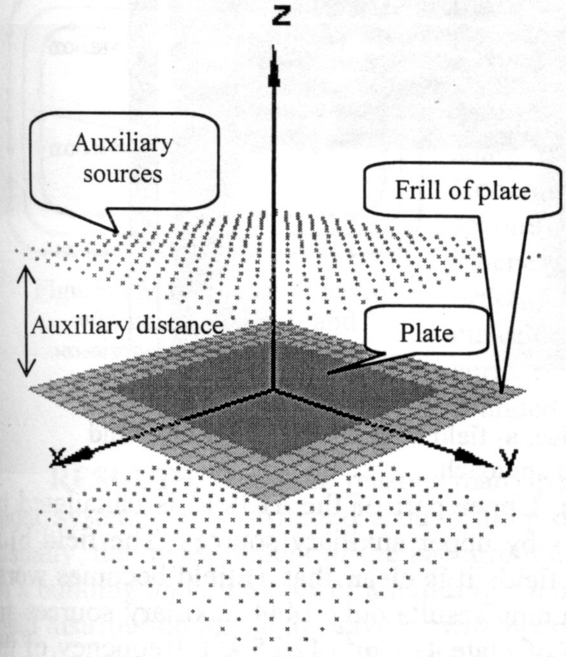


Figure.4 Geometrical model of MAS's approach for plate

MAS APPROACH FOR THIN OBJECTS AND CAVITIES WITH APERTURES. The applying of the conventional MAS is restricted for thin objects and needs expansion. The MAS is very powerful and efficient method for solving boundary problems. And it is applicable, when object has the closed surface and enough thickness. The possibility to shift the auxiliary sources from real surface determines efficiency of the MAS.

It is clear, there is no place inside of thin object and the conventional application of the MAS is impossible. To resolve this problem next approach is proposed. It implies the finding of the field which is very close to the scattered field on the object surface, further determining the scattered field in whole space by using integral representations.

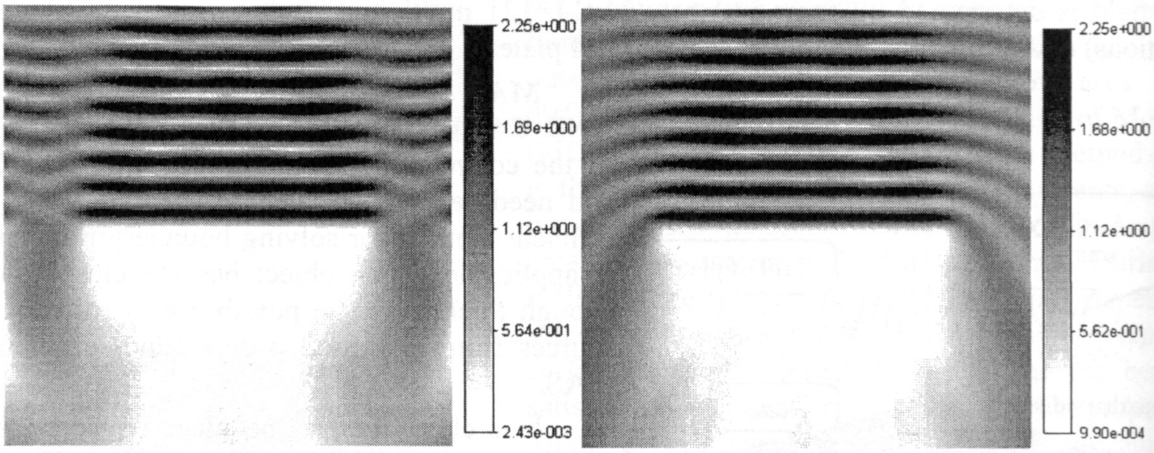
For better understanding of this approach the problem of the electromagnetic plane wave's diffraction on the PEC plate is considered, where incident field comes from Z direction, having X polarization and unit amplitude.

The plate with square form is placed on XOY plane (as it is Figure.4). Figuratively the space is divided into two half-spaces, by the infinite plane taking place on the plate. Two set of auxiliary sources are placed in each half space, above and under of the plate. Each set creates the field in the opposite half-space. Boundary condition - $E_\tau=0$ is required in collocation points on both sides of the plate. There is area around the plate like frill. Continuity of tangential components of the E and H fields in collocation points of this frill area are required additionally. To find amplitudes of auxiliary sources, as usual, the problem is reduced to the solving of the system of linear equations. Presenting the solution by sum of fields of auxiliary sources with corresponding amplitudes, the obtained solution is correct only in space close to plate. The field becomes worse when the distance from plate increases. The knowing of components of the scattered field on plate is enough to determine the field in whole space, using generalization of Kirchhoff method for vector fields.

$$\vec{E}(\vec{r},t)=\frac{1}{4\pi}\int_{S'}dS'\frac{\exp(i(kr-\omega t))}{r}\left[ik\vec{j}_e\sqrt{\frac{\mu_0}{\varepsilon_0}}-\left(ik-\frac{1}{r}\right)\left(\vec{j}_m\times\vec{r}_0+q_e\vec{r}_0\right)\right] \quad (1)$$

$$\vec{H}(\vec{r},t)=-\frac{1}{4\pi}\int_{S'}dS'\frac{\exp(i(kr-\omega t))}{r}\left[ik\vec{j}_m\sqrt{\frac{\varepsilon_0}{\mu_0}}+\left(ik-\frac{1}{r}\right)\left(\vec{j}_e\times\vec{r}_0+q_m\vec{r}_0\right)\right] \quad (2)$$

where $\vec{r}=\vec{R}-\vec{R}'$, $r=|\vec{r}|$, $\vec{r}_0=\vec{r}/r$, $\vec{j}_e=\vec{n}\times\vec{H}$, $\vec{j}_m=\vec{n}\times\vec{E}$, $q_e=\vec{n}*\vec{E}$, $q_m=\vec{n}*\vec{H}$



a) Figure 5. b)

Amplitude distribution of E_x total field in YOZ slice, a) field of auxiliary sources b) Field obtained by proposed approach.

Figure.5 shows distribution of fields for two cases. Upper part of the a) field is calculated by auxiliary sources placed under plate and the lower part – by upper auxiliary sources. The field b) is calculated by integral representation (1). Comparing two fields it is clear, that a) field becomes worse away from plate, while b) is clear and realistic. For obtaining results only 1444 auxiliary sources are needed, it is little bit less then 36-unknowns per λ^2 (area of plate 1x1 m^2 ($42.25\ \lambda^2$), frequency of the incident field is 1.8GHz).

The MAS allows easily calculating satisfaction of boundary conditions, estimating precision of solution. So, the proper distribution of AS requires an analysis of the scatterer's boundary surface, considering location of the field's source and experiences. Essentially, efficient MAS application uses principles from Geometric Optics and allows solving problems of the scattering at high and even quasi-optical frequencies.

Usually in MAS, auxiliary sources are fundamental solutions of wave equation. In three-dimensional case, the finding of an effective auxiliary surface for complicated shapes is often impossible. Contribution of electric charges dominates in near electrical field of Hertz's dipole. Describing continuous current's field becomes complicated. In this case, the increase in density of auxiliary sources is necessary, which reduces efficiency of the MAS. The Hertz's dipole has no geometrical dimensions and arisen problem with charge's field must be removed by the increasing of dipoles density on auxiliary surface. This circumstance guides to integration and integration means the using distributed currents.

Easiest and effective way of the representing of current on auxiliary surface is network, where segments of network are elements of current and corresponding charges are concentrated in junctions. This distribution provides continuous current on auxiliary surface and satisfaction of Kirchhoff's rule. Auxiliary currents are continuous on auxiliary surface. At the same time this approach is effective from the points of view of convergence, calculation time, and in case when auxiliary surface is closed to real surface. Furthermore, it allows hybridization with the Method of Moments [3].

For diffraction problems modeling on the cavities with apertures MAS proposes to supplement incomplete surface of cavities by imaginary surface. Now having the closed area inner and outer auxiliary surfaces can be set. Next, two sets of AS are placed on the auxiliary surfaces, l_{in} inside and l_{out} outside as shown in Figure.6. The inner AS on surface l_{in} represents the field outside the cavity and on the boundary l, and the outer AS located on surface l_{out} represents the field inside the cavity and on the surface l. The Boundary conditions for the perfectly conducting bodies are used on the both sides of the cavity's surface and on the imaginary surface the continuity of the total tangential magnetic and electric fields is enforced, which leads to the system of linear equations relatively to unknown coefficients. The algorithm can be applied for solving problems where dielectrics are partially covered with conductive patches.

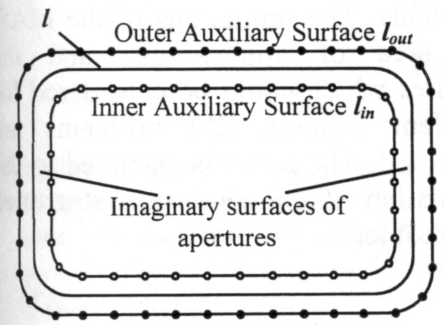


Figure.6 MAS model of cavity with using auxiliary and imaginary surfaces

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. A smooth surface needs to be selected. Generally, the imaginary surface should have continuity of the second order of spatial derivative and with minimal value whenever possible, while usually only a continuity of the first order derivative is sufficient. It is advisable to select a large curvature radius, since it allows coverage of a large section of the surface with only a few AS. In practice, finding an appropriate rounded surface does not pose difficulties.

RESULTS. For some reasons many powerful high frequency transmitters for communication or radar systems are distributed around us, producing high values of EM field's background radiation. Usually, the measurement of the background has a place in outdoor environments – in the street, close to a building and on a roof of a building. One of the major aspects of EM Ecology is to understand EM field distribution inside the cavities with apertures, such as living or working places [4].

For the numerical modeling the cavity like room with dimensions 5mx3mx2.5m is offered (see. Figure.7). The cavity has two apertures on frontal and back side. Dimensions of apertures are 1.5m^{x}1.0m. For simplicity, the bounds of cavity are considered as PEC. Plane Electromagnetic wave propagates from x directions. E field has –y polarization and H field has z correspondingly. The magnitude of E is 1v/m. The frequency range is 10-400 MHz. The diffraction problem is solved on three numerical models with different numbers of unknowns: 1) n=4144, 2) n=6192, 3) n=7872. The Shielding Efficiency for middle point in cavity is calculated (see Figure 8). The Shielding Efficiency for electric field is obtained by formula $SE = -20 * \log_{10}(E_t / E_i)$, where E_t is total E field and where E_i is incident E field. It is well known, that exposure to RF and microwave radiation can produce adverse biological effects in human beings. Below, some study of possible influence of the EM field, producing high localized RF energy deposition on the live organisms, located in external field. Figure.9. presents the results of calculation EM field distribution into 2 cases of the room: with two windows one along to another Fig.7a, and just one window (Figure 9b). The incident field remains the same with amplitude 1, and directed to the open window. On the roller from the right side in the Figure.9a. there are the maximum values of the E field. In first case the E fields max possess the value is about 2v/m. In second case on the Figure 9b. roller points, that maximal value of E field is more then 5v/m. It is clear that the Q factor in second case is more than Q factor of first cavity. The result underlines fact that the resonant factor plays very important role at the evaluation of EM fields in cavities.

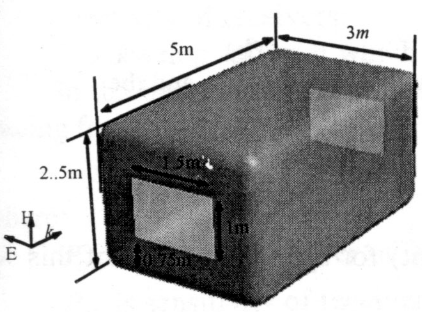


Figure.7 Dimensions of room like cavity with apertures and problem statement

CONCLUSION. The motivation of the article in big frame is to investigate electrodynamic, resonant properties of the semi open living place structures in miens of satisfaction of the safety and sanitary standards. Paper summarizes the acquisition of expert knowledge within the main principles

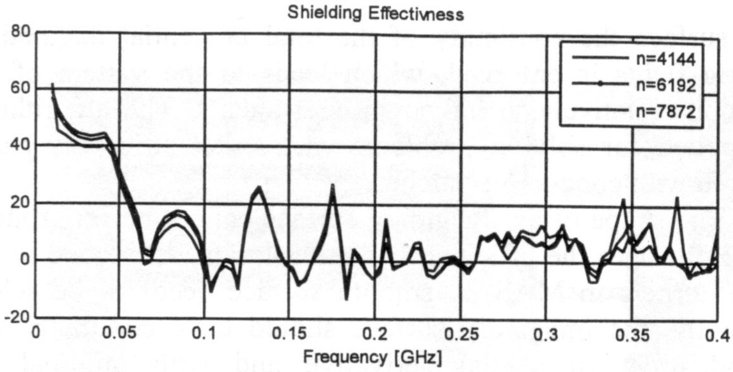


Figure.8 The Frequency characteristic of shielding efficiency in middle point of the cavity computed for three numerical models with different numbers of unknowns.

and features of the MAS numerical technique in application to 3-D problems. The limitations of the MAS, the area of applications, and the features which could be considered for efficient solution EM problems are presented. The MAS is extended to the simulation of the semi-open structures and problems.

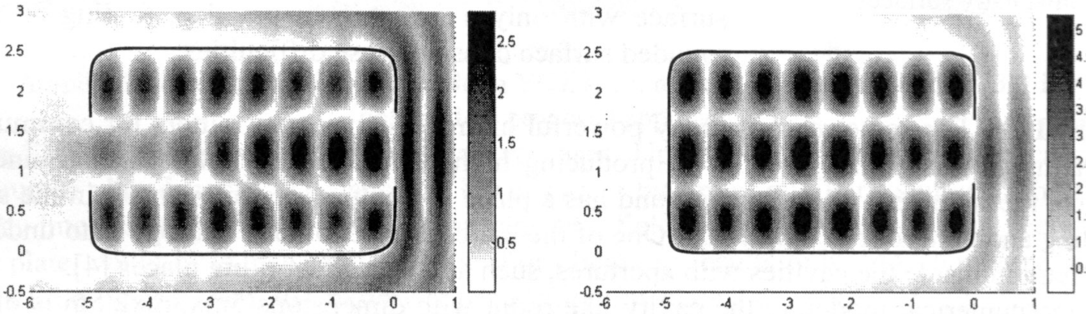


Figure.9

a) b)

E_y field distributions in XOZ slice for two cases: the cavity with two apertures and the cavity without back aperture

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