

APPLICATION OF THE METHOD OF AUXILIARY SOURCES TO THE THIN OPEN SURFACES

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Abstract - the study of the electromagnetic wave diffraction on the thin, perfectly conductor surfaces using the Method of Auxiliary Sources (MAS) is presented in this paper. Plane, corrugated and rounded plate cases are considered. Details of numerical realizations are discussed. Comparison of the numerical results obtained using MAS and Method of Moments (MOM) are given, from which the advantage of the MAS is for this cases is shown.

I. INTRODUCTION

The MAS in general represents the powerful numerical method. Using this method it is possible to solve many diffraction and wave scattering problems when the scatterer is bounded with the closed surface [1-3]. As it is known using the MAS the scattered field outside of the scatterer is described with the auxiliary sources located inside of the object and the field inside of the object (in case of the dielectric)-determined by outer auxiliary sources. In case of the open surfaces from the first look, the possibilities of the MAS are restricted, because it is not clear where we can distribute auxiliary sources. In this paper development of the MAS is considered to solve efficiently EM problems with open surfaces too. To deal with the thin, open surfaces, it is impossible to distribute the auxiliary sources inside the object. In this case MAS will reduce to the Method of the Integral Equations (MIE) or, in the best case, to the Method of Moments (MOM). In order to apply the MAS via proposed algorithm, investigated thin layer is continued using some finite size imaginary surface, which has the properties of the free space. From the both sides of this complete surface, the auxiliary sources are uniformly distributed. By satisfaction corresponding boundary condition on the plate and imaginary parts, the amplitudes of the auxiliary sources are determined. Finally, the scattered field could be studied around the object, including the surface.

II. APPLICATION OF THE MAS IN CASE OF THE OPEN SURFACES

Consider finite size thin conductor (not plane in general) which is irradiated by the certain electromagnetic wave. Let's continue the geometry of the plate by a finite imaginary surface with free space properties like it is shown on Fig.1. Then, let's distribute the auxiliary surfaces of similar up and down of the considered plate in certain distance. Auxiliary sources in a form of the mutually perpendicular elementary dipoles with unknown amplitudes are chosen:

$$\vec{E}_{el} = \frac{e^{ikR}}{4\pi\epsilon} \left\{ \left(\frac{1}{R^3} - \frac{ik}{R^2} \right) \left[3\vec{R}_0 \cdot (\vec{R}_0 \cdot \vec{\tau}) - \vec{\tau} \right] - \frac{k^2}{R} (\vec{R}_0 \times (\vec{R}_0 \times \vec{\tau})) \right\},$$

$$\vec{H}_{el} = \frac{i\omega e^{ikR}}{4\pi} \left(\frac{1}{R^2} - \frac{ik}{R} \right) (\vec{R}_0 \times \vec{\tau}).$$

Here \vec{R}_0 is the unit vector, which is directed from the dipole location to the observation point, R is the distance between the dipole location and the observation point, and $\vec{\tau}$ is the unit polarization vector of the dipole. The distributed system of the auxiliary sources on each auxiliary surface will describe the scattered field in the opposite semi-space. Their unknown amplitudes can be found considering the satisfaction of the boundary conditions the whole diffracted field on the plate and also around on the imaginary surfaces.

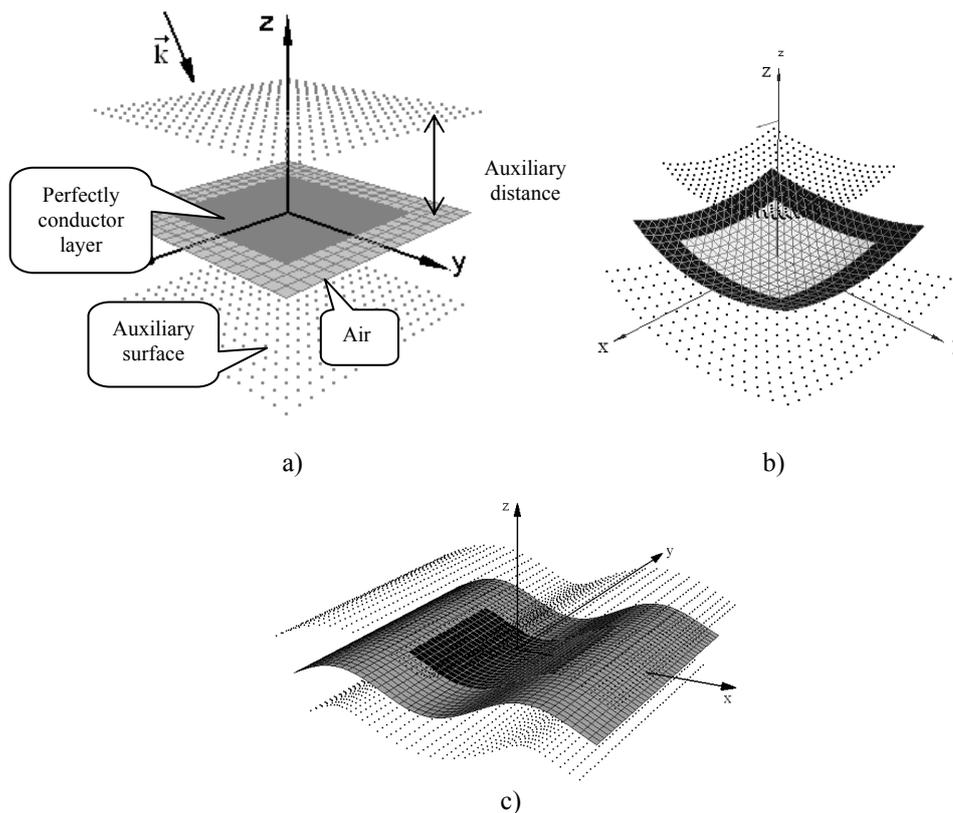


Figure 1. Considered surfaces

The surface of the plate is a conductor and thus the tangential component of the total electric field should be zero on this surface $E_t=0$. The imaginary surface is a free space and, therefore, the continuity of the tangential components of the total electric and magnetic fields is required: $E_{1\tau}=E_{2\tau}$, $H_{1\tau}=H_{2\tau}$. Using the mentioned boundary conditions the finding of the auxiliary sources amplitudes is reduced to the solution of the linear algebraic equation's system. Field in an upper semi-space must be determining as a sum of the incident field and field of the down located auxiliary sources. Field in a down semi-space will be the incident field plus field of the upper auxiliary sources. Here arises a new parameter – the size of the imaginary part of the free space, which could be determined by the convergence of the results of calculation and checking the boundary conditions good satisfaction everywhere on the complete surface.

III. NUMERICAL RESULTS

First the solution's accuracy dependence: on the N - number of the collocation points on the square wavelength; on the auxiliary sources distance d from the plate surface; on the size of imaginary part was investigated. It can be mentioned, that the main features of MAS realization remain the same (consideration of the scattered field's singularities as well as how to avoid the case of over determined system of linear equations). Generally, it is well known, that the shift of the auxiliary sources from the real surface makes scattered field function smoother on the surface of the body. The good scattered field's matching with the incident field in the collocation points remains in other surface's points too. Thus the convergence is achieved by using essentially less auxiliary sources. This shifting is restricted by the scattered field's singularities. In case of the plane surface and plane incident field it is not restricted because the image of the incident field is on the infinite distance. In regard to the scattered field's singularities which creates the edge's currents, we suppose, that this kind of distributed auxiliary sources will be able to describe it.

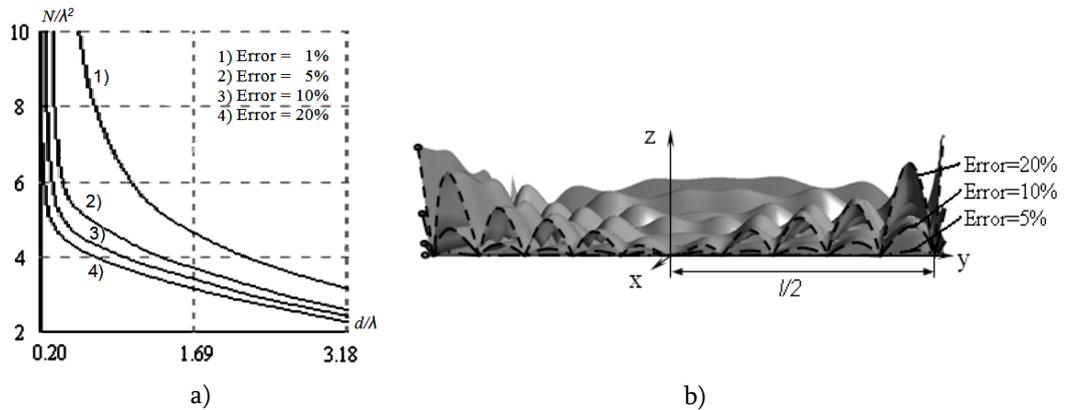


Figure 2. a) The accuracy of the boundary condition satisfaction;
 b) Error dependence on the auxiliary sources shifting. ($N/\lambda^2 = 6$)

The diffraction on the plane conductor has been studied. Figure 2a) shows collocation points (and, respectively, auxiliary sources) number per wavelength square (N/λ^2) dependence on the d/λ value in case of the different calculations error. With the increase the distance between the auxiliary sources and real surface up to $d/\lambda = 0.5$ substantially less sources are needs. Farther displacement is not so significant for calculation accuracy. At the same time it is well seen on the Fig. 2b) that increasing of the collocation point's number decreases the solution error. Study in details show that the worse satisfactions of the boundary conditions satisfaction are on the border of the plate and imaginary part. It is very crucial to choose positions of the auxiliary sources as well as collocation points exactly on the of conductor's and imaginary part's border. Study of the size of the imaginary part shows that it can be continued at least up to one-two wavelength. In comparison with other numerical methods such as FDTD or MOM, MAS allows to represent the field by a smaller number of unknowns. Figure 3 shows distribution of the near fields for two cases. On the figure 3a) result is shown for diffraction problem solved by using MAS and on the figure 3b) by MOM, for comparison. The area of the conducted plate is $64 \lambda^2$. In case of the MAS in fig 3a, when error of the calculation is approximately 1% we can see good shadow in transmitted wave. Whereas other numerical methods usually needs at least 100 unknowns per wavelength square on 3-D surface problems, proposed one uses significantly less computational resources. So, the MAS allow representing of field everywhere, including on the scatter's surface by a smaller number of unknowns as indicated above. In series of problems, proposed numerical technique MAS uses less computational resources and increases computation efficiency. Besides, this method allows calculating scattered field in immediate vicinity of the plate and even induced current on Fig. 4. Elementary source of the incident field in this case was located above the plate in near vicinity.

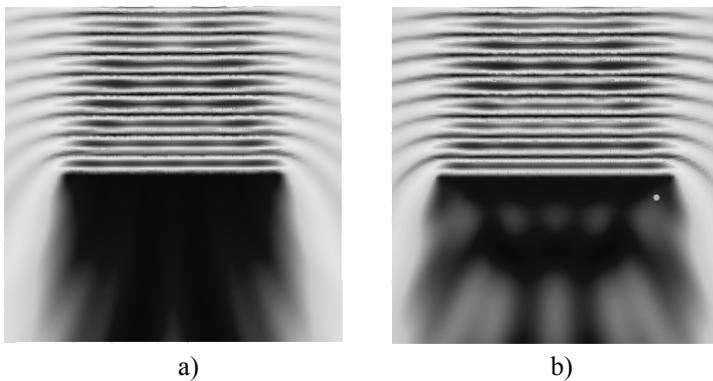


Figure 3. Comparison of MAS and MoM

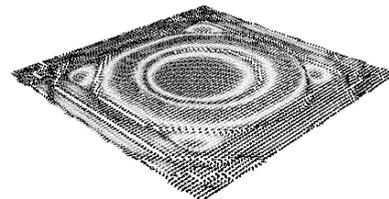


Figure 4. The currents distribution.

In case of the curved surface (fig. 1b) the simulation principles are same. For surfaces with pretty big curvature R – more then 10 wavelength auxiliary sources are constructed analogously. In this case auxiliary sources geometrical place are surfaces with radius of curvature $(R+d, \text{down})$ and $(R-d, \text{up})$. On figure 5 there is the complete (scattered and incident) near field's distribution. The plate almost completely shields the transmitted wave which confirms good satisfaction of the boundary conditions.

The described approach was applied also to the corrugated in one X axes direction, (Figure 1c.) sinusoidal surface with λ amplitude. Dipole form elementary source of the incident field is located on the 6λ distance above, along the Z axes with E_y polarization. The size of the conductor layer's area is $9\lambda^2$. Imaginary part was continued by 1.5λ to the all directions in the same way. In this case we have to consider scattered field's singularities position, which depends on the radius of the corrugated plate's curvature and the position of the EM field's source image in the plate. It means that we can not distribute the auxiliary sources very far from the real surface. But, anyway, looking on the fig 2a, even small shifting makes good advantage in calculation accuracy. In this case auxiliary sources are sifted to the surface along the collocation point's normal (See fig. 1c) on the 0.3λ distance. Fig.6 represents the near field distribution around the plate in XOZ and YOZ sections.

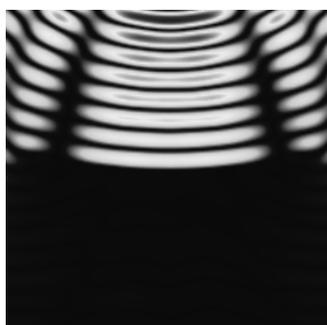


Figure 5. Simulated field distribution near the curved surface

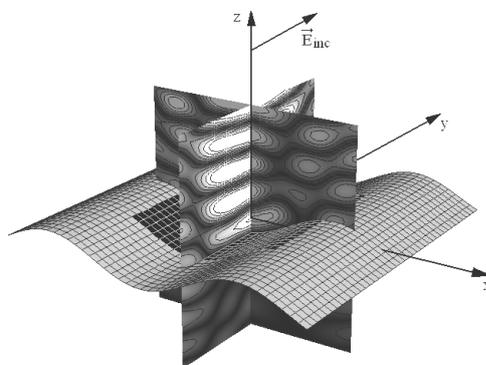


Figure 6. The near field distribution

IV. CONCLUSION

The MAS is extended to the simulation of open structures and problems. The paper demonstrates the ability of using MAS applied to diffraction problem on thin plates. Simulation results for several cases of thin plates are presented. The comparison with MoM simulation was conducted and advantage of the MAS is shown. More about the details of the proposed algorithm and features of numerical realization will be discussed during the presentation.

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