ADAPTED RADIATING BOUNDARIES (ARB) FOR EFFICIENT TIME DOMAIN SIMULATION OF ELECTROMAGNETIC INTERFERENCES

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Abstract

The novel method of Adapted Radiating Boundaries (ARB) is a very fast and powerful tool for the field simulation of electromagnetic interference in time domain. The ARB method shows a high stability of the algorithm and a very fast computational time. The ARB method is especially suitable for the efficient simulation of transient electromagnetic interferences between various lossy structures of complex geometry.

Introduction

EMI phenomena find increasing attention in many fields of technology. This leads to the demand for efficient simulation of transient electromagnetic interferences between different structures of nearly arbitrary shape. This demand cannot be fulfilled efficiently by the pure numerical field simulation methods:

The field simulation of very general structures exhibiting complex geometry and lossy materials may be performed by space discretizing methods like the Finite Difference Method (FDTD) or the TLM-Method [1,2,3]. On the other hand wide free space regions can not be effectively modeled with these methods.

For the simulation of fields radiating into free space regions the integral equation based Method of Moments (MoM) is very powerful [4,5]. In this case only two-dimensional manifolds have to be discretized. The computational effort is considerably reduced compared with space discretizing methods. On the other hand the MoM always is restricted to special classes of electromagnetic structures for which an analytical preprocessing has been done.

We have introduced the Transmission Line Matrix Integral Equation (TLMIE) method [6]. The TLMIE Method is a combination of the space discretizing TLM Method for the treatment of the near field behaviour and the integral equation method for the treatment of the free space electromagnetic field propagation over larger distances. The TLMIE method is powerful for the treatment of electromagnetic structures consisting of a number of substructures separated by large regions of free space. In this method each of these substructures is embedded into a closed spatial subdomain. Inside these closed spatial subdomains the space is discretized and Maxwell´s equations are solved using the TLM Method. The tangential electric and magnetic field components on the subdomain boundaries are related via Green´s functions and integral equations. The integral equations are solved by the method of moments. The numerical solution of the integral equation demands for the solution of a system of equations at every time step. For this reason convergence problems may occur.

In this paper we present the novel method of Adapted Radiating Boundaries (ARB). Using the ARB method the solution of a system of equations is not required. Without reduction of accuracy all the interacting fields are calcuated explicitly in time domain. This leads to a high stability of the calculation process and to a very fast computational time which is 10% of the time required by the TLM-Method.

The ARB method

To describe the ARB method we consider two complex electromagnetic structures exhibiting various lossy and dielectric materials and metallic layers of finite thickness. Each structure is embedded into a closed volume which is discretized spatially (Fig.1).

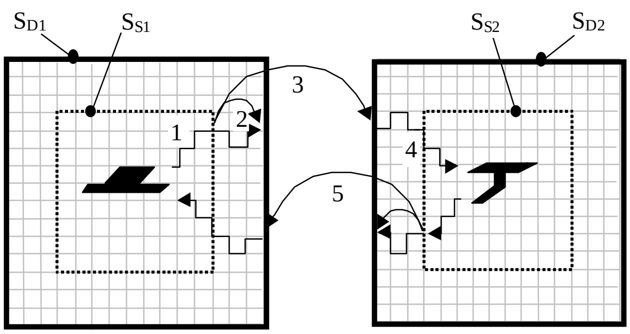

Fig.1: Signal paths between the modeled structures with open and radiating boundaries.

In our example the TLM method with symmetrical condensed nodes is used to solve Maxwell´s equations inside the subdomains [2]. However an FDTD scheme [1] can be used as well. The following consideration can be extended easily to more than two closed subdomains.

In the ARB method we introduce two kinds of surfaces:

- The test surfaces are closed surfaces where samples of the electromagnetic field components are taken.
- The free space boundary (FSB) surfaces are closed surfaces represent the boundary to free space

Each substructure is embedded in a region bounded by a test surface and this region again is embedded in a larger region bounded by a FSB surface. The estimates of the electromagnetic field components on the FSB surfaces are computed via time domain Greens functions from the field samples taken from the test surface. Due to the spatial separation between test surfaces and FSB surfaces there is a retarded dependence of field the FSB surface on the test surface field.

In our example the S_{D1} and S_{D2} are FSB surfaces and S_{S1} and S_{S2} are the test surfaces. S_{D1} and S_{D2} describe equivalent radiation sources. Following the path of a signal which is radiated from the structure 1 the propagation is simulated in the first path by the TLM scheme (path 1 in Fig.1).

In the TLM scheme the space is discretized into a mesh of transmission lines and nodes. The fields are mapped on incident waves **a** which are scattered at the nodes. The scattered waves **b** propagate along the transmission lines to the neighbouring nodes. The electric field is represented by $\mathbf{F}_E$ and the magnetic field is represented by $\mathbf{P}\ \mathbf{F}_M$ [7].

$$a = 1/2(\boldsymbol{F}_E + \boldsymbol{P}\boldsymbol{F}_M) \tag{1}$$

The total tangential field $\mathbf{E}_D$, $\mathbf{H}_D$ on the FSB surfaces is derived via Green´s functions from all the fields $\mathbf{E}_S$, $\mathbf{H}_S$ at the test surfaces of the different structures. In Fig.1 S_{D1} represents the destination points of the signal on path 2 and of all the signals which are radiated or backscattered via path 5 from the structure 2. In the case of path 2 special TLM-Greens-functions are used. The e.m. field propagation from structure 1 to structure 2 is described via dyadic Green´s functions in path 3 and via the

TLM-algorithm in path 4. The signal flow from structure 2 to structure 1 is simultanous.

When **r** is the location of a point on one of the open boundaries the total tangential field $\mathbf{E}_D$ is derived according to [4]. The vector **n** represents the normal vector to S_S. **r´**are the locations on the surfaces S_S. **R** is (**r**- **r**´):

$$\boldsymbol{E}_D(\boldsymbol{r},t)=\frac{1}{4\pi}\iint_{S_G}\left\{-\frac{\mu_0}{R}\frac{\partial}{\partial t}\left(\boldsymbol{n}(\boldsymbol{r}')\times\boldsymbol{H}_S(\boldsymbol{r}',t-\Delta t)\right)+\right.$$
$$+\frac{1}{R^3}\left[1+\Delta t\frac{\partial}{\partial t}\right]\left[\left(\boldsymbol{n}(\boldsymbol{r}')\times\boldsymbol{E}_S(\boldsymbol{r}',t-\Delta t)\right)\times\boldsymbol{R}+\right. \quad (2)$$
$$\left.\left.+\left(\boldsymbol{n}(\boldsymbol{r}')\cdot\boldsymbol{E}_S(\boldsymbol{r}',t-\Delta t)\right)\boldsymbol{R}\right]\right\}$$

The total tangential field $\mathbf{H}_D$ is derived in an analoguous way. The fields $\mathbf{E}_S$, $\mathbf{H}_S$ represent equivalent sources on the test surface S_S. For the discretized open boundary around the discretized regions the coupling of the fields can be expressed as a sum over those field contributions radiated from the discretized source points. This leads e.g. to the electric field:

$$\boldsymbol{E}^j_{D\mu}=\frac{\Delta l^2}{4\pi}\sum_{\nu_G}\left\{-\frac{\mu_0}{R_{\mu,\nu}\Delta t}\left(\boldsymbol{n}_\nu\times\left(\boldsymbol{H}^i_{S\nu}-\boldsymbol{H}^{i-1}_{S\nu}\right)\right)\right.$$
$$+\left[\left(\boldsymbol{n}_\nu\times\left((j-i+1)\boldsymbol{E}^i_{S\nu}+(i-j)\boldsymbol{E}^{i-1}_{S\nu}\right)\right)\times\left(\frac{\boldsymbol{R}}{R^3}\right)_{\mu,\nu}+\right. \quad (3)$$
$$\left.\left.+\quad\left(\boldsymbol{n}_\nu\cdot\left((j-i+1)\boldsymbol{E}^i_{S\nu}+(i-j)\boldsymbol{E}^{i-1}_{S\nu}\right)\right)\left(\frac{\boldsymbol{R}}{R^3}\right)_{\mu,\nu}\right]\right\}$$

The time step is chosen according to the TLM algorithm $\Delta t=\Delta l/2c$. The index μ is the index of all surface elements on the open boundaries while ν is the index of all surface elements on the radiating boundaries. The indices j and i are the time indices of the destination points and the source points respectively.

$$j=i+(2R)/\Delta l \quad (4)$$

Results

We consider a typical metallic enclosure with the height of 10 cm, a frontwidth of 34 cm, and a length of 16 cm (see [8]). The thickness of the metallic walls is 5mm. It has got two apertures with a length of 23 cm, referring to Fig.3. An electric dipole is placed in front of the enclosure. It is fed by a pulse with gaussian time dependence. We investigate the backscattering and the resonances of the metallic enclosure which is interfered by the antenna at a point P_1 in distance of 5 cm from the apertures in front of the enclosure and P_2 in the same distance inside the enclosure (Fig.3).

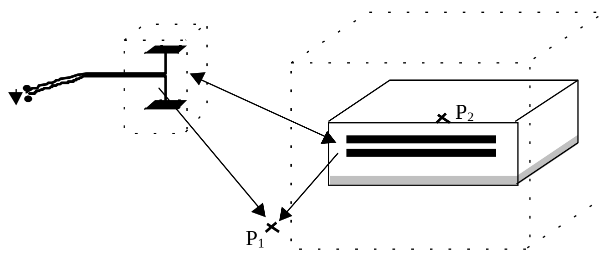

Fig.3: A short dipole antenna interfering with a metallic enclosure, discretized regions of the ARB-method

First we consider the vertical electric field at point P_1. In Fig.4 the contribution of the vertical electric field component is shown, which is radiated directly from the short dipole antenna. It is a short pulse. In Fig.5 the total vertical electric field is shown with the field backscattered from the metallic enclosure. After the pulse from the antenna the direct reflections at the enclosure are seen after 2.5 to 3.5 ns. Then the field is shown which is radiated from the enclosure which behaves like a cavity. The results of the ARB-method are compared to results of the TLM-Method where the TLM-method has been applied in a region, enclosing all structures. The results show very good agreement.

The computational time of the ARB-method is ten times lower. In Fig.6 the time dependence of the vertical electric field component inside the enclosure at point P_2 is shown. The resonating fields in the enclosure, which are excited by the antenna through the apertures are two times higher than the direct reflections.

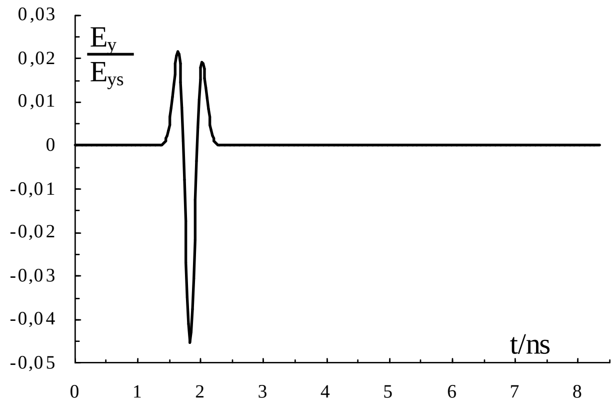

Fig.4: Contribution to the vertical field radiated from the short dipole antenna at point P_1.

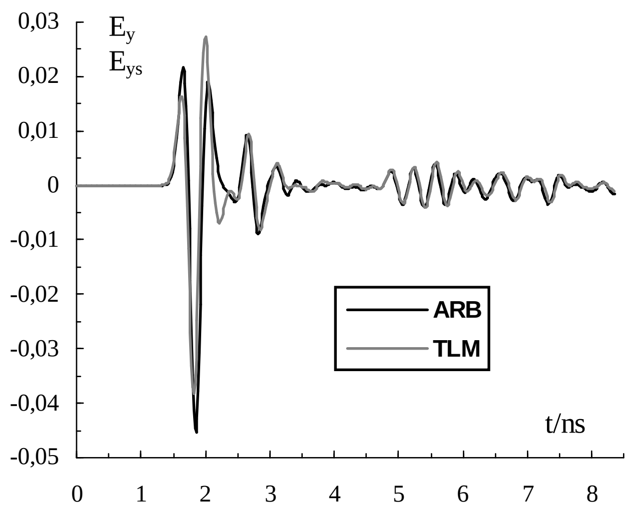

Fig.5: Field at point P_1, comparison of results from the ARB-method and the TLM-method

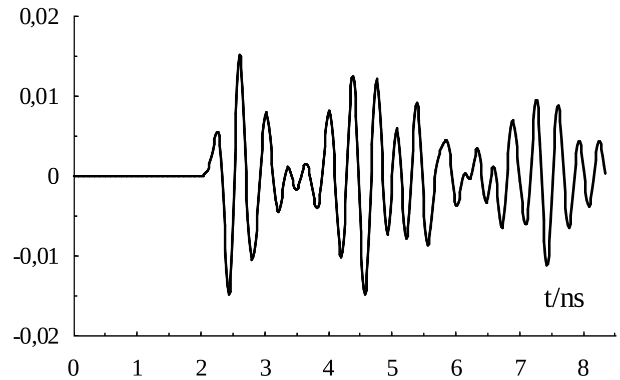

Fig.6: The vertical electric field at point P_2 inside the enclosure

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Conclusions

We have presented the novel ARB method for efficient field analysis of interfering radiating structures of complex geometry which may be separated by wide distances. All interactions and backscattering processes are taken into consideration in the ARB method.The ARB method is a very fast and flexible simulation tool for the general application to different structures of complex structure interfering with each other. The near field results calculated by the ARB method were compared with results of the pure TLM-method for an area of high extension. The CPU-time of the ARB-method is 10% of the time required by the pure TLM-method. The results show very good agreement.

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