TIME-DOMAIN MODELING OF TRANSIENT PROCESSES IN OPEN RESONANCE STRUCTURES

Y. K. Sirenko[1,2], A. O. Perov[1], and E. Yaldiz[2,3]

[1]*Institute of Radiophysics and Electronics, Kharkov, Ukraine*
[2]*Gebze Institute of Technology, Gebze/Kocaeli, Turkey*
[3]*Selcuk University, Konya , Turkey*

The problem of correct and efficient truncation of computational domain of finite-difference methods used for analysis of transient processes in infinite two-dimensional regions with compact resonance inhomogeneities is solved. The basis for the approach is the formulation and incorporation into a computational scheme of the exact "absorbing" conditions in a Cartesian grid.

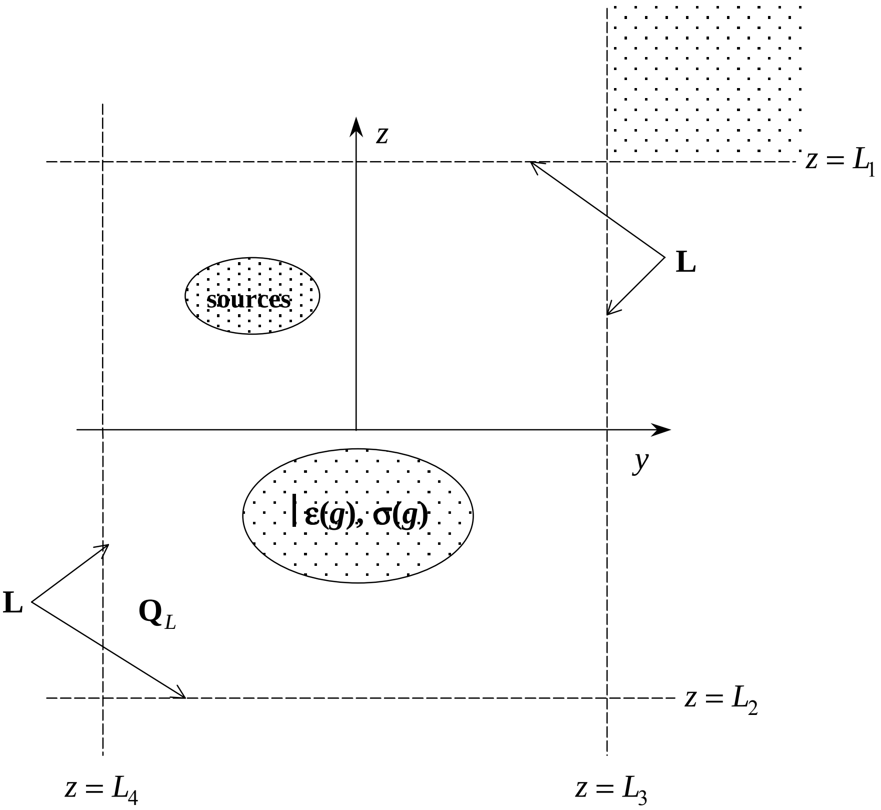
The initial boundary value problem

$$\begin{cases} \left[-\varepsilon(g)\dfrac{\partial^2}{\partial t^2}-\sigma(g)\dfrac{\partial}{\partial t}+\dfrac{\partial^2}{\partial z^2}+\dfrac{\partial^2}{\partial y^2}\right]U(g,t)=F(g,t), \\ \qquad t>0, \quad g=\{y,z\}\in\mathbf{Q}=\mathbf{R}^2, \\ U(g,t)\big|_{t=0}=\varphi(g), \quad \dfrac{\partial}{\partial t}U(g,t)\Big|_{t=0}=\psi(g), \\ U(g,t)=E_x,\ E_y=E_z=H_x\equiv 0, \\ \dfrac{\partial}{\partial t}H_y=-\dfrac{1}{\eta_0}\dfrac{\partial}{\partial z}E_x, \quad \dfrac{\partial}{\partial t}H_z=\dfrac{1}{\eta_0}\dfrac{\partial}{\partial y}E_x \end{cases} \tag{1}$$

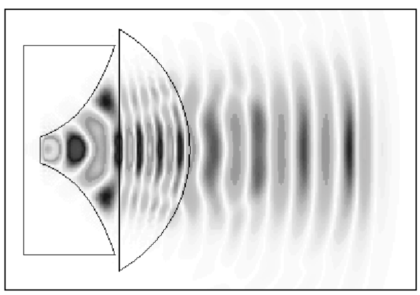
describes the radiation, propagation, and scattering processes of nonsinusoidal E-polarized waves in the space $\mathbf{R}^2=\{g=\{y,z\}:|y|<\infty,|z|<\infty\}$. The inhomogeneities are given by real finite functions $\sigma(g)=\sigma_0(g)\eta_0$ ($\sigma_0(g)$ is a specific conductivity and $\eta_0=(\mu_0/\varepsilon_0)^{1/2}$ is an impedance of a free space) and $\varepsilon(g)-1$ ($\varepsilon(g)$ is a relative permittivity).

In [1–3] we have already considered such problems and have obtained there rigorous solutions by finite-difference methods through the truncation of the computational domain by a coordinate (in a polar grid) virtual boundary enveloping all sources and effective scatterers. In the present paper a similar solution for the Cartesian grid is proposed. The main purpose of such a change-over is to get rid of a number of essential inconveniences arising from discretization in polar coordinates, where computer resources are not exploited reasonably. The matter is that l, the discretization step in time, and h, the spatial step, squared should be of the same order of magnitude in order to ensure the stability of finite-difference computational schemes in a polar grid. That requirement increases the computational time by a factor of 10 as compared with the operation in the Cartesian grid, where l can be comparable with h. Another reason, noticeably strengthening a negative effect of the first one, is associated with the following physically justified requirement [4]: the maximal size of the spatial grid mesh has to be at least two times smaller than a typical size of the analyzed object. Because of this, the large outer radius of computational space is a cause for substantial reducing the spatial grid meshes in an angular variable. One could close the analyzed domain by a coordinate boundary in the polar grid and solve the problem in the Cartesian grid. However, such a straightforward solution poses a number of problems in correct approximation of exact conditions from one coordinate grid onto another one. This fact properly sacrifices almost all basic advantages of the use of the exact "absorbing" conditions.

In the present work we suggest a solution of the problem specified above and use all accumulated experience for constructing exact "absorbing" conditions such that they allow one to discretize initial boundary value problems (1) in the Cartesian grid correctly and efficiently. In all cases considered before, the basis for constructing exact "absorbing" conditions was formed by the radiation conditions for elements of an evolutionary basis of signals propagating along various regular waveguide structures [3] such as closed waveguides and Floquet channels, horn-type waveguides, a free space and so on. The properties of evolutionary bases (such bases are invariable under changes of a type of a guiding structure) have enabled the analyzed domains in open problems to be closed by transverse (with respect to a



a



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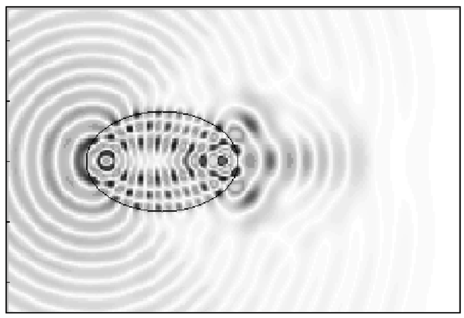

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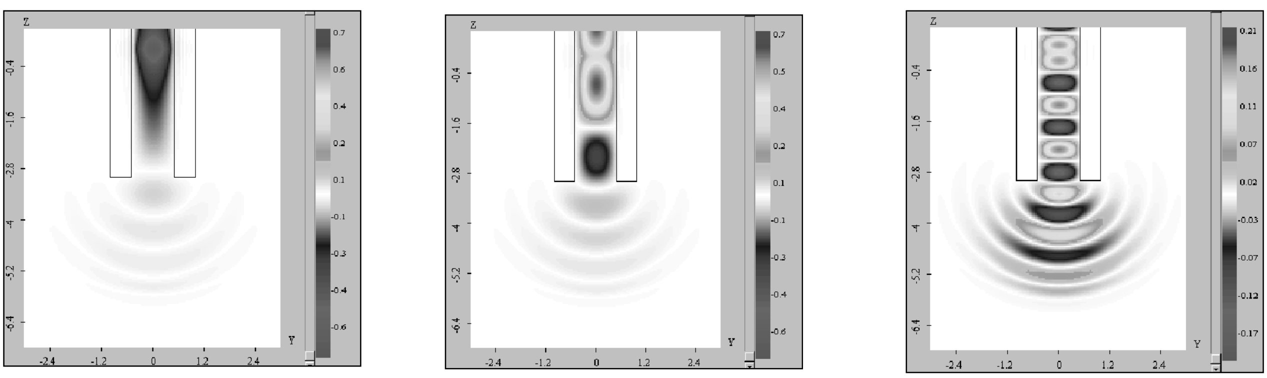

d

Figure 1. Geometry of model problems (a) and examples
of their numerical solution (c–d).

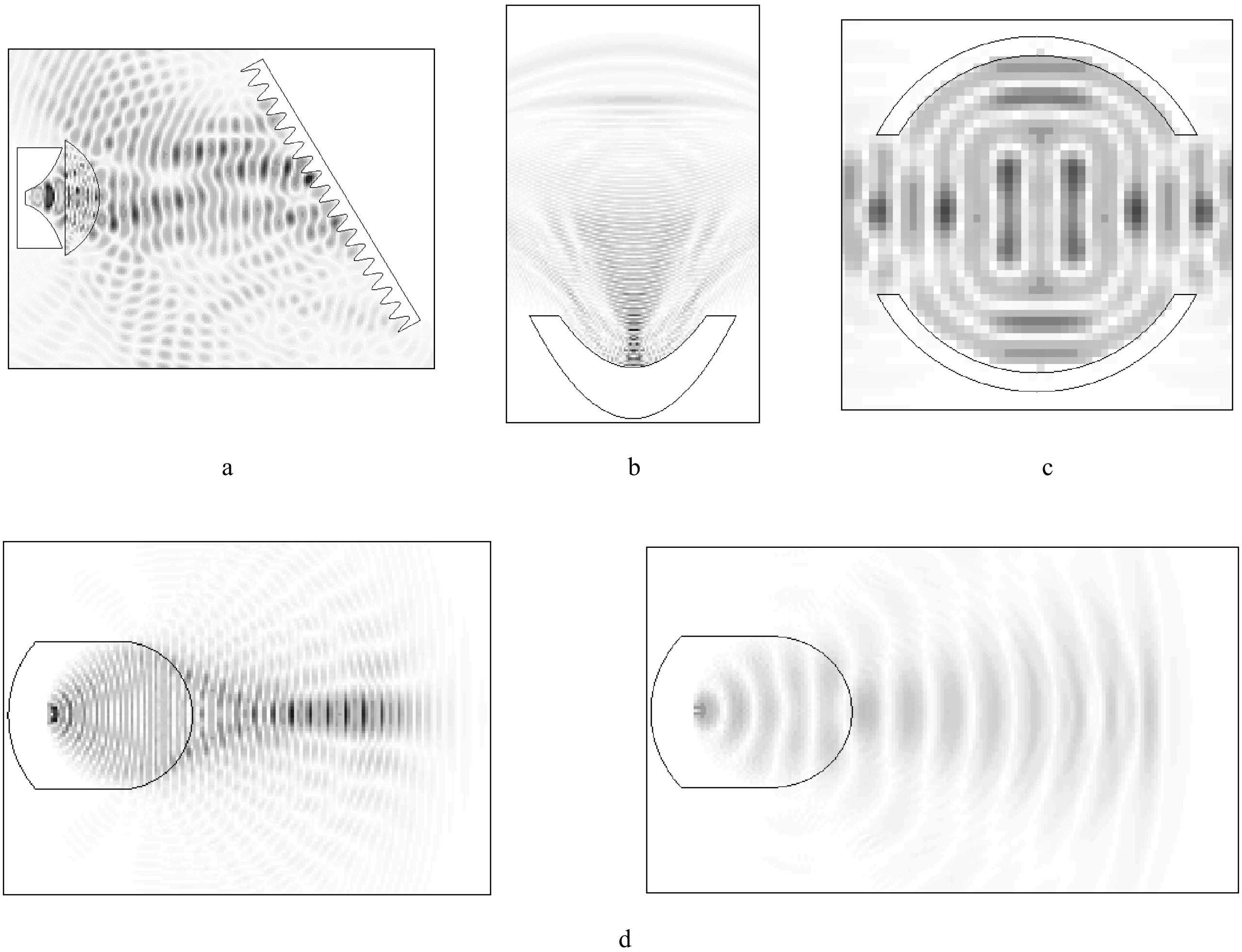

Figure 2. Examples of numerical solutions for problems (1).

wave propagation direction) coordinate boundaries: one boundary for one propagation channel of "outgoing" wave. In the case considered below, we are coming up against the necessity of "closing" one radiation channel by four coordinate boundaries. The analyzed domain is constricted to $\mathbf{Q}_L = \{ g \in \mathbf{Q} :\ L_4 < y < L_3;\ L_2 < z < L_1 \}$ (see Fig. 1,a). The problem of corner points (the points of intersection of coordinate boundaries [5,6]) arises. It is just this problem that receive our primary attention, because the technique for constructing exact "absorbing" conditions and algorithmization of arising "closed" initial boundary value problems remains practically unchanged [3].

In Figures 1 and 2 we give illustrative examples of the numerical solution for problems (1). The fragments of these figures display spatial distribution of the electric field intensity for semi-infinite step-function of the excitation $F(g,t)$ at different observation times t in the: exponential horn with a dielectric lens (Fig. 1,b), dielectric ellipse (Fig. 1,c; the source is placed near the left focus), open end of a plane-parallel waveguide (Fig. 1,d), structure "radiator – finite metal grating" (Fig. 2,a), parabolic radiator (Fig. 2,b), open resonator with cylindrical mirrors (Fig. 2,c), and the near zone of Luneberg lens with a metal screen (Fig. 2,d).

Below (see Fig. 3) we give one more example. A teflon radiating element

$$\varepsilon(g) = 1 + 1.1\big(\chi(y)\chi(10.1-y)\chi(1.35-|z|) + \\ + \chi(y-10.1)\chi(12.1-y)\chi(0.75-|z|)\big)$$

is placed into the aluminum sleeve

$$\sigma(g) = 13.3\times 10^{7}\,\big(\chi(y+0.25)\chi(2.5-y)\chi(1.6-|z|) - \\ - \chi(y)\chi(2.5-y)\chi(1.35-|z|)\big)$$

and is exited by the 'soft' source

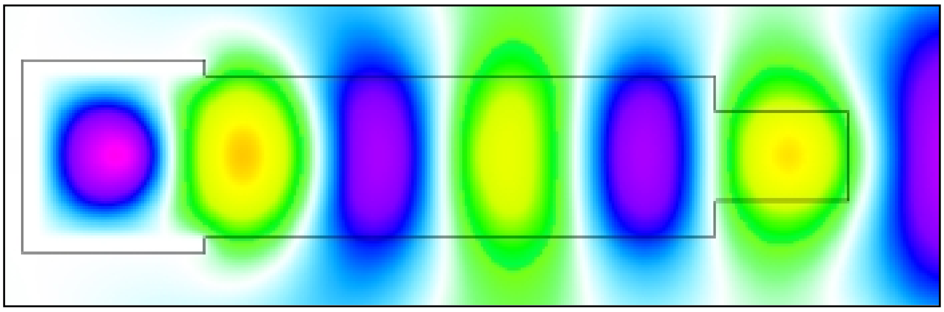

Figure 3. Simulation of the antenna for a radar for subsurface sensing.

$$F(g,t)=10\chi\left[0.25^2-z^2-(y-1.25)^2\right]\cos(1.2t),$$
$$\varphi(g)=\psi(g)\equiv 0.$$

Here χ is a Heaviside function. The closure of the analysis domain is $\overline{\mathbf{Q}_L}=[-0.5\le y\le 15]\times\times[-2.5\le z\le 2.5]$, the grid step size in time equals to 0.01; the value σ is chosen in line with the assumption that all dimensions are given in centimeters. The two-dimensional figures show the distribution of the intensity of the electrical field $U(g,t)=E_x$ everywhere in $\mathbf{Q}_L$ for various observation moments t. It is simulated the realistic antenna used in the radar for subsurface sensing (the product of the Turkish-Ukrainian Joint Research Lab., TUBITAK-MRC, Turkey, headed by A. A. Vertiy).

REFERENCES

1. Perov A. O., Sirenko Y. K., and Yashina N. P. Explicit conditions for virtual boundaries in initial boundary value problems in the theory of wave scattering // JEWA. – 1999. – V. 13, № 10. – P. 1343–1371.
2. Perov A. O., Sirenko Y. K., and Yaldiz E. Exact conditions on virtual boundaries for FDTD-method in model problems of pulse sensing. In the book “International Workshop on Direct and Inverse Wave Scattering”. – Gebze, Turkey: Gebze Inst. of Technology, 2000. – P. 6-37–6-46.
3. Sirenko Y. K., Sukharevsky I. V., et al, ‘Fundamental and Applied Problems in the Theory of Electromagnetic Wave Scattering’, Ed. by Y. K. Sirenko, Krok, Kharkov, 2000.
4. Taflove A. Computational Electrodynamics – the Finite Difference Time Domain Method. – Massachusetts: Artech House, 1995.
5. Bamberger A., Joly P., and Roberts J. E. Second order absorbing boundary conditions for the wave equation: a solution for the corner problem // SIAM J. Numer. Anal. – 1990. – V. 27, № 2. – P. 323–352.
6. Collino F. Conditions absorbantes d`ordre eleve pour des modeles de propagation d`onde dans des domaines rectangulaires. – Rocquencourt, France: I.N.R.I.A. report №1790, 1993.