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Interactive Application for Visualization of the Basic Phenomena in RF and Microwave Devices

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Abstract—**An interactive computer application visualizing the basic phenomena in RF and microwave devices is presented. Such kind of educational package can be a very helpful tool for the students as well as for the teachers (of electronics and related fields). This paper is focused on three exemplary problems only and involves: movement of electric charge, filtering of electromagnetic waves and interference phenomena in antenna arrays. The main part of the application (engine) is based on standard techniques. The package is designed in a game form which should increase the attractiveness of the application and improves learning outcomes.**

I. Introduction

This paper concerns an interactive computer application visualizing the basic phenomena in RF and microwave devices. It is motivated by weakening interest of this important but difficult knowledge among the students of electronics and related fields. This educational package can be a very helpful tool for the students as well as for the teachers. In order to increase the attractiveness of the application and improve learning outcomes it is designed in a game form. This paper is focused on three exemplary problems only, however, the package will ultimately be extended):

- behavior of an electric charge in electromagnetic (static) field,
- filtering of electromagnetic waves in simple waveguiding structures,
- interference of the electromagnetic field generated by simple antenna arrays.

The computational part of the application is based on standard techniques such as finite difference method, mode matching and analytical formulas.

II. Formulation of the problems

All the considered problems are implemented as a separate stages of the package but the convention of the educational game is similar. Each stage has several levels of different difficulty, which require better knowledge and understanding of the phenomena to realize the quest. The interface is clear and intuitive and its operation should not cause any problems even for inexperienced user.

A. Electric charge in electromagnetic (static) field

The problem concerns an electric charge moving in the static field generated by other charges and conductors with current (depending on the difficulty level). The issue is reduced to two dimensional space. The idea of this stage can be briefly described by the following sequence of operations:

1) The user chooses a difficulty level (number of charges and conductors).
2) A random configuration of charges and/or conductors is generated and the trajectory of the considered charge is determined (the configuration and the trajectory are invisible to the user).
3) On the base of the calculated trajectory the allowed path of the charge is estimated and shown to the user (the allowed path is obtain by extension of the trajectory to a specified thickness). Also a new random configuration of the sources is generated - see Fig. 1a.
4) The user has to reconstruct the configuration of the charges and/or conductors in order to obtain the movement inside the allowed path.
5) After the reconstruction try, the user starts the simulation of the charge movement to check its correctness (see Fig. 1b.)
6) If the reconstructed configuration is correct (see Fig. 1c.) the charge moves inside the path and the level is completed. Otherwise the configuration can be modified again and the simulation can be repeated until the charge trajectory is acceptable.

It is worth mentioning, that at any time the user may observe the field distribution in the considered space, which can be very helpful in understanding and anticipating of the charge movement.

The main part of this simulation (the charge movement) is based on central finite difference technique. Starting from Lorentz force and the second Newton's law (for two dimensional case) the charge position $\vec{r}(t) = [x(t), y(t)]$ is determined by a set of differential equations

$$\begin{cases} m\frac{d^2x}{dt^2} = qE_x\big(x(t),y(t)\big) + q\frac{dx}{dt}B_z\big(x(t),y(t)\big) \\ m\frac{d^2y}{dt^2} = qE_y\big(x(t),y(t)\big) + q\frac{dy}{dt}B_z\big(x(t),y(t)\big) \end{cases} \tag{1}$$

where m represents mass of the charge, E_x, E_y and B_z represent the electric and magnetic fields generated by the sources. Using central finite difference method the equation (1) simplifies to algebraic iterative formula [1], [2]:

$$\begin{bmatrix} x^{[n+1]} \\ y^{[n+1]} \end{bmatrix} = \begin{bmatrix} \frac{2m}{q\Delta t} & -B_z^{[n]} \\ B_z^{[n]} & \frac{2m}{q\Delta t} \end{bmatrix}^{-1} \begin{bmatrix} \frac{2m}{q\Delta t}(2x^{[n]} + x^{[n-1]}) - B_z^{[n]} y^{[n-1]} + 2\Delta t E_x^{[n]} \\ \frac{2m}{q\Delta t}(2y^{[n]} + y^{[n-1]}) + B_z^{[n]} x^{[n-1]} + 2\Delta t E_y^{[n]} \end{bmatrix} \quad (2)$$

where $x^{[n+1]}$, $y^{[n+1]}$ represent discrete position of the charge, and Δt is the time step (two first steps can be obtained from the initial conditions).

B. Filtering of electromagnetic waves in simple waveguiding structures

In this stage a few waveguide filters (with different number of resonant chambers and/or metal obstacles) are considered with the use of mode matching technique [3] . Also in this case, it is convenient to describe the stage with a brief list:

1) The user chooses a difficulty level, which represents a kind of filter (number of resonators and/or obstacles)
2) A random characteristic of the filter is taken from the database (corresponding to the chosen filter type) and it is presented to the user as a goal to be achieved - see Fig. 3a.
3) A chosen type of a filter is generated (with some random dimensions - see Fig. 2) and the user has to modify its dimensions to obtain the assumed characteristic.
4) When the dimension are chosen, the user can start the simulation process and observe if the obtained characteristic fulfills the initial assumption.
5) If the obtained characteristic is ”similar” (acceptable) to the assumed one the level is completed (see Fig. 3c). Otherwise (see Fig. 3b), the configuration can be modified again and the simulation can be repeated until the results are acceptable.

It is worth mentioning, that also in this stage the user may observe the field distribution inside the structure (for a fixed frequency). Such option can be very helpful in understanding the phenomena of filtering and may improve this manual optimization process.

C. Interference of electromagnetic field generated by simple antenna arrays

The aim of the next stage is to familiarize students with the principle of operation of simple antenna arrays. These systems are designed to shape the total radiation pattern, by direct interference of the fields from single isotropic radiators. The total characteristic can be estimated using simple analytical formula (array factor [5])

$$\Phi(\theta) = \sum_{n=0}^{N-1} \Phi_n(\theta) \exp\left[j(2\pi \frac{d}{\lambda} cos(\theta) + \alpha)n\right] \quad (3)$$

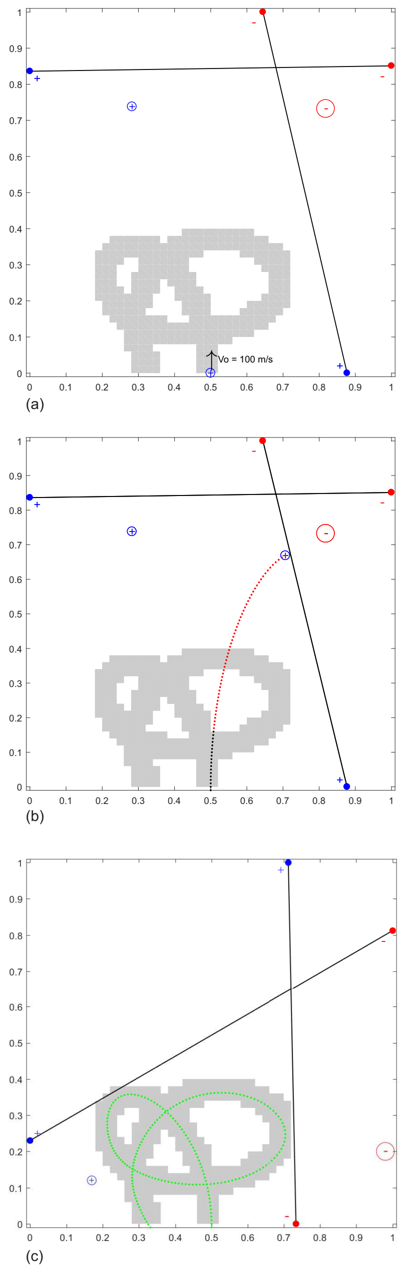

Fig. 1. Electric charge movement in electromagnetic (static) field generated by the other charges and conductors with current: (a) allowed path (gray), (b) unsuccessful try (for random configuration of the sources), (c) successful try (after reconfiguration o the sources).

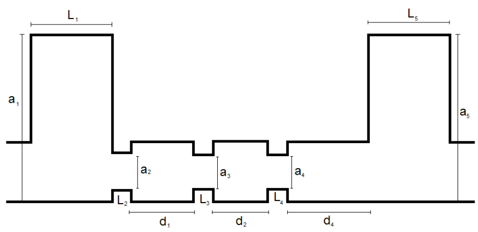

Fig. 2. The third order waveguide filter scheme [4].

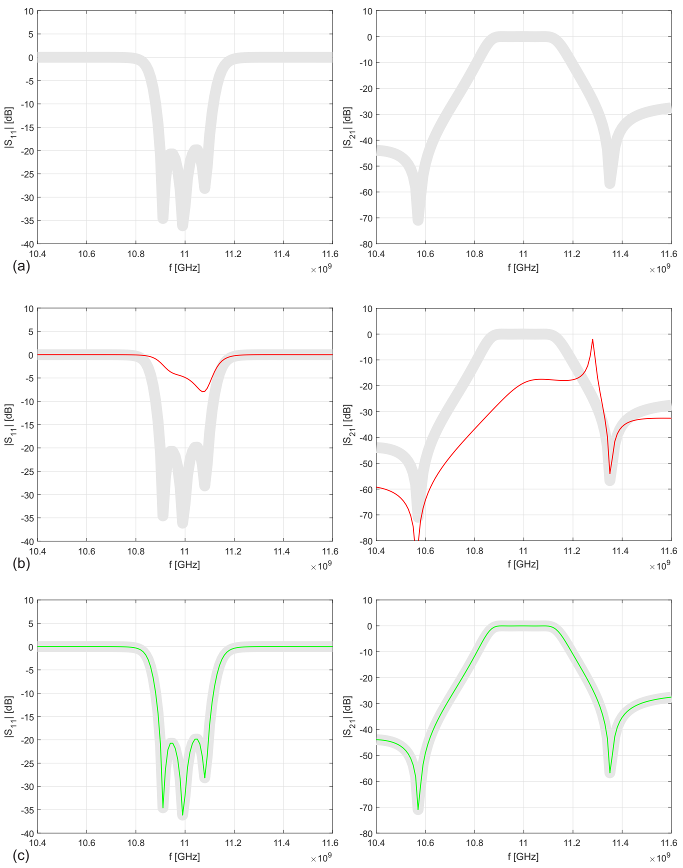

Fig. 3. The third order waveguide filter characteristic: (a) acceptable shape (gray), (b) unsuccessful try (for random geometry), (c) successful try (after reconfiguration o the structure).

where $\Phi_n(\theta) = const$ represents the radiation from single radiator (isotropic), N is number of radiators, d is distance between the radiators and α is phase shift.

As in the previous stages, it is convenient to describe the problem in the list of following steps:

1) The user chooses a difficulty level, where different parametres of the structure are unknown (number of radiators, distance, phase shift).
2) A random radiation characteristic of the array is taken from the database and it is presented to the user as a goal to be achieved - see Fig. 4a.
3) The user has to chose the array parameters: number of radiators, distance and phase shift (depending on the difficulty level) to obtain the assumed characteristic.
4) For the chosen parameters the radiation characteristic is estimated and its correctness is verified.
5) If the obtained characteristic is acceptable the level is completed (see Fig. 4c). Otherwise (see Fig. 4b), the parameters can be modified again and the verification can be repeated until the results become similar to the initial characteristic.

An important advantage of this stage is the direct presentation of the field interference for any chosen set of parameters

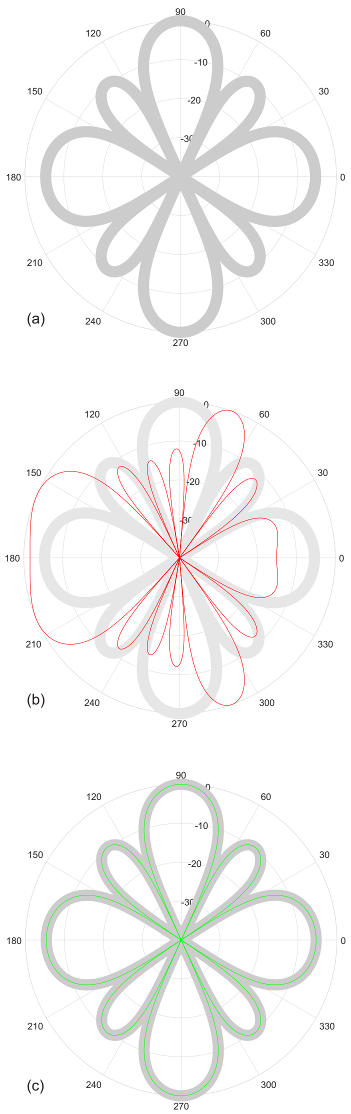

Fig. 4. Example of radiation pattern for frequency $f = 2.4$ GHz and $d/\lambda = 0.8$:(a) acceptable pattern (gray), (b) unsuccessful try (for random geometry), (c) successful try (after reconfiguration of the structure parameters).

(also in near-filed). Such feature can significantly improve the understanding of the phenomenon and helps in completing the task. Some general aspects of education in antennas are discussed in more detail in [6].

III. Conclusion

An educational package visualizing the basic phenomena in RF and microwave devices has been presented. Such an application can be a very helpful tool for the students as well as for the teachers. The package is designed in a game form which should increase the attractiveness of the application and improves learning outcomes. The movement of the charge in static fields is a first step into the world of electromagnetism. The user can become familiar with the simplest interactions between fields and matter. In the second stage the user can observe the electromagnetic wave propagation inside the wavegiude discontinuities, which is a base to understanding phenomena of filtering. The last stage, interference of electromagnetic field, is particularly important in explaining the principle of operation of antenna arrays.

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