Simulation of Electromagnetic Waves in Free Space

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Abstract:

In this paper, considers a solution of Maxwell's curl equations by using the finite-difference time-domain (FDTD) method. We simulated electromagnetic waves propagation in free space. The electric and magnetic fields generated in two cases to make a comparison between the models. All models were computed using the same parameters. This study showed that the intensities of the fields affected when adding three excited sources pointed in three locations. However, it was noted that three sources placed in the same location improved the distributions of the fields. Therefore, this difference in excitation position leads to change the image intensity distribution.

Key words: *Electromagnetic, electric field, magnetic field, Finite Difference Time Domain (FDTD) method.*

1.Introduction.

Some applications require radiation characteristics that may not be reachable by a single element. The arrangement of the elements in space may be such that the element adds up to give a radiation maximum in a particular direction or minimum in others. To study the dependence of the field distribution on the number and position of the sources, the field components (E_x, E_y, E_z, H_x, H_y and H_z) were calculated using the FDTD. In this study, we made a comparison between two models the first model the signals generated by three sources that were placed in the same position, and second model, we placed the sources in three locations.

Method:

In electromagnetic problems, there are many methods that can be used such as the Method of Moment (MOM), Transmission Line Matrix (TLM) method and Finite-Difference Time-Domain method. The FDTD is a time domain numerical method that can be used numerically to solve differential equations. It is a computer simulation technique and now becoming the most popular method and a powerful method to solve Maxwell's equations in the time domain. The FDTD was first proposed by K. S. Yee in 1966 [1]. The Yee cell showed in figure 1 has the following features: the electric field is defined at the edge of a cube and the magnetic field is defined at the face of the cube as shown in figure 1. The problem space is converted into a regular mesh that consists of small Yee cells. This method directly discretized Ampere's and Faraday's lows into a system of difference equations based on the electric and magnetic fields. It is designed to calculate spatially discretized electric field at time instants and spatially discretized magnetic field as well. It is a direct implementation of the time dependent Maxwell's equations. This method is used to solve Maxwell's curl equations and can be written as [2]:

$$\frac{\partial \mathbf{H}}{\partial t} = -\frac{1}{\mu_0}\nabla \times \mathbf{E}, \qquad \text{.......................................} \qquad (1)$$

$$\frac{\partial \mathbf{E}}{\partial t} = \frac{1}{\varepsilon_0}\nabla \times \mathbf{H} \qquad \text{.......................................} \qquad (2)$$

In the magnetic field strength (***t*** is the time and x, y, z are the spatial coordinate) and μ_o is the permeability and ε_o is the permittivity of free space. The Yee cell is used for the FDTD technique and this method can be used for very complicated inhomogeneous dielectric structures as well.

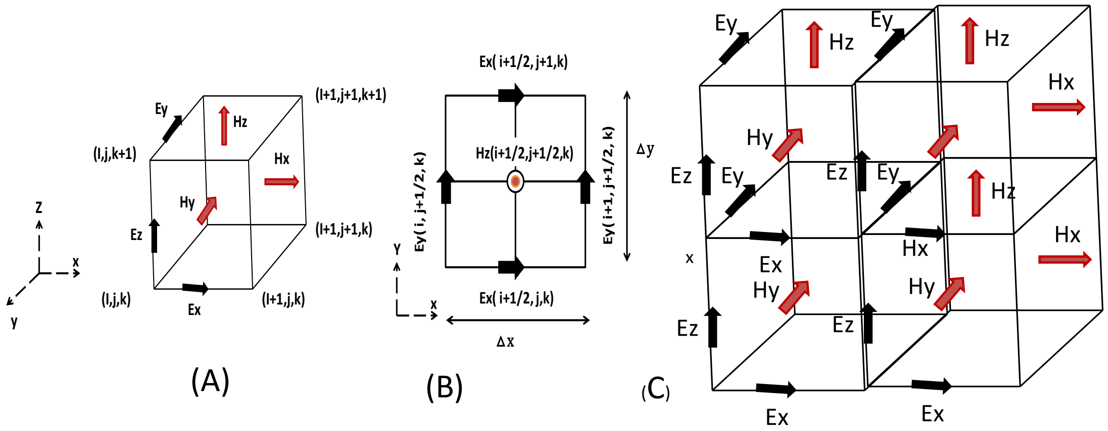


Figure 1: A standard Cartesian Yee cell (A) and geometrical relationship between E and H fields in the cell: (E-Electric field Edges centres and H-magnetic fields face centres) (B). The FDTD cubic grid has $N_x \times N_y \times N_z$ cube cells and $N_x \times N_y \times N_z$ corner nodes. A three dimensional space lattice consists of a multiplicity of such Yee cells (C) [3].

The nodal electric field is located exactly half way between magnetic field nodes as shown in figure 1. The electric field can be calculated using the surrounding magnetic field components and also the magnetic field can be computed from the surrounding electric field components. The finite difference approximation for the x component of equations (1) and (2) can be written as [3]:

$$E_x^{n+1}\left(i+\tfrac{1}{2},j,k\right) = E_x^{n}\left(i+\tfrac{1}{2},j,k\right) + \frac{\Delta t}{\sqrt{\varepsilon_0\mu_0}\Delta x}\left[H_z^{n+\frac{1}{2}}\left(i+\tfrac{1}{2},j+\tfrac{1}{2},k\right) - H_z^{n+\frac{1}{2}}\left(i+\tfrac{1}{2},j-\tfrac{1}{2},k\right) + H_y^{n+\frac{1}{2}}\left(i+\tfrac{1}{2},j,k-\tfrac{1}{2}\right) - H_y^{n+\frac{1}{2}}\left(i+\tfrac{1}{2},j,k+\tfrac{1}{2}\right)\right] \quad \dots (3)$$

$$H_x^{n+\frac{1}{2}}\left(i,j+\tfrac{1}{2},k+\tfrac{1}{2}\right) = H_x^{n-\frac{1}{2}}\left(i,j+\tfrac{1}{2},k+\tfrac{1}{2}\right) + \frac{\Delta t}{\sqrt{\varepsilon_0\mu_0}\Delta x}[E_y^{n}\left(i,j+\tfrac{1}{2},k+1\right) - E_y^{n}\left(i,j+\tfrac{1}{2},k\right) + E_z^{n}\left(i,j,k+\tfrac{1}{2}\right) - E_z^{n}\left(i,j+1,k+\tfrac{1}{2}\right) \quad \dots (4)$$

There are similar expressions for *y* and *z* field components. These are known as an update equations and it demonstrates that the future values of (E_x, E_y, E_z) and (H_x, H_y, H_z) depend on previous values and neighbouring electric and magnetic fields. It can be seen that the dividing line between future and past values has moved forward a half temporal step. Therefore, the half cell and half time step are necessary.

The FDTD approach that is based on Yee's cell and formulation is adopted for this work. The aim of this calculation is that the simulation of a pulse propagating in free space in three dimensions.

Moreover, the work is focused on the modelling electromagnetic wave generate by using the three sources emitting signals, in order to evaluate the influence of adding more sources on the distributions of the electromagnetic waves. All calculations were computed by using MATLAB 7.10 (R 2010 a). The program was written based on solving the time dependent Maxwell's curl equations in free space. Computer simulations were performed with the same grid in order to make a comparison between the models. The calculation domain consisted of $36 \times 36 \times 36$ cubic cells with a cell size of 0.01 *m*. Many signals have been used in the FDTD and the most common are a Gaussian pulse, modulated Gaussian and sinusoidal signal.

In this study, it was driven with a Gaussian pulses. They were placed overlapping each other and pointing in three directions. The signals that emitted from the sources were combined in each time step to generate the electric and magnetic fields by using the root of sum of squares method. The fields were computed in each cell and vowel at each time step. When the cell size is selected, the maximum time step can be calculated based on the Courant condition [4]. The stability condition is given:

$$\Delta t \leq \frac{1}{c\sqrt{1/\Delta x^2 + 1/\Delta y^2 + 1/\Delta z^2}}, \quad \text{..........................} \quad (5)$$

The most important feature of the simulations is the ability to show how generate fields depend on the positions of the sources. It can be assumed that a point source will act as the radiated fields of the short dipole which generates the waves in free space. In this study the sources of excitation are placed in the centre of FDTD domain.

Results and Discussion:

Calculations were performed with a Gaussian pulse for 22 time steps with the same grids. The fields can be generated by adding three excited sources in the program and placing them overlapping each other by assigned the values to E_x, E_y and E_z. Moreover, the **E** and **H** fields calculated pixel by pixel each time step. The calculation presented as images in three planes (x-y, x-z and y-z) as shown in figure 2.

The simulations have shown that, signals distributed everywhere in free space. It was observed that the fields appeared as a small dipole emitted signals in three dimensions. The simulations of figures 3, 4 and 5 show that, the fields have affected in terms of distributions when exciting at three locations. Moreover, the magnetic and electric fields were generated by three sources simultaneously in both simulations. The fields added and also cancelled each other in some pixels as showed in the images. This is due to cancel the signals when adding the images together and from a combination of propagtion waves.

These images below represent point by point fields. The figures showed that the six components fields (E_x, E_y, E_z, H_x, H_y and H_z). Furthermore, the components in the three slices close to each other were calculated and then can be compared.

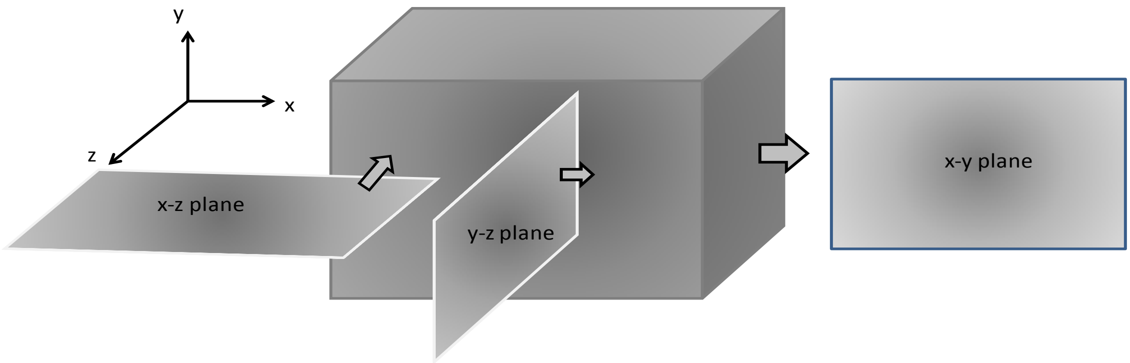
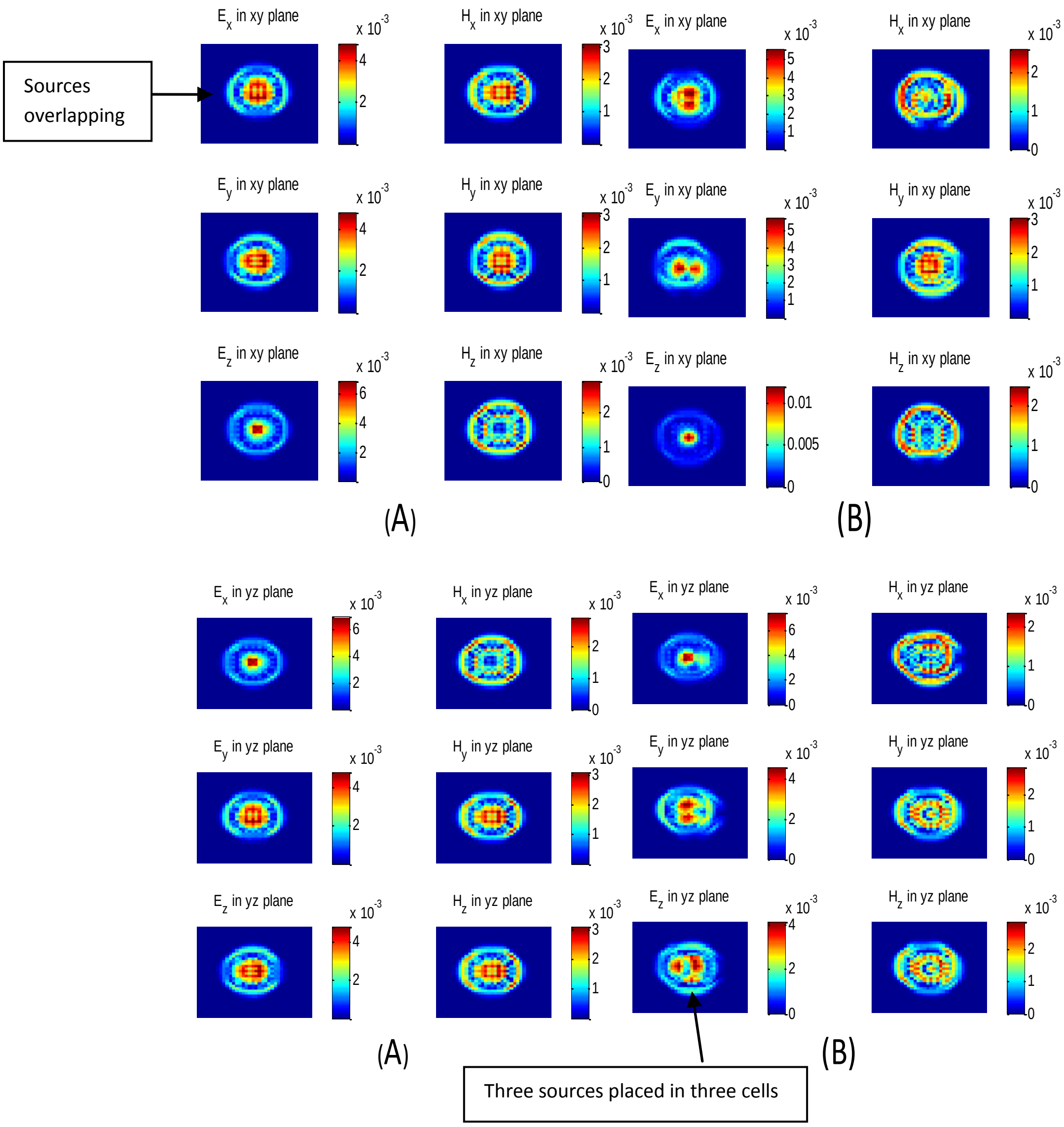


Figure 2: Diagram shows three slices that will be computed in the x-y, x-z and y-z planes.


Sources overlapping
Ex in xy plane
Hx in xy plane
Ey in xy plane
Hy in xy plane
Ez in xy plane
Hz in xy plane
(A)
(B)
Ex in yz plane
Hx in yz plane
Ey in yz plane
Hy in yz plane
Ez in yz plane
Hz in yz plane
(A)
(B)
Three sources placed in three cells

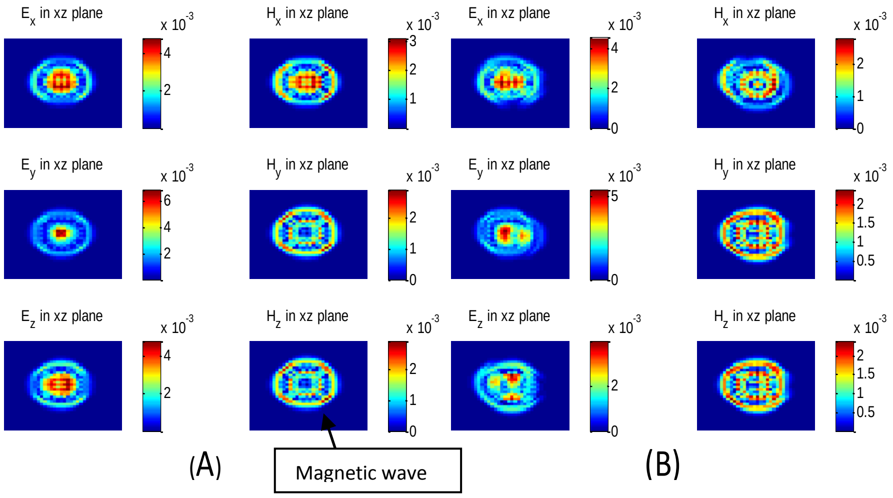


Figure 3 shows 3D FDTD simulation: the space has been excited by the Gaussian sources at the centre of the space: (slice=1), mapping of the electric (V/m) and magnetic fields (A/m) in the *x-y*, *y-z* and *x-z* planes after excitation. Three sources located in the same location (A) and also placed in three locations (B).

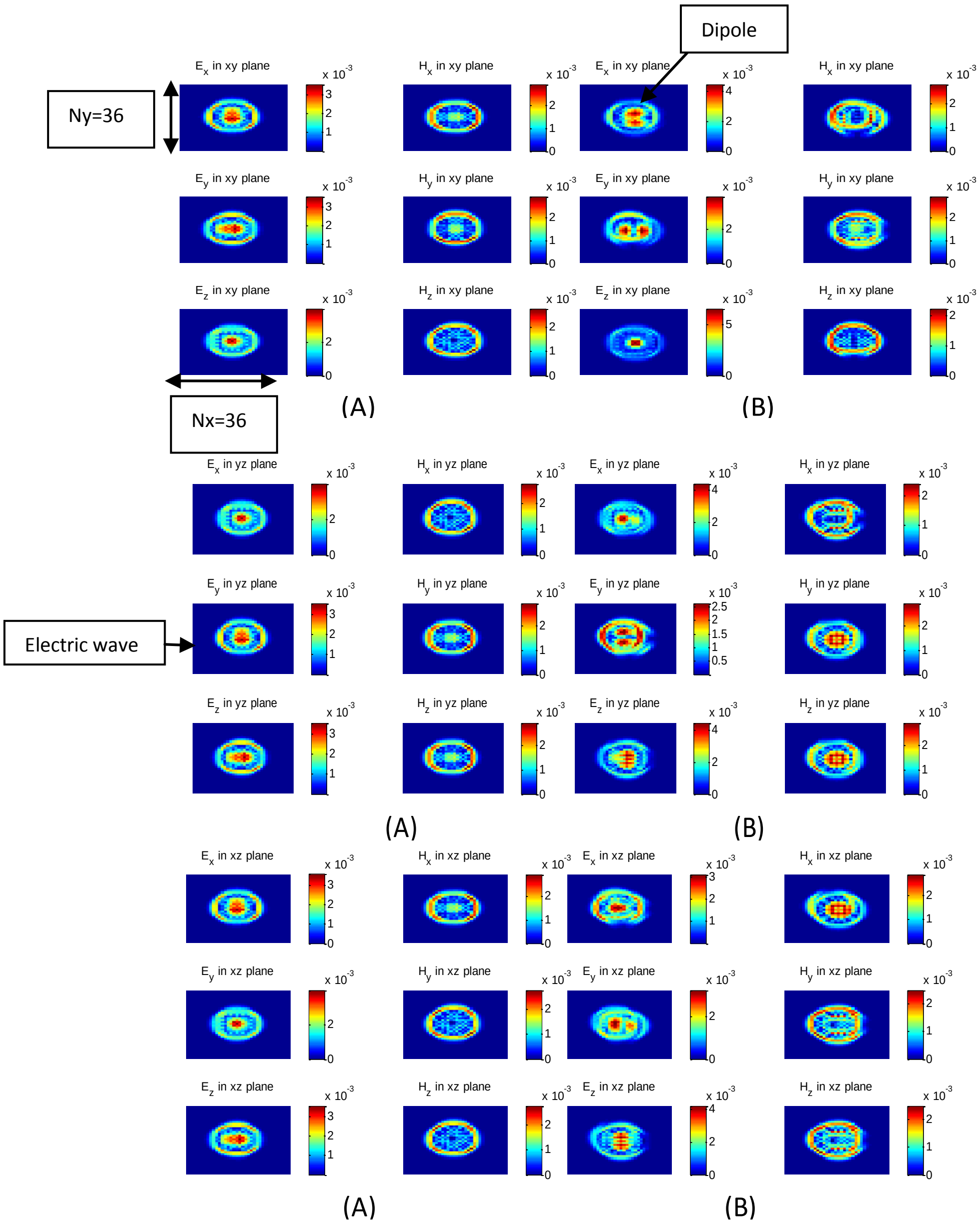


Figure 4 shows 3D FDTD simulation: slice 2 mapping of the electric (V/m) and magnetic fields (A/m) in the *x-y*, *y-z* and *x-z* planes after excitation. Three sources located in the same location (A) and also placed in three locations (B).

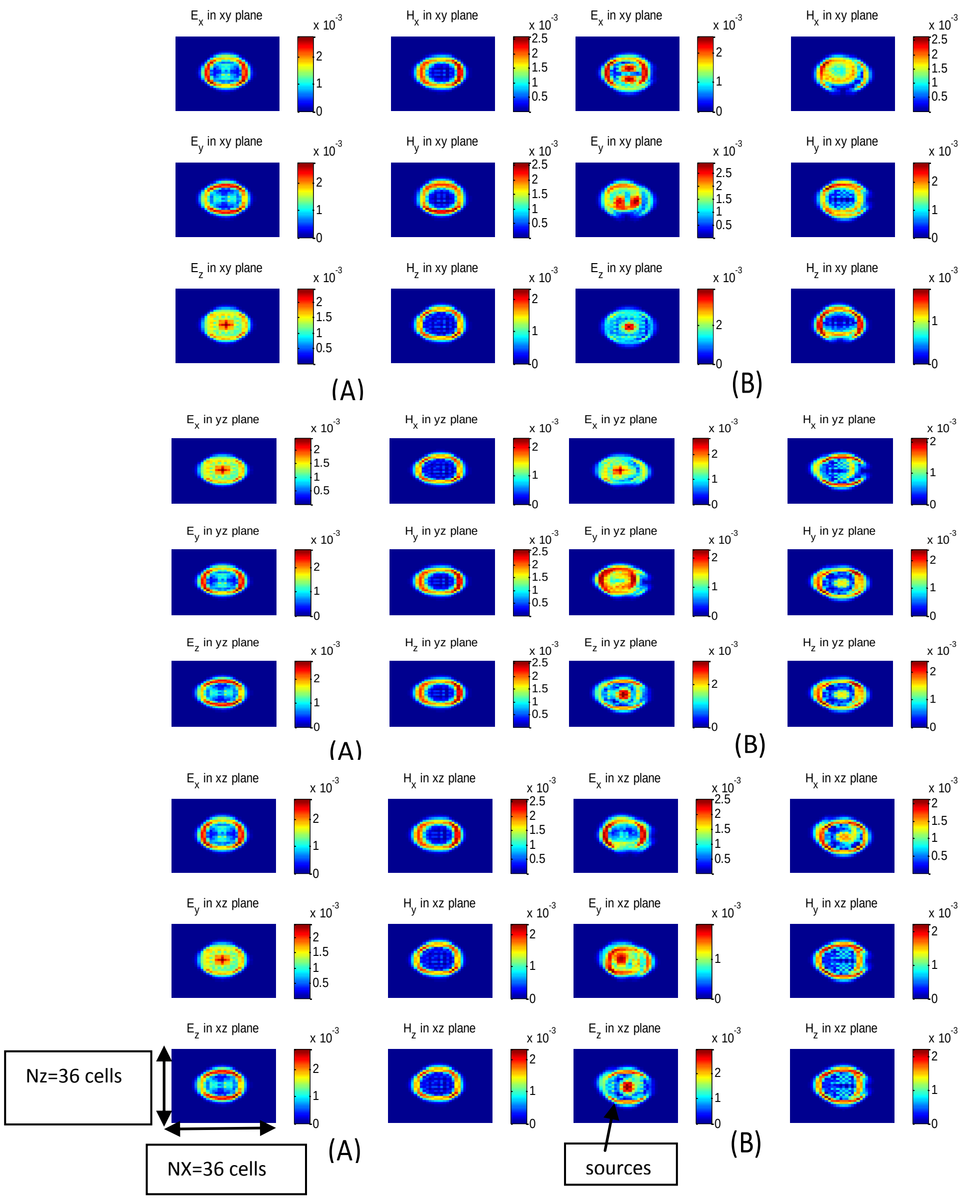


Figure 5: shows 3D FDTD simulation: slice 3 mapping of the electric (V/m) and magnetic fields (A/m) in the *x-y, y-z* and *x-z* planes Three sources located in the same location (A) and also placed in three locations (B).

Conclusion:

In this study, the FDTD numerical method was used to calculate the electromagnetic fields. This method can solve models that would be difficult or impossible with analytical methods. Therefors, an important observation is the electric and magnetic fields generated in voxel by voxel in a small box. However, adding three exitted sources distributed of electromagnetic waves everywhere in space. All interactions between the sources involve energy transfer to free space. It was noted that traveling waves interfer constuctively and destructively with eatch other. It was obseved that the electromagnetic waves had very good uniformity when three source eimitting from the same position. Moreover, it has been proved that this simulation is able to control the locations of the sources that can affect the distribution and also uniformity of the field.

References:

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