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An Efficient Algorithm for the Evaluate of the Electromagnetic Field near Several Radio Base Stations

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Abstract: This paper is motivated by the increased presence of the radio base stations, and the need to calculate the electromagnetic field near them. The debate on the effects of the electromagnetic field exposure, in line with the increased success and presence of the mobile telephony, has attracted the public interest and it has become a concern for the community. The standard procedures in place for estimation of the electromagnetic field require prior knowledge of the criteria for the field evaluation, be it near field, far field, presence of one or several base stations, the operating frequencies bands and their combinations. Aiming to have a practical method for the evaluation, the authors will try to do develop a theoretic model, on which base the authors will simulate the antenna of the base station and prepare the numeric method that will provide the baseline for the application. They will than compare the calculations for real situations for which all know the geometrical features, with the ones calculated based on a known theoretical method also knows as method of the moments MoM, simulated with NEC-2 (numerical electromagnetic code), and further more with the values measured in the field under the same conditions as the ones for the simulated environments. The results are interpreted in order to define the efficiency of the proposed method as well as to have an idea on the simplicity, accuracy and computing capacities.

Key words: Evaluation, base stations, far field, FDTD method, algorithm.

1. Introduction

The task to be accomplished in this paper are the theoretical calculations of the electric and magnetic field, the density of power caused by the antennas of the radio base stations, considering that this is caused by joint presence of several base stations at a given place. The proposed calculation method is based on the below requirements:

The need for a simple, and practical method, to evaluate the field nearby the radio base stations.

The need to define the security zones Iso-Curves (spaces inside which the values of the electromagnetic field are higher than the standard recommended ones)

The need for quick evaluations—be it time—wise as well as space—wise: In Albania are operating 4 cellular operators AMC, VODAFONE, EAGLE and PLUS. These operators are obliged to monitor the levels of the field in the vicinity of the radio base stations, and to assure that the levels are within the reference values of safety, this in the framework of the client care. By monitoring it means the constant measurement of the levels of electromagnetic field near the stations. This is translated in relatively high costs due to man work travel and density of the measurements in time.

The presence of several operators in the same space causes the levels of the electromagnetic field to increase, independently that each individual antenna contribution is within the allowed limits. Under these circumstances it is required that the regulatory body checks frequently the levels in the public spaces and for the safety of the public. The state authorities are trying to protect the population and at the same time they must promote the cellular companies and encourage new emerging services.

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The literature [1-5] offered many models and numerical methods for the calculation of the electromagnetic field near the radio base stations.

The basis of these methods is the conversion of the integral equations in a linear system, which can be further computed in a computer. The simulations in software environments provide accurate results but they require a lot of processing power and they require a lot of time to be processed.

In this paper the authors have selected a theoretical model which implementation is based on the numerical method FDTD (finite-difference time-domain) by using the formula of the far field.

They are presenting the theoretical calculations in real life scenarios in which the geometry of the antennas in a group of radio base stations is known, and the results are compared with the values acquired by the simulator NEC-2 (numerical electromagnetic code) and further compared to the measured values acquired in the field by using the NARDA SRM 3000 equipment, for the same conditions of the radio base stations simulated via the two methods.

The paper is organized as follows: Section 2 describes the proposed theoretical model for the evaluation of the far field; Section 3 describes the numerical method and the respective proposals; Section 4 presents the proposed algorithm; Section 5 presents results and discussions; Section 6 gives conclusions.

2. The Proposed Theoretical Model for the Far Field

Modeling of the electromagnetic field near the radio base stations is a way to evaluate and define the excluded zones near these stations. The selection of an appropriate model is important in order to have a good estimation of the levels of the radiation.

In the literature [1-5] can be found many models for the definition of the zones of the near field as well as the far field. Attention must be paid to the fact that in the zones of the near field, the levels of the radiation depends not only on the distance from the antenna but also one the movement along the vertical axis, whereas in the case of the far field the levels depend only on the distance not on the movement along the vertical axes. The models of the far field aim towards a simple formulation and based on them can be applied numerical methods which make possible the estimation of the electromagnetic field in a short time and with modest computer processing power.

The proposed model is based on the model "Far-field Gain-based" [6] as Eq. (1). This model provides a simple and efficient method for the evaluation of the levels of the electromagnetic field radiated by the antennas of the radio base stations with uniform groups of cells in the zone of the near field and the ones of far field. The above is achieved in two steps:

The first step, electrical intensity of the antenna is calculated by combining the radiation of the far field of the antenna elements, and the group factors, by accepting that the antennas of the radio base stations are an uniform group of cells. (Fig. 1):

$$E(d,\theta,\varphi) \approx \left| \sum_{i=1}^{N} \frac{\sqrt{30 P_{in} G_e(\theta_i,\varphi_i)}}{d_i} e^{-j\phi_i} u(\theta_i,\varphi_i) \right|, d > 3\lambda \quad (1)$$

Second step as Eq. (2):

$$G_e(\theta_i,\varphi_i) \approx \frac{G_M D_{Ve}(\theta) D_{He}(\varphi)}{N} \quad (2)$$

$$\phi_i = (i-1)\phi + \frac{2\pi d_i}{\lambda} \quad (3)$$

where, N number of radiating cells, (di, θi, φi) spherical coordinates of the i-th element up to the N-th one, Pin total radiated power by a given group, Ge (θi, φi) amplification of the radiating element, di distance from the i-th element, u (θi, φi) unit vector of the i-th element, λ wave length ,GM maximal gain of the antenna, *DVe*(θ), *DHe* (φ) the models of the radiating element in the vertical and horizontal plan and Φi the differences of the phases between the coefficients of the radiating element.

In this paper reference is made to Kathrein antennas specifically to the models, 80010670, 80010671 and

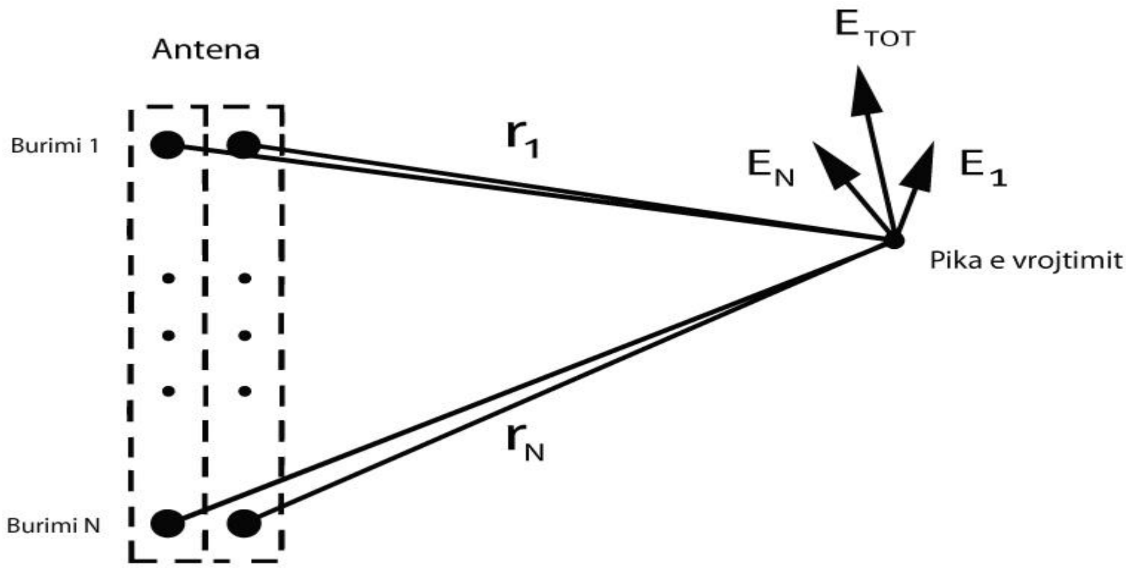

Fig. 1 Modeling the antenna with *N* source cells.

80010672. The Kathrein model 80010671 [7] is used for the spectrums 900/1800/2100 MHZ. The intensity of the electric field calculated for each of the elements (cells) of the antenna is vectorial and it can be projected according to the axis x, y, z, and obtain the respective components for each of the axes. The electric and magnetic fields in the Cartesian coordinates are composed of each of the three components E_x, E_y and E_z for each and every frequency the same is valid for the magnetic field with respective H_x, H_y and H_z components [8] as Eq. (4):

$$E_{\mathrm{Rezultante}} = \sqrt{(E_x)^2 + (E_y)^2 + (E_z)^2} \qquad (4)$$

The authors propose for the modeling of the base antennas the below:

(1) The use of the "Far-field Gain-based" model ins which the intensity of the electric field is calculated by the Eq. (1) with the approximation that $e^{-j\phi_i}u(\theta_i,\varphi_i)=1$. This approximation influences the accuracy of the model "Far-field Gain-based" for the near fields up to 15 λ. This falls within the safety distances as defined by the standards.

The acquired equation is as Eq. (5):

$$E(d,\theta,\varphi) \approx \left| \sum_{i=1}^{N} \frac{\sqrt{30P_{in}G_e(\theta_i,\varphi_i)}}{d_i} \right| \qquad (5)$$

(2) The statistical study considered is "the worst case scenario the vectors E_{x1} E_{x2}… E_{xn} in the same phase as the E_y and E_z" This definition will lead to and overestimation of the electromagnetic field on the given point. The intensity of the electrical field in a given point (weight per frequency) near the antenna of a radio base station when the antenna is Three-Band (900/1800/2100) and by considering the "vectors E_{x1} E_{x2}… E_{xn} in the same phase as the E_y and E_z" is as per the Eq. (6).

$E_{Rfrekuence\text{-}i\text{-}th}$—the electromagnetic field radiated by the antenna for the *i*-th frequency on the calculated point [9] .

$$E_{Rfrekuence-i-th} = \sqrt{(\sum_{1}^{N}(E_x))^2 + (\sum_{1}^{N}(E_y))^2 + (\sum_{1}^{N}(E_z))^2} \qquad (6)$$

The intensity of the electrical field in a given point (weight for the three frequencies) near the antenna of a radio base station when the antenna is Three-Band (900/1800/2100) is as Eq. (7).

$E_{RTotale\ Frekuence}$—The electromagnetic field radiated for the three frequencies on the calculated point [9]

$$E_{RTotaleFrekuence} = \sqrt{(E_{Frekuenca1})^2 + (E_{Frekuenca2})^2 + (E_{Frekuenca3})^2} \qquad (7)$$

In the majority of the real situations are encountered antennas which operate in different systems that cover the same fields or have their radiating diagrams overwritten in their main lobbies. It comes as a natural need to evaluate the generated electric field by considering at the same time the radiation of each and every antenna. By the assumption that the signal sources are not correlated, the contribution of the field is added in quadrature therefore the electrical field in a given point will be as Eq. (8). [9]

$$E = \sqrt{(\sum_{1}^{n}(E_i)^2} \quad (8)$$

where n is the total number of the antennas which generate the field and E_i is the contribution from the i-th antenna.

Eq. (5) is the formula proposed for the far field in the vicinity of a radio base station. The overall electromagnetic field is calculated by overlapping the electrical intensity of the electromagnetic field calculated for each of the contributing antenna as Eq. (9):

$$E_{Rn}(d,\theta,\varphi) \approx \sqrt{\sum_{j=1}^{n}\left[\sum_{i=1}^{N}\frac{\sqrt{30P_{in}G_e(\theta_i,\varphi_i)}}{d_i}\right]^2} \quad (9)$$

The approximation of the far field can result in and overestimation of the measured electromagnetic field. The intensity of the electrical field in a given point (weight per frequency) near some radio base stations where the antennas are three-band (900/1800/2100) as Eq. (10):

$$E_{Rn_{Frekuence-i-th}} = \sqrt{\sum_{1}^{n}\sum_{1}^{N}(E_X)^2 + (\sum_{1}^{n}\sum_{1}^{N}(E_y) + \sum_{1}^{n}\sum_{1}^{N}(E_z)^2} \quad (10)$$

The intensity of the electrical field in a given point (the weight for the three frequencies) near some radio base stations where the antennas are three-band (900/1800/2100) as Eq. (11):

$$E_{RTotaleFrekuence} = \sqrt{(E_{Frekuenca1})^2 + (E_{Frekuenca2})^2 + (E_{Frekuenca3})^2} \quad (11)$$

3. The Proposed Numerical Method

The FDTD (finite-difference time-domain) method is a numerical one suitable for solving the electromagnetic problems. The space in this method is divided in tiny rectangular cells. Modeling the dielectric materials or the antenna structures in the stations is very simple by the use of this method [9]. As the result the FDTD is an appropriate nomination for the evaluation of the electromagnetic radiation near the radio base stations. As it is now known the simulation of the full waves requires more and more computing power and time. In order to increase the efficiency a simple geometry for the antenna is proposed, by using an optimization algorithm to meet the required specifications for the antenna.

The proposal is based on the numerical method of the finite differences in the time domain FDTD with the below changes:

(1) discretization of the antenna of the radio base stations, defining the elementary cell (the cell size meets the criteria $\Delta < \lambda/10$);

(2) the space from the radio base station to the given point is considered as free space;

(3) discretization of the Maxwell's equations in the time domain, explaining scheme as per the proposed theoretical model;

(4) solving of the discretized equation and the selection of the transitional step (time step Δt must meet the CFL criteria);

(5) interpreting the results.

The antenna model used in this study is presented schematically (Fig. 2). The physical dimensions of the antenna (height and width) 2,000 mm × 240 mm. The cells in the cubical form size is Δx (= Δy = Δz) = 10 mm. The accuracy of the model "cylindrical-wave" is reduced when the distance from the antenna is increased. At the same time the model "spherical-wave" accuracy is increased.

The selection of the numerical method FDTD with the respective proposal (discretizing only the antenna of the radio base stations and the space from the antenna to the observation point as free space) influents by decreasing the execution time as compared

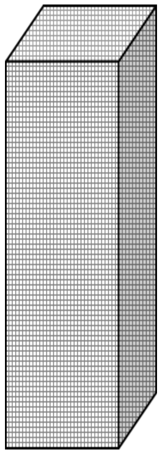

Fig. 2 Modeling the antenna according to FDTD.

with the NEC-2 simulation for the same machine.

The proposed model leads to an overestimation of the electromagnetic field. This should not be interpreted as a weakness of the model because the goal is calculation of the field and comparison of the calculated values with the reference ones. Therefore the overestimation contributes to the understanding that the real value is somewhat percent less than the calculated one.

4. The Proposed Algorithm

This algorithm allows a simple and fast estimation of the electromagnetic environment starting from the antenna model. The essence of this method is the calculation in the so called “free space” of the electromagnetic field, based on the same model used for the far field. The 2D model is rebuilt by the criteria of the projection placed in the algorithm. The applicability of this method is based on the assumption that the field radiates independently from the direction of the observation.

Eq. (5) is the proposed theoretical model for the antenna of a radio base station.

Eq. (9) is the theoretical model proposed for the estimation of the electromagnetic field near some radio base stations. The total field is achieved through overlapping of electrical intensity of the respective electrical intensity of the electromagnetic field calculated for each and every antenna. The approximation of the far field can result in an overestimation of the electromagnetic field due to the fact that the statistical study used on this case does scalar sum.

Eq. (10) is valid for the electromagnetic field created by the contribution of n antennas at a given point for the i-the frequency.

Eq. (11) gives the total field from the n antennas at the given point for the three frequencies 900/1800/2100MHz. By using the open source code [10] for the calculation of the intensity of the electric field for the far field scenario, the proposed algorithm solves numerically as per the proposed FDTD the Eqs. (9)-(11).

Afterwards by using the worst case criteria for the projection of the surfaces in the plans Oxy, Oxz and Oyz the authors build the iso-curves with the values of the electric intensity E > 41V/m and define the safety distances near these radio base stations.

The total value of the intensity of the electric field for a frequency will be calculated as result of the quadratic sum of the contribution from each and every antenna in the particular frequency. On the other hand the total value of the entire frequency spectrum for the intensity of the electric field will be evaluated based on the same procedure.

The proposed algorithm enables the calculation of the electromagnetic field for up to 12 radio base stations. For each antenna of the radio base stations is required prior knowledge of some characteristics which are presented as the inputs for antennas:

(1) Label of the antenna (not required for calculation, it is the label in the final graphic);

(2) antenna gain (dBi);

(3) antenna mechanical down tilt (+/-): The electrical down tilt should be included in the radiation pattern of the antenna;

(4) horizontal plane rotation angle of the antenna main beam (with reference to a fixed coordinate system);

(5) antenna centre X-position;

(6) antenna centre Y-position;

(7) antenna centre Z-position;

(8) name of the file containing the horizontal plane radiation pattern;

(9) name of the file containing the vertical plane radiation pattern;

(10) input power to the antenna (W).

At the end of the file a routine can require the punctual calculation of the EM field in some points identified by their Cartesian coordinates this routine produces the calculated EM field values to be printed in the output window.

The program output is represented by the following data, for each iso-curve level introduced in the input file:

(1) Iso-curve safety zone on the x-y plane (graphic window), representing the total contribution of the antennas and the single safety zone of each antenna;

(2) Iso-curve safety zone on the y-z plane (graphic window), representing the total contribution of the antennas and the single safety zone of each antenna;

(3) Iso-curve safety zone on the x-z plane (graphic window), representing the total contribution of the antennas and the single safety zone of each antenna;

(4) safety distances.

Errors in the input file are indicated by a warning message, and this leads to the termination of the program.

5. Results and Discussion

To judge the algorithm for evaluating the intensity of the electric field radiated by the antenna of the radio base stations what is proposed is related in the following three steps:

(1) Through the proposed model and the application of the FDTD numerical method, the values of the intensity of the electrical field are defined, depending on the distance along the axis X, Y, Z and this is presented in a graphical form;

(2) The simulations are performed for the same given points along the X, Y and Z axis using the NEC-2 program implementation of MoM [11];

(3) The intensity of the electrical field is measured by using the NARDA SRM 3000 [12] in the same points as the simulated and calculated ones, and the results are presented graphically in the same graph with the ones of the above steps.

Through the proposed method the authors are capable to have a quick evaluation be it for the near zones, as well as for the far ones, and the calculations complexity is significantly reduced. The cases the authors have considered consist in a situation in which there are three cellular operators; each operator has three antennas in the GSM 900, GSM 1800 and GSM 2100 (in total 9 antennas, 3 for each band). Reference is made to Kathrein antennas specifically to the models 80010670, 80010671 and 80010672.

Fig. 3 shows the three cellular operators (three antennas each) in cartesian coordinates space for the middle point values antenna 1(5, 5 ,5), antenna 2(2,8,6) antenna 3(-4 ,-3 ,7).The distances are in meters *m*.

The calculations are performed for the three frequencies 900/1800/2100MHz jointly for the below cases:

Intensity of the electrical field in the X axis (Y = 0 and Z = 0)

Intensity of the electrical field in the Y axis (X = 0 and Z = 0)

Intensity of the electrical field in the Z axis (X = 0 and Y = 0)

In the case according to the X axis the values are for points between negative value -4 *m* to 11 *m* (30 samples).

Fig. 4 shows the intensity of the electrical field, magnetic field and the power density for two calculating methods the NEC-2 (MoM method) and Emf calculation Alg, as well as the measured values in the site.

In the case according to Y axis the values are for points between the negative -6 *m* up to 10 *m* (30 samples). The graphs below present the intensity of the electrical field, magnetic field and the density of

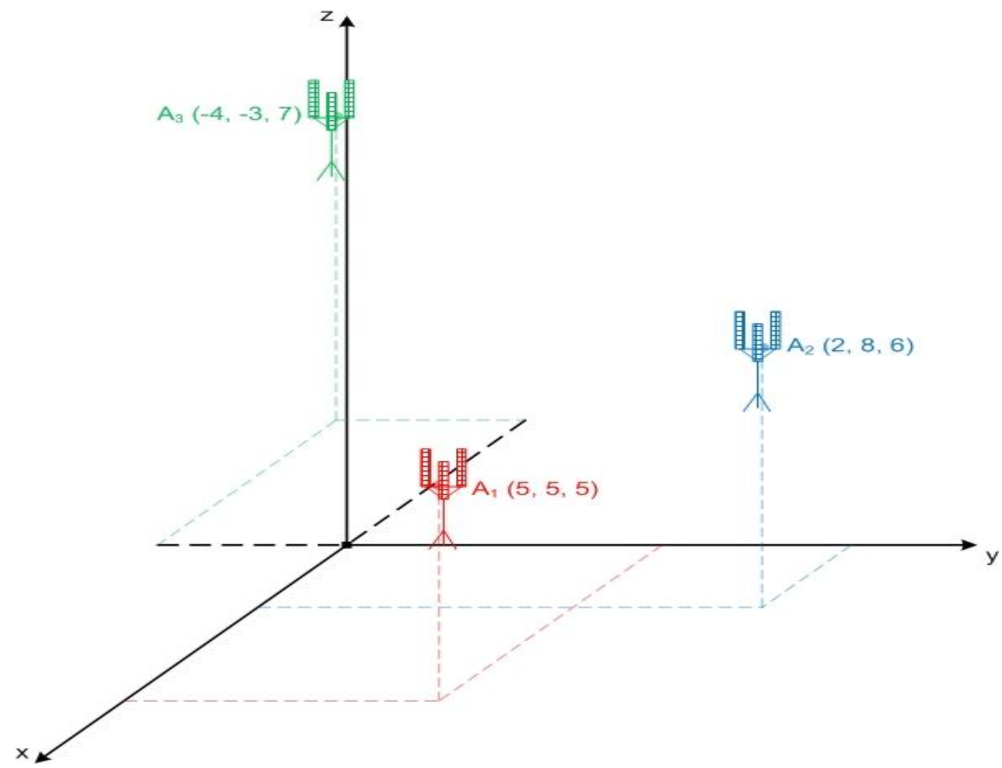

Fig. 3 Geometry of the simulation.

power for both methods, and the measured in site values (Fig. 5):

In the case according to Z axis the values are for points between negative -1.5 m up to 4 m (12 samples) The graphs upper present the intensity of the electrical field, magnetic field and the density of power for both methods, and the measured in site values (Fig. 6):

Table 1 presents the intensity of the electric field as per the x axis (*m*) (y = 0 and z = 0) sampling step 0.5*m*.

The values of the intensity of the electric field(v/m) are due for three methods.

Simulation by NEC-2 software [11].

The value of a single sample is calculated for an average time 80-85 s. The total time for the calculation of the entire blue graph in the Fig. 4 for 30 samples is 2,550 s.

Simulation by using the proposed algorithm Emf Calculation Alg. The value for a sample is calculated for an average time of 20 s. The total time for the calculation of the entire pink graph in the Fig. 4 for 30 samples is 600 s.

The measurement by using the NARDA SRM 3000 [12]. The value for a sample is achieved by an average of measurements that last 360 s. The total time for the yellow graph (Fig. 4) for 30 samples is 10,800 s.

The simulations with the NEC-2 and Emf calculation Alg are performed on the same machine with the specifications; Server IBM x3650 M4, processor Xeon 2.0GHz/1333MHz / RAM 8GB.

6. Conclusions

The algorithm for the evaluation of the radiation of the field in the presence of several radio base stations was devoleped by using the proposed theoretical model for the far field, and the method of FDTD (finite –differences time-domain) with the respective assumptions. The proposed algorithm "Emf Calculation Alg" for the calculation of the electromagnetic field requires prior knowledge about the antennas, usually provided by the manufacturer (emitting space in the horizontal plan and vertical plan).

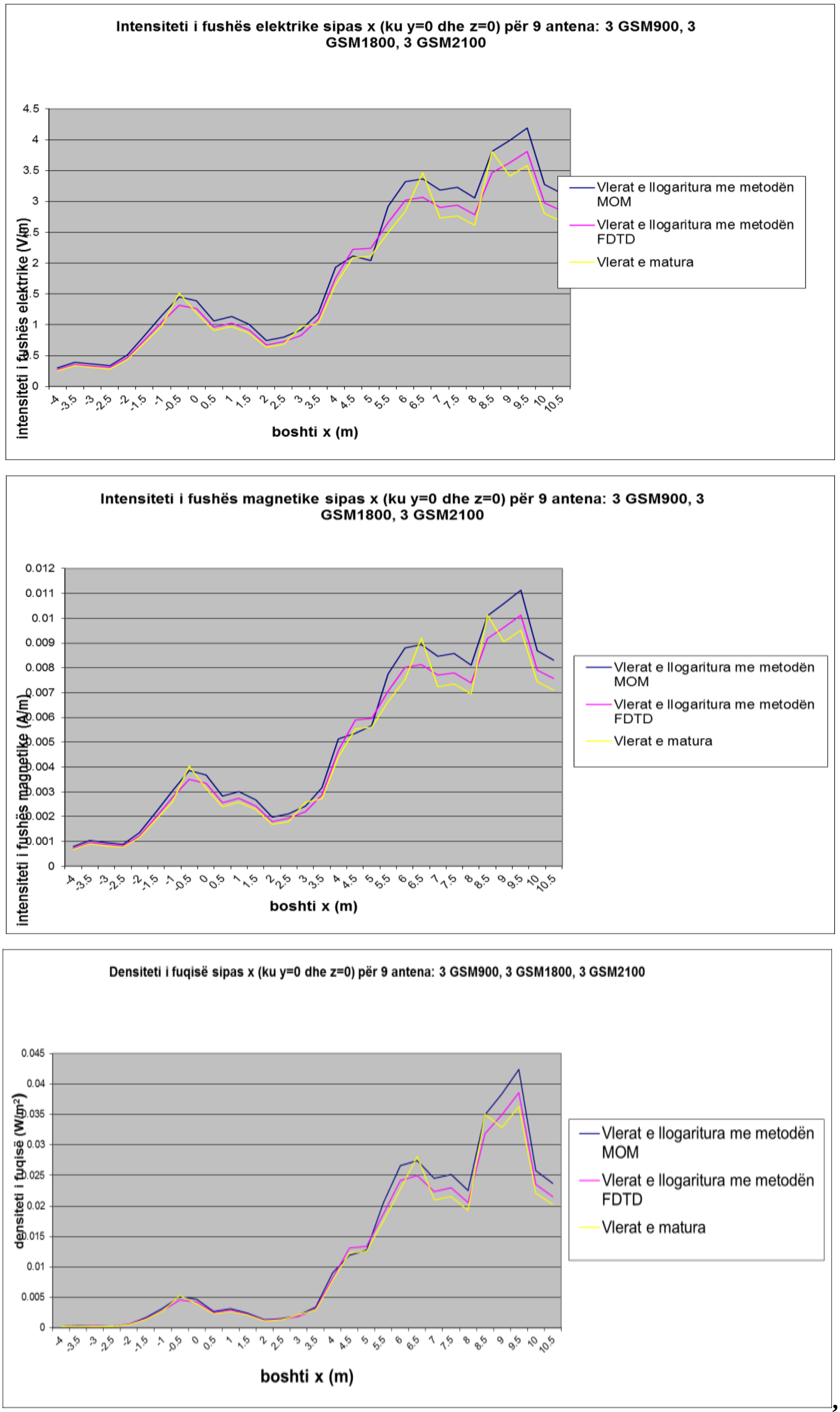

Fig. 4 Dependence of E, H and S in x axis (*m*) (y = 0 and z = 0).

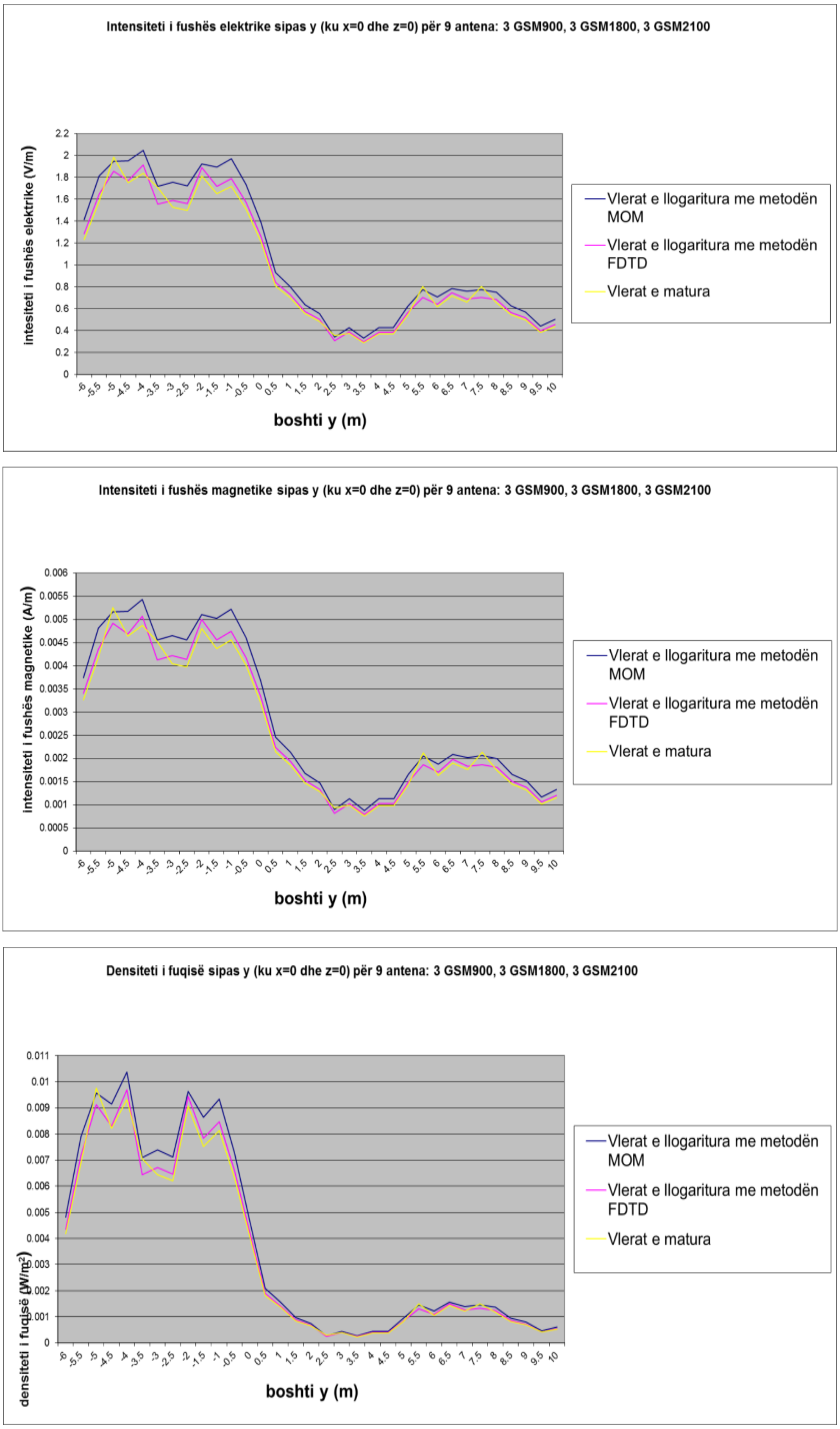

Fig. 5 Dependence of E, H and S in y axis (*m*) (x = 0 and z = 0)

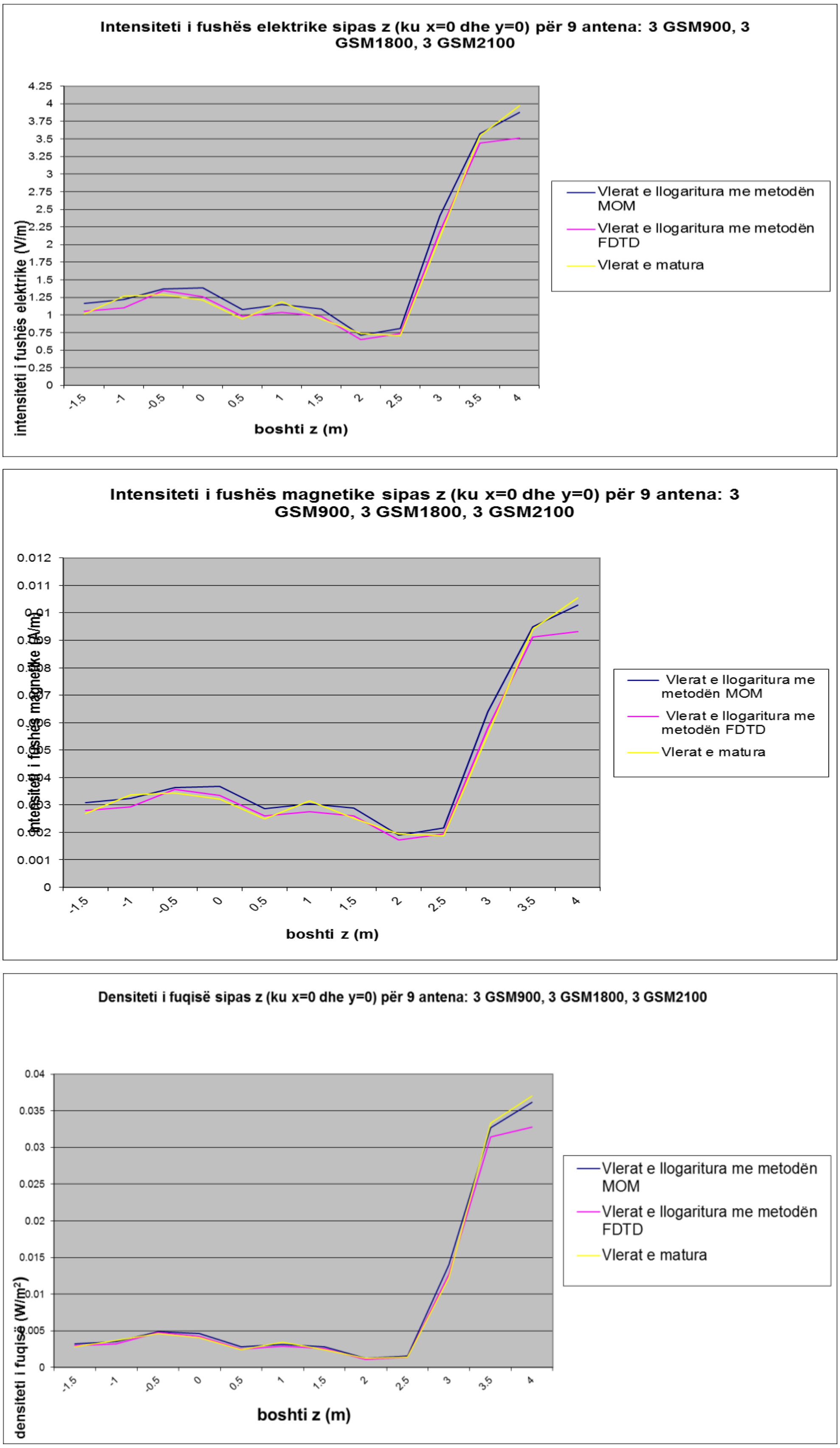

Fig. 6 Dependence of E, H and S in z axis (*m*) (x = 0 and y = 0).

Table 1 Comparative result.

Samples	Coordinates (X.Y.Z)	Values NEC-2	Values Emf Calculation Alg	Values measured NARDA SRM3000
1	-4.0.0	0.30200514	0.2749	0.258406
3	-3. 0. 0	0.36012108	0.3278	0.308132
5	-2. 0. 0	0.50579544	0.4604	0.432776
7	-1. 0. 0	1.14880602	1.0457	0.982958
9	0 .0 .0	1.3853346	1.261	1.18534
11	1. 0. 0	1.1321073	1.0305	0.96867
13	2. 0. 0	0.74199444	0.6754	0.634876
15	3. 0. 0	0.91304646	0.8311	0.972387
17	4. 0. 0	1.93309656	1.7596	1.654024
19	5. 0. 0	2.043587	2.2457	2.110958
21	6. 0. 0	3.31821144	3.0204	2.839176
23	7. 0. 0	3.18835692	2.9022	2.728068
25	8. 0. 0	3.0563052	2.782	2.61508
27	8. 0. 0	3.0563052	2.782	2.61508
29	9. 0. 0	3.98989548	3.6318	3.413892
31	10. 0. 0	3.27196038	2.9783	2.799602

Analysis and comparison between the calculated values and the measured ones concludes that the proposed algorithm provides accurate results for the field close and far from the radio base stations (up to 12 BTS antennas) in a given urban area. The error between calculated and measured values is less than 10%.

Analysis and comparison between the values calculated with the proposed algorithm and the ones simulated with the NEC-2 software, concludes in values that converge, thus confirming the accuracy of the proposed algorithm.

Analysis and comparison between the time required for running the proposed algorithm, and the NEC-2 simulation confirms the speed of calculations for the authors' algorithm, making it suitable for low computing capacity machines.

For the reviewed radio base stations which operate at the same time in the frequencies band 900/1800/2100MHz the algorithm "Emf caclultion Alg" calculates the safety zones in the Iso-kurves (the space where the $E \geq 41$ V/m) in the plans x-y, x-z and y-z.

In an environment in the presence of several radio base stations can be calculated the intensity of the electrical field, magnetic field and the density of power for different distances from the antenna in a short period of time providing confident and accurate results.

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