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Modeling of total electromagnetic field distribution in vicinity of BS concentration

***Abstract:** The paper presents modeling software developed by the authors which facilitates calculation of field intensity when there are several antennas mounted at different points in space. The software is based on analytical method of EMF calculation.*

***Streszczenie.** Artykuł przedstawia opracowane przez autorów oprogramowanie komputerowe oraz wyniki symulacji natężenia pola kilku anten rozmieszczonych w różnych punktach przestrzeni. Podstawą oprogramowania są analityczne metody obliczeń pola elektromagnetycznego. (**Modelowanie sumarycznego pola elektromagnetycznego w otoczeniu grupy stacji bazowych**).*

Keywords: EMF intensity, EMF modeling, near vicinity, mobile networks
Słowa kluczowe: natężenie pola elektromagnetycznego, modelowanie pola, strefa bliska, sieci komunikacji ruchomej.

Introduction

The last decade was marked by rapid development of mobile cellular networks (GSM, DCS, UMTS), new wireless technologies were widely deployed (Wi–Fi, Wi-MAX, LTE). In order to improve the capacity and coverage of mobile cellular systems and ensure adequate quality of service, network operators are forced to modernize the structure of telecommunication networks by introducing many new base stations (BS) and antenna towers. The newly-introduced base stations are often located in areas of high end-user concentration. The same place (e. g. antennas' tower) is used for base stations of couple wireless networks. As a result there are a high number of antennas on the same roof of a building or on a tower.

It is obvious that under such circumstances when antennas of individual transmitters are located at different locations and heights, electromagnetic situation near BS becomes quite complex. Therefore the problem of calculation and analysis of total EMF intensity distribution around the sources of radiation is very relevant.

It should be noted that in some European countries, including Lithuania, installation conditions of radiation sources and their generated EMF intensity parameters are strictly regulated by normative documents. Lithuania, for example, has a hygiene norm [1]. The standard requires calculation of EMF distribution for every newly deployed radio equipment or after change of base station's technical parameters (power, electrical or mechanical downtilt and etc.). These calculations should be performed at up to five different height levels above ground level and the heights levels are selected taking into account heights of surrounding buildings. Also total EMF intensity distributions should be calculated at the same heights. These calculations should take into account all sources of radiation which are located in 300–500 meters radius around the projected radio equipment.

Currently there are at least a few powerful software packages for EMF calculations but the majority of them are designed for network planning. This work presents capabilities of software developed by authors and dedicated to calculation of EMF intensity. The software is based on analytic method of EMF intensity calculation and it can evaluate the impact of many radiation sources located at different places. The final result of software application is EMF intensity distribution in a given territory. Some data analysis capabilities are integrated in the software.

Model for cumulative EMF intensity distribution evaluation

The total EMF intensity generated by many radiation sources (these may belong to different operators and in general are mounted at different points in space (fig. 1)) can be expressed as follows:

$$S = \sum_{i=1}^{N} S_i \quad [\mu W/cm^2], \tag{1}$$

where S – cumulative EMF power flow density, μW/cm²; S_i – EMF power flow density created by i-th radiation source at a space point, μW/cm².

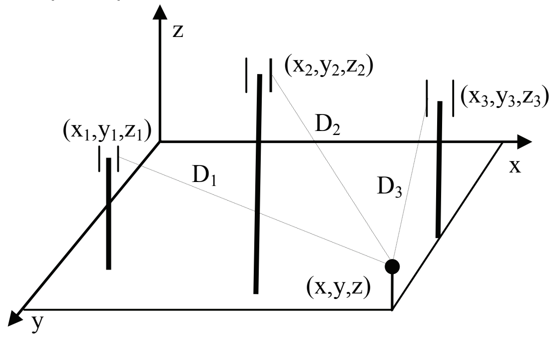

Fig. 1. The impact of a few antennas on cumulative EMF intensity at the location of analyzed point (x,y,z)

Taking into account the well known formula [2, 3] for evaluation of power flow density created by one antenna and the below given formula

$$S = \frac{E^2}{3.77} \quad [\mu W/cm^2], \tag{2}$$

where *E* – strength of electrical component of electromagnetic field (V/m). It is possible to write an expression for EMF intensity (μW/cm²) created by several antennas at particular point:

$$S = \frac{1}{3.77}\sum_{i=1}^{N}\frac{\left[F_i(\Delta)F_i(\varphi)K_Z K_H\sqrt{30P_iG_i\eta_i}\right]^2}{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2}. \tag{3}$$

Where N – number of antennas, P_i – output power of i-th transmitter, [W]; G_i – gain of i-th transmitter's antenna; η_i - power losses of i-th transmitter taking into account cables loss and reflection coefficient of the antenna; $F_i(\Delta)$ - directivity coefficient of i-th antenna in vertical plane; $F_i(\varphi)$ -directivity coefficient of i-th antenna in horizontal plane; K_H – coefficient taking into account inequality of i-th antenna's directivity diagram; x, y, z – coordinates of the investigated point; x_i, y_i, z_i – coordinates of geometric center of i-th antenna.

Investigation of distribution of EMF intensity created by many radiation sources

When designing a new base station, electromagnetic radiation should be evaluated in the radius of 300–500 meters depending of transmitter power (EIRP). According to hygiene requirements [1], the results of calculations should be presented in polar coordinate system, where the center of coordinates matches with the mast of antenna. Software created by authors makes all calculations and presents results in polar coordinate system, though for the sake of convenience some calculations are performed in Cartesian coordinate system.

The program provides dual graphic presentation of results. The first case gives precise view of EMF intensity distribution at a given height in horizontal plan. This visualization type is well suited for network design problems and allows the assessment of interactions between multiply antennas (Fig. 2.).

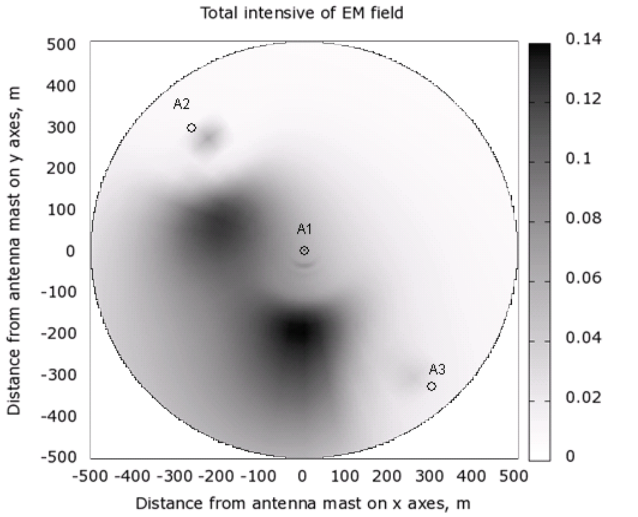

Fig. 2. Cumulative distribution of EMF intensity created by three antennas at 3 m height above ground. Points in the picture show positions of the antennas. Antennas A1 belongs to projected BS, so calculation points are given in relation to this antenna. Azimuths of antennas directions: A1 – 180°, A2 – 170°, A3 – 270°. Heights of antennas centers A1 – 40 m, A2 – 35 m, A3 – 45 m. Power at antennas input: A1 – 5 W, A2, A3 – 20 W. All antennas are of the same model – Kathrein 742271, 947 MHz frequency, 4 degree electrical tilt. Mechanical tilt of A1 is 5°

Since calculations are carried out in polar coordinate system and graphical results are presented in rectangular system, generated picture may be visually not clear. To improve the readability of graphical material two-dimensional linear interpolation is used for calculation of additional points.

The second way of results representation is a table of calculated EMF intensity values at given azimuth and distance points. This information is needed for hygiene expertise and planned measurements of the projected base station. The interpretation of the table is non-informative in polar coordinate system thus the results are presented as show in Fig. 3. The tabulated data is required for the cases when control measurements are done. In such cases it is necessary to have precise numerical values of EMF.

No limits exist for the number of antennas in created software. The only limit is computing resources. Average situation of EMF field distribution calculation involves up to 20-30 antennas. Taking into account the law of EMF decay in the vicinity of BS and the specifics of directivity diagrams of mobile wireless systems, mesh of variable length is used for field evaluation.

In practice while performing EMF modeling, azimuth is changed using 10 degrees steps and the distance between antenna ant investigated point is changed using 2-20 m step until 300 meters and 50 m steps from 300 to 500 meters. Such a mesh of distances is sufficient to obtain a clear view of electromagnetic distribution.

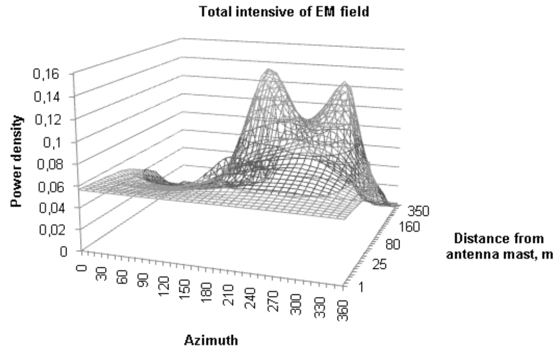

Fig. 3. Graphical representation of cumulative EML intensity created by 3 antennas (Fig.2).

EMF distribution usually is calculated in respect to the projected base station. In this case other antennas located in 500 meters radius will be displaced in relation to projected BS. Fig. 4 shows this situation.

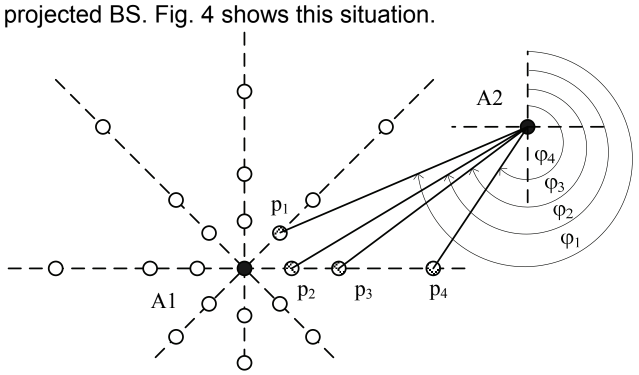

Fig. 4. An evaluation of impact of directivity diagram of antenna A2 should consider the angles between this antenna and the point where EMF is calculated

Directivity diagram of the second antenna A2 should be evaluated considering an angle between an azimuth of A2 and the points of a mesh at which calculations are performed.

Quite often antennas of the projected base station are not placed on the same mast and are displaced up to few tens of meters. As an example consider antennas mounted on a multistory building roof or walls. Formally EMF should be calculated in respect to every antenna of a projected base station. But this situation raises a problem when control measurements are performed for the projected BS. These measurements should be compared to calculated values. It becomes difficult to choose reference points with respect to which measurements should be performed. To easy the choosing of these points it is possible to form reports according to every displaced antenna. Considering that mobile antennas are usually directional, results are presented for every sector of the antenna. The width of a sector is chosen automatically by the program. There is also a possibility to choose the width of a sector manually. Graphical example of such reports is shown in Fig. 5.

Fig. 2 and Fig. 3 are generated using formula (4). But for precise EML intensity calculation additionally for every antenna the following parameters are evaluated: electrical tilt of antenna (corresponding radiation pattern is chosen), mechanical tilt, orientation of antenna – azimuth angle.

For more detail analysis of electromagnetic situation exists a possibility to monitor EML intensity distribution created by each separate antenna. Frequently it is useful if we want to find out which antenna's field is dominating at particular point.

The described EMF calculation model was implemented using several programming environments. For the analysis of individual electromagnetic situations while solving research problems, model was implemented using MATLAB. More user friendly interface was done using Python programming language but this version has very limited information analysis and data output means. More complex situations when detailed analysis of EMF distribution is needed, are solved using MS Excel based solution. An advantage of this version is the presentation of results – these are presented as tables and graphs. This version also exploits additional possibilities offered by spreadsheets. This way, EMF analysis at various sections can be performed. The result of changed initial data can be immediately observed. For example Fig. 6 shows EMF distribution on the wall of a house nearest to the antenna in situation shown in Fig. 2. Fig. 7 shows the distribution of EMF in the direction of maximum radiation.

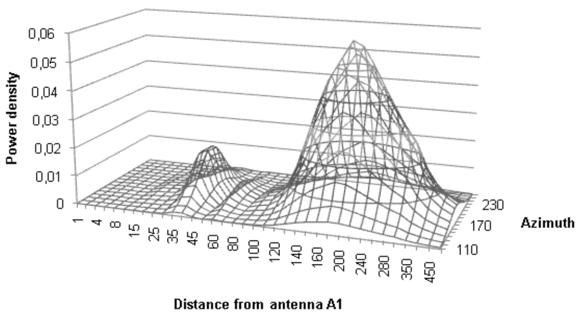

Fig. 5. An example of EMF distribution in respect to antenna A1

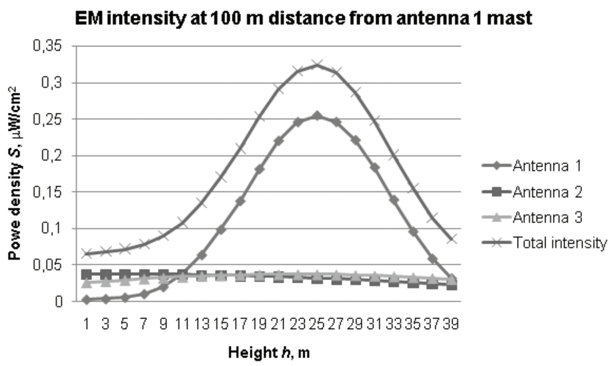

Fig. 6. EMF intensity distribution on the outer wall (vertical) of a building created by three antennas located at different points in space. The building is located within 100 meters from the mast of the first antenna. The building is in direction of maximum radiation of the antenna 1 (azimuth = 180°).

Non continuous step of distance and quite a big step of azimuth (step of 10 degrees) create and some problems. When one of antennas (for example belonging to other network operator) is relatively far (>300 m) from projected BS, graphical representations sometimes shows a peak. Intuitively it is clear that this is not correct. This effect is observed because of a big step (50 m) when distance exceeds 300 meters. In such cases also in the distance range of 300-500 meters, distance step should be decreased. This obviously increases the time needed for calculations.

The program also can take into account the land relief. In this case coordinates of base station are used as a reference point. Coordinates of all the other points are calculated using publicly available Internet resources and altitudes of these points are obtained.

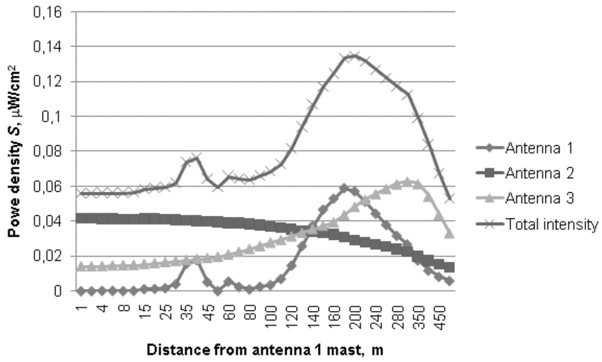

Fig. 7. EMF intensity distribution created by three BS antennas in the direction of maximum radiation of the first antenna (azimuth = 180).

Conclusions

1. Calculation-modeling of EMF intensity distribution created by many BS is one of the main tasks of radio hygiene expertise.

2. The software created by authors allows automation of EMF intensity distribution calculation when the field is created by many base stations.

3. Chosen non continuous distance step and relatively big azimuth step allows minimization the time of EMF intensity distribution modeling.

4. The created software may be applied not only for hygiene expertise of radio technical object but also for the investigation of particular electromagnetic situation where there is a big concentration of EM radiation sources.

5. There is a possibility of graphical presentation of EMF intensity distribution created by particular antenna. This allows to reveal the dominant sources of electromagnetic radiation.

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