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Visualization Of Electromagnetic Environment Near GSM Antennae

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Abstract. Web-enabled mobile phone enhancement has determined a sharp increase of mobile base station quantity, which has led to a surge of electromagnetic noise in metropolitan areas. Electromagnetic noise permanently influences adult and child population; the impossibility to remove this impact has promoted the electromagnetic monitoring. The most accessible form of socially oriented monitoring is a visualization of energy flux density for GSM base station antennae. Forecast calculation routines take antenna construction and location into an account; they also allow giving the recommendations on electromagnetic environment improvement basing on physical interpretation the obtained results.

1. Introduction

In modern mobile phones – smartphones - there are web-enabled applications available [1] along with voice transmission. The increase of smartphone users (353 million users in 2015 [2]) has led to a surge of GSM base station quantity. In Russia alone in 2013 the number of base stations has totaled to 82 211, with packing density equal to 11 km^{-2} and 90 km^{-2} in metropolitan areas. As a result, in densely populated areas a complete cover of nonionizing radiation from base station antenna is generated. Electromagnetic fields excited by 100 watt transmitters give about 60% of a total exposure in radio frequencies; they have a permanent around the clock impact on population health, including children, elderly and unhealthy persons. Moreover, changing the rooftop location of base station antennae from high-rise apartment buildings to stand-alone supermarkets (on the level of 2-3 floor of apartment buildings) aggravates electromagnetic environment of residential area even more.

Electromagnetic field radiated by an antenna can be controlled in various ways, like, by coating antenna support-structures with composites described in [3]. The field structure changes are shown in [4]. But it is impossible to exclude all the antenna support-structure diffraction. Hence, regulatory documents [8-10], wherein the energy flux density (EFD) for frequencies ranging from 300 MHz to 300 GHz was limited, were issued basing on theoretical and experimental results, like the ones given in [5-7]. Maximum permissible level of power flux density (PFD), which causes no irreversible changes on human body, is 10 μW/cm^2 for GSM base station antenna. It’s important to stress that this

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level is of sanitary and not ecological nature, because various environment components are more sensitive to electromagnetic field than a human being; they degrade or peter out really fast [11].

Maximum permissible level of radiation introduction implies regular influence factor monitoring of GSM stations locations, forecasting the environmental assessment, i.e. electromagnetic field monitoring and its sub-type, which is socially-oriented monitoring [12]. This kind of monitoring encircles large areas and promotes timely and situational provision of information to the public concerning electromagnetic pollution level; it limits sanitary protection zones (SPZ) measured at height of 2 m above ground or above top floor of building if antenna is located at the rooftop. Sanitary protection zone limits correspond to maximum permissible level of 10 $\mu W/cm^2$.

Population comprehensibility and capability of continuous adjustment to new electromagnetic environment problems are core requirements to socially-oriented monitoring results. The best graphic representation of results is their visualization with software graphical functionalities as it is shown in [13].

The paper objective is to estimate electromagnetic environment near GSM base station antennae with the visualization of the results obtained with forecast calculation method.

2. Characteristics of electromagnetic environment visualization

Proximity of electromagnetic environment visualization in GSM antenna locations is defined by both input data accuracy and graphical package functionality. The first factor is influenced greatly by a method for obtaining energy flux density distribution data. The second factor defines the capability to give population-friendly interpretation of the results. In-line adjustment of visualization results is also linked to the method for obtaining electromagnetic environment data.

2.1. Methods for obtaining electromagnetic environment data

To obtain information about electromagnetic environment near GSM antenna, as it is shown in [13], two methods are used: instrumental procedure and forecast calculation technique. The instrumental procedure has two major deficiencies in meeting the visualization requirements, i.e. low responsiveness to radiating objects location changes within the area of investigations and impossibility of measuring at every desired point. Forecast calculation technique is based on application of strict electrodynamic models; it allows obtaining electrodynamic field structure data for every point in antenna near-field zone and real time updating the measurement results.

EFD calculation technique for isolated points for various antenna design and antenna deployment depends on a specific antenna construction, its location and bandwidth. The technique is described in [10]. Its peculiarity is an application of “preventive principle”, which is recommended by the World Health Organization [14]. This principle allows for preventive actions to reduce possible harmful effect of electromagnetic radiation on human beings even if the effect itself is not proven, but is assumed with contemporary level of scientific knowledge. As a result, sanitary protection zone limits would exceed the real ones.

2.2. Software products

There are specific requirements imposed on software for visual representation of electromagnetic environment near GSM antennae under socially-oriented monitoring.

- It should use forecast calculation technique, while the mathematical models should consider electrodynamic effects, i.e. antenna design and deployment.
- The routine output should present EFD near antenna location on surface plots in horizontal and vertical sections. One should set the section position relative to antenna phase center.
- Sanitary protection zone limits (10 $\mu W/cm^2$ level) must be visible.

Well-known software commercial products like SanZone [15] and PR2 [16], which are used mostly to calculate certificate of hygiene for radiating objects, do not meet all of these requirements of socially-oriented monitoring. Hence, the necessity of specialized program development arises [17]. The descriptions of MathCad and MATLAB-based EFD distribution visualization programs in horizontal and vertical sections are given in other works of the authors, like [18-20].

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3. Results and Discussion

3.1. Electromagnetic environment estimation by forecast calculation

Electromagnetic environment has been estimated near GSM antennae with the routine developed by the authors. Specific antenna types have been selected according to mobile antenna market research given in [19]. That paper has showed that old standards like IMT-2000 have been used along with the new ones, i.e. 3G and 4G. The following frequencies are given for mobile radio of IMT-2000 standard under the recommendations of International Telecommunication Union ITU-R M.1036-3: 806-960 MHz, 1720-1885 MHz and 2500-2690 MHz. Antenna electrical characteristics for the most common mobile communication system in Russia are given in table 1.

Table 1. Electrical characteristics of considered base station antennae [19]

Antenna model	Frequency range, MHz	Gain, dB	Aperture angle, degree		Input power rating, W
			H-plane	E-plane	
TETRA antennae					
RAV-2UL-90	400-430	8	37	90	400
RAV-4UL-90	400-430	11	18	90	400
RAO-4U-120	400-470	8	36	120	400
RAX-2UL-70	400-430	9	36	70	400
RAX-4UL-70	400-430	12	18	70	400
RAO-2U-60	380-440	10	36	60	500
GSM (3G) antennae					
RAO-11GL-60	860-970	11	30	60	50
RAO3-10GH-60	1710-1880	13	18	60	50
RAO-14GL-70	860-970	14	15	70	50
LTE (4G) antennae					
RAX-14Yota-70	2400-2700	14.2	8	65	50

Upper sanitary protection zone limits calculated for maximum radiation level according to the “preventive principle” are shown on figure 1.

Figure 1 analysis shows that the worst case antenna could be pinpointed for each communication standard. It is trunking antenna RAX-4UL-70, 4G antenna RAX-14Yota-70 and 3G antenna RAO-14GL-70.

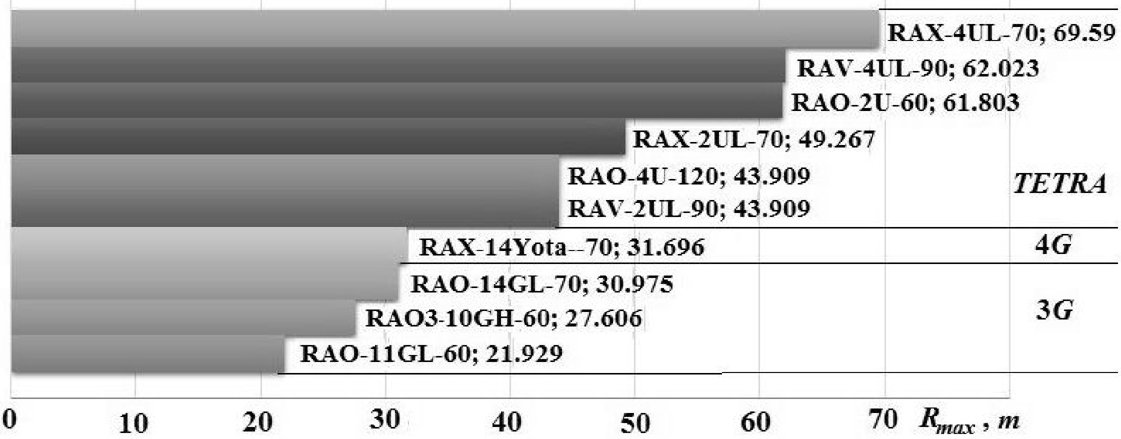

Figure 1. SPZ limits according to the “preventive principle”

EFD distribution in vertical section calculated for 3G antenna RAO-14GL-70 deployed 5 m above the rooftop, if antenna is located in the roof edge center of 30 m tall building, is shown on figure 2. Roof corner point coordinates were defined by $A(0,0,30)$, $B(-7,4,30)$, $C(-13.5,-4,30)$, $D(-2.5,-8.5,30)$. All measures are given in meters.

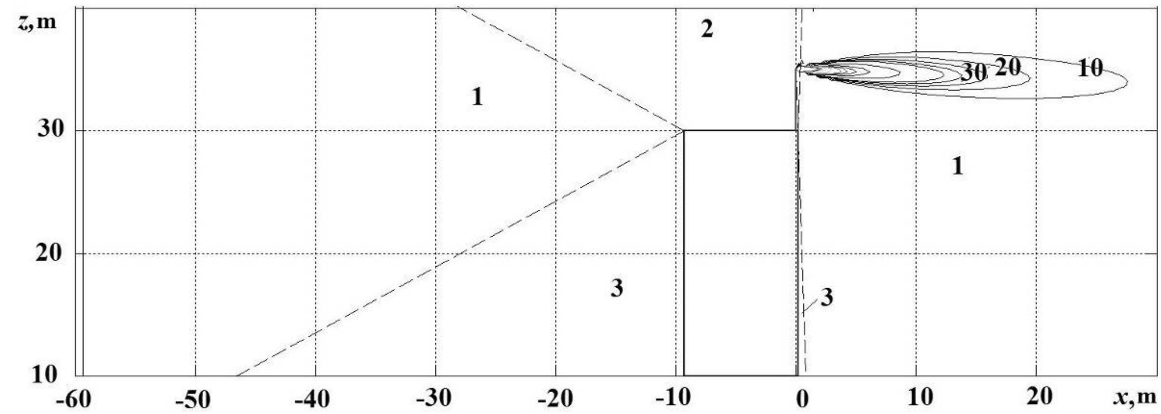

Figure 2. EFD distribution in vertical section for RAO-14GL-70 antenna

As a comparison, figure 3 and figure 4 show omnidirectional antenna field distribution in vertical section containing antenna phase center, and in horizontal section at 2 m above the rooftop. Power and location of omnidirectional antenna are equivalent to the case shown on figure 2. At figures 2 and 3 number 1 stands for the one-beam zone (incident beam), 2 – for the two-beam zone (incident beam and the one reflected by the roof), 3 – for shadow zone.

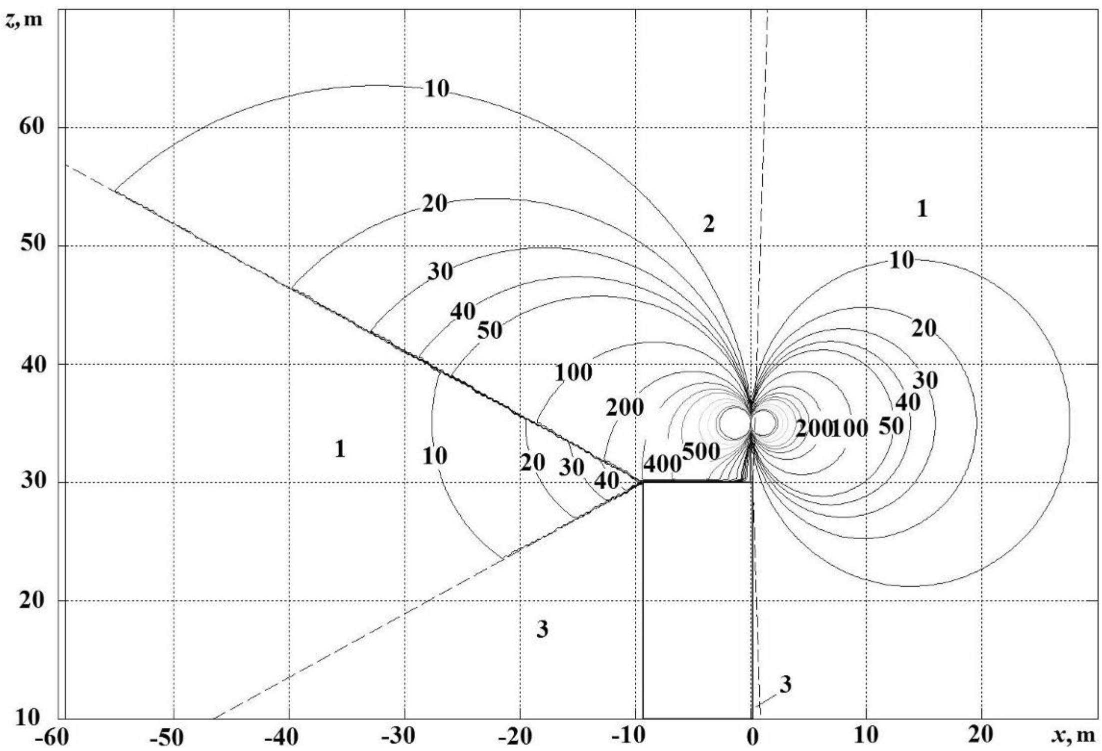

Figure 3. Vertical section of EFD distribution for omnidirectional antenna

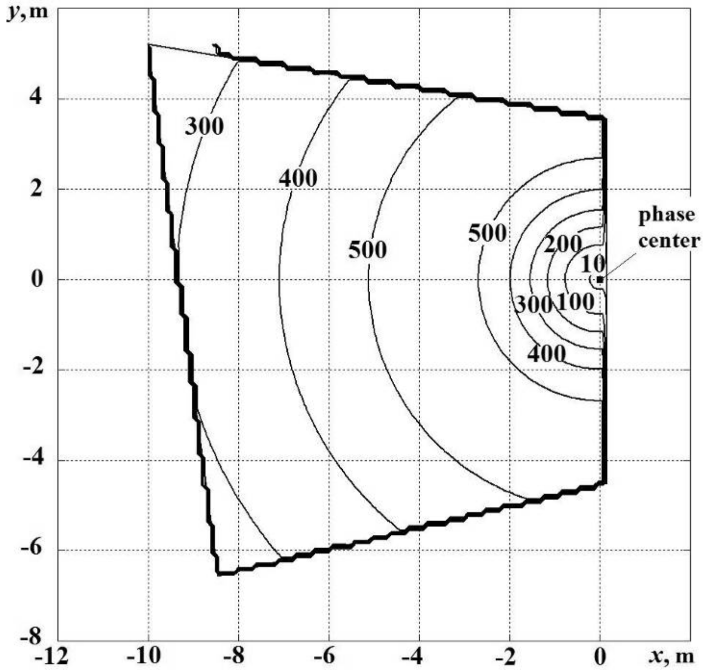

Figure 4. Horizontal section of EFD distribution for omnidirectional antenna

The analysis of the obtained EFD distributions shows that omnidirectional antennae have EFD level of 500 μW/cm^2 in horizontal section at 2 m above the rooftop; it exceeds maximum permissible level by several orders. Moreover, a zone with radiation level greater than maximum permissible level appears in antenna back half-space area sized about 60 m horizontally and 30 m in vertically. SPZ horizontal limits in antenna front half-space are only 30 m. Directional GSM antennae with back-lobe level of less than -20 dB do not exceed the radiation level of 0.021 μW/cm^2 on the rooftop. Even if GSM antennae are deployed with standard configuration – three in a circle spaced at intervals of 120 degrees – EFD level in horizontal section at 2 m above the rooftop would be less than maximum permissible level.

3.2. Comparison of electromagnetic environment estimation results obtained with forecast calculation technique and with instrumental procedure

Let's compare the results given in the section 3.1 and ecological environment data obtained with instrumental procedure and taken form [21]. In the last paper the results have been measured within a 300 m radius of base station antenna at levels of 0.5 m and 2 m above bearing surface. It should be noted that the level of 0.5 m above the bearing surface characterizes electromagnetic environment ecologically. Data on antenna position upon a roof, height of a building, and antenna directional properties are not given in [21]. The EFD measurements from [21] for rooftop antenna are shown in table 2.

Table 2. Electromagnetic environment data obtained with instrumental procedure [21]

Measurement point locations	Mean EFD value, μW/cm^2	Maximum permissible EFD level, μW/cm^2
Roof	2-10	500
Accommodation under base station antenna	<2	10
Adjacent grounds intended for building	0.2-0.7	5
In first and second line buildings	0.5-1	30

Let's compare the results from table 2, figure 2 and figure 4, which are obtained with different methods. As is easy to see, that for omnidirectional antenna the values of highest EFD level by forecast calculation and the one by instrumental procedure coincide and are equal to 500 μW/cm^2. It proves the correctness of the software routine, which has been developed by the authors. The routine itself is given in [18-20].

The discrepancy within the results can be easily explained. The research area of 300 m radius, which has been considered in [21], holds for ecological estimation of maximum permissible level of 1 μW/cm^2 that has been suggested to use in the paper. If the value of maximum permissible level is taken from the standards [10] of sanitary and hygienic estimation and is considered to be 10 μW/cm^2, the research area can be decreased by about an order; it was shown on figures 2-4. If we the visualization results of EFD distribution for rooftop antenna obtained with a strict electrodynamic model (figure 2) are considered, it is easy to notice that the accommodations under the antenna are in the shadow zone. Hence, the EFD value will be minimal in this direction. GSM antenna field affects only the open balconies of the upper floors, if the balconies are large enough. This reasoning is supported with instrumental procedure results. It is impossible to evaluate the instrumental procedure results for adjacent grounds and in first and second line buildings, because in the paper [21] there are no data on antenna height above the ground, distance to the first and second line buildings and their height.

Thus, forecast calculation, which was implemented in the EFD distribution visualization routines developed by authors for horizontal and vertical sections, may be said to give consistent results in an accessible form; their physical interpretation promotes recommendations on electromagnetic environment improvement. Hence, the routines can be used in socially-oriented electromagnetic monitoring.

4. Conclusion

The increase of GSM base stations quantity causes a serious decline of electromagnetic environment, especially in metropolitan areas. The impossibility to change this makes electromagnetic environment monitoring necessary. The most accessible form of giving out results of socially oriented monitoring is their visualization with specially developed software routines.

The developed EFD visualization routines for GSM base station antennae are based on forecast calculation method with an account of electrodynamic effects caused by antenna construction and location. The calculations are also based on Russian standards for land-based mobile communication location and operation.

The analysis of EFD distributions has shown that omnidirectional GSM antennae have EFD of 500 μW/cm^2 in horizontal section at 2 m above the ground level, which exceeds maximum permissible level by several orders. A zone with radiation level greater than maximum permissible level appears in antenna back half-space area sized about 60 m horizontally and 30 m in vertically. SPZ horizontal limits in antenna front half-space are only 30 m. Directional GSM antennae with back-lobe level of less than -20 dB do not exceed the radiation level of 0.021 μW/cm^2 on the rooftop. Even if GSM antennae are deployed with standard configuration – three in a circle spaced at intervals of 120 degrees – EFD level in horizontal section at 2 m above the rooftop would be less than maximum permissible level.

The results obtained with the developed software routines and their comparison to instrumental measurements have shown that the forecast calculation, which had been implemented in the developed routines for EFD visualization in horizontal and vertical sections, gives consistent results in an accessible form. Their physical interpretation promotes recommendations on electromagnetic environment improvement. Hence, the routines can be used in socially-oriented electromagnetic monitoring.

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