Determination of electromagnetic field exposure in public spaces

Jugoslav Joković
Tijana Dimitrijević
Aleksandar Atanasković
Nebojša Dončov

Abstract – *The monitoring of electromagnetic (EM) field, caused by the presence of radio frequency (RF) and microwave radiation from ICT devices as various sources of EM field, has emerged as an important technical and social challenge in terms of planning, management and usage of open public spaces. Considering the necessity of EM field level determination in the context of using ICT devices in service areas, as well as monitoring of EM field exposure in public spaces, the several technical issues have been foreseen in the analyses based on corresponding examples: from the method for modelling of EM field propagation in the vicinity of RF and microwave sources - base stations for mobile networks, broadcasting transmitters, local wireless networks, together with the distribution of EM field from ICT devices, through the appropriate measurement and exposure assessment methods, to the adequate software support for geo-visualisation, the data acquisition and processing.*

Keywords— public spaces; electromagnetic field exposure, mobile communication, base station

I. INTRODUCTION

Along with the growth of services and products used in modern information technology applications, wireless communication systems have become an essential part of everyday life. The rapid development of wireless communication technologies using radiofrequencies (RF) have induced a substantial increase in numerous electromagnetic field (EMF) sources, which can be divided in two main categories: fixed ambient sources, such as radio/TV broadcast transmitters or mobile phone base stations, and portable personal sources, such as mobile phones and other terminals used for wireless communication. The majority of the world's population is using mobile phones in urban environments. The worldwide use of mobile telephony has increased considerably with the development of the digital technologies over the past 20 years. The penetration of the mobile phone is beyond 100% in almost all European countries implying that Europe leads in mobile penetration worldwide. The increased use of mobile phones has led to an increased deployment of base stations, the number of which depends on several factors such as the number of network providers, number of users, number of simultaneous calls, etc. The base stations are often situated close to public spaces and become the cause for concerns of human exposure ([1], [2]).

In most public spaces visitors also use mobile phones and other portable devices for the purpose of communication, but most people are not aware of the health implication and possible safety measures.

In general, the data most widely available on exposure of the public to radiofrequency (RF) electromagnetic field (EMF) within the microwave range of spectrum (300 MHz–300 GHz) relates to technology for mobile telecommunications – GSM (Global System for Mobile Communication) and UMTS (Universal Mobile Telecommunication System), coexisting with another technology occupying the microwave spectrum, such as radio and television broadcasting, RF identification system and wireless communications applications: WiFi, WLAN (Wireless Local Area Network) and WiMax (Worldwide Interoperability for Microwave Access). The newest generation of mobile telecommunications networks – LTE (Long Term Evolution) also represents a growing source of RF EMF exposure. Due to the omnipresence of mobile phone base stations and mobile phone handsets, this technology dominates the exposure in the outdoor urban environments [1,2].

The fast changing world of information technologies and particularly mobile telecommunications has raised concern over possible health effects from exposure to EMF radiated from cellular base stations and mobile phone handsets. Therefore the people in public spaces situated in the vicinity of base stations are now asking questions today, regarding EMF exposure in comparison to the acceptable level and avoiding potential adverse health effects. This paper will try to summarise these questions, starting with basic concepts of electromagnetics and theoretical background of EMF radiation, in terms of exposure metrics and standards. Taking into account previously published papers and scientific literature, this paper reviews the estimation and evaluation of the EMF exposure in public spaces using a different methodology based on measurements and modelling. In order to illustrate the determination of radiated EMF from cellular base stations which aim to verify the exposure compliance with human protection guidelines, measured results of electric field level in frequency ranges of mobile communication systems are presented.

II. EMF EXPOSURE

A. Basic theory of Electromagnetic radiation

The range of frequencies that are found within the band 3 kHz to 300 GHz (called radio frequencies) are used in various applications that require radio waves - radio and television broadcasting, radar and microwave systems and cellular mobile communication. Generally, radio waves propagated by an antenna in free space are called electromagnetic (EM) waves [3], that may have diverse energy levels transmitted from a source; this is generally known as EM radiation. The EM radiation is a form of energy exhibiting wave-like behavior as it travels through space. It has both electric and magnetic field components, which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. When referring to biological radiation exposures, EM radiation is divided into two types: ionising and non-ionising. Since the human body is composed of about 60 percent water, different types of radiations refer to whether the RF energy is high enough to break chemical bonds of water (ionising) or not (non-ionising). The ionising radiation affects the human organs to greater extent, while the non-ionising radiation does not alter the atomic structure of creatures, but still affects the human cells and may create negative health effects [4].

Figure 1 shows a graphical representation of the spectrum of EM energy or radiation, together with the application area of corresponding frequency range. For telecommunication purposes, EMF between a few MHz to some GHz are of particular interest, where numerous mobile telephony systems can be found in addition to broadcasting sources and commercial radio systems.

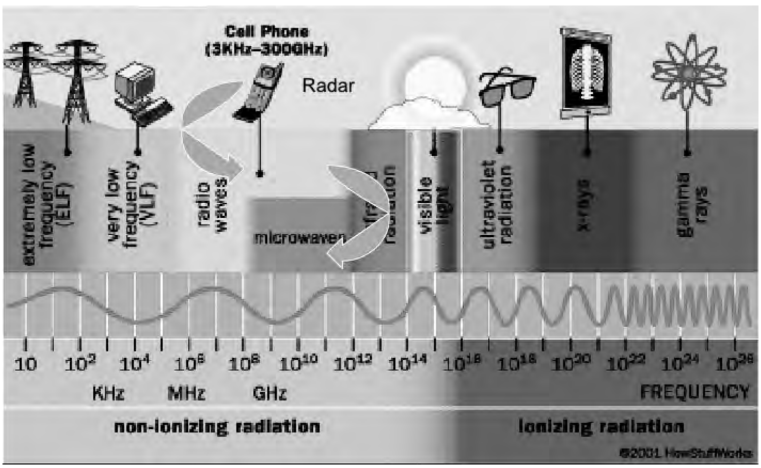

Fig. 1. Spectrum of EM radiation (http://www.astrosurf.com/luxorion/)

Mobile phones communicate by radio signals passing between the phone and the base station antennas. Mobile telephones are connected to the base station by two separate radio links: the uplink from phone to base station – in frequency ranges 880–915, 1710–1785, 1920–1980 MHz, and the downlink from the base station to phone – related to ranges 925–960, 1805–1880, 2110–2170 MHz, for GSM 900, GSM 1800 and UMTS 2100, respectively. The base station antenna transmits in the frequency range that is divided into sub-bands, which are allocated to various operators. There may be several carrier frequencies allotted to one operator, where each carrier frequency may transmit 10 to 20W of power. Taking into account that there may be 3-4 operators on the same rooftop or tower, thereby the total transmitted power may achieve the order of 100W of power. In addition, directional antennas with a typical gain of 10-20 dB (numeric value is 10-100) are used, and therefore several KW of power may be transmitted effectively, in the main beam direction.

In general, the distribution of EMF is temporally and spatially highly variable [5]. There are a variety of reasons for variations in the transmitted power at any given time: how many channels are in use, how many of the time slots in the traffic channels are used, and whether a function that deactivates the transmission if there is no voice detected is used or not. Accordingly, the emitted power from a base station may vary over the day and week from a minimal power of e.g. 10 W during times with low to modest traffic, to up to several times that level at peak traffic. Any attempt to characterise the exposure around a base station should take this traffic-dependent time-variation into account. Information from the operator of the base station on traffic statistics could provide a basis on how this should be done. Options could include sampling (for an average situation) and/or choosing a probable maximum traffic time (for the worst case situation).

Besides emission variations with time, EMF radiation varies with distance from the base station. There are different types of antennas regarding directionality. Omni antennas radiate in every direction (seen horizontally), while sector antennas effectively only radiate in a sector. In order to permit increased re-use of frequencies, as well as reduced interference, most base stations in high traffic density areas, such as cities, are of the sector type. As previously mentioned, the preferred sector antenna gain is between 10 and 20 dB meaning that the emitted power may be between 10 - 100 times stronger in the intended directions compared to an omni antenna, while it will be correspondingly weaker in other directions [3]. For example, the exposure behind a sector antenna could be 300 times weaker than in the main lobe. In addition to this horizontal directionality, the antenna lobe will also have a strong vertical directionality, with a fairly narrow beam, which is often tilted slightly downward.

B. Metrics for EMF exposure

This section gives an overview of current metrics for evaluating radio-frequency (RF) electromagnetic field (EMF) exposure in the frequency range of the microwave spectrum: the most often used quantities and their usage.

International guidelines limit the levels of quantities to protect people against adverse health effects from exposure to EMF. Basic measures to protect people from exposure to EMF are independently defined for the base station and for the personal mobile devices. In the frequency range of our interest, several quantities are used to express exposure: incident field levels (E and H), incident power density (S) and specific absorption rate in the human body (SAR) are the most common quantities.

The exposure to incident radio-frequency EMF is assessed in terms of power density, electric field and magnetic field. In the far-field of a source, the power density, electric field and the magnetic field are related through the characteristic impedance in free space:

$$S = E_{rms}^2/Z_0 = Z_0 H_{rms}^2 \qquad (1)$$

with Z_0 the characteristic impedance in free space (377ohm), E_{rms} the root-mean-squared (RMS) electric field (V/m) and H_{rms} the RMS magnetic field (A/m).

The far-field region can be expected at a distance $2D^2/\lambda$, where D is the largest dimension of the antenna, and λ is the wavelength. In this region, the source can be approximated as a point, suggesting that the power density S (W/m^2) for an isotropic antenna, and in the absence of any interfering objects, will decrease as $1/r^2$, where r is distance from antenna.

In the close vicinity of base stations, calculations are more difficult because of the so-called near-field conditions. In this region, the relationships between the electric and the magnetic fields are much more complex and separate evaluation of them should be performed. Calculations have indicated that using the far-field approximation at, say, 10 m from a large base station antenna would overestimate the exposure by a few percentage, while at 1 m the overestimate would be some 10-20 times. Accordingly, from a practical point of view, beyond a distance of about 10 m from the base station antenna, far-field based calculations are suitable for determining and surveying the EMF exposures.

In the near-field, at distances somewhat smaller than one wavelength (usually less than 10 cm from a mobile telephony source), there is a dynamic energy interaction between the source and the human body. As a consequence, instead of field strengths other methods of evaluations must be used. The SAR (Specific Absorption Rate) is a measure for the induced EMF inside the human body, which is defined as:

$$SAR = \sigma E_{rms}^2/\rho \qquad (2)$$

with σ the conductivity (S/m) and ρ the mass density (kg/m^3).

Besides, new quantities are defined in scientific literature, such as dose and exposure ratios, to determine realistic exposure of people to EMF. Generally, the nature of EMF (frequency, intensity, duration of exposure) offers a large variety of quantities which can be used as exposure metrics [6]. Moreover, a wide range of exposure conditions can exist: individual or multiple source exposure, near or far-field exposure, short- or long-term exposure. So far, multiple methods to assess the exposure are present in the epidemiological literature. In case of multiple-source exposure, other metrics can be defined, based on the contribution of each source to the total exposure. Guidelines and standards defined ratios to evaluate compliance in the case of simultaneous exposure to fields of different frequencies. Other definitions provide exposure ratio metrics, like the average contribution (AC), and the maximal contribution (MC) of different sources to the total exposure value.

C. Standards and recommendation for exposure limits

In any particular exposure situation, measured or calculated values of quantities like field levels (electric/magnetic field intensity), power density and specific absorption rate (SAR), can be compared with the appropriate reference level. If the measured or calculated value exceeds the reference level, it is necessary to test compliance with the relevant field quantity and to determine whether additional protective measures are necessary. In this section, the derived limits and reference levels of different international and national standards, regulations and other documents are presented, with the main focus on the limits in the frequency range around 900 MHz and 1800 MHz and 2100 MHz to cover exposure next to base stations.

The International Commission for Non-Ionizing Radiation Protection (ICNIRP) formulated guidelines on exposure limits for EMF, based on health effects resulting from absorption of energy during exposure to EMF between 100 kHz and 300 GHz [7]. The European Union published recommendations to limit the exposure of the general public in EMF [8] that rely on the ICNIRP guidelines and are therefore based on scientific appraisal of risk-related data. Some countries have established similar national laws, regulations, guidelines or standards for exposure to RF fields, while others have adopted the ICNIRP guidelines.

In general, international documents of this type are those of ICNIRP, IEEE and CENELEC [9], as well as national guidelines from Austria (ÖNORM 1992), the UK (NRPB, 1993) and the Netherlands (NEL, 1997), and are based on the concept of avoiding the established short-term health effects of exposure. In some countries regulations were adopted containing exposure limits far below the ICNIRP recommendations (Hungary, 1986; Italy, 1998; Austria - SvorGW, 1998; Switzerland - NISV, 1999), which are generally based on precautionary concepts strongly depending on social and political arguments in addition to scientific considerations. Generally, the public limits of the documents for the electric field strengths are given for frequency between 0.1 MHz and 300 GHz. However, in order to better compare the limits in the frequency bands of mobile systems a more detailed overview on the limits of the mentioned documents is given for the frequency range 100 MHz to 10 GHz in Figure 2. As seen in Figure 2, there is a frequency variation in these levels in some guidelines. Considering operating frequencies for cellular systems, the limits of the electric field strength of considered documents at 900 MHz vary between 0.6 and 112.5 V/m (corresponding to a range of 0.001 to 33 W/m² for power density limits), while at 1800 MHz, the range is from 0.6 to 194 V/m (0.001 to 100 W/m²). As an illustration, numerical values of the electric field strength and power density limits defined by international guidelines ICNIRP and IEEE, at 900 MHz, 1800 MHz and 2100 MHz are given in Table I.

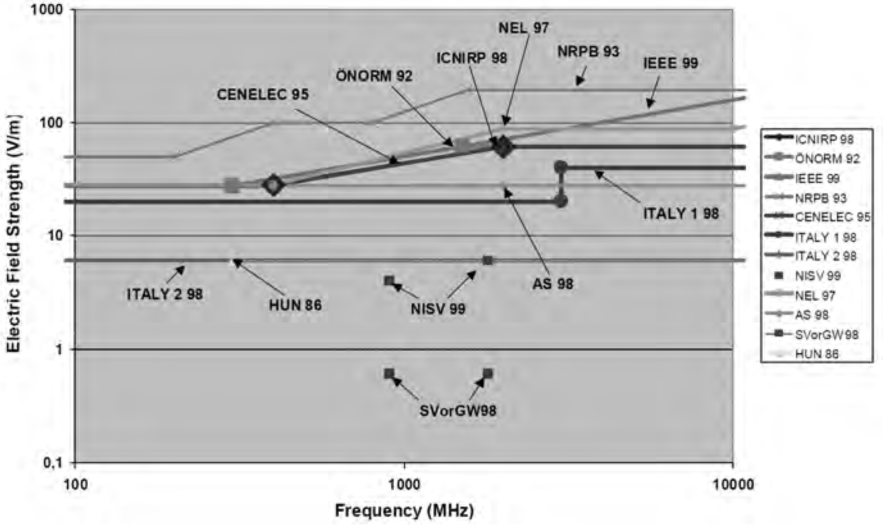

Fig. 2. Comparison of limits for radiofrequency fields

TABLE I. REFERENCE LEVELS FOR EXPOSURE AT 900 AND 1800 MHZ

Limits at frequency	Reference levels for the general public		
	International standard	*Electric field (V/m)*	*Power density (W/m2)*
900 MHz	ICNIRP	41.25	4.50
	IEEE	47.60	6.00
1800 MHz	ICNIRP	58.30	9.00
	IEEE	67.30	12.00
2100 MHz	ICNIRP	61.00	10.00
	IEEE	71.00	13.50

III. EMF DETERMINATION AND MONITORING

A. Numerical modelling of EMF exposure

The numerical investigation of the EMF exposure is limited. The three-dimensional (3D) ray-tracing tools are used to predict the exposure in a certain area during the network design stage. In the near-field of antennas, such as base station antennas, 3D electromagnetic solvers are employed to investigate the incident exposure. Simulations provide detailed information of the field distribution around and inside the body, but numerical tools have the drawback of always being an approximation of the real world and often require long runtimes and a large amount of processing power.

Different geospatial propagation models have been developed to compute environmental EMF exposure from fixed site transmitters (mobile phone base stations and broadcast transmitters), considering the three dimensional environment by including topography and buildings in the model computations [10]. The model calculation is generally based on a data of transmitters (position, transmission direction, antenna types and radiation pattern, transmitter power and number of channels) and a 3D building model of the study area, considering, for example, shielding and diffraction by buildings and topography [4]. Furthermore, detailed information about the transmitters, such as antenna pattern and vertical tilt, may also be taken into account. In general, three main model inputs are antenna data, 3D building geometry and a digital terrain model, together with detailed information of all cell antennas from the mobile phone network operators: coordinates, height, horizontal direction, vertical tilt, antenna type, frequency, start date of operation and output power of each antenna [11]. The models usually compute the field strengths of different frequency bands, corresponding to different exposure sources, such as GSM900, GSM1800 and UMTS2100. The models are based on different radio wave propagation algorithms to estimate EMF exposure, such as the COST–Walfisch–Ikegami model [12] and models developed by the International Telecommunications Union (ITU), for example the ITU-R P.1546-1 [13] or principles described in ITU-R P.1411 [14].

B. EMF exposure measurement

The exposure to incident EMF is mainly assessed by measurements, usually by using broadband and/or frequency selective equipment. Generally, two types of measurement procedures have been applied for EMF exposure determination: fixed-location and mobile monitoring. Fixed-location measurements with a spectrum analyser are very accurate for determination of exposure at a specific point in time and space. The signal to the spectrum analyser is expressed in electric field strengths (in V/m) using instrument design parameters such as antenna factor and cable loss. For practical purposes, the results are often given in decibels, where e.g. dBV/m = 10logV/m. Due to high spatial variation of EMF around base stations, this type of exposure monitoring is time and resource intensive in terms of equipment, costs and trained personnel ([2], [15]). On the other hand, portable exposure meters (PEMs) are more convenient for collecting data representing typical exposure levels over time in a wide geographic area. Therefore, despite some limitations [2] such devices have been applied for collecting numerous measurements with relative little effort at different locations ([4], [16], [17], [18], [19], [20]).

In the last 20 years exposure measurement campaigns were performed in all European countries by systematic planning processes and also on request of the public or local authorities [1]. Most of them were focused on the exposure to RF of mobile phone base stations. Regarding some samples of data by countries, the locations near the base stations and sensitive places (green zones parks, hospitals or schools) were investigated. For example, in Germany within the campaign in 1997, the maximum measured RF power densities were 0,04 W/m² while the mean value was 0,0052 W/m² [21]. In Spain, the maximum power density obtained by measurement that was achieved was 0,0118 W/m², which is quite small compared to the limits (4,5 W/m²). In a Spanish case study the medium power density in outdoor urban area showed 0,000082 W/m². In Italy innovative communication actions were combined with a measurement campaign. The action was introduced in 2003 where a mobile EMF laboratory called "BluBus" and later "BluShuttle" cars were moving across the country equipped with a wideband portable RF field meter and an autonomous control centre. According to the summary of these measurements more than 88% of recorded electric field strength was below 1 V/m, 8,1% between 1-3 V/m, 2,6% between 3-6 V/m and less than 0,3% above 6 V/m. Within a large measurement campaign in France more than 20,000 site measurements have been carried out by ANFR (Agence Nationale des Fréquences) since 2001. More than 60% of measured total field was below 1V/m, less than 0,1% above 20 V/m and around 2,8% between 6 V/m and 20 V/m. The main focus of campaign elaborated in three countries, Belgium, Netherlands and Sweden between 2009 September and 2010 April, was to measure the environmental exposure. The maximal total field was 3,9 V/m in a residential environment mainly due to the GSM900 signal.

Many countries upload their measurement results on the Internet and/or publish the data annually. A comparative analysis of the results of EMF measurements in the EU indicated that mean electric field strengths were between 0.08 V/m and 1.8 V/m. In summary, the general results of European site measurement surveys showed that more than 60% of measured total EMF exposure was below 1 V/m (~0,003 W/m2), less than 1% above 6 V/m (0,095 W/m^2) and only less than 0,1% was above 20 V/m (1 W/m^2) field strength (power density). The relevant recommended exposure limit for the public is in the range of 40-60 V/m (4-10 W/m^2). The absorbed power in the human body is related to the power density in free space. No exposure data above the public exposure limit was obtained from these surveys.

C. EMF exposure from mobile phones

Cellular phones are specific EMF sources, since they are used in close vicinity of the head: either on the ear or in front of the face. The exposure to EMF emitted by mobile phone handsets is determined as values of the specific absorption rate (SAR). Exposure evaluation can be based either on dedicated measurements or on numerical modelling.

The field strength and distribution of SAR within the head are dependent on the phone design and the communication system. It is important to emphasise that at a distance of 10 cm from the mobile phone the absorbed power in the head decreases more than 10 times compared to when assessed close to the ear. At 40 cm in front of the head the maximum SAR over 10g is close to 1% of the SAR touching the phone to the head.

During normal use of mobile phones with maximum output powers of 1 to 2 W, the localised SAR is less than 2 W/kg [22]. Estimating the cumulative exposure, about 30 min of mobile phone use corresponds to a 1-day exposure from far field source at an incident level of 1–2 V/m [23]. However the EU limit of permissible SAR in the head is 2 W/kg; the real life exposure to RF fields from mobile devices is less than the results of compliance tests.

In general, new phone models with higher frequencies emit less power than older types, and since the year 2001 the mobile phone manufactures have been required to notify the SAR levels of their new phone models. The mobile phones also control the transmitted power according to the network coverage. The better the network coverage, the less transmitted power of a cellular phone is needed to communicate with the base station. According to the exposure assessment of epidemiological studies and the information from the operators, the phones in GSM mode work 30-50% of their time in maximum power, while in 3G mode only 1% of their time.

The number of calls and duration of calls can be a sufficient parameter to estimate the cumulative power emitted by the handset of a cellular telephone. According to the Swiss QUALIFEX study the average mobile phone call time of the participants was 25,6 minutes per week. The average output power was 133 mW for GSM 900 mobile phone, 62,2 mW for GSM 1800 and 650 μ W for UMTS phone [4].

Using mobile phones to transmit data may increase power levels up to three times higher than those transmitted in speaking mode. In these cases the mobile phone is usually further away from the body. In addition, the use of a hands-free device and even a small distance to the body reduces the exposure of the phone user.

IV. RESULTS

In order to illustrate measurements applied for EMF exposure determination using spectrum analyser NARDA SRM-3000, Figure 3 shows corresponding results of electric field levels in bands related to GSM900, GSM 1800 and UMTS, respectively. From the experiment we found that the maximum value of electric field (less than 90 dBμV/m corresponding with 1V/m) radiated from base station antenna does not exceed ICNIRP levels. However, it is important to note that the threshold limits defined by the ICNIRP are considered to be rather too generous and therefore it becomes the subject matter of public interest in the context of possible environmental adverse effects.

V. CONCLUSION

We considered different aspects of EMF exposure from cellular base station, as well as mobile devices, including a comparison of measured results of EMF level with reference ones defined by international standards.

The levels of EMF exposure radiated from fixed outdoor body far-fixed sources of wireless telecommunication systems, such as mobile base stations (GSM, 3G, LTE) vary in space and time. The most characteristic exposure units are the electric and magnetic field strength, as well as power density. The exposure is continuous and maximum exposure levels are significantly below the recommended European exposure limits (typically less than 1 V/m). This category of EMF exposure has importance for risk analysis in terms of investigations of long-term changes of exposure to RF of population in public spaces.

The exposure levels from the mobile phones and wireless body-close portable devices are highly variable and local. The most characteristic of this exposure unit is the SAR (W/kg). The levels of exposure from mobile handsets (GSM, 3G) are below the recommended European exposure limit (2 W/kg), but the local maximum may be close to the limit.

ACKNOWLEDGEMENT

The authors would like to thank Montserrat Pallares Barbera, Universidad Autonoma de Barcelona, and Fernando Alvarez Franco, Universidad de Extremadura, for supervision during the development of the research concept and supporting the STSM 26848 within COST Action TU 1306 CyberParks.

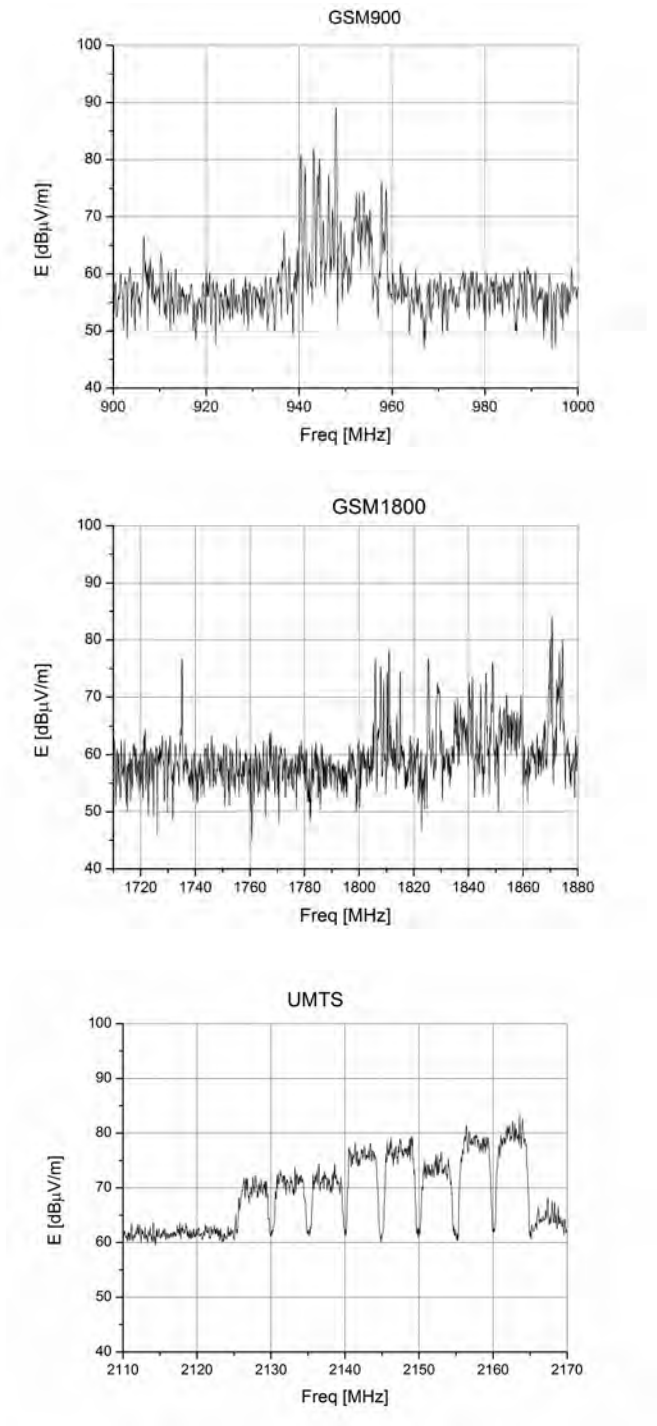

Fig. 3. Measured results of EMF level for GSM 900, GSM 1800 and UMTS

REFERENCES

[1] Gajsek, P., Ravazzani, P., Wiart, J., Grellier, J., Samaras, T., & Thuroczy, G. (2015). Electromagnetic field exposure assessment in Europe radiofrequency fields (10MHz-6GHz). *J Expos Sci Environ Epidemiol, 25*(1), 37-44. doi: 10.1038/jes.2013.40

[2] Joseph, W., Frei, P., Roösli, M., Thuróczy, G., Gajsek, P., Trcek, T., Martens, L. (2010). Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. *Environmental Research, 110*(7), 658-663. doi: http://dx.doi.org/10.1016/j.envres.2010.06.009

[3] Balanis, C. A. (1989). *Advanced Engineering Electromagnetics*. New York: John Wiley and Sons.

[4] Gandhi, G., & Pahwa, K. (2015). Analysis of Electromagnetic Radiation from Base Station Antennas to Prevent Health Hazards. *International Journal of Advanced Research in Computer Science and Software Engineering, 5*(1), 526-530.

[5] Frei, P., Mohler, E., Bürgi, A., Fröhlich, J., Neubauer, G., Braun-Fahrländer, C., & Röösli, M. (2009). A prediction model for personal radio frequency electromagnetic field exposure. *Science of The Total Environment, 408*(1), 102-108. doi: http://dx.doi.org/10.1016/j.scitotenv.2009.09.023

[6] Mann, S., Addison, D. S., Blackwell, R. P., & Kewhalid, M. (2005). Personal Dosimetry of RF Radiation – Laboratory and Volunteers Trials of an RF Personal Exposure Meter, Health Protection Agency: Centre for Radiation, Chemical and Environmental Hazards, Radiation Protection Division.

[7] ICNIRP. (1998). International Commission on Non-Ionizing Radiation Protection, Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (1 Hz - 300 GHz). *Health Physics, 78*, 494-522.

[8] Council. (1999). Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC). *Official Journal of the European Communities, 42*.

[9] CENELEC. (1995). ENV 50166-2, Human Exposure to EM Fields, High Frequency (10 kHz to 300 GHz), CENELEC, European Prestandard, ICS 29.020.

[10] Burgi, A., Theis, G., Siegenthaler, A., & Roosli, M. (2007). Exposure modeling of high-frequency electromagnetic fields. *J Expos Sci Environ Epidemiol, 18*(2), 183-191.

[11] Beekhuizen, J., Vermeulen, R., Kromhout, H., Bürgi, A., & Huss, A. (2013). Geospatial modelling of electromagnetic fields from mobile phone base stations. *Science of The Total Environment, 445–446*, 202-209. doi: http://dx.doi.org/10.1016/j.scitotenv.2012.12.020

[12] Kürner, T. (1999). Propagation prediction models. In:Damosso E, editor. COST Telecommunications—digital mobile radio towards future generation systems *final report. European Communities* (pp. 134-148).

[13] ITU. (2003). ITU-R P.1546-1: method for point-to-area prediction for terrestrial services in the frequency range 30 MHz to 3000 MHz.

[14] ITU. (2009). ITU-R P.1411-5: propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz.

[15] Joseph, W., Verloock, L., Tanghe, E., & Martens, L. (2009). In-Situ Measurement Procedures for Temporal RF Electromagnetic Field Exposure of the General Public. *Health Physics, 96*(5), 529-542. doi: 10.1097/01.HP.0000341327.37310.c8

[16] Bolte, J. F. B., & Eikelboom, T. (2012). Personal radiofrequency electromagnetic field measurements in the Netherlands: Exposure level and variability for everyday activities, times of day and types of area. *Environment international, 48*, 133-142. doi: http://dx.doi.org/10.1016/j.envint.2012.07.006

[17] Röösli, M., Frei, P., Bolte, J., Neubauer, G., Cardis, E., Feychting, M., Vrijheid, M. (2010). Conduct of a personal radiofrequency electromagnetic field measurement study: proposed study protocol. *Environmental Health, 9*(1), 1-14. doi: 10.1186/1476-069x-9-23

[18] Thuróczy, G., Molnár, F., Jánossy, G., Nagy, N., Kubinyi, G., Bakos, J., & Szabó †, J. (2008). Personal RF exposimetry in urban area. *Annals of telecommunications, 63*(1), 87-96. doi: 10.1007/s12243-007-0008-z

[19] Viel, J. F., Tiv, M., Moissonnier, M., Cardis, E., & Hours, M. (2011). Variability of radiofrequency exposure across days of the week: A population-based study. *Environmental Research, 111*(4), 510-513. doi: http://dx.doi.org/10.1016/j.envres.2011.02.015

[20] Viel, J.-F., Cardis, E., Moissonnier, M., de Seze, R., & Hours, M. (2009). Radiofrequency exposure in the French general population: Band, time, location and activity variability. *Environment international, 35*(8), 1150-1154. doi: http://dx.doi.org/10.1016/j.envint.2009.07.007

[21] Bornkessel, C., & Schubert, M. (2004). Entwicklung von Mess- und Berechnungsverfahren zur Ermittlung der Exposition der Bevölkerung durch elekrtromagnetische Felder in der Umgebung von Mobilfunk Basisstationen *Study for the German Federal Office for Radiation Protection, IMST GmbH, Kamp-Lintfort*.

[22] Directive. (2004). Directive 2004/40/EC of The European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields).

[23] Neubauer, G., Feychting, M., Hamnerius, Y., Kheifets, L., Kuster, N., Ruiz, I., Röösli, M. (2007). Feasibility of future epidemiological studies on possible health effects of mobile phone base stations. *Bioelectromagnetics, 28*(3), 224-230. doi: 10.1002/bem.20298

Jugoslav Joković
Faculty of Electronic Engineering
University of Niš
Nis, Serbia
jugoslav.jokovic@elfak.ni.ac.rs

Tijana Dimitrijević
Faculty of Electronic Engineering
University of Niš
Nis, Serbia
tijana.dimitrijevic@elfak.ni.ac.rs

Aleksandar Atanasković
Faculty of Electronic Engineering
University of Niš
Nis, Serbia
aleksandar.atanaskovic@elfak.ni.ac.rs

Nebojša Dončov
Faculty of Electronic Engineering
University of Niš
Nis, Serbia
nebojsa.doncov@elfak.ni.ac.rs