MEASUREMENT OF LOW-LEVEL RADIOFREQUENCY ELECTROMAGNETIC FIELDS IN THE HUMAN ENVIRONMENT

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Abstract

In recent years there has been an increase in development of electromagnetic (EM) technology in the telecommunication industry, resulting in an increase in human non-ionizing exposure. This fact has initiated a number of scientific studies on possible health effects of EM fields on human organism. Totally four representative microenvironments were investigated for RF EM fields distribution, namely: city center, residential area, rural area, and extra-village area. Each microenvironment was measured 20 times in accordance with the International Commission for Non-Ionizing Radiation Protection (ICNIRP) guidelines. The extra-village measurements were taken as the base values that reflect the E-field intensities with the lowest amplitudes. The statistical analysis revealed notable statistical significance ($p < 0.001$) in almost all measured frequency bands except the Wi-Fi where the p-values were less than 0.05 for the city center and residential area but not significant for rural area. The highest total E-field intensity was measured in the residential area (approximately 1.85 V/m). All measured values were below the legal limits of the Slovak Republic and ICNIRP safety guidelines. However, the ICNIRP safety limits were written in 1998 considering only the thermal effects of RF radiation. They were updated in 2009 without any changes in the limits and still recommend 27.5 – 61 V/m (2 – 10 W/m^2) for the RF frequency band of 400–2,000 MHz. The BioInitiative Report of 2012 established the scientific benchmark for possible health risks as 30–60 μW/m^2 (approximately 0.1 – 0.15 V/m). Thus, all measured values were above the scientifically derived limits.

Key words: base transceiver station, environment exposure, mobile communication, cell phone

INTRODUCTION

In recent years there has been an increase in development of electromagnetic (EM) technology in the telecommunication industry, resulting in an increase in human non-ionizing exposure. This fact has initiated a number of scientific studies on possible health effects of EM fields on human organism. Human head and associated body parts that engage during mobile communication are exposed to radiofrequency (RF) EM fields in a limited time even with higher intensities. However, base transceiver station (BTS) is a source of low energy but permanent whole-body exposure with intensities being approximately constant through the human body (1). However, the exposure pattern changes in the environment (2,3). Studies of low energy and long-term RF exposure revealed e.g. the effects on the cortisol and thyroid gland hormones in humans living near by the BTSs (4,5) and also neurotransmitters, noradrenaline, adrenaline, dopamine, and phenyletylamine after constant exposure from BTSs (6). Some other studies (7) revealed e.g. lipid peroxidation or protein oxidation after the 30 days of RF exposure. There has been an evidence presented by Kopani et al. (8) that even a short-time downlink exposure could lead to accumulation of iron in rabbit´s cerebellum.

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Methods of analytical simulations may not always involve the influences of various factors such as absorption and reflection from trees or buildings, but it is easier for implementation (9). Another method is personal exposure with a large amount of volunteers and close body-worn exposure meter could lead to concern of underestimation of the exposure by so called “body shadow” (10). Exposure level assessment could be also achieved by the field measurement directly in the environment where the spatial resolution is limited but there is possibility to stick to the measurement protocol strictly (11). Our study was not intended to determine a potential risk on human health directly. However, the aim of this study was to assess external exposure to RF EMF in selected areas of the environment by direct measurement and compare the results with defined standards.

METHODS

Selected areas of the microenvironment

Totally four representative microenvironments were investigated for RF EM fields distribution. Each microenvironment was measured 20 times in accordance with the International Commission for Non-Ionizing Radiation Protection (ICNIRP) (12) guidelines that specify RF EM measurements have to be averaged through 6 min intervals.

The microenvironments were chosen to fulfil several requirements for comparison of basic human environments such as: city center, residential area, rural area, and extra-village area. Measurement spots were investigated by digital EM maps published by VUJE company (13). They were designed to obtain information of the EM fields’ levels in a simple way to make them available to the general public. The maps also contain information about distribution of the base transceiver stations (BTS).

1.) **City center**: The location of Andrej Hlinka Square is situated in the historical center of Zilina city with a shopping center, various kinds of business premises, offices, and a permanent movement of people in the vicinity. There is also an increased number of different transmitters such as six GSM900 transmitters, two UMTS2100 transmitters, one FM transmitter for very short wave radio broadcasting, and several non-specified low frequency broadcast transmitters in a range of approximately 200 m from the place of the measurement.

2.) **Residential area** Solinky is a living area situated at the south of the Zilina center. It has approximately 4,300 households with about 14,000 inhabitants. The measurements were carried out in the central part of the residential area with direct visibility to the four GSM900 transmitters, several non-specified low frequency transmitters, and tens of Wi-Fi access points.

3.) **Rural area**: This BTS is located in the village of Rosina near the Zilina city but far enough from densely inhabited areas. In the vicinity there were only small family houses eliminating reflections from higher buildings compared to the city and the residential area. The BTS was approximately 100 m away from the place of the measurement.

4.) **Extra-village area**: Last BTS was located outside of the village and inhabited area near village of Visnove. This location was selected due to the absence of BTS (at least 1 km), low occurrence of people, and distance from residential areas.

Measuring device

The selective radiation meter Narda SRM3006 (Narda Safety Test Solutions, Germany) was used to measure the values. The meter is able to analyze RF EM field within the frequency range of 9 kHz – 6 GHz. For our study we utilized the three-axis isotropic antenna Narda 3502/01 (Narda Safety Test Solutions, Germany) with the selective frequency range of 420 MHz – 6 GHz. The antenna is suitable to directly measure the intensity of electric field (E-field) within the specified range. The antenna and the base unit were interconnected by Narda PMM 3601-01 (Narda Safety Test Solutions, Germany) RF 1.5 m coaxial wire

(14). Multi-pin connectors also allow the transfer of antenna parameters what enables automatic calibration of the measurement procedure. The base unit was held on a tripod about 1 m above the ground and the antenna was held on a tripod about 1.5 m above the ground (Fig. 1).

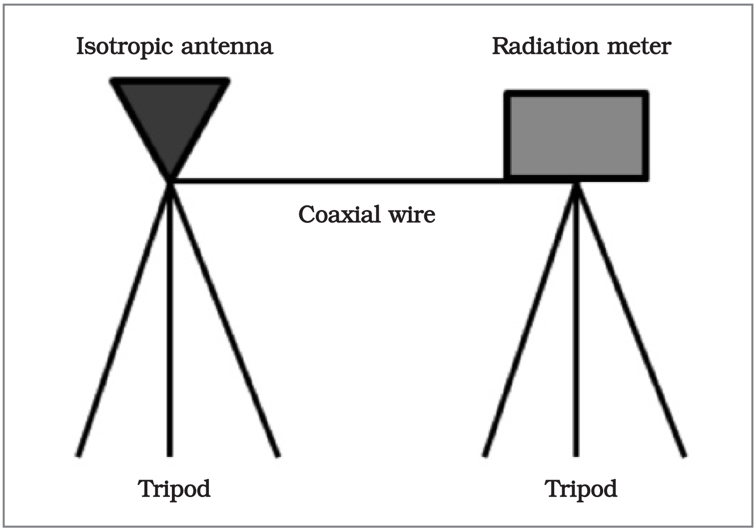

Fig. 1 Block schematic of the measuring device

The following frequency ranges were analyzed:

- **DVB-T** (Digital Video Broadcasting – Terestrial) 471 – 860 MHz, representing the digital television broadcasting standard
- **LTE800** (Long Term Evolution) 791 – 862 MHz, representing the standard for high-speed internet for mobile devices.
- **GSM900** (Global System for Mobile Communicatons) 917 – 960 MHz, representing the worldwide standard for mobile communication
- **GSM1800** 1.7101 – 1.8711 GHz
- **UMTS** (Universal Mobile Telecommunication System) 1.9 – 2.17 GHz, representing the 3rd generation of mobile communication standard
- **Wi-Fi** 2.4 – 2.4835 GHz, representing the standard for wireless local area internet networking
- **LTE2600** 2.5 – 2.69 GHz.

Statistical analysis

The extra-village measurements were taken as the base values that reflect the E-field intensities with the lowest amplitudes. The statistical evaluation was carried out using GraphPad InStat (USA) software by Student´s paired t-test. The confidence interval was set at 99.9% ($p < 0.001$).

RESULTS

The statistical analysis revealed notable statistical significance ($p < 0.001$) in almost all measured frequency bands except the Wi-Fi where the p-values were less than 0.005 for the city center and 0.001 for the residential area but not significant for rural area (Tab. 1). All measured values were below the legal limits of the Slovak Republic and the ICNIRP safety guidelines (12). The highest total E-field intensity was measured in the residential area (approximately 1.85 V/m).

Table 1. Table showing E-field in the selected frequency bands and appertaining environments ** $p < 0.001$; * $p < 0.005$

	City center	Residential area	Rural area	Extra-village area
DVBT (V/m)	** 0.045 ± 0.001	* 0.035 ± 0.001	** 0.041 ± 0.003	0.032 ± 0.002
LTE800 (V/m)	** 0.17 ± 0.02	** 0.19 ± 0.01	** 0.18 ± 0.02	0.01 ± 0.0008
GSM900 (V/m)	** 0.31 ± 0.02	** 0.35 ± 0.003	** 0.13 ± 0.02	0.01 ± 0.0002
GSM1800 (V/m)	** 0.32 ± 0.04	** 0.31 ± 0.01	** 0.02 ± 0.003	0.01 ± 0.00004
UMTS (V/m)	** 0.16 ± 0.02	** 0.51 ± 0.01	** 0.11 ± 0.02	0.01 ± 0.00005
WiFi $(V/m)x10^{-3}$	* 9.81 ± 3.66	** 8.67 ± 0.22	7.50 ± 0.19	7.22 ± 1.04
LTE2600 (V/m)	** 0.048 ± 0.005	** 0.450 ± 0.017	** 0.017 ± 0.003	0.011 ± 0.00005
Total (V/m)	1.072	1.852	0.510	0.093

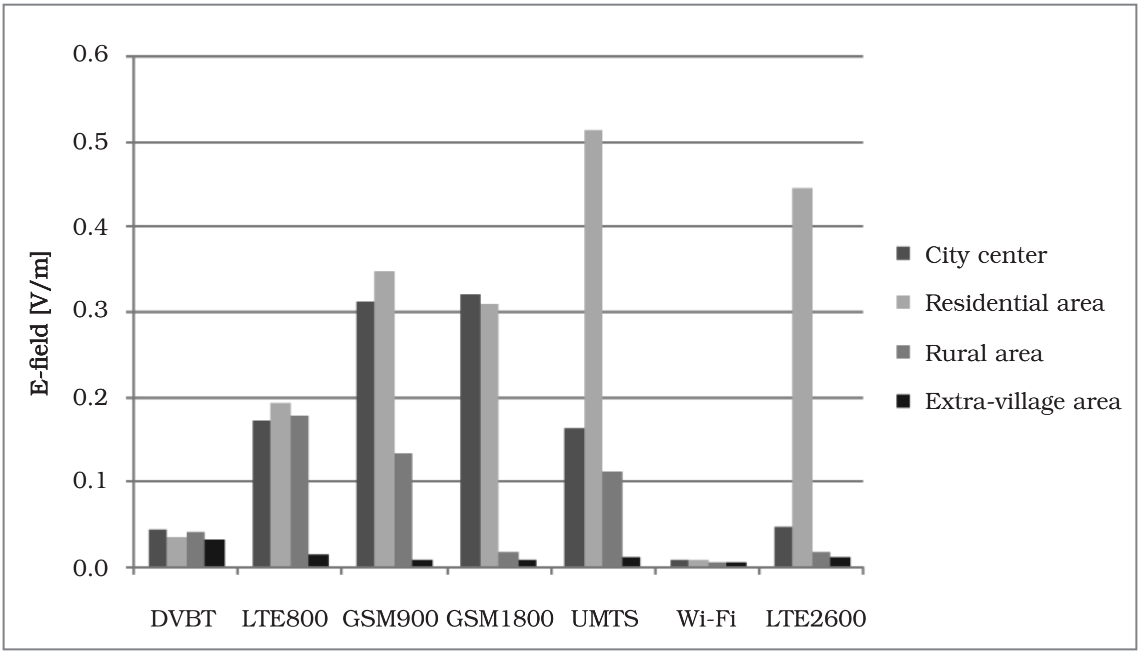

Fig. 2 Graphic representation of all frequency bands in each of the microenvironment.

Almost all frequency bands showed the highest E-field intensities in the residential area and the city center. The most significant increase was observed for UMTS and LTE2600 in the residential area. It was also dominant in LTE800, GSM900, GSM1800, and Wi-Fi frequency bands. The rural area had the lowest E-field intensity for UMTS among the habituated areas. It is interesting that the Wi-Fi and DVB-T intensities have approximately the same level in the extra-village comparing to the other areas (Fig. 2).

DISCUSSION

Four representative microenvironments were measured to investigate E-field intensities for different frequency bands. Results from the city center may be affected by the time when the measurement was made. In the afternoon we can predict an increased number of people who would use cell phone and, thus, we can expect higher E-field values. However, as the data noticed, the highest total E-field value was measured in the residential area. This result is anticipated as there is a large number of households with many wireless devices such as Wi-Fi routers, laptops, tablets, TVs, several cell phones, etc. Each cell phone receives or sends data quite frequently, resulting in RF radiation and communication with base station (BTS) or Wi-Fi router. Even if a cell phone is not currently active ("standby" mode) it sends RF data giving BTS information about its availability (1). All these devices may affect the E-field intensity in the measurement area. In the residential area we assumed increased Wi-Fi signal compared to the other areas, as today's coverage of residential units by wireless internet is significant.

As expected, the extra-village area was covered especially by GSM900. Longer wavelengths are able to penetrate an environment more easily even for longer distances. Each less occupied or no occupied environment has significantly dominant lower frequencies that are distinctive for the older standard of GSM. This is very interesting while some of the telecom giants (e.g. AT&T in the USA) noted that they will turn the GSM standard (2nd generation) off within couple years to keep the 3rd and the 4th generation networks. (15). However, as Telenor Norway stated, it is better to keep the 2nd and the 4th generations because almost all of today´s devices are still embedded with the 2nd generation network and, thus, it is still important for the market. Our research also points out the need for lower frequency bands since GSM900 play a major role in mobile communication in more remote areas.

Exposure to RF EM fields was classified as a possible carcinogen (group 2B) by the ICNIRP and WHO (16). However, the ICNIRP safety limits were written in 1998 considering only the thermal effects of the RF radiation. They were updated in 2009 without any changes in the limits and still recommend 27.5 – 61 V/m (2 – 10 W/m^2) for the RF frequency band of 400 – 2,000 MHz. The BioInitiative Report of 2012 (17) established the scientific benchmark for possible health risks as 30 – 60 μW/m^2 (approximately 0.1 – 0.15 V/m). As it was stated before, all measurements were far below the limits of SR derived from the ICNIRP guidelines but above the scientific derived limits.

A recent study from Hardell group (18) underwent similar measurements where six places of Stockholm´s Old Town (Sweden) were investigated. They revealed the highest mean levels for LTE2600, GSM+UMTS900, and UMTS2100, which is in line with our results for the residential area. However, for city center the GSM1800 predominates the LTE2600 frequency band. The reason could be in a better LTE signal coverage by a higher number of LTE transmitters. This phenomenon occurs in more developed countries where LTE serves for mobile data only.

Study group Sagar et al. (19) performed the study in Switzerland where 6 types of microenvironments were measured: city centers, central residential areas, non-central residential areas, rural residential areas, rural centers, and industry areas in frequency bands between 87.5 – 5875 MHz. Mean RF exposure was 0.53 V/m in industrial zones, 0.47 V/m in city centers, 0.32 V/m in central residential areas, 0.25 V/m non-central residential areas, 0.23 V/m in rural centers and rural residential areas. These results are 2-5times lower compared to our study even though the frequency band was wider in Sagar group. It could be explained by EM policy and limits in Switzerland. However, these results are still higher than reported in the BioInitiative Report. Another study of the same group Sagar et al. (20) investigated 6 countries (Switzerland, Ethiopia, Nepal, South Africa, Australia, and the USA) to compare RF EM outdoor exposure in the microenvironments. The results again sustained two major contributors as city centers (0.48 – 1.46 V/m) and residential areas (0.35 – 1.44 V/m). Two countries with the highest overall exposure were Australia and the USA with the EM levels very close to our measurements.

A recent study of Birks et al. (21) reported results from personal RF EM environmental exposure levels in European children (Denmark, Netherland, Slovenia, Switzerland, and Spain) in the frequency range of 87.5 MHz – 6 GHz. They found that the highest median exposure was outside (157.0 $\mu W/m^2$; approximately 0.5 V/m) and much lower at home (33.0 $\mu W/m^2$) or in school (35.1 $\mu W/m^2$). This fact suggests that major contributors of overall EM exposure are BTSs and broadcasting. Comparing to our study, the outside exposure was about 2-3 times lower. They also suggested that "urbanicity" is the most important determinant of total exposure where children living in urban environments had higher exposure compared to rural environment. These findings are in line with our results.

The limitation of our study is a relatively small number of measurements. The authors are also aware that only short term measurements were performed, which did not involve changes in BTS radiation exposure over time during a day or a week (22).

CONCLUSION

Totally four representative microenvironments were investigated for RF EM fields distribution, namely: city center, residential area, rural area, and extra-village area. All measured values were below the ICNIRP safety guidelines. However, the ICNIRP safety limits were written in 1998 considering only the thermal effects of the RF radiation. They were updated in 2009 without any changes in the limits. The BioInitiative Report of 2012 established the scientific benchmark for possible health risks where all measured values were above these scientifically derived limits. Since the microenvironments are part of the external environment they cannot be easily eliminated. We highlight more important proper and legally established monitoring of each new BTS with determination of its impact on the environment and the quality of human life living in the vicinity.

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