Distribution of High-Frequency Electromagnetic Fields on the Basis of Total Exposure Quotients

B. Tanatarec*, D. Šimunić **
* Centar za mjerenja u okolišu d.o.o, Zagreb, Croatia
** Faculty of Electrical Engineering and Computing, University of Zagreb, Zagreb, Croatia
btanatarec@cmo.hr

***Abstract* – Extensive non-ionizing high-frequency electromagnetic field (HF EMF) measurements were carried out in Republic of Croatia during 2018. Measurements of electric field strength on 812 locations were analysed. This paper focuses on distribution of HF EMF given on the basis of ICNIRP`s total exposure quotients (TEQ). Main objective is to establish which HF EMF sources affect TEQ values the most and to create classification of human exposure to HF EMF in respect to TEQ. Collocated HF EMF sources were also analysed, because they dominantly affect TEQ values on every point of investigation. There is an ongoing need for occasional controlled measurements of HF EMF, because on some points of investigation values of TEQ can exceed the established criteria and can have potentially negative effect on human health. Those locations are usually collocated with different HF EMF sources, which can be found on top of buildings or on one or more masts built very close to one another.**

Key words – distribution of non-ionizing high-frequency electromagnetic fields; total exposure quotients

I. INTRODUCTION

Consciousness about sustainable development and social responsibility in all aspects of balanced sustainable development infiltrates many societies with different cultures and different scientific and technological developments [1]. Although documents concerning social responsibility [2 - 4] are well accepted on an international level they are not obligatory and they simply give guidance on the principles of social responsibility and on ways to integrate socially responsible behaviour into an organisation [3]. Socially responsible behaviour includes care about protection of workers as well as protection of general public exposed to HF EMF. At European Union level series of documents about occupational an general public protection against established adverse health effects from electromagnetic fields were published [5 - 8].

Basic European legal documents on HF EMF protection are described in [8] and mandatory for all European Union member states to integrate them into their legal policies. European Union has published three technical documents [9 - 11] as non-binding practical guides to good practice to help the implementation its legal documents into technical aspects of member states. Medical and technical backgroud for limitting exposure to elecromagnetic fields (100 kHz to 300 GHz) are given in documents published by Commission on Non-Ionizing Radiation Protection (ICNIRP) [12 -15]. ICNIRP is an independent non-profit scientific organization chartered in Germany. It was founded in 1992 by the International Radiation Protection Association (IRPA) to which it maintains close relations. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR) to protect people and the environment from detrimental NIR exposure. Non-ionizing radiation refers to electromagnetic radiation such as ultraviolet, light, infrared, and radio waves, and mechanical waves such as infra- and ultrasound. In daily life, common sources of NIR include the sun, household electrical appliances, mobile phones, Wi-Fi and microwave ovens [16].

II. MEASUREMENTS

Measurements were performed by accredited CMO Lab laboratory with several Rohde & Schwarz measurement systems which consisted of a spectrum analyser FSH and an isotropic probe TS-EMF-B1. Equipment was properly and periodically calibrated in accredited laboratories. Isotropic (tri-axial) electric field probe consists of three independent electric dipoles placed orthogonally and because of that it can be used in any orientation with respect to the field [24]. Isotropic probe measures the resultant field strength as the root sum-square according to equation (1):

$$E = \sqrt{\left(E_1^2 + E_2^2 + E_3^2\right)} \tag{1}$$

In the vicinity of non-ionizing HF EMF sources, electric field strength measurements in frequency range from 30 MHz to 3 GHz were carried out during 2018. Measurements were carried out within legal obligations of HF EMF sources owners to regularly check in specific time intervals whether human health is protected from unacceptable HF EMF levels. Measurement sample consisted of electric field strength measurements conducted on 812 locations. On each location six measurements were carried out giving total of 4872 electric field strength measurement results which were analysed. On every location only one out of six measuring points was selected, namely where maximum TEQ value was calculated according to equation (2):

$$\sum_{30\,\mathrm{MHz}}^{3\,\mathrm{GHz}} \left(\frac{E_\mathrm{f}}{E_\mathrm{g,f}} \right)^2 \leq 1 \tag{2}$$

where E_f is electric field strength in V/m at frequency *f*, while $E_{g,f}$ is electric field reference level in V/m at frequency *f*. The above summation formula assumes worst-case conditions among the fields from the multiple sources [12].

According to internationally accepted scientific laboratory and epidemiological studies ICNIRP considers basic exposure criteria given in (2) as a safety precaution that provide protection against known adverse health effects. Since the sample was extensive and represents close to a third of all HF EMF measurements carried out in Republic of Croatia in 2018, it is possible to obtain relevant and representative data for further analysis of human exposure to non-ionizing HF EMF. HF EMF sources were from different owners, allocated throughout the entire territory of Republic of Croatia and usually consisted of several different generation mobile telephony sources radio transmitters, as well as other sources mentioned in table I.

TABLE I. HF EMF SOURCES WITH FREQUENCY RANGE DETECTED ON A SAMPLE OF 812 LOCATIONS DURING 2018 IN CROATIA

HF EMF sources	Frequency range
TV	470,0 MHz – 790,0 MHz
FM	87,5 MHz – 108,0 MHz
LTE 800	791,0 MHz – 821,0 MHz
GSM 900	925,0 MHz – 960,0 MHz
UMTS 900	
DCS 1800	1805,0 MHz – 1880,0 MHz
LTE 1800	
UMTS 2100	2110,0 MHz – 2170,0 MHz
LTE 2100	

Measurements of non-ionizing HF EMF have been done for many years in Croatia in the vicinity of EMF sources according to Croatian legislation [17 - 20] and were based on [21 - 27] standards requirements. Previous measurement results have been analysed and described for example in studies [28 - 30]. According to its basic purpose HF EMF sources include mobile telephony, commercial radio, television and other. Mobile telephony sources can be classified according to type and effective radiated power of basic base station [30] as:

1. Broad range base station based on macro cells,
2. Medium range base station based on micro cells,
3. Local base station based on pico cells and
4. Home base station based on femto cells.

Installation of HF EMF sources can be various – on free standing mast, on the top of a building, on the side of a building, inside building, inside tunnel or it can be temporary installed as a portable source. Sources which are installed inside building or tunnel usually have a part of equipment installed outside building or a tunnel. HF EMF sources can be classified according to a location of their installment as follows:

1. Densely inhabited urban areas,
2. Suburban areas,
3. Rural areas,
4. Industrial zones,
5. Beside roads or lanes and
6. Poorly inhabited mountainous or maritime areas.

HF EMF sources can also be classified according to especially sensitive population or areas where HF EMF sources are installed such as in the vicinity of kindergartens, schools, hospitals or other facilities and/or military facilities, polygon or specially protected areas.

III. MEASUREMENT RESULTS

On each point of investigation measurements were performed with an isotropic field probe placed on non-conductive stand at a point where maximum field level was preliminary measured. Each measurement lasted for six minutes or longer and it refers to the exact moment in time and it is possible that in other moment measurement result might be different. Nevertheless, all measurement results paint a picture about existing, ongoing and future possible effects of HF EMF. As it can be seen in table II on one location TEQ value exceeds criteria given in (2). Aforementioned location is collocated with different HF EMF sources. Detailed analysis is given further on in this paper.

TABLE II. TOTAL EXPOSURE QUOTIENTS (TEQ) CALCULATED FOR ALL LOCATIONS IN A SAMPLE

Number of all locations in a sample	Number of locations in a sample with TEQ values			
	0 - 0,01	**0,01 - 0,1**	**0,1 - 1**	**> 1**
812	384	367	58	3
Number of collocated locations in a sample	**Number of collocated locations in a sample with TEQ values**			
	0 - 0,01	**0,01 - 0,1**	**0,1 - 1**	**> 1**
747	343	348	53	3

Extensive measurements demonstrated that in frequency spectre from 30 MHz to 3 GHz participate series of different HF EMF sources (see table I). According to previous studies and articles based on previous large sample measurements in Croatia [17 - 19] it was noticed that in most cases those sources are collocated. Collocated HF EMF sources can be divided into two groups:

1. Sources which are allocated on the same mast or a building and are comprised of several same or different types of installed equipment which emit HF EMF (see figure 1).

2. Sources which are allocated on two or more masts or buildings where masts or buildings are located in close vicinity of few tens of meters from one another and are comprised of several same or different types of installed equipment which emit HF EMF (see figures 2 and 3).

Figure 1. Collocated HF EMF sources installed on a building comprised of followin systems: FM, TV, LTE 800, GSM 900, UMTS 900, LTE 1800, LTE 2100

Figure 2. Collocated HF EMF sources installed on two masts comprised of following systems: FM, TV, LTE 800, GSM 900, UMTS 900, LTE 1800, LTE 1800, UMTS 2100

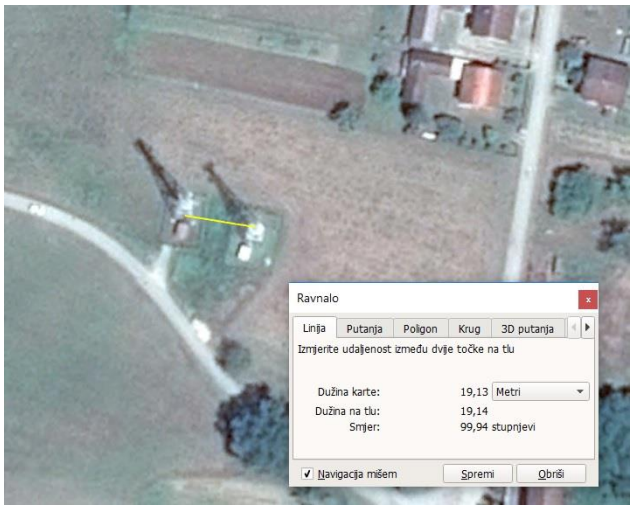

Figure 3. Collocated HF EMF sources installed on two masts comprised of following systems: FM, TV, LTE 800, GSM 900, UMTS 900, LTE 1800, LTE 1800, UMTS 2100 (a view from above)

IV. CONCLUSION

Results of extensive HF EMF measurements research taken in the vicinity of 812 locations in Croatia show that those results can be distributed in four different classes of possible HF EMF influence on human health and environment. Table II shows that majority of results according to basic exposure criteria have very little or little possible influence on human health and only on 61 out of 812 locations which represents 7,5 % of all locations in a sample have possibly significant influence. Results of TEQ on only three locations are above value that ICNIRP considers unacceptable. Further analysis established that on 56 out of 61 critical locations are collocations of different HF EMF sources. On basis of this research, risk of adverse health effects from HF EMF sources was very small, but it comes with a warning that future research would have to be focused on estimations and measurements in the vicinity of collocated HF EMF sources. Future steps have already been taken, since research will be extended with the data collected in 2019 and 2020. The purpose for even more extensive non-ionizing HF EMF measurements will be to determine whether general public is well protected according to today's knowledge about cumulative exposure to HF EMF transmissions. One of the objectives will also be to establish a correlation between HF EMF measurements and estimations.

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