Electromagnetic pollution estimation in a communication laboratory

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Abstract – **A case of the electromagnetic pollution in a communications laboratory at the Faculty of Electronic Engineering in Niš, Serbia, is investigated in this paper. In order to estimate whether the EM exposure limits are respected, the EM safety standards both in Bulgaria and Serbia are presented and compared. On the basis of these standards, the analysis of measured data is performed and obtained results are discussed. Finally, some rrecommendations for working with equipment in a communications laboratory are given.**

Keywords – **Electromagnetic pollution, EMF exposure levels, EM safety standards**

I. Introduction

In the large laboratories with many communication devices, the question arises whether it is safe for the health to work in them, i.e. whether the level of EM radiation does not exceed the limit values. The study of electromagnetic pollution in a communications laboratory was done in the Laboratory for the Microwave Technique and Wireless Communications at the Faculty of Electronic Engineering of the University of Nis, Republic of Serbia.

Electromagnetic radiation is classified broadly into ionizing and non-ionizing radiation. Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF), and extremely low frequency (ELF). Microwave and RF frequency ranges are of the particular interest because there are a lot of wireless communication applications in these areas.

The impact of electromagnetic fields (EMF) on the human body has two aspects: direct biological effects and indirect effects [1]. Direct effects occur in the human body as a direct result of its presence in an electromagnetic field. They include thermal effects, such as tissue heating due to absorption of energy from electromagnetic fields, and non-thermal effects like the stimulation of muscles, nerves or sensory organs. The non-thermal effects can harm the mental and physical health and cause symptoms such as dizziness, visual disturbances, annoyance, sleep disorders, etc. [2][3][4]. Indirect effects include interference with medical electronic equipment and devices, such as cardiac pacemakers, metal prostheses, defibrillators and cochlear implants.

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There are many studies on the effects of electromagnetic fields on human health. The International Agency for Research on Cancer (IARC) scored emission of electromagnetic fields as a possible carcinogen (group 2B). However the available data is not convincing and is insufficient to establish a direct link between possible carcinogenic effects and long-term exposure to electromagnetic fields.

II. Safety regarding the exposure levels of EMF

The quantities which are important from the aspect of EM safety standards are shown in table 1 [5].

TABLE I
ELECTRIC, MAGNETIC, ELECTROMAGNETIC, AND DOSIMETRY QUANTITIES AND CORRESPONDING SI UNITS

Quantity	Symbol	Unit
Current density	J	Ampere per square meter (A m^{-2})
Electric field strength	E	Volt per meter (V m^{-1})
Magnetic field strength	H	Ampere per meter (A m^{-1})
Magnetic flux density	B	Tesla
Power density	S	Watt per square meter (W m^{-2})
Specific energy absorption	SA	Joule per kilogram (J kg^{-1})
Specific energy absorption rate	SAR	Watt per kilogram (W kg^{-1})

To measure the impact of EMF on the human body at frequencies up to 10 GHz, the quantities: Electric field strength E [V/m], Magnetic field strength H [A/m] and Specific energy absorption rate SAR [W/kg] are most often used. SAR is defined as the rate of power dissipation normalized by the material density. At frequencies higher than 10 GHz, the field penetration depth in the tissues is small. Therefore, the power density S [W/m^2] is a more appropriate quantity than SAR.

Standards related to the limitation of human exposure to EMF determine either the limits of emissions radiating from the devices or the limits of the exposure of people originating from all devices in the environment [6]. They are divided into exposure standards, emission standards and measurement standards. Exposure standards are basically personal protection standards and refer to the maximum levels of human exposure from any number of radiating devices. Emission standards set different specifications for electrical devices and are based on engineering solutions, such as optimizing performance.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) issued guidelines on exposures in 1998 covering the frequency range up to 300 GHz [5]. The ICNIRP 1998 guidelines have been endorsed by WHO, the International Labor Office (ILO) and the International Telecommunications Union (ITU), and they have been adopted as their national standard by more than 50 countries worldwide.

In Bulgaria Ordinance No 9 [7] of the Ministry of Health from 14.03.1991, limit levels of strength and power density of EMF in populated territory are defined. In addition to the limit values of EMF in populated areas, there are defined safety zones around the radiating objects. In the presence of more than one radiation source in a frequency range - up to 300 MHz, the geometric sum of the strength of the EMF must be smaller than the limit level. If all emitters operate in the range of 0.3 to 30 GHz, the arithmetic sum of the power density of EMF must be less than the limit permissible level 10 μW/cm2. If there are multiple sources of electromagnetic radiation operating at different frequencies in the area, the condition in Formula 1 must be satisfied:

$$\left(\frac{E_1}{E_{H_1}}\right)^2+\left(\frac{E_2}{E_{H_2}}\right)^2+\ldots+\left(\frac{E_n}{E_{H_n}}\right)^2+\frac{S_{sum}}{10}\leq 1 \qquad (1)$$

where E_1, $E_2, \ldots, E_n$ are the electric field strengths, created by the individual emitters in different frequency bands or aggregated strengths emitters of the same band at a transmitting frequency below 0,3 GHz; E_{H1}, E_{H2} ...... E_{Hn} – are the limit levels for the band; S_{sum} is the total power density of emitters with operating frequency exceeding 0,3 GHz.

Limit levels of strength and power density of EMF in Bulgaria are shown in Table II.

TABLE II
LIMIT LEVELS OF STRENGTH AND POWER DENSITY OF EMF IN BULGARIA

№	Transmitter Frequency range	Limit levels of electrical field strength (E) and power density (S) of EMF
1.	30 - 300 kHz	25 V/m (E)
2.	0,3 - 3 MHz	15 V/m (E)
3.	3 - 30 MHz	10 V/m (E)
4.	30 - 300 MHz	3 V/m (E)
5.	0,3 - 30 GHz	10 μW/cm^2 (S)

The provisions of Directive 2013/35 / EU of the European Parliament and of the Council of 26 June 2013 on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) are introduced in the Ordinance No RD-07-5 (2016) in Bulgaria [8]. This Directive specifies the exposure limits for health effects, the exposure limit values for sensitivity effects and the values for action by employers.

In the Republic of Serbia, the conditions and measures for the protection of human health and the environment from the harmful effects of non-ionizing radiation are regulated by the Law on Non-Ionizing Radiation Protection, (Official Gazette of the Republic of Serbia No. 36/2009) [9]. According to Art. 6 (6) (1) of this Law, a Rulebook on the limits of exposure to non-ionizing radiation (Official Gazette of the Republic of Serbia No 104/2009) [10] defined the reference boundary exposure levels of electric, magnetic and electromagnetic fields (0 Hz to 300 GHz) in Republic of Serbia, Table III.

In the case of simultaneous exposure of fields with different frequencies, they must respond the following criteria of Formula 2 in terms of the main limitations.

$$\sum_{i=100kHz}^{1MHz}\left(\frac{E_i}{c}\right)^2+\sum_{i>1MHz}^{300GHz}\left(\frac{E_i}{E_{L_i}}\right)\leq 1 \qquad (2)$$

where E_i is the field strength measured at frequency i; $E_{L,i}$ is the reference field of the electric field in Table III; c is $87/f^{1/2}$ V/m.

III. TESTBED DESCRIPTION AND EXPERIMENTAL SET-UP

For the purpose of the experiment, a simple communication system that simulates the operation of GSM communication was made. A signal generator MXG N5182B KEYSIGHT, which operates at frequencies from 9 kHz to 3 GHz, was used as the transmitter. The generator was set to a frequency of 1200 MHz, with GSM modulation. The output signal was set up to 20 dBm (0,1W), and was emitted by an antenna. The antenna was a Comet SMA-703 - three-band. The antenna bands are 144 MHz, 400 MHz and 1200 MHz, with a gain of 3.4 dBi at 1200 MHz. The measurements are carried out in the antenna far field. The receiver was implemented with USRP NI2920, connected to a PC via Gigabit Ethernet. The strength of the electromagnetic field at various distances from the generator was measured by Selective Radiation Meter SRM 3000 Narda, Fig 1, which works at frequencies 100 kHz to 3 GHz [11].

Fig.1 Selective Radiation Meter SRM 3000 Narda

A. Results

In the "**Spectrum Analysis**" mode of the selective radiation meter, the field strength curves E [V/m] were taken depending on the frequency. The data is recorded in Excel files presented in Table IV for each measurement. File data is processed with MATLAB and displayed in Fig 2. The series of field strength curves show how the signal attenuates with distance.

In the SRM 3000 "**Safety Evaluation**" mode field strength was measured throughout the full operating range of the device: selected from the menu. For each regulated band, the field is from 47 MHz to 2,5 GHz. For this purpose, Full Band EU was

TABLE III
REFERENCE BOUNDARY LEVELS FOR THE EXPOSURE OF THE POPULATION TO ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS (0 HZ TO 300 GHZ) IN SERBIA

Frequency f	Electric field strength E (V/m)	Magnetic field strength H (A/m)	Magnetic flux density B (μT)	Power density (equivalent plane wave) S_{ekv} (W/m^2)	Time average t (minutes)
< 1 Hz	5 600	12 800	16 000		*
1-8 Hz	4 000	12 800/f^2	16 000/f^2		*
8-25 Hz	4 000	1 600/f	2 000/f		*
0,025-0,8 kHz	100/f	1,6/f	2/f		*
0,8-3 kHz	100/f	2	2,5		*
3-100 kHz	34,8	2	2,5		*
100-150 kHz	34,8	2	2,5		6
0,15-1 MHz	34,8	0,292/f	0,368/f		6
1-10 MHz	34,8/ f$^{1/2}$	0,292/f	0,368/f		6
10-400 MHz	11,2	0,0292	0,0368	0,326	6
400-2000 MHz	0,55 f$^{1/2}$	0,00148 f$^{1/2}$	0,00184 f$^{1/2}$	f/1250	6
2-10 GHz	24,4	0,064	0,08	1,6	6
10-300 GHz	24,4	0,064	0,08	1,6	68/f^{1,05}

measured, the data is automatically summed and saved to a file. If there are levels measured in other, unregulated bands, they are added together and marked on a separate line in the table. The data from the selective radiation meter are presented in Table V. The results are compared with the limit values given in [7] and [10].

TABLE IV
DISTANCE OF THE MEASUREMENT

File	Distance [m]
1,1	0,3
2,1	5
3,1	8, behind one partition wall
4,1	12, behind two partition walls
5,1	15, behind two partition walls
6,1	8, behind two partition walls
7,1	15, behind three partition walls
8,1	20, behind three partition walls

The calculations show that in our experiment, in the situation of simultaneous exposure to fields of different frequencies, the criteria given by equations (1) and (2) are not fulfilled and the total exposure is higher than the limit given in national guidelines. In both cases, sums on the left side shouldn't be higher than 1. For the calculations of Formula 1, the value of the sum is 2,676. If we apply Formula 2, the value of the sum is 1,702. It should also be noted that these values are calculated only for the regulated frequency bands. If we would account the exposure to EMF in the other bands, the results would be even worse. For instance, the sum of the power densities for the regulated frequency bands is 0,134 W/m2 and the power density of other bands is 0,122 W/m2, giving the total value of power density of 0,256 W/m2.

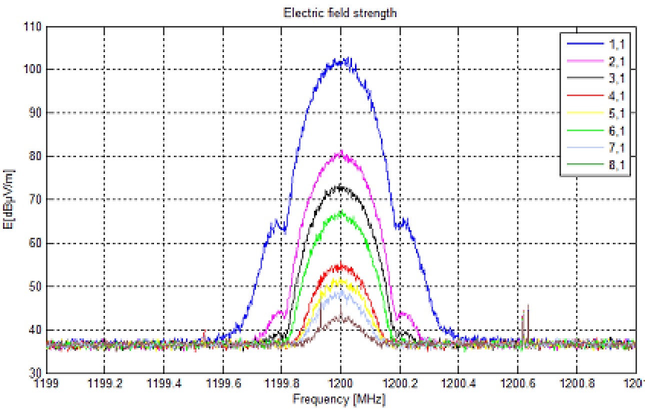

Fig.2 Series of field strength curves on the frequency 1200 MHz for different distances from the generator

B. Recommendations

The recommendations for working with communication equipment, can be given in several directions:

- When installing new equipment, test it for electromagnetic radiation.
- Optimize the operator's time for working with communication equipment as the energy and power limit values absorbed by a unit of body mass in the person body as a result of exposure to electrical and magnetic fields are averaged over 6 minutes, (see Table III). If this is not possible - optimize the location of the equipment inside the laboratory. The relevant distance could be calculated using the Friis Transmission Formula.
- Introduce periodic inspection of the equipment and the levels of electromagnetic pollution inside the laboratory.
- Provide written instructions for work in the laboratory in a visible location.

TABLE V
SUMMARY OF FIELD STRENGTH MEASUREMENT RESULTS IN FULL BAND EU

Service Table Name *Full Band EU*
Total Value [W/m²] *0,25624001*

Measured values		Frequency band of interest				Reference levels Serbia		Calculations	Reference levels Bulgaria		Calculations	
Electric field strength E [V/m]	Power density S [W/m^2]	Name	Low Frequency [MHz]	High frequency [MHz]	Average frequency [MHz]	Electric field strength E [V/m]	Power density S [W/m2]	E_i/E_{Li}	Electric field strength E [V/m]	Power density S [W/m2]	S_{cym}	$(E_i/E_{Hi})^2$
3,3006	0,029377	TV Band I	47	68	57,500	11,2	0,326	0,2946964	3			1,21044
2,0893	0,010888	FM-Radio	88	108	97,750	11,2	0,326	0,1865446	3			0,485019
1,8789	0,0094249	Mid Wave	137	165	151,000	11,2	0,326	0,1677589	3			0,392252
0,9639	0,0025211	Paging	165	174	169,500	11,2	0,326	0,0860589	3			0,103225
2,0743	0,011211	BandIII (DVB-T)	174	230	202,000	11,2	0,326	0,1852054	3			0,47808
0,1398	9,01E-05	Trains	467	468	467,875	11,8967	0,3743	0,0117511		0,1	9,01E-05	
2,8035	0,020927	BandIV (DVB-T)	470	790	630,000	13,8049	0,504	0,2030802		0,1	0,020927	
1,1366	0,0035092	BandV (DAB)	790	862	826,000	15,8071	0,6608	0,0719043		0,1	0,0035092	
0,2605	0,0001619	GSM-R	876	880	878,000	16,2971	0,7024	0,0159826		0,1	0,0001619	
0,9994	0,0027008	GSM 900	890	960	925,000	16,7276	0,74	0,0597432		0,1	0,0027008	
0,8953	0,002097	L-Band (DAB)	1 452	1 492	1 472,000	21,1017	1,1776	0,0424298		0,1	0,002097	
1,8448	0,0090142	GSM 1800	1 710	1 880	1 795,000	23,3021	1,436	0,0791689		0,1	0,0090142	
0,6621	0,0012613	DECT	1 880	1 900	1 890,000	23,9108	1,512	0,0276909		0,1	0,0012613	
1,7669	0,0082797	UMTS-TDD	1 900	2 025	1 962,500	24,3651	1,57	0,0725178		0,1	0,0082797	
1,4478	0,005698	UMTS DL	2 110	2 170	2 140,000	24,4000	1,6	0,0593361		0,1	0,005698	
2,3304	0,014298	W-LAN	2 400	2 484	2 441,750	24,4000	1,6	0,0955082		0,1	0,014298	
1,0456	0,0028911	ISM	2 484	2 500	2 491,750	24,4000	1,6	0,0428525		0,1	0,0028911	
6,7321	**0,12189**	**Others Value**									0,0709	2,669016
	0,2562403							***1,7022***			***2,6761***	

IV. CONCLUSION

The paper describes the measurement of EMF in a communication laboratory. The results show increased levels of EMF power density. In the measurements made, in addition to electric field strength and power density in regulated frequency bands, there is also a significant contribution to the total EM pollution originating from other, unregulated bands. It is difficult to determine the source of this field - it may be due to different sources of signal in the environment. Whether a communication equipment represents a risk to human health depends on the distance between it and the worker and on its time of service. The levels of electromagnetic pollution inside the laboratories should be regularly monitored and, if necessary, the locations of the transmitting equipment could be optimized, in order to avoid a risk for human health.

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