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Electromagnetic Interference in the Primary Electromagnetic Laboratory

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This paper describes the measurements of the electromagnetic fields performed in the Primary Electromagnetic Laboratory at the Faculty of Electrical Engineering and Computing. Because of the many instruments present in the laboratory and the vulnerability to the ambient electromagnetic fields, it was interesting to investigate if the level of exposure to microwave frequencies exceeds the international and Croatian standards. The measurements were performed in the frequency range from 75 MHz to 3 GHz. The highest fields came from the nearby base station, but still less than 0.3 V/m, which is rather low.

Keywords: electromagnetic interference, precise measurements, selective radiometer

1. INTRODUCTION

THE level of electromagnetic interference (EMI), also referred to as electromagnetic noise or electromagnetic pollution, is of critical importance to the daily operation of any laboratory that performs precise measurements. It is also the requirement of various ISO standards, such as ISO/IEC 17025:2005 [1], to evaluate the influence of EMI on the results of measurements. From that requirement follows the need for monitoring and checking the levels of EMI within the laboratory for a wide frequency range.

The EMI includes interference from various outside sources, such as high voltage transmission lines, radio and TV installations, and mobile phone base stations. It also includes the interference from the power and signal lines, as well as the interference generated inside the laboratory from the various electrical equipment. Even fluorescent lights can cause problems during the performance of sensitive measurements. The rather old standard ISA-RP52.1 requirement states that in the frequency range from 1 kHz to 2 GHz, the maximum allowed electric field in the precise electromagnetic laboratory is 100 μV/m. This requirement comes from the susceptibility measurements on precision measuring instruments. The EMI from outside can be suppressed by appropriate shielding of the laboratory rooms (or space where precise measurements have to be done), while various methods of reduction are possible for EMI generated inside laboratory, such as RF-shielded lenses, power line filters for fluorescent lightning, etc.

The presence of electromagnetic fields in the environment and its biological effects have also been the topic of recent research. Different organizations, such as International Commission on Non-Ionizing Radiation Protection, have proposed guidelines for reference levels for occupational exposure to time-varying electric and magnetic fields [2]. Therefore, it is important to measure the EMI in the laboratory oriented to precise measurements due to: (i) the influence of outside EMI sources on the results of measurements; (ii) the large number of measuring instruments and sources within laboratory, as possible inside EMI sources with mutual influences; (iii) the possible exposure to the electromagnetic field of the laboratory staff.

The Primary Electromagnetic Laboratory (PEL) at the Faculty of Electrical Engineering and Computing maintains the Croatian national standards of dc voltage (1 V to 10 V), resistance (1 mΩ to 100 MΩ) and capacitance (100 pF), and performs precise electromagnetic measurements in a wide range of quantities (ac voltage, current, power, higher voltages, etc.). The laboratory, placed in the basement of the faculty building, consists of two rooms without electromagnetic shielding, and it is exposed to the various outside EMI sources. On the other hand, the possible sources of inside EMI are many instruments (calibrators, generators, multimeters, and other sources).

Fig. 1. PEL, Zagreb

Some similar experiments were performed in the past [3-5], and the levels of electric and magnetic fields at a frequency of 50 Hz were already measured at PEL in 2004. It was found that at most positions the measured electric and magnetic fields are lower than 10 V/m and 0.5 A/m, respectively. Therefore, the new measurement set-up allowed us to measure the EMI for a much higher frequency range, from 75 MHz to 3 GHz.

2. EXPOSURE LEVELS

One of the main objectives of the bio-electromagnetics research is to establish guidelines for limiting electromagnetic field exposure that provides protection against up to now known adverse health effects. International guidelines are related to limiting the exposure to electromagnetic radiation in two categories:

a) Basic restrictions – Restrictions on exposure to the time varying electromagnetic fields based directly on established health effects. Depending on the field frequency, the physical quantities used to quantify these restrictions are *specific absorption rate* ***SAR*** (in W/kg), *induced current density* ***J*** (in A/m^2), and *induced power density* ***S*** (in W/m^2).

b) Reference levels – The reference levels are provided for practical exposure assessment purposes to estimate if the basic restrictions are exceeded. The derived quantities are *electric field intensity* ***E*** (in V/m), *magnetic field intensity* ***H*** (in A/m) and *power density* ***S*** (in W/m^2).

The fundamental quest in protection of humans exposed to electromagnetic radiation is to satisfy the given basic restrictions. When it is not possible to calculate (or directly measure) these quantities, then the comparison with reference levels can be used for the compliance and safety tests. Basically, if the reference levels are exceeded it does not necessarily mean that the basic restrictions are exceeded as well. However, when the reference levels are exceeded, it is necessary to test compliance with the relevant basic restrictions and to figure out if additional protective measures are necessary.

A. Reference levels for workers exposure

There are differences in exposure levels for workers and general public, because workers are supposed to know that they are exposed to electromagnetic fields and can undergo certain protective measures, while the general public is usually unaware of the hazards. The reference levels for human exposure to electromagnetic fields are given in Table 1 in the first row of each cell according to [6], whereas in the second row of each cell the values according to the Croatian standard [7] are pointed out; these levels are somewhat lower than those prescribed by international bodies.

Table 1. Reference levels for continuous workers exposure according to [6] and [7]

Frequency f (in MHz)	RMS value of electric field strength E (in V/m)	RMS value of magnetic field strength H (in A/m)	Mean power density A. S (in W/m^2)
10 to 400	61.4 28	0.16 0,073	10 2
400 to 2000	$3 \cdot f^{1/2}$ $1.375 \cdot f^{1/2}$	$0.008 \cdot f^{1/2}$ $0.0037 \cdot f^{1/2}$	$f/40$ $f/200$
2000 to 150000	137 61	0.364 0.16	50 10

Reference levels for the pulsed radiation (Table 2) are higher for the same frequency range than those for the continuous exposure. They can, however, produce other effects, such as auditory perception of microwave pulses in addition to those associated with continuous microwave radiation.

Table 2. Reference levels for pulsed radiation [6]

Frequency f (in MHz)	Peak value of electric field strength E (in V/m)	Peak value of magnetic field strength H (in A/m)	Peak power density S (in W/m^2)
10 to 400	1775	4.6	8160
400 to 2000	$88.8 \cdot f^{1/2}$	$0.23 \cdot f^{1/2}$	$20.4 \cdot f$
2000 to 150000	$10.3 \cdot f^{1/2}$	$2.66 \cdot 10^{-2} \cdot f^{1/2}$	$0.274 \cdot f$

B. Reference levels for general public exposure

In Table 3, the reference levels for the general public continuous exposure are pointed out: in the first row of each cell according to [6], and in the second row according to the Croatian standard [7].

Table 3. Reference levels for general public continuous exposure according to [6] and [7]

Frequency f (in MHz)	RMS value of electric field strength E (in V/m)	RMS value of magnetic field strength H (in A/m)	Mean power density B. S (in W/m^2)
10 to 400	27.5 11.2	0.07 0.0292	2 0.326
400 to 2000	$1.37 \cdot f^{1/2}$ $0.55 \cdot f^{1/2}$	$0.00364 \cdot f^{1/2}$ $0.00148 \cdot f^{1/2}$	$f/200$ $f/1250$
2000 to 150000	61.4 24.4	0.163 0.064	10 1.6

Reference levels for the general public exposure to the pulsed radiation are pointed out in Table 4.

Table 4. Reference levels for pulsed radiation [6]

Frequency f (in MHz)	Peak value of electric field strength E (in V/m)	Peak value of magnetic field strength H (in A/m)	Peak power density S (in W/m^2)
10 to 400	794	2	1588
400 to 2000	$39.7 \cdot f^{1/2}$	$0.1 \cdot f^{1/2}$	$3.97 \cdot f$
2000 to 150000	1775	4.17	7934

If simultaneous irradiation from more sources of different frequencies is present, the following formulas apply:

$$\sum_i \left(\frac{E_i}{L_{E,i}} \right)^2 \leq 1 , \quad (1)$$

$$\sum_j \left(\frac{H_j}{L_{H,j}} \right)^2 \leq 1 . \quad (2)$$

This is valid for the frequency range $700\,\text{kHz} \leq f \leq 300\,\text{GHz}$, where E_i is the electric field component in V/m from the i-th source, H_j is the magnetic field component in A/m from the j-th source, and $L_{E,i}$ and $L_{H,j}$ are corresponding electric and magnetic field reference levels. All the values given in the above tables are valid for the exposure time $t \geq 6$ min. It is the time period (from medical research) in which the body can assure thermoregulation processes. If the exposure time is less than six minutes, then field strengths have to be averaged, i.e. the following must be achieved:

$$\sum_i \left(E_i^2 \cdot t_i \right) \leq \left(6 \cdot L_{E,i}^2 \right) \quad \text{in} \quad (\text{V/m})^2 \cdot \text{min} \quad (3)$$

$$\sum_i \left(H_i^2 \cdot t_i \right) \leq \left(6 \cdot L_{H,i}^2 \right) \quad \text{in} \quad (\text{A/m})^2 \cdot \text{min} \quad (4)$$

where E_i is the electric rms-field strength during the i-th exposure in V/m, H_i is the magnetic rms-field strength during the i-th exposure in A/m, and $L_{E,i}$ and $L_{H,i}$ are the reference levels of electric and magnetic fields for exposure times $t \geq 6$ min.

3. Measurement Setup

Equipment for field strength measurements usually consists of the probe, connecting leads and the instrumentation (spectrum analyzer). Dipoles are used for measuring the electric fields and loops for the magnetic measurements. The measurements should not be significantly affected by environmental conditions (humidity, temperature), field interference caused by the proximity of the person carrying the equipment and the conducted electromagnetic interference. It is desirable that the instrument (spectrum analyzer) does not need the external power supply.

The measurements reported in this work were performed by using a NARDA SRM 3000 selective radiometer (Fig. 2). The instrument automatically measures all emitters in a user-selected frequency band. It can label their percentage of standard, add up and display the total radiation from all emitters. The SRM-3000 probe is precision-calibrated to provide extremely linear performance from 80 MHz to 3 GHz. It consists of three orthogonally mounted isotropic monopole antennas. The antennas are automatically switched at high speed, and the received signals are sent at their original frequency to the instrument through a special ferrite-shielded cable. Then the spectrum analyzer section of SRM-3000 processes the signals.

Fig. 2. NARDA SRM 3000 selective radiometer

4. Results

The measurements were done on many different positions within the laboratory rooms. Fig. 3 shows typical results obtained for the E-field distribution within the whole frequency range 75 MHz to 3 GHz. This means that two spikes are typical, the first one around 900 MHz, and the second one around 1.8 GHz, as well as the increase of noise that influences measurements at the beginning and the end of the frequency range. Due to the presence of the nearby GSM base station, it is obvious that its influence was measured. However, since the peak-measured value was lower than 0.3 V/m, this influence is rather small.

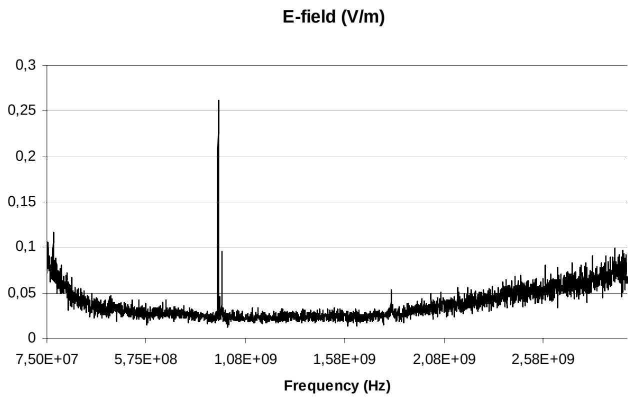

Fig. 3. E-field distribution in the laboratory room at position P1 (the whole frequency range)

Fig. 4 shows the measured values for E-field distribution for the frequency range 750 MHz to 2.2 GHz at another position within the laboratory; it is evident that the peak-measured value is lower than 0.16 V/m, which is even smaller than in the previous example.

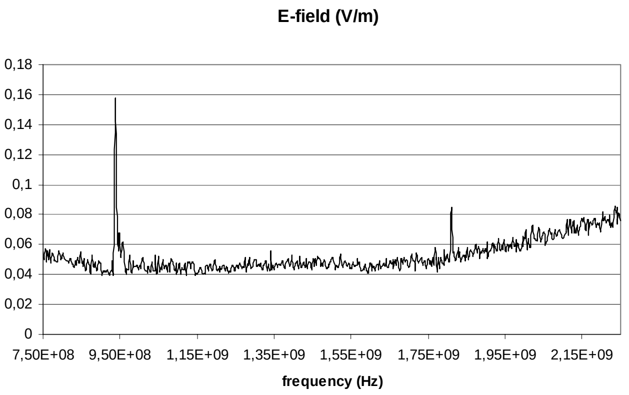

Fig. 4. E-field distribution in the laboratory room at position P2 (range from 750 MHz to 2.2 GHz)

Fig. 5 shows the measured values for E-field distribution for frequencies from 890 MHz to 990 MHz at another position within the laboratory; it is evident that the peak-measured value is lower than 0.14 V/m, which is even smaller than in the previous two examples.

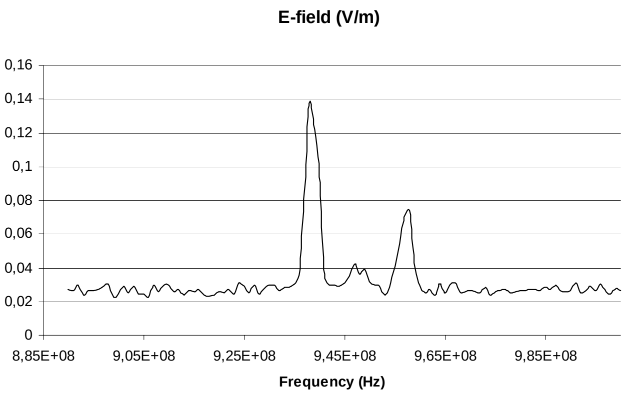

Fig. 5. E-field distribution in the laboratory room at position P3 (range from 890 MHz to 990 MHz)

The results presented in Fig. 3 to 5 can be seen as representative for the whole laboratory, because peak-measured values at any position within the laboratory rooms were below 0.3 V/m. This is almost negligible comparing to any reference levels pointed out in Tables 1 to 4. For a comparison, the measured radiation from the mobile phone showed peak value of 30 V/m during a call. It is 100 times higher than the one from the base mobile station.

5. CONCLUSION

From the performed measurements it can be concluded that the measured values of the E-field are below the ones prescribed by the international and Croatian standards. Although the base station is in the vicinity of the laboratory, the results show that the E-field values are much smaller than the reference levels. The radiation from the mobile phone is by far the greatest source of electromagnetic fields in the measured frequency range, and certainly should not be used within the laboratory rooms. Therefore, the laboratory staff is not exposed to the E-field levels higher than those given by the current standards.

On the other hand, the repeatable frequency distribution of E-field measured at different positions within the laboratory rooms shows dominant contributions at the frequencies associated to the base stations (near by 900 MHz and 1.8 GHz), which means that there is no contribution from other measurement equipment in the measured frequency range from 75 MHz to 3 GHz.

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