The measurement of radiofrequency electromagnetic fields in some special places

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Abstract-In this paper we present the levels of electromagnetic fields, due to the radiofrequency communication systems, in some special places as: hospitals, laboratories in the city and houses situated near broadcastings towers. Comparative measurements were made, using some types of near field probes and antennas in 90 MHz ÷ 2700 MHz frequency domain. We also determined both the root mean square – r.m.s. values of the three perpendicular components of the electric fields and the r.m.s. values of the maximum electric field vector, and then we compared the results. The aim of our measurements is the evaluation of the electromagnetic fields levels generated by communication systems, because of their possible interaction on the human body, electronic medical equipment and generally electrical devices.

I. Introduction

The widespread electromagnetic field sources are the radiofrequency communication systems: FM radio, TV, base stations for mobile phones, wireless local area networks, etc. The electromagnetic fields generated by these man made sources can affect both the electrical systems and human beings [1], [2]. Thus, there are preoccupations in the determination and the control of the electromagnetic fields due to these sources and to estimate their effects on electronic devices and/or the specific absorption rate [3]. In this paper we made a characterisation of the radiofrequency electromagnetic environment in some hospitals in the city and some houses situated near broadcasting towers. Referring to hospitals and related electronic medical equipment, the reduction of electromagnetic interferences in medical devices is of critically important. Thus, the fields generated by radiofrequency communication systems can interact with: the bioelectrical signal recording systems, disrupting the electrocardiograph monitoring, [4]; implantable neurostimulators as pacemakers and defibrillators [5], etc. The measurements of electromagnetic fields in houses situated near broadcasting towers or generally in residential areas, are important in health and biological effects estimation, especially because of the relative large values of the fields and of the long term exposure of the human beings in these places [6] - [10]. Because of the very complex electromagnetic environment in these places, the great spatial and temporal variability of the fields, we made measurements using different field probes, in view of comparing the results, and we made a statistical processing. Also, we determined and compared the levels of the maximum electric field vectors and the levels of the resultant electric field vectors. For all considered places, we determined the relative exposure indices based on ICNIRP reference levels for general public [1].

II. Measurement procedures and results

We made measurements of the radiofrequency electric fields in some hospitals and institutions situated in the city, and in some houses situated near a broadcasting tower (FM radio and television transmitters): House 1, situated at about 1500 meters; House 2 at about 400 meters; House 3 at about 250 meters, distance from a broadcasting tower with some communication systems.
The electromagnetic environment in these special places is very complex because of the numerous communication systems (multiple frequency and amplitude levels) and because of the multiple reflections in these indoor spaces.
The instrumentation used in these measurements is represented by: an IFR 2398 Spectrum Analyser, frequency range 9 kHz ÷ 2.7 GHz, measurement range between - 105 dBm and +20 dBm; a near-field probe set, model 7405, ETS, EMECO, frequency range 100 kHz ÷ 500 MHz; a near-field probe set, Hameg Instruments, HZ 530, frequency range 100 kHz ÷ 1 GHz); an horn antenna, model AT4002A,

amplifier research, frequency range 0,8 GHz ÷ 5 GHz.

The value of the electric field expressed in dBμV/m is:

$$E = U + PF$$
(1)

where U is the voltage developed by the probe expressed in dBμV and PF is the probe performance factor or antenna factor - AF, expressed in dB1/m.

First we explored all frequency range to obtain a general view of the emission spectrum. Then we set some frequency spans where are included the main emissions, namely 90 MHz ÷ 110 MHz, for radio broadcastings; 180 MHz ÷ 210 MHz, for television broadcastings; 800 MHz ÷ 2700 MHz, for mobile communication and wireless technologies.

For each frequency span, the field sensors or antennas were rotated in all directions and the maximum values or the time average value, for each electric field vector was memorized by the spectrum analyzer in "Max Hold" trace mode, respectively in "Average" trace mode. In these modes we considered both electric field vector orientation and the temporal variability of the electromagnetic fields and we determined the maximum value and average value of the electric field for each frequency. The measurement time in each of the two situations was some minutes. In all tables of this paper, we considered only the r.m.s. values of the maximum electric field vector, namely the spectrum analyzer in "Max Hold" trace mode, owing to this is the worst case. Thus, the levels of the electrical fields in considered places are, generally, smaller than these displayed on spectrum analyzer and reported in this paper.

Table 1 presents the maximum values of the electric fields in the considered places, which were memorised by the spectrum analyser in trace "Max Hold" mode, when the 904E near field probe was rotated in all directions. In this mode we obtained a lot of information in a short measurement time.

Table 1: The maximum values of electric fields in some places, due to FM radio (90 MHz ÷ 110 MHz) and TV (180 MHz ÷ 210 MHz) emitters, obtained with 904E field probe

Frequency MHz	E at an hospital and an laboratory situated in the city			E in houses situated near FM radio and TV transmitters		
	Hospital		Laboratory	House 1	House 2	House 3
	Point 1	Point 2				
92	0,036 V/m	0,144V/m	-	1,363 V/m	0,221 V/m	0,404 V/m
94,96	0,057 V/m	-	0,228 V/m	-	-	-
96,3	0,099 V/m	0,28 V/m	0,229 V/m	2,521 V/m	0,904 V/m	2,002 V/m
99	0,118 V/m	0,126 V/m	0,131 V/m	0,883 V/m	0,259 V/m	0,724 V/m
101	0,156 V/m	0,228 V/m	0,365 V/m	1,399 V/m	1,0151 V/m	1,585 V/m
103	-	0,251 V/m	0,137 V/m	1,237 V/m	1,187 V/m	2,106 V/m
104	0,525 V/m	0,282 V/m	0,081 V/m	-	-	-
105	0,232 V/m	0,05 V/m	0,163 V/m	-	-	-
199	0,128 V/m	0,152 V/m	0,145 V/m	4,088 V/m	3,577 V/m	6,31 V/m
205	0,049 V/m	0,066 V/m	0,057 V/m	1,897 V/m	1,078 V/m	1,995 V/m

The levels of the electrical fields in the hospital are much different from those obtained in the laboratory, although both institutions are situated in the city. Moreover, the electromagnetic fields levels in Point 1 and Point 2 in the hospital, or the electric field levels in some points in the laboratory are very different. Thus, there is a great spatial variability for the electric fields.

Of course, the levels of the electric fields in houses situated near FM radio and TV transmitters are about tens time greater than the levels of the fields in the considered institutions in the city, situated at about 10 km distance from the transmitters.

Two displays of electromagnetic environment, due to FM radio transmitters, are shown in Figure 1 and Figure 2.

Figure 1 shows the maximum electric field values (spectrum analyser trace "Max Hold"), in 90 MHz ÷ 110 MHz frequency range, obtained in a point in the laboratory situated in the city.

Figure 2 shows the average electric field values (spectrum analyser trace "Average"), in 90 MHz ÷ 105 MHz frequency range, obtained in a room of House 3, which is situate at about 250 meters distances from transmitters.

As can be seen from Figure 1 and Figure 2, in case of the electromagnetic environment displays obtained at houses situated near transmitters, the FM radio emissions are clearer separated and the electromagnetic background is lower compared with the case of displays obtained in hospitals and laboratories situated in city.
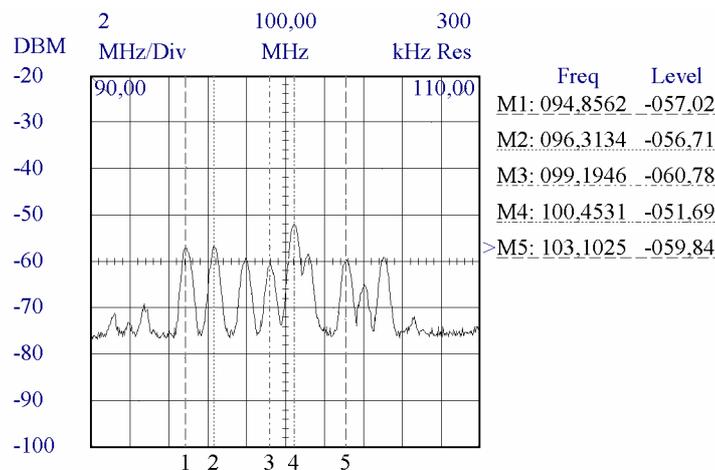
Figure 1. The maximum E values in 90 ÷ 110 MHz frequency
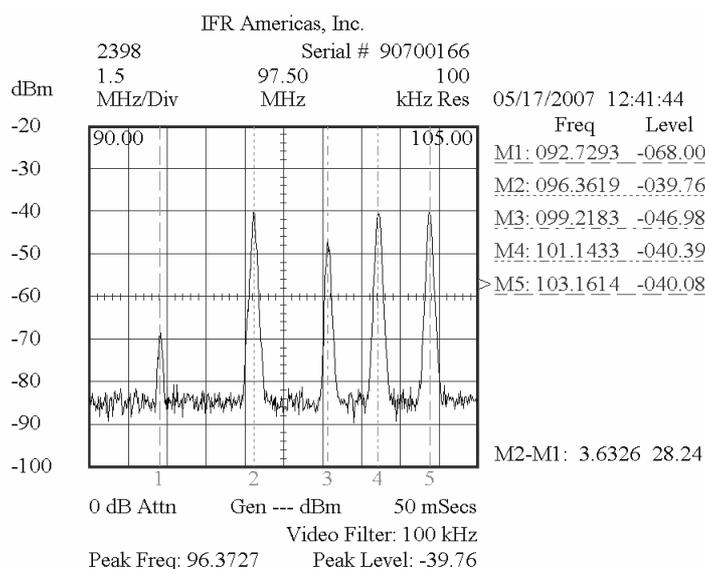range, for one point in Laboratory situated in city

Figure 2. The average E values in 90 ÷ 105 MHz frequency range, for one
point in House 3 situated near transmitters

Referring to the houses situated near FM radio and TV transmitters, there are also great differences between the levels of the electric fields for the same frequency both in different houses, namely distances from the transmitter and for the same house or room.

In House 1 we made electric field measurements in the same point at a short time interval using two types of near field probe: 904 E probe, model 7405 ETS and then active E probe, model HZ 530.

With each probe, we determined the levels of electric fields in two modes.

Firstly, he maximum values of the E field vectors were memorised by the spectrum analyser in trace "Max Hold" mode, when the electric field probe was rotated in all directions.

Secondly, with the spectrum analyser in trace "max hold" mode, we determined the three perpendicular components of the fields E_x, E_y, E_z, as root mean square - r.m.s. values and then we calculated the r.m.s. value of the resultant electric field vector, E, with the relation:

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad (2)$$

The results of these comparative measurements are given in Table 2.

Table 2: The maximum values of electric fields in House 1 obtained with two electric field probes and two modes of the electric field vector determination

Frequency MHz	904 E probe, model 7405 ETS		Active E probe, model HZ 530	
	E obtained rotating the probe	E calculated with (2) from the three perpendicular components	E obtained rotating the probe	E calculated with (2) from the three perpendicular components
92	1,363 V/m	1,539 V/m	1,479 V/m	1,774 V/m
96,3	2,521 V/m	2,213 V/m	2,195 V/m	2,369 V/m
99	0,883 V/m	1,135 V/m	0,744 V/m	0,952 V/m
101	1,399 V/m	1,556 V/m	1,285 V/m	1,629 V/m
103	1,237 V/m	1,547 V/m	1,282 V/m	1,509 V/m
199	4,088 V/m	3,820 V/m	2,618 V/m	4,384 V/m
205	1,897 V/m	1,962 V/m	1,318 V/m	1,727 V/m

Although the four sets of measurements were made successively and thus they were affected by time variability of the electric fields, there is a good agreement between the obtained results. Thus, it can be observed a good concordance between the levels of the electromagnetic fields obtained rotating the field probes in all the directions for detecting the values of the maximum electric field vector and the levels of the resultant electric field vector obtained from the three orthogonal measurements.
Referring to the electromagnetic field in 800 MHz ÷ 2700 MHz frequency range, generated by GSM base stations and wireless technologies, we measured the fields in two points of a hall, situated at the last floor of the Hospital (Point 1 and Point 2) and the fields in five points of a Laboratory. Both the hospital and the laboratory are situated in the city. Near each of them, at about some hundreds of meters distance, there are some GSM antennas.
The value of the electric field was determined with relation (1) and the antenna factor in this case, when we used the horn antenna, is:

$$AF = 20 \cdot \log_{10} \frac{9,73}{\lambda \cdot \sqrt{G}} \qquad (3)$$

where λ is the field wavelength, and G is the antenna gain.
Although the considered points in the hospital are situated at the extremities of the hall, at about 100 m distance each other, the levels of the electric fields in these points are different both in 90 MHz ÷ 110 MHz and 180 MHz ÷ 210 MHz frequency ranges as is shown in Table 1 and in the frequency domain 800 MHz ÷ 2700 MHz as is shown in Table 3.
In view of considering the spatial variability of the electromagnetic fields, at the laboratory in the city situated near some GSM antennas, we made measurements in five points and then we determined for each frequency the extremes (Min and Max), the mean value and the standard deviation of the electrical field. Table 3 presents the results of electric field measurements in 800 MHz ÷ 2700 MHz frequency range, in the considered two points from the hospital, and a statistical processing for the five points considered in the laboratory. For all measurement points, the spectrum analyser was in "Max Hold" mode, and horn antenna was rotated with 360°, with a view to determine the maximum values of the electric field vectors.

Table 3: The maximum values of the electric fields in Hospital and Laboratory, due to mobile communication and wireless technologies

Frequency MHz	E at Hospital (in the city)		E at a laboratory (in the city)			
	Point 1	Point 2	Min	Max	Average	Standard deviation
929	0,064 V/m	0,029 V/m	0.041 V/m	0.172 V/m	0.079 V/m	0.058 V/m
1815	0,011 V/m	0,016 V/m	0.018 V/m	0.115 V/m	0.054 V/m	0.043 V/m
2107	0,012 V/m	0,013 V/m	-	-	-	-
2134	0,004 V/m	0,007 V/m	0.011 V/m	0.113 V/m	0.05 V/m	0.038 V/m
2160	0,014 V/m	0,005 V/m	0.011 V/m	0.03 V/m	0.021 V/m	0.007 V/m

Figure 3 shows the display of the spectrum analyser in 800 MHz ÷ 2700 MHz frequency range, obtained in a point near window in the laboratory, where the electrical fields were found as bigger.
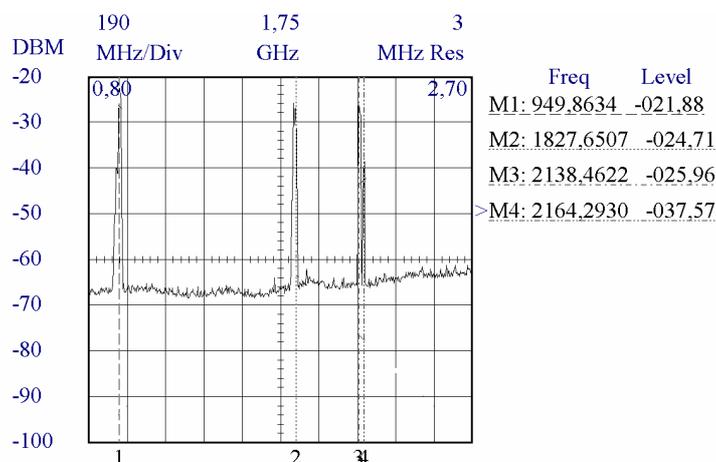

Figure 3. The electric fields for frequency range 800 MHz ÷ 2700 MHz, in a point situated near the window indoor the laboratory

Because the electromagnetic fields in the considered places consist of many frequencies for the estimation of the human exposure at electromagnetic field, the normalised indices, such as the relative exposure RE, are used:

$$ RE = \frac{E_{f_1}^2}{E_{\lim f_1}^2} + \frac{E_{f_2}^2}{E_{\lim f_2}^2} + ... + \frac{E_{f_n}^2}{E_{\lim f_n}^2} \tag{4} $$

where the r.m.s. values of the electric fields squared for all frequencies are at numerators and at denominators the corresponding exposure limits (r.m.s. values squared).

The normalised indices are calculated for E^2, H^2, S (power density) conforming (4), or sometimes in linear mode (E, H - r.m.s. values only) and the results (e.g. the relative exposure - RE) should not exceed unity.

Table 4 presents the relative exposure indices- RE for Point 1 and Point 2 in the hospital, for laboratory, both situated in the city and in the houses situated near RF radio and TV transmitters, calculated using (4) for: 90 MHz ÷ 210 MHz - FM radio and TV transmitters; 800 MHz ÷ 2700 MHz – mobile communication and wireless technologies; 90 MHz ÷ 2700 MHz - all frequency domain.

Table 4: The relative exposure indices- RE for considered places

Frequency domain MHz	RE in Hospital and Laboratory, situated in city			RE in houses situated near FM radio and TV transmitters		
	Hospital		Laboratory	House 1	House 2	House 3
	Point 1	Point 2				
90 ÷ 210	0,00051	0,00043	0,00083	0,04	0,02	0,07
800 ÷ 2700	0,000034	0,00000062	0,0000052	-	-	-
90 ÷ 2700	0,000544	0,00043062	0,0008352			

For all considered places, the relative exposure indices- RE, related only for communication systems, are much smaller than the unity. The contribution of the field generated by mobile communication and wireless technologies to RE is smaller than the one of FM radio and TV transmitters. Of course relative exposure indices in houses situated near FM radio and TV transmitters is bigger than the one obtained in the hospital and the laboratory, situated in the city.

III. Conclusions

We made the electric field measurements in order to determine the electromagnetic fields, due to FM radio and TV transmitters, base stations for mobile communication and wireless technologies, in some special places. The places considered for the measurements, namely hospitals, laboratories situated in

the city and houses situated near broadcasting emitters are important owing to the interaction of radio wave on medical devices and on the human body. Because the electromagnetic environment in these places is very complex, having a large temporal and spatial variability, we made a great number of measurements and a statistical processing of results. In the same points, at short time interval, we determined both the r.m.s. value of the maximum electric field vector and the r.m.s. value of the resultant electric field vector and we observed a good concordance between them. For the considered places in this paper the electric field levels at each frequency are much smaller than the reference levels for general public exposure, recommended by ICNIRP. Also, the relative exposure indices, due to communication systems, are much smaller than the unity, ranging from 0,008 - maximum value in the city, to 0,07 – maximum value in the houses situated near FM radio and TV transmitters. Our goal was to determine the electromagnetic fields due to the communication systems in these special places and to identify the modality of their electromagnetic characterisation.

Acknowledgements

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