A New Wire Patch Cell for the Exposure of Cell Cultures to Electromagnetic Fields at 2.45 GHz: Design and Numerical Characterization

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***Abstract*— Studies on the interaction between electromagnetic (EM) fields and biological systems have recently gathered further momentum due to the huge diffusion of wireless networks.**
In order to investigate possible effects on cultured cells of EM fields, in the frequency range typical of such a kind of communication, an *in vitro* exposure system has been designed and numerically characterized. The system is a Wire Patch Cell (WPC) operating at 2.45 GHz which enables the contemporary exposure of four 35 mm Petri dishes and can be inserted into a commercial incubator. Numerical dosimetry has been carried out by means of the CST Microwave Studio ® simulator. Results indicate a good efficiency, in terms of Specific Absorption Rate (SAR) in the biological sample per 1 W of input power. Moreover, the homogeneity of the SAR distribution inside each Petri dish is around 70 %, considered an acceptable value for such a kind of biological experiments.

I. Introduction

In recent years, wireless local networks have been increasingly deployed inside homes and in public areas. This has aroused concern about possible health effects of the prolonged exposure to the EM fields emitted by such a kind of wireless devices.

The Wireless Fidelity (Wi-Fi) signal, as stated by the communication protocols *IEEE 802.11b* and *IEEE 802.11g*, consists of several channels (11 in the USA and 13 in the EU) spanning the frequency band 2.4000÷2.4835 GHz, with maximum radiated power of 30 dBm in the USA and 20 dBm in Europe [1]-[3].

In order to identify possible specific effects of the exposure to low-level EM fields at around 2.45 GHz, biological experiments are needed, both *in vivo* and *in vitro*, which require the use of exposure systems operating in the frequency range of interest. For what concerns the *in vitro* experiments, the most used exposure systems, among different research groups, are TEM cells, rectangular waveguides, short-circuited waveguides and WPC [4]. Most of the existing setups have been specially designed to operate at the frequencies typical of mobile telephony (0.950 GHz and 1.750 GHz for GSM, and 1.950 GHz for UMTS) [4]. Some of these systems, such as short-circuited waveguides and WPC, are based on narrow-band EM structures and thus cannot be employed at 2.45 GHz; for the other systems, such as TEM cells, the onset of higher order modes may occur. In any case, the existing setups cannot be directly used at the frequencies of Wi-Fi communications.

In this work, the WPC structure has been chosen due to its reduced dimensions, fitting inside a commercial incubator, the quite good efficiency, and the easy fabrication [5]. Moreover, such a kind of exposure systems has been already used in some European Projects of the 5th Framework Program such as RAMP and GUARD.

Moving from the existing WPCs, operating at 0.90 GHz [5], 1.80 GHz [6], and 1.95 GHz [7], a new setup has been designed for the contemporary exposure of four 35 mm Petri dishes at 2.45 GHz.

EM simulations, using the commercial software CST Microwave Studio ®, have been performed to support the design step and to carry out numerical dosimetry.

The design procedure and the numerical dosimetric analysis are described in Sections II and III, respectively. In Section IV conclusions are given.

II. Design

A WPC is an EM structure based on a wire patch antenna. It consists of a coaxially-fed antenna with ground wires (props) connecting the patch (roof) to the ground plane. Such a structure, if properly dimensioned, can be used to expose cell cultures between the patch and the ground plane [5]. The WPC is a symmetric structure, with two square metallic planes of the same sizes, one coaxial probe, at the centre of the cell, and four props located at each corner of the cell, to maintain a large free area between the two metallic planes where biological samples can be placed.

The main biological requirement [8] for the system design is the possibility of inserting four 35 mm Petri dishes between the two WPC planes. This implies lower bounds on the planes dimensions and on their distance. Moreover, from an EM point of view, the system has to be matched at 2.45 GHz and should guarantee a good homogeneity of the electric (E) field in the whole region occupied by the four samples.

Previous data [5]-[7] reveal that the antenna matching to the 50 Ω feeding coaxial cable depends on some critical parameters: the side of two plates (L), the distance between ground and roof (D), the radius of the props (R), and their distance from the plate edge (d).

In the work of Laval [5], the WPC operating at 0.9 GHz had plates of 190 mm of side (about $\lambda/2$), distant from each other 29 mm (about $\lambda/10$). For the dimensioning of WPCs at 1.80 GHz [6] and 1.95 GHz [7] it was not possible to follow the same approach since the resulting system should had been too small to contain the biological samples. This led to a new empirical dimensioning of the two structures with L and D equal to about 0.83λ and 0.12λ, respectively. In both cases, the resulting structure dimensions allowed one to place four 35 mm Petri dishes inside. The trade off of this enlargement was a worsening in the homogeneity of the E field between the two plates, which was still considered acceptable.

In this work, the WPC has been first dimensioned on the bases of previous literature contributions, successively numerical simulations have been carried out to optimize the scattering parameter S_{11}, as a measure of the matching, and the distribution of the E field inside the WPC with respect to the design parameters L, D, R, and d.

As a first choice, L and D were set to 150 mm ($\approx 0.83\lambda$) and 15 mm ($\approx 0.12\lambda$), respectively. According to [6], [7], props were cylinders of radius R=5 mm, with the centre placed 8 mm away from the edges of the two plates. The resulting behaviour of S_{11} shows a minimum (below -40 dB) at around 2.45 GHz, indicating a very good matching at the frequency of interest. Numerical simulations show that variations of L of the order of 10 mm correspond to a shift in the position of the S_{11} minimum of about 200 MHz. On the other hand, variations of D of the order of 1 mm do not induce a shift of the minimum but only an increasing of its value, indicating a worsening of the matching. Therefore, the first choice of L and D dimensions seems to be a good one. For what concerns parameter R, variations of 1 mm induce only slight shifts (less than 10 MHz) on the position of the S_{11} minimum. On the other hand, the S_{11} behaviour substantially changes if the props are moved towards the inner of the structure. Therefore, their initial position has not been changed. The only parameter, which can be changed without disrupting the matching at 2.45 GHz, is R. In particular, R can vary between 5 mm and 6 mm. The final value has been chosen on the basis of the E field distribution on a plane parallel to the two plates and equally distant from each of them.

Results of simulations show that the E field near the centre of the structure is almost orthogonal to the metallic plates and presents values higher than 200 V/m in an almost circular region (Figs. 1 and 2). As evident from Figs. 1 and 2, such a region is wider for R=6 mm than for R=5 mm. Therefore, R= 6 mm has been chosen.

With such a value, the S_{11} presents a minimum below -20 dB at around 2.5 GHz (blue line in Fig. 3). The matching at 2.45 GHz is worse than for R=5 mm but still acceptable.

In Table I the final values of parameters L, D, R, and d are displayed.

With this choice the resulting structure can contain the four Petri dishes and, in the same time, is small enough to be easily inserted in a standard incubator.

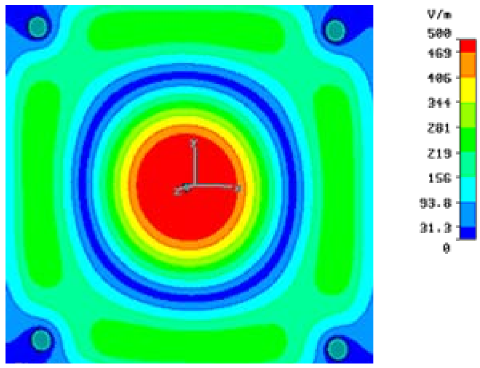

Fig. 1 Distribution of |E| inside the WPC (top view) for R=5 mm

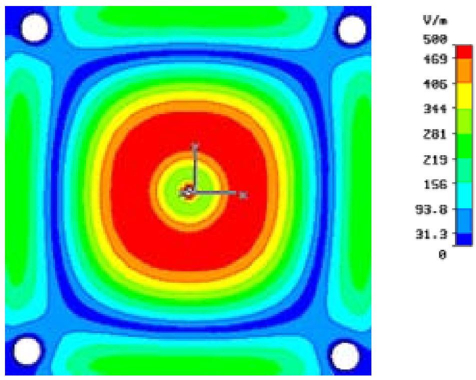

Fig. 2 Distribution of |E| inside the WPC (top view) for R=6 mm

TABLE I
DESIGN PARAMETERS WITH THEIR VALUES

Parameter	Value (mm)
Length of the plane side (L)	150
Distance between the two planes (D)	15
Radius of props (R)	6
Distance of the centre of the props from the plane edge (d)	8

III. Numerical Characterization

Four Petri dishes with diameter of 35 mm and height of 10 mm have been inserted between ground and roof at 1.5 mm from the bottom plate and 32.14 mm away from the central feeding cable (Fig. 4). Sample holders have been modelled as hollow cylinders of Perspex (ε_r=2.6, σ=0 S/m) with wall thickness of 1 mm. Petri dishes have been filled with 2 ml of CRADA solution (ε_r=77, σ=2.2 S/m, ρ=1 g/cm^3), a biological medium for cell cultures. Metallic plates and props have been set to Perfect Electric Conductor (PEC). The structure with the biological samples has been numerically characterized using the software CST Microwave Studio ® version 2008.06, based on the Finite Integration Technique.

The S_{11} behaviour, in the presence of the four samples, slightly changes with respect to that obtained in the empty structure (Fig. 3). In particular, the minimum value (below -25 dB) shifts toward lower frequencies being positioned just around 2.45 GHz (red line in Fig. 3). Thus, the presence of the sample enhances the matching at the frequency of interest.

The local SAR distribution inside the four samples, calculated by means of simulations with 1053570 mesh cells, is shown in Fig. 4. As evident from the figure, distributions are very similar among the four Petri dishes, due to the symmetry of the structure. Moreover, the SAR homogeneity inside each Petri dish seems to be acceptable.

Moving to a quantitative evaluation, in Table II the mean SAR with its standard deviation and the coefficient of variation (standard deviation/mean value) in each sample are displayed. In particular, statistical values have been evaluated either in the whole CRADA solution (cell suspension) or in a thin (0.5 mm) slice on the bottom of each Petri dish, representative of a cell monolayer. Data of Table II confirm the qualitative analysis reported above: variations among the four samples are negligible; the inhomogeneity inside each sample, quantified by the coefficient of variation, is always below 20 % for cell monolayers and about 30 % for cell suspensions. This latter value is still considered acceptable for such a kind of experiments [8].

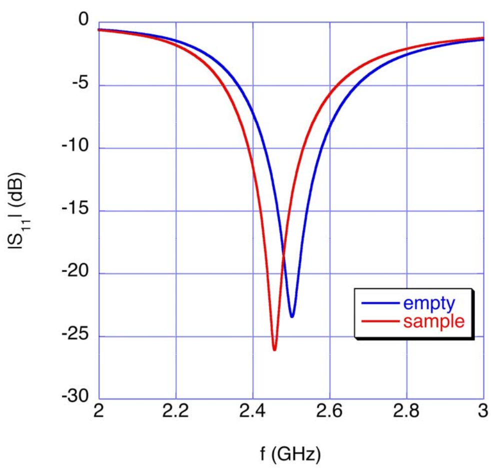

Fig. 3 Comparison between the $|S_{11}|$ values versus frequency for the structure alone (blue line) and loaded with four Petri dishes, each filled with 2 ml of culture medium (red line)

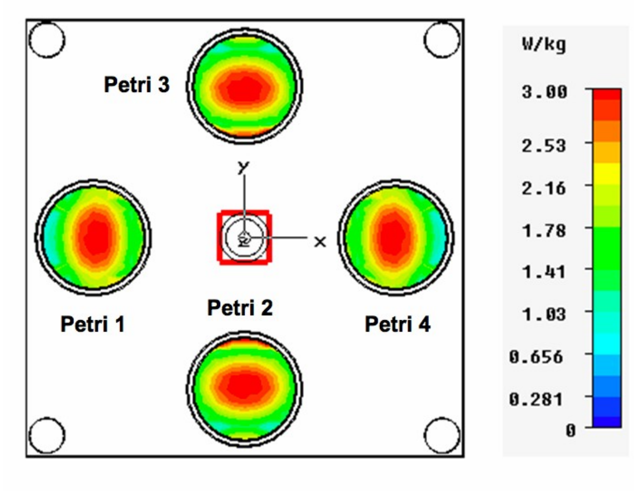

Fig. 4 Distribution of the SAR inside the culture medium in each Petri dish (top view)

TABLE II
Estimated SAR in the Four Petri Dishes: Whole Solution (Suspension) and Slice on the Bottom (Monolayer)

		Mean value (W/kg)	**Standard Deviation (W/kg)**	**Coefficient of Variation**
Petri 1	***Suspension***	1.312	0.428	0.326
	Monolayer	0.971	0.174	0.179
Petri 2	***Suspension***	1.312	0.428	0.326
	Monolayer	0.972	0.174	0.179
Petri 3	***Suspension***	1.316	0.426	0.324
	Monolayer	0.974	0.176	0.181
Petri 4	***Suspension***	1.315	0.426	0.324
	Monolayer	0.974	0.176	0.181

Moreover, the efficiency of the system has been calculated in terms of induced SAR per 1 W of incident power. Taking into account that the default incident power assigned by CST to the feeding port is equal to 1 W, the efficiency is numerically equal to the mean SAR among the four samples: $\approx$ 0.97 (W/kg)/W for cell monolayers and $\approx$ 1.31 (W/kg)/W for cell suspensions. This latter value is comparable to that reported in [6] for the WPC at 1.80 GHz.

IV. Conclusions

The huge diffusion of wireless local networks inside homes or in public areas, such as schools and hospitals, has aroused a renewed interest on biological experiments aiming at the evaluation of possible hazardous effects of the EM fields at frequencies around 2.45 GHz.

In this context, an *in vitro* setup for the contemporary exposure of four 35 mm Petri dishes, filled with cell cultures, has been designed and numerically characterized. The system consists in a WPC operating at 2.45 GHz, typical frequency of the *IEEE 802.11b* and *IEEE 802.11g* communication protocols [2], [3].

During the design step the system has been first dimensioned moving from the existing WPCs operating at 0.90, 1.80, and 1.95 GHz [5]-[7]. Then, numerical simulations by means of CST Microwave Studio ® have been conducted to optimize the matching of the structure at 2.45 GHz and the homogeneity of the E field inside it, with respect to its main geometric parameters.

The optimized system has been finally numerically characterized from a dosimetric point of view. Results of simulations show a good value of the efficiency, both for cell suspensions (about 1.3 (W/kg)/W) and for cell monolayers (about 0.97 (W/kg)/W). Moreover, variations in SAR distributions among the four Petri dishes are negligible, due to the symmetry of the structure. The SAR inhomogeneity inside each sample, in terms of the ratio between the standard deviation and the mean value of the SAR, are always below 20 % for monolayers and around 30 % for cell suspensions. Such values are considered acceptable by the scientific community for this kind of biological experiments [8].

Therefore, the designed exposure system is a suitable one for the *in vitro* experiments aiming at the evaluation of possible biological effects induced by the EM fields emitted by Wi-Fi devices.

References

[1] *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification*, IEEE Std. 802.11, 1997.

[2] *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification: Higher-Speed Physical Layer Extension in the 2.4 GHz Band*, IEEE Std. 802.11b, 1999.

[3] *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification: Higher-Speed Physical Layer Extension to 54 Mbps*, IEEE Std. 802.11g, 2003.

[4] A. Paffi, R. Pinto, M. Liberti, F. Apollonio, G. A. Lovisolo, G. D'Inzeo, "Review of exposure setups for biological experiments in the radiofrequency range: specifications and emerging trends," proceedings of the *XXIX General Assembly International Union of Radio Science*, Chicago, USA, 7-16 August, 2008.

[5] L. Laval, Ph. Leveque, B. Jecko, "A New InVitro Exposure Device for the Mobile Frequency of 900 MHz," *Bioelectromagnetics*, vol. 21, pp.255-263, 2000.

[6] L. Ardoino, V. Lopresto, S. Mancini, R. Pinto and G. A. Lovisolo, "1800 MHz in vitro Exposure Device for Experimental Studies on the Effects of Mobile Communication Systems," *Radiation Protection Dosimetry*, vol. 112, n.3, pp. 419-428, 2004.

[7] V. Lopresto, L. Ardoino, S. Mancini, R. Pinto, G. A. Lovisolo, "An in vitro Exposure Device for Experimental Studies on the Effects of UMTS Mobile Communication System," proceedings of *Bioelectromagnetics 2005,* pp. 363-365, Dublin, Ireland, 20-24 June, 2005.

[8] N. Kuster and F. Schonbon, "Recommended minimal requirements and development guidelines for exposure setups of bio-experiments addressing the health risk concern wireless communications," *Bioelectromagnetics*, vol. 21, pp. 508–514, 2000.