



Progetto, Realizzazione e Caratterizzazione di Sistemi Espositivi per la Sperimentazione nel Bioelettromagnetismo

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Negli ultimi decenni si è osservato un notevole incremento della sperimentazione biologica in ambito bioelettromagnetico, al fine di valutare eventuali effetti indotti dall'esposizione a campi elettromagnetici (EM), quali quelli generati dagli apparati di telefonia mobile, su specifici campioni biologici. Tali studi, tuttavia, hanno dato luogo a risultati spesso contrastanti, e pertanto di difficile interpretazione, evidenziando il problema della riproducibilità nella sperimentazione biologica. A tale proposito, l'Organizzazione Mondiale della Sanità [1] ha richiamato l'attenzione sulla necessità di progettare sistemi espositivi in grado di garantire condizioni di esposizione controllata durante gli esperimenti e quindi di condurre una accurata valutazione dosimetrica preliminare che consenta di conoscere la "dose" di campo EM presente nel campione biologico in esame. Si comprende, pertanto, come i solutori numerici del problema elettromagnetico rappresentino un valido strumento, sia in fase di progetto che in fase di caratterizzazione dei sistemi espositivi.

Nel presente intervento si mostrerà un esempio di uso del software commerciale Ansoft HFSS per il raffinamento del progetto e per la caratterizzazione, in termini di dose, uniformità del campo sul campione ed interferenza con la strumentazione di laboratorio, di un sistema espositivo a microonde per registrazioni elettrofisiologiche in tempo reale [2] da fettine cerebrali.

[1] WHO "International Electromagnetic Field Project 2000", <http://www.who.int/phe-emf>

[2] M. Liberti, F. Apollonio, A. Paffi, M. Pellegrino, G. d'Inzeo, "A Coplanar Waveguide System for Cell Exposure during Electrophysiological Recordings", IEEE Trans. on MTT, Nov. 2004, vol. 52, pp. 252-2528.

DESIGN, REALIZATION AND CHARACTERIZATION OF EXPOSURE SYSTEMS FOR THE EXPERIMENTAL INVESTIGATION IN BIOELECTROMAGNETICS

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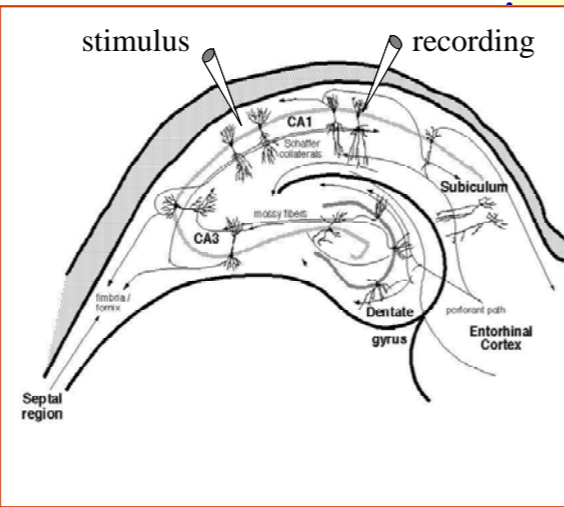
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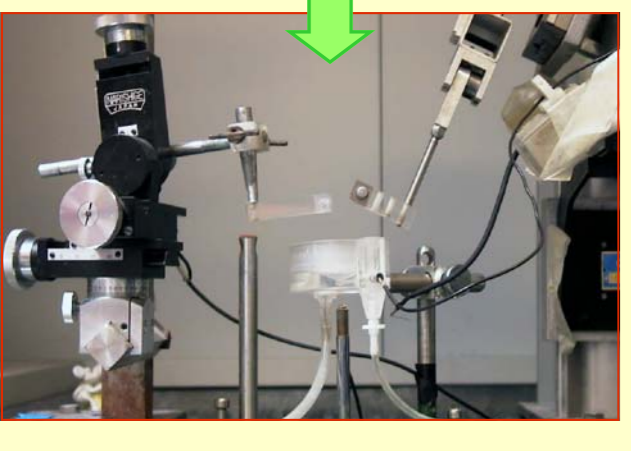
1 CONTEXT & OBJECTIVES

The neuronal activity of the hippocampus is related to high cognitive functions, such as learning and memory [1]. Hippocampal slices are therefore considered as appropriate structures to evidence possible changes induced by electromagnetic (EM) fields in the coordinate activity of neuronal networks [2].

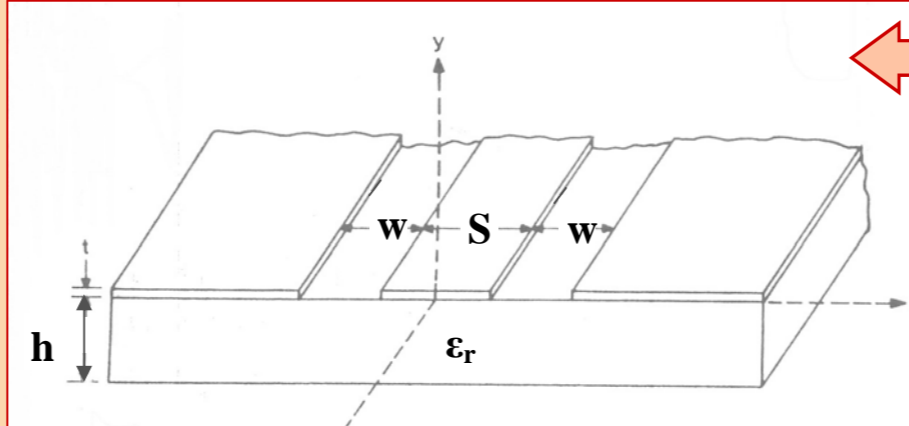
In electrophysiological recordings, brain slices are inserted in a perfused chamber and are monitored with a direct microscope. A fiber-optics is placed under the chamber for the correct positioning of the electrodes.



Aim of this work is to realize a real-time microwave (MW) exposure system suitable for such a kind of experimental activity. Besides satisfying general requirements recommended in [3], the exposure system has to guarantee a **uniform distribution of the fields in the whole slice** for the frequency range of (800+2000) MHz, typical of current mobile communication systems. (RAMP2001Project)



2 DESIGN AND REALIZATION

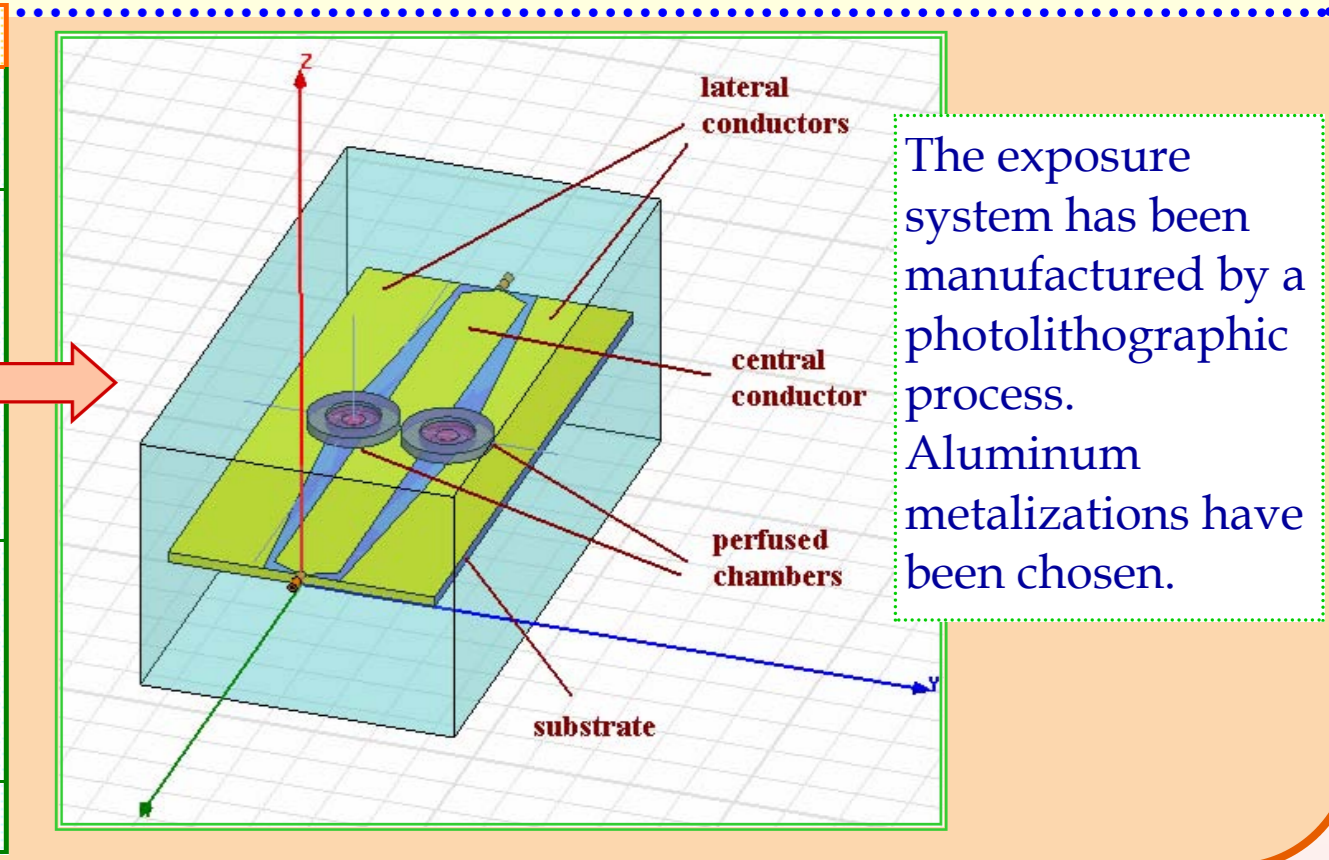


The chosen EM structure: a coplanar waveguide (CPW) [4, 5].

Why a CPW?

Our CPW...

Requirements	Motivations	Design choices
Transparent substrate	Lighting of the biological sample by a fiber-optics coming from below	Glass substrate ($\epsilon_r=5.5$)
$h < 0.1\lambda_d$ (λ_d = wavelength in the substrate, h = thickness of the substrate)	Guarantee of the absence of radiation losses, given minimum λ_d [4, 8]	$h=0.4$ cm
$w \geq 0.8$ cm (w = width of the visibility window)	Obtaining an exposure as uniform as possible in the whole slice (diameter=0.8 cm)	$w=1.2$ cm
$S \geq 2.4$ cm (S = width of the central conductor)	Using in the same time two perfused chambers (diameter=3.5 cm), one for each exposure window, in order to maintain the symmetry of field distribution in the structure	$S=2.4$ cm
Input impedance $Z=50 \Omega$	Reducing input reflection losses	Linear ending tapering [5]



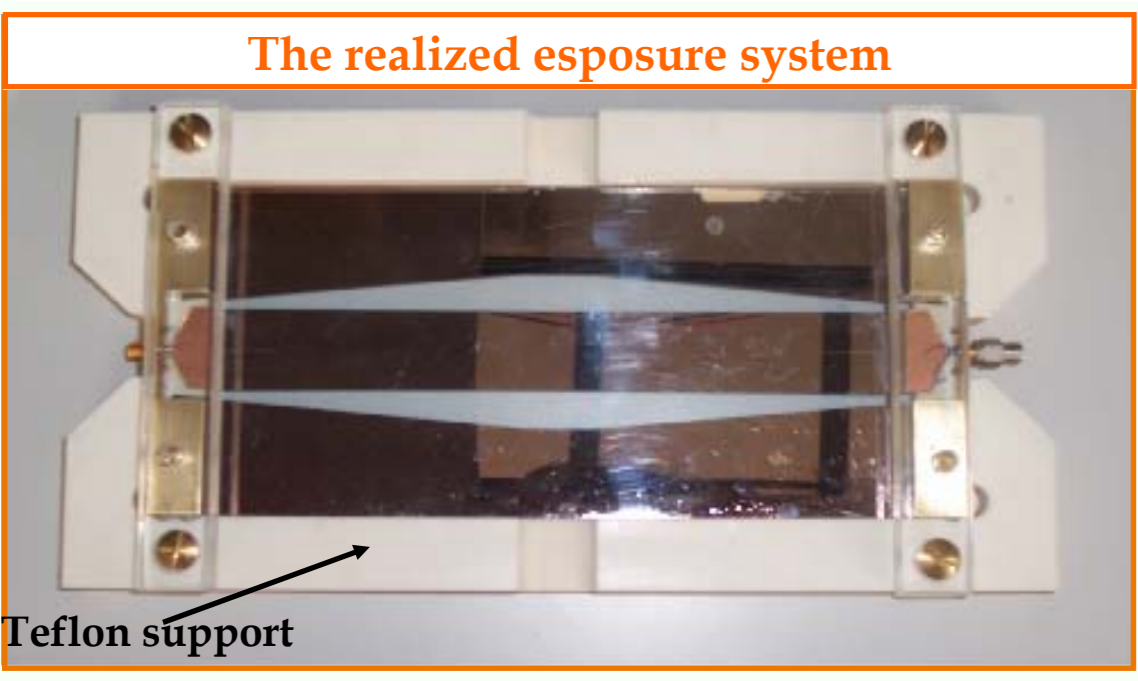
Compared with other exposure systems already existent for electrophysiological recordings from brain slices [6, 7], the CPW is an open structure, with the E field lines almost parallel to its surface [4]. Therefore:

- a real-time exposure is allowed;
- an easy access to the biological sample and reduced dimensions are guaranteed;
- the interferences between the field and the electrodes are minimized.

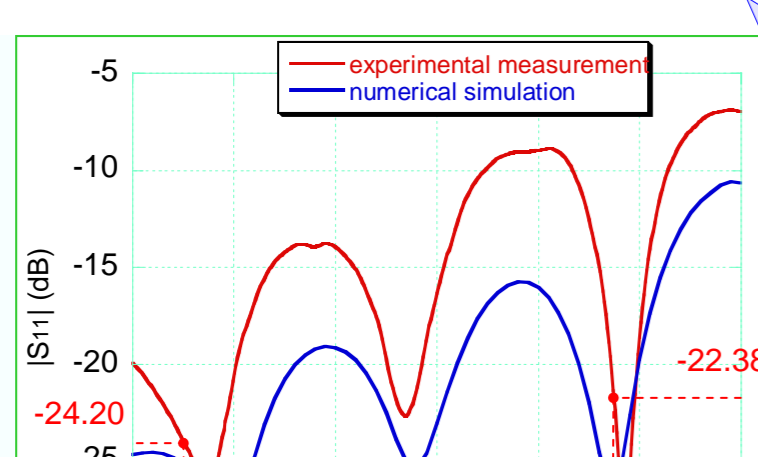
3 ELECTROMAGNETIC CHARACTERIZATION* OF THE EXPOSURE SYSTEM

*Numerical characterization has been carried out by using the commercial code High Frequency Structure Simulator (HFSS) 9.1 by Ansoft Corporation.

3a WITHOUT THE BIOLOGICAL SAMPLE

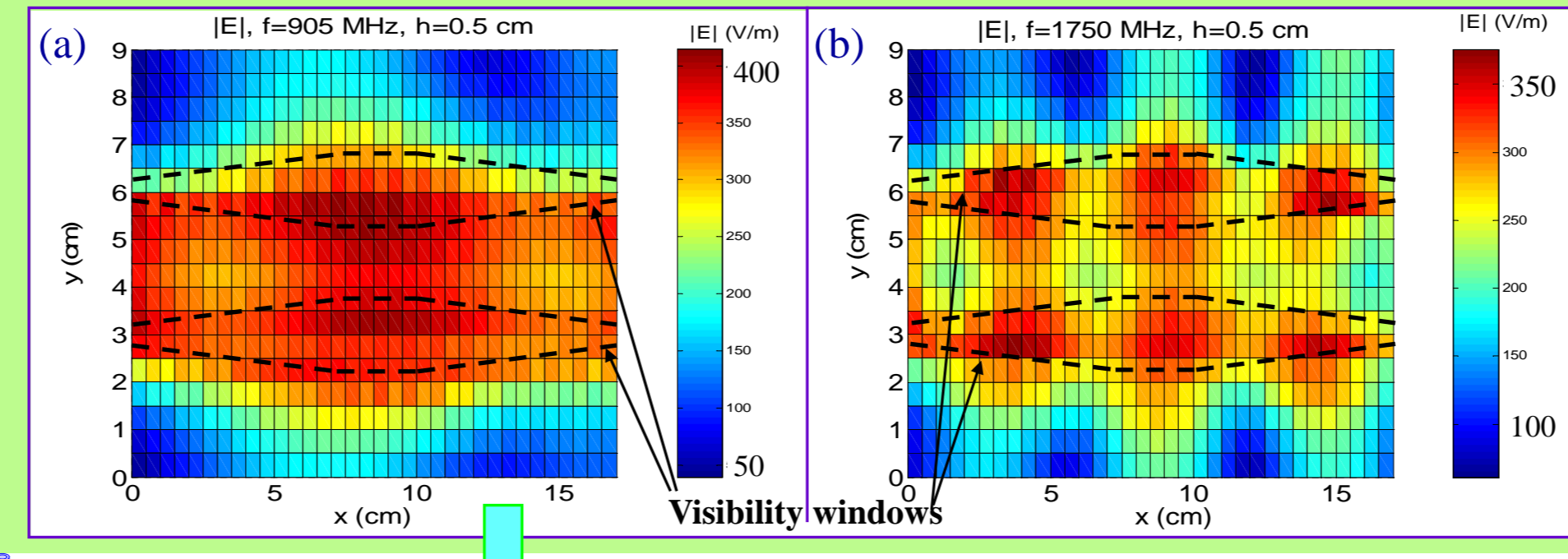


|S₁₁| behavior
Scattering parameters have been measured by an Anritsu MS4624D network analyzer. Values of |S₁₁| (red line) show a good impedance matching in the entire range of frequencies. The experimental measurement presents a similar behavior with respect to the simulation results (blue line).



|E| and |H| field measurements

|E| and |H| have been measured with Schmid & Partner, Engineering AG: ET3DV5R and H3DV6 probes, respectively, for an incident power of 1 W. Measurements have been conducted at the distances of 0.5, 1, 2, 4, and 8 cm from the CPW surface. Probes were moved by an automated swinging system in a grid of 17x9 cm², centred with the CPW, with a step of 0.5 cm along the x- and y-directions.



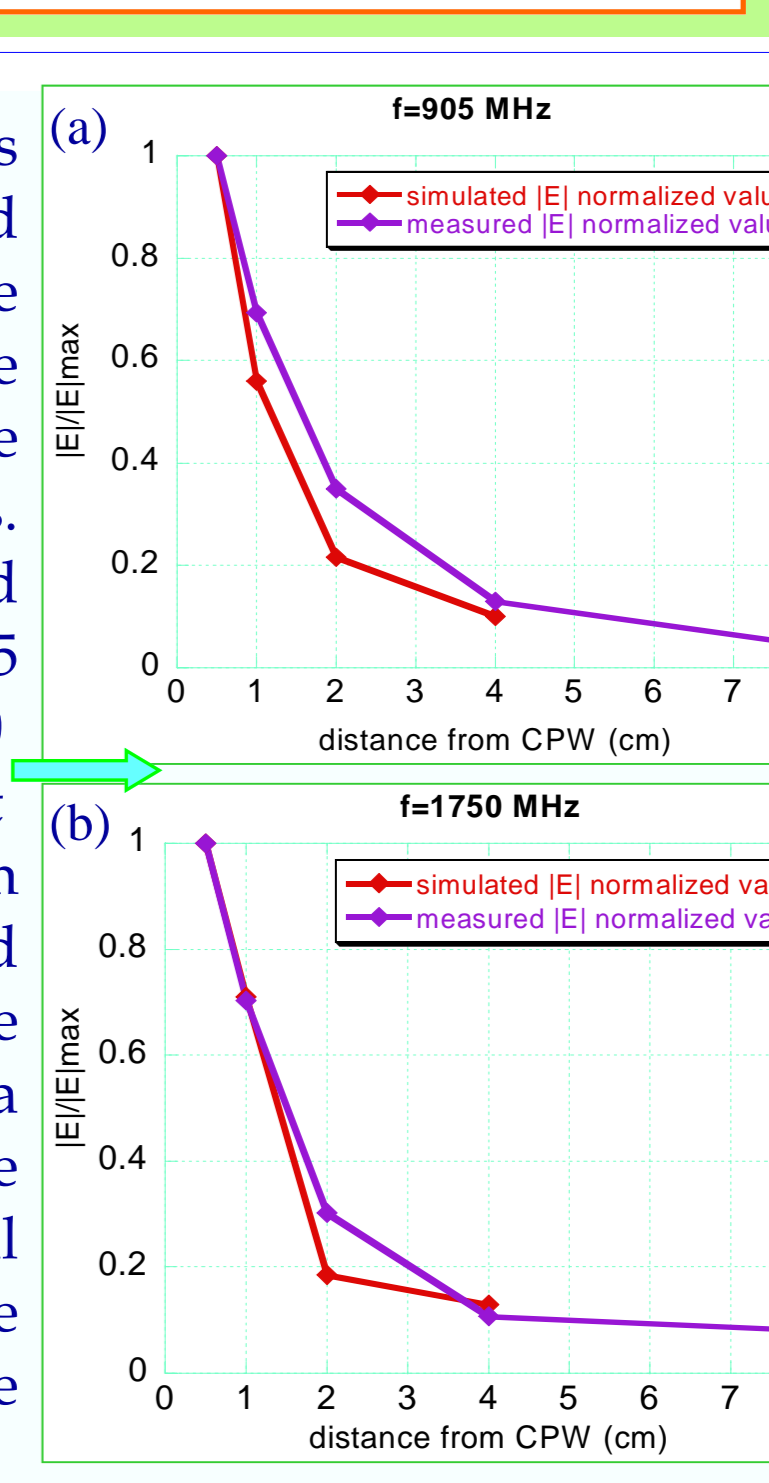
Both surface maps at 905 MHz (a) and 1750 MHz (b) show that the |E| field, measured at a distance of 0.5 cm from the CPW surface, is symmetric with respect to the x- and y-direction and reaches its maximum values on the two visibility windows (represented with black dashed lines). Homogeneity of |E| and |H| fields has been evaluated in the exposure zones (squares of 1x1 cm², centred in the points with coordinates of (8.5, 3) and of (8.5, 6) cm). Results show values of maximum percentage difference always lower than 30%. In particular, |E| field homogeneity decreases at the higher frequency, where it is more evident the presence of a standing wave. Nevertheless, the value of the standing wave ratio (SWR) is good at both 905 and 1750 MHz (max. value=1.7).

Fields	Frequency (MHz)	Mean value (V/m)	Std. dev. (V/m)	Maximum perc. diff. (%)	Perc. diff. (%)
E	905	348.40	16.46	13.42	4.73
E	1750	312.18	25.29	25.29	8.10
H	905	2.56	0.32	28.42	12.69
H	1750	3.16	0.27	23.46	8.54

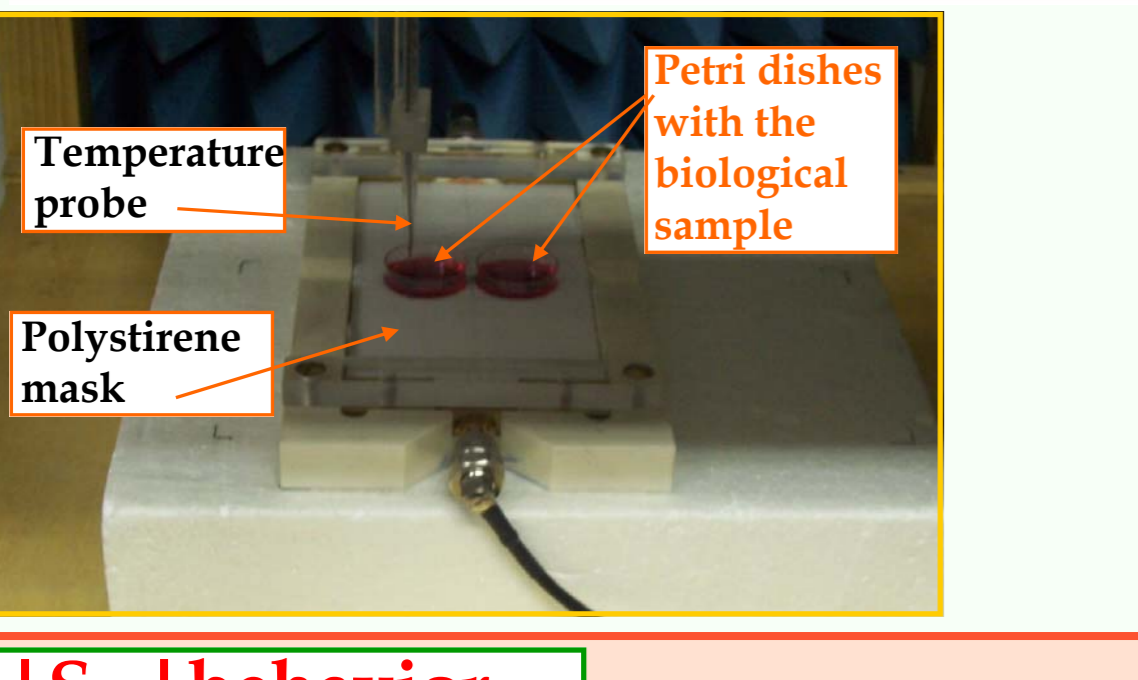
Frequency (MHz)	SWR
905	1.43
1750	1.70

|E| field decay: comparison between simulations and measurements

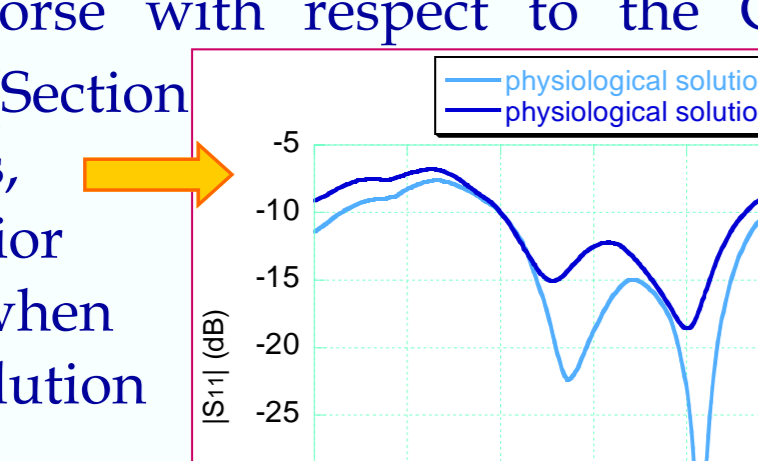
|E| and |H| fields have been evaluated along a vertical line passing through the centre of one of the CPW exposure zones. Measured electric field (violet line) at 905 MHz (a) and 1750 MHz (b) indicates that 20% of the maximum amplitude is reached at about 3 cm above the structure, so a minimum interference occurs with external objects distant more than 3 cm from the CPW. The field decay in experimental conditions is less rapid than simulated one; this is plausible due to losses of real conductivity of metals and seals.



3b WITH THE BIOLOGICAL SAMPLE

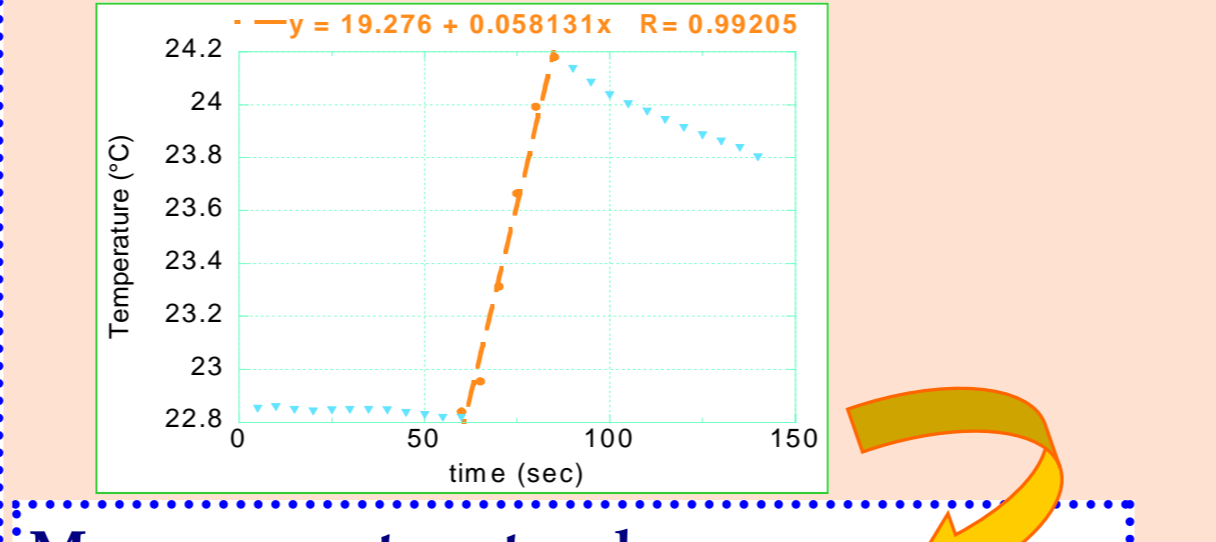


|S₁₁| behavior
Scattering parameters have been measured for the CPW in presence of two Petri dishes filled with 2 ml (light blue line) and 4 ml (dark blue line) of physiological solution. In both cases a mismatching is introduced, and the mean values of |S₁₁| get worse with respect to the CPW without sample (Section 3a). Nevertheless, frequency behavior becomes flatter when the volume of solution increases.



Temperature measurements for evaluation of SAR and efficiency

In order to evaluate SAR and efficiency of the exposure system, temperature measurements in the biological sample have been carried out by means of a VitekTP100 probe (test bench shown in Section 3a). Twelve measure points equally spaced (6 in the exposure zone and 6 in the metallic strips) have been chosen in each of the two Petri dishes, filled with 4 ml of saline solution*. Five measures for each point have been performed at 905 and 1750 MHz.



Measurement protocol:
• 60 sec before MW exposure;
• 20 sec of exposure (incident power equal to 2.5 W);
• 60 sec after exposure.
Temperature has been recorded every 5 sec by an automated system.
Elaboration of measurements:
1. Interpolation of the temperature values: related to the exposure interval with a linear regression method;
2. Evaluation of SAR and efficiency by the angular coefficient of the straight line (dT/dt), according to the formulas:
 $SAR = 4186 \cdot \epsilon \cdot \Delta T / \Delta t$ (W/kg) (specific heat)
 $Efficiency = SAR / Inc. Power$ ((W/kg)/W)

ΔT(°C) values and standard errors

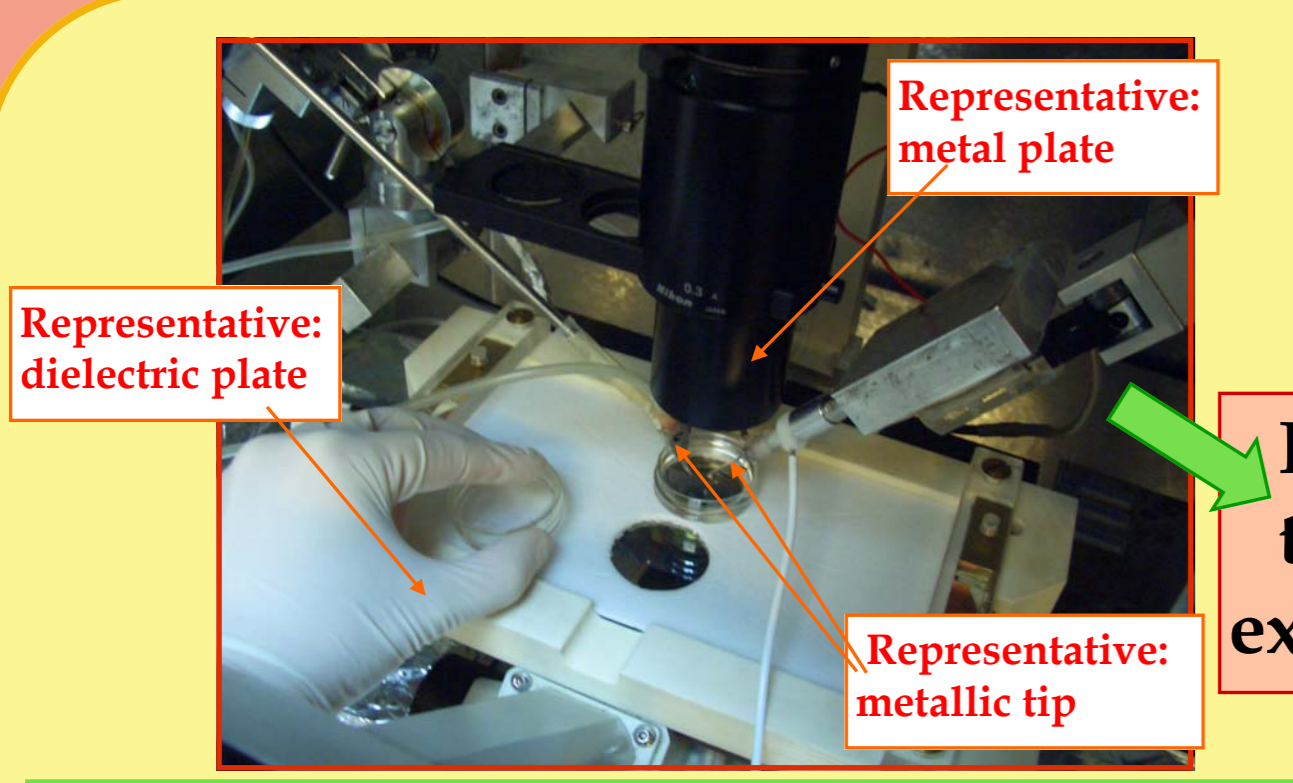
Point	905 Frequency (MHz)	1750 Frequency (MHz)
1	0.173±0.004	1.038±0.009
2	0.244±0.004	0.854±0.013
3	0.221±0.005	0.610±0.014
4	0.254±0.003	1.418±0.016
5	0.348±0.004	0.888±0.026
6	0.340±0.005	0.622±0.020
7	0.269±0.008	1.431±0.017
8	0.350±0.012	0.938±0.026
9	0.345±0.010	0.661±0.018
10	0.168±0.005	1.082±0.010
11	0.173±0.003	0.764±0.009
12	0.170±0.003	0.576±0.006

Efficiency values ((W/kg)/W) in the visibility windows

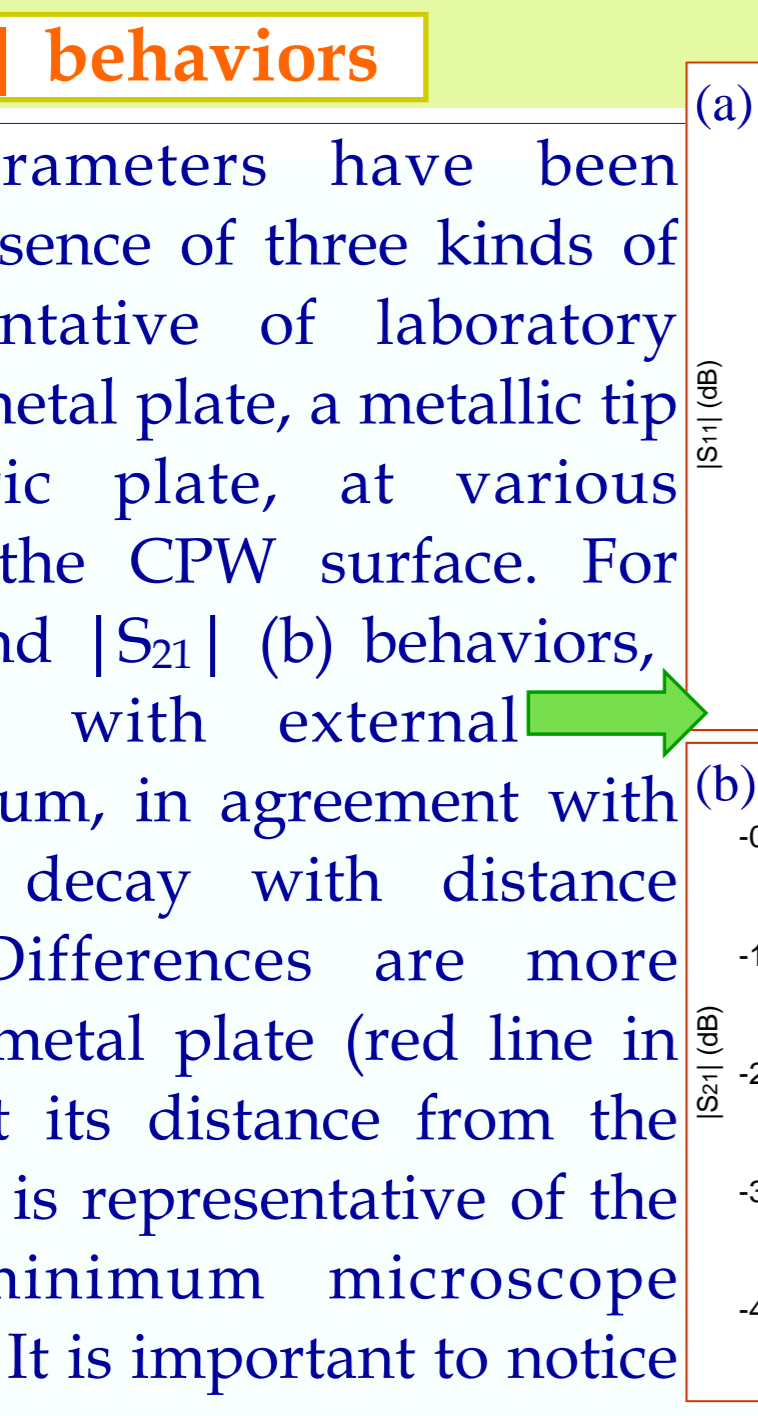
Point	905 Frequency (MHz)	1750 Frequency (MHz)
4	20.17	112.81
5	27.646	70.626
6	27.01	49.502
7	21.411	113.83
8	27.805	74.571
9	27.455	52.588

Frequency (MHz)	Mean value ((W/kg)/W)	Std. error ((W/kg)/W)	Maximum perc. diff. (%)	Perc. diff. (%)
905	25.249	78.988	1.4234	11.567
1750	27.46	56.51	27.46	35.81

Being the trend of temperature the same in the two Petri dishes, here results of measurements and evaluation of efficiency refer only to one of them. At both frequencies, temperature increases confirm the focusing of the E field on the visibility windows (points 4-9). More in detail, measured values show good homogeneity at 905 MHz, rather than at 1750 MHz. This was expected, since at the higher frequency the standing wave is more evident and the dissipation in the biological sample is greater. Simulations confirmed this behavior too, being the maximum percentage difference of the |E| field in the sample equal to 7% and 20% at 905 and 1750 MHz, respectively, along the x-direction (i.e. propagating direction). These results give an indication to the electrophysiologist for the choice of the appropriate positioning of the slice in the perfused chamber. Efficiency mean values in the visibility windows (the only ones of experimental interest) are good at both frequencies.



|S₁₁| and |S₂₁| behaviors
Scattering parameters have been measured in presence of three kinds of objects, representative of laboratory environment: a metal plate, a metallic tip and a dielectric plate, at various distances from the CPW surface. For both |S₁₁| (a) and |S₂₁| (b) behaviors, the interaction with external objects is minimum, in agreement with the |E| field decay with distance (Section 3a). Differences are more marked for the metal plate (red line in (a) and (b)), but its distance from the CPW (h=0.8 cm) is representative of the worst case (minimum microscope distance ≈ 1 cm). It is important to notice that the metallic tip dimensions (diameter=0.3 cm) also represent unrealistic experimental conditions, since electrode diameter is usually about tenths of mm.



The influence of the metallic electrode

It is clear that the presence of the stimulating metallic electrode determines a focusing of the EM fields around its tip and, as a consequence, a local perturbation of the E and H fields distribution, even when the electrode position is almost orthogonal to the CPW surface. This matter has been investigated by numerical simulations conducted at 1200 MHz (central in the range (800+2000) MHz), trying to answer to these questions:

- How much does the electrode locally modify the field distribution?
- Does an "optimal" position for the electrode exist, able to minimize such a perturbation?

A prism with 8 faces has been chosen as electrode geometry in the numerical model, in order to obtain a better numerical solution of the EM problem around the electrode tip [9].

Electrode placed in the center of the exposure zone
The presence of the electrode determines a high focusing of the |E| field around its tip (the figure refers only to one of the exposure zones). Percentage differences for the |E| and the |H| fields are $\Delta|E|=+211\%$ and $\Delta|H|=-25\%$. It is important to stress that such a focusing is local, since |E| field variations become only of 4% at a distance of 2 mm from the electrode tip. Moreover, the perturbation is not symmetrical along the y-direction; thus investigations on fields perturbation in correspondence of different positions for the electrode has been carried out.

Electrode placed in different positions in the exposure zone (positions 1, 2, 3)
Results show that when the electrode is placed near the lateral conductor (position 3, red line) the local perturbation of the |E| field is lower than in the other cases (center of the exposure zone (position 1, blue line) and lateral conductor (position 2, gray line)). Percentage variations of the |H| field confirm this behavior, too. As a consequence, a clear indication for the electrophysiologist, relative to the "optimal" position of the stimulating electrode in the slice, can be extracted.

Position	Δ E (%)	Δ H (%)
1	+211%	-25%
2	+600%	-35%
3	+69%	-22.8%

5 CONCLUSIONS

A real-time exposure system suitable for electrophysiological recordings from brain slices has been designed, realized, and both numerically and experimentally characterized. The chosen structure is a CPW and its main features are:

- wide range of operating frequencies;
- good homogeneity of |E| and |H| fields in the biological sample;
- high efficiency values in the exposure zones;
- minimum interaction with external objects.

Moreover, very useful guidelines for the electrophysiologist can be established for an "optimal" direction of the experimental activity, in terms of appropriate positioning of both the slice and of the stimulating electrode in the exposure zones.

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