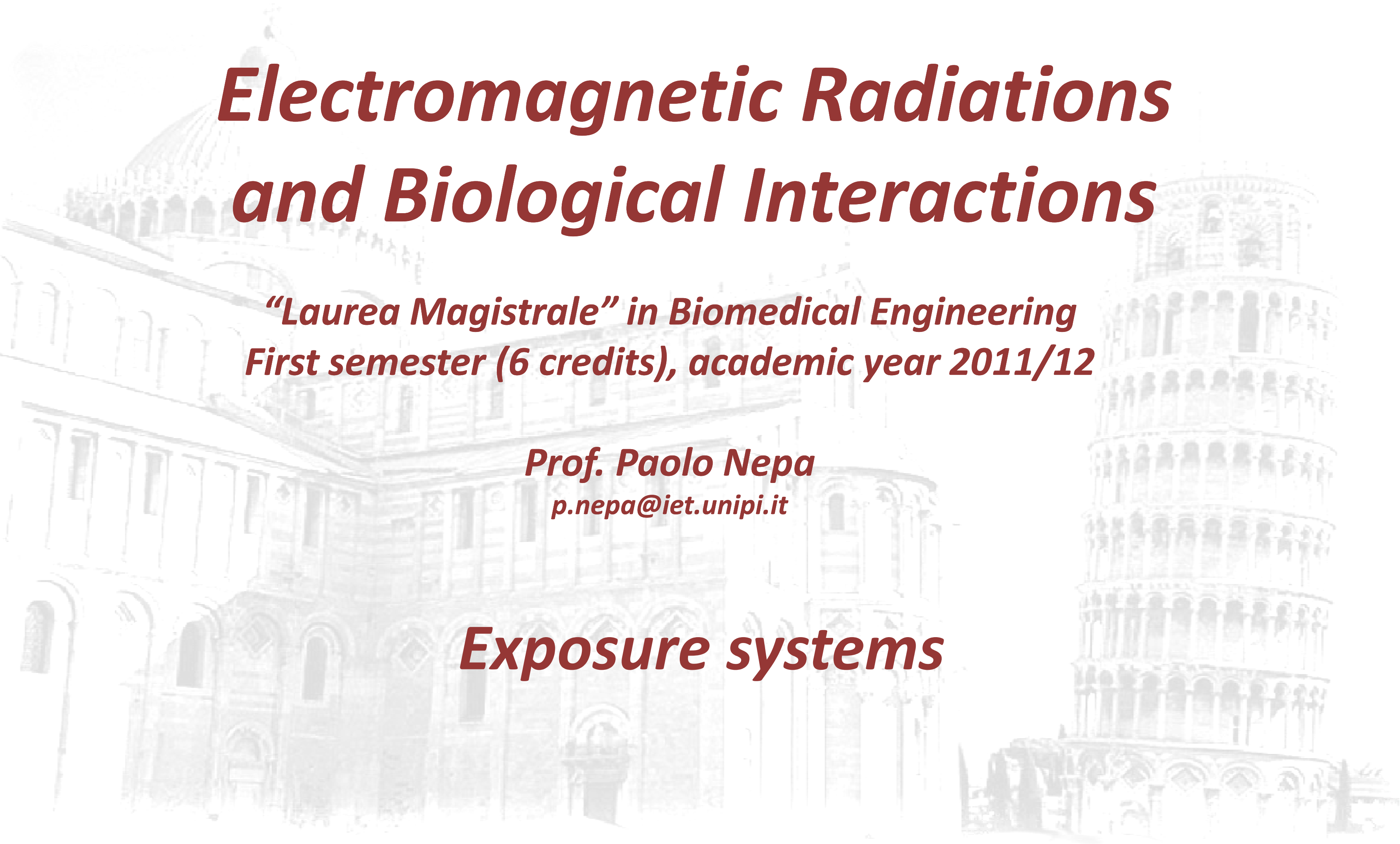

Electromagnetic Radiations and Biological Interactions

"Laurea Magistrale" in Biomedical Engineering
First semester (6 credits), academic year 2011/12

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Exposure systems

Edited by Dr. Anda Guraliuc

Lecture Content

- Biological effects
- Exposure systems
  - TEM cell/GTEM cell
  - Rack Loop Antenna Array
  - Horn antenna & dielectric lens
  - WPC cell
  - Shorted waveguide
  - Ferris-Wheel exposure system

Introduction

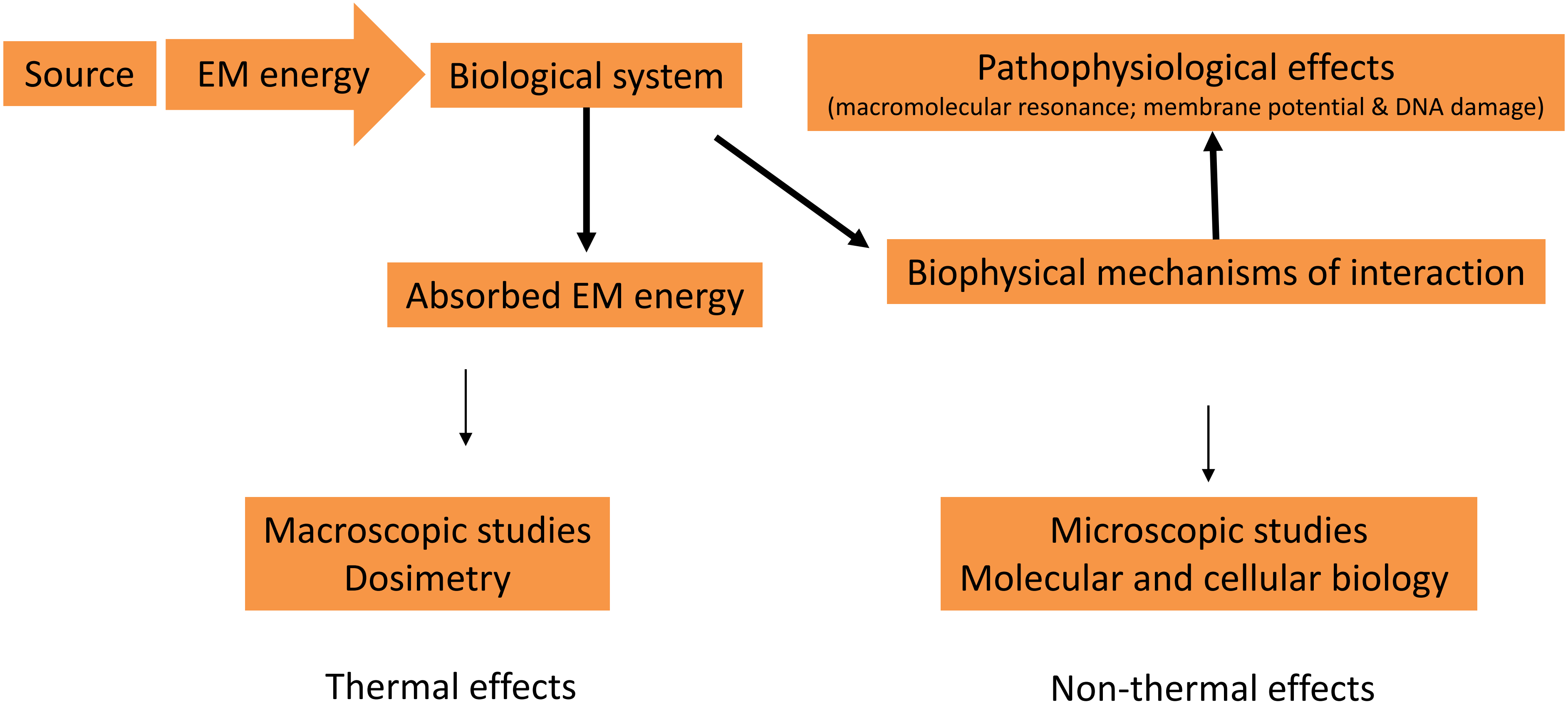
➢ The electromagnetic field source expansion, such as antennas for mobile phones and wireless communication systems, has increased the human exposure levels to EM fields and generated the perception of damage risk.

➢ Despite a large amount of research works, more than thousands of publications, the scientific community is still involved in studying the interaction mechanism between electromagnetic waves and living matter, because there is no complete and definitive understanding of the biological effects of EM fields.

➢ To study the EM fields biological tissue effects different experiments can be required: *in vivo* (on rats, mice etc.) and *in vitro* (on biological tissues).

EM field – Biological system interaction

The interaction of EM fields with a biological system can result in pathological effects whose origin is to be found in the biological mechanisms of interaction.



Source

EM energy

Biological system

Pathophysiological effects

(macromolecular resonance; membrane potential & DNA damage)

Absorbed EM energy

Biophysical mechanisms of interaction

Macroscopic studies

Dosimetry

Microscopic studies

Molecular and cellular biology

Thermal effects

Non-thermal effects

Interaction – biological effect - damage

Interaction	➢ When a human body interacts with an EM field, its electric equilibrium is definitely disturbed, but there is not necessarily a biological effect or a damage.
Biological effect	➢ When morphologic and functional variations occur in the body/organs.
Damage	➢ It occurs when the effect exceeds the effectiveness limits of body adapting mechanisms.

Biological effects

Effects

thermal

- ➢ The energy carried by a wave passes through a biological tissue and is dissipated within the tissue itself as heat, which produces a temperature increase.
- ➢ Are indirect interaction: EM field-> heat->biological effects
- ➢ When the temperature increases, the body reacts: it tries to eliminate the excess heat and keep its temperature constant.
- ➢ If the temperature elevation is above a certain level, there is a local or general hyperthermia.
- ➢ Thermal effects hazards are well established and safety levels are well documented.

non-thermal

- ➢ Can be classified as micro-thermal (e.g. auditory effect that occurs for pulse modulated microwave exposure – radar emissions).
- ➢ Are direct interactions of EM fields with biological cells.
- ➢ Depends on the field intensity, frequency and signal shape.
- ➢ Are not as well understood: specifically, mechanisms are not fully explored nor consistently documented.

	Level	Parameter	Effects
Thermal	Body	Absorbed power density	General temperature increase
	Organs		Local temperature increase
Non-thermal	Cell cultures	Forces on charges (ions, electrons) and on dipolar molecules (permanent or induced)	Macromolecular resonance Membrane potential damage DNA damage Dormant tumor cell reactivation
	Cell (membrane/nucleus)		
	Molecule		

At risk?

Are those tissues with lower blood concentration

- eyes
- gall bladder
- testes

because are unable to dissipate heat through the active thermoregulatory mechanism of blood flow

Effects due to different frequency of the EM field

Low-frequency high fields

- cause non-thermal effects
- cause electric currents in the human body able to influence excitable cells
- the effects depend on the current density induced in the body
- a strong EM field can produce central nervous system disorders, blood pressure increases and cardiac arrhythmias

High-frequency fields

- cause thermal effects
- high frequency radiations are absorbed and dissipated inside the body as heat
- the effects depend on the intensity, duration and frequency of the EM field
- if the increase of body heat exceeds a certain level, the effect is equal to that produced by fever or extreme heat, and leads to a reduction of mental activity and a disturbance of body functions
- the eyes are particularly affected

Low-frequency low fields

- are of interest for long-term exposure
- cause predominantly non-thermal effects because the intensity is not high enough to significantly change tissue temperature
- can influence the cellular membrane permeability and melatonin metabolism
- there are many research studies that statistically connect the low-frequency low fields (above 0.4μT) to the childhood leukemia occurrence

Studies and research

Epidemiologic studies	• are mainly related to the cancer risk and reproductive effects in residential and employment environments
In vivo studies	• regard systems like: nervous, endocrine, cardiovascular, immune, reproductive etc.
In vitro studies	• are studies at cellular membrane level on ions flow alteration and protein behavior • are studies at cellular nucleus level on DNA damage, dormant tumor cell reactivation, growth cell rate alteration

Epidemiologic studies

Epidemiology is the study of health-event, health-characteristic, or health-determinant patterns in a population.
Epidemiology is a study designed to investigate hypothesized causal relationships; tries to determine why disease is occurring and is based on tests hypothesis.

The quality indicators for the epidemiological studies are:

- Good definition of the study population
- Representative control group of the population which generated the cases
- High rates of participation and not associated with disease state and /or exposure
- Complete, accurate and precise information on exposure and disease
- Appropriate methods of analysis with information on accuracy and variability of the relative risk estimations

The exposure estimation is particularly difficult in the epidemiology of electromagnetic fields for the following reasons:

- the exposure is imperceptible due to multiple sources highly variable over time and over short distances
- the relevant exposure period is prior to the period when it can be realistically measured
- the appropriate exposure metric is unknown, and there are no reference biological data about it

➢ *In the absence of experimental evidence, and given the methodological uncertainties in the epidemiological literature, there is currently no chronic disease for which a stable connection with EM fields exposure can be established.*

Exposure systems

- Exposure systems are mostly used in bioelectromagnetic experiments to study the biological effects of electromagnetic fields.

- One key aspect in the study of the biological effects of EM field exposure conditions is to create the exposure conditions: known, controlled and repeatable. These will allow to correlate the biological effect to the cause that produce it.

- The characteristics and effectiveness of an exposure system depends on:

  - nature and size of the exposed object
  - experiment duration
  - frequency
  - power
  - micro-clime conditions

Exposure systems

- Exposure systems classification:

- propagating systems: TEM/GTEM cells and various waveguides (rectangular, circular, radial, coplanar). Their advantage is versatility and RF field uniformity.

- radiating systems: consists of commercial or ad hoc antennas, like horn, microstrip antennas, loop antennas, generally exposing samples in the far field region. They allow simultaneous sample exposure, but have low uniformity of dose among samples and reduced efficiency in terms of SAR per unit of input power.

- resonant systems: shorted-waveguide. Are closed and compact, are easily placed in an incubator for environmental conditions control. The positioning of the sample is critical due to extremely localized region of field uniformity.

- special resonant systems: wire patch cell based on patch antenna, with the samples placed between two patches short-circuited by metallic rods

Exposure systems – TEM cell

➢ Is a typical exposure system used for *in vitro* experiments, characterized by:

- generation of uniform field or a homogeneous plane wave
- it has an usable cell volume to place biological samples
- it is shielded from electromagnetic influence both from outside and inside
- it operates over a wide frequency band
- field strength can be computed from radiofrequency power travelling through the cell
- TEM cell shows cavity effects, like resonances at frequencies at which the cell dimensions are about half the wavelength. Absorbing materials can be used to minimize resonances and reflections.

➢ Transverse Electromagnetic (TEM) cell consists of a rectangular coaxial transmission line with large cross section, continued at both ends with pyramidal sections that make transition to 50 ohms coaxial standard connectors. Its walls are metallic, usually aluminum.

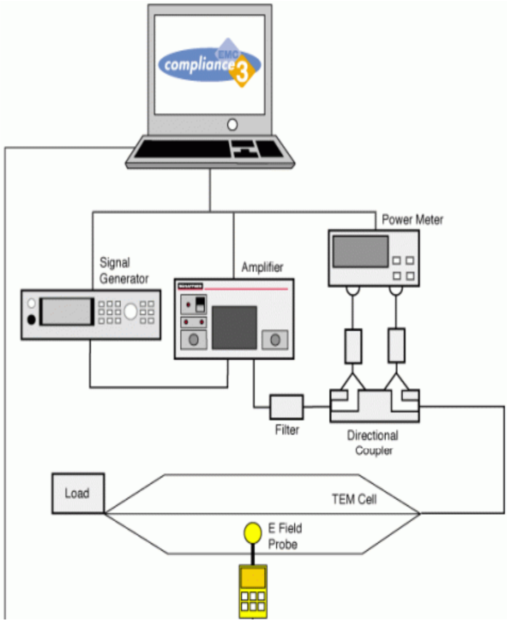
➢ To calculate its dimensions two end points need to be taken into account: desired operation frequency and the needed volume to expose samples (animals).

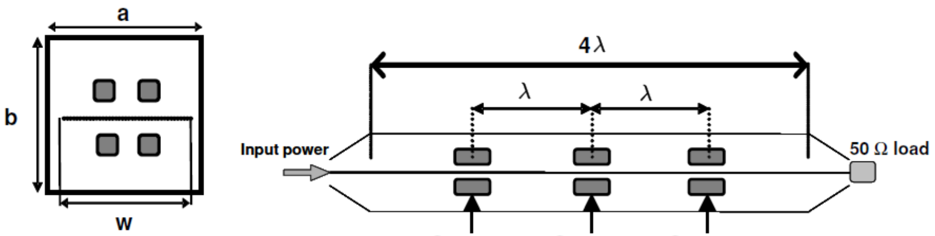
➢ Cross-section dimensions depend on the cut-off frequency, while its length is 4λ to allow a good reconstruction of the TEM mode in the presence of biological samples placed longitudinally.

➢ In a transversal plane, the electric field distribution presents two uniform field regions that allow to place the biological samples (animals) without significantly changing the field distribution.

Exposure systems – TEM cell - example

Typical test set-up:





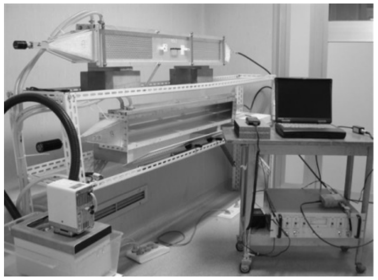
(a) *(b)*

Transversal section—front view (a), and longitudinal section—side view (b) of the TEM cell; the positioning of mice within the cell is also shown.

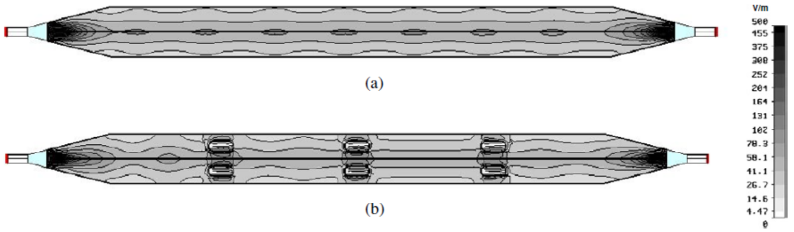
[L. Ardoino et al, "A radio-frequency system for in vivo pilot experiments aimed at the studies on biological effects of electromagnetic fields", Phys. Med. Biol. 50 (2005)3643-3654]

TEM cell - example

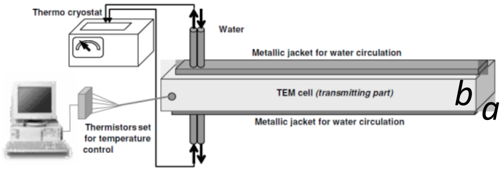
- An exposure system consisting in two TEM cells, operating at 900MHz were used to investigate possible effects of exposure to EM fields produced by wireless communication systems. The system allows a significant simultaneous animals exposure (up to 12 mice per cell).
- Each cell is 120cm long (4λ@900MHz, λ being the wavelength), and presents a cut-off frequency of 1.2GHz.
- To prevent temperature increase in the RF-exposed animals with respect to the sham-exposed ones, and to maintain comfortable and well-known environmental conditions within the cells, a temperature control system has been implemented for the two TEM cells.
- The TEM cell has equal transversal dimensions (*a=b=12cm*)
- The heating/refrigerating system for environmental condition control consists in two external metallic jackets filled with circulating water, fed by a thermostatic bath (control the water temperature), and placed in contact with the top and bottom walls of the cell.



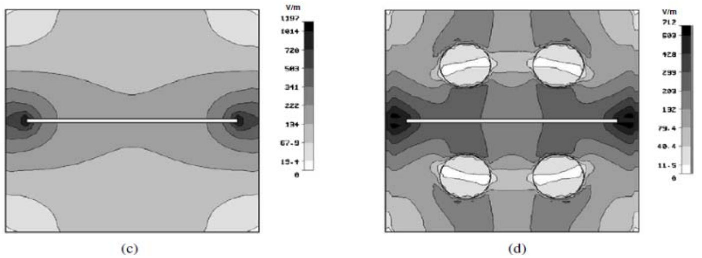
Set-up of TEM cell exposure system with blind control



Numerical electric field amplitude distribution within the TEM in a longitudinal plane for 1W peak input power: (a) cell empty and (b) charged with 12 mice



Heating/refrigerating system for controlling the environmental conditions within the TEM cell.



Numerical electric field amplitude distribution within the TEM in a transversal plane for 1W peak input power : (c) cell empty and (d) charged with 12 mice

[L. Ardoino et al, "A radio-frequency system for in vivo pilot experiments aimed at the studies on biological effects of electromagnetic fields", Phys. Med. Biol. 50 (2005)3643-3654]

Dosimetry in TEM cell

- Experimental dosimetry on both phantoms and living mice (adults and new born) has been performed using the power balance method.
- Numerical model of adult mouse: weight 24g and length 6cm, made of a material with the following characteristics at 900MHz: $c=4102 J kg^{-1} {}^{\circ}C^{-1}$, $\sigma=1.02 S/m$, $\varepsilon_r=55.03$, $\rho=0.96 g/cm3$.
- The average RF power absorbed by each mouse:

$$P_{abs} = \frac{1}{n}\left[P_{in} - P_{out} - \left(P_{refl} + P_{loss}\right)\right]$$

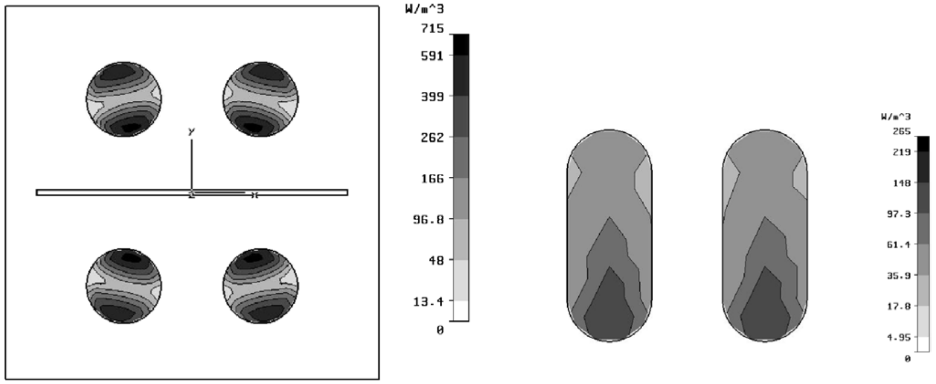
dissipated power in the cell structure

nr. of mice

reflected power at the input port

cell input power

dissipated power in the 50Ω terminal load



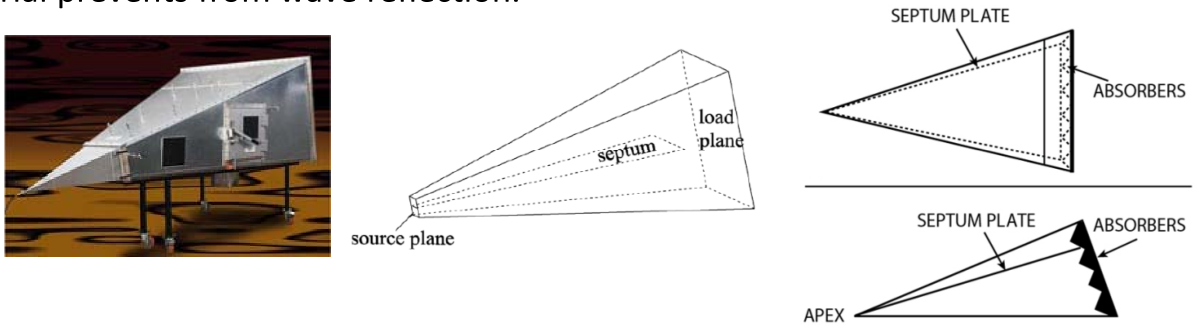
⇨ *highest SAR values were located in the back part of the body, as mice were irradiated from the bottom*

Power loss density distributions calculated at 900 MHz, within an adult mice for 1W peak input power on: (a) transversal section and (b) longitudinal section

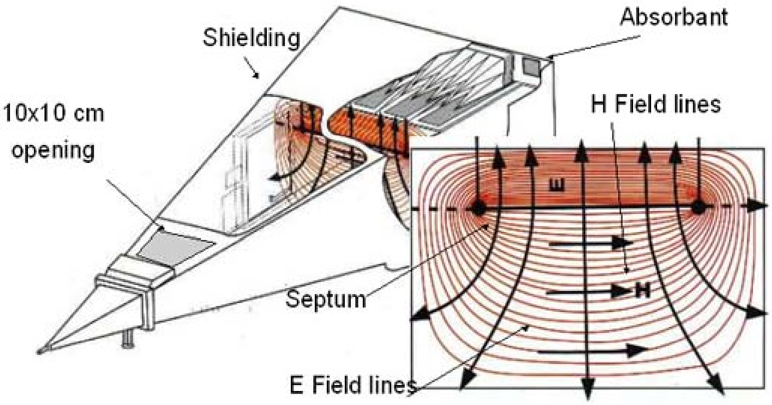
[L. Ardoino et al, "A radio-frequency system for in vivo pilot experiments aimed at the studies on biological effects of electromagnetic fields", Phys. Med. Biol. 50 (2005)3643-3654]

Exposure systems – GTEM cell

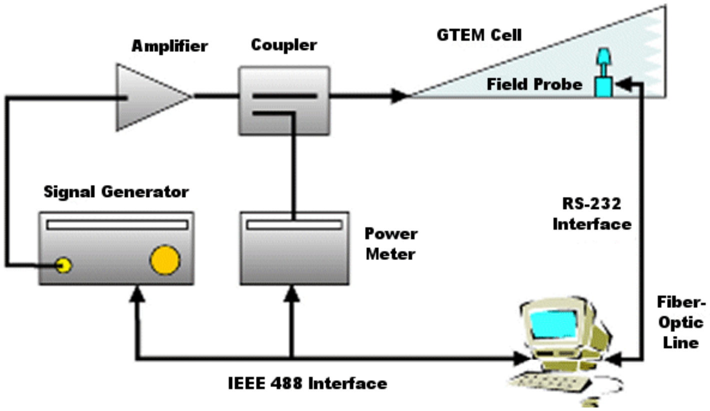
- Is a typical exposure system used for *in vitro* experiments for frequencies above 1GHz and up to 18GHz.
- The GTEM cell is a broadband variant of the TEM cell.
- It consists of a tapered rectangular coaxial transmission line. The inner conductor (the septum) is a flat tapered plate and the outer conductor is a rectangular tube with a cross-sectional area that increases in size along the line.
- The apex of the GTEM cell is connected to an RF pulse generator. UWB pulses propagate longitudinally along the line and are absorbed by low- and high-frequency terminations at the load end. Biological samples containers are placed within the GTEM cell along its bottom surface beneath the septum and are exposed to the propagating fields.
- The absorber material prevents from wave reflection.



GTEM cell structure



Typical E and H field lines inside of a GETM cell

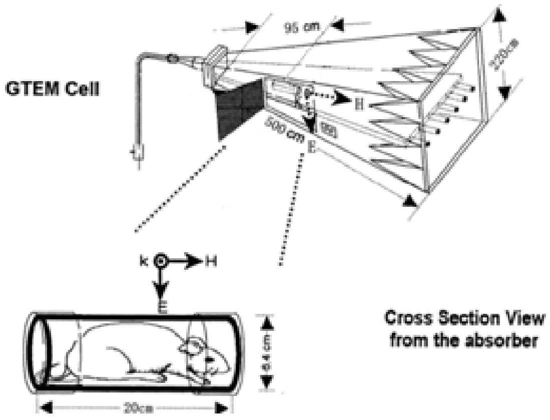


Typical test set-up

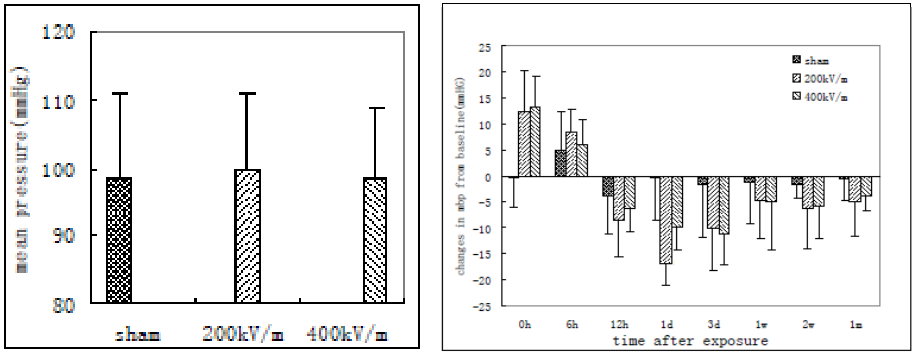
[http://www.evaluationengineering.com/index.php/solutions/emcesd/immunity-testing-considerations.html]

GTEM cell - example

- GTEM cell exposure system was used as an exposure system to study possible biological effects due to EM pulses on the heart rate, systolic, mean and diastolic pressure in rats.
- EM pulse is a special kind of electromagnetic radiation which is produced as short high-voltage pulses with an extremely fast rise, from 0Hz to 1.5GHz.
- EM pulses were generated by a spark gap pulse generator and transmitted into a GTEM cell. In the GTEM cell, there are different electric field intensities at different distances (400kV/m at 10cm and 200kV/m at 95cm) from the source end of GTEM cell. The major axis of the animal was placed parallel with magnetic vector on the ground at 10cm or 95cm from the source end of GTEM cell.
- Three groups of rats were used: one for sham exposure, one for low EM pulse and one for high EM pulse exposure.
- Pre-exposure baseline of heart rate and arterial pressure was determined. Post-exposure measurements were determined from instant to 4 weeks after EM pulse exposure.



Mean pressure (mmHg)



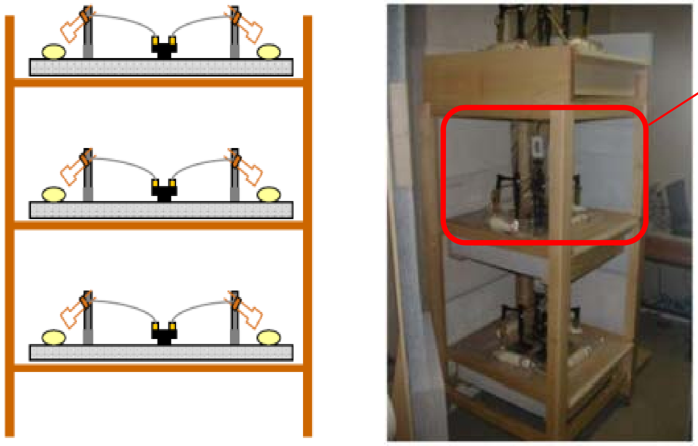
Pre-exposed ***Post-exposed***

With respect to the mean arterial pressure of sham-exposed rats, higher values in exposed rats ware noticed at 0h, and lower values at 1day after exposure.

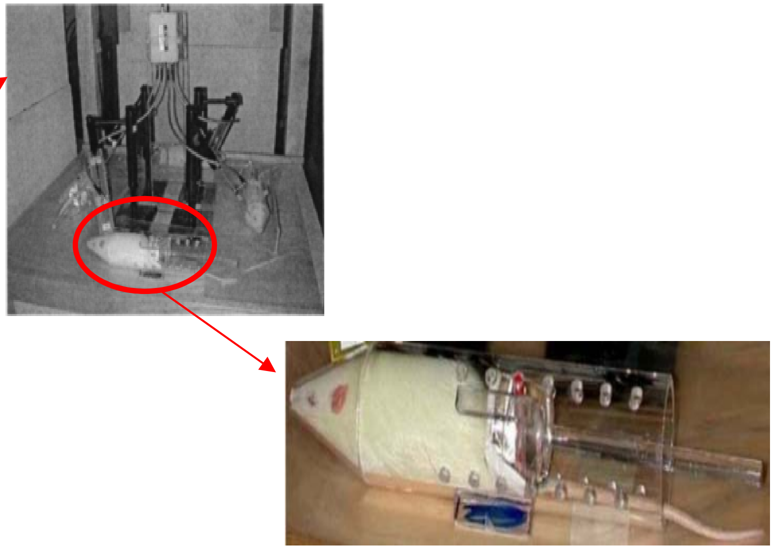
[B.F. Li, G.Z. Guo, D.Q. Ren, J. Li, D.D. Sun, Y. Wan, “Electromagnetic pulses induced fluctuation in arterial pressure without changes in the heart rate in rats”, CEEM, 2006.]

Exposure systems – Rack Loop Antenna Array

- This system can be used in *in vivo* experiments.
- Consists in four loop antennas that allow to expose more samples simultaneously.
- Each antenna is made using the coplanar line technique on dielectric substrate. The near field of such a loop antenna simulates the localized exposure of a biological sample exposed to an EM field.
- The exposure setup is assembled in a wooden rack with three distinct arrays of four loop antennas positioned at different levels. RF absorbing panels were inserted between the levels (and on three sides of the wooden rack) to avoid interference signals involving the biological samples.



The wooden rack, foam panels and loop arrays



Rats used as biological samples

[P. Galloni et al, "Electromagnetic fields from mobile phones do not affect the inner auditory system of Sprague-Dawley rats", Rad. Research 164 (2005) 798-804.]

Rack Loop Antenna Array - example

➢ This system was used to assess potential effects on animals (rats) after exposure to low-intensity electromagnetic fields produced by mobile phones at frequencies of 900MHz and 1800MHz.

➢ The loop antennas were design to operate at 900MHz and 1800MHz. The near field of the loop antenna simulates the localized exposure of a human head exposed to a cellular phone. Each antenna was held perpendicular to the head surface over the ear of animals in contact with the external side of the plastic jig.

➢ Three loop arrays were used: two for real exposure and the third for sham exposure.

Animals: male Sprague-Dawley rats 10 weeks old and 250-300g at the beginning of the experiment

Exposure parameters:
- 2h/day x 5days/week x 4weeks
- frequencies: 900MHz & 1800MHz, GSM modulation

➢ The initial temperature was measured in the absence of power, then a 30s RF pulse was applied. The increased temperature (0.5°C) was measured using a fiber-optic probe.

➢ The maximum SAR measured inside the rat head (5mm from the surface, in the cochlea's location) with an input power of 1W was 4.5W/kg @900MHz, and 5W/kg @ 1800MHz.

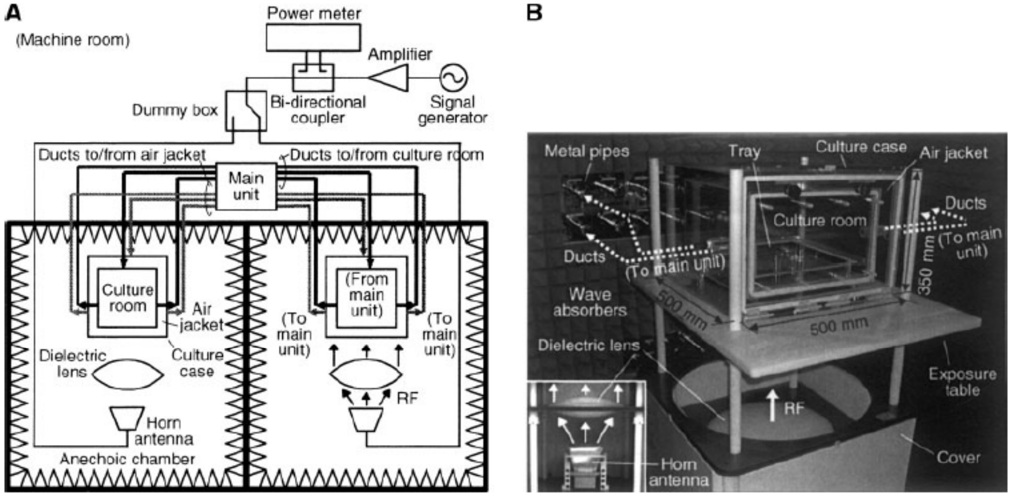
➢ The measured local SAR in a single point that corresponds to the tip of the fiber-optic probe inserted in the cochlea of the rat cadaver:

Frequency [MHz]	**SAR (W/kg)**
900	4.42±1.2
1800	5.5±1.0

[P. Galloni et al, "Electromagnetic fields from mobile phones do not affect the inner auditory system of Sprague-Dawley rats", Rad. Research 164 (2005) 798-804.]

Horn Antenna & Dielectric Lens

- For a simultaneous biological samples exposure, an open type beam formed RF exposure-incubator in an anechoic chamber can be designed. For a stable long term culture condition, a self-contained environmental control unit separated from the RF exposure source is used to supplied air at an appropriate temperature, CO_2 density and humidity to the culture case. Two identical RF exposure-incubators, one for exposure and one for sham exposure are established in separate anechoic chambers.
- The RF exposure source is a horn antenna and a dielectric lens radiates RF upwards. The horn antenna is facing upwards.
- The dielectric lens is constructed of high density polyethylene and is placed above the antenna. It allows RF energy to be focused in the direction of the main beam of the horn antenna.
- The RF exposure source operates at 2142.5 MHz.
- The exposure table constructed of polyester, on which the culture case is set, is above the dielectric lens.
- Usually, except for the horn antenna and RF connectors, the RF exposure source is constructed using materials of low relative permittivity (less than 5).
- The RF signal, which is fed from a signal generator and amplified, is fed to either RF exposure source located in the respective anechoic chamber . The selection of RF exposure or sham exposure is actuated by a mechanical switching in a dummy box. Forward and reflected powers are monitored by a bidirectional coupler, two power sensors and a dual channel power meter. All the equipment, except exposure-incubators, are placed outside the anechoic chambers.



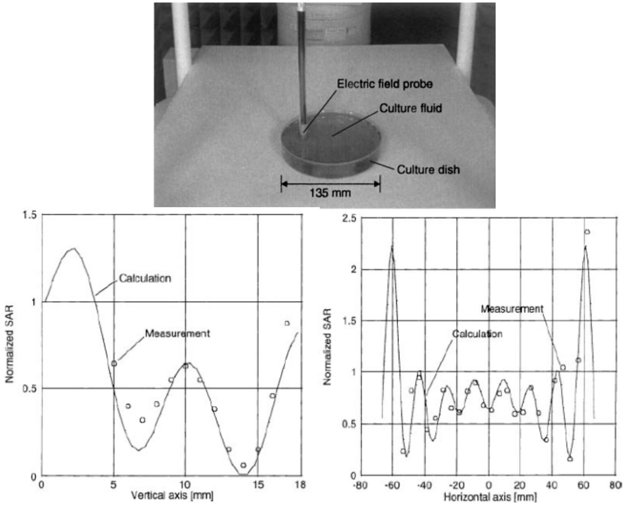
Arrows from the horn antenna indicate the RF travels direction.
A: Schematic diagram of the electrical design and the air circulation in the RF exposure system.
B: Exposure systems photo. Dotted lines indicate the ducts for air circulation. Photograph at the lower left illustrates the inside of the covers of the RF exposure source.

[T. Iyama et al, "Large scale in vitro experiment system for 2GHz exposure", Bioeletromagnetics 25:599-606, 2004.]

Horn Antenna & Dielectric Lens - example

- A horn and lens based exposure system was used for an in vitro experiment at 2142.5MHz (center frequency of IMT2000).
- The horn antenna has an aperture 187x146mm.
- Dielectric lens has diameter of 430mm and is constructed of high density polyethylene, with relative permittivity 2.3.
- The distance between horn antenna and dielectric lens was 450mm.
- The exposure table was made of polyester and was placed at 500mm above the dielectric lens.
- An array of 7x7 of 35mm diameter Petri dishes was used as sample.
- The RF exposure level of the cells was determined as the SAR of the culture fluid at the bottom of the dish. Electric field probe technique was compared with the numerical method FDTD.

Comparison of experimental and numerical SAR distributions in the culture fluid in a large (135 mm diameter) culture dish.



The electric field probe scanned along the central vertical axis in 1mm steps in the culture fluid and along the horizontal axis 10mm above the bottom of the dish, along a 5mm grid in the culture fluid.

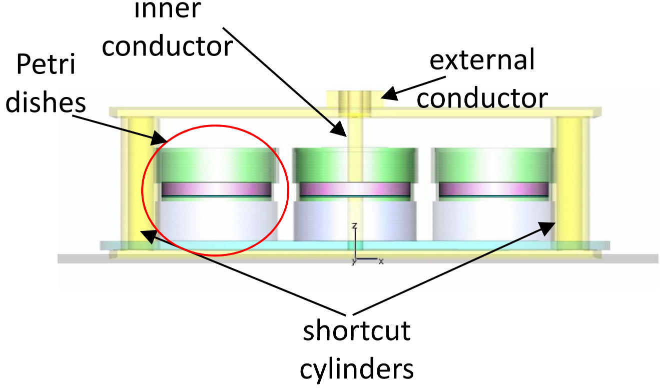
To achieve a mean SAR of 0.08W/kg (the basic restriction for general public exposure recommended by ICNIRP) at the bottom of culture fluid, an antenna input power of 0.46W is required.

[T. Iyama et al, "Large scale in vitro experiment system for 2GHz exposure", Bioeletromagnetics 25:599-606, 2004.]

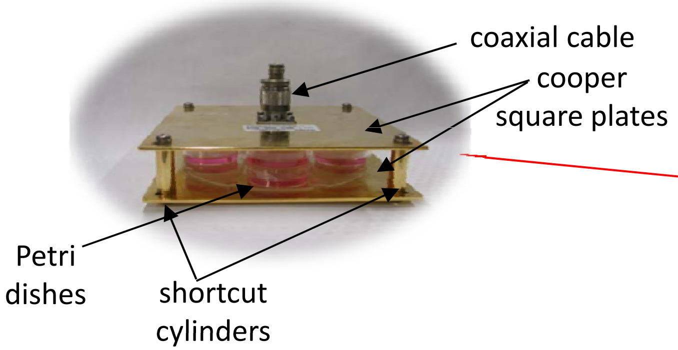
Exposure systems - Wire Patch Cell

- ➢ WPC was designed to expose cell cultures during *in vitro* experiments.
- ➢ Must operate in micro-clime controlled conditions that ensure the cell cultures survival: 37°C, 5% CO_2, and humidity conditions at saturation.
- ➢ It is placed in a standard incubator where the environment conditions can be easily controlled.
- ➢ Is based on a wire patch antenna with a highly homogeneous field inside the antenna cavity.
- ➢ The designed cell structure is symmetric and provides a rather homogeneous field distribution in a large area around its centre.
- ➢ Consists in two parallel square plates (the ground plane and roof), of the same size, spaced apart using four metallic grounding contacts (shortcuts metallic cylinders) located at each corner of the cell.
- ➢ A coaxial cable is used as feeding: the external conductor is connected to the upper plate, while the inner conductor is connected to the bottom plate.
- ➢ It allows a simultaneous exposure of four Petri dishes at an electric field orthogonal to the square metallic plates.
- ➢ To avoid interference with the incubator control system and unwanted reflections on the internal walls, each device is inserted into a shielded cage with absorbing walls

WPC schematic view



Wire Patch Cell (WPC)

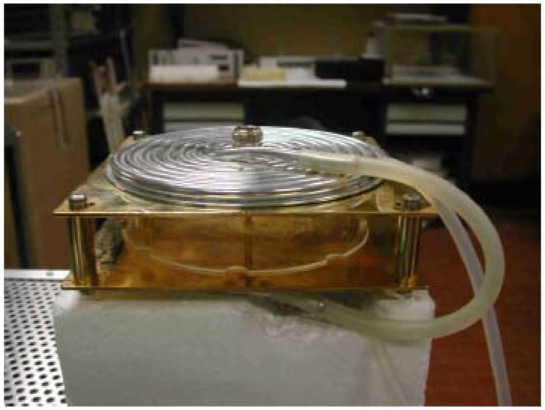


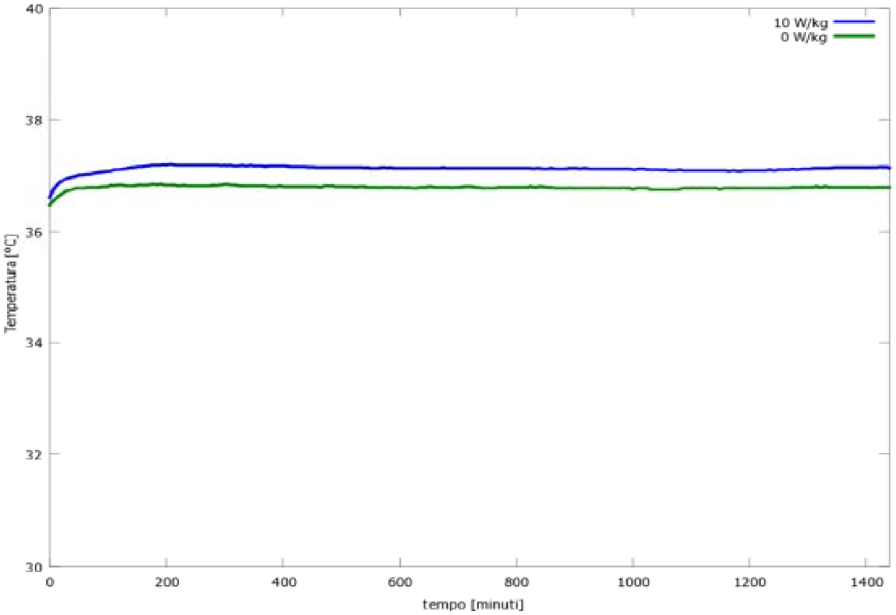
Incubator

[M. Sarti, "Elettromagnetismo computazionale e bioelectromagnetismo"]

Thermal control

- A thermal control system is necessary to avoid temperature increases in the WPC due to high level SAR exposure.
- It consists in two metallic spirals, in which water is flowing, are place on the external surface of the WPC.
- <u>Example</u>: mean temperature in the Petri dishes: 36.8-37.1°C for 0 and 10W/kg.



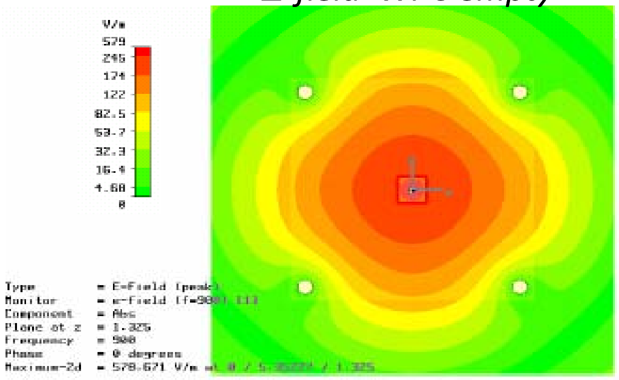


[M. Sarti, "Elettromagnetismo computazionale e bioelectromagnetismo"]

E & *H* fields in WPC: numerical results

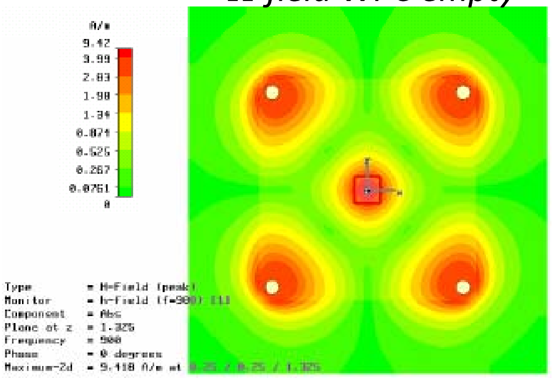
- ➢ WPC was used to expose cell cultures during *in vitro* experiments to study possible effects of mobile phones.
- ➢ The wire patch antenna were designed to work at 900 MHz (or 1800MHz).
- ➢The two parallel square plates had the same size: 15x15cm^2 at 900MHz or 20x20cm^2 at 1800MHz, and were spaced 2,9cm apart using four shortcuts metallic cylinders. Four Petri dishes of 3.5cm diameter each were used for a simultaneous exposure.

E-field WPC empty



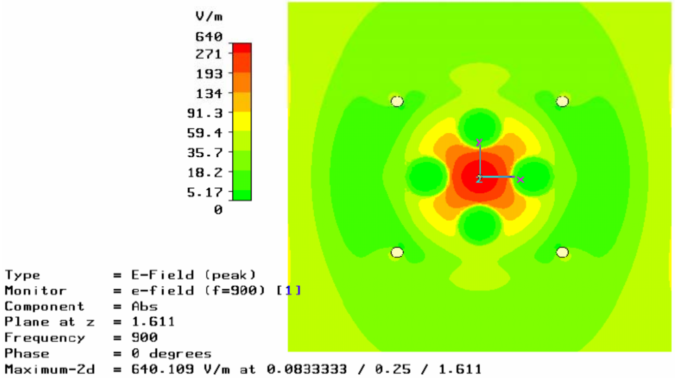
```
Type         = E-Field (peak)
Monitor      = e-field (f=900) [1]
Component    = Abs
Plane at z   = 1.325
Frequency    = 900
Phase        = 0 degrees
Maximum-2d   = 579.671 V/m at 0 / [illegible] / 1.325
```

H-field WPC empty



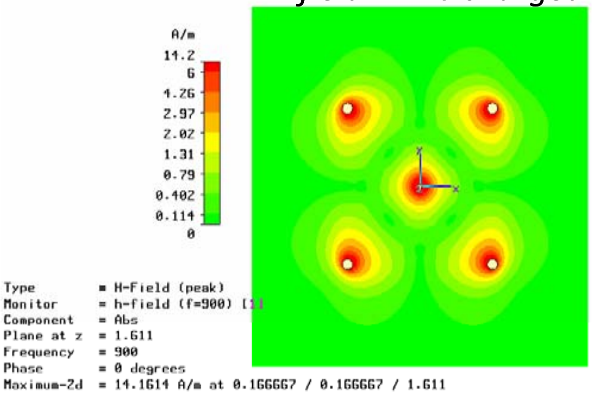
```
Type         = H-Field (peak)
Monitor      = h-field (f=900) [1]
Component    = Abs
Plane at z   = 1.325
Frequency    = 900
Phase        = 0 degrees
Maximum-2d   = 9.418 A/m at 0.25 / 0.25 / 1.325
```

E-field WPC charged



```
Type         = E-Field (peak)
Monitor      = e-field (f=900) [1]
Component    = Abs
Plane at z   = 1.611
Frequency    = 900
Phase        = 0 degrees
Maximum-2d   = 640.109 V/m at 0.0833333 / 0.25 / 1.611
```

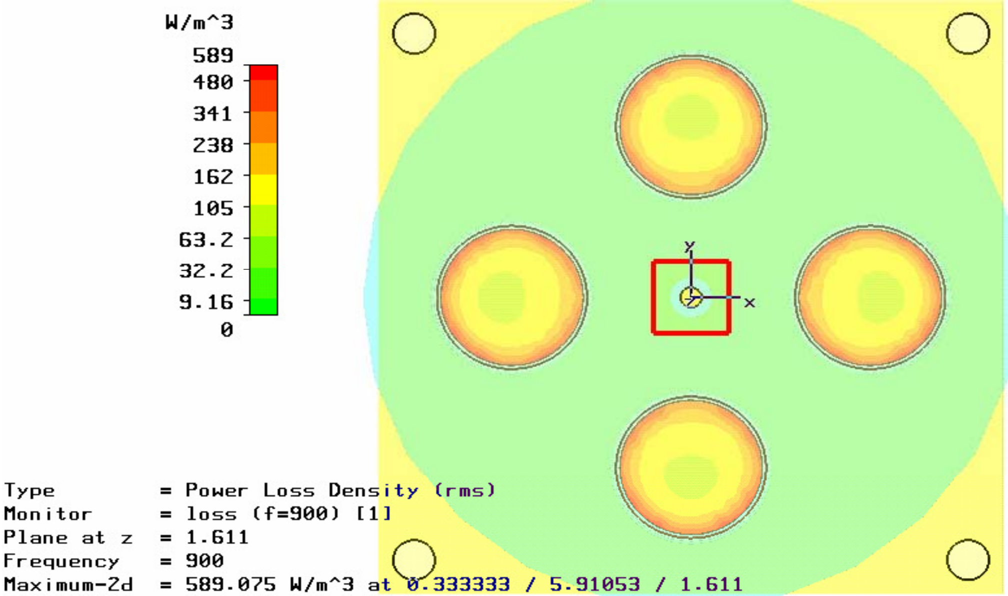
H-field WPC charged



```
Type         = H-Field (peak)
Monitor      = h-field (f=900) [1]
Component    = Abs
Plane at z   = 1.611
Frequency    = 900
Phase        = 0 degrees
Maximum-2d   = 14.1614 A/m at 0.166667 / 0.166667 / 1.611
```

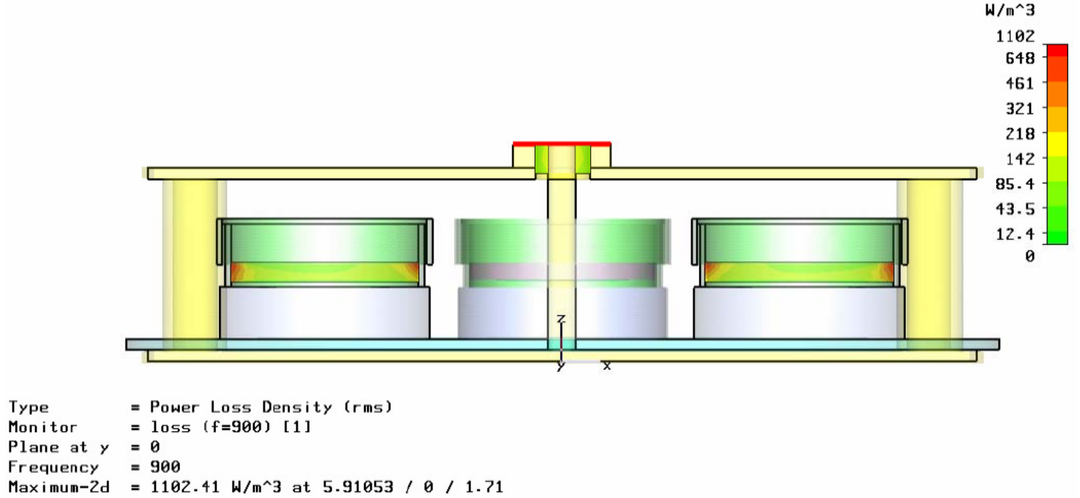
[M. Sarti, “Elettromagnetismo computazionale e bioelectromagnetismo”]

ABSORBED POWER DENSITY



```
Type          = Power Loss Density (rms)
Monitor       = loss (f=900) [1]
Plane at z    = 1.611
Frequency     = 900
Maximum-2d    = 589.075 W/m^3 at 0.333333 / 5.91053 / 1.611
```

- ✓ **The absorbed power density is maximum at the Petri dishes border, and becomes minimum in its center**

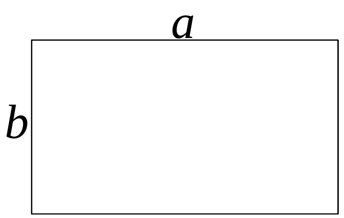


```
Type          = Power Loss Density (rms)
Monitor       = loss (f=900) [1]
Plane at y    = 0
Frequency     = 900
Maximum-2d    = 1102.41 W/m^3 at 5.91053 / 0 / 1.71
```

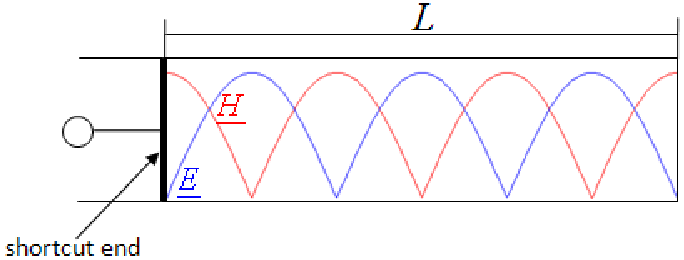
[M. Sarti, "Elettromagnetismo computazionale e bioelectromagnetismo"]

Shorted Waveguide

- To study possible effects at high frequency fields a shorted rectangular waveguide can be designed.
- It consists in a metallic shorted rectangular waveguide.
- At one end it is ended by a mobile shortcut, which allows to vary the resonance frequency.



Transverse section of a rectangular wave guide



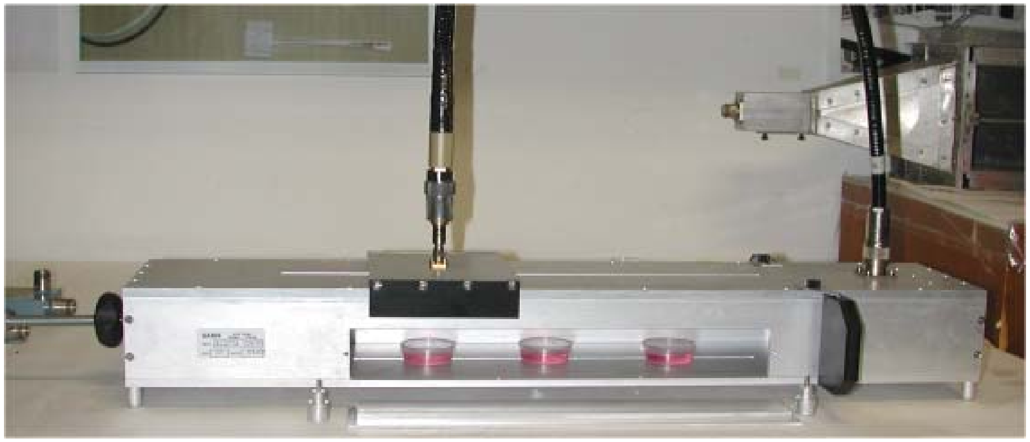
Sagittal section of a rectangular wave guide

$$L = N\frac{\lambda_g}{2}$$

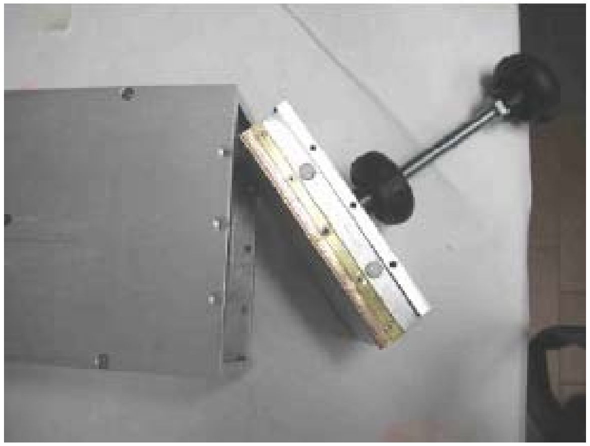
$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{f_t}{f}\right)^2}} \longrightarrow \text{guide wavelength}$$

$$f_t = \frac{c}{2a} \longrightarrow \text{cut-off frequency}$$

$$c = 3\cdot 10^8\, m/s$$



Shorted waveguide with Petri dishes

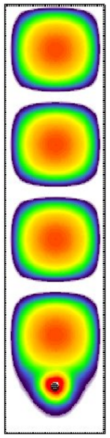


Mobile shortcut

[M. Cavagnaro, "Dosimetria dei campi elettromagnetici"]

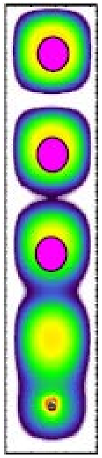
E, *H* fields & *SAR* distributions in a shorted waveguide

- To study the possible effects of mobile phones in the UMTS frequency range (1.8-2.2GHz), an aluminum 15.2cmx5.6cmx51.6cm shorted rectangular waveguide was designed.

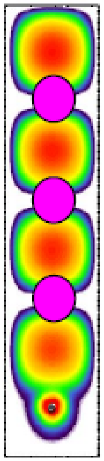


E-field in an empty waveguide structure

- The electric field shows a stationary plane wave distribution, with maximum and minimum. It results that the Petri dishes can be placed in a maximum of the electric or magnetic field.



E-field distribution when Petri dishes placed in a maximum of the E-field

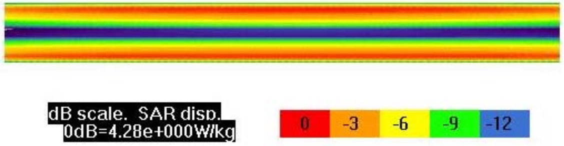


E-field distribution when Petri dishes placed in a maximum of the H-field

<u>Consider</u>: a vertical plane crossing the Petri dishes center, when these are placed in a position corresponding to the maximum of the electric or magnetic field

SAR distribution: Petri dishes are placed in a maximum of the E- field

SAR distribution: Petri dishes are placed in a maximum of the H- field



- When the Petri dishes are placed at a magnetic field maximum, it can be noticed a non-uniform *SAR* distribution.
- These distributions are important in the study of EM field effects on lymphocyte cells- that remain on suspension, or on neuronal cells- that lay on the bottom of the dishes.

[M. Cavagnaro, "Dosimetria dei campi elettromagnetici"]

Exposure systems comparison

- Exposure systems can be compared as a function of the structure efficiency

$$\eta = \frac{SAR}{P_{abs}} \qquad P_{abs} = P_{in} - P_{refl}$$

Exposure systems classification as a function of: biological sample, frequency and exposure efficiency

		In vivo systems		***In vitro systems***	
		TEM cell	***Loop***	***WPC***	***Shorted Waveguide***
Biological sample		Mice	Rats	Cell cultures	Cell cultures
Frequency [MHz]		900	900 1800	900 1800	1800 2200
Efficiency $\left(\frac{\frac{W}{kg}}{W}\right)$	Numerical	0.44	5.5	0.3	-
	Experimental	0.8±1dB (homogeneous phantom) 0.4±0.5dB (mice)	4.5±1dB (900MHz)	0.41±1dB (900MHz)	15±0.5dB (1800MHz)

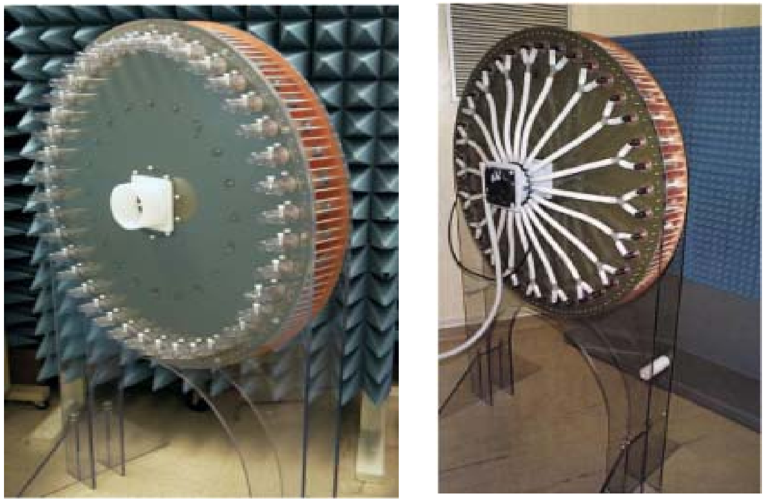
! The highest efficiency is obtained with the shorted waveguide due to its resonance properties.

[L. Ardoino, R. Pinto, S. Mancini, G.A. Lovisolo, F. Apollonio, G.D. D'Inzeo, "Progetto e realizzazione di sistemi espositivi per esperimenti biologici"]

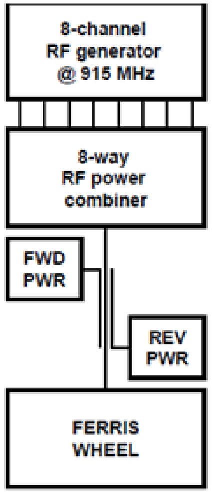
Dosimetric study using Ferris-Wheel exposure system

- The Ferris-Wheel consists in a radial cavity where an electromagnetic field is excited by means of a tunable feeder placed at the geometrical center.
- The radial cavity is formed by parallel circular plates mounted on a polycarbonate frame, joined around the perimeter by an array of shorting posts. The plates are separated by a 10cm long hollow Teflon cylinder about 10cm radius and 1.8cm thick.
- A tunable transition from a 50- coaxial feed line excites a cylindrical TEM wave that impinges on a carousel of 40 symmetrically arranged biological samples, which are equidistant from the exciter. The long axis of the sample container is co-polarized with the incident E-field to maximize the absorption of RF energy.
- The symmetric arrangement provides uniform exposure to the samples, while the whole-body TEM illumination induces fairly uniform RF absorption within each sample.

Ferris-Wheel exposure system



with airflow system

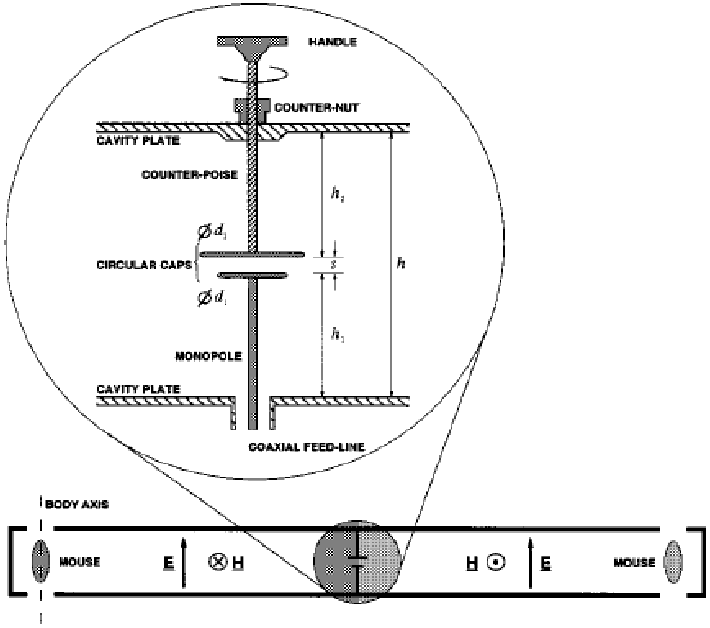


Typical set-up

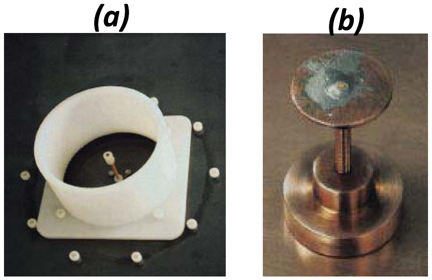
[Q. Balzano et al, "An efficient RF exposure system with precise whole-body average SAR determination for in vivo animal studies at 900MHz", IEEE trans. On MTT, vol. 48, no. 11, November 2000.]

Tunable coax-to-radial cavity transition

- Tuning ability of the cavity exciter is desired to ensure proper matching to the RF source over a relatively wide range of possible loading conditions. A tunable transition from the coaxial feed line to the radial cavity is required to maximize the modal conversion to the fundamental cavity mode by keeping the exciter's current as uniform as possible.
- The transition is formed by a top-loaded monopole antenna capacitively coupled with a passive counterpoise.
- The accumulation of electric charges is concentrated in the small region comprising the capacitive loads so that the current along the monopole as well as the counterpoise is kept fairly uniform.
- Tuning of the loaded cavity is performed through adjusting the capacitive coupling by moving the counterpoise closer or farther from the monopole, which is easily accomplished by threads on its arm. A plastic counter-nut ensures good electrical contact of the counterpoise with the cavity plate.



Sketch of the tunable transition from the coaxial feed line to the radial cavity.

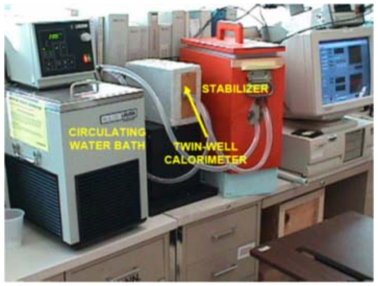


Tunable transition: (a) Tuner handle with hollow Teflon cylinder (cap not shown) protecting from inadvertent crash. (b) Tuning element with mechanical support.

[Q. Balzano et al, "An efficient RF exposure system with precise whole-body average SAR determination for in vivo animal studies at 900MHz", IEEE trans. On MTT, vol. 48, no. 11, November 2000.]

Dosimetric study using Ferris-Wheel exposure system

- The Ferris-Wheel dosimetry results can be used to estimate RF exposure levels experienced by the mice over long time exposure period.
- 1200 mice were exposed to pulsed RF energy at 900MHz.
- Twin-well calorimetry was employed to measure the SAR_{WB} of mice for three body masses: 23g, 32g and 36g.
- A differential twin-well calorimeter technique was used to determine the SAR_{WBAV} . The twin-well calorimeter allows differential heat measurements between samples (exposed and sham) of very similar mass. The difference in the heat exchanged with constant temperature envelope of the calorimeter was determined by measuring and integrating over time the output voltage, which is produced by a thermocouple. The calorimeter envelope was kept at a constant temperature by means of a circulating water bath.



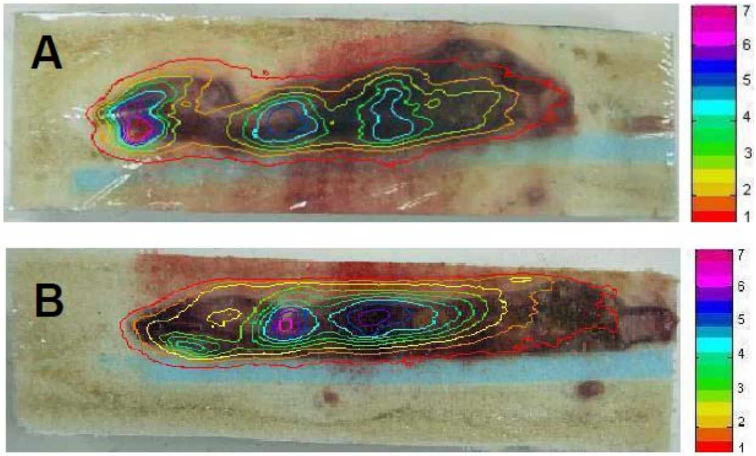

Twin-well calorimetry

- Before exposure, one mouse cadaver was placed in the wheel and one mouse in a “sham” restrainer identical to those employed in Ferris-Wheel. Input power: 280-300W, corresponding to SAR_{WB} in the range of 200-300W/kg depending on the collective mass of mice (0.92-1.45kg), for 30s (to induce an average whole-body temperature increase of 1.5-3°C).
- Immediately after exposure, both mice were simultaneous transferred to the calorimeter. The output voltage was collected at 2s sampling interval.

[A. Faraone et al, “RF dosimetry for the Ferris-Wheel mouse exposure system”, Motorola Labs - Final Report, August 2004.]

SAR distribution

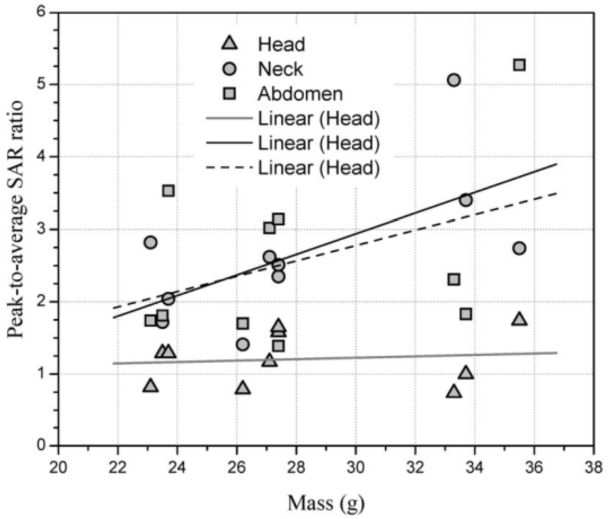
- Infrared thermography provided *SAR* distributions over the sagittal plane of the mouse cadaver.



Temperature distribution measured over the sagittal plane of 24-g mouse cadavers exposed at the top (A) and the bottom (B) locations on the Ferris-Wheel. Temperature isolines are superimposed on the photographs taken before exposure. The scale is in degree Celsius.

- three “hot spots” regions were noticed: they correspond to an area in the head, where highly conductive high-water content tissues are found; an area in the neck, due to high current density induced by the narrowing of the current path; and in the abdomen due to eddy currents.
- this qualitative information was used to select the locations where “RF-transparent” thermometers were placed to perform absolute measurements.

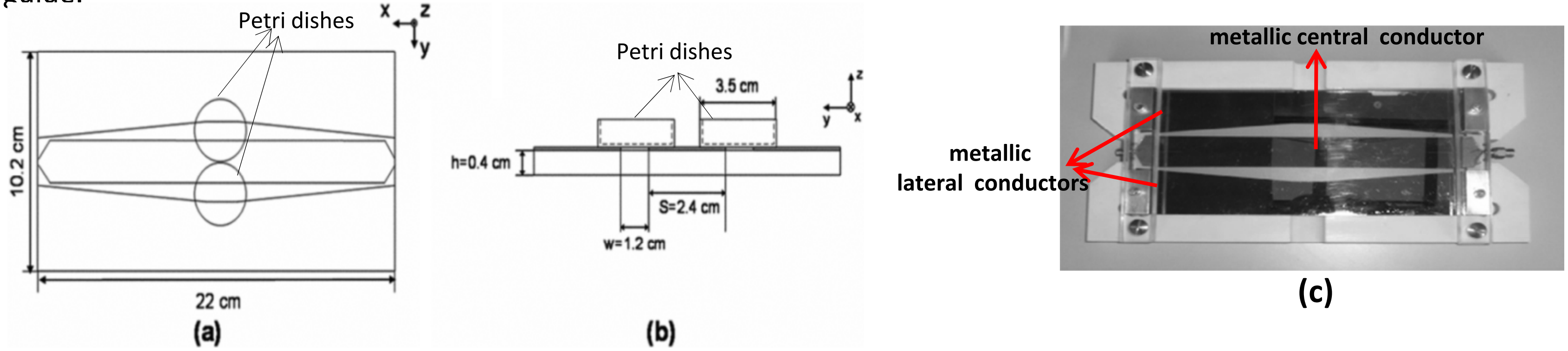
- Temperature sensors were used to determine the local *SAR* in areas of the sagittal plane where thermographic images showed exposure peaks consistently.
- Peak-to-average SAR ratios measured at the hot-spots in the head, neck, and abdomen, of ten mouse cadavers:



[A. Faraone et al, “RF dosimetry for the Ferris-Wheel mouse exposure system”, Motorola Labs - Final Report, August 2004.]

Coplanar Waveguide Exposure System

- Coplanar waveguide (CPW) exposure system is a real-time radiating system. Its design appeared as a consequence of studies of children exposure to low-level EM fields to evaluate possible adverse effects on brain and cognitive functions (learning, memory). The brain slice is the most prevalent and known *in vitro* structure for electrophysiological investigations.
- The recording of brain slice neuronal activity has to be performed during EM exposure (real-time acquisition) and requires the presence of two electrodes, one for stimulating and one for recording, and the use of a microscope for good positioning of the electrodes within the slice. Homogeneous field distribution is required.
- The open structure allows easy access to the samples, and the fundamental quasi-TEM mode propagating in the structure, with the E-field parallel to the sample and minimizes interferences with the electrodes. Its configuration allows a sample to be exposed to an EM dose with up to 60% higher uniformity.
- The stimulating electrode is metallic, and the recording ones is an Ag/AgCl wire inserted in a glass micropipette filled with saline solution.
- The CPW needs to avoid losses both due to radiation and dissipation in the dielectric substrate, and a good impedance matching with a 50-load. These requirements are controlled by the dimensions of the openings between the central and the two lateral conductors, the width of the central conductor, the thickness, and the dielectric constant of the substrate.
- Two perfusion chambers are needed, one for each exposure window in the CPW. The two chambers preserve the symmetry of the field distribution in the structure and provide the possibility of online temperature monitoring.
- The thickness of the dielectric substrate (of thickness h) needs to guarantee the absence of losses due to dissipation in the dielectric (soda-lime glass plate is usually used).
- The CPW dimensions need to be tapered to those of the coaxial cable for impedance matching. The axis of the cable coincides with the axis of symmetry of the central conductor in order to have the field in the cable perfectly coaxial with the one propagating in the guide.



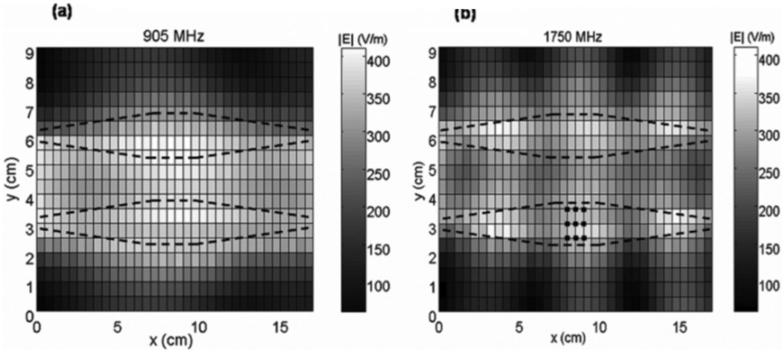
(a) Top view and (b) frontal view of the exposure system with the two perfusion chambers on it. (c) Exposure system

[A. Paffi et al, "A real-time exposure system for electrophysiological recording in brain slices", IEEE Trans. On MTT, 55 (11), 2007.]

E and H field distributions

➢CPW was designed for studies at 905, 1750 and 1950MHz – uplink band for GSM900, GSM1800 and UMTS, and some parameters are reported:

Parameters	Values
width of the exposure window: w	1.2 cm
width of the central conductor: S	2.4 cm
thickness of the substrate: h	0.4 cm
total width: D	10.2 cm
total length: l	22 cm
substrate permittivity: ε_r	5.5

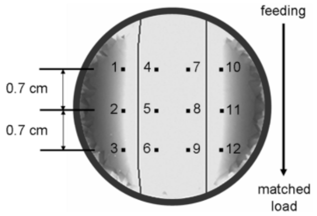


Surface map of the E-field values at a distance of 0.5 cm from the CPW: a) 905MHz and (b) 1750MHz. The exposure windows are represented by black dashed lines. The biological sample is positioned to correspond to the nine points indicated in the center of the exposure zone (b).

➢*SAR* distribution was obtained by measurements on 3.5cm Petri dishes filled with physiological solution.

➢Temperature measurements (in different points) were carried out using thermistors and *SAR* was determined for an input power of 2.5W. To quantify the real dose absorbed by the slice, the efficiency was calculated particularly from measurements of middle points, where it is assumed that the slice is positioned.

Temperature measurement points in the Petri dish.



Points	ΔT (°C)	SAR (W/kg)
4	0.254±0.003	50.42
5	0.348±0.004	69.11
6	0.340±0.005	67.52
7	0.269±0.008	53.53
8	0.350±0.012	69.51
9	0.345±0.010	68.64

Efficiency ((W/kg)/W)	905MHz		1750MHz	
	Point 5	Point 8	Point 5	Point 8
	28.1	25.4	73	79

[A. Paffi et al, "A real-time exposure system for electrophysiological recording in brain slices", IEEE Trans. On MTT, 55 (11), 2007.]

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