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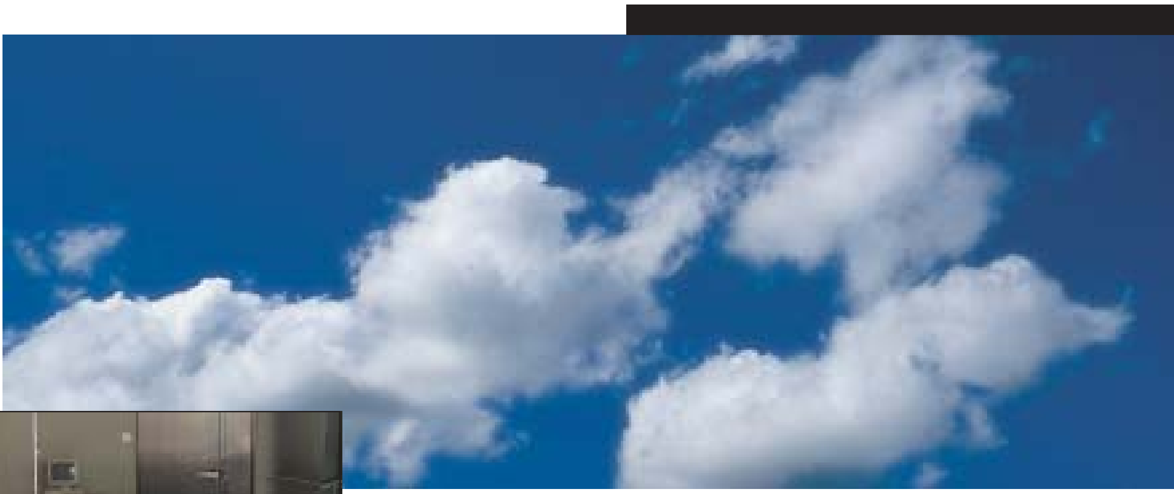

Joachim Streckert

Technical equipment requirements in investigations of radiofrequency electromagnetic field effects on biological systems

Lecture held during the scientific symposium in Berlin, September 19th, 2002, on occasion of the ten-year anniversary of the Forschungsgemeinschaft Funk e.V. (FGF - Research Association for Radio Applications)

Forschungsgemeinschaft Funk

Editorial

On occasion of its 10-year existence, the FGF hosted a scientific symposium in Berlin.

Due to the very positive feedback after the symposium and the requests for the manuscripts of the lectures, we asked the lecturers to submit more detailed versions of their lectures. Four contributions provided inventories from the perspective of experts from different disciplines.

The introductory lecture of this symposium was held by Prof. Roland Glaser: "The situation of research on potential dangers from electromagnetic fields." This lecture is found in the festschrift on the ten-year celebration of the FGF. The expanded versions of the other lectures will also be made available in the series "Edition Wissenschaft". The series begins with the lecture on technical requirements of radiofrequency exposure systems.

The thermal effects of concentrated radiofrequency radiation are widely known: biological tissue is heated and can even be destroyed at very high intensities. The threshold for thermal effects can be exactly determined and is used to derive maximally permitted exposure limits for electromagnetic quantities that may not be exceeded by technical applications. With the use of mathematical models, the heat input can even be theoretically anticipated.

Beside thermal effects, discussion evolves around other possible effects below thermal efficacy. Since no reproducible evidence for biological effects from weak electromagnetic fields has been found until today, despite several years of research, mathematical models describing such mechanisms could not be developed either. The only possibility to reach objective conclusions is to carefully perform scientific experiments under clearly defined framework conditions.

More than ten years ago, the Forschungsgemeinschaft Funk e.V. has begun to initiate research projects in this area and to financially promote their performance by independent research institutes.

Experiments on biological effects from electromagnetic fields primarily focus on the biological/medical test design. But for conducting experiments on radiofrequency exposure of the involved objects taking place under clearly defined conditions, a deepened electrical engineering knowledge is required when the aim is, for example, to reach a desired spatial distribution of the electromagnetic field across all exposed samples.

The report of Dr. Joachim Streckert, who opens the lecture series of the Edition Wissenschaft, provides examples from the area of mobile radio to depict the elaborate requirements that must be met by engineering sciences (especially "radiofrequency technology") regarding the technical equipment used in experiments for the investigation of effects from radiofrequency electromagnetic fields on biological systems.

Yours,

Gerd Friedrich

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Dr. Joachim Streckert

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Introduction

The question of potential adverse or even damaging impact on biological systems from electromagnetic fields is widely discussed all over the world. The only non-controversial, provable and reproducible mechanism known so far is heat production in biological systems, i.e. the so-called “thermal effects“. By using mathematical models, i.e. relations expressed in formulas, the heating of cellular tissue can also be theoretically predicted.

Beyond this, there are public concerns especially about the use of radio applications, like e.g. mobile radio, due to the suspicion that effects or damages may also occur <u>below</u> thermal efficacy. Since there is no reproducible proof of biological effects from weak electromagnetic fields yet, despite several years of research, mathematical models describing such mechanisms and allowing further investigation at the theoretical level could not be developed either. So we have to continue to rely on observations making sense only when derived from scientific experiments carefully performed under clearly defined frame conditions. This approach is professionally and technically demanding and expensive. However, in view of the existing controversies which often are also characterized by a lack of objectivity – as is reflected in media coverage –, it is the only possibility to come to objective conclusions.

The focus of experiments investigating biological effects of electromagnetic fields is primarily the biological/medical test design, as well as the question which objects (e.g. tissue cells, small animals or test persons) will be exposed, and which parameters (e.g. membrane currents, tumor promotion or response capacity) will be examined. A deepened electrical engineering knowledge is required, though, in order to perform radiofrequency exposure of the biological objects involved in the experiment under clearly defined conditions, for example to achieve a desired spatial distribution of the electromagnetic field across all samples in an exposure system, or to calculate the radiofrequency transmission power required for a given exposure strength at a given frequency or signal shape.

Using examples from the area of mobile radio, this contribution will describe the solutions offered by engineering sciences to optimize radiofrequency exposure systems for different biological objects regarding replicability and uniformity of the applied electromagnetic fields.

Exposure of biological objects

In general, a radiofrequency exposure system – as shown in figure 1 – consists of a radiofrequency signal generator, in most cases followed by a power amplifier, the exposure unit for the biological test objects itself, for example comprising a measurement room with an antenna, or either a small measurement chamber with appropriate feeding, and of a defined absorbing or reflecting material at its end. Nowadays, parallel tests comprising a control group located in an equivalent exposure setup without radio-frequency signal (so-called sham exposure) are mandatory.

The generator produces the radio-frequency signal modulated by a typical mobile radio signal at a carrier frequency in the range of the simulated radio system (e.g. 900 MHz for GSM (D1/D2-net), 1800 MHz for GSM (E-net), or 2000 MHz for UMTS). As signal parameters can be arbitrarily varied, standard signal patterns for biological experiments with GSM and UMTS signals were developed by FGF working groups. Figure 2 and 3 show schematic diagrams of the time and spectral courses of these GSM and UMTS signals. A detailed description of the generic UMTS signal is found in [Streckert et al. 2001, Ndoumbè et al. 2004].

The amplifier following the generator elevates the signal to the power level required for the experiment.

Among other things, the exposure setup shall provide clearly defined and reproducible fields. From the perspective of radiofrequency

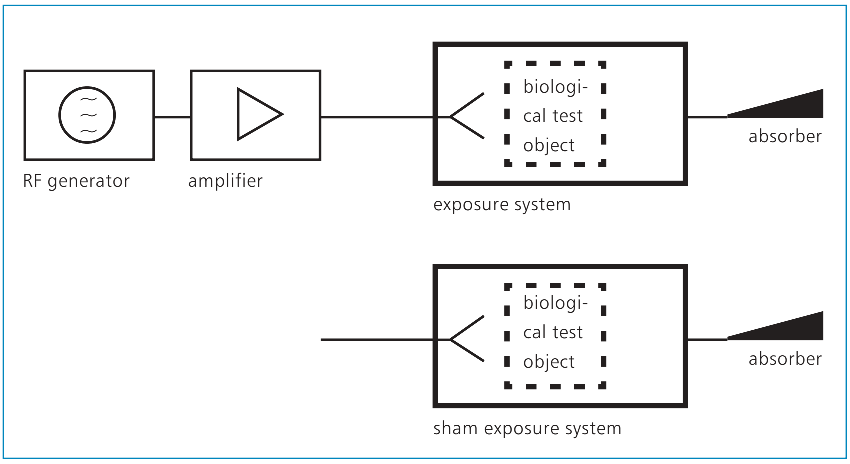

Figure 1: Schematic diagram of an exposure system

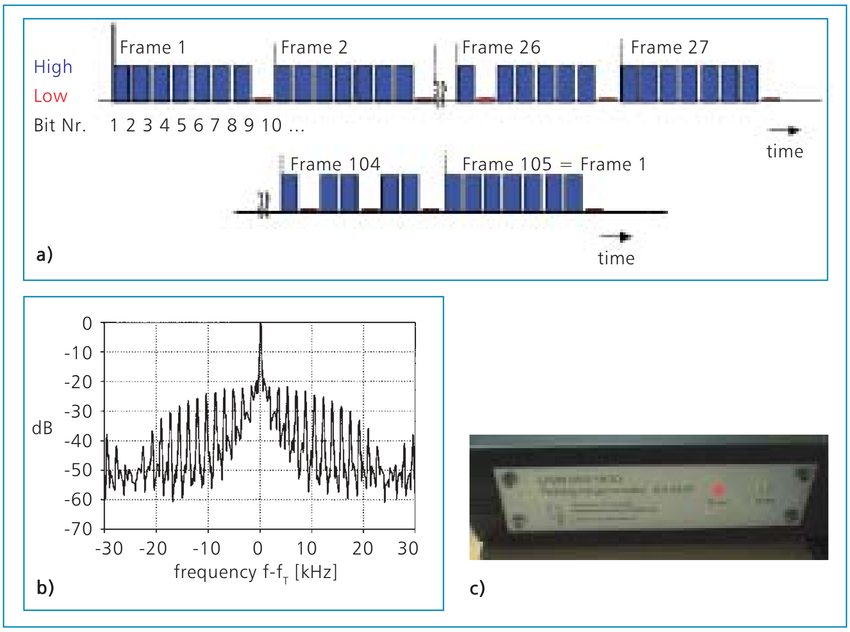

Figure 2: Generic GSM test signal

a) temporal modulation scheme of the radiofrequency carrier

b) frequency spectrum around the carrier frequency f_T

c) view of the modulation signal generator developed on behalf of the FGF

Requirements of radiofrequency exposure systems
Volume sufficient for measurement
Shielding against external fields
Generation of clearly defined field distributions at the test object
Equivalent exposure of all objects/volunteers
Input of light, air, nutrients, heat, etc.
Integration of measurement equipment, etc.

Table 1: Required characteristics of exposure systems

technology, this implies above all to avoid uncontrollable interferential effects due to multiple reflections or superpositions with non-desired waveforms, as well as taking protective measures against external field influences (see table 1).

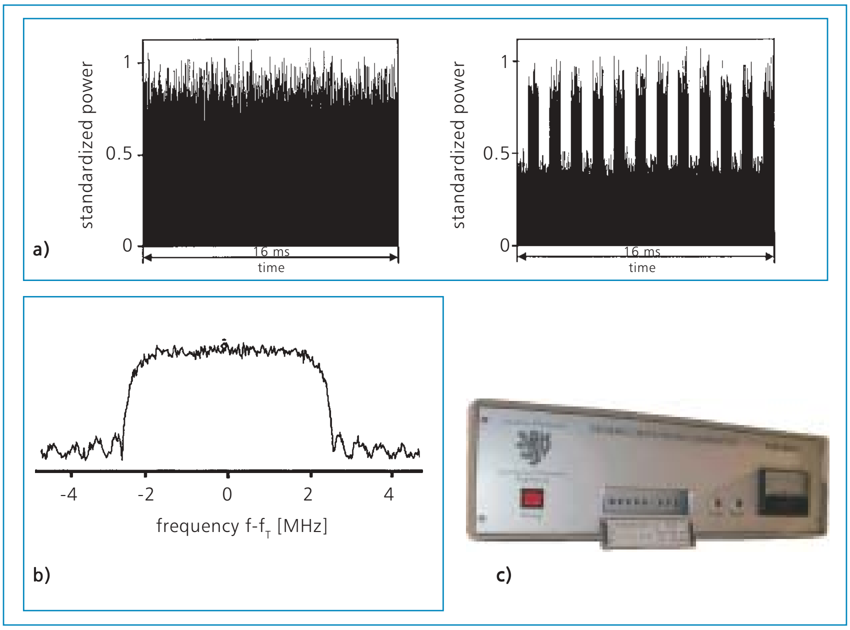

Figure 3: Generic UMTS test signal

a) segments of the time course of the radiofrequency signal

b) frequency spectrum around the carrier frequency f_T

c) view of the RF signal generator developed on behalf of the FGF

A variety of designs can be used for the exposure system, depending on the size and number of the measurement objects. Closed measurement cells are to be preferred for small sample volumes; due to their dimensions as a waveguide, they are developed for the frequency range of basic modes with solid, characteristic field distributions.

The application of linear measurement cells, such as rectangular waveguides (figure 4), has its limitations when many samples are to be exposed at the same time. The exposure of the individual samples, due to shadowing effects, will become too irregular. In such cases, e.g. a radial waveguide can be applied (figure 5). In principle, its diameter can be arbitrarily adapted to the number of measurement objects. It too can be designed as a closed measurement cell shielded against external radiofrequency fields.

If the dimensions of test objects are distinctly larger than one-half wavelength, one can only use rooms with absorber lining ('anechoic chambers') for exposure that are additionally equipped with metal shielding (figure 6). The RF field is generated via an antenna system inside the measurement chamber, so the field distribution obviously does

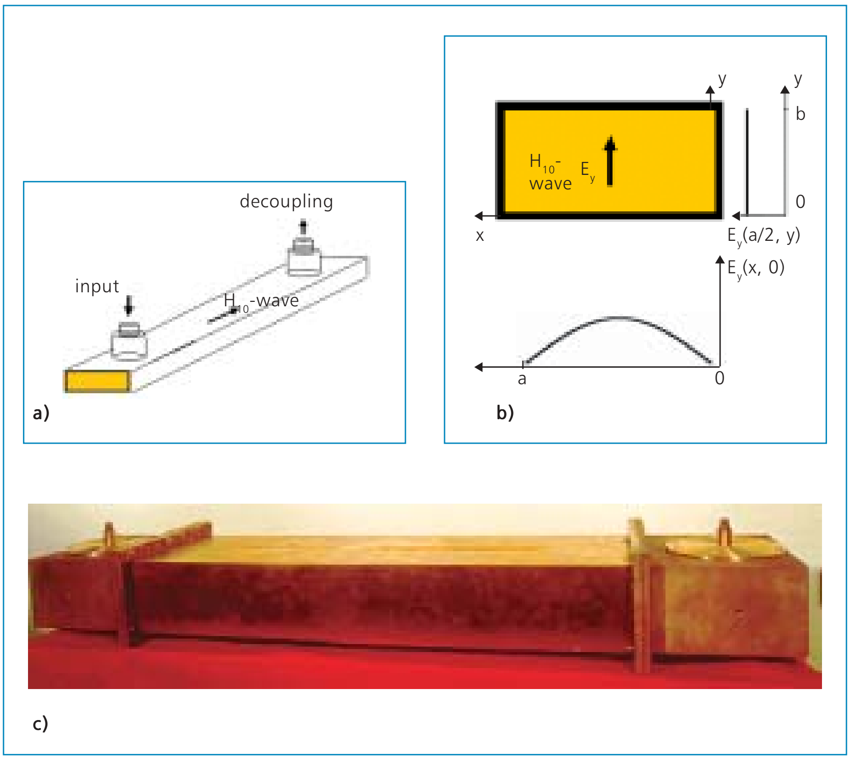

Figure 4: Rectangular waveguide

a) standard setup

b) transversal field distribution of the fundamental mode

c) waveguide – example

not solely depend on the properties of the room but also on the specific antenna configuration.

The development of an appropriate exposure system for a specific experiment happens through several steps:

1. Regardless of number and size of the measurement objects, the first step is the optimization of the empty exposure setup. The purpose of this step is to create an electromagnetic field above the whole subsequent exposure volume, with a clearly defined (in most cases as homogeneous as possible) spatial distribution. Field amplitudes are controlled by the input power only. For resolving the problem of the electromagnetic field, analytical and/or numerical methods of calculation are applied which are supported by measurements of the empty field at the installed exposure setup.
2. In the second step, the biological measurement objects are considered. Since most biological matters are dielectrics with intrinsic loss which, moreover, are often tied to very inhomogeneous structures, only numerical methods can be applied for the dosimetrical analysis. Especially the Finite Difference Method [Taflove and Hagness 2000] on the temporal dimension has shown to be adequate for biological arrays. In most cases, a purely metrological approach with field probes mostly does not apply for different reasons (falsification of field, sterility, destruction of the tissue).

If the fields penetrating the biological objects are known, the specific absorption rate too can be determined:

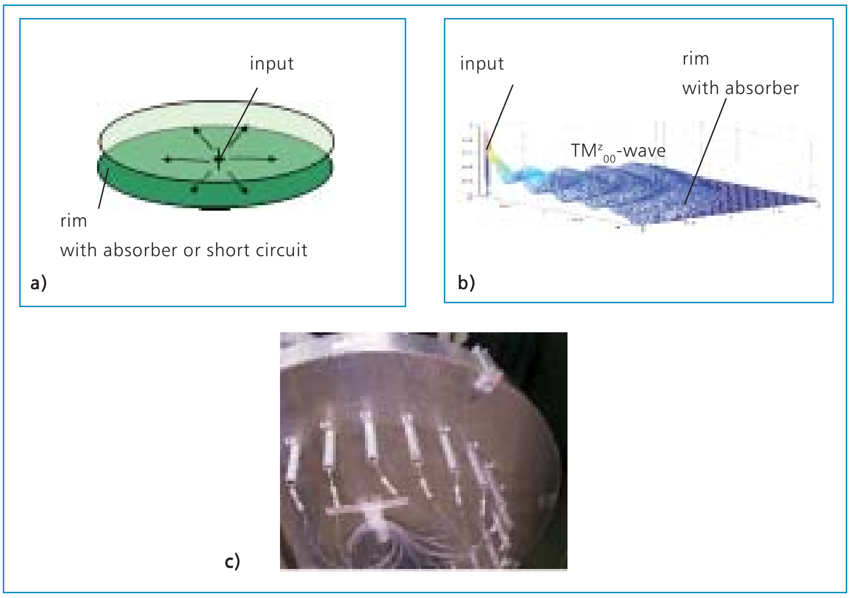

Figure 5: Radial waveguide
a) standard setup
b) radial field distribution of the fundamental mode
c) example

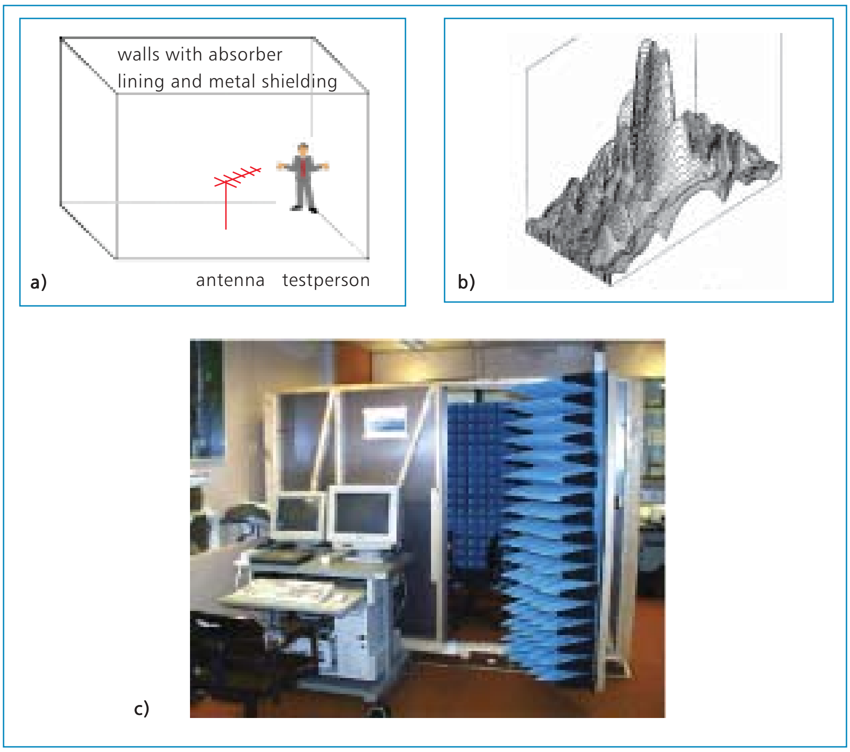

Figure 6: anechoic chamber
a) standard setup
b) example of field distribution inside the chamber
c) example (photograph: G. Schmid, ARCS Seibersdorf)

$$SAR = \frac{1}{2}\frac{\kappa}{\rho}\left|\vec{E}\right|^2$$

(K: electric conductivity of the tissue; ρ: material density; E: phasor of the electric field strength) which, according to [IEC 1997], is defined as the field energy W_D dissipated and subsequently transformed into heat per unit mass Δm (e.g. tissue) per unit time:

$$SAR = \frac{d}{dt}\left(\frac{\Delta W_D}{\Delta m}\right)$$

In experiments with test persons, the SAR can be directly used to differentiate thermal and non-thermal effects of radiofrequency fields, since exposure limits for humans are known and set in corresponding standards (e.g. [26. BImSchV 1996], [ICNIRP 1998] and [BGR B11 2001].

In other biological objects, i.e. test animals and especially cells, absolute SARs cannot be applied without additional standardization of temperature as a criterion for the evaluation of exposure strength. This is due to test animals for example having other thermal thresholds than humans and the SAR in cell cultures being strongly dependent on sample shape and volume. Therefore, exposure applied in in vivo and in vitro experiments is often better described by field strengths or power densities than by SARs.

Examples of exposure systems

1. Experiments with cell cultures

A. Single cells

In a project performed in cooperation with the working group of Prof. Dr. R. Meyer at the University of Bonn, the potential influence of mobile radio signals on the calcium ion flux through the cell wall of heart muscle cells was examined. As an electric bridge to the inside of the cell, the so-called patch clamp technique was used which allows simultaneous exposure of the cell to radiofrequency fields. A flat rectangular waveguide (measures: 3 cm x 12 cm x 50 cm) with the openings required for applying the patch clamp technique and a specially designed sample holder were built (figure 7).

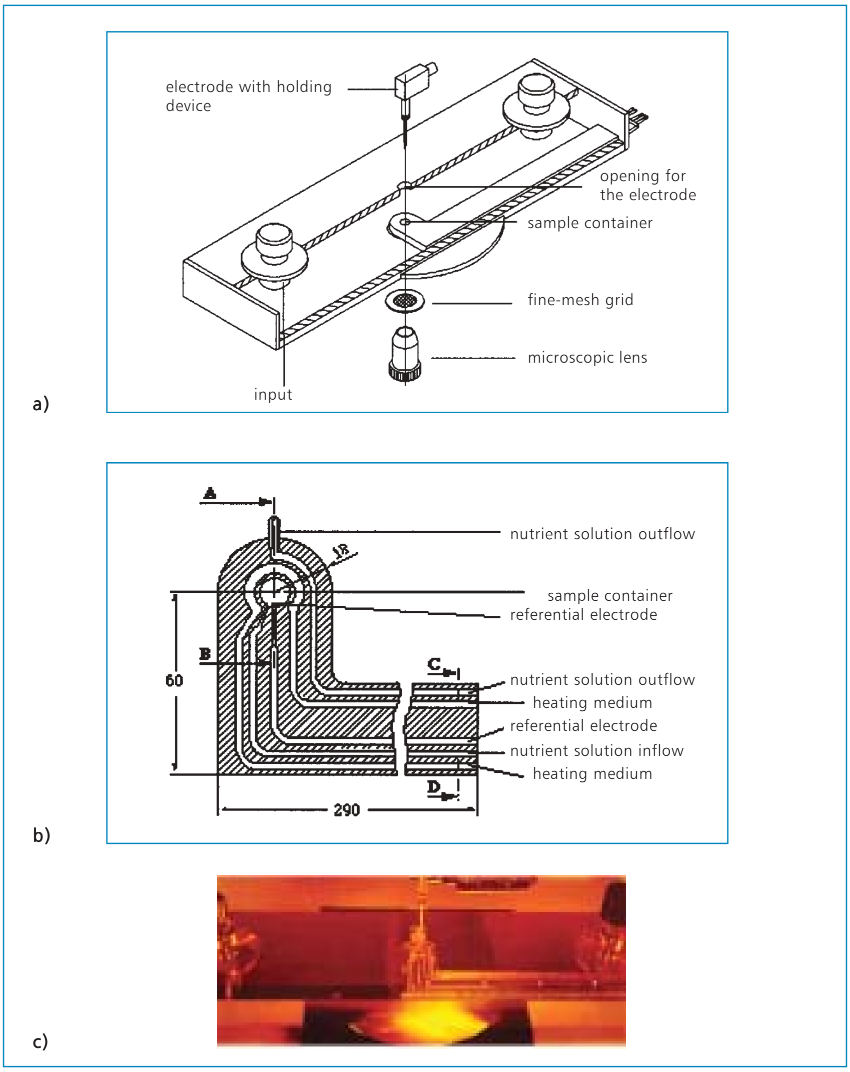

Bild 7: Figure 7: Patch clamp experiments inside a rectangular waveguide
a) standard setup
b) acrylic glass sample holder
c) 1800 MHz waveguide with patch clamp electrode and sample holder (here: placed on the cover of the waveguide)

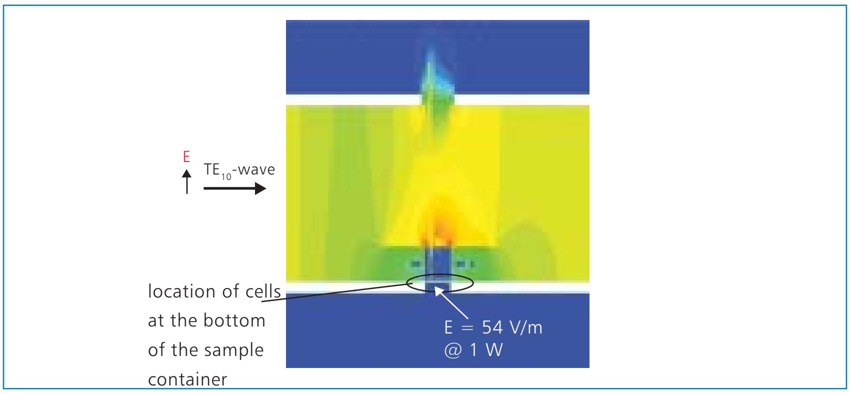

Figure 8:Calculated field distribution (magnitude of electric field strength) at 1800 MHz in a longitudinal cross-section of the waveguide with inserted sample holder

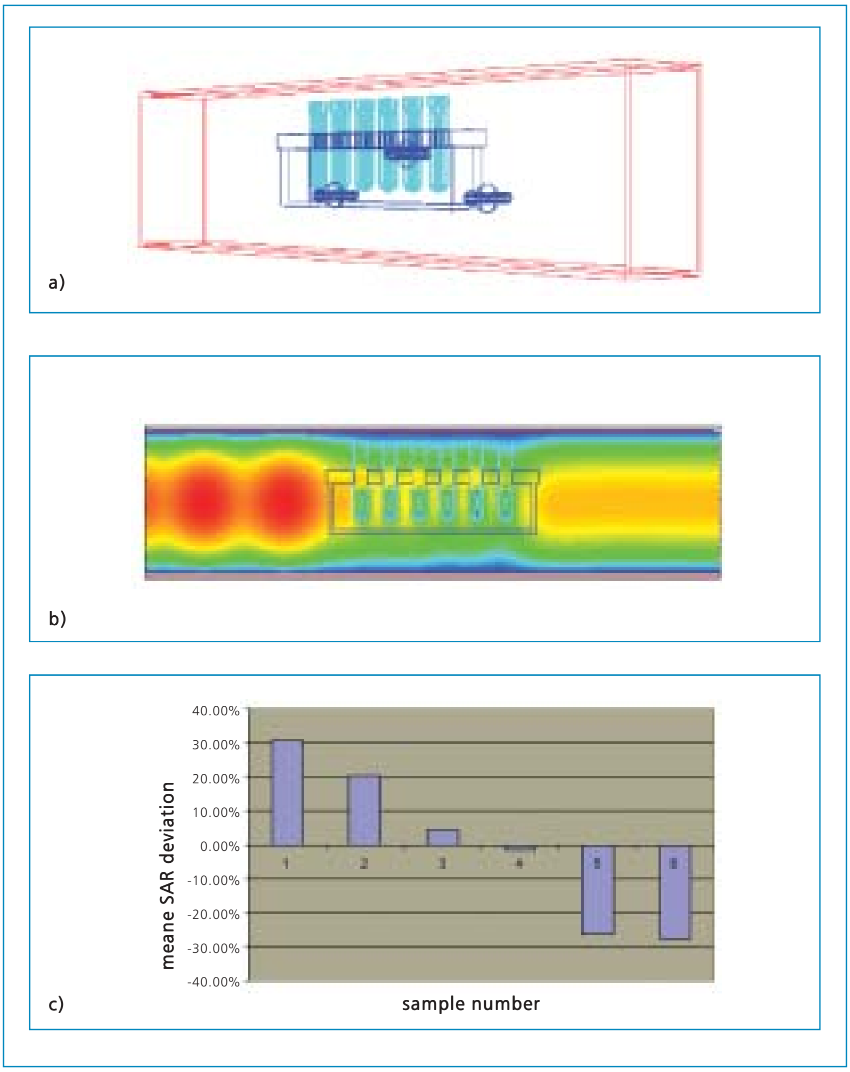

Figure 9: Exposure of 6 samples inside a rectangular waveguide
a) array of sample containers inside rectangular waveguide placed on its narrow side
b) calculated field distribution (magnitude of electric field strength) at 1800 MHz
c) percentage deviation of the mean SAR for each sample from the total average

Computer simulations of the configuration showed that, at 1800 MHz and 1 W input power, an electric field strength of 54 V/m (deviation smaller than 10%) can be expected at the potential location of the cells (figure 8).

B. Cell cultures with small sample number

The number of possible samples inside a waveguide at larger volume cell cultures is very limited. As an example, figure 9 shows the model of a linear array of sample containers, each one filled with 5 cm^3 nutrient solution with biological cells. The exposure field differs widely across samples already at only 6 samples, so that the mean specific absorption rate across the row of samples varies by approx. +/- 30%.

C. Cell cultures with many samples

Inside radial waveguides, much more uniform exposures can be achieved at distinctly increased sample numbers. Figure 10 shows a radial waveguide developed for the exposure of 30 samples. The cone antenna for the wave excitation can be optimally adapted to the coaxial waveguide's characteristic impedance. The Teflon insulation helps to hold the sample containers in place and to simultaneously reduce the free-space waveguide volume where pollution can occur. At the rim, a flat absorber helps to minimize the influence of the reflected wave on the exposure field. Two such exposure systems were set up for a project investigating the behavior of the blood-brain barrier at exposure to UMTS signals performed by the working group of

PD Dr. F. Stögbauer at the Münster University Clinics. The waveguides with a total diameter of 40 cm, a plate spacing of 11 mm and a sample diameter of 24 mm can be housed all at once inside an incubator (figure 11a). The measured variation of the electric field strength is depicted for both waveguides in figure 11b. The field at the sample site varies by less than +/- 7% inside the empty waveguides.

The in vitro model developed in Münster for the investigation of blood-brain barrier permeability consists of a planar cell layer of approx. 1 cm². It serves to perform electrical impedance measurements during radiofrequency exposure in the frequency range between 1 Hz to 1 MHz. To this end, a special sample-holding device was designed (figure 12) which contains the cell layer, the sample container with the nutrient solution, and the measurement electrodes with the outlet for the connector, at the same time shielding the waveguide against radiofrequency. The disc-shaped measurement electrodes were placed at the level of the waveguide plates in order to avoid disturbances of the wave propagation inside the radial waveguide.

Figure 13 shows the distribution of the electric field strength across the cell layer at a frequency of 2 GHz and for a power of 5 W fed into the radial waveguide. The spatial field variation is due only to the cylindrical shape of the sample container and the structure of the biological object, respectively, and thus is physically unavoidable. It does not indicate a lack of homogeneity of the exposure field produced by the waveguide. There is a mean peak field strength of 150 V/m at a standard deviation of 34%. The average SAR for a sample container filled with 3.5 ml nutrient solution is 4.5 W/kg. High-sensitive temperature measurements were performed to ensure that the RF exposure complied with the target temperature of 37° C +/-0.3° C given by the incubator.

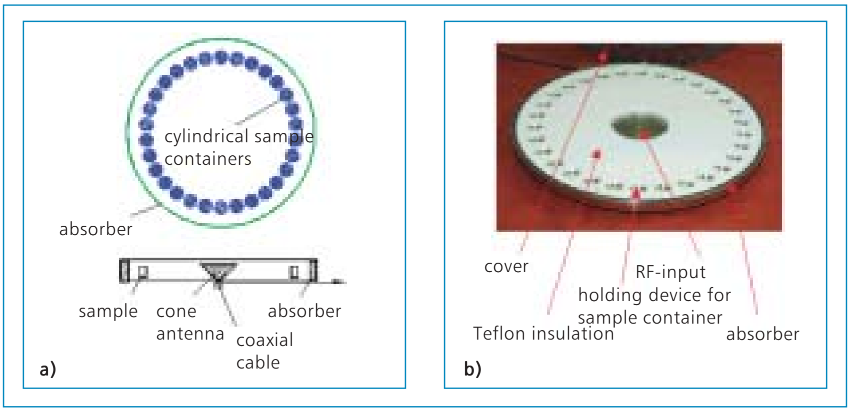

Figure 10: Radial waveguide for 30 samples
a) schematic drawing of the waveguide seen from above and in cross-section
b) set-up waveguide (with upper plate and cone antenna removed)

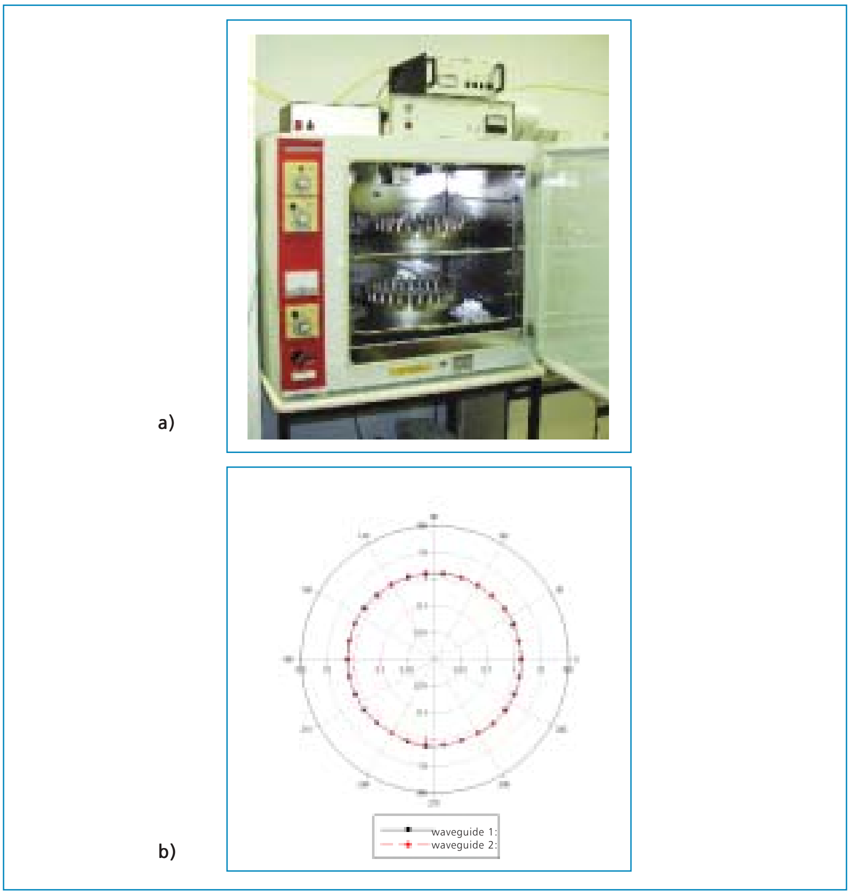

Figure 11: Exposure system for experiments investigating the blood-brain barrier
a) test setup with incubator, 2 waveguides, signal generator and amplifier
b) measurement results for the electric field strength at the site of sample containers

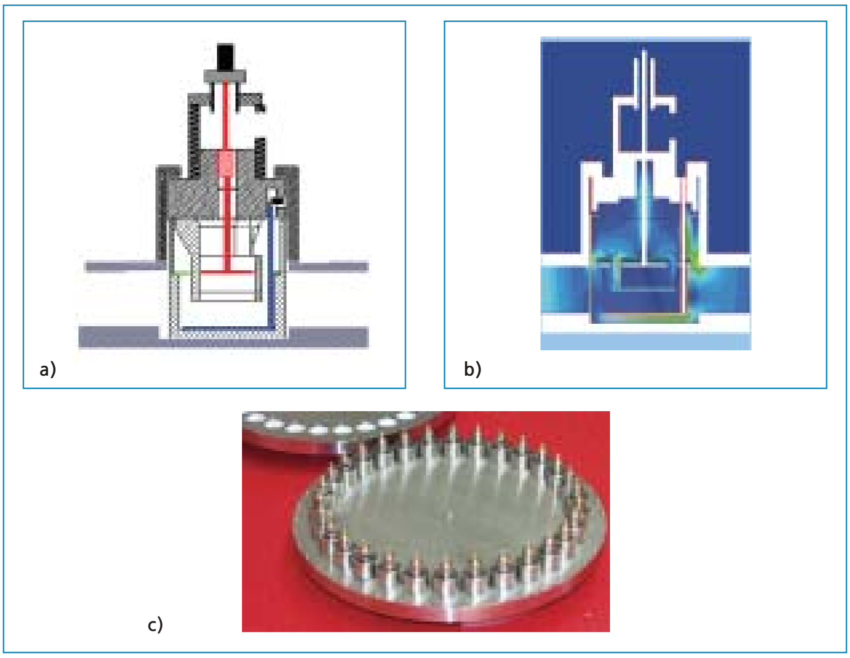

Figure 12: Sample holder
a) setup with sample holder for nutrient solution, insert with membrane and blood-brain barrier cellular model, main, counter and shielding electrode, cover with filter and SMB plug, as well as bolting
b) computer simulation of the radiofrequency field inside the sample holder
c) exposure system with sample holders

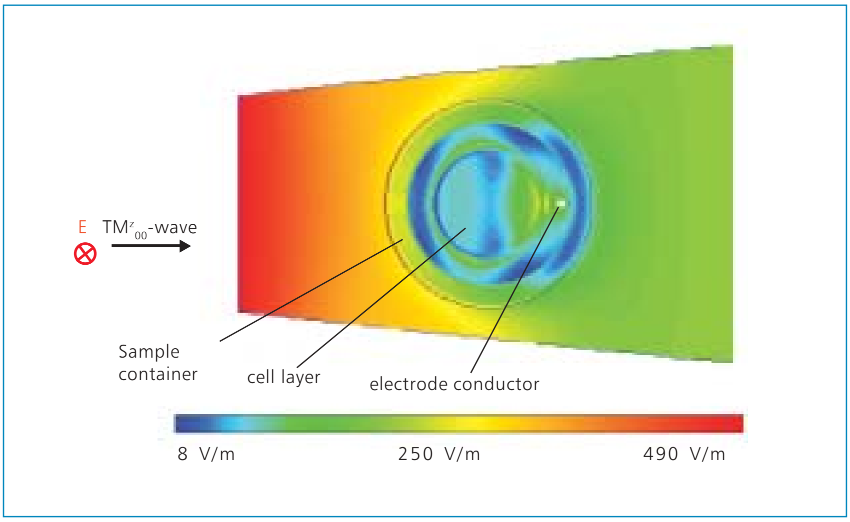

Figure 13: Distribution of the electric field strength across of the cell layer

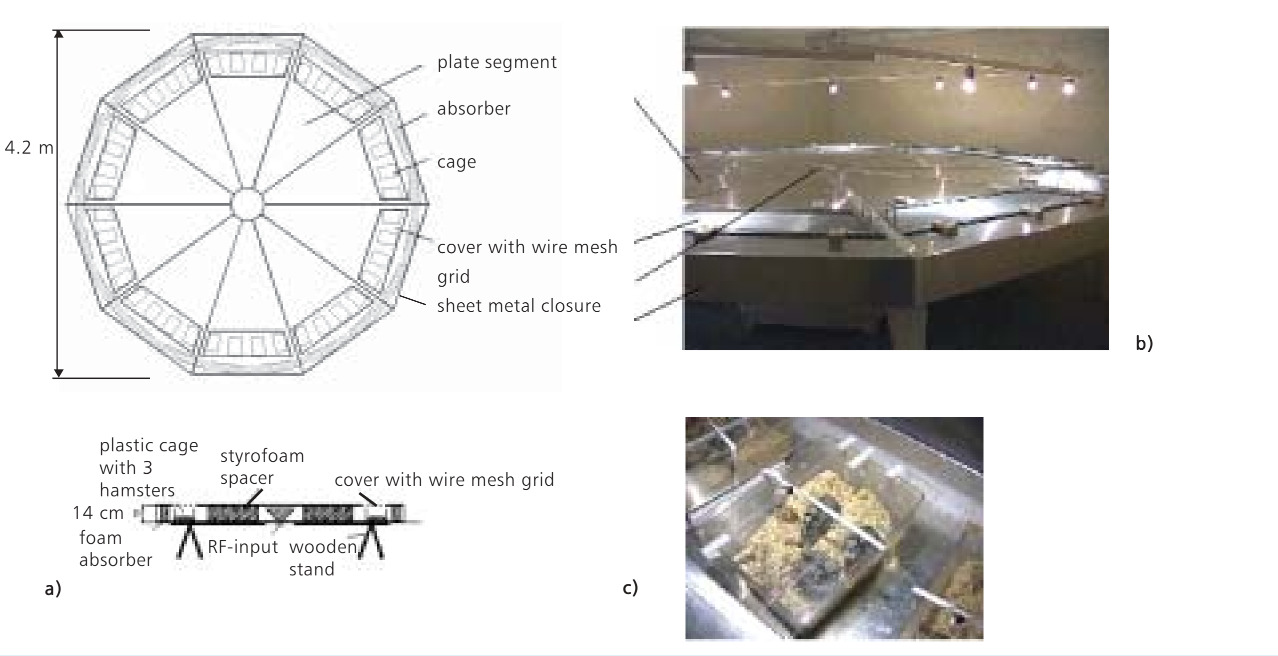

Figure 14: Exposure system for 120 hamsters
a) design of the radial waveguide
b) seen from the outside
c) plastic cage with 3 hamsters (with wire mesh grid removed)

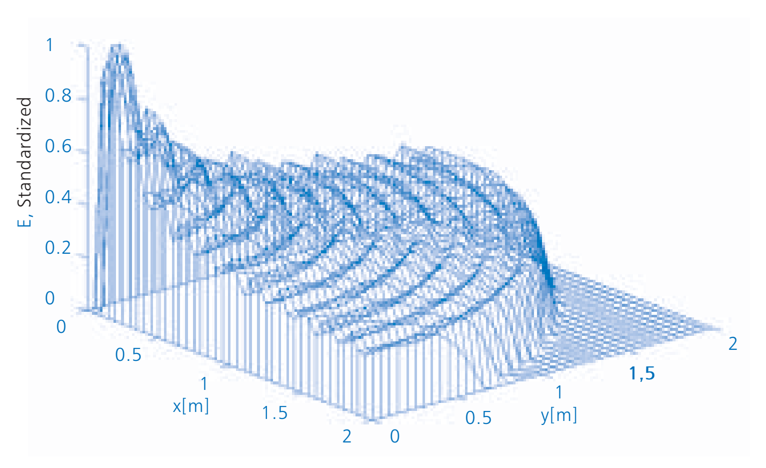

Figure 15: Spatial distribution of the electric field inside the empty radial waveguide

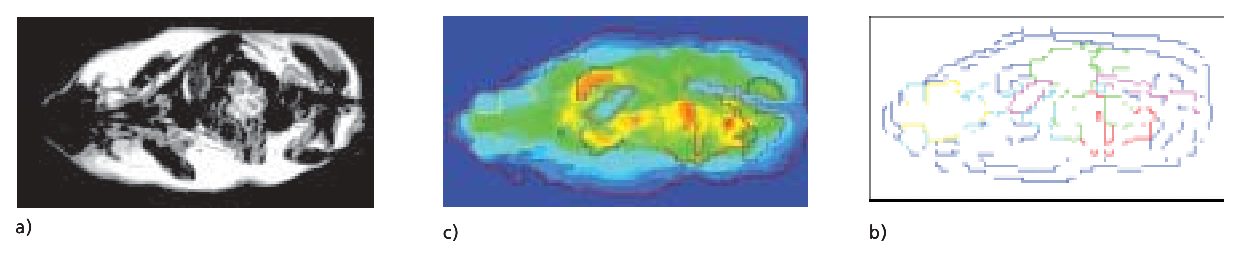

Figure 16: Computerized model of a hamster
a) NMR recording, b) cross-section of 3-D structural model, c) SAR distribution at the level of the cross-section

2. Experiments with freely moving animals

During the above described experiments with a fixed array of biological test objects, technical measures have to ensure that there is an as uniform electromagnetic field distribution at all sample sites as possible. The exposure of test animals that are restrained during the experiment, has to meet approximately the same field requirements as in vitro studies. But for different reasons, the biologists and animal medicine scientists doing research commissioned by the FGF prefer a test design allowing the animals to move more or less freely, as in a regular cage holding. This means that produced fields have to be kept homogeneous, consistent and thus reproducible in facilities that are much larger than those of ‘restrained animal studies’. Considerable technical expenditure is needed, depending on animal size and number, to at least approximatingly reach this goal.

A. Hamsters

In a joint project with the working group of Prof. Dr. A. Lerchl at the University of Münster, the influence of GSM mobile radio fields on growth, melatonin and reproductive functions of Djungarian hamsters was investigated. A radial waveguide with a diameter of nearly 4.5 m was built for the simultaneous exposure of 120 animals at 900 MHz (GSM signal) (figure 14).

3 hamsters each were kept in one plastic cage. With 14 cm, the spacing between the waveguide plates was well below one-half wavelength ($\lambda/2 = 16.7$ cm at 900 MHz). The advantage of this approach is that the homogeneity of the exposure field solely depends on the quality of the closure and on the rotational symmetry of the waveguide resp. the RF input which has to be very carefully monitored in order to obtain only the desired TM^{z}_{00} fundamental mode. The calculated field distribution shown in figure 15 has an excellent azimuthal symmetry. The waviness in radial direction is due to the overlaying of the wave reflected at the closure. For the cited project, a commercially available foam absorber with approx. -20 dB reflection was used for termination. Measurements of the electric field strength in the areas of the cages demonstrated a variation of below 7% in the direction of the perimeter. For the determination of the specific absorption rate in the animals, a 3-D computerized hamster model was built based on NMR imaging (figure 16). The evaluation of all numerical calculations and measurements considering different body positions and relative positions of the animals led to an average ratio between whole body SAR and input RF power of 28 mW/(kg·W), with a standard deviation of only 30%.

As a control group, additional 120 hamsters were kept in an equivalent system without RF signal during the experiments. A more detailed description of the exposure system is found in [Hansen et al. 2000].

B. Rats

In experiments with larger test animals, it is more difficult to expose all cages consistently: The cross-sectional dimensions of the waveguide increase with cage dimensions, and upper waveforms will be able to propagate. Their fields, dependent on the location, overlay the desired field of the ground wave and lead to undefined exposure conditions. Thus, the aim is to suppress the excitation of upper waveforms.

Two measures to achieve this goal were performed in a cooperation with Dr. J. Buschmann of the Fraunhofer Institute for Toxicology and Aerosol Research, Hannover, when building a 900 MHz GSM exposure system for Wistar rats.

24 cages with a height of 17 cm were located inside a radial waveguide with a diameter of 3.5 m

Figure 17: Radial waveguide as an exposure system for 24 rats

(figure 17). At a plate spacing required for inserting the cages of more than $\lambda/2 = 16.7$ cm, besides the TM$^z_{00}$ ground wave also the TM$^z_{01}$ and TE$^z_{01}$ modes could exist (figure 18a). The height of the waveguide was reduced by additional metal plates built in from the input port up to the front of the cages in order to excite only the fundamental mode in the exposed area. Thus, higher order modes were not able to propagate from there (figure 18b). Field energy coupling to higher order modes which could propagate in the exposed area had to be avoided as far as possible. Therefore, additional metal bars were installed between the cages (figure 18c), thereby shifting the cutoff frequencies of these waves to the range above the exposure frequency for ensuring an effective damping of their evanescent fields. Figure 19 demonstrates the conducting bars and a calculated field distribution inside the cage with inserted rat model. Due to these metal bars, the field basically stays homogeneous; the scattered field developing at the animal is spatially limited.

Exposure should be performed at the upper boundary of the athermal range, i.e. RF power was selected to ensure that the thermoregulation of the animals just was capable to keep body temperature constant (see figure 20, upper curve). Power density inside the cages thus was regulated at 60 W/m²; for this, an average power of 203 W fed into the radial waveguide was required. To avoid heat buildup inside the waveguide and to conduct the developing heat energy quickly outside, an active ventilation system with an opening for suction was installed under each cage (figure 21).

Computer simulations for dosimetry using a high-resolution rat model (figure 22) resulted in a whole body SAR of 1.28 W/kg for the selected exposure, averaged across 24 animals, at a dispersion of 41%. All field variations as well as different body positions and animal positions inside the cages are considered here.

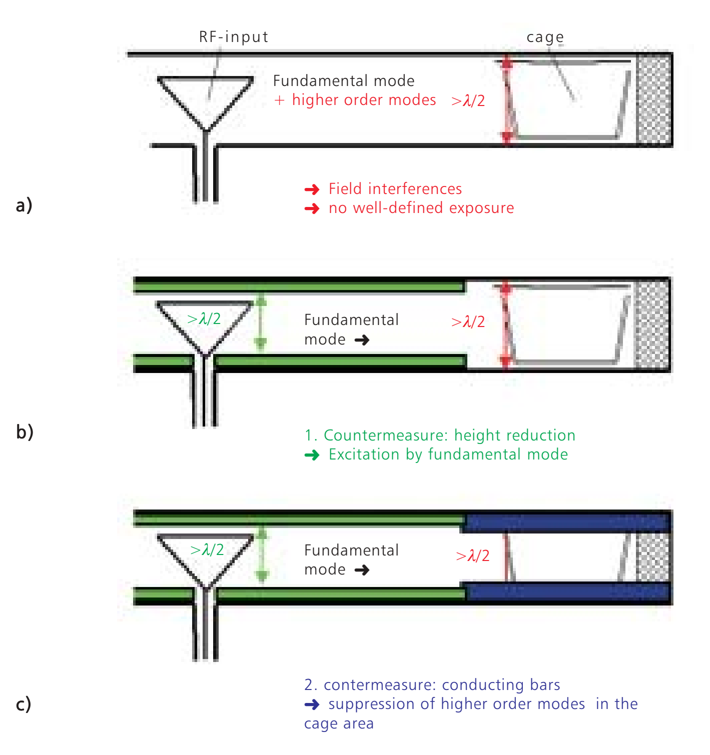

Figure 18: Measures to avoid higher order modes inside the radial waveguide
a) multi-mode waveguide
b) single-mode excitation of the exposed area
c) shift of the cutoff frequncies of higher order modes in the exposed area

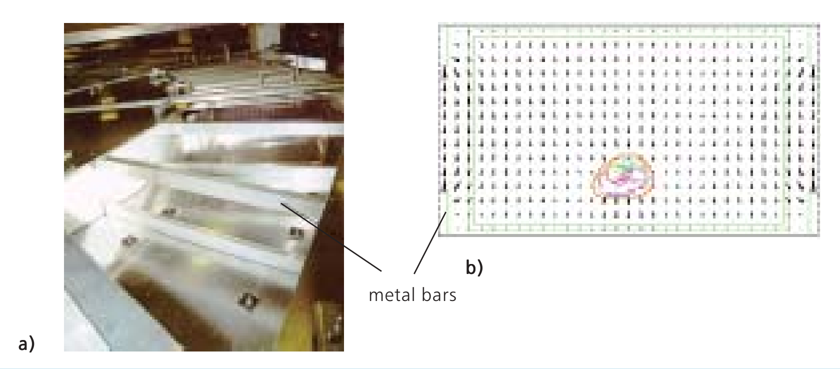

Figure 19: Metal bars inside the radial waveguide
a) exposed area with cages
b) calculated electric field distribution in exposed area with rat model

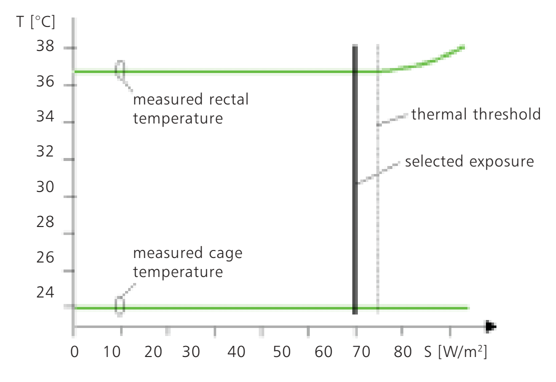

Figure 20: Measurement of cage and body temperature as a function of the power density at 900 MHz

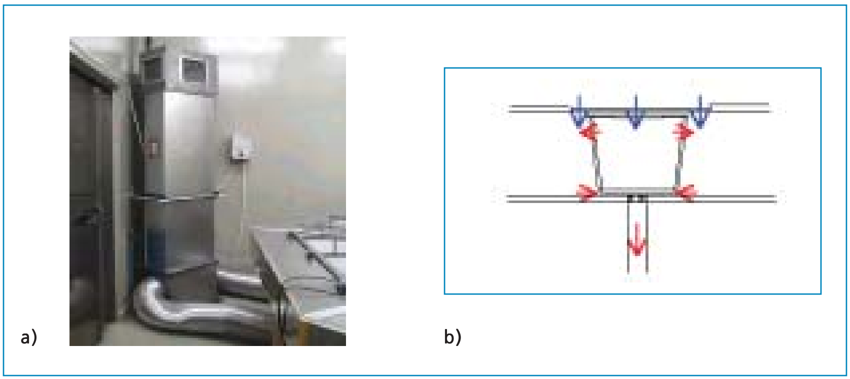

Figure 21: Ventilation system
a) central air suction unit
b) schematic diagram of air flow at the cage

A specific requirement was the provision of the animals with fresh water from the outside. In order to bring the water into the cage area without disturbing the exposure field too strongly, the glass nipples were inserted through circular waveguides operated below their cutoff frequency (figure 23) that were installed above the cage lids. Although they are mechanically open, no electromagnetic field energy can pass through.
In the same laboratory, an identical sham exposure system was installed for the control group. Inside it was shielded with more than 75 dB against the exposure field.

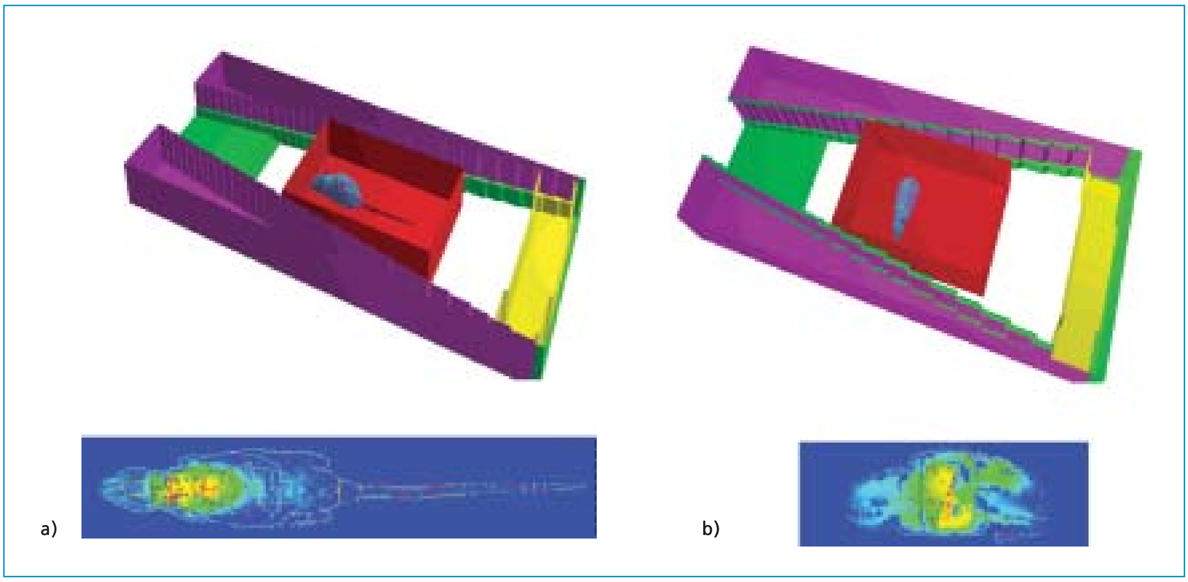

Figure 22: Dosimetry at high-resolution rat model inside radial waveguide
a) whole model and SAR distribution at exposure to the side of the head
b) whole model and SAR distribution at exposure from the side

Figure 23: Circular waveguide segments above the cages for the insertion of glass nipples for drinking water

exposure area	SAR whole body	SAR local, averaged over 10 g
1 (instructed people; controlled areas)	400 mW/kg	10 W/kg
2 (general public; freely accessible areas)	80 mW/kg	2 W/kg

Table 2: Specific absorption rate limits for the protection of persons in freely accessible and controlled areas

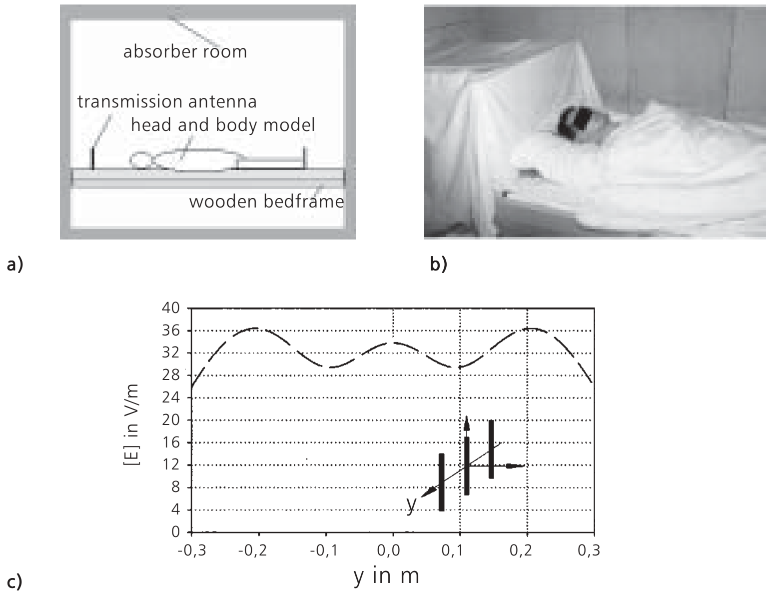

Figure 24: Head exposure in sleeping volunteers
a) array of bed and antenna inside an absorber room
b) volunteer in front of the covered antenna system
c) electric field distribution transversal to the body axis at a distance of 40 cm to the antenna system (transmission power: 1 W)

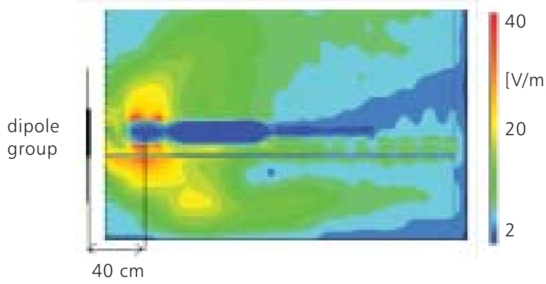

Figure 25: Electric field distribution for the test design with test person

3. Experiments with test persons

Experiments where humans are exposed to electromagnetic fields involve much more restrainment than in vitro or in vivo tests.
The reason is that human experiments, on the one side, have to comply with legally prescribed field strength limits resp. specific absorption rate limits (table 2).
On the other side, due to the unfavourable ratio between body size and wavelength above 300 MHz, waveguides cannot be applied as an exposure system, but only antenna arrays in absorber rooms entailing considerable additional expenditure. This is why the percentage of past experiments performed with test persons is comparably small. Moreover, only localized exposures, especially of the head, were conducted in order to examine potential influences on parameters such as response capacity, sleep behaviour or visual capacity.

One example that shall be mentioned here is a project (one of several) commissioned by the FGF, a study conducted at the Clinics for Psychiatry and Psychotherapy at the University of Kiel, directed by Prof. Dr. J. Aldenhoff. The aim was to investigate the effects of electromagnetic radiofrequency fields on the quality of human sleep. To this end, electroencephalograms of sleeping test persons were recorded who simultaneously were exposed to a defined electromagnetic mobile radio field at 900 MHz.
On the side of electrotechnics, the Bergische Universität Wuppertal regulated the layout of the test room, the configuration and the position of antennas, the signal type and the transmission power so that a reproducible and efficient exposure of the head was achieved. Figure 24 shows a schematic diagram of the test setup. Around the metal-free bed for the volunteers a (approx.) 3.1 m x 1.8 m x 2.4 m (L x W x H) absorber chamber was installed in order to suppress the standing wave character of the field in the space. The antenna configuration consisting of three single dipoles was inserted into a holding device made of wood and styrofoam which simultaneously provided visual protection and a specific spacing, so that the head of the test person was at a distance of at least 30 cm to the transmission antennas. The three antennas were arranged and fed as to avoid any major change in exposure, even if the test person moved the head to the side. The computer simulation performed in addition to field measurings confirms (figure 25) that the field maximum generated by the antennas occurs in the area of the head. The numerical evaluation of these calculations showed a local specific absorption rate at the head of up to 1 W/kg for a transmission power of 25 W, and a whole body SAR of 24 mW/kg, i.e. well below exposure limits.

Conclusion

We described a selection of radiofrequency exposure systems having been developed over the last 10 years by the Bergische Universität Wuppertal for projects commissioned by the Forschungsgemeinschaft Funk. The depicted examples confirm that exposure systems have to be carefully designed both technically and theoretically if potential reproducible non-thermal effects of radiofrequency electromagnetic fields on biological systems shall be identified. The expenditure needed for this increases with the increasing complexity of test objects and their environment, and also with the increasing ratio between object size and wavelength.

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Dr. Joachim Steckert, Chair for Theoretical Electrical Engineering,
Bergische University- Polytechnic Wuppertal

Requirements for technical institutions investigating the effects of high frequency electromagnetic fields on biological Systems

It has been known for a long time that concentrated high frequency irradiation of biological tissue increases its temperature and at very high intensities it can also destroy it. In the meantime a controlled use of these warming effects, e.g. as a therapeutic agent or in microwave ovens is quite widespread today. The threshold for thermal effects is accurately definable and is used, for example, to derive for the maximum permissible exposure limits of electromagnetic field sizes, in particular to protect people while using technical appliances, especially those which are legally prescribed, for mobile radio radiation and especially field generators must adhere to the exposure limits. With the help of mathematical equations the thermal effects can be predicted. The question as to whether or not biological systems are affected by mobile radio radiation below the thermal effectiveness is, as in the past, still being discussed. Since to date, no reproducible proof of biological effects of weak electromagnetic fields could be established, there are also no mathematical models, i.e., no formal relationships, which would describe this kind of mechanism and would permit the further investigation on a theoretical level.

As in the pioneer days of the discovery of today generally understood physical phenomena, one is dependent on observations, which are significant only in the context of carefully carried out scientific experiments under clearly defined boundary conditions. This way of proceeding is very cost intensive in terms of personnel and technology, however this represents the only possibility to be able to make an objective statement on the issue, when one considers the controversy involved and at times public opinion is anything but objective; this is also reflected in the media.

The Forschungsgemeinschaft Funk began 10 years ago to initiate research projects in these fringe areas between biology/medicine and between engineering/physics. The FGF has also promoted and financially supported the execution of this research with independent research institutions. What has come to light is the fact that these types of experiments have an interdisciplinary approach; what is necessary, however is collaboration between biologists and high frequency technicians who are able to design an experimental approach which is suitable to the task at hand.

For those doing the experiments the complexity of determining exposure conditions and exposure values, which are influenced by various material and geometrical factors, is always a great challenge. Many practical examples help in making the right choice concerning what research approach should be taken and which method will be used for taking measurements. Actually, one can emphasize that every experiment requires its very own approach in establishing a suitable technique for taking measurements because this decision is based on the diversity of the biological conditions.

Nevertheless, a successful attempt is being made to standardize the technical measuring procedure, in order to allow for a better comparability of the experiments.

In order to support this the FGF has published a guide for experiments investigating the effects of high frequency electromagnetic fields on biological systems in “Edition Wissenschaft” (edition no. 11;

Summary

September 1996; author: Professor Volkert Hansen, Chair of Electromagnetic Theory, University Wuppertal. This article demonstrates with some examples which technical procedures were used to develop the required high frequency irradiation equipment for very different biological specimens, such as, tissue cells, small animals or test persons and to optimise the replication and symmetry of the applied electromagnetic fields. An example of this is shown in a photograph on one of the posters on display here. It is a picture of an installation of approx. 4m in diameter, in which 24 female pregnant rats were exposed to a typical mobile radio field of 900 MHz for over 3 weeks, 20 hours a day in order to find out if there were any possible effects on their offspring.

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