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HF exposure

of biological systems in radial waveguides

WAVEGUIDES

Summary

For a study on the melatonin synthesis in Djungarian hamsters exposure set-ups based upon the principle of radial wave conduction were designed, as well as analysed metrologically and dosimetrically. Experiments were conducted at 383 MHz (BOS frequency band) using a signal form equivalent to the TETRA 25 standard and at 900 MHz with a synthetic GSM standard. For in vivo experiments 120 hamsters with an average specific absorption rate (SAR) of 80 mW/kg per hamster were to be exposed. Though the hamsters could move freely within their cages, SAR variation in the developed waveguides was only 30%. For in vitro experiments also radial waveguides were used, however especially designed for the exposure of the hamsters' pineal glands. Because of the stationary array of sample dishes und the small size of the pineal glands (around 1 mm^3) calculations showed a variation of only 2,4%.

The quite small variations in both tests result of the excellent homogeneity of the electromagnetic field propagation in the exposure area. This is a direct consequence of the high rotation symmetry of the radial waveguides essentially influenced by coupling design and the feed line end of wave conduction. This report focuses on the technical aspects of the exposure set-up.

1. Introduction

For some years now, interdisciplinary working groups deal with the question whether low electromagnetic fields have an impact on biological organisms. In the context of these research activities, the Faculty of Theoretical Electrotechnics of the University Wuppertal developed different exposure set-ups based upon rectangular hollow conductors (1, 2), radial waveguides (3, 4) and absorber chambers (5). Whereas basic requirements of each individual exposure set-up are identical und therefore known to each scientist (6), special side conditions of different experiments can differ widely.

This report exclusively deals with radial waveguides designed for exposure of a large number of living animals and cultivated biological samples, in particular considering practical application of the design, as well as the characteristics regarding exposure. As to the field theoretical basis of radial waveguiding see (7). Some useful details regarding the exposure of biological cultures may also be found in (8).

2. Basic details

Basically, the radial waveguide consists of two circular, parallel metal plates (fig. 1). A cone antenna positioned in the center (fig. 2) excites waves that propagate in radial direction. At the edge of the metal plates absorbers are added in order to prevent strong standing wave field propagation caused by the reflections at the waveguide's end.

A given adequate plate distance the electromagnetic field within the conductor only consists of the transversal electromagnetic (TEM) wave. Under the condition of constant radius, this waveform has a homo-

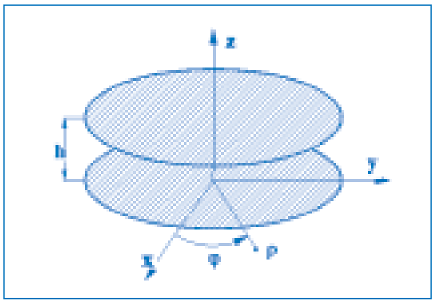

fig. 1: Basic set-up of a radial waveguide

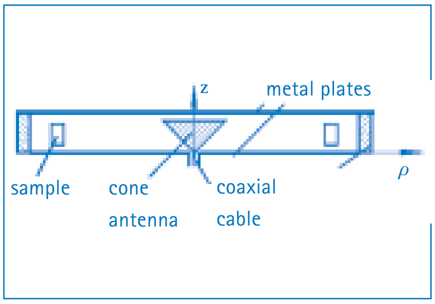

fig. 2: Section of a radial waveguide

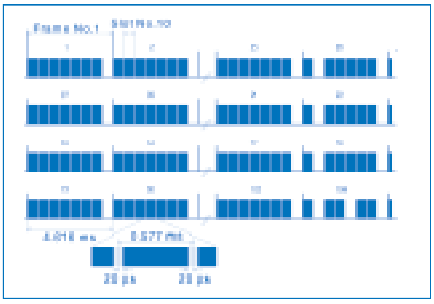

fig. 3a: Modulation signal for the synthetic GSM signal

geneous field propagation at cross-section and is only dependent of radius ρ. For large distances to the input source this dependency can be calculated approximately by means of the value $\rho^{-1/2}$. Wave excitation caused by a slot antenna, as proposed in (9), in comparison does not fulfil the conditions of a homogeneous field propagation in the exposure area.

In vivo experiments

A. Biological and technical conditions

For the in vivo experiments 240 hamsters of approximately the same size and weight (about 50 g) were selected to achieve statistically highly valid results. For the tests designed as a double-blind study 120 hamsters formed the exposure group, the other 120 hamsters formed the control group. Both groups were set up in identical radial waveguides; the staff conducting the tests did not know which of the two waveguides was feeded with high-frequency power. Each exposure chamber had 40 cages (L x B x H; 0.3 m x 0.2 m x 0.1 m) each containing 3 hamsters. During 60-days tests ventilation and lighting of the cages was held constant. Since he animals were examined in regular intervals, the removal of the cages from the waveguides had to be made as simply as possible. The average SAR value per hamster was to be 80 mW/kg with as small variation as possible and without exceeding the limit value of 2 W/kg of the ICNIRP standard (10) in the animals by local SAR values. In a pretest a carrier frequency of 900 MHz with a synthetic GSM signal was used simulating the combined influences of the downlink distance of a base station and the uplink connection of a mobile phone including the frequency components of DTX mode (11; fig. 3a).

The second experiment applied a carrier frequency of 383 MHz with a modulation of TETRA 25 standard (fig. 3b).

B. Design of the exposure set-up

The array of cages was circular with a constant distance towards the cone antenna, as well as sufficient distance between cages and towards the absorber (fig. 4).

Therefore, a conductor diameter of 4 m had to be selected. Because of the required cage height the distance between plates was 14 cm. Conductor height also guaranteed that the rotation symmetrical input represented by the cone antenna exclusively excited the TEM waveform.

In order to meet all above mentioned biological requirements the basic set-up of the radial waveguide had to be partially adapted.

For better handling, both metal plates were partitioned. The bottom segments were screwed to a wooden rack, the distance between bottom and top segments was locked by polystyrene blocks. All remaining slots between plates were covered by aluminium shielding tape to prevent irradition of the HF power through the slots. Each top metal segment has a trapeziform aperture (ca. 1 m x 0.4 m) through which cages can be removed from/inserted into the conductor. These apertures are sealed by metal frames covered by a metal wire tissue with a mesh width of about 1 mm allowing for the ventilation and lighting of the cages. Frame and mesh width of the metal wire tissue were selected to prevent interferences of wave conduction within the conductor, as well as to achieve a high shield attenuation and thus a decoupling from external space. At 900 MHz commercially available flat foam material absorbers with a reflection factor of around -15 dB were applied, whereas at 383 MHz self-built absorbers were used, since pyramidal absorbers normally used in this frequency range are too large. These self-built absorbers consist of a short-circuit in front of which we put up a resistance foil adapted to 377 ohm in a distance of lamda 4. Thus the same reflection properties as at 900 MHz could be achieved.

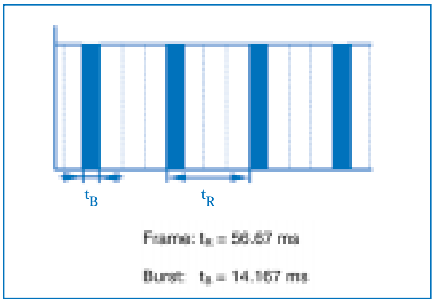

fig. 3b: Modulation signal for the TETRA 25 signal

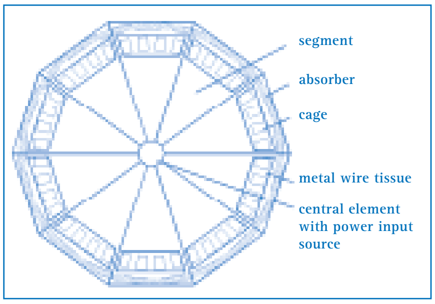

fig. 4: Top view of the radial waveguide for the in vivo experiments

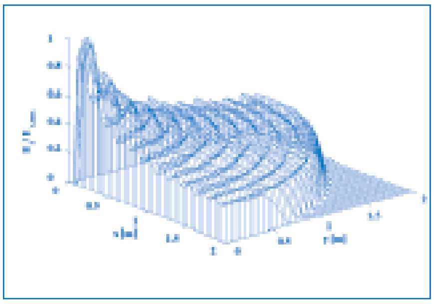

fig. 5: Values of the component z of the electric field in a 90(sector of the vacant radial waveguide at 900 MHz

The measured coupling factor of the exposure/sham exposure chamber lay below -75 dB.

C. Field propagation and dosimetry

Field propagation in the radial waveguide among other things was analysed numerically by means of the Finite Time Difference Domain method (12).

Fig. 5 shows the electric field strength at 900 MHz and at 383 MHz in a 90(sector of the vacant radial waveguide. The p - 1/2 dependence of field strength is overlapped by the standing waveform as a consequence of reflections at the realistic absorber model. The field strength is characterised by constant volume direction.

It is to be expected that field propagation in the vacant conductor changes after adding the hamsters. Field measurements as well as numeric calculations using different set-ups of hamster phantoms were made in order to confirm that the hamsters do not excite unwanted higher waveforms and/or cause too strong field disturbances within the waveguide. A further important aspect was the mutual shadowing of the hamsters in the cage and resulting SAR distributions in the animals. For the examination of general effects of the hamsters on the field propagation within the waveguide at first simplified hamster phantoms were used as a basis for calculations, consisting of homogeneous ellipsoids with a length of 7 cm, with semi-axes of 2 cm and with the material parameters ε_r = 50 and K = 1.25 S/m.

Figure 6 shows the field propagation in the 90° sector with the randomly arranged hamster phantoms at 900 MHz. As was to be expected, reflections and field disturbances occur in the hamsters being however restricted to their immediate environment. Another result of these calculations was that field components indicating the excitation of higher modi is negligible. Thus, exposure area is entirely characterised by the TEM wave.

For a more exact examination of the effects of hamster positions on SAR distributions in the animals a 9° sector of the radial waveguide at the sides limited by magnetic walls with a cage and different arrays of the three hamsters was simulated (fig. 7).

Figure 8 demonstrates the field propagation of four different arrays of the phantoms at 900 MHz. Corresponding calculations showed that at an averaged total input of 2,9 W an average SAR value per hamster of 80 mW/kg is achieved. As for the here applied GSM test signal with a pulse ratio of around 7:8, this means that an input of 3.3 W has to be provided in the burst. The standard deviation of the whole body SAR value is 30% considering

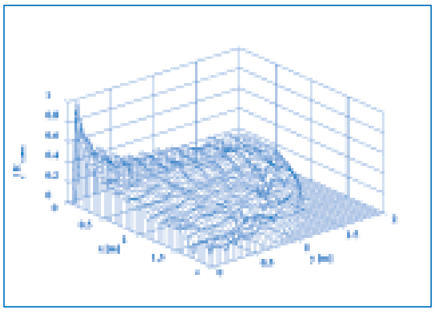

fig. 6: Values of the component z of the electric field in a 90(sector of the radial waveguide with randomly arranged hamster phantoms at 900 MHz

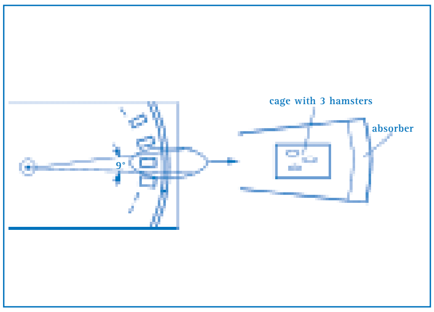

fig. 7: 9° sector of the radial waveguide with a cage and 3 hamsters

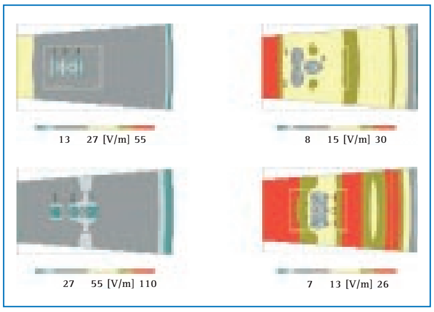

fig. 8: Electric field propagation in a 9° sector of the radial waveguide for different arrays of the three hamsters at an input power of 1 W

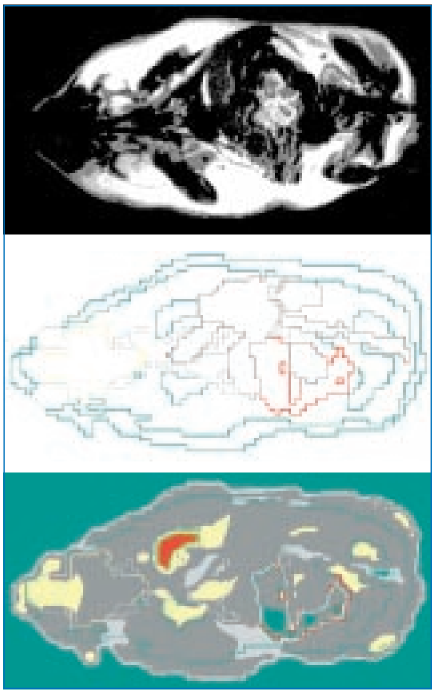

fig. 9: SAR calculation for the hamster phantom based upon magnetic resonance images
a) Magnetic resonance image
b) hamster phantom for numeric calculations
c) SAR distribution

the not perfectly homogeneous reflection properties of the absorber in each sector of the conductor and the resulting field strength variation in volume direction of 7%. We may add that 25% out of the 30% standard deviations are caused by the biological design with unrestricted animals.

Because of the bigger wavelength at 383 Mhz and the resulting more favorable ratio towards the hamsters' body measures the standard deviation of the specific absorption rate per hamster at this frequency is only 16%. The average value of 80 mW/kg is achieved at a time-averaged power of 45 W. As the TETRA 25 signal has a pulse ratio of 1:4, a power of 180 W is needed in the burst of the signal.

Based upon magnetic resonance images for the calculation of local SAR values a hamster phantom was developed having a spatial solution of 1 mm^2 and considering 22 different tissue types (fig. 9).

Calculations confirmed that an in 1 g tissue averaged local SAR value of 600 mW/kg is not exceeded in the hamster.

3. In vitro experiments

For the exposure of the pineal glands of the Djungarian hamster to the synthetic GSM test signal at carrier frequencies of 900 MHz and 1.8 GHz radial waveguides were used, too. The chambers for exposure and control groups were designed for simultaneous treatment of 24 samples (fig. 10).

Pineal glands are set up in cylindrical glass tubes being 0.8 cm in diameter and 1.5 cm in height, at the top and at the bottom fastened by a rubber seal. As each sample must be supplied with nutrient solution via thin tubes during tests, we had to develop appropriate inlets for the tubes leading into the waveguide. These inlets must not have an effect on wave conduction and on the shielding against external influences. Shielding plays an important part, since both waveguides are set up in the same incubator. Tests are to be conducted at different in a pineal organ averaged SAR values of 8, 80 and 800 mW/kg. Further, it should be made as simply as possible to add/remove sample dishes to/from the waveguides.

To achieve a homogeneous exposure the individual samples are arranged within a distance of 30 cm around the central antenna. The waveguide's diameter is dependent of the thickness of the applied absorbers. During the experiment at both frequencies flat foam absorber are used. Thus a diameter of 1.1 m is sufficient. The selected distance between plates was 7 cm. Measurements of the field strength at the site of the samples in the conductor showed a field strength variation of 2.4 %.

A particular problem was inserting the tubes through the metal plates of the waveguide. Until now apertures in the metal plates were sealed by removable lids. However, this method proved time-consuming and tedious. At the radial waveguides used here, for each of the 24 samples a metal pipe was screwed to bottom and top metal plate. Diameter and length were those of round hollow conductors operated far below limit frequency of their basic wave. Here, it is sufficient to select a diameter that allows inserting the sample dishes at the top. The bottom of the round hollow conductors has to fit in only with the nutrient solution tubes (fig. 11).

The round hollow conductors do not necessarily have to be sealed, since they operate below limit frequency exciting only coupled fields of non-propagating wave types. Thus easy handling as well as high shielding of the waveguide are ensured.

An initial rough dimensioning of the inlets was made on the basis of the traditional conduction theory. In addition, numeric calculations were made, since the round hollow conductor contains strong loss material (nutrient solution). These calculations aimed to determine the propagation constant of the basic wave and corresponding field attenuation.

Figure 12 shows a section (see marked area in fig. 11) of the field propagation in the upper half of the sample dish and in the top inlet. At a diameter of 1 cm and a length of 2.5 cm the attenuation of the inlet is 42 dB. The attenuation of the bottom round hollow conductor with a diameter of 0.15 cm and a length of 1 cm amounts to 52 dB.

Calculations of field propagation for a pineal gland showed a largely homogeneous SAR distribution in the sample dish. At 900 MHz there is a specific absorption rate of 340 mW/kg at an input power of 1 W. Thus, a time-averaged power of 2.35 W is needed to achieve a specific absorption rate of 800 mW/kg. In the course of the study further calculations at both frequencies will be carried out. In particular, an improved modelling of the pineal organ is planned in order to examine more closely the effects of changed positions and direction of the organ regarding SAR values.

5. Conclusions

It was shown that radial waveguides because of their highly symmetrical geometry are well suited for uniform exposure of a great number of biological samples. Though the here shown examples had apertures for ventilation, lighting and inlets for sample dishes and tubes, the design provided sufficient external decoupling. As the power was limited to the conductor's cross-section, we additionally achieved high efficiency regarding absorbed and input power.

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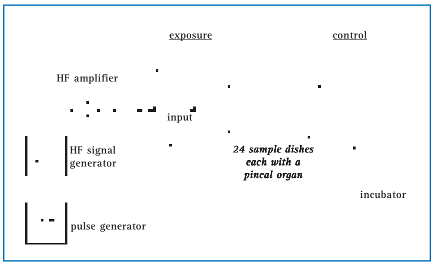

fig. 10: Set-up for in vitro experiments

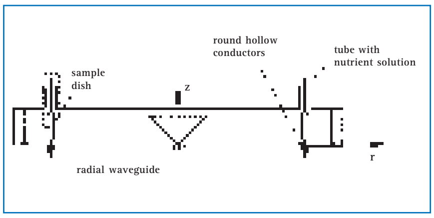

fig. 11: Inlets in the metal plates of the radial waveguide. Inlets are round hollow conductors operated far below limit frequency of their basic wave.

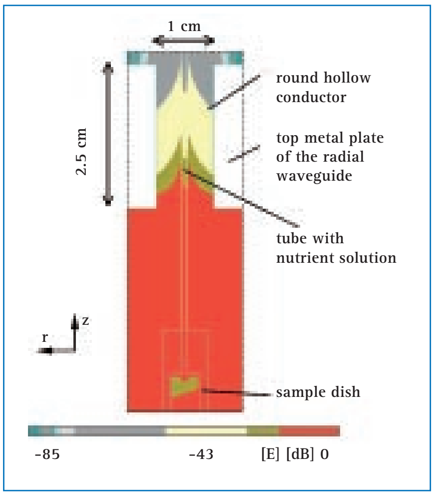

fig. 12: Electric field propagation in the area marked by the hatching in fig. 11