Numerical computation of field and temperature distribution for a device aiming at local brain exposure of rodents in vivo at 2 GHz

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Abstract—A device for the 2 GHz (UMTS) local exposure of six rats in vivo based on a double-cone waveguide is presented. Further numerical computations of field and temperature distribution in the rats’ head for investigations of possible influences of mobile communication signals on the brain are shown.

I. INTRODUCTION

One of the biological systems that is often suspected to be sensitive to electromagnetic exposure is the blood-brain barrier (BBB). There are controversially discussed results from several in vitro and in vivo investigations. In this project effects of microwave exposure (UMTS modulation) on the pattern of mRNA / protein expression in rats is studied. To do so partial brain exposure in vivo is necessary, since the blood compartment and the components of the BBB vessel wall are a functional entity and should be maintained during experiments, whereas none of the in vitro models used so far acquires the complex interaction of structural BBB components. The contribution describes the exposure concept for the running experiments. A number of 6 restrained rats shall be exposed simultaneously for at least 2 hours, whereby in sequentially performed tests a blinded scrambling of different applied specific absorption rates (0 W/kg, 2 W/kg, and 10 W/kg) shall be provided. The exposure of the rats’ brains shall be as localized and as uniform as possible, but with \( SAR_{\text{max}} \) not exceeding the thermal limit which was recently acquired in a pilot study. The stability of the exposure field and therefore also the rf shielding of the set-up is another point of importance.

II. RF EXPOSURE SYSTEM

For the rf exposure of a number of animals an approved concept is to arrange the subjects on a circle around a common source, e.g. to use a carousel [1] or a radial waveguide [2] arrangement, and to align the snouts towards the feed. For the case of investigations of BBB, however, such a concept has been criticized by experts [3], arguing that the sensitive sensors around the rodents’ snouts could be overexposed thus masking the expected small effects from the brain. Another concept which avoids the latter is to place a loop antenna directly onto the head of a restrained rat [4]. The use of such an open structure, yet, is disadvantageous if multiple animals must be exposed, because of electromagnetic coupling between adjacent antennas and due to the rising complexity of the feeding network. In order to overcome these problems we modified the concept of the flat radial waveguide and constructed a spherical TEM waveguide [5] with a coaxial feed at the tip and the exposure field leaking from the rim (Fig. 1).

(a)

(b)

Fig. 1. Evolution from a flat cylindrical radial waveguide (a) to a spherical waveguide (b)

The spherical waveguide has been approached by a double-cone with a hexagonal basis for reasons of fabrication (Fig 2a). In the feed element at the top the input power is uniformly distributed over the six compartments of the waveguide. Since the exposure field should be concentrated to a rather small area at the lower aperture of the double-cone a pair of metal bars with a gap of 6 mm in between was built into each
compartment (Fig 2b).

Fig. 2. Double-cone waveguide (a) with inner bar structure (b)

The 6 rocket restrainers for the immobilisation of the rats are fixed in such a way that the rats’ brains are always positioned immediately below the gap between the bars (Fig. 3). Thereby, a very localized exposure is achieved.

Fig. 3. Positioning of the restrainers below the bar structure of the waveguide

In order to avoid electromagnetic coupling between the exposure fields of adjacent animals the restrainers are placed into compartments (Fig. 4) which are shielded against each other and against the environment by using metal walls and hinged flaps covered with finely woven metal grids.

The size of the ground plane is 1.1m x 1.1m, the height from the ground plane to the tip is 40 cm. Figure 5 shows the scheme of the experimental apparatus. The signal source consists of a UMTS generator and a booster amplifier whereby the applied power is controlled by the computerized experimental protocol. The actual input power level is also monitored via a coupler/detector combination.

III. RESULTS

As a consequence of the unavoidable reflection from the rats the ratio between the field strengths in the waveguide and in the rats’ head is rather high. Still, due to the very strong magnitude of the field in the bar structure an electrical exposure field within the rats’ brain of more than 385 V/m is achieved for a total feed power of 1 W. Fig. 6 shows a typical...
line plot of the electric field for the present sequence of layers.

The cut of the normalized electrical field distribution shown in fig. 7 demonstrates that the field concentrates mainly in the rat’s head and that the field radiated from the rat’s body is very small. Thus, the measures for shielding the outer space from the exposure field can be kept rather simple. For the field strength at the location of the rats’ heads within the six rocket restrainers the max/min-ratio is only 1.09.

![Field Distribution](image)

Fig. 7. Numerically calculated field distribution on the basis of an anatomical Wistar rat model

Fig. 8 gives the SAR distribution across the anatomical rat model in a logarithmic (a) and in a linear (b) scale. Obviously, the electromagnetic field energy is mainly dissipated within the central region of the head, as desired. The evaluation of the computations yields an SAR, averaged over the total volume of the brain (mass 2 g), of 8.2 W/kg per 100 mW input power at the tip of the waveguide.

![SAR Distribution](image)

Fig. 8. Numerically calculated SAR distribution (a) logarithmic plot (b) linear plot

The calculation of the temperature distribution by numerical solution of the bio-heat equation also reflects the localized exposure of the animals (Fig. 9) and gives additional hints on the local heat-flow due to the thermal isolation and transition properties of the different kinds of tissue.

![Temperature Distribution](image)

Fig. 9. Numerically calculated temperature distribution (a) absolute steady-state temperature for 357 mW input power (b) temperature difference between rf exposed case and unexposed case assuming a constant ambient temperature of 24°C and a blood temperature of 37°C

Furthermore, measurements of the local brain temperature in rf exposed cadavers of rats were performed. To do so, a fibre optic temperature probe was contacted to the brain of the subjects via a tiny bore through the cranial bone and temperature change was recorded during application of the rf field at 2 GHz. A typical time course of the temperature development between onset and switch-off of the rf signal for an input power of 100 mW is shown in fig. 10.

From the slope of the temperature curve one can also derive the SAR exhibiting an average value of 7.75 W/kg @ 100 mW. Applying the standard deviation of ±18% this measured value fits well with the SAR calculated from the electrical field distribution.

In order to adjust the power for the final experiments in such a way that no thermal effect occurs (i.e. ΔT < 0.1°C) one has to consider that - in contrast to the temperature development
in cadavers - the temperature change in living animals is much smaller due to the blood flow and due to the thermal regulatory system. From Fig. 10, for instance, a temperature rise in the cadaver of more than 2°C can be read. The calculation of the temperature in Fig. 9 already considers the influence of the blood flow. Therefore, re-calculated for the standard input power of 100 mW, a temperature rise of only 0.3°C is found. This corresponds famously to results that were achieved by temperature measurements with narcotised rats for the same exposure field. The temperature rise in vital rats is expected to be even smaller due to the active thermal regulation. Thus, the calculations from the thermal rat model and the measurements with narcotised animals, respectively, are judged to give worst case results for the temperature increase enabling an rf power adjustment with a sufficient safety distance for an experiment with healthy living rats.

IV. CONCLUSION

An exposure device for the local application of 2 GHz-fields to the brain of rats was described and characterised by field and SAR calculations and measurements. Moreover, numerical and experimental determinations of the brain temperature were shown and a procedure was presented for the adjustment of the power that excludes a thermal overload of the animals.

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