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EXPOSURE SETUPS FOR LABORATORY ANIMALS AND VOLUNTEER STUDIES USING BODY-MOUNTED ANTENNAS

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For two different *in vivo* exposure setups body-mounted antenna systems have been designed. The first setup is designed for investigation of volunteers during simulated mobile phone usage. The setup consists of a dual-band antenna for GSM/WCDMA with enhanced carrying properties, which enables exposure for at least 8 h a day. The 10 g averaged localised SAR—normalised to an antenna input power of 1 W—measured in the flat phantom area of the SAM phantom amounts to 7.82 mW g^{-1} (900 MHz) and 10.98 mW g^{-1} (1966 MHz). The second exposure setup is used for a laboratory behavioural study on rats. The design goal was a localised, well-defined SAR distribution inside the animals' heads at 900 MHz. To fulfil the biological requirements, a loop antenna was developed. For tissues around the ears, a localised SAR value of 50.12 W kg^{-1} averaged over a mass of 2.2 g for an antenna input power of 1 W is obtained.

INTRODUCTION

For health risk assessment of mobile phone exposure different *in vivo* exposure setups are used for human volunteer and animal studies, respectively. In the first case, the most obvious exposure system comprises the use of commercially available mobile phones. Actions have to be taken in order to guarantee double-blind protocols in terms of temperature load and acoustic sensations of the mobile phone. In addition, a device holder has to be considered which guarantees a standard telephone position. More sophisticated systems for GSM RF head exposure using e.g. patch antennas have been proposed too[(1)]. In this paper, we present a novel exposure system for simulating GSM and also WCDMA mobile phone usage. The setup is used in a project[(2)] aiming at analysing possible effects of high-frequency electromagnetic fields emitted by mobile phones on brain activity in sleeping and waking.

Exposure setups used in animal studies can be categorised as local or whole body exposure systems. For local exposure, a rat head exposure system is suggested in[(3)]. The rat is restrained in a tube to expose it locally by a printed loop antenna. For the animal study discussed here a new exposure system for local exposure in the head of a rat was developed. The exposure setup is used in a project[(4)] in order to investigate the potential correlation between tinnitus and GSM mobile phone usage. The rats in this project need to be unrestrained due to the design of the experiments. To fulfil the biological requirements, a meandered loop antenna for 900 MHz was developed.

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EXPOSURE SYSTEMS

Signals

In order to simulate GSM mobile phone usage, a 900 MHz pulse modulated carrier was used[(5)]. The 1966 MHz WCDMA signal is generated according to[(6)].

Exposure setups

Figure 1 shows the setup for the volunteer study.

It consists of a GSM and a WCDMA signal generator, a RF switch, a power amplifier, a directional power meter and a dual-band antenna. The antenna is connected to the power metre via 5 m coaxial cable in order to guarantee a sufficient mobility. The whole setup is computer controlled. Double-blind scenarios are realised by the RF switch that enables GSM, WCDMA and sham exposure. Sham exposure is at least 80 dB below the GSM and WCDMA signal levels due to the RF switch isolation.

The setup for the animal study is shown in Figure 2. It consists of a GSM signal generator, a power amplifier, a directional power metre, a directional coupler, a programmable attenuator, two power dividers, several switches and eight loop antennas connected to rotary joints. The whole system is computer controlled.

The exposure setup is divided into two groups of four cages (System I and System II) that can be exposed simultaneously by a double-blind protocol with different SAR levels up to 20 W kg^{-1} and sham exposure, respectively. During an exposure of 120 min the power is divided to the eight loop antennas according to an exposure scheme.

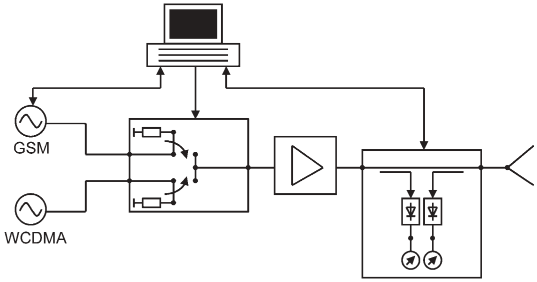

Figure 1. Block diagram of the exposure setup for stimulating GSM and WCDMA mobile phone usage.

The directional coupler, the attenuator and the switch (SW) allow the individual operation in each group with the intended SAR levels. The performance (s11) of each antenna is checked before and after an exposure automatically. Free movement of the rats within the cages is guaranteed by rotary joints, which are connected to the feeding lines of the antennas. Furthermore, the feeding lines are protected against gnawing by using small tubes of plastic.

Antenna design

Essential components of both exposure setups are the antennas. In the volunteer study, the antenna has to be placed close to the ear yielding a local exposure situation. The electromagnetic near-field near the antenna is intended to be similar to that of a common GSM and WCDMA mobile phone with an integrated antenna. Kivekäs *et al.*(7) showed that SAR distributions of common mobile phones with integrated antennas mainly depend on the length of the mobile. For this reason the length of the PCB for mounting the radiating element has to be in the order of a typical mobile phone. Mobile phones with other antenna types (monopole, helix, etc.) may have different SAR distributions. Furthermore exposure

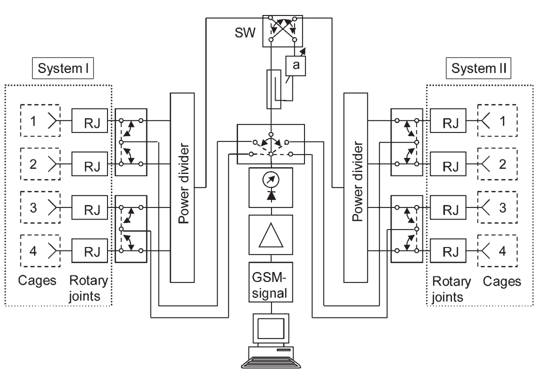

Figure 2. Block diagram of the system for rat head exposure.

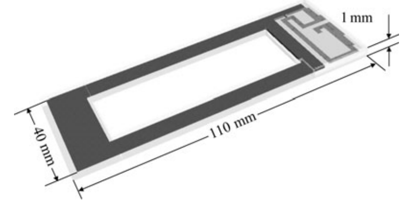

Figure 3. CAD model of the dual-band antenna.

of volunteers should be possible day and night with total exposure times of 8 h. On the basis of these specifications a thin dual band antenna with a mass of 14 g was developed (Figure 3). It consists of a PCB with typical mobile phone dimensions and a radiating element similar to common PIFA radiators of modern mobile phones.

In order to account for good carrying properties, the design is completely planar with a total thickness of 1 mm. Metal parts are covered with foam and a washable textile cover. Carrying properties are further enhanced by a slot inside the PCB. This enables an exposure position where the antenna is placed at the head surface and the pinna is put through the slot of the antenna.

In the animal study, a localised, well-definied SAR distribution inside the head of a rat is required. For the behavioural experiments, the rats need to be unrestrained. A meandered loop antenna was developed to meet the biological requirements. The antenna is meandered to achieve self-resonance at 900 MHz. As depicted in Figure 4, the metallic structure etched on Kapton foil is glued on a ring of plastic.

The reflection coefficient of the antennas is shown in Figure 5. For the volunteer study, the measurement was carried out under free space condition. The antenna has two main resonances in the 900 and 1950 MHz range. In addition, two parasitic resonances due to the PCB itself and the slot therein can be identified. The reflection coefficient of the loop antenna used in the animal study is analysed in body-mounted configuration. Good agreement has been found between the simulated – based on a

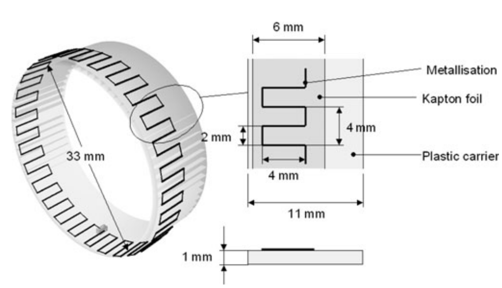

Figure 4. CAD model of the meandered loop antenna.

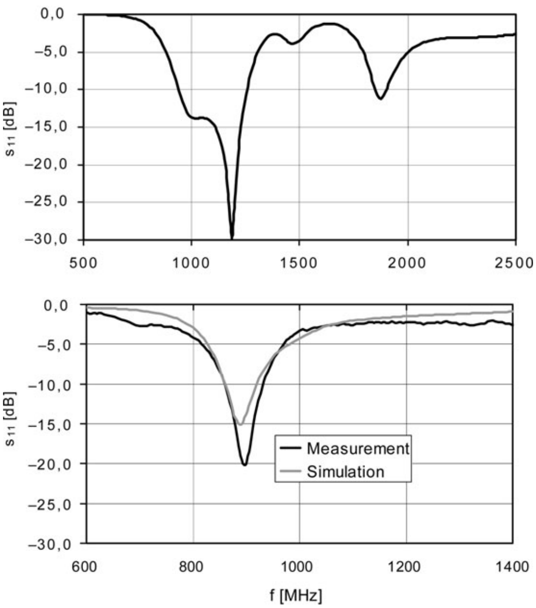

Figure 5. Reflection coefficients of the antennas for the volunteer study (top) and animal study (bottom).

numerical rat model – and the *in vivo* measured reflection coefficients.

METHODS

Measurement and simulation

The SAR was measured with a DASY 4 measurement system. For compliance testing of mobile phones (e.g. EN 50361, IEEE 1528), the SAM phantom should be used. The dual-band antenna used in the volunteer study is placed behind the pinna rather than on the pinna. This position cannot be simulated with the ear spacer that is usually used with the SAM phantom. Therefore, the flat section of the phantom was used for the dosimetric assessment. For the measurements, the phantom was filled with head tissue-equivalent liquid with a mass density of $\rho = 1000\ \mathrm{kg\ m^{-3}}$. The measured dielectric properties of the liquid were $\epsilon_r = 40.8 \pm 2.1$, $\sigma = 0.98 \pm 0.05\ \mathrm{mho\ m^{-1}}$ for GSM and $\epsilon_r = 38.5 \pm 2.0$, $\sigma = 1.42 \pm 0.08\ \mathrm{mho\ m^{-1}}$ for the WCDMA FDD frequency range.

For the animal study no standardised phantom is available. Therefore, a cylindrical phantom was used to validate the numerical method. The phantom shell is made of low-loss dielectric material ($\epsilon_r = 3$) filled with head tissue-equivalent liquid with a mass density of $\rho = 1000\ \mathrm{kg\ m^{-3}}$. The measured dielectric properties of the liquid were $\epsilon_r = 42.5 \pm 2.1$ and $\epsilon_r = 0.95 \pm 0.05\ \mathrm{mho\ m^{-1}}$ for GSM900.

The numerical dosimetric assessment was carried out with inhomogeneous models (Figure 6) obtained

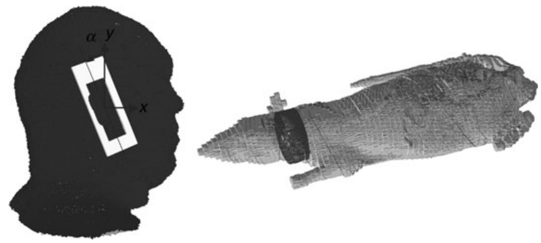

Figure 6. Human head and rat model with antennas.

from Air Force Research Laboratory[8]. The voxel size of the anatomically shaped human head model is $1 \times 1 \times 1$ mm and of the rat model $0.39 \times 0.39 \times 1$ mm.

The dual-band antenna is placed directly at the human head model. This implies that some voxels of the compressed pinna are overwritten by antenna voxels. The coordinate system is defined with respect to the main axes of the human head. Angle α is defined between the *y*-axis and the projection of the vertical centreline of the antenna on the *xy*-plane. The rat model wears the loop antenna around the neck in order to excite well-defined SAR levels in the head.

RESULTS

SAR in the phantom

The measured and simulated SAR distributions of the dual-band antenna are depicted in Figures 7 and 8.

For 900 MHz, a widespread SAR maximum is located near the middle of the antenna and in the direction to the radiating element. The SAR maximum is more pronounced at 1966 MHz. Similar results were published in[9] for mobile phones. Comparing simulations and measurements, a good qualitative agreement can be observed.

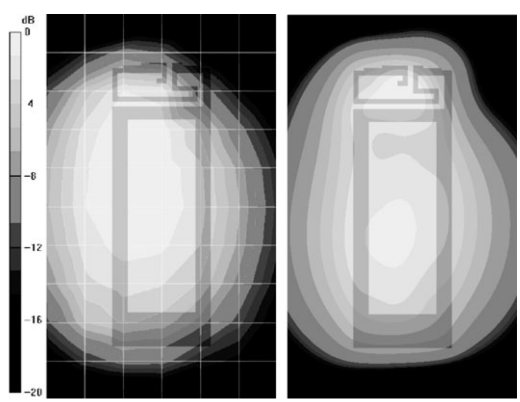

Figure 7. Normalised SAR distribution at 900 MHz measured (left) and simulated (right).

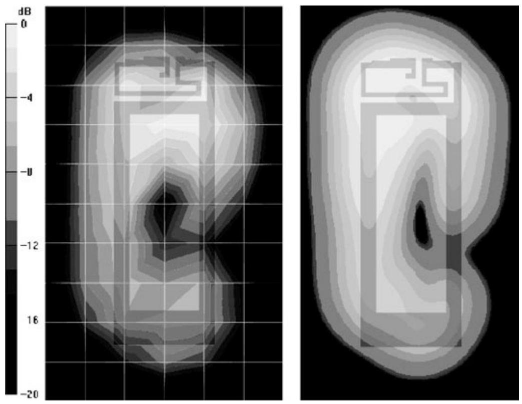

Figure 8. Normalised SAR distribution at 1966 MHz measured (left) and simulated (right).

For the animal study, the local SAR distribution was measured along the centreline of a cylindrical phantom with the meandered antenna placed in the middle of the phantom. Compared with computational simulations, the measured SAR distribution deviates up to 32% only. Differences can be attributed to antenna losses in the measurement.

SAR in the heterogeneous model

For the dual-band antenna placed at the numerical head model, the averaged SAR values for three different positions are summarised in Figure 9.

For the SAR evaluation the compressed pinna of the human head model is not considered. As depicted in Figure 9, the SAR_{1g} change is $<28\%$ at 900 MHz. The SAR value is more sensitive to an increase of the antenna distance to the human head compared with an additional antenna rotation. In contrast to SAR_{1g}, the SAR_{10g} change is not significant ($<2\%$). For 1966 MHz, the corresponding

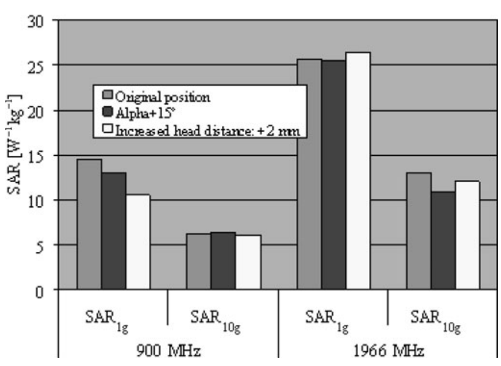

Figure 9. SAR variation for three different positions of the dual-band antenna.

numbers are 3% (SAR_{1g}) and 17% (SAR_{10g}), respectively.

Numerical results for the local SAR distribution in the rat model show that the maximum SAR is excited at the periphery of the head. For the input power of 1 W, a local SAR of 50.12 W kg^{-1} averaged over the tissues near the ear with a mass of 2.2 g is obtained.

CONCLUSION

Two antenna systems were designed for studies on long time local exposure of volunteers and unrestrained rats, respectively. The exposure setups are fully computer controlled, allowing double-blind protocols. A good agreement can be observed between numerical and measured results.

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