# EXPOSURE SETUPS FOR IN VIVO EXPERIMENTS WITH NON-RESTRAINED RODENTS AT GSM AND UMTS FREQUENCIES

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## INTRODUCTION

Rodents like hamsters, mice and rats are scientifically well-described subjects which are routinely used in experiments concerning the investigation of possible adverse effects due to the exposure to rf radiation occurring in digital mobile communication systems.

Two different concepts for such 'in vivo' experiments have been applied: the first prevents movements of the animals by restraining them in ventilated plastic tubes during exposure, the second is based on freely moving animals that are kept in their accustomed cages. The advantage of the first concept with respect to the latter is that a very uniform exposure can be achieved due to the fixed position and orientation of the animals. On the other hand, restrained animals can only be exposed for a short time in order to avoid an increased stress level that could superpose the bio-electromagnetic effects searched for. Thus, for long-term experiments to be discussed here, only non-restrained animals are usable. Without doubt, the development of exposure setups for such cases aiming at an exposure with a high degree of uniformity is the more challenging task from an engineering point of view. It can be shown that by suitable choice of the kind of exposure device and by optimization of the field distribution rather small standard deviations of the whole body SAR can indeed be obtained even for freely moving animals.

## EXPOSURE SETUPS

For the exposure of rodents kept in cages the following two basic concepts exist:

### Open Arrangements

Setups of this kind are characterised by an antenna as radiation source aiming at a target area where the animals are located. Since the field energy is not guided the field and SAR distribution is substantially determined by the antenna ‘s radiation pattern and by the electromagnetic properties of the room enclosing the arrangement. In case of metallic walls, for instance, large field inhomogeneities due to reflections and interferences were observed. If the arrangement is placed into an anechoic chamber, i.e. a shielded room lined with absorbing material the reflections can be reduced. Such chambers are widely used for EMI tests in order to simulate free-space conditions. For experiments under consideration, the cages would be arranged as a spaced matrix in the far-field of a radiating antenna, usually a sector antenna. Such a setup requires much space, is very costly, and needs amplifiers with high output power, since substantial amounts of the field are not dissipated by the test objects. Because of residual reflections at the absorber and due to the antenna shaping it is still impossible to produce a uniform field distribution over the total cage region, especially if many targets are to be exposed. Another drawback is that this configuration cannot be fully analysed by numerical procedures, since the large ratio of total field volume (the anechoic chamber) and 'biological' volume (the animals) would require an extraordinary large number of discretization points and, as a result, a huge amount of computer resources. Therefore, only parts of the setup, for instance one cage with animals, can be modelled and numerically analysed in order to estimate the whole body SARs. The additional SAR-variations due to the field inhomogeneities must be estimated by considering the field strengths measured at the different cage positions inside the anechoic chamber.

### Closed waveguide

On the other hand, arrangements embedded into electrically closed waveguides with confined volume benefit from the guidance of energy between source and target. Primarily, the spatial field distribution is determined by the superposition of the propagating eigenmodes of the waveguide. In order to achieve a uniquely defined exposure only the fundamental mode should preferably propagate. This implies measures to suppress higher-order modes, if the waveguide's cross sectional size exceeds half the wavelength $\lambda$, as it is often the case for experiments in the GSM and UMTS frequency range. Basically, the achievement of a substantially homogeneous exposure field is desirable in order to reduce variations of the exposure due to movements of the rodents. Therefore, waveguides with constant fields of the fundamental mode should be chosen, if possible, e.g. transmission lines propagating TEM waves.

One of the most important demands of a biological experiment is the high statistical power of the results, therefore a large number of animals exposed to the same electromagnetic field distribution is needed. An exposure setup which enables the uniform exposure of many animals in addition with other favorable features is represented by the radial waveguide.

## RADIAL WAVEGUIDES

Radial waveguides mainly consist of two parallel circular metal plates. They are able to propagate waves in radial direction which are excited by an antenna in the center. The waveguide is terminated by absorbing material at its radial boundary, and the cages are arranged on a circle line around the antenna. Due to this symmetrical arrangement a highly uniform field distribution across the cages is achieved. The field is bound to the space between the metal plates, thus yielding a good power efficiency. Within certain limits, the distance of the plates can be chosen arbitrarily according to the height of the cages. An additional advantage of this setup is that the entire waveguide can be fully analyzed by numerical procedures. Moreover, there is no need to shield the laboratory from external electromagnetic fields, because the waveguide is a fully enclosed system.

### Electromagnetic Field Distribution

The fundamental mode of the radial waveguide is the TEM-mode with regard to the radial direction of propagation. In biological experiments the preferred operating mode should be the fundamental TEM-mode for reasons of uniqueness of the exposure field. By combination of a small plate distance, a circularly symmetric excitation and an effective absorber at the outer boundary with uniform reflectivity it is possible to achieve a good power efficiency and a highly constant azimuthal field distribution that changes only slightly in radial direction. As mentioned before, higher order modes with a z–dependency are not able to propagate if the plate distance h is chosen electrically small, e.g. if $h < \lambda/2$ holds. In order to match this condition, in an air-filled waveguide the height may not exceed 16.7 cm at 900 MHz, for instance. This implies that, higher order modes need to be suppressed in order to retain a uniquely defined exposure field. In order to achieve this, different concepts were examined, for example:

*Fundamental mode excitation of the exposure region*
The height of the radial waveguide is kept so small for low radii that only the fundamental mode can exist there, while a stepwise increase to the necessary height for inserting the cages follows immediately in front of the exposure region.

*Modification of cutoff frequencies in the exposure regions*
A method known from microwave resonators in order to avoid undesired modes aims at shifting the cutoff frequencies of these modes outside the operating range by inserting dielectric bodies or by changing the geometry of the guiding structure.

*Electromagnetic separation of the exposure regions*
If the size of the animals is very large as compared to the wavelength (e.g. rats exposed at UMTS frequencies) a total suppression of higher order modes may be impossible. In such cases an electromagnetic decoupling of adjacent exposure regions (cages) can be performed, for instance by introducing walls with suitably matched surface impedances between the cages. In order to allow for TEM wave propagation (constant fields in transversal direction) no metallic walls can be used. A convincing solution seems to be the application of photonic band gap structures simulating magnetic walls.

## CONCLUSION

Results for all three measures including dosimetrical analyses of implemented radial waveguide systems for different kinds of rodents and various frequency regions will be presented.