LOCALIZED EXPOSURE SYSTEM OF 2.45 GHZ MICROWAVE TO THE RABBIT EYE

Kanako Wake[(1)], **Hiroyuki Hongo**[(2)], **Soichi Watanabe**[(3)], **Yukio Yamanaka**[(4)], **Masao Taki**[(5)], **Yoshitsugu Kamimura**[(6)], **Toru Uno**[(7)], **Masami Kojima**[(8)], **Ikuho Hata**[(9)], **Kazuyuki Sasaki**[(10)], **Itaru Yamamoto**[(11)]

[(1)] ***Communications Research Laboratory, 4-2-1 Nukuikitamachi, Koganei, Tokyo 184-8795, Japan. kana@crl.go.jp*** [(2)] ***Tokyo University of Agriculture and Technology, 2-24-16 Nakamachi, Koganei, Tokyo 184-8588, Japan:*** [(3)] ***As (1) above, but E-mail: wata@crl.go.jp*** [(4)] ***As (1) above, but E-mail: yama@crl.go.jp*** [(5)] ***Tokyo Metropolitan University, 1-1 Minami-osawa, Hachioji, Tokyo 192-0397, Japan: taki@eei.metro-u.ac.jp*** [(6)] ***Utsunomiya University, 7-1-2 Yoto, Utsunomiya, Tochigi 321-8585, Japan: gami@ieee.org*** [(7)] ***As (2) above, but E-mail: uno@cc.tuat.ac.jp*** [(8)] ***Kanazawa Medical University, Daigaku 1-1, Uchinada, Kahoku, Ishikawa 920-0293, Japan: hata-i@kanazawa-med.ac.jp*** [(9)] ***As (8) above, but E-mail: m-kojima@kanazawa-med.ac.jp*** [(10)] ***As (8) above, but E-mail: sasaki-k@kanazawa-med.ac.jp*** [(11)] ***As (8) above, but E-mail: itaru@kanazawa-med.ac.jp***

ABSTRACT

We developed an experimental setup to expose an eye of a rabbit locally to continuous and pulsed microwaves of 2.45 GHz. A coaxial-to-waveguide adapter filled with low-loss dielectric material was used as an antenna for localizing the exposure on the eye of the rabbit. We made a rabbit model based on X-ray CT data for dosimetry. According to the dosimetry, SAR was localized near the exposed eye of the rabbit. We also estimated the temperature elevation during the exposure by numerical analysis.

INTRODUCTION

The eye (especially lens and cornea) is thought to be a critical organ that can be affected by MW (microwave) irradiation due to the absence of blood circulations. Guy *et al.* investigated the effects of 2.45 GHz continuous MW to the eye of rabbit and reported the threshold temperature of 41 °C for cataract by MW exposure (incident power density of 150 mW/cm^2 for 100 minutes) [1]. This effects had been taken into consideration for several guidelines.

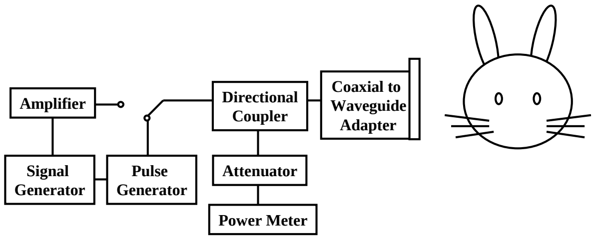
Kues et al. reported the corneal endothelial abnormalities in laboratory animal exposed to continuous and pulsed MWs at 2.45 GHz [2]. However, another study by Kamimura et al. showed the opposite results for the continuous MW irradiation [3]. The absence of the reproducibility suggests that further investigation on the effects of MWs on eyes with large number of animals, quantitative exposure without thermal effect of whole body and well-established dosimetry is needed. In this study, we developed a new system to expose an eye of a rabbit to MWs.

EXPOSURE SYSTEM

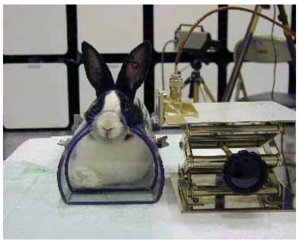
We developed an experimental setup to expose the eye of the rabbit locally to continuous and pulsed microwaves of 2.45 GHz (Figure 1). A coaxial-to-waveguide adapter is used as the antenna to generate MWs. The aperture size of the ordinary waveguide at 2.45 GHz is about 43.2×86.4 mm^2 and is comparable with the size of the rabbit head. We developed a small antenna by filling low-loss dielectric material (macerite) inside the waveguide to localize the MW exposure on eyes and to avoid thermal effects of whole body. The relative permittivity of the macerite is about 5.5. We achieved to reduce the aperture size of the small waveguide to 12.6×18.5 mm^2. The rabbit eye is located at the distance of 40 mm from the antenna. This distance was determined by the condition that the antenna input impedance was not changed by the movement of rabbit and fairly high input power density to the eye was maintained.

In the previous studies, animals were sometimes anesthetized and sometimes not anesthetized, and the results were different from each other [2][3]. In our experimental setup, rabbits are put under constraint with a plastic holder, which makes us possible to investigate the effects of anesthesia.

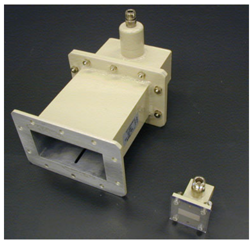
Electric fields near the ordinary waveguide and our small waveguide were measured using a small isotropic electric field probe (SPEAG, ER3DV5). Figure 2 shows the electric field distributions at a distance of 30 mm from the aperture of each waveguide. Filling the low-loss material inside the waveguide localized electric fields compared to the ordinary one. With this exposure system, antenna input power of about 0.07 W can generate the microwave whose incident power density at the position of the eye (40 mm from the aperture of waveguide) is 1.0 mW/cm^2.



(a) Schematic view

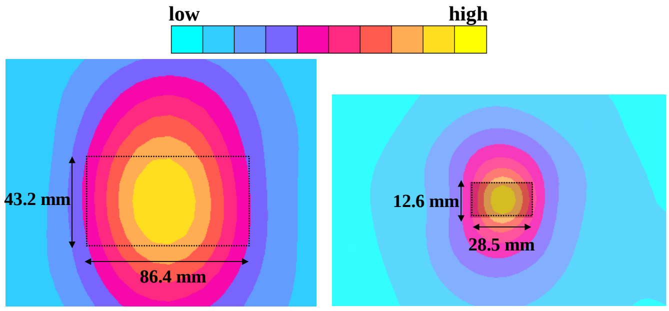


(c) Photograph



(b) Waveguides

Figure 1: Exposure system.



(a) Ordinary waveguide (b) Small waveguide

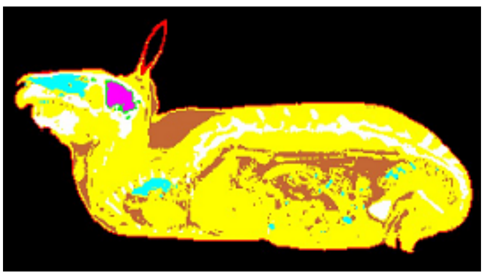
Figure 2: Electric field measure at a distance of 30 mm from both waveguide.

MODELS AND METHODS

For the evaluation of SAR inside the rabbit, we used a numerical rabbit model for numerical dosimetry and solid rabbit phantoms for experimental dosimetry.

We developed a rabbit model based on X-ray CT images. The X-ray CT images of a rabbit constrained by the plastic holder were taken with anesthesia at Kanazawa Medical University. Conversion and discrimination from CT data to numerical model were partly automated [4]. Because we are interested in eyes, we modeled eyes precisely. The developed model consists of 11 types of tissues and the resolution of the model was 1 mm (Figure 3(a)). Table 1 shows the tissues and their electrical properties used for calculation. The antenna was also modeled for numerical dosimetry. The finite-difference time-domain (FDTD) method was used for calculating the SAR distribution in the rabbit model. The calculation region was $240\times335\times241$ meshes and the resolution of each mesh was 1 mm. The calculated antenna input impedance was fairly equal to the measured data (Figure 4).

Solid phantoms of the rabbit (Figure 3(b)) had same shape as the numerical model but made by homogeneous material. For experimental dosimetry, phantoms were exposed by the antenna and temperature elevation due to exposure were measured using a thermographic camera.



(a) Numerical model

(b) Experimental phantom

Figure 3: Rabbit model.

Table 1: Tissues and their electrical properties (ε_r, σ [S/m])

Tissue	ε_r	σ	Tissue	ε_r	σ	Tissue	ε_r	σ
muscle	53.57	1.810	bone	14.97	0.6	fat	10.82	0.268
brain	42.54	1.511	CSF	66.24	3.458	skin	38.01	1.464
sclera	52.63	2.033	vitreous humor	68.21	2.478	cornea	51.61	2.295
lens	44.63	1.504	anterior chamber	68.21	2.478			

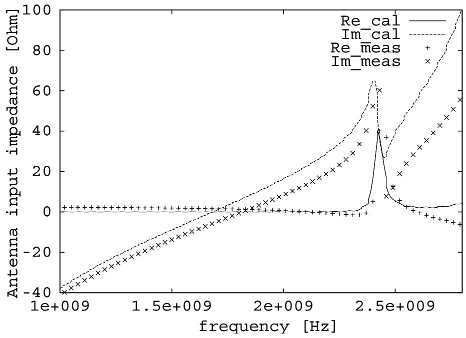


Figure 4: Calculated and measured antenna input impedance

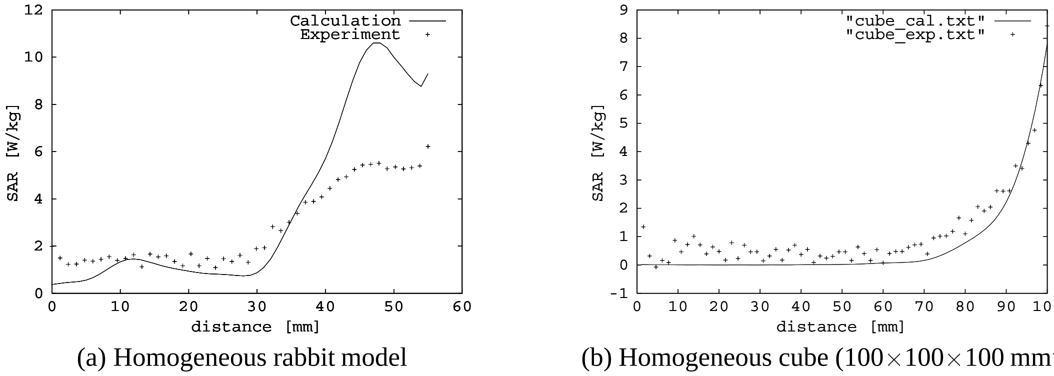
SAR EVALUATION

Comparison Between Calculation and Experiment

We compared the SARs calculated in the homogeneous numerical model with those evaluated by the experimental dosimetry using the homogeneous solid phantom. Figure 5 (a) shows the SAR value along the axis through one eye to another eye in the rabbit model. We also compared between calculation and experiment using $100\times100\times100$ mm^3 cubic model (Figure 5 (b)). Although the SAR values of calculation and experiment agreed well with cubic model, measured SARs around the exposed eye in the rabbit by experiment were smaller than calculated results. Complex shape of the rabbit, especially around eyes whose curvature was large, was thought to be one of the reasons of such difference.

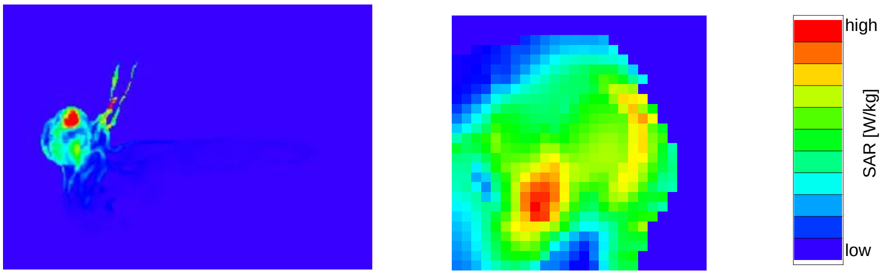
SAR Distribution in the Rabbit Model

SAR distribution calculated with heterogeneous numerical model were shown in Figure 6. High SAR was found near the exposed eye of the rabbit. The averaged SAR over the exposed eye and whole body were 0.36 and 0.0061 W/kg, respectively, by the input power density at the eye of 1 mW/cm^2. The ratio of the eye averaged SAR to whole body averaged SAR was about 60. These results show that the localized exposure to the rabbit eye was achieved by this exposure system without causing the whole-body thermal effects.



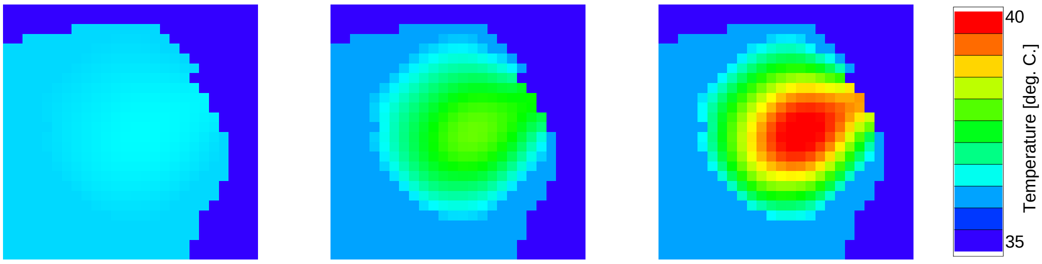
(a) Homogeneous rabbit model (b) Homogeneous cube ($100\times100\times100$ mm^3)

Figure 5: SAR values along the axis through one eye to another eye



(a) Sagittal section of whole body (b) Vertical plane across the eye

Figure 6: SAR distribution in heterogeneous rabbit model



(a) 10 mW/cm^2 (b) 150 mW/cm^2 (c) 300 mW/cm^2

Figure 7: Temperature distribution in vertical section across the eye

TEMPERATURE ELEVATION DUE TO EXPOSURE

To investigate the mechanisms of the effect of MWs on the eye, evaluation of temperature distribution due to the exposure is also important. The temperature elevation due to the exposure can be calculated using bioheat equation [5][6]. For the thermal problem associated with the eye, the eye was usually assumed to be thermally isolated [5][6]. Table 2 shows the thermal parameter of the eye used for calculation. C, K and ρ denote specific heat capacity, thermal conductivity and density of tissues, respectively. During the thermal analysis, an ambient temperature of 24 °C and tissue temperature outside the eyes of 37 °C were assumed.

SAR distribution around the eye and temperature distribution at steady-state for each incident power density are shown in Figures 6 (b) and 7. The temperature of the lens can reach 41 °C by the exposure whose incident power density is 300 mW/cm^2 by this exposure system.

Table 2: Thermal parameters of the eye

	vitreous humor	lens	cornea & sclera	anterior chamber
C [J/kg· °C]	3997	3000	4178	3997
K [W/m· °C]	0.603	0.40	0.58	0.603
ρ [kg/m^3]	1000	1050	1050	1000

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