Adolf Glaser

POLARIZATION AND FREQUENCY EFFECTS ON WHOLE ANIMAL ABSORPTION OF RF ENERGY*

O. P. Gandhi
Electrical Engineering Department
University of Utah
Salt Lake City, Utah

ABSTRACT

A parallel plate waveguide is used to determine wideband RF (285 to 4000 MHz) absorption characteristics of 96 to 390 gm rats and biological-phantom prolate spheroidal bodies, and compared to results for free space irradiation. Power deposition more than an order of magnitude greater is observed at resonance for waves polarized along the long dimension.

---

* This work was performed at the Department of Microwave Research, Walter Reed Army Institute of Research, Washington, D. C., and supported by Task Order 74-19 under the U. S. Army Research Office, Durham Scientific Services Program, as conducted by Battelle Columbus Laboratories.

1973-59

0

POLARIZATION AND FREQUENCY EFFECTS ON WHOLE ANIMAL ABSORPTION ON RF ENERGY

A parallel plate waveguide (WG) has been used to measure wideband RF absorption of biological systems as applicable to plane wave fields. The WG cross-sectional dimensions (6.35 x 15.9 cm^2) are such as to accommodate the animal to fill no more than 10 to 30 percent of the cross-sectional area at any axial location. A ground plate of somewhat larger width of 20.3 cm is used to allow for the region of fringing fields. Using a HP8410A network analyzer, the WG is used to measure absorption characteristics of 96 to 390 gm Wistar rats, 25 gm mouse, and brain-phantom prolate spheroidal bodies of several aspect (a/b) ratios to 5.75 (the value taken for humans) over the frequency band of 285 to 4000 MHz. In order to check the validity of the measuring system, absorption characteristics of different size spheres of brain-phantom material are run in the first instance. For nine spheres of diameter (2a) varying from 3.3 to 5.6 cm, the frequencies of peak absorption are found to vary from 1610 to 974 MHz, each corresponding to the value of ka = 0.55 to 0.59 as compared to the theoretical value[1] (from Mie theory) on the order of 0.50 to 0.52.

From the absorption characteristics of 25 gm mice and prolate spheroidal bodies for the three orientations $\hat{E} \| \hat{a}$, $\hat{H} \| \hat{a}$, and $\hat{k} \| \hat{a}$ (where $\hat{a}$ is along the major length), a strong orientational effect is observed, and this is sketched qualitatively in Fig. 1. The $\hat{E} \| \hat{a}$ orientation is found to be the most absorbing[2] and $\hat{H} \| \hat{a}$ the least absorbing, with the configuration $\hat{k} \| \hat{a}$ only slightly more absorbing than the $\hat{H} \| \hat{a}$ orientation. Also, peak absorption in the $\hat{E} \| \hat{a}$ configuration occurs at the lowest

frequency (ka ≈ 0.75 to 1.0). Maximum absorption for $\hat{k} \| \hat{a}$ and $\hat{H} \| \hat{a}$ orientations occurs at successively higher frequencies, with ka for these configurations on the order of a/2b. The observed values of ka for resonance in the different orientations are approximately obtained by requiring that, as for sphere,[1,3] the shortest circumference for the lossy creeping waves launched at the center of the shadow plane be 0.5 λ.

Alternative experiments, using plane waves at 1700 MHz to heat saline-filled prolate spheroidal bodies of fixed aspect ratio of 5.75 but changing overall dimensions, corroborate the main features of the WG results. The temperature increase for each minute of exposure to 200 mW/cm^2 radiation is plotted for the three orientations in Fig. 2. Following Anne, et al.,[4] the relative absorption coefficient S (= the absorption cross section/shadow area) at resonance is calculated and is listed in Table 1.

Table 1. Comparison of the relative absorption coefficients determined from the free space exposure and WG data.

Orientation	Resonance S for Free Space Prolate Spheroids (a/b = 5.75)	Resonance S from WG Measured Prolate Spheroids (a/b = 5.00)
1. $\hat{E} \| \hat{a}$	2.02	1.72
2. $\hat{k} \| \hat{a}$	4.14	3.59
3. $\hat{H} \| \hat{a}$	0.49	0.36

An excellent correlation between the two sets of values is noteworthy. The values of $(S)_{\hat{k} \| \hat{a}}$ for prolate spheroids of different a/b are plotted in Fig. 3 and testify to the viability of using a parallel plate

WG as a simple method of determining broadband absorption characteristics of biological systems. Figure 4 shows the thermographically recorded temperature variation along the major axis of a prolate spheroid of aspect ratio 5.75 for the three orientations. The tremendous disparity in the amount of heating between the $\hat{E} \| \hat{a}$ and $\hat{H} \| \hat{a}$ configurations is once again dramatized.

The WG has been used to measure the absorption characteristics (Fig. 5) of 96, 158, 261, and 390 gm Wistar rats (weight W varying by more than 1:4) selected randomly from a rat colony. Because of the limitation of the WG dimensions, only $\hat{k} \| \hat{a}$ orientation is used. Maximum absorption is observed at frequencies of 1217, 1020, 900, and 760 MHz, respectively. The frequencies of peak absorption and the absorption thereat are found to vary as $W^{-1/3}$ and $W^{2/3}$, respectively. The relative absorption coefficient S (at resonance) of 3.27 correlates well (see Fig. 3) with the values for prolate spheroids in the $\hat{k} \| \hat{a}$ configuration.

The measured data are in quantitative agreement with the results of the behavioral experiments.[5] From the WG measurements the absorption at 1700 MHz is more than that at 2450 MHz which, in turn, is larger than that at 3000 MHz. In the behavioral experiments the time from the onset of microwave irradiation to work stoppage is found to be in the reverse relationship, with the value at 1700 MHz being the lowest of the three frequencies.

From the above results the RF power deposition is found to vary significantly with orientation and with frequency. RF absorption larger by an order of magnitude or more may occur at resonance for $\hat{E} \| \hat{a}$ orientation than for other configurations. This should be taken into account in microwave biological effects research.

ACKNOWLEDGMENT

The author is indebted to Joseph Sharp and H. M. Grove for their support during his stay at Walter Reed. The assistance of Thomas Andrews and Peter Brown in many facets of this work is greatly appreciated.

REFERENCES

1. C. C. Johnson and A. W. Guy, "Nonionizing Electromagnetic Wave Effects in Biological Materials and Systems", *Proceedings of the IEEE*, Vol. 60, 1972, pp. 692-718.

2. For below-resonance regions this result is in qualitative agreement with the small-ka theory of C. H. Durney and C. C. Johnson (to be published).

3. T. B. A. Senior and R. F. Goodrich, "Scattering by a Sphere", *Proceedings of the IEE*, Vol. 111, 1964, pp. 907-916.

4. A. Anne, M. Saito, O. M. Salati, and H. P. Schwan, "Relative Microwave Absorption Cross Sections of Biological Significance", pp. 153-177 in Vol. 1 of *Biological Effects of Microwave Radiation*, Plenum Press, 1960.

5. T. D. Hawkins, H. M. Grove, T. W. Heiple, and J. Schrot, "Some Biological Effects of Microwave Irradiation in the Rat", to be published.

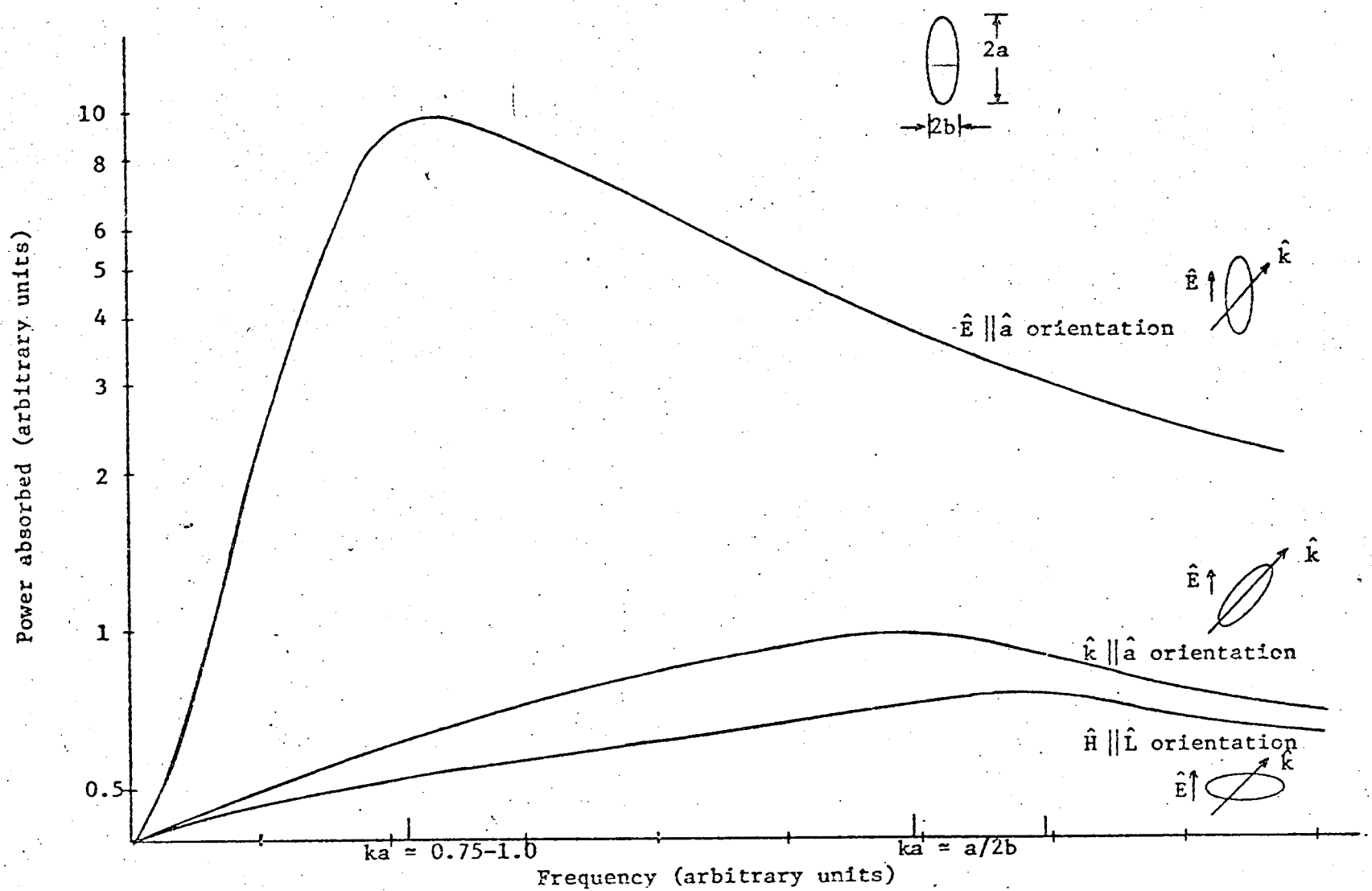


Fig. 1. Typical RF absorption curves for animals and bodies of prolate spheroidal shape.

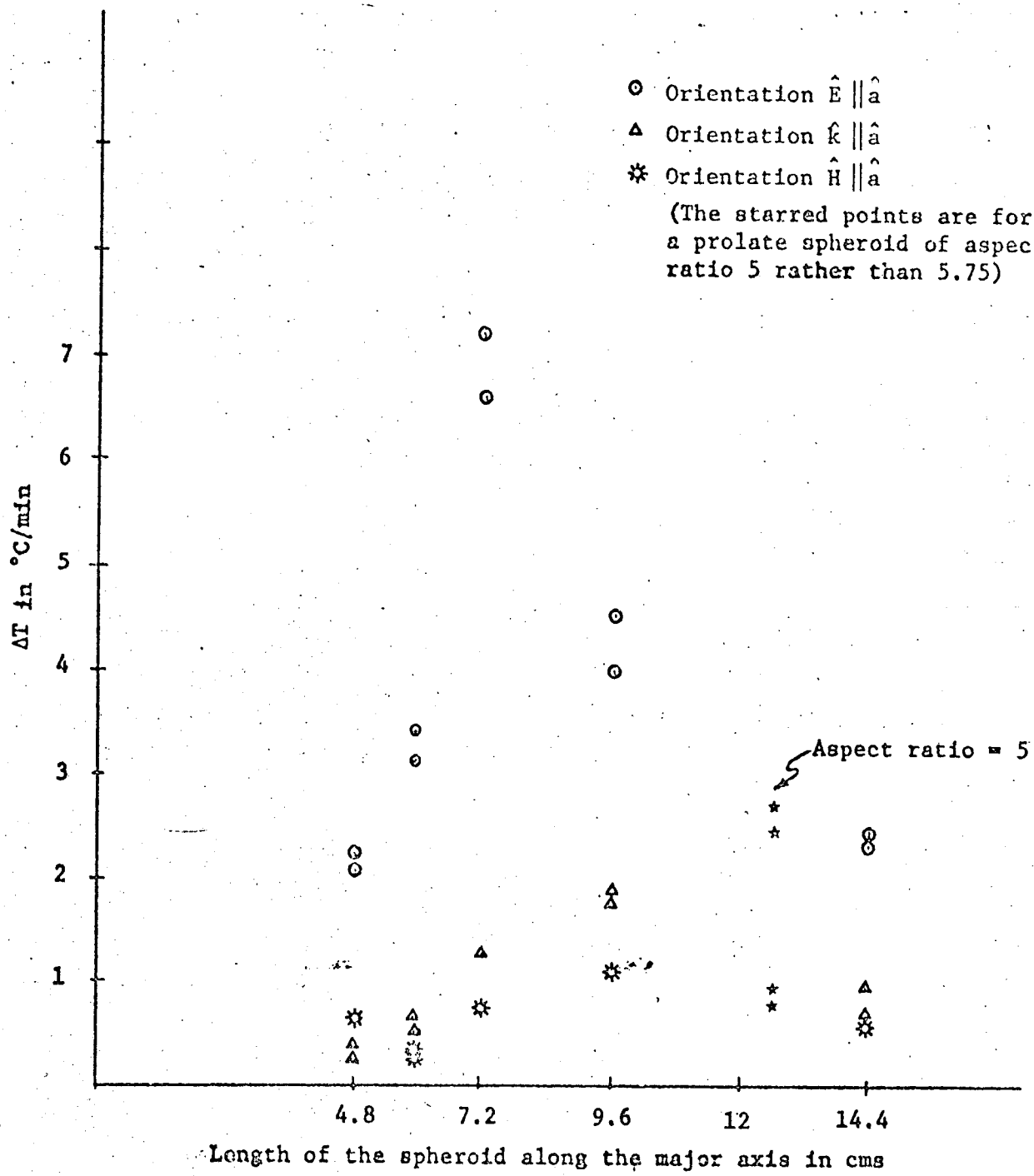


Fig. 2. Plot of heating of saline for prolate spheroids of aspect ratio 5.75 in degrees centigrade/min. of exposure to microwaves of power density of 200 mW/cm^2 at 1700 MHz.

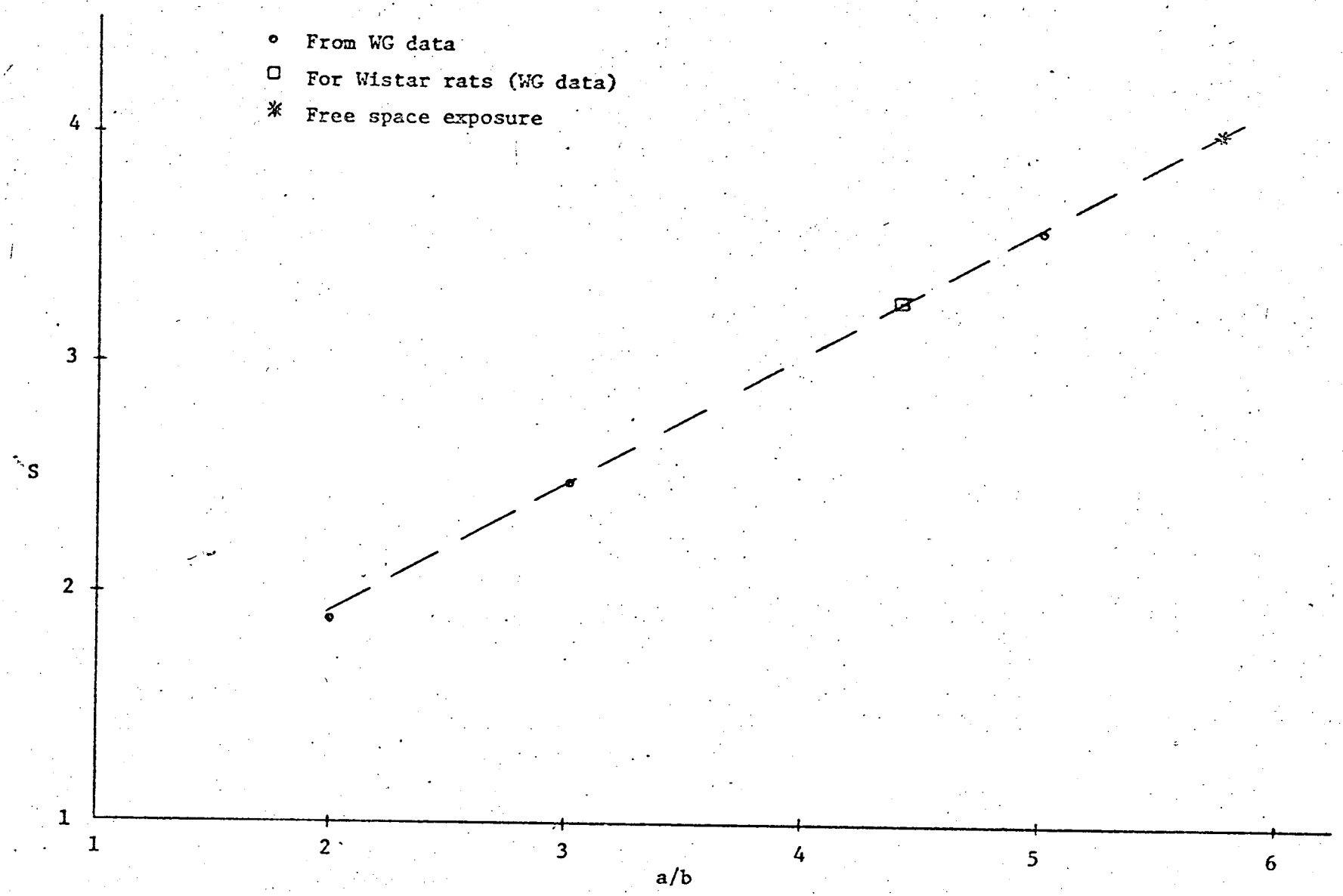
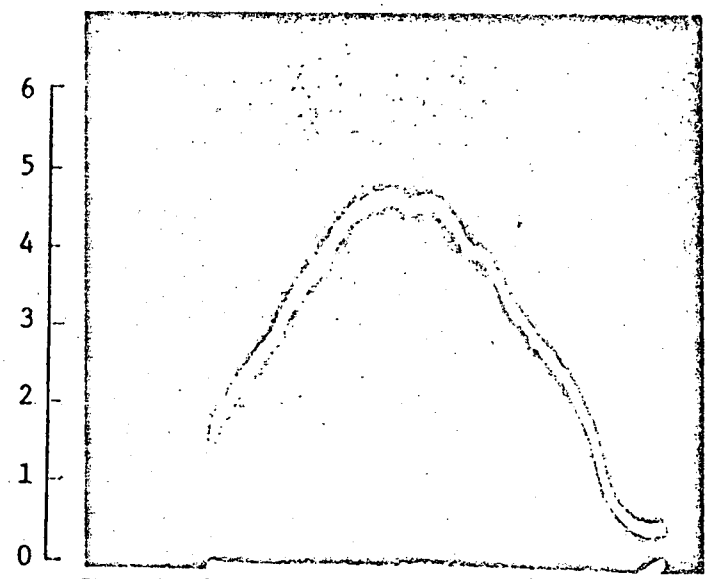
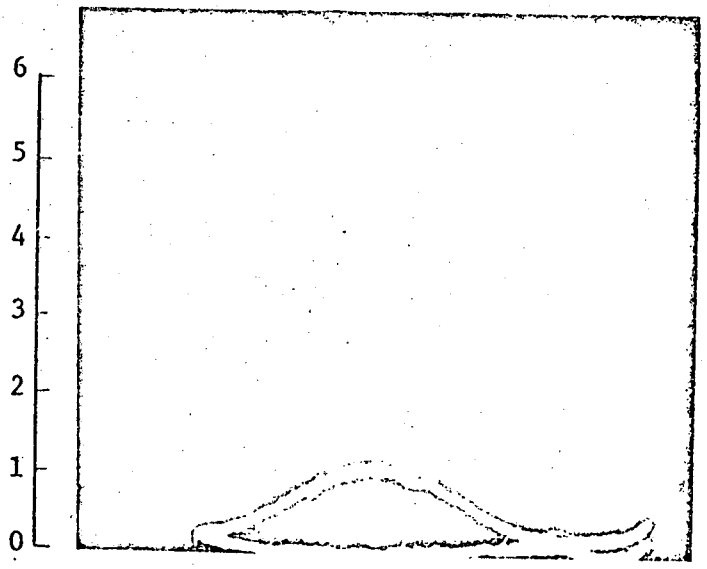


Fig. 3. Relative absorption coefficient S in the $\hat{k} \| \hat{a}$ orientation of prolate spheroids of different a/b.



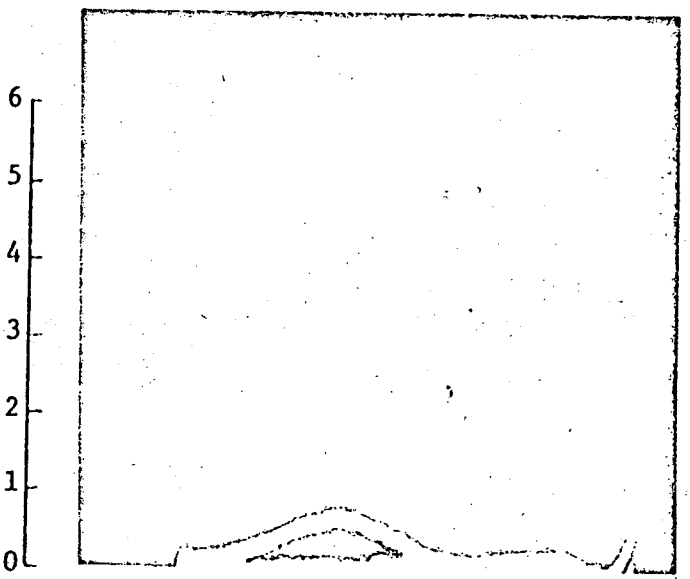
T ≈ 21° C

Vertical scale: 1 cm = 4.5°C
$\hat{E} \| \hat{a}$ orientation



T ≈ 4.5° C

Vertical scale: 1 cm = 4.5°C
$\hat{k} \| \hat{a}$ orientation



T ≈ 1.2° C

Vertical scale: 1 cm = 1.5°C
$\hat{H} \| \hat{a}$ orientation

Fig. 4. Thermograms of the major axis of a = 4.8 cm, b = 0.84 biological-phantom prolate spheroid; a/b = 5.75 is selected to correspond to humans. Heating doge by plane waves of frequency 1700 MHz; intensity 200 mW/cm^2; exposure time 4 minutes.

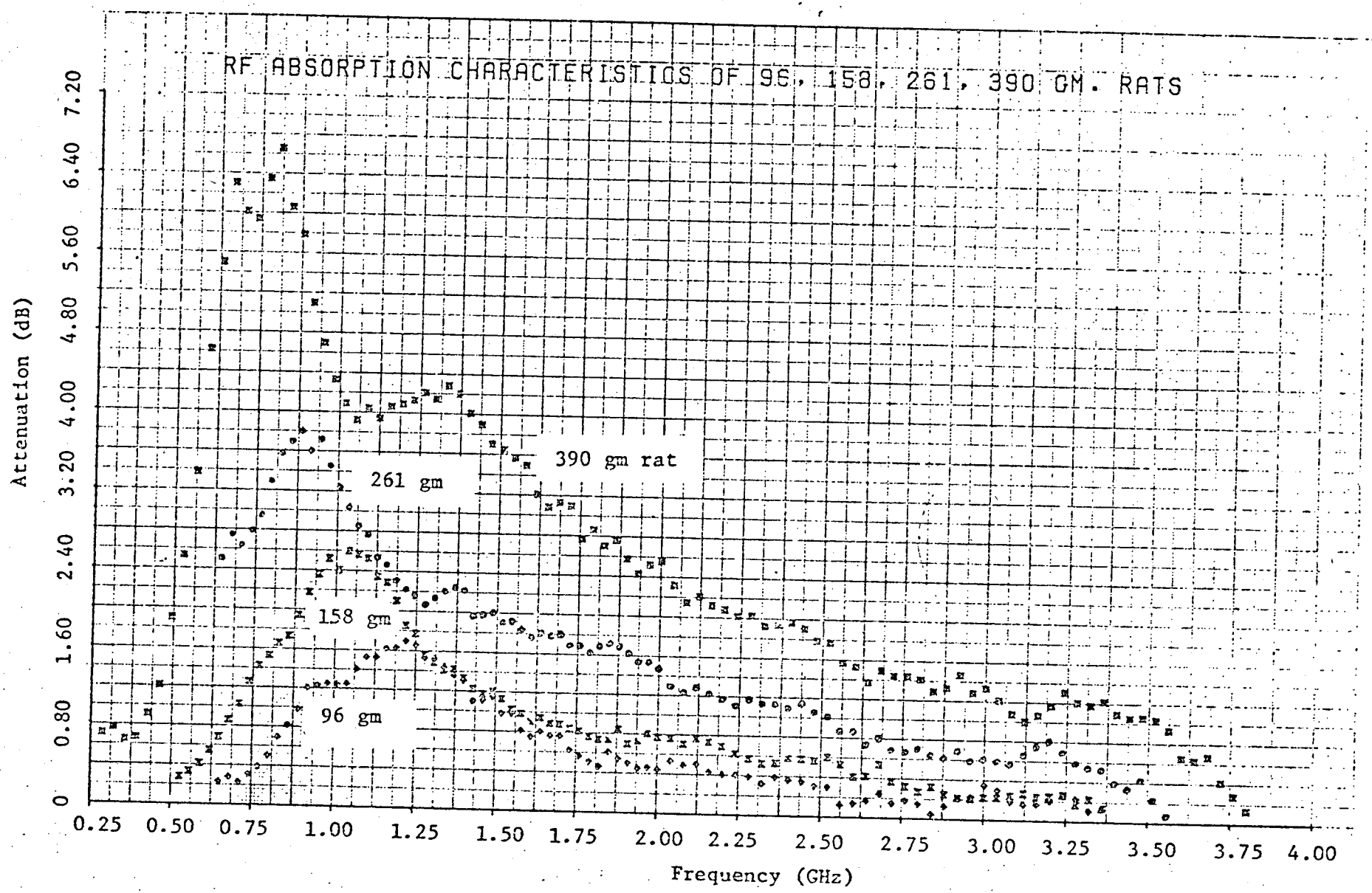


Fig. 5. RF absorption for different size rats.