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Theoretical calculation of frequencies and thresholds of microwave-induced auditory signals

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Previously developed thermoelastic models of microwave-induced auditory sensations are applied to calculate the frequency and amplitude of the acoustic signals that are generated in human beings and laboratory animals. Graphs of computed displacement and pressure as a function of time are presented for several species.

1. INTRODUCTION

Auditory sensations are produced in human beings and in animals that are irradiated with rectangular pulses of microwave radiation of high peak density [*Frey*, 1961; *Frey and Messenger*, 1973; *Guy et al.*, 1973, 1975; *Taylor and Ashleman*, 1974; *Rissman and Cain*, 1975; *Chou et al.*, 1975, 1976]. Several physical mechanisms of interaction have been considered in attempts to account for the conversion of microwaves to acoustic energy [*Sommer and Von Gierke*, 1964; *Foster and Finch*, 1974; *Sharp et al.*, 1974; *Guy et al.*, 1975].

Recently, a comparison of the pressure amplitude as produced in a semi-infinite layer of homogeneous brain material that is irradiated by a microwave pulse indicated that the peak pressure due to thermal expansion is much greater than either radiation pressure or electrostriction [*Lin*, 1975, 1976]. A theoretical model based on thermal expansion has therefore been developed for spherical heads that are irradiated by pulsed microwave energy [*Lin*, 1977a,b]. Some experimental data obtained by others were compared and were found to agree favorably with preliminary calculations, thus indicating the usefulness of the model.

In this paper the theoretical formulation is applied to the heads of cats and of guinea pigs irradiated by 2450-MHz microwaves and to heads of infants and adult human beings exposed to 918-MHz radiation in order to obtain displacement data and pressure waveforms. The data are of value in estimating the characteristics of acoustic signals that are generated in standard laboratory animals and human subjects. They may also serve as a guide to the design of laboratory experiments that are aimed at resolving the exact mechanism of interaction in terms of the signal levels and frequency responses of test instruments. Furthermore, the results will be useful to individuals concerned with establishing a realistic safety standard for microwave radiation.

2. THEORY

The explicit expressions for the acoustic waves that are generated in a spherical model of the head as irradiated by rectangular pulses (t_0 = pulse width) of microwave energy have previously been presented [*Lin*, 1977a,b]. Briefly, it was shown that the pattern of absorbed energy inside a spherical head may be approximated by the spherically symmetric function $\sin(N\pi r/a)/(N\pi r/a)$ for many combinations of sizes and frequencies, where r is the radial variable, a is the radius of the sphere, and N is the number of standing-wave-like oscillations in the absorption pattern.

Taking advantage of the symmetry of the absorption pattern and assuming that thermal conduction does not take place within the short periods of time under consideration, the inhomogeneous thermoelastic equation of motion was solved for the acoustic wave parameters under both stress-free and constrained-surface conditions. In particular, it was found that under the stress-free assumption the fundamental frequency of sound generated in the head without shear stress is given by

$$f_{1f} = c_1/2a \tag{1}$$

where c_1 is the velocity of bulk acoustic-wave propagation in brain material. The displacement is given by

$$u_f = u_0\, Qt + \sum_{m=1}^{\infty} A_m j_1(k_m r)(\sin\omega_m t/\omega_m), \quad 0 \leqslant t \leqslant t_0 \tag{2}$$

$$u_f = u_0\, Qt_0 + \sum_{m=1}^{\infty} A_m j_1(k_m r)[(\sin\omega_m t)/\omega_m - \sin\omega_m(t-t_0)/\omega_m], \quad t \geqslant t_0 \tag{3}$$

and the radial stress (pressure) is

$$\sigma_f = 4\mu\, u_0\, St + \sum_{m=1}^{\infty} A_m k_m M_m(\sin\omega_m t/\omega_m), \quad 0 \leqslant t \leqslant t_0 \tag{4}$$