Journal of Microwave Power

ISSN: 0022-2739 (Print) (Online) Journal homepage: http://www.tandfonline.com/loi/tpee19

Cochlear Microphonics Generated By Microwave Pulses

Chou Chung-Kwang, Robert Galambos, Arthur W. Guy & Richard H. Lovely

To cite this article: Chou Chung-Kwang, Robert Galambos, Arthur W. Guy & Richard H. Lovely (1975) Cochlear Microphonics Generated By Microwave Pulses, Journal of Microwave Power, 10:4, 361-367, DOI: 10.1080/00222739.1975.11688973

To link to this article: https://doi.org/10.1080/00222739.1975.11688973

Published online: 17 Jun 2016.

Cochlear Microphonics Generated By Microwave Pulses*

**Chung-Kwang Chou†, Robert Galambos‡
Arthur W. Guy† and Richard H. Lovely†**

ABSTRACT

Oscillations at 50 kHz have been recorded from the round window of guinea pigs during irradiation by 918-MHz pulsed microwaves. The oscillations promptly follow the stimulus, outlast it by about 200 μsec and measure to 50 μV in amplitude. They precede the auditory nerve's response and disappear with death. They are interpreted to be a cochlear microphonic and hence to demonstrate that the microwave auditory effect, in the guinea pig at least, is accompanied by a mechanical disturbance of the hair cells of the cochlea.

Pulsed microwaves produce auditory sensations in man [1, 2, 3] and they evoke electrical responses from the brains of cats and guinea pigs [3, 4, 5]. Bilateral cochlear destruction resulted in total loss of all evoked potentials due to microwave and acoustic stimuli, there is strong support for the contention that the microwave auditory effect is exerted on the animal in the same manner as are conventional acoustic stimuli [3]. However, the cochlear microphonic (CM), the sign of cochlear hair-cell activation, has never been recorded during microwave irradiation and this has led to the suggestion that microwaves, unlike conventional acoustic stimuli, might not act directly upon the sensor prior to acting on the inner ear [4].

Mechanical distortion of the hair cells in the cochlea is generally conceded to be a crucial event in the production of the CM [6, 7]. Acoustic transients occur when pulsed microwaves are absorbed in water [8] and in other materials [3], events presumably due to thermal expansion of these materials. In tissues, absorbed microwave pulses cause a negligible rise of temperature ($5x10^{-6}$°C) at threshold of hearing, but this, conceivably, is nevertheless capable of generating acoustic transients in a similar manner [3, 8]. Such acoustic transients, if conducted to the hair cells in the cochlea of man and animals would be revealed by their response, the CM. Whether this happens in the guinea pig is the question answered affirmatively by the experiments reported here.

---

* Manuscript received July 14, 1975; in revised form September, 22, 1975.

† Bioelectromagnetics Research Laboratory, Department of Rehabilitation Medicine RJ-30, University of Washington, School of Medicine, Seattle, Washington 98195.

‡ Department of Neurosciences, School of Medicine, University of California, San Diego, La Jolla, California 92037.

Five guinea pigs (0.4-0.6 kg) were anesthetized with pentobarbital sodium (40 mg/kg, IP) and allowed to breathe normally through an inserted tracheal cannula. After exposing either the right or left bulla, a fine (microwave transparent) carbon lead was placed against the round window and cemented onto the bulla. An indifferent electrode was connected to the nearby tissue. Unless the maximum magnitude of the CM to 70 dB speaker clicks exceeded 0.5 mV at this point, the ear was not used. The head of the guinea pig was then placed through a hole into a cylindrical circular waveguide (Figure 1) and was supported

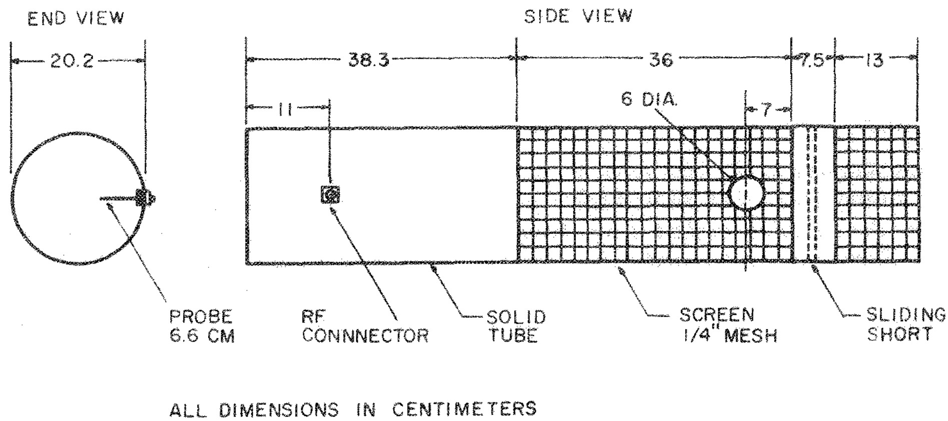

Figure 1 Circular waveguide used for coupling energy into a guinea pig's head.

inside the waveguide by a piece of microwave transparent polystyrene foam. With the animal's head in the waveguide; the VSWR was tuned for a minimal value (1.04 was easily achieved) by adjusting the position of the sliding short and the distance of penetration of the guinea pig's head inside the waveguide. The leakage around the neck of the guinea pig was checked with the Narda 8100 survey meter and was found to be less than 0.1% of the input power. Therefore, the microwave energy propagating in the TE_{11} mode was nearly completely absorbed by the head (weight: 75 gm) of the subject. In this way an averaged absorbed energy per pulse of 1.33 joules/kg was achieved, an order of magnitude greater than the maximum thus far delivered in previous experiments by radiation fields [3]. The parameter used here will be energy only instead of power, since the threshold of microwave tuditory effect is related to the energy per pulse for pulses less than 30 μsec [3]. Direct comparison of power density in the waveguide to free field power density is improper, since the efficiency of energy coupling is ten times higher than the free field radiation. It is estimated that a radiation energy density of 0.5 to 33.2 J/m^2 would have to be delivered to produce the same effect. Microwave pulse-artifacts were considably reduced by placing the irradiation equipment (Applied Microwave Laboratory model PH 40K signal source, 10 kW maximum peak power) and experimental subject in a shielded room and transmitting the recorded signals via coaxial leads to physiological amplifiers (Tektronix 3A9) outside the room, as shown in Figure 2. A sound level in the region of the guinea pig's head of about 65 dB a good portion of it was due to the noise produced by the microwave pulse generator. The animals were irradiated intermittently for durations of 1.5 minutes by 918-MHz microwave pulses of

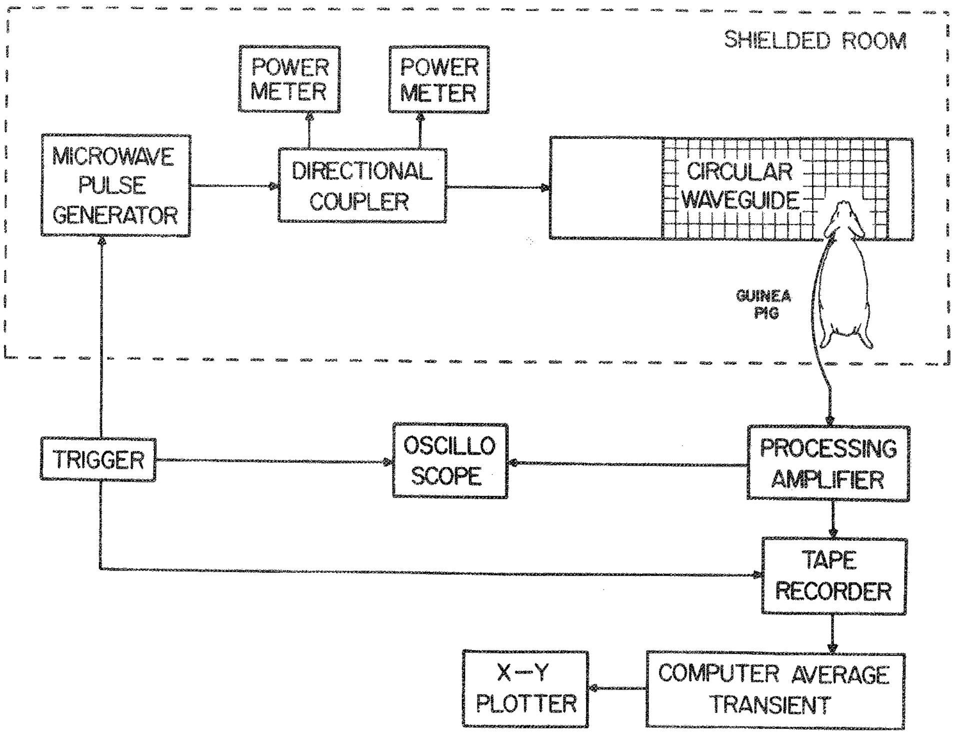

Figure 2 Experimental equipment for recording microwave-induced cochlear microphonics in the guinea pig.

1 to 10 μsec in duration [9] and 100-Hz pulse repetition-rate at various peak power levels below 10 kW. The response after amplification (gain 20K; band pass 100 kHz) were recorded on a magnetic tape system (Honeywell model 7600) with a frequency response to 80 kHz. After a 3-5 hour experiment, the animals were killed, either by an overdose of anesthetic or by anoxia, and response recording was continued until the physiological potentials disappeared completely. The recorded data were averaged off-line by a computer of averaged transients (TMC model 400 C).

Figure 3a shows the electrical responses at the round window of a guinea pig that was stimulated with single acoustic clicks (resonance frequency 10 kHz). The responses of the hair cells, or CM, precede the synchronized action potential of the auditory nerve, N_1, and are followed by another response, N_2, whose origin is less well understood. As is well known, the polarity of CM alone reverses when the polarity of the electrical pulses delivered to the speaker is inverted as is seen in Figure 3a.

Figure 3b shows the response of the round window of the same guinea pig stimulated by a single microwave pulse. It shows in addition to N_1 and N_2 an electrical event immediately following the microwave stimulus artifact. A time-expansion of this event, also shown in the figure, reveals it to approximate 50 kHz in frequency, 50 μV in amplitude and 200 μsec in duration. This is the event that we have observed in five preparations and call the microwave-induced cochlear microphonic response.

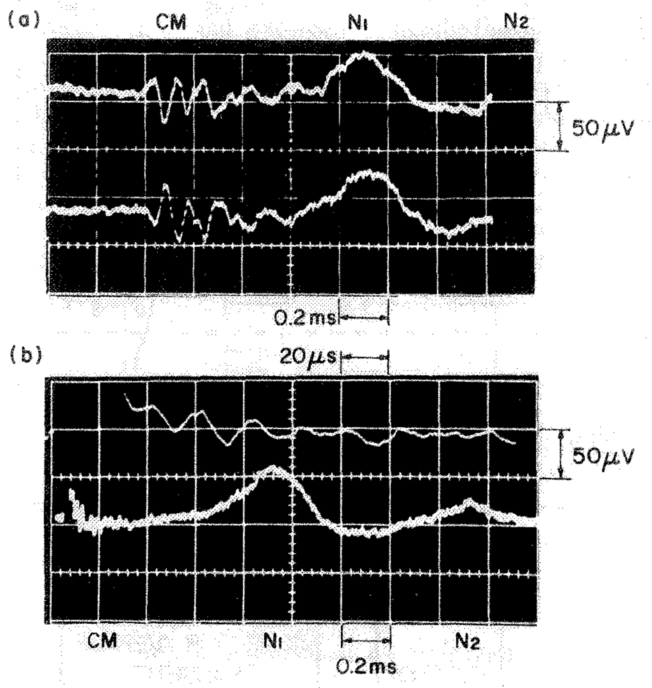

Figure 3 (a) Round window responses evoked by single acoustic clicks; click phase is reversed in upper and lower traces. (b) Round window responses evoked by a single 918 MHz microwave pulse (10 μsec pulse width, 1.33 joule/kg averaged absorbed energy per pulse). Upper trace is expansion of the initial 200 μsec of lower trace.

Figure 4 shows comparisons of the CM evoked by microwave pulses of 10 μsec, 5 μsec and 1 μsec at the same peak power (10 kW). Each trace is the result of averaging 400 responses as replayed from the tape and shows an artifact at the left which, due to the limited frequency response of the tape recorder, lasted 60 μsec instead of 30 μsec as in the on-line record of Figure 3b. The artifact apparently masks the actual onset of the CM in every case. Figure 4 also shows that the frequency of the CM remained constant, but its amplitude dropped as pulse width narrowed and absorption of energy correspondingly decreased. The successive oscillations of the CM occurred however at approximately the same latency for all of the microwave pulses. These data all support the conclusion that what we call CM's, a physiological response that is time-locked to the onset of microwave pulses, is generated within the guinea pig's cochlea. Since the CM elicited by microwave irradiation is followed by auditory nerve activity (N_1) after an interval of time that closely resembles that seen in the acoustically stimulated ear (Figure 3a), it is reasonable to assign this event to hair cell activation.

With death of an animal, whether by anoxia or by a drug, the N_1 and N_2 responses disappeared before the CM, a disappearance that also occurs during acoustical stimulation of the dead animal. After many minutes, CM also disappeared, but the artifact persisted, indicating that the 50-kHz oscillatory signal is a genuine physiological response.

As shown in Figure 5, the amplitudes of CM and of N_1 as well as the latency of the N_1 response varied as a function of the averaged absorbed energy per pulse. The CM amplitude saturation seen with high intensity microwave stimulation finally resembles its behavior at high pressure levels of sound [10].

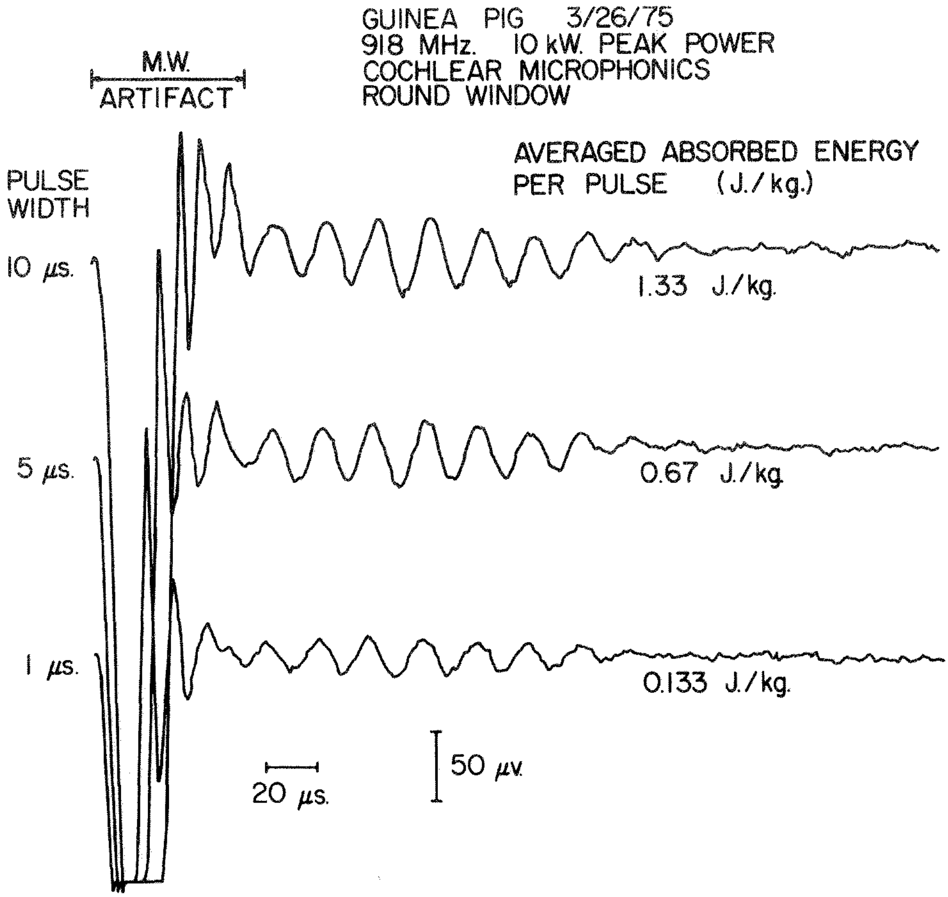

Figure 4 Average of 400 CM responses evoked by 918 MHz microwave pulses 10, 5, and 1 μsec pulse width, at the same peak power, 10 kW. The averaged absorbed energy per pulse is shown below and to the right of each trace.

Previous failures to observe the microwave-induced CM reported here may be related to the following:

1. Failure was certain in our situation if an acoustic stimulus of modest intensity did not evoke a CM that was greater than 0.5 mV in amplitude.
2. The energy absorbed by the head must be at least 0.02 J/kg (Figure 5).
3. The microwave pulse-artifact, if prolonged beyond 200 microsecond, will entirely mask the response.
4. A physiological amplifier band pass that does not include 50 kHz will not amplify the response.

The threshold energy for producing the microwave auditory effect was 20 mJ/kg in the guinea pig head. This is in the same order of magnitude as the threshold energy of 10-16 mJ/kg in the cat head and 16 mJ/kg for the human head [3]. When exposing the guinea pig to free field radiation produced by an applicator driven by the AML PH 40K pulse generator, although the nerve response is obvious, it is very difficult to observe the microwave-induced CM

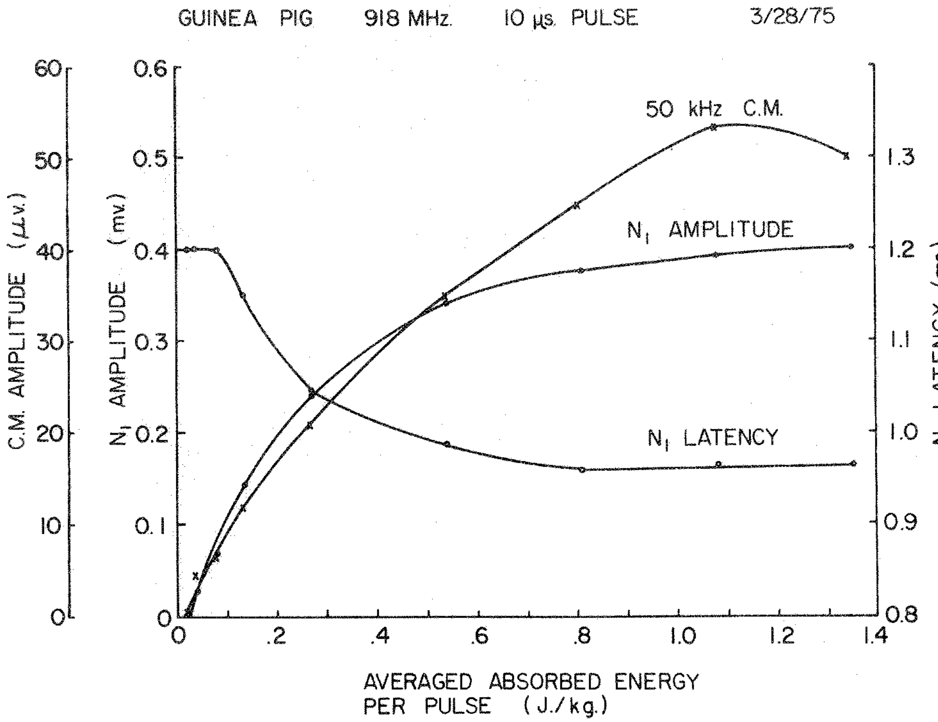

Figure 5 Amplitudes of microwave induced CM and N_1, and latency of N_1, as a function of the averaged absorbed energy per pulse.

directly with an oscilloscope. The circular waveguide used in this study made it possible to observe the microwave-induced CM directly on an oscilloscope by increasing the energy coupling to the animal's head.

The possible artifact due to the audible or ultrasonic clicks in synchrony with the microwave pulses has been excluded, since the CM and N_1, N_2 responses decrease correspondingly when less energy was coupled to the head. This was accomplished by detuning the head position while the rest of the exposure system was kept the same. In addition, any response due to air-conducted sound should have a longer latency than that shown in Figure 3b. The same control experiment also excluded the possibility of electrophonic effect due to the microwave artifact voltage.

It is known that guinea pigs can respond to high frequency tones up to 100 kHz [11]. The 50 kHz CM induced by microwave pulses seems to be related to the size of the guinea pig's skull. Since the individuals with high frequency hearing losses (above 5 kHz) cannot hear the microwave pulses [1], the frequency of microwave-induced CM probably lies between 5-18 kHz for human. For a head size like that of the cat, the frequency of the microwave-induced CM can be estimated to be between 15-50 kHz. This estimate is consistent with the fact that masking noises of 50 Hz to 15kHz did not effect the threshold of evoked responses in the medial geniculate of cats [3].

The question of what structure in the guinea pig head transduces the microwave energy into acoustic energy cannot be answered from the data at hand. The main possibilities would appear to be 1) the bones of the skull 2) the bones of the middle ear and 3) the cochlear fluids. Which, if any of these, plays the major role remains to be uncovered by further experiments.

To summarize: a microwave-induced electrical event, 50 kHz in frequency, 50 μV in emplitude and 200 μsec in duration, has been recorded regularly from the round window of guinea pigs. The event is time-locked to the onset of the microwave pulses. It precedes a discharge by the auditory nerve and it disappears with death. Its intensity function versus amount of absorbed microwave energy resembles that of the cochlear microphonic versus sound pressure level. It is reasonable to conclude that this event is a sound-induced response of the cochlear hair cells to pulsed microwaves.

Acknowledgements

Ths work was supported in part by the Bureau of Radiological Health Grant R01 FD00646-05; the Office of Naval Research Grant N00014-75-C-0464; and the Social and Rehabilitation Service Grant 16-P-56818/0-13. We also thank Dr. David McPherson for valuable discussions.

References and Notes

1 Frey, A. H., "Human auditory system response to modulated electromagnetic energy," J. Applied Physiol., *17*, pp. 689-692, 1962.

2 Frey, A. H. and Messenger, R., "Human perception of illumination with pulsed ultra-high-frequency electromagnetic energy," Science, *181*, pp. 356-358, 1973.

3 Guy, A. W., Chou, C. K., Lin, J. C. and Christensen, D., "Microwave-induced acoustic effects in mammalian auditory systems and physical materials," Ann. NY Acad. Sci., *247*, pp. 194-218, 1975.

4 Frey, A. H., "Biological function as influenced by low-power modulated rf energy," IEEE Trans. Microwave Theory Tech., *19*(2), pp. 153-164, 1971.

5 Taylor, E. M. and Ashleman, B., "Analysis of central nervous system involvement in microwave auditory effect," Brain Res., *74*, pp. 201-208, 1974.

6 Honrubia, V. and Ward, P. H., "Mechanism of production of cochlear microphonics," J. Acous. Soc. Amer., *47*, pp. 498-503, 1970.

7 Karlan, M. S., Tonndorf, J. and Khanna, S. M., "Dual origin of the cochlear microphonics: inner and outer hair cells," Ann. Otol-Rhinol-Laryngol, *81*, pp. 696-704, 1972.

8 Foster, K. R. and Finch, E. D., "Microwave hearing: evidence for thermoacoustic auditory stimulation by pulsed microwaves," Science, *185*, pp. 256-258, 1974.

9 Microwave pulses of 1 to 10 μsec in duration was used in the experiments, since the AML PH40K can only generate pulses from 0.5 to 30 μsec. It has been shown [3] that, in this range negligible difference in evoked responses was observed as long as the energy in each pulse was the same.

10 Honrubia, V., Strelioff, D. and Ward, P. H., "A quantitative study of cochlear potentials along the scala media of the guinea pig," J. Acous. Soc. Amer., *54*, pp. 600-609, 1973.

11 Wever, E. G., Vernon, J. A. and Peterson, E. A., "The high-frequency sensitivity of the guinea pig ear," Proc. Natl. Acad. Sci. *US49*, pp. 319-322, 1963.