FIELD-INDUCED FORCES AT DIELECTRIC
INTERFACES AS A POSSIBLE MECHANISM OF
RF HEARING EFFECTS

WILLIAM T. JOINES
Department of Electrical Engineering,
Duke University,
Durham, NC 27706, U.S.A.

BLAKE S. WILSON
Research Triangle Institute,
Research Triangle Park, NC 27709, U.S.A.

A possible mechanism for effects of microwave radiation on the auditory system is the
generation of field-induced forces at interfaces that divide materials of dissimilar electrical
properties. A general expression for these “Maxwell stresses” is derived and then used to
calculate the approximate magnitude of field-induced force within the organ of Corti during
microwave exposure. Comparison of the results with data on the force needed to excite
cochlear hair cells indicates auditory responses could be evoked by this mechanism at
power densities near the threshold of rf hearing sensations.

1. Introduction. Results of numerous studies have established that pulses
of microwave radiation can elicit auditory responses in man (Frey, 1961;
Frey and Messenger, 1973; Guy et al., 1975) and laboratory animals (Cain
and Rissmann, 1978; Guy et al., 1975; Johnson et al., 1976; Taylor and
Ashleman, 1974) at average power densities far below 10 mW/cm². Microwave-evoked potentials in the auditory nerve, medial geniculate
body, and auditory cortex of cats are abolished when the cochlea is
destroyed (Taylor and Ashleman, 1974), indicating that the initial site or
sites of stimulation must be within or peripheral to the organ of Corti.
This and other findings (Chou et al., 1975) have been interpreted as
evidence of mechanical excitation of the cochlea via field-induced waves of
intracranial pressure. Recordings of single-unit activity in the cat's auditory
nerve have, in fact, demonstrated responses to pulses of microwave
irradiation with latencies (i.e. delays after stimulus onset) essentially
identical to those of responses to acoustic clicks at the eardrum (Wilson et al.,
Thus, all the time-consuming steps of signal processing and transmission used in the cochlea for conversion of acoustic clicks into neural discharges are also used in producing one class of auditory responses to pulsed microwave radiation.

While this last result confirms the presence of induced pressure waves above the threshold of bone-conduction hearing, it does not rule out the possibility of a more direct action of the microwave radiation within the organ of Corti. Indeed, recently discovered responses in the auditory system to continuous-wave (CW) microwave radiation cannot be explained by postulating forces or pressures peripheral to the hair cells or their accessory structures (Wilson et al., 1980). Moreover, both we (Wilson et al., 1976) and Lebovitz and Seaman (see Figure 3, Lebovitz and Seaman, 1977) have found units in the auditory nerve that respond to microwave pulses at latencies in the region of 700 µs. This brief delay corresponds to the time required for forward transmission across the chemically-operated synapse separating cochlear hair cells from afferent dendrites of the auditory nerve (about 550 µs; see Davis et al., 1950; Furukawa et al., 1972) plus the time required for neural transmission from the synapse to the monitoring electrode (between 100 and 200 µs; see Peake and Kiang, 1962). Because much greater latencies were always observed in these units for conventional responses to acoustic clicks at the eardrum, responses at the latency of 700 µs suggest a direct stimulation of cochlear hair cells.

The purpose of this paper is to develop a more complete theory for the effects of microwave radiation on the auditory system by considering forces, often called "Maxwell stresses", that can be induced at interfaces dividing materials of dissimilar electrical properties. A general expression of Maxwell stresses is derived from fundamental principles (Paris and Hurd, 1969; Plonus, 1978; Stratton, 1941) and then used to calculate the approximate magnitude of field-induced force within the organ of Corti during microwave exposure. The results show that the force induced at the lowest reported threshold of rf hearing sensations is roughly equal to the minimum force needed for hair cell excitation.

2. General Expression of Maxwell Stresses. The Lorentz equation for the force acting on a distribution of charges and currents within a linear, homogeneous, isotropic medium is

\[ F = \int_V [\rho \vec{E} + \vec{J} \times \vec{B}] \, dV, \]  

(1)