# RADIO FREQUENCY ENERGY ABSORPTION IN TISSUE: LINEAR AND NON LINEAR INTERACTIONS

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**INTRODUCTION:** The reported significance of low frequency modulation at non-heating exposure levels cannot be understood in terms of the bulk properties of an aqueous dielectric system. The observations could be the result of nonlinear interactions between the RF field and a small fraction of biomolecules [Illinger 1982 Bioelectromagnetics 3:9-16], although direct physical observations have not found nonlinear interactions involving biological matter above about 10 MHz. Because of their highly polar nature, water molecules in a RF field undergo rotational motions that subsequently transfer energy to the thermodynamic system through collisions. RF energy absorption is represented thermodynamically by an increase in the entropy S of the bosons (photons and vibrational modes) that ends (dS=0) when the incident radiation and the molecular oscillators are in thermodynamic equilibrium. For a linear system, the spectrum scattered from a RF-exposed biosystem has no spectral features other than those of the incident signal.

**THEORY:** We considered a system of biological cells in thermodynamic equilibrium at temperature T that are exposed to a flux dM/dt of RF photons at angular frequency $\omega$ in a cavity. The system, which has vibrational energy at frequencies $\omega_k$, and a chemical potential energy $\mu$, has this number of interacting photons and vibrational states:

$$n(\hbar\omega_k,T,\mu) = [(1 - \alpha)\cdot\varphi_k^{-1}\cdot\hbar\omega\cdot dM/dt+1]\cdot[\exp\beta(\hbar\omega_k - \mu) -1]^{-1}, \quad (1)$$

where $\alpha$ is the fraction of dissipated energy ($\alpha = 0$ for totally elastic photon interactions), and $\varphi_k$ is the transition probability for oscillators with energy $\hbar\omega = \hbar(\omega_k - \omega_{k-1})$. Also, $\beta = (kT)^{-1}$, k, the Boltzmann constant; h, the Planck constant; $\hbar = h\cdot(2\pi)^{-1}$. Eq. (1) states that at equilibrium all energy entering the cavity is either dissipated or reradiated by the oscillators of the system. The case dM/dt = 0 yields the usual Planck formula. If totally transparent to RF, $\varphi_k = 0$ and the first term diverges as a consequence of ignoring cavity losses. For a square-law nonlinearity, the steady state condition $(\partial [ n(\hbar\omega_k,T,\mu ) + n(\hbar\omega_{2k},T,\mu )] / \partial t =0)$ leads to this expression

$$(1-\acute{\alpha})\, dM/dt = \psi_k\{n(\hbar\omega_k,T,\mu)\cdot[\exp\beta(\hbar\omega_k - \mu)-1]-1\}+ \psi_{2k}\{n(\hbar\omega_{2k},T,\mu)\cdot[\exp\beta(\hbar\omega_{2k} - \mu)-1]-1\}, \quad (2)$$

that has linear and quadratic terms with photons at frequencies $\omega_k$, $\omega_{2k}$, respectively, where $\acute{\alpha}$ represent the energy lost in the linear and the nonlinear interaction, and $\psi_k$ and $\psi_{2k}$ are transition probability rates. Additional frequencies at $2\Omega$, $\omega_k \pm \Omega$, and $2\omega_k \pm \Omega$ appear when the incident RF signal is amplitude modulated at $\Omega$ ($\Omega \ll \omega_k$). Linear interactions of the RF field with vibrational modes introduce lines at $\omega \pm n\Omega$, n = 1, 3… whereas lines resulting from non-linearities would appear at $m(\omega \pm 2n\Omega)$, m = 2, 3….

**EXPERIMENTAL METHOD:** Balzano [Bioelectromagnetics 2002 in press] previously proposed direct spectroscopic detection of lines at $n\omega$ and $n(\omega \pm \Omega)$, n = 2, 3, …, but a different technique is needed to detect energy at frequencies $\omega \pm 2n\Omega$, that is, lines lying very close to the incident frequency $\omega$. We propose a cavity operating in the $TM_{010}$ and $TM_{011}$ modes in order to provide nearly constant magnetic excitation of an annular exposure volume of as much as 90 $cm^3$ containing the biological sample that is excited with a 100% amplitude-modulated carrier. Reradiated energy is picked up by two loop antennas located to provide signals 180º out of phase in order to reduce noise in the side bands originating within the sample. A modulation analyzer and digital signal processing permit detection of the harmonic at $\omega \pm 2n\Omega$ to a limit estimated as –120 dB below the incident amplitude modulated signal.

**CONCLUSIONS:** A thermodynamics-based analysis shows that if there are nonlinear interactions involving vibrational energy, previous experimental techniques designed to detect harmonics of the carrier need to be extended to permit detection of energies of $m\hbar(\omega \pm 2n\Omega)$. A cavity operating in the $TM_{010}$ and $TM_{011}$ modes, digital filtering and low-noise amplification provide a practical way to observe such energies in biological cells down to very low levels.