X-Band Pulsed Microwave Thermoelastic Effects in a Multilayer Head Model for DE Health Assessment

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PANTHER

Abstract

X-band directed-energy systems can expose personnel to short, high-intensity microwave pulses. We used a 2-D axisymmetric multilayer head model to evaluate frequency- and pulse-width-dependent thermoelastic responses across 8–12 GHz at 1000 mW/cm².

Microwave absorption produced microkelvin-scale heating while generating transient pressure waves that converged near the brain center at approximately 65 µs. Higher frequencies confined energy to the skin and reduced peak center pressure from −0.35 Pa at 8 GHz to −0.057 Pa at 12 GHz. These results establish a pulse-width-resolved computational baseline for directed-energy health-effects assessment.

I. Computational Model and Physics

- Built and simulated in COMSOL Multiphysics using frequency-dependent tissue properties from the IT'IS Multipole Debye model.
- Across 8–12 GHz, tissue conductivity increases while relative permittivity decreases.
- This dispersion-based approach captures frequency-dependent absorption and supports accurate SAR, heating, and pressure predictions.

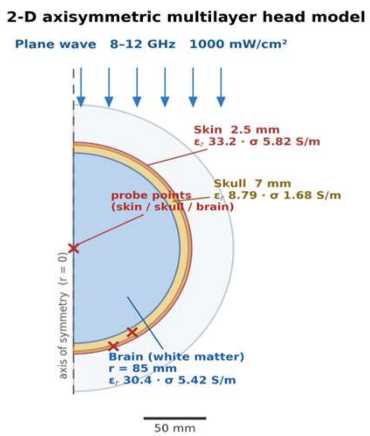

Fig. 1 2-D axisymmetric multilayer head model under axial plane-wave incidence, 8–12 GHz. Material properties shown at 8 GHz (IT'IS Database).

Sequential Multiphysics Coupling in COMSOL

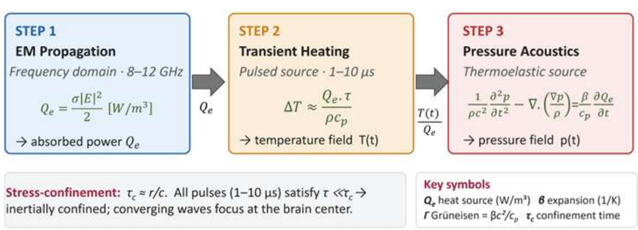

Fig. 2 Each physics step's output becomes the next step's source, from absorbed power to a focused thermoelastic pressure wave

II. Frequency-Dependent Energy Deposition

- Higher frequencies confine energy near the skin surface.
- Peak absorbed power density in the skin rises 2.1× from 8 to 12 GHz (1.9→4.0 ×10⁶ W/m³).
- Rising tissue conductivity with frequency drives faster field decay with depth, making **skin the dose-limiting tissue** at the high end of X-band.

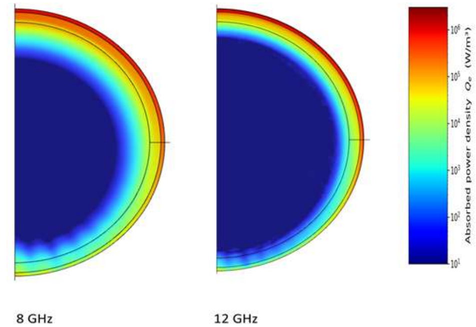

Fig. 3 Absorbed power density concentrates sharply in the skin as frequency rises, sparing deeper brain tissue.

III. Pulse-Width-Dependent Temperature Rise

- Peak ΔT rises linearly with pulse width in all tissues, reaching only µK levels at 1000 mW/cm².
- Skin heats ~80× more than brain at every τ — duration changes how much, not where.

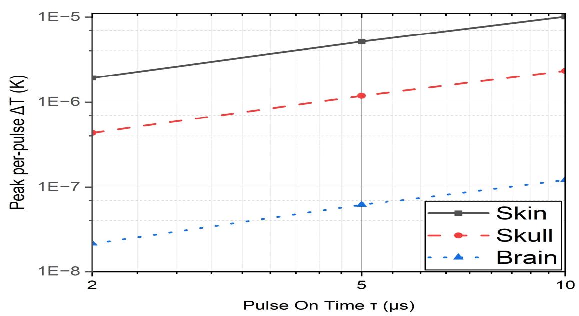

Fig. 4 Peak per-pulse ΔT scales linearly with pulse width across skin, skull, and brain (log-log slope ≈ 1), confirming ΔT ∝ $Q_e \cdot \tau$.

IV. How Pressure Waves Focus, and How Strongly, Across X-Band

- Convergent pressure waves reach the brain center near the acoustic-transit time.
- The arrival time remains nearly constant across 8–12 GHz, while the focused pressure magnitude decreases with frequency.

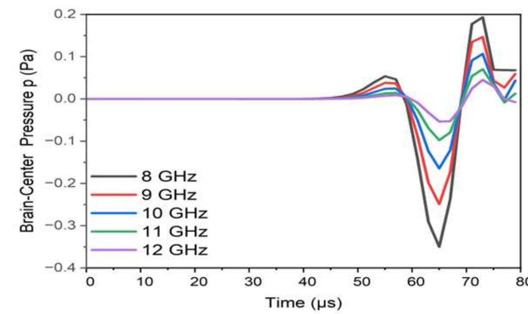

Fig. 5 Brain-center pressure builds after pulse onset and reaches peak tensile focus at t ≈ 65 µs.

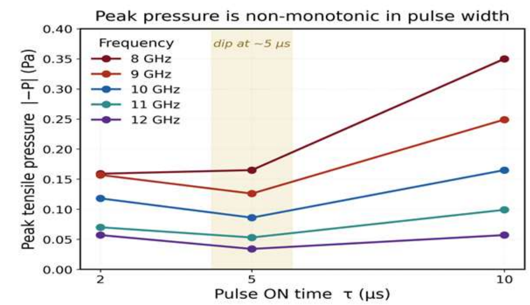

Fig. 6 Peak pressure varies with pulse width and decreases from 8 to 12 GHz.

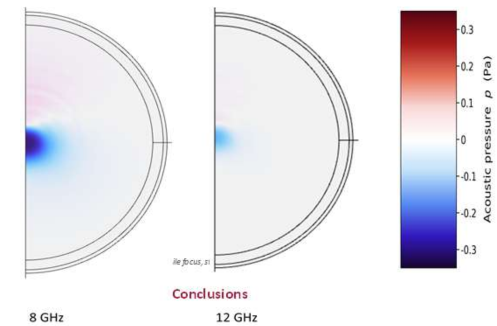

Fig. 7 Pressure field at peak focus (t = 65 µs). The convergent tensile pattern is strong and well-defined at 8 GHz, but 6× weaker at 12 GHz on the same scale.

V. Conclusion

- X-band pulses produced microkelvin-scale heating and convergent thermoelastic pressure that decreased with frequency.
- Future work will vary pulse rise time to determine how the temporal gradient of absorbed power density governs pressure amplitude.

Acknowledgement

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