Microwave heating of biological tissues

Presentation by John Bordelon

What Are Microwaves?

- Microwaves are electromagnetic waves with wavelengths between 3mm (100GHz) and 30cm (1GHz).
- Maxwell's equations govern the propagation of electromagnetic waves through space.
- The only material parameters of interest are the electrical permittivity, ε, and the magnetic permeability, μ.

Microwaves as cancer treatment

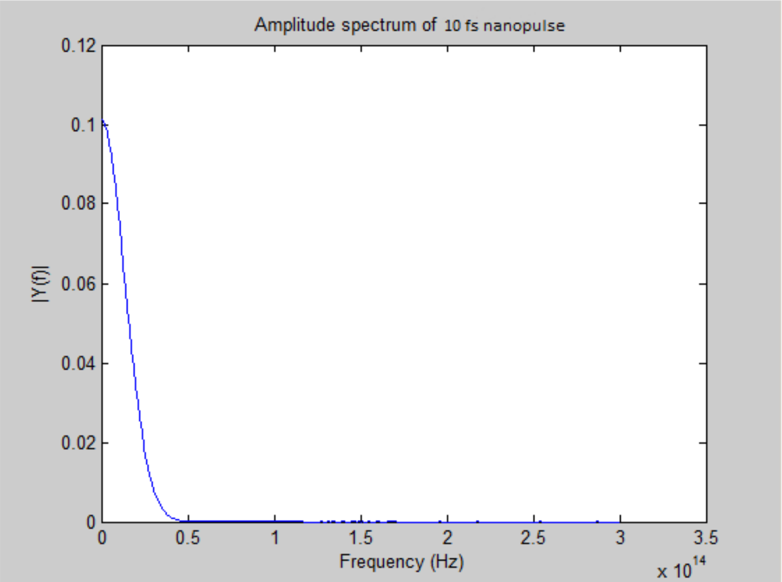
- The idea behind microwave cancer therapy is that a cell which is heated 8K above body temperature will undergo hyperthermia, killing it.
- Because cancer cells and healthy tissue have differing permittivities, by carefully choosing a pulse there is the possibility of killing cancerous tissue while sparing the nearby healthy tissue.

Microwaves through media

- As a microwave travels through a medium, material properties influence the displacement field, $\overrightarrow{D}$, and in turn create the electric field, $\vec{E}$.
- $\overrightarrow{D} = \varepsilon\vec{E}$
- If ε is a function of frequency, i.e. ε(ω), then the material is dispersive. All materials are dispersive, but some more than others.

Dispersion problem

- The high dispersivity of biological tissues poses problems for simulating pulses. This is because a pulse contains a continuous spread in frequencies.



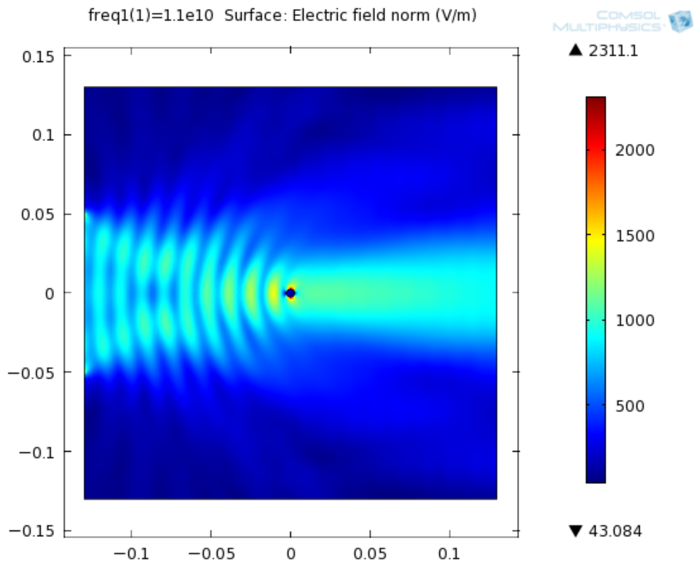
Our solution

- Linking the frequency dependence of the permittivity into the time is not supported.
- Our solution to this problem, given time limitations, is to use a single frequency rather than a pulse. This allows a single complex valued ε to replace the frequency dependent form.

How does microwave heating work?

- In mediums which are heated by microwaves (not all are) there exist dipoles. As an electromagnetic wave passes near these dipoles, they will oscillate because of the electric/magnetic repulsion/attraction.
- This movement causes friction which converts electromagnetic energy into heat.
- If the material is conductive, there will also be ohmic losses from induced currents.

Our COMSOL Simulation



First, we solved the stationary response in COMSOL for a single frequency.

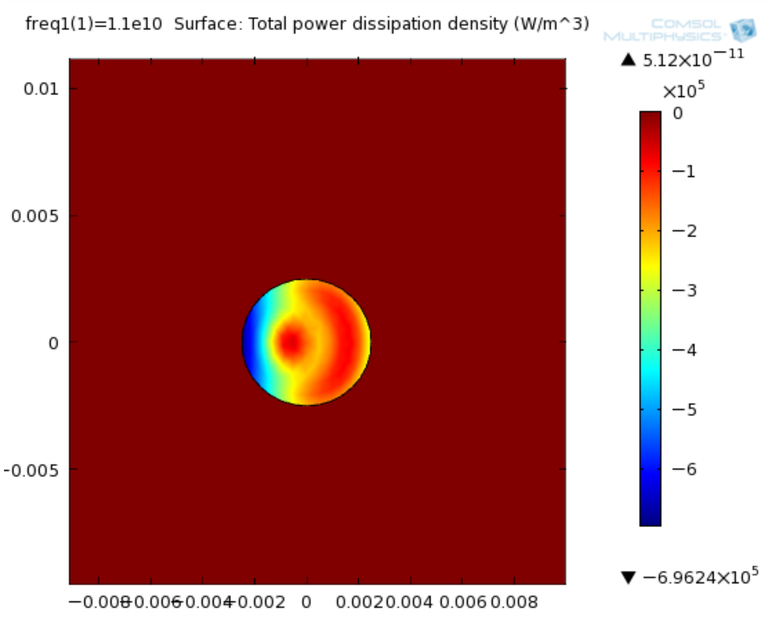
This represents the steady-state response after all initial transients have died off.

In doing so we assume the initial transients are negligible.

This is a reasonable assumption because of the long running time compared to the period of the wave.

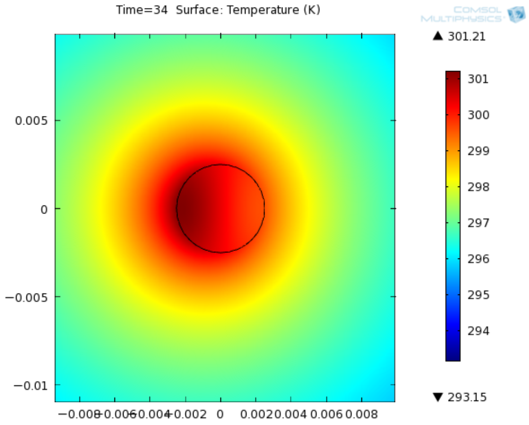
Next steps

- COMSOL automatically solves the steady state power dissipation density.
- This power density is stored and used in the next time domain study.

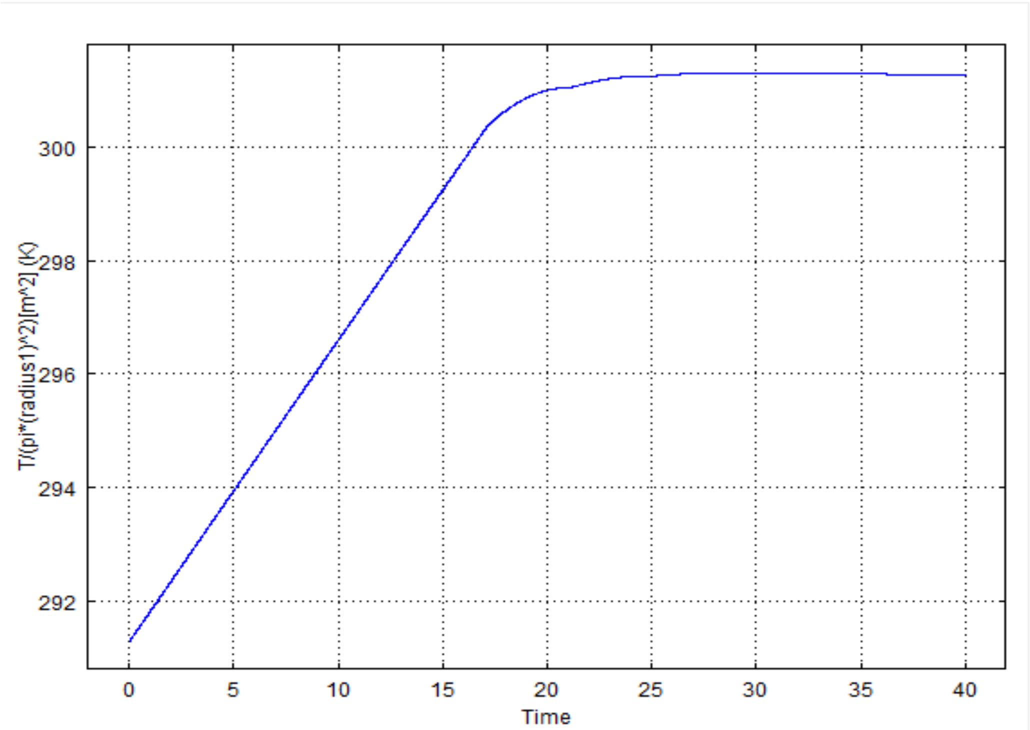


Time domain

- The next step is to run a time dependent study where the saved power dissipation density is set as a heat source.
- This allows us to moniter how quickly and in what fashion the tissues would heat up.



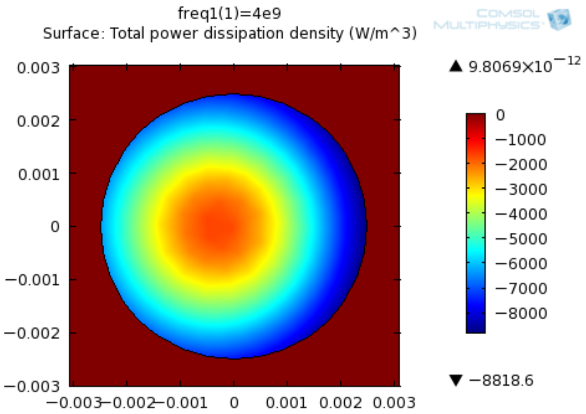
Results

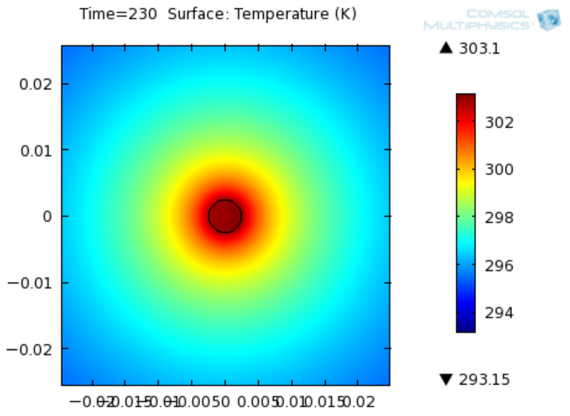


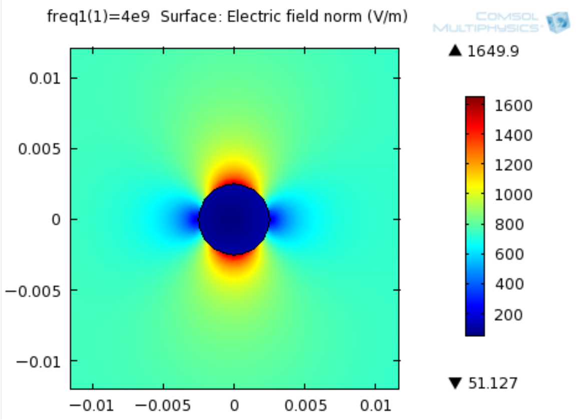
- We tested two frequencies, 4GHz and 11GHz.
- At 11GHz, heating was not even.
- Because of this we can the simulation much longer than needed, and performed a surface integration divided by the area to calculate the average temperature vs. time.
- We then found when the average temperature was what we wanted and turned the heat source off at that time.
- We then waited until the heat had evenly spread out.

4GHz Example:

- Here are the pictures for white matter at 4GHz:



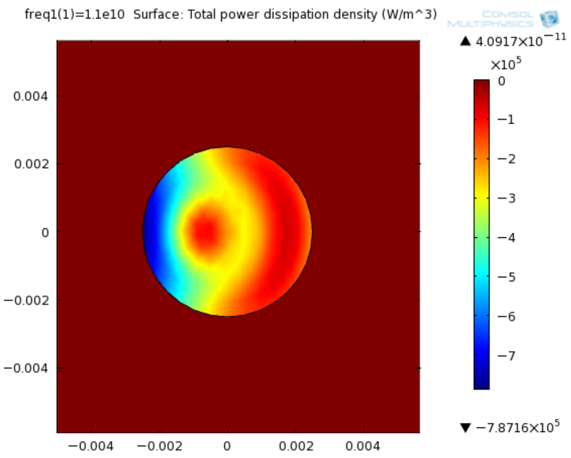


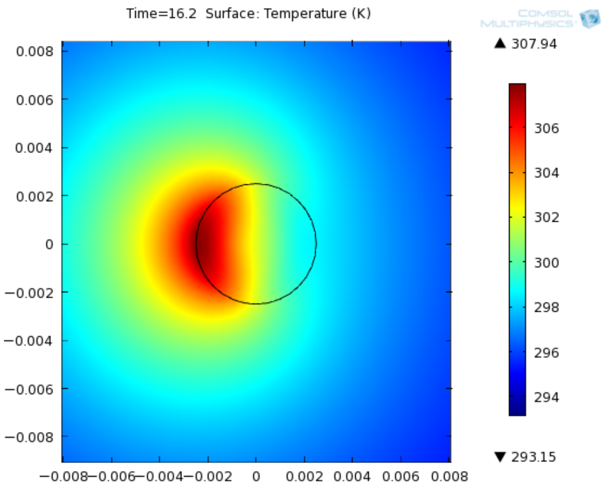


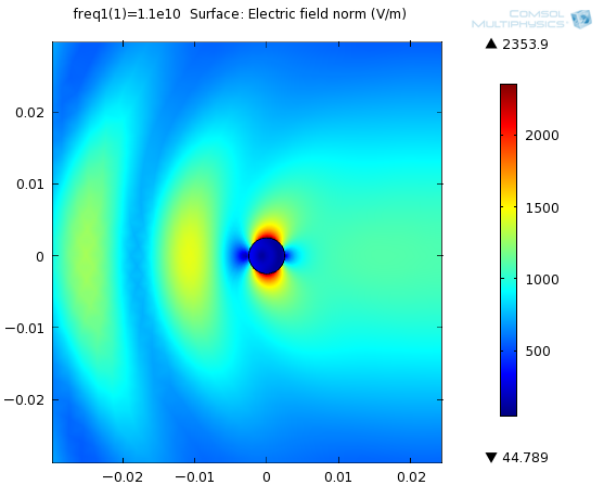
- As you can see, the power density causes even heating. There is no needed additional time for the heat to spread out.

11GHz Example

- On the contrary, at 11GHz, heating was very localized and needed time to spread out.







Charts

The time needed to reach an average temperature of 301.15K (*t0*) and for the heat to evenly distribute (*teven*) vs. tissue type and frequency. At 4GHz there was no extra time needed for the heat to evenly distribute (*teven=t0*).

Table 2

	Muscle		Heart		Kidney		Liver		Skin		White Matter		Grey Matter	
	t_0	t_{even}	t_0	t_{even}	t_0	t_{even}	t_0	t_{even}	t_0	t_{even}	t_0	t_{even}	t_0	t_{even}
4GHz	120		127.5		140		130		220		230		140	
11GHz	18.56	34	15.06	45	16.24	40	16.24	45	14	60	11.1	41	16.2	45

Conclusions and next steps

- Our geometry of a 2.5mm radius cell could be modified to any shape (and to 3-d) easily to simulate a more practical situation. In addition to changing the size and dimensions, COMSOL can easily simulate a more accurate biological heating model, which accepts parameters such as the blood perfusion rate, etc, to perhaps study the heating of a tumor surrounded by tissue.
- Because the permittivities of the tumor and the surrounding tissue are different, it could be possible to find a frequency which would heat the tumor more than nearby healthy tissue.

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