Electromagnetic and Thermal Analysis of Microwave Ablation Using FDTD Simulations

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Outline

1. What is Microwave Ablation?
2. Motivation.
3. Antenna and model in QW
4. Results
5. Conclusion

Microwave Ablation (MWA)

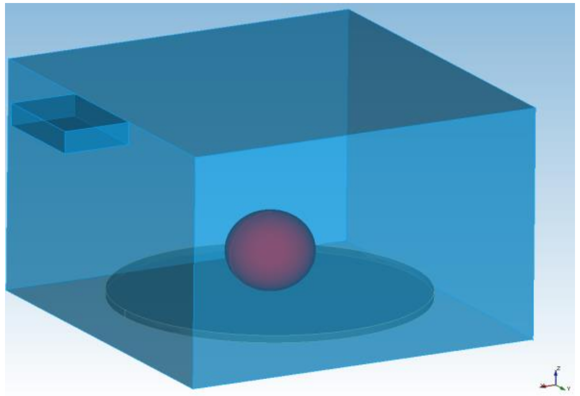
- Thermal cancer treatment that uses microwave energy
- Heating caused by friction of oscillating water molecules
- Typically 915 MHz, 2.45 GHz
- Cancer tissues are more likely to heat (more water molecules, higher conductivity and pearmittivity)
- Modified coaxial cable is the simplest example of the MWA antenna
- Ablation Zone ≥ 60°C

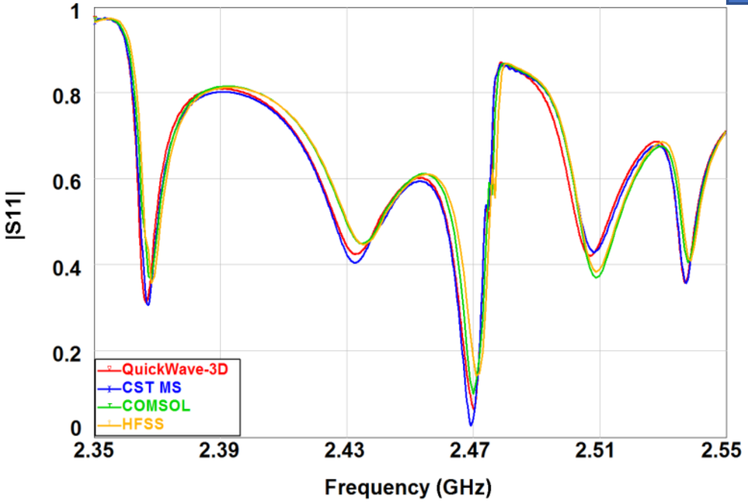
Motivation

- Accurate simulations of microwave ablation antennas are essential for optimizing their design, predicting thermal distribution and improving clinical outcomes.
- We want to test and show capabilities of QuickWave (FDTD) in simulating the MWA and further improve it.
- We want to raise awareness of the importance of experimental measurements when using simulations.

3D EM Modelling Benchmarks

Simple microwave heating benchmarks
& microwave heating phenomena studies*



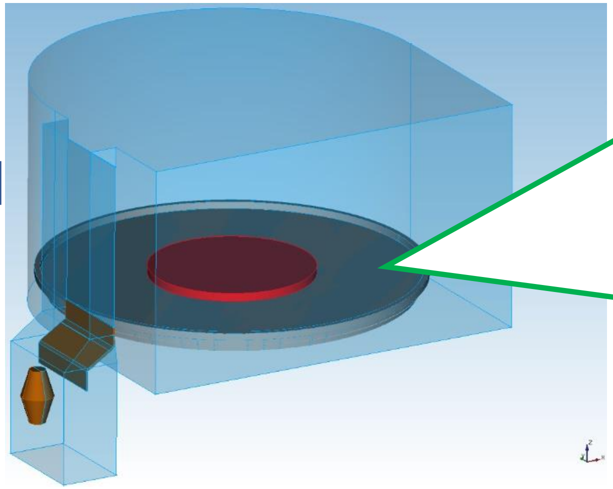


- heat transfer & load dynamics
- Load rotation & arbitrary movement during heating
- Source parameters tuning – regime for solid state sources
- Temperature dependence of material parameters

Freezing to file the state of the simulation

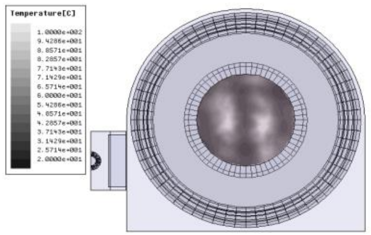
De-freezing on arbitrary computer at convenient time

Design & analysis of real-life microwave oven cavities, incl. complicated cavity shapes and advanced feeding system*

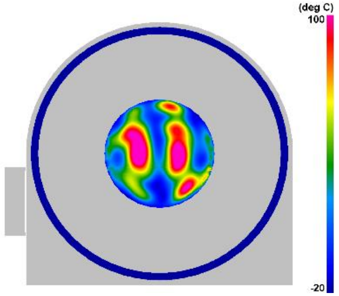


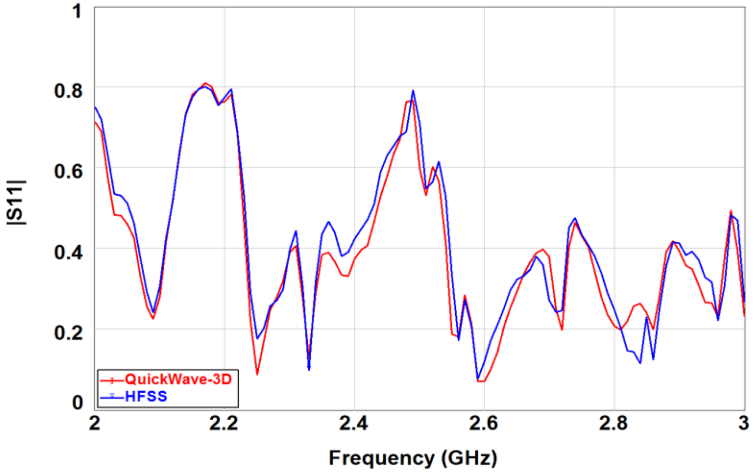
Courtesy of Whirlpool Inc. – Whirlpool MAX oven

HFSS v11



QuickWave 3D & BHM





With QuickWave EM computation as fast as **1 min 18s** on a **low-cost video card** – supporting **all** graphic cards **with OpenCL**

* M.Celuch, P.Kopyt & M. Olszewska-Placha in eds. M. Lorence, P. S. Pesheck, U. Erle, *Development of packaging and products for use in microwave ovens*, 2nd Ed. Elsevier 2020.

T. Nalecz @ AMPERE 2025 @ Bari, Italy
18.09.2025

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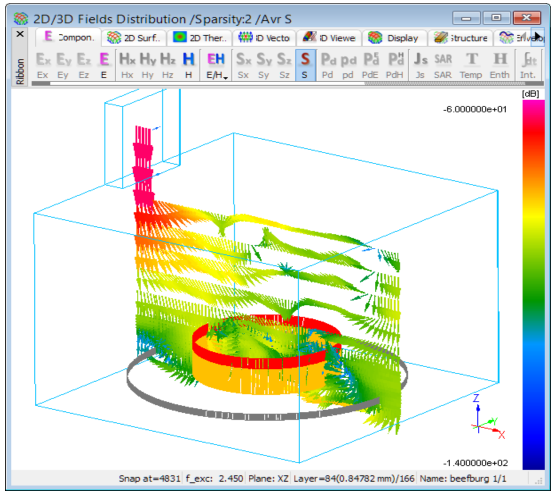
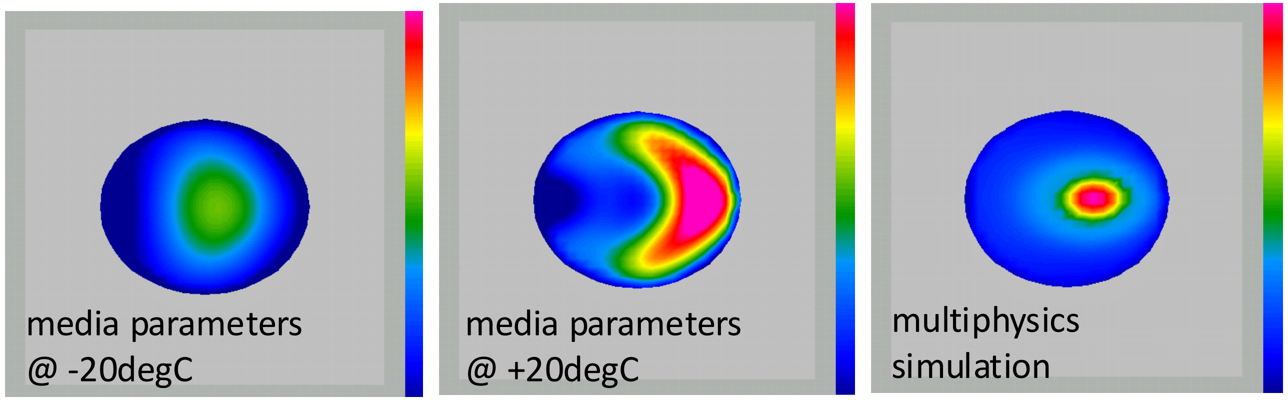
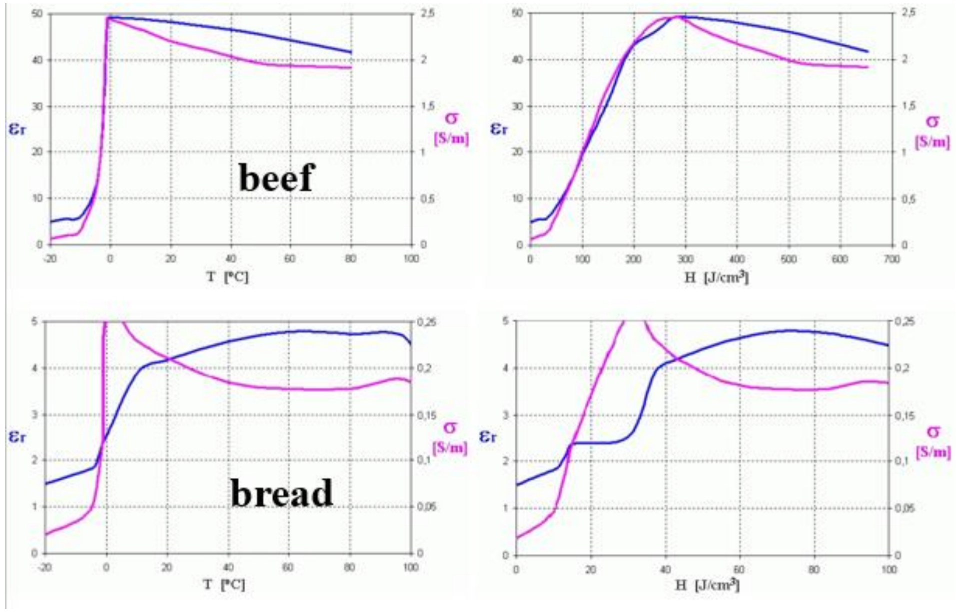
3D Multiphysics Modelling Regimes in QuickWave







FDTD analysis with sinusoidal excitation at *f=f0*

↓

Calculation of 3D pattern of *dissipated power* $P_{avg}(x,y,z)$

↓

***Enthalpy* update in 3D domain**

$$H^{n+1}(x,y,z) = H^{n}(x,y,z) + \frac{P^{n}_{avg}(x,y,z)\Delta\tau^{n}}{\Delta V(x,y,z)}$$

↓

***Temperature* update in 3D domain**

$$T(x,y,z) = T[H(x,y,z)]$$

from *.pmo file

→

Load movement/rotation

Translation of the object and thermal quantities along user-defined trajectory

↑

Calculation of heat transfer

***Enthalpy* and *temperature* update in 3D domain**

↑

***Material* and *thermal parameters* update in 3D domain** $\varepsilon(x,y,z) = \varepsilon[T(x,y,z)]$

$$\sigma(x,y,z) = \sigma[T(x,y,z)]$$

from *.pmo file

↑

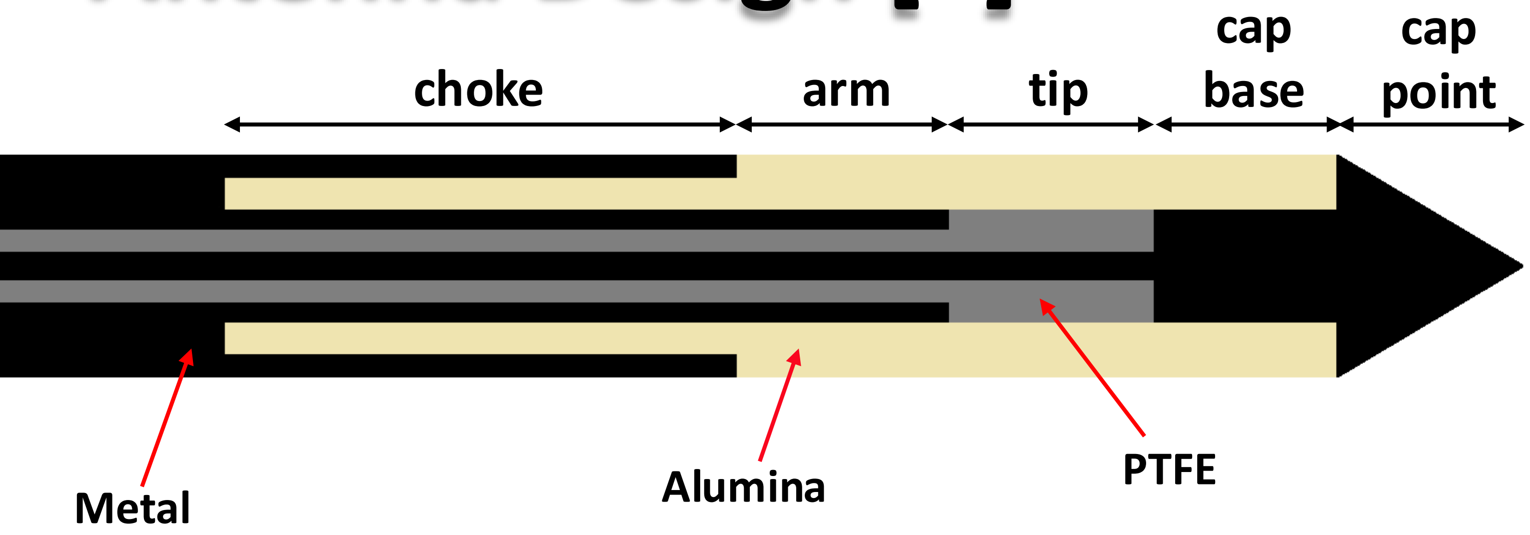
Source tuning* to *f=f1

Changing operating frequency: automatically to the deepest resonance or manually upon user's criterion

→ (back to FDTD analysis)

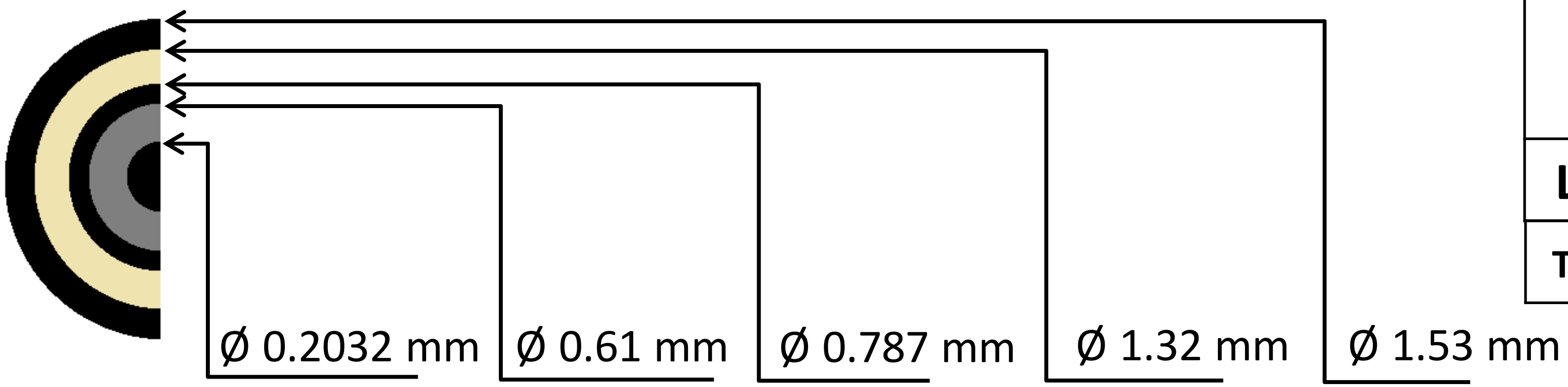
M. Celuch @ IMPI 59 @ Edmonton, Canada
26.06.2025

Antenna Design [*]



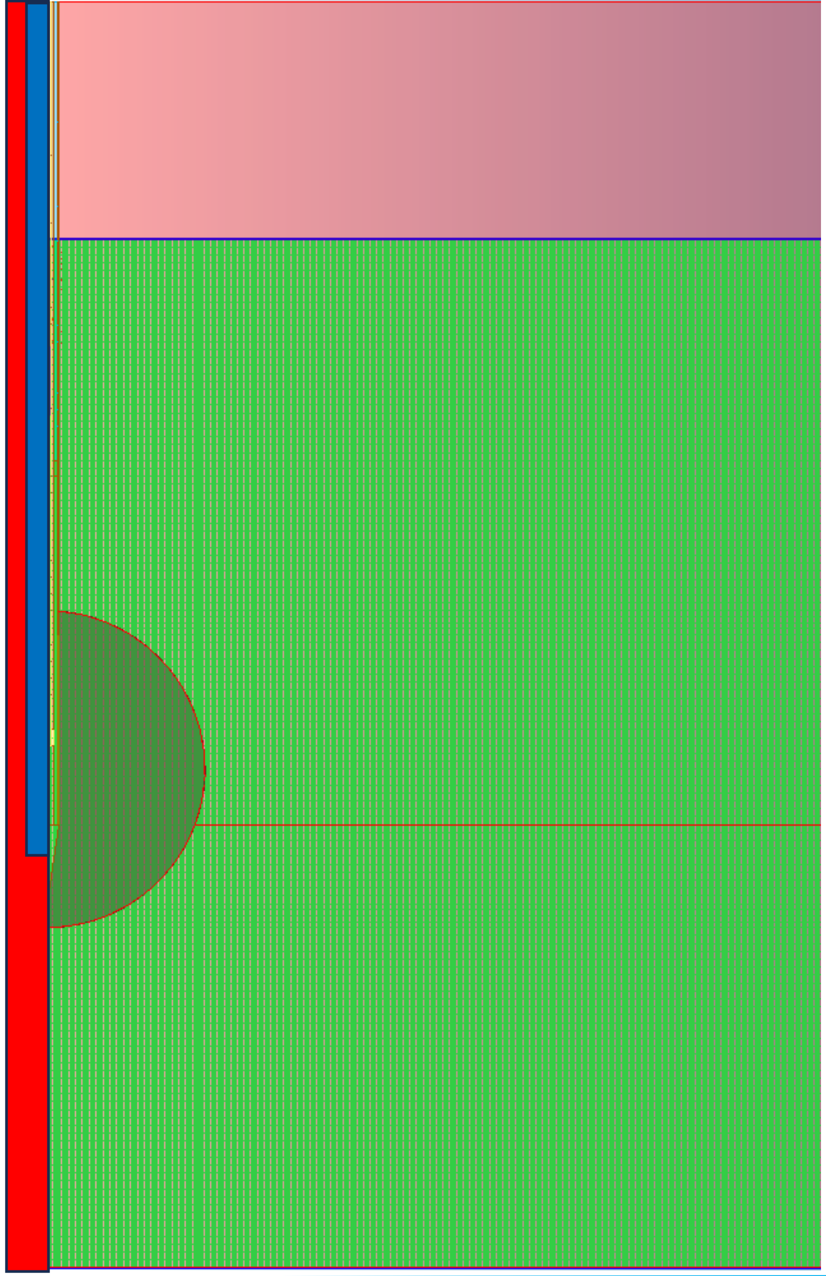
Medium	PTFE	Alumina
Permittivity	2.2	10

Choke	Arm	Tip	Cap Base	Cap Point
10 mm	6 mm	1 mm	5 mm	5 mm



	ε_r	σ (S/m)	ρ (kg/m³)	C (J/kg·°C)	K (J/s·m·°C)
Liver	43.03	1.69	1041	3600	0.51
Tumor	57	3	1050	3500	0.50

[*] M. Cavagnaro, C. Amabile, P. Bernardi, S. Pisa and N. Tosoratti, "A Minimally Invasive Antenna for Microwave Ablation Therapies: Design, Performances, and Experimental Assessment,"



Antenna Model in QW

BOR V2D

Neumann boundary condition was set as the external boundary condition

Cell size: dx = 0.5 mm
dy = 0.1 mm

Tumor radius R = 10 mm
Centered at 33 mm

Number of cells with boundaries: 136144

Project size (RAM): ~13 MB

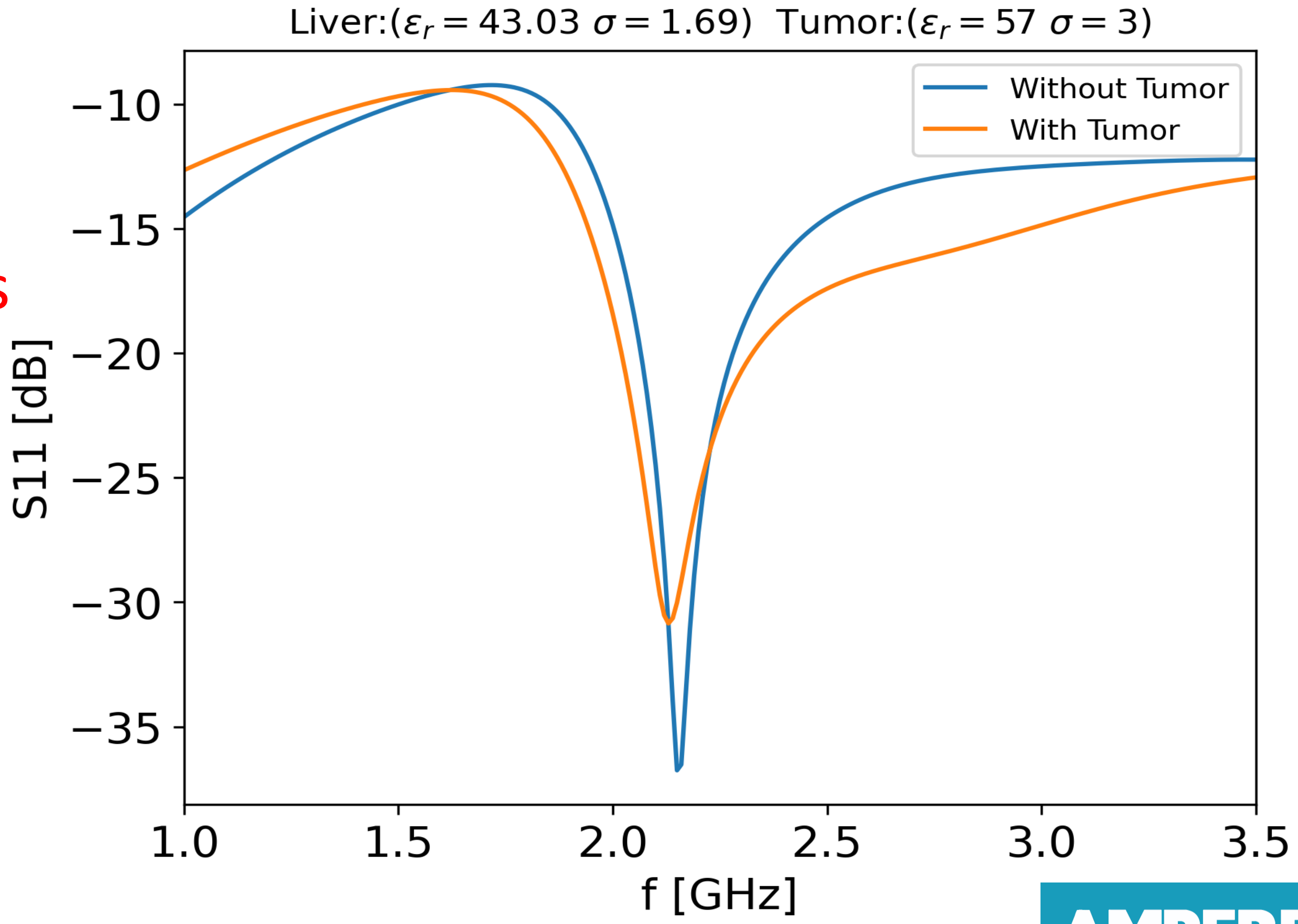
Whole model size: 65 mm x 50 mm

Length of the antenna: 42 mm

TEM exciation at 2.45 GHz

Comparision between with and without a tumor – S11 Parameters

S11 coefficient changes with the occurrence of tumor!

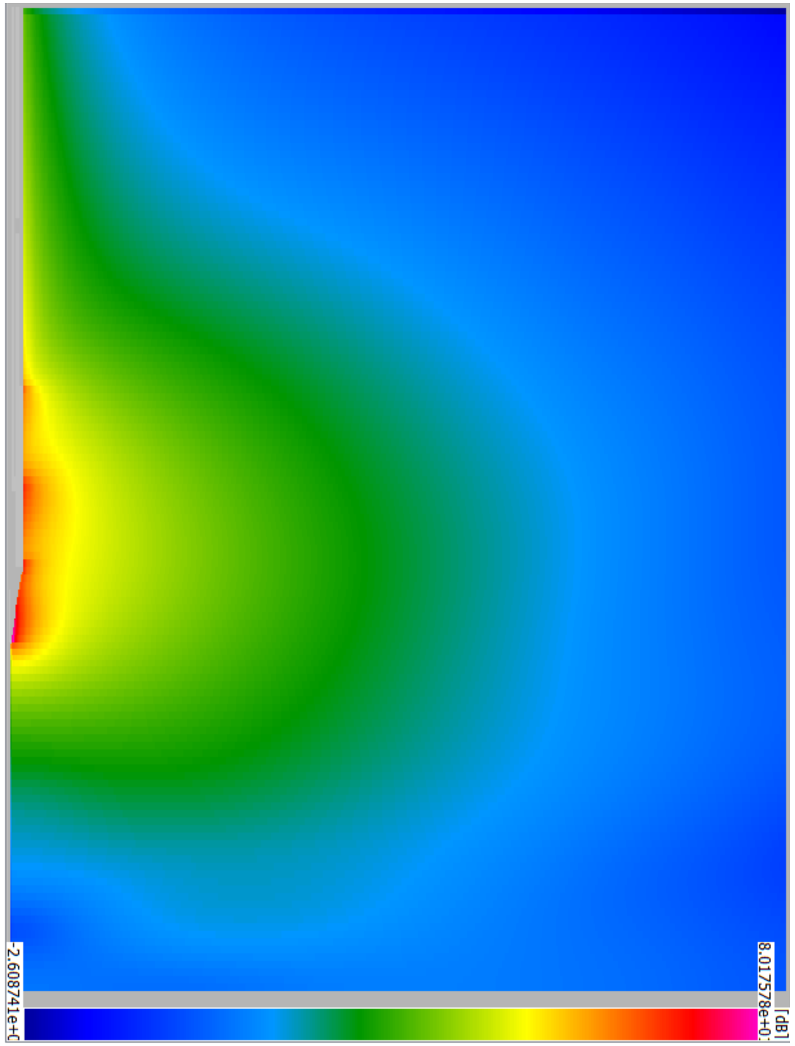


Comparision between with and without a tumor – SAR distribution

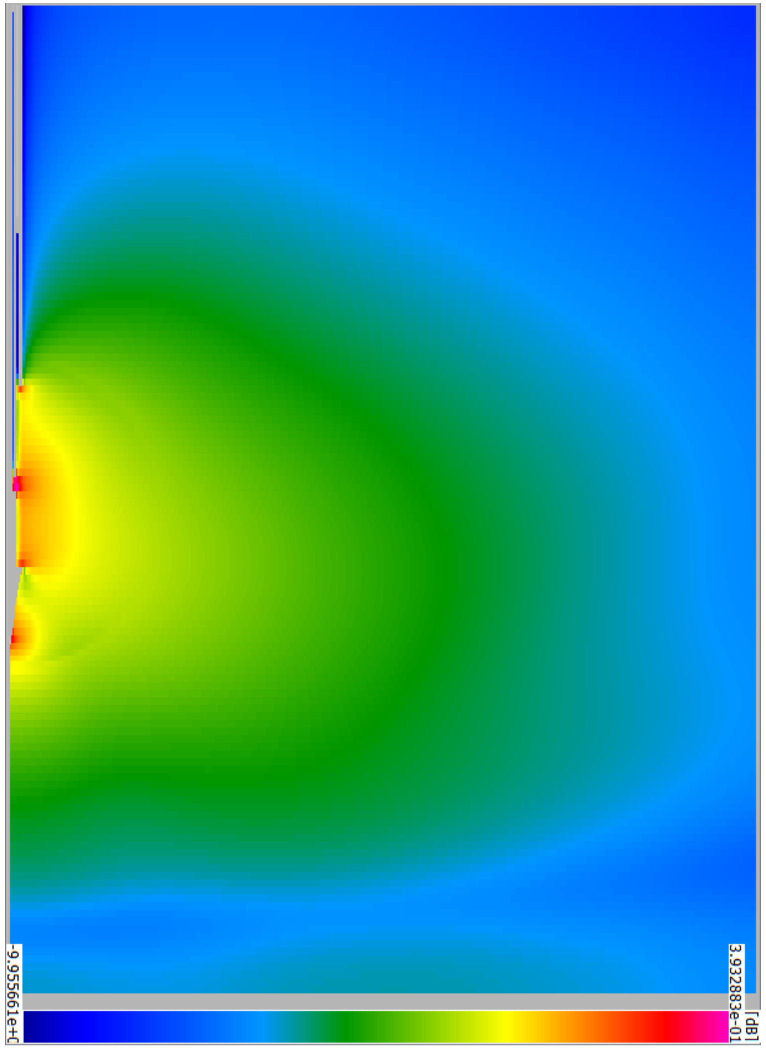
So does
the SAR distribution

A – without a tumor

B – with a tumor



A



B

Antenna Model in QW Robin Boundary Condition

Convective heat transfer coefficient [W cm^{-2} K^{-1}]

```
# Boundary conditions definiton file for thermal QW3D module
!Temperature      Enthalpy       Ha
37                0.8            0.01
40                0.8            0.01
45                0.8            0.01
50                0.8            0.01
55                0.8            0.01
60                0.8            0.01
65                0.8            0.01
70                0.8            0.01
75                0.8            0.01
80                0.8            0.01
```

Special cases:

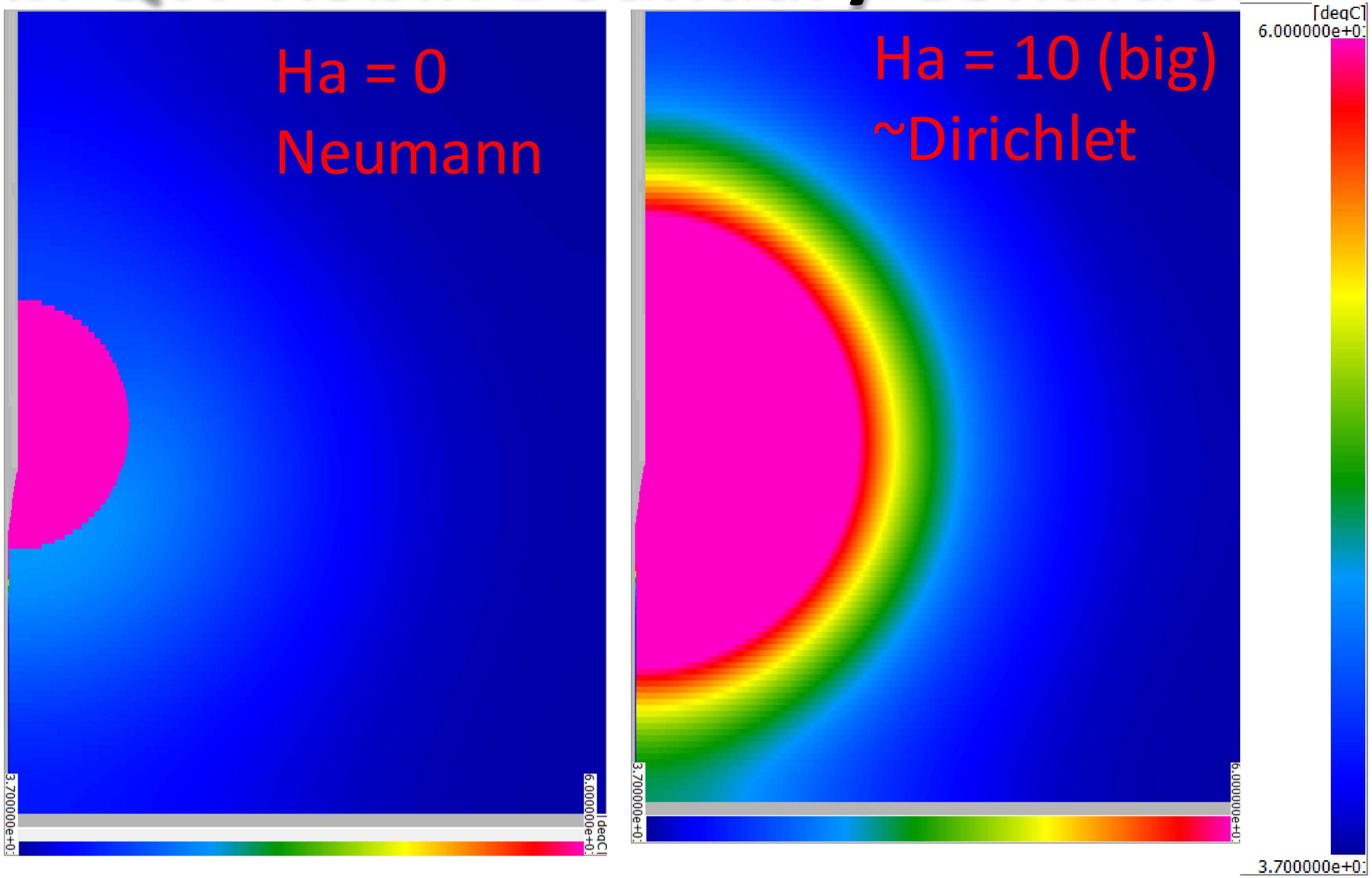
Ha = 0 → Neumann BC

Ha = +INF → Dirichlet BC

Antenna Model in QW Robin Boundary Condition

Thermal Distribution

20W – 15 min



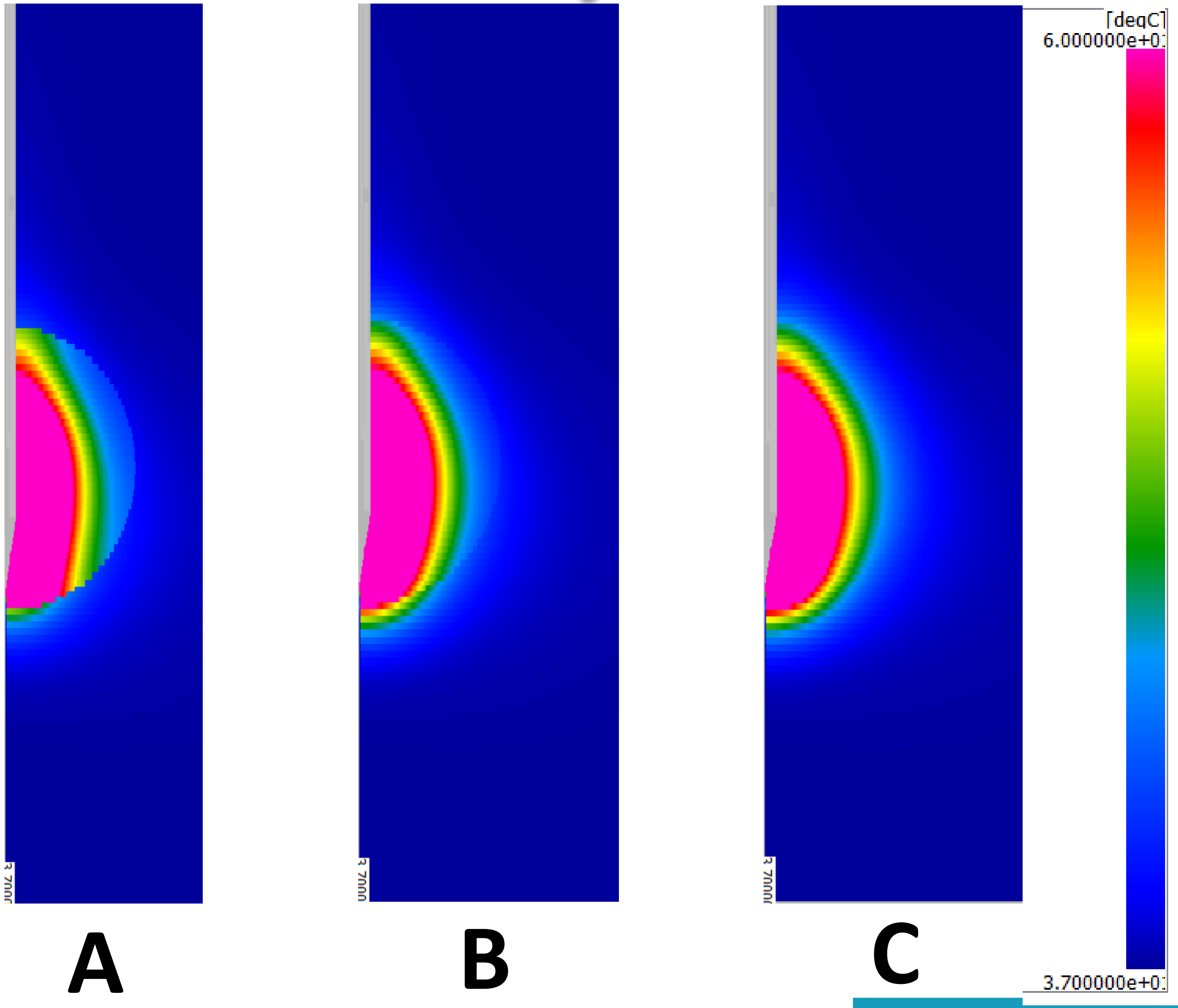
Antenna Model in QW Robin Boundary Condition

20W – 40 seconds

A – Ha = 0.01 W cm^{-2} K^{-1}

B – Ha = 0.1 W cm^{-2} K^{-1}

C – Ha = 0.5 W cm^{-2} K^{-1}



Conclusions

- The results of the electromangetic analysis vary depending on the presence of tumor.
- Using Robin Boundary Condition maybe not be an usual practice, but it can show you how important is knowledge of experimental results.
- These cases (also from IMPI conference) shows us the capabilites of QW in MWA simulations and what it's need to be improved.

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We are open to new collaborations!

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