Presented at the COMSOL Conference 2009 Milan

3rd European COMSOL Conference 2009

October 14-16 2009, MILAN, ITALY

Leonardo Da Vinci Hotel & Convention Center

NUMERICAL VALIDATION OF THE EFFICIENCY OF DOUBLE OR DUAL-FREQUENCY RADIO FREQUENCY ABLATION

A. Candeo[(1)], F. Dughiero[(2)]

(1) Dept. Electrical Engineering, University of Padova, Padova, Italy

E-mail: alessandro.candeo@unipd.it

Outline

- Introduction
- Model layout
- Single frequency comparison (20 vs. 500 kHz)
- Dual-frequency simultaneous operation
  - w/ constant feeding input
  - w/ power switching control
- Conclusion and future perspectives

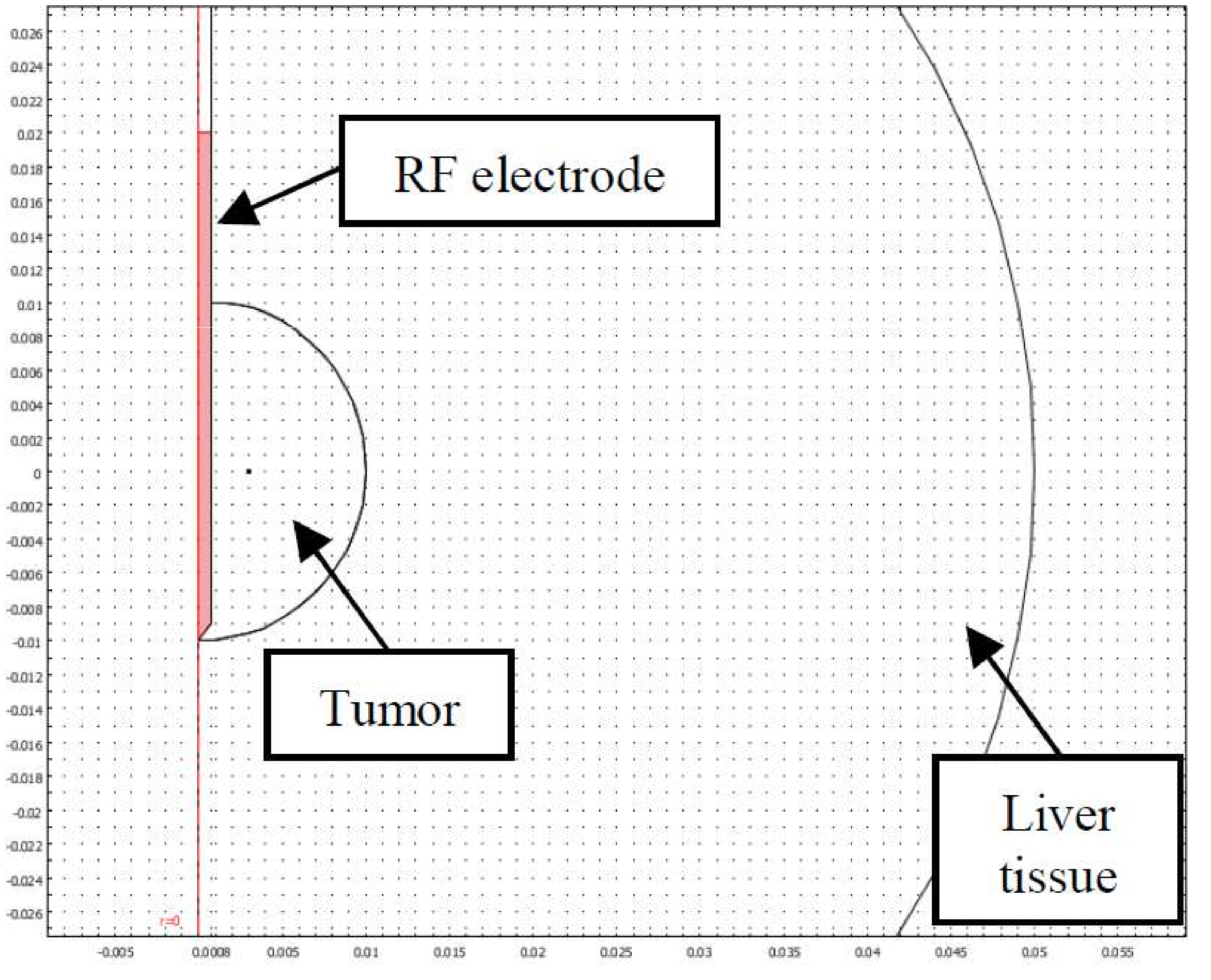
Introduction

- Clinical hyperthermia (CH) consists in inducing a selective heating within a tumor-involved region of the body (typical range: 40-42 C)
- CH rationale is based on the different heat sensitivity of healthy vs. impaired tissues, in terms of different thermal conductivity values
- Radiofrequency ablation (RFA) uses AC (500 kHz) in order to produce higher and faster heating, thus ‘burning’ the tumor mass (typical range: 50-90 C)
- RFA represents a valid alternative for treating liver metastases in medically complicated patients
- Recent studies on RFA claimed higher current densities and better heating of tumor mass compared to surrounding tissue when lower frequencies (i.e., 20 kHz) are used
- The effects of different frequency values will be here investigated and compared, including a novel dual-frequency approach

Model layout

- The district under analysis is represented by an axis-symmetric model which includes:
  - tumor nodule (diameter: 2 cm)
  - surrounding tissue (diameter: 10 cm)
  - internally-cooled active RF electrode (length: 3 cm) covering the whole nodule and a marginal area of liver tissue
- Coupled dielectro-thermal transient analysis (600 s)
  - Meridional electric currents (AC/DC module)
  - Bio-heat equation (Heat transfer module)
- Different frequency of sources in the harmonic simulation (20 kHz, 500 kHz)

Model layout



- Temperature-dependent conductivities

$$\sigma = \sigma_{37}\left(1+\alpha_{\sigma}(T-37)\right), \quad \alpha_{\sigma} = 0.015\,(°\mathrm{C}^{-1})$$

$$k = k_{37} + \alpha_{k}(T-37), \quad \alpha_{k} = 0.00116\,(\mathrm{W/m/°C^{2}})$$

- Frequency-dependent dielectric properties

$$\sigma = \sigma(\omega); \quad \varepsilon = \varepsilon(\omega)$$

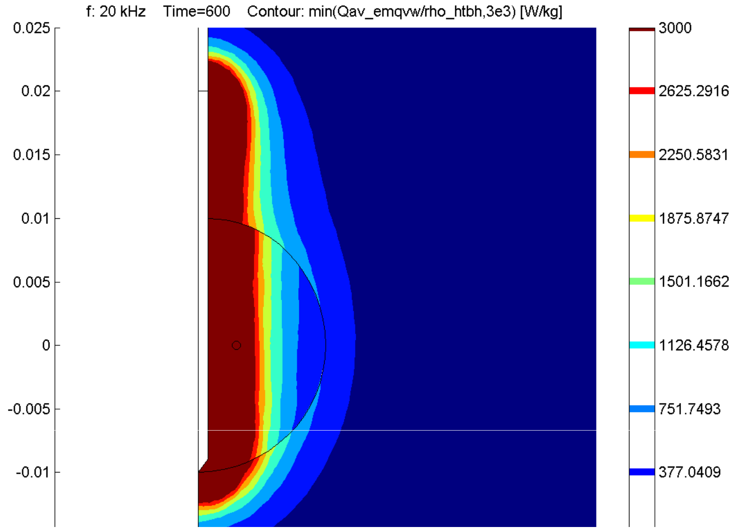
- Constant blood perfusion coefficient

Property	Liver	Tumor	Unit
relative permittivity ε_r (20 kHz)	18516		-
relative permittivity ε_r (500 kHz)	2770		-
dielectric conductivity σ (20 kHz)	0.17	0.31	S/m
dielectric conductivity σ (500 kHz)	0.36	0.45	S/m
thermal conductivity k	0.512	0.570	W/m/ C
perfusion ω_b	16.670e-3	0.416e-3	s^{-1}

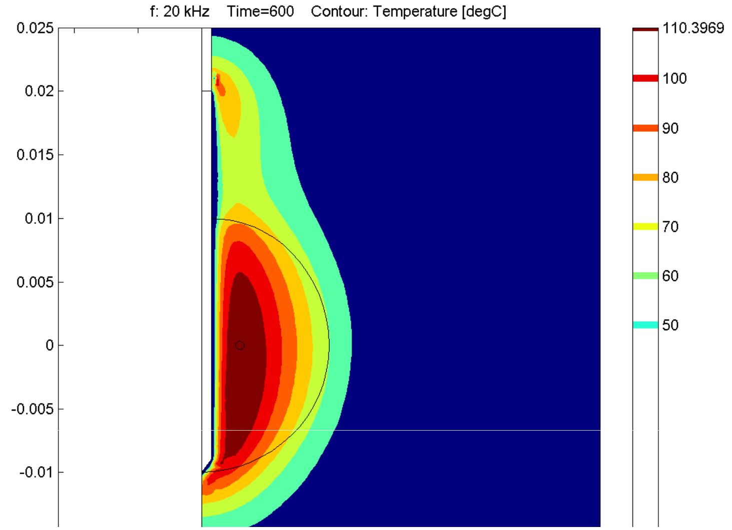
Single & Dual-frequency

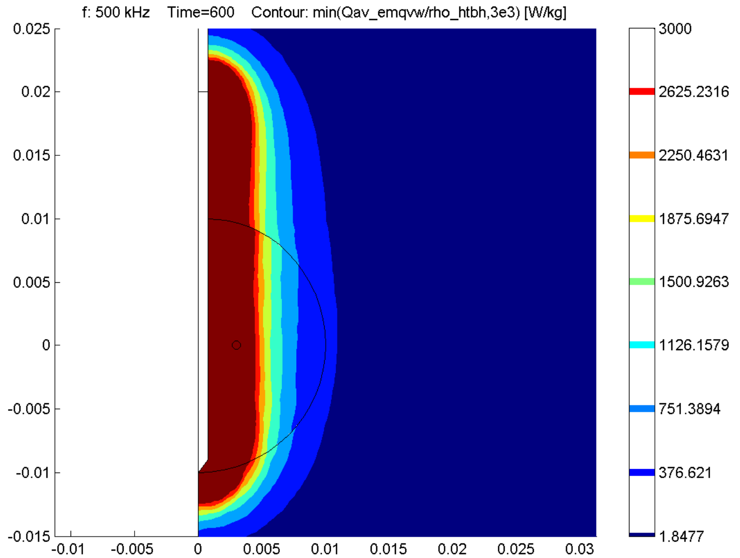
- Effect of frequency value in a constant voltage/power configuration (e.g., 40 W)
- Evaluation of SAR and T distributions in the domain
- Comparison of temperature profiles in space and time
- Investigation of the “tail-effect” along the insertion path
- Concept: average (steady state) power equivalence

- SAR deposition (W/kg)
- T distribution (C)

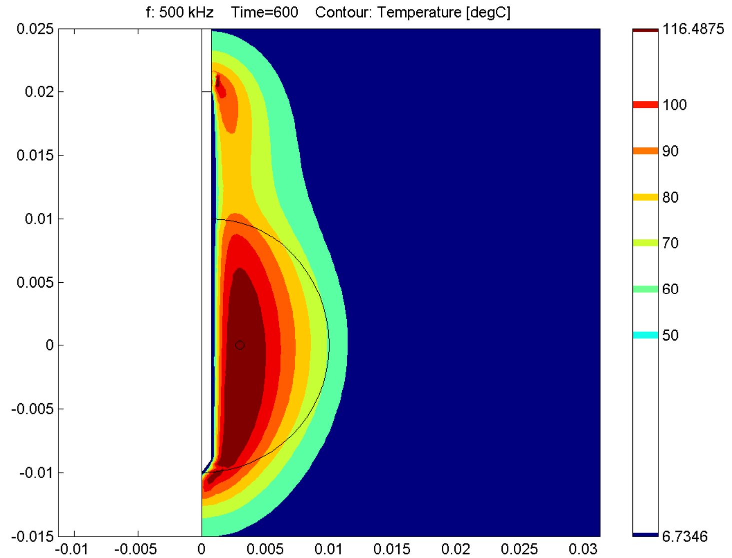


20 kHz

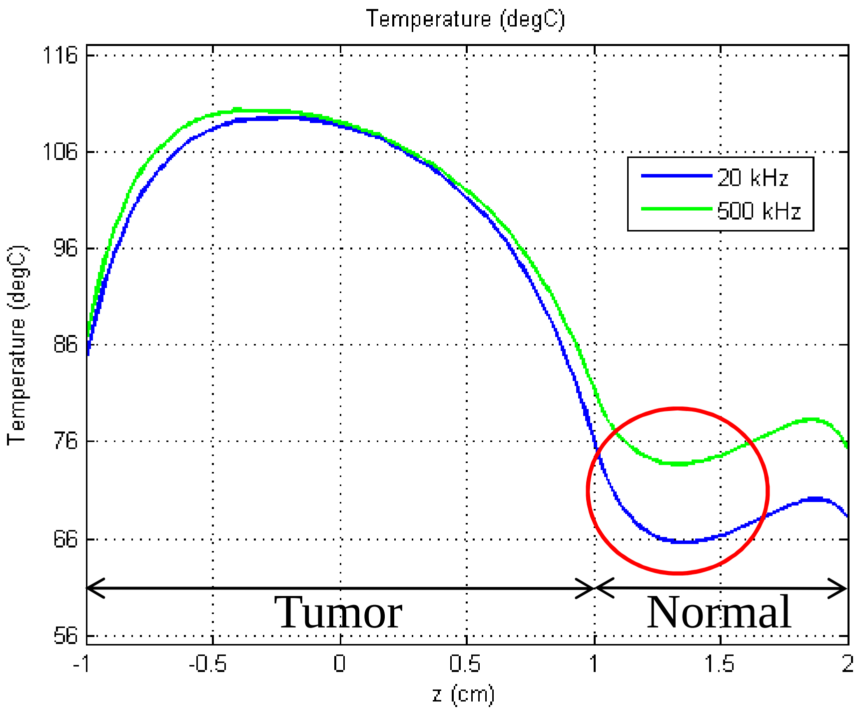


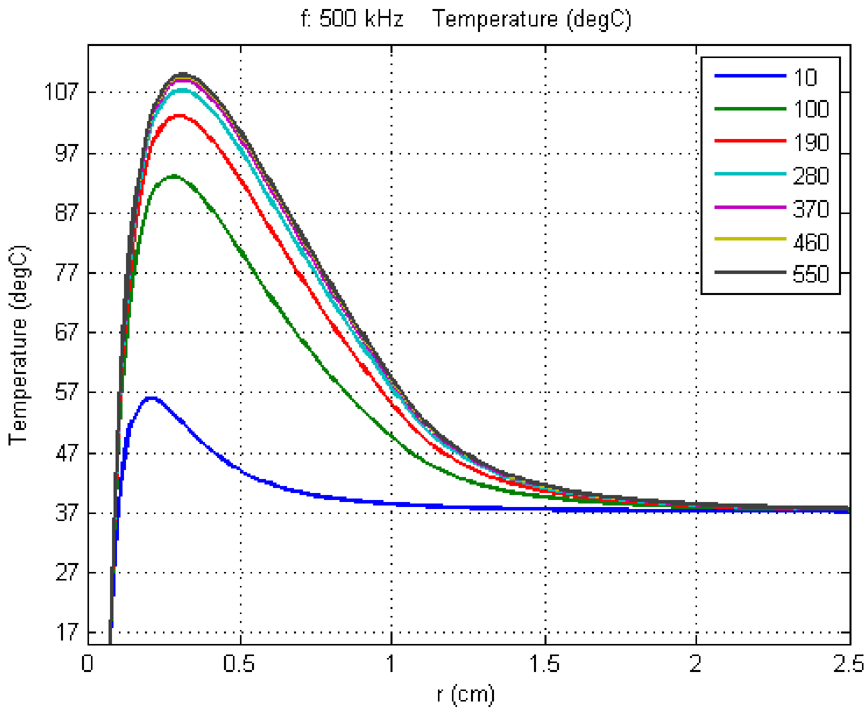


500 kHz



- Comparable peak (max temperature) evolution
- Comparable radial temperature distribution
- Comparable heating of tumor
- More pronounced "tail-effect" with 500 kHz



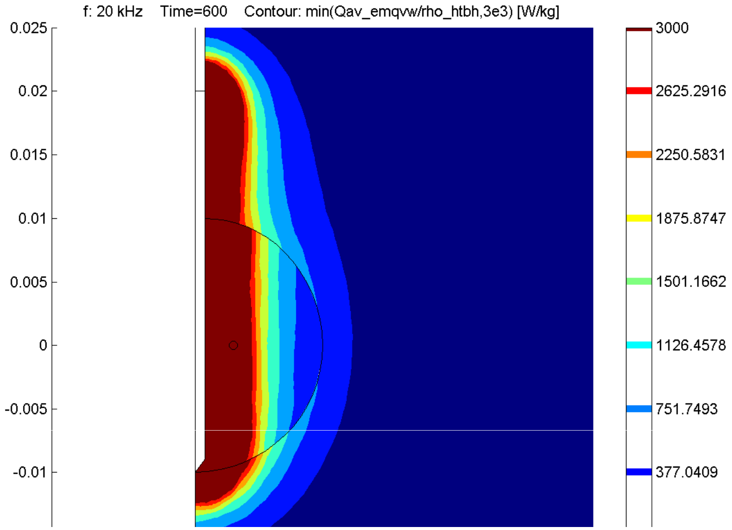


DUAL-FREQUENCY

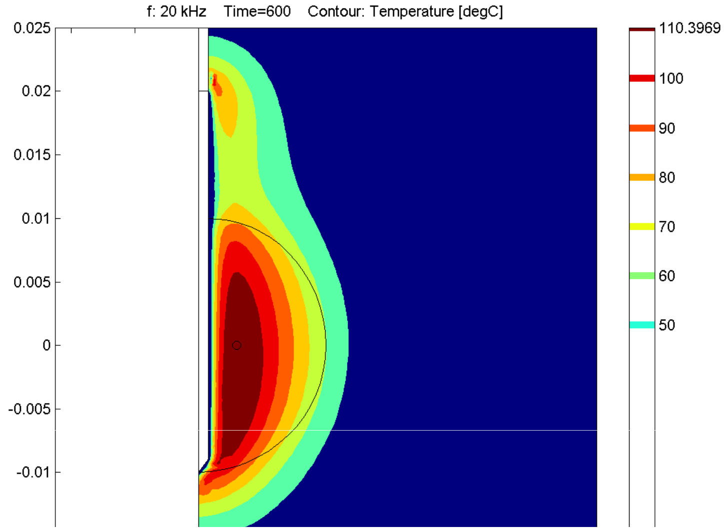
SAR – TEMP MAPS

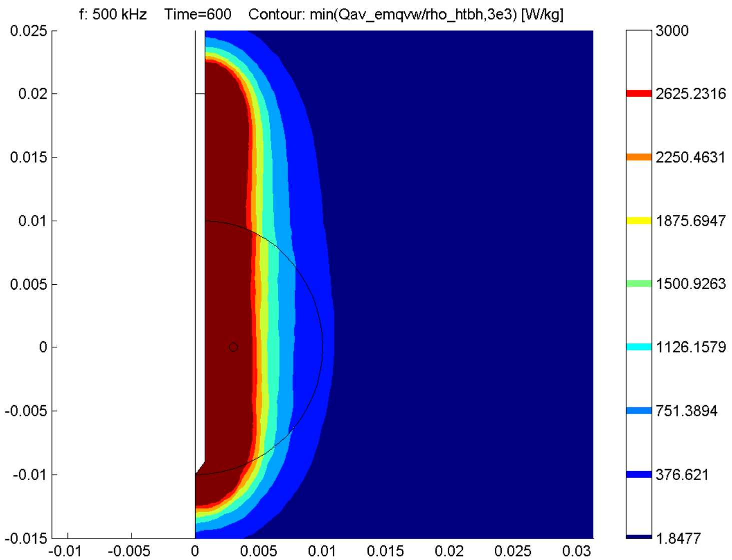
SAR deposition (W/kg)

T distribution (C)

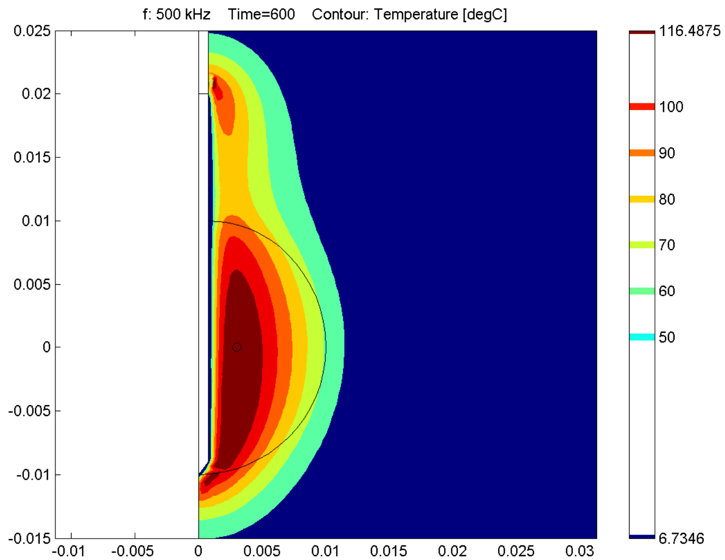


20 kHz





500 kHz

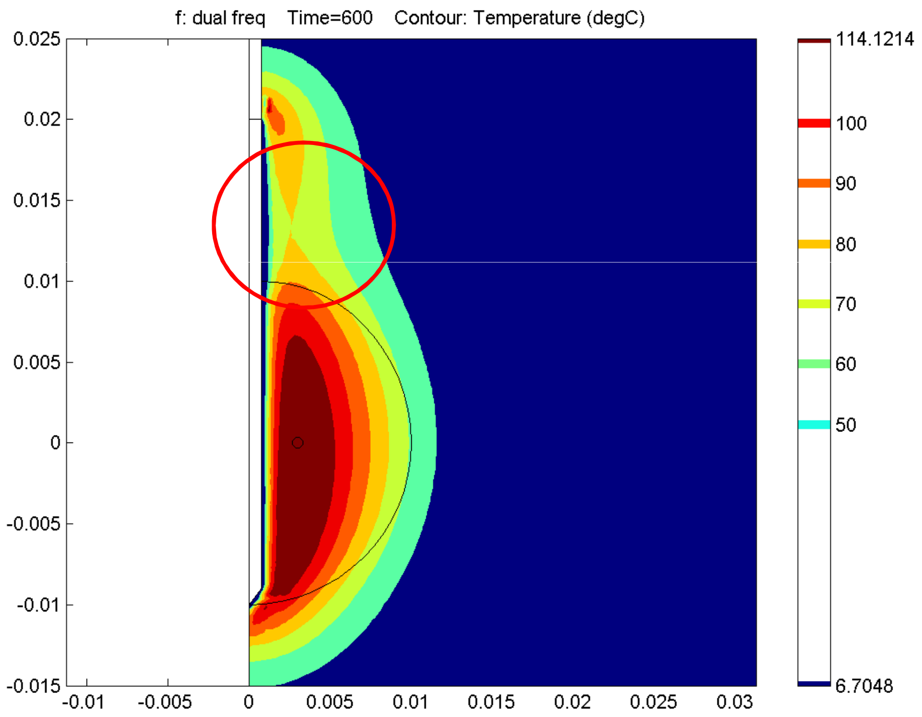


DUAL-FREQUENCY

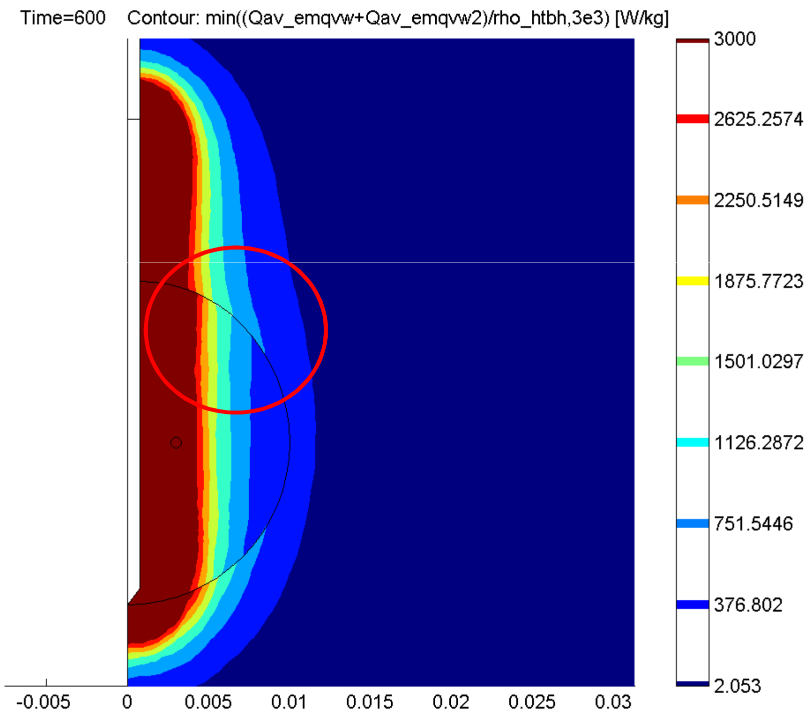
SAR – TEMP MAPS

- SAR deposition (W/kg)
- T distribution (C)

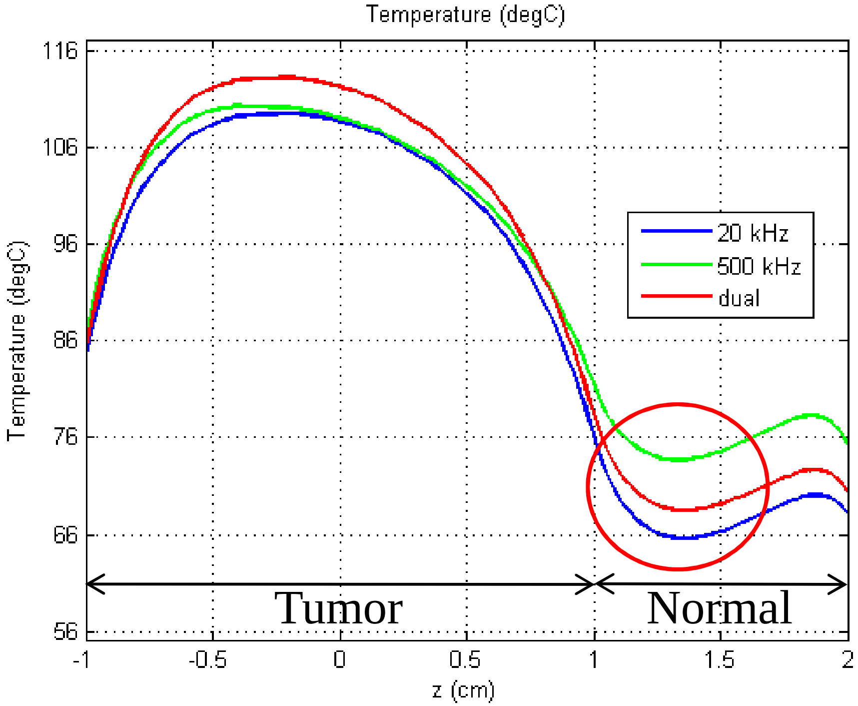
dual frequency

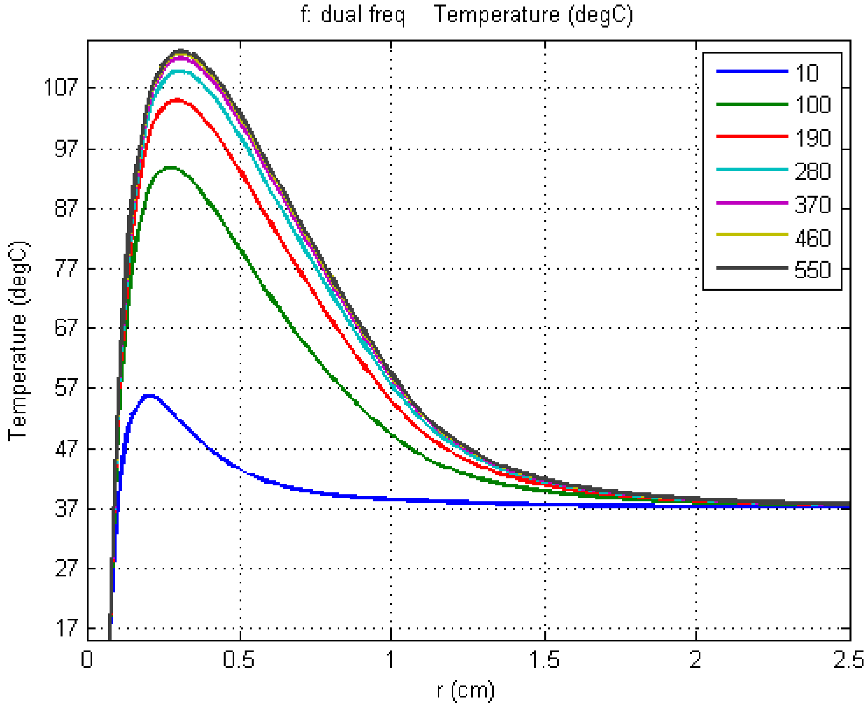


dual frequency



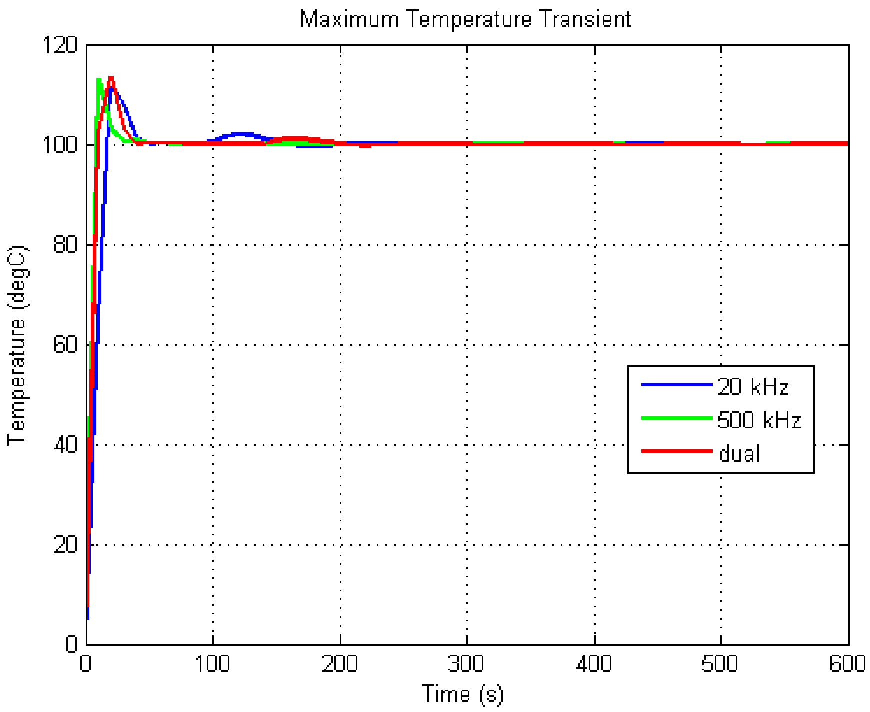
- Slightly higher peak (max temperature) evolution
- Higher final radial temperature distribution
- More effective heating of tumor
- Reduced “tail-effect” compared to 500 kHz

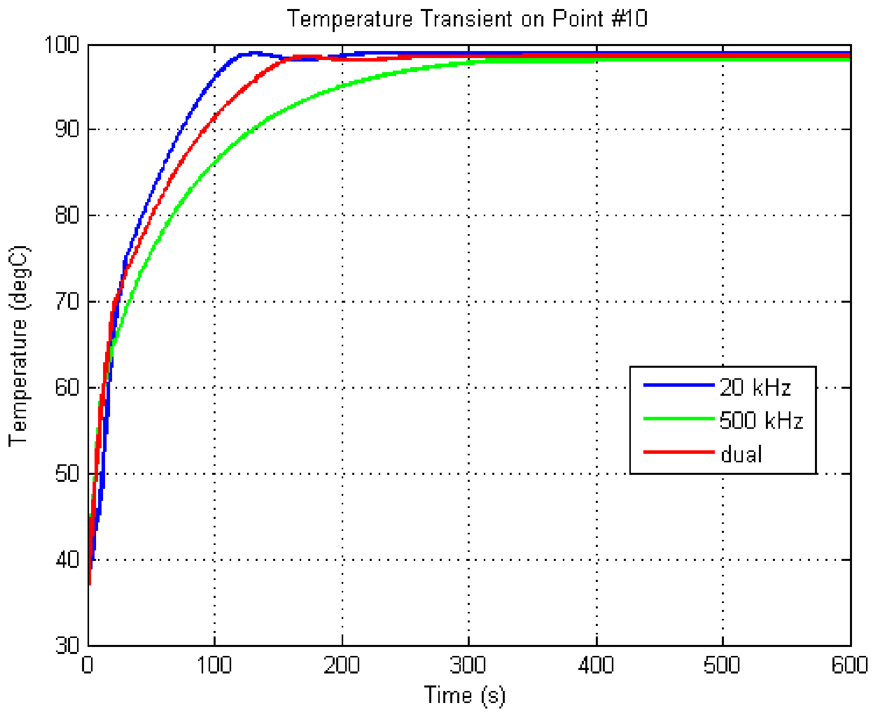




Dual-frequency with power control

- Implementation of a proportional controller adjusting the voltage feed so as to keep the desired max temperature (using MATLAB© connection)
- Concept: transient voltage equivalence

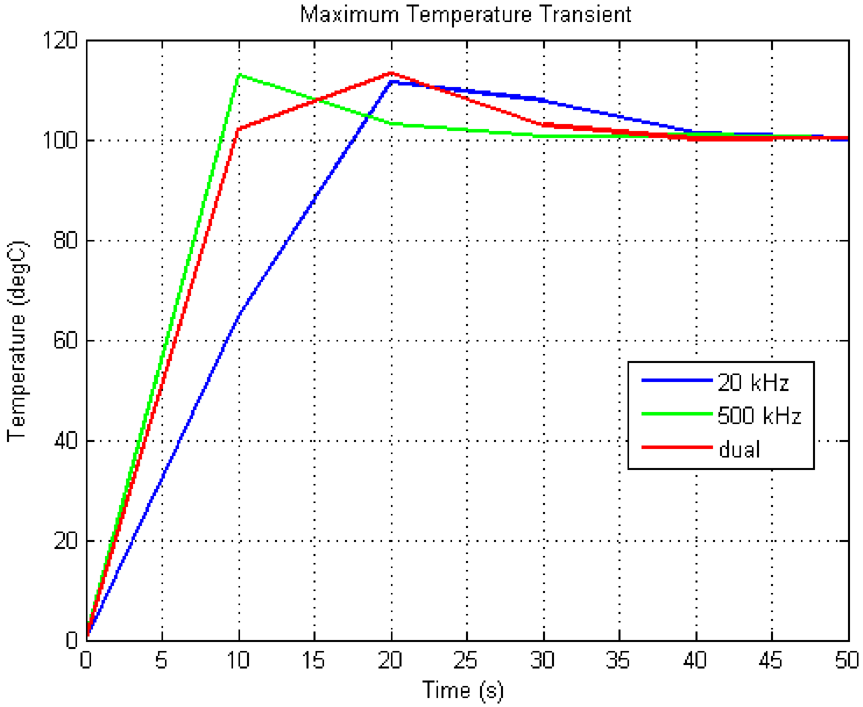


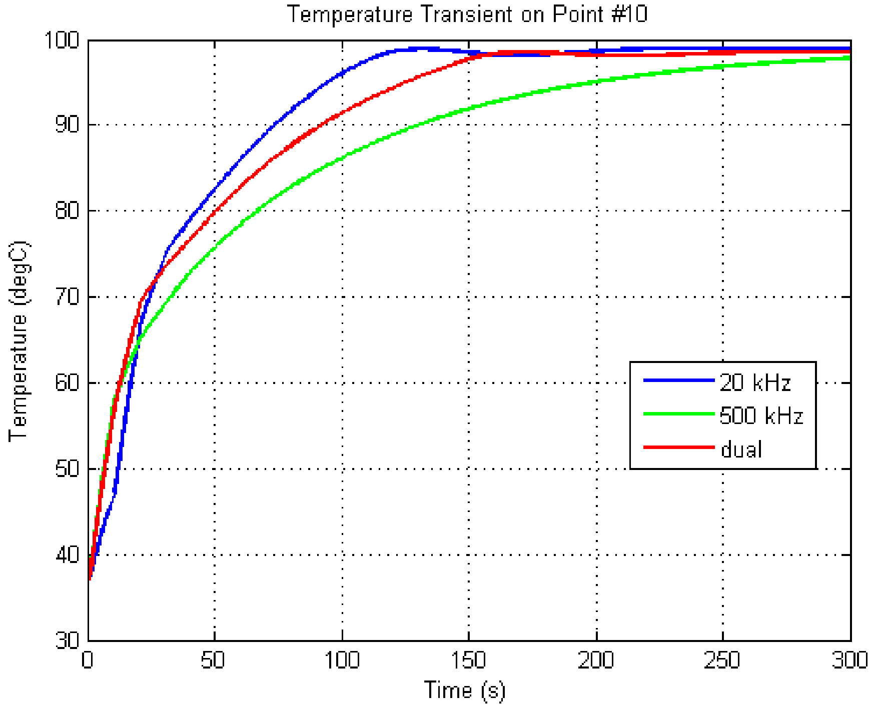


DUAL-FREQUENCY W/ CONTROL

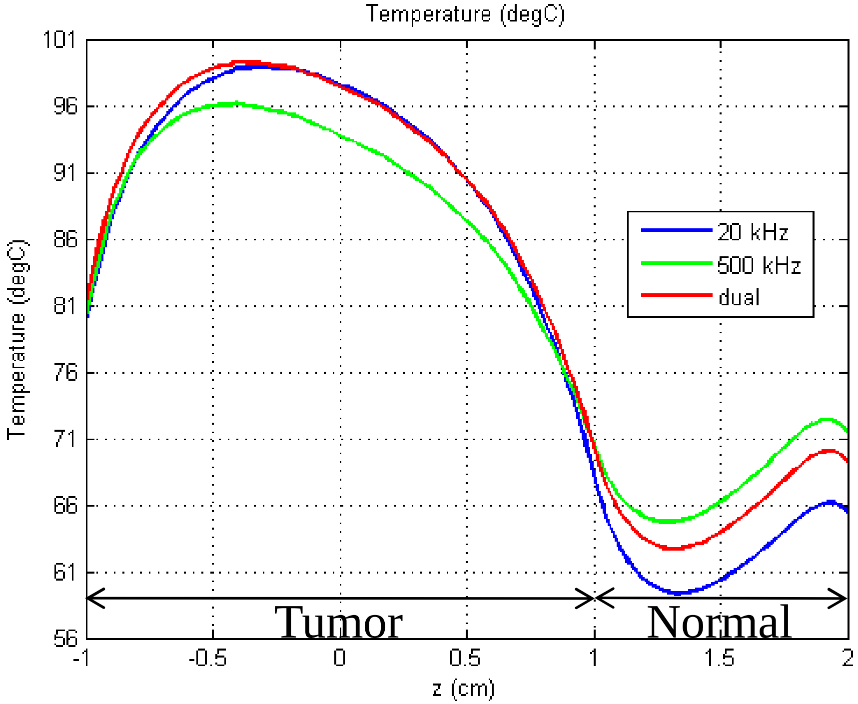
TRANSIENT PLOTS

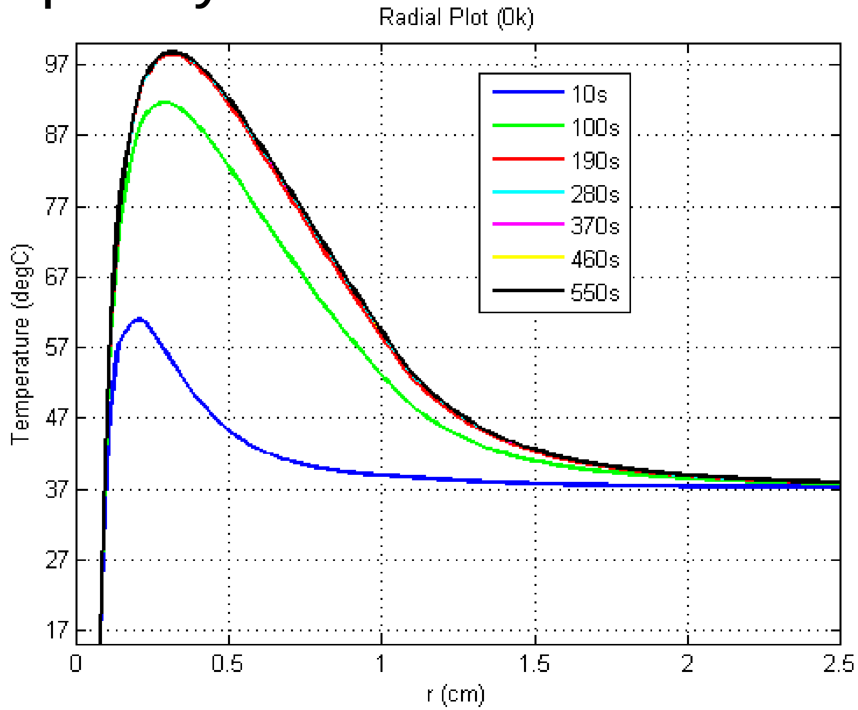
- Shorter heat-up time with 500 kHz
- Better radial heating with 20 kHz
- Faster heating and more effective treating with dual-frequency





- Transient effect for t<190s ➔ different thermal evolutions
- Steady state for t>200s ➔ thermal equilibrium reached
- Faster heat diffusion with 20 kHz
- Shorter heat-up time with 500 kHz
- Combined effect with dual-frequency

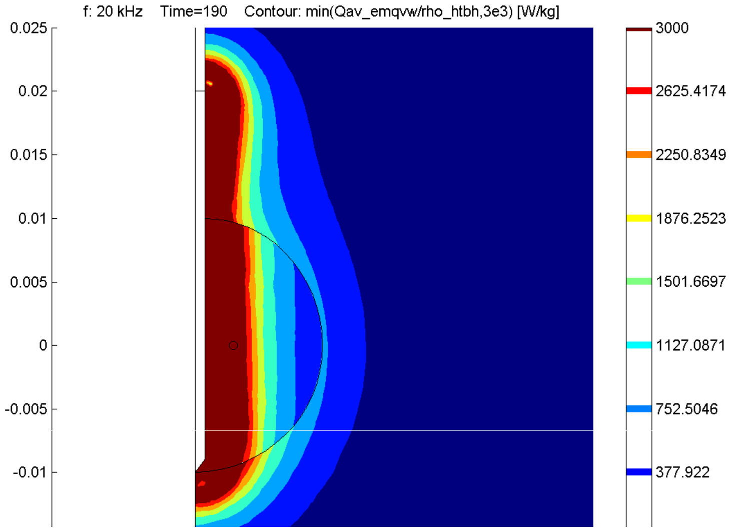


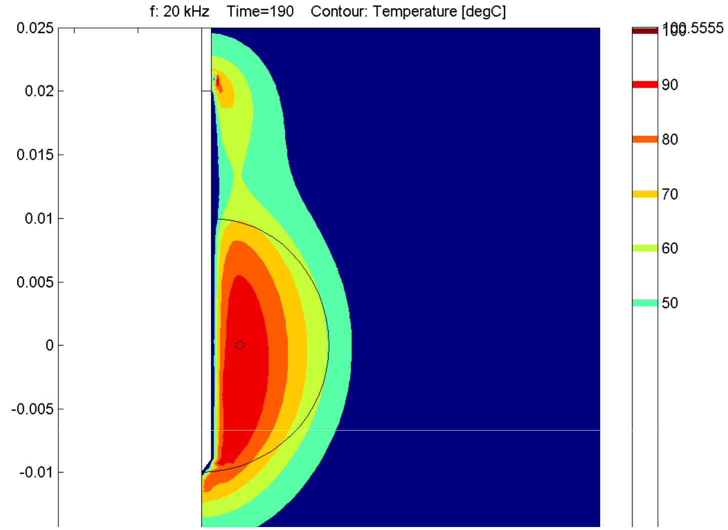


DUAL-FREQUENCY W/ CONTROL

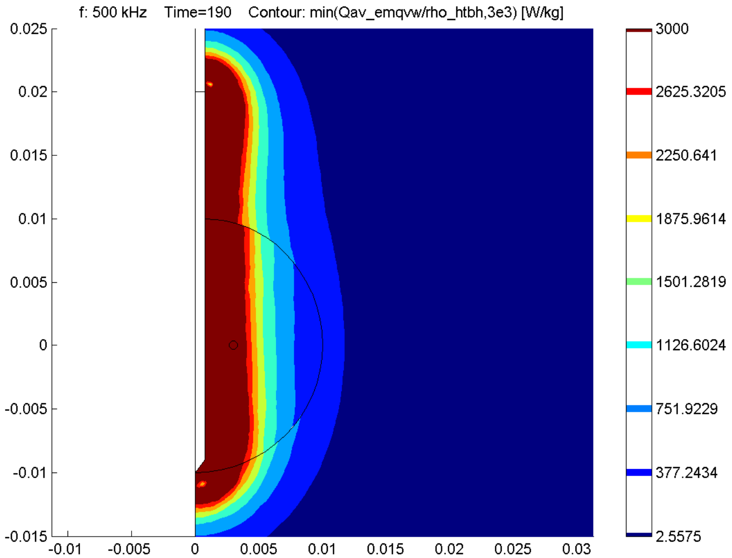
SAR – TEMP MAPS

- SAR deposition (W/kg)
- T distribution (C)

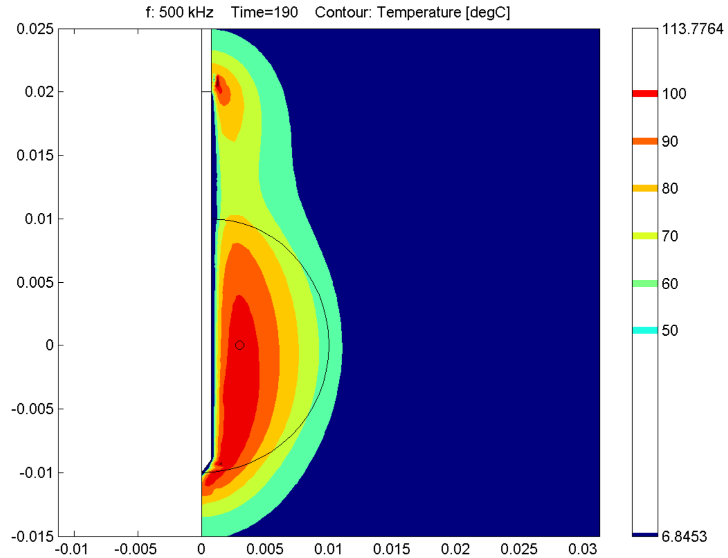




20 kHz



500 kHz

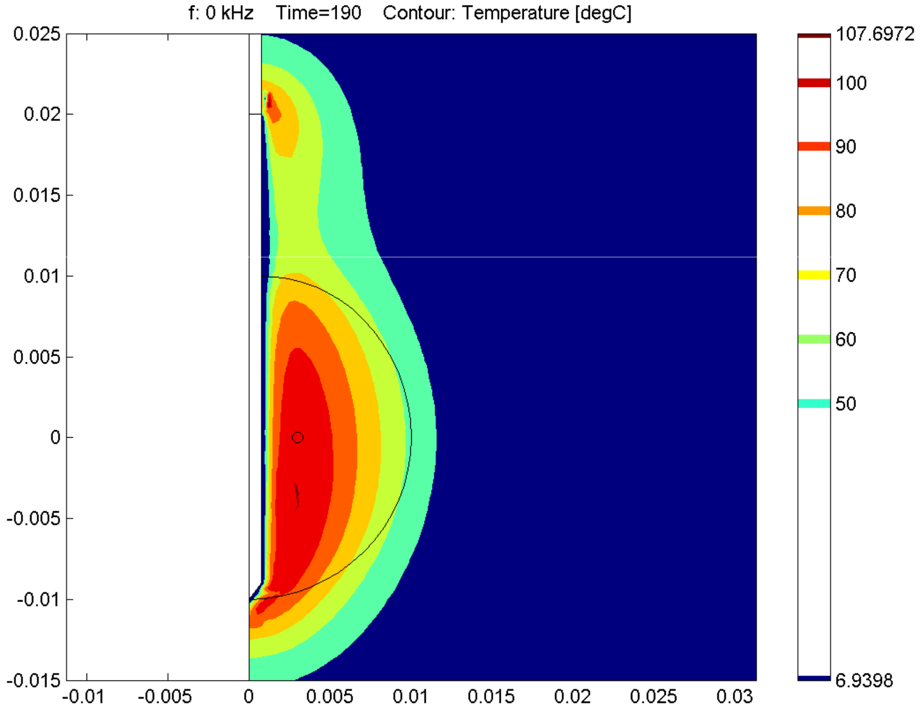


DUAL-FREQUENCY W/ CONTROL

SAR – TEMP MAPS

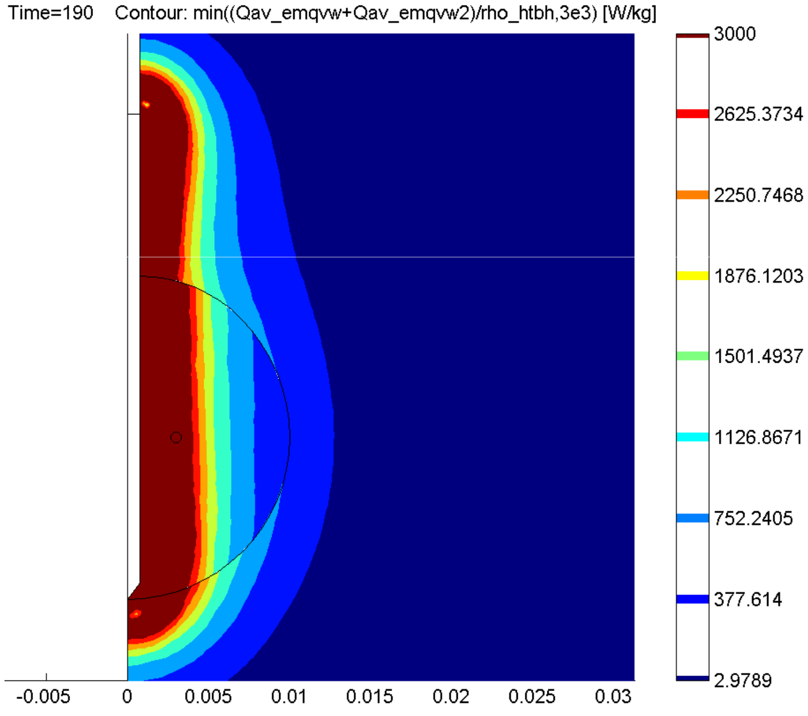
- SAR deposition (W/kg)

dual frequency



- T distribution (C)

dual frequency



Conclusion

- Comparison table

Frequency	PROs	CONs
20 kHz	Faster tumor heating (core temperature)	Muscle excitation issues
500 kHz	Faster heat-up time (peak temperature)	More pronounced “tail-effect”
dual freq	Fast tumor heating (core temperature)	-
	Fast heat-up time (peak temperature)	Tissue stimulation?
	Reduced “tail-effect”	-

Future perspectives

- Non-linear temperature-dependent model for tumor/tissue blood perfusion
- Cessation of perfusion model (e.g., Arrhenius tissue damage)
- Investigation of other types of feed coupling (e.g., capacitive) and electrode (e.g., multi-prong)
- Influence of discrete vasculature
- Effects in a real anatomy model
- Measurements & validation on phantom
- Device implementation issues

THANK YOU FOR YOUR ATTENTION!
(ANY QUESTIONS?)

A. Candeo(1), F. Dughiero(2)

(1) Dept. Electrical Engineering, University of Padova, Padova, Italy

E-mail: alessandro.candeo@unipd.it

Solving procedure flow-chart