FAKULTA BIOMEDICÍNSKÉHO INŽENÝRSTVÍ ČVUT V PRAZE

Design of a simple MTA applicator using CST Studio Suite, and simulation of the electromagnetic field and temperature distributions during ex vivo MTA procedure

Subject: Microwave Thermal Ablation for Cancer Therapy
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Required equipment:
Computer with Sim4life

1. Introduction:

Approximately 70% of people. who have contracted cancer of the liver are unable to undergo surgical treatment and are considered to have inoperable cancer. Among the most successful minimally invasive treatments is the direct application of energy using treatments such as Microwave Thermal Ablation (MTA) or Radio Frequency Thermoablation (RFT).

The goal of thermoablation is to deposit MW/RF energy in a tumor. Catheter based applicators are inserted into the tumor and under the guidance of either ultrasound, CT or MRI, energy is deposited into the tumor. The subsequent heating of the region destroys the tumor and tissue in a small circumferential region around the tip of the electrode used for depositing the energy. The amount of deposited energy is carefully controlled in order to minimize damage of healthy tissue.

The finite integration technique is very well suited to simulating the EM interaction between thin metallic radiators and heterogeneous voxel based anatomical models. In order to determine the temperature distribution in the liver due to the electromagnetic fields in the body, a co-simulation was performed using SEMCAD and Sim4life software. The simulation set-up consists of an electrode, a voxel model of the human muscle and a reference (grounding) plate.

Interstitial applicators for microwave ablation are introduced directly into the tumorous tissue by using a special type of catheter. The most used frequency for the MTA is 2.45 GHz. Such applicator could be used for the treatment of small tumors up to 5 cm in diameter. The advantage of MTA applicators is their compatibility with the plastic catheters widely used for brachytherapy.

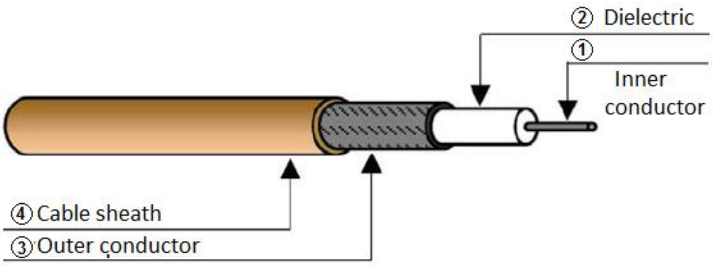

Fig. 1 Coaxial cable RG -178.

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Table 1.: Cable parameters RG -178 (see Fig. 1)

	Parts	Diameter
1	Inner conductor	0.31 mm
2	Dielectrics	0.83 mm
3	Conductive braiding	1.33
4	Cable sheath	1.8

2. Exercise:

2.1 Applicator design – dimensions calculation

The following calculations are used to approximate the applicator parameters for its design.

Total mean permittivity ε_{rs}

$$\varepsilon_{rs} = \frac{\varepsilon_{rdiel} + \varepsilon_{liver} + \varepsilon_{rplastic}}{3} = \frac{2.1 + 52.7 + 2.1}{3} = 18.97(-) \tag{1}$$

Calculate the reduced wavelength:

$$\lambda_r = \frac{c}{f \cdot \sqrt{\varepsilon_{rs}}} \tag{2}$$

where λ_r is the reduced wavelength, *c* is speed of light, *f* is the operating frequency of the applicator.

Calculate the helix diameter on cable dielectrics according the following formula:

$$D_1 = b + 2 \cdot \frac{d}{2} = b + d \tag{3}$$

where *b* is the diameter of dielectrics in cable, *d* diameter of inner conductor-

Calculate the helix circumference on the cable casing

$$D_2 = a + 2 \cdot \frac{d}{2} = a + d \tag{4}$$

where *a* is the diameter of the coaxial cable.

Circumference of helix on dielectric core

$$C_1 = \pi \cdot D_1 \tag{5}$$

Circumference of helix on cable sheath:

$$C_2 = \pi \cdot D_2 \tag{6}$$

Calculate the number of threads of pitch of 1.5 mm – helix on dielectrics of cable length *L*:

$$N = \frac{\lambda_r}{L} = \frac{\lambda_r}{\sqrt{\pi^2 \cdot D_1^2 + S^2}} \tag{7}$$

Length of helix on the cable casing:

$$L = N \cdot S \tag{8}$$

1. Use computer, where the numerical simulator of EM field Sim4life light is installed. Open the Sim4life light numerical model with the name: MTA_model.smash. The model is visible in the Fig 2.
2. Go to the model section and compare the imported model with your calculations (See Fig. 2).
3. Adjust the model according to your calculated parameters (see Fig. 2 – arrow 2).

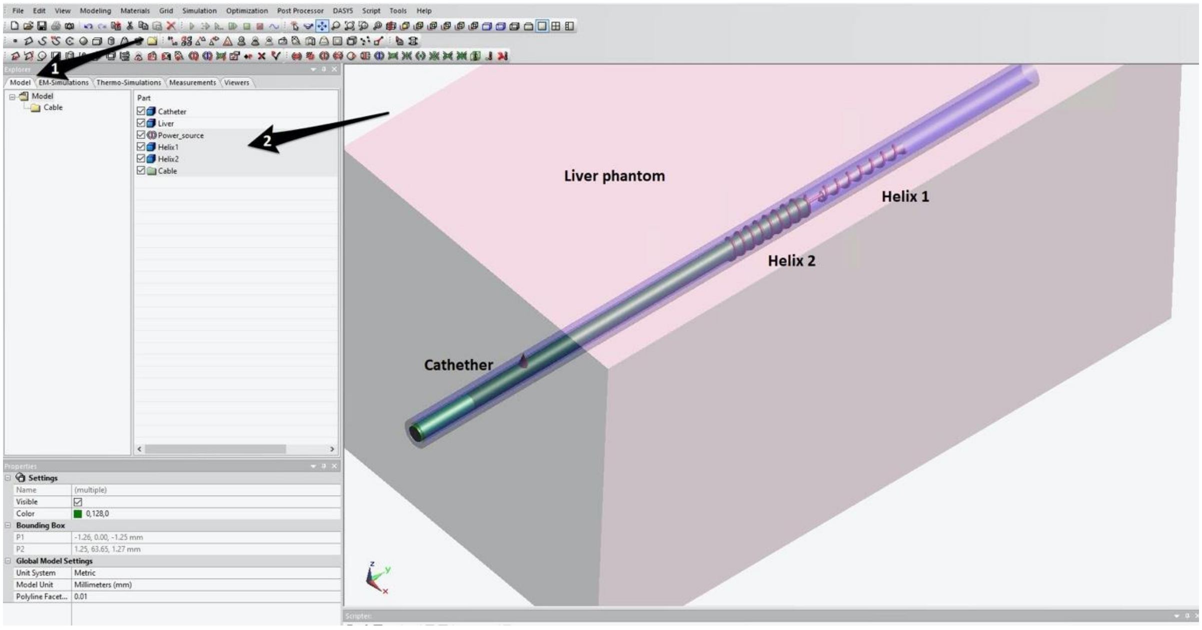

Fig. 2.: Screenshot from the simulator with the workflow indicated by arrows.

4. Click on the bookmark “EM-Simulation”. Set the settings properties according to the Fig. 4 (arrow 2). Set the proper frequency, which will be applied (2450 MHz).
5. Click on the bookmark “Solid regions (arrow 3 in the Fig. 3)”. Update the dielectric properties according to the Fig. 5.

Dielectric parameters:

Relative permittivity of cable (dielectrics): $\varepsilon_{rk} = 2.1$

Relative permittivity of muscle tissue: $\varepsilon_{r\_muscle} = 52.73$

Relative permittivity of liver tissue: $\varepsilon_{r\_livers} = 43.035$

Conductivity of muscle tissue: $\sigma = 1.7388$ S/m

Conductivity of liver tissue: $\sigma = 1.6864$ S/m

6. Control the voxels – (arrow 4 and 5 in the Fig. 3). Click on the “view voxels” and visualize Helix 1 and Helix 2. If the number of voxels is insufficient (see Fig. 3 (a)), increase the number of voxels to get the better result (see Fig. 6).

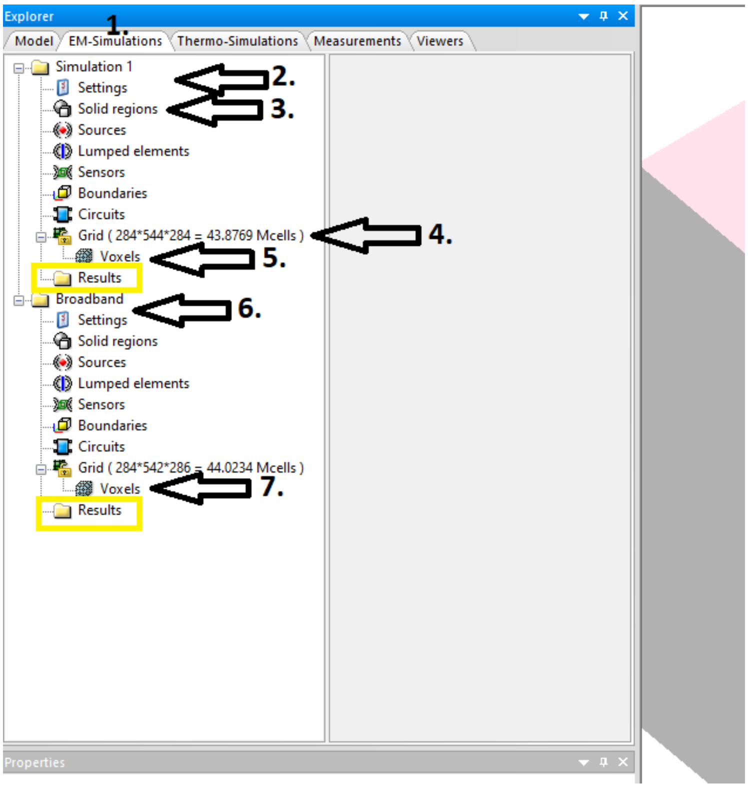

Fig. 3.: Simulation settings and simulator settings procedure.

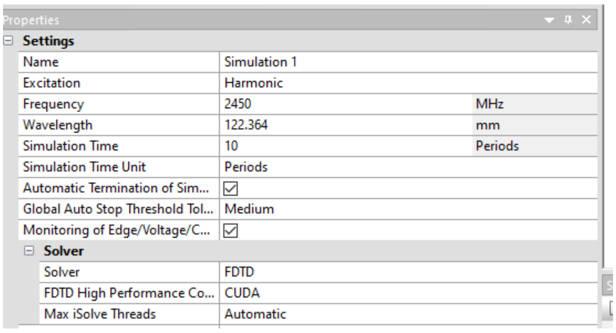

Fig. 4.: Setup properties of the Simulation 1.

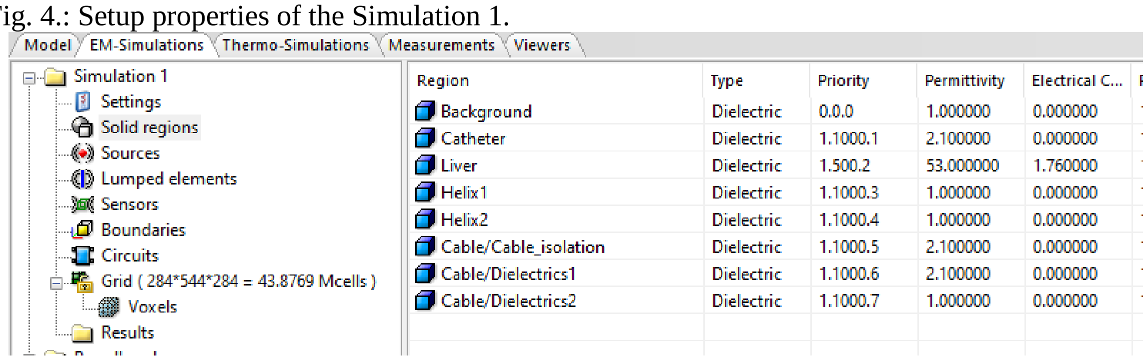

Fig. 5.: Solid regions – dielectric properties settings.

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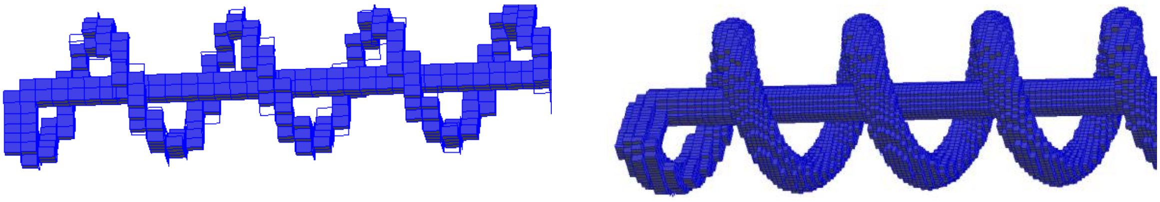

Fig. 6.: Voxeling quality: Poor – left, Good – right.

7. Click on the second simulation in the list (“Broadband”) – arrow 6 in the Fig. XX. Set the simulation settings according the Fig. 7.

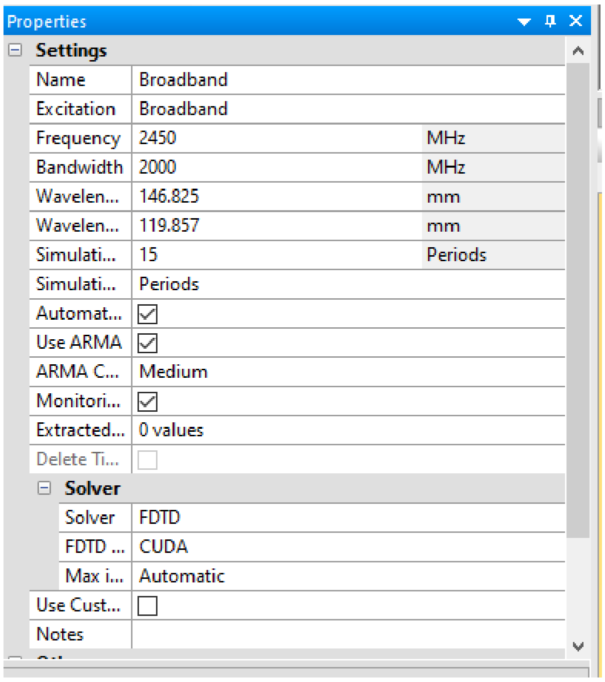

Fig. 7.: Settings of the Broadband simulation.

8. Set the rest settings as in the previous “Simulation 1”. Repeat points 5 and 6.
9. Right click on Voxels and click on Make voxels in Simulation 1 and in Broadband. The model will be voxeled.
10. Run the simulation (both simulation) clicking on green arrow on the top of the settings list.

2.2 Results Analysis

1. Click on the part Results in the Broadband simulation – see Fig. 8 arrow 1. Then click on the Sensor of Edge Source 1 (arrow 2) and right click on S11 (f), click on 2D curve plot view.
2. See the $|S_{11}|$ curve. Analyze the results of $|S_{11}|$ curve for liver tissue and muscle tissue (Fig. 9).
3. Click on the part Results in the Simulation 1– see Fig. 8. Then click on the Overall Field and right click on SAR (x,y,z,f0), click on Slice field view.
4. Analyze the SAR distribution in the cross-section perpendicular to the applicator
5. Recalculate the SAR distribution to temperature distribution via following equation:

$$SAR = c_t \cdot \frac{\Delta T}{\Delta t} \tag{9}$$

where T is the temperature, c is the specific heat capacity, t is time.

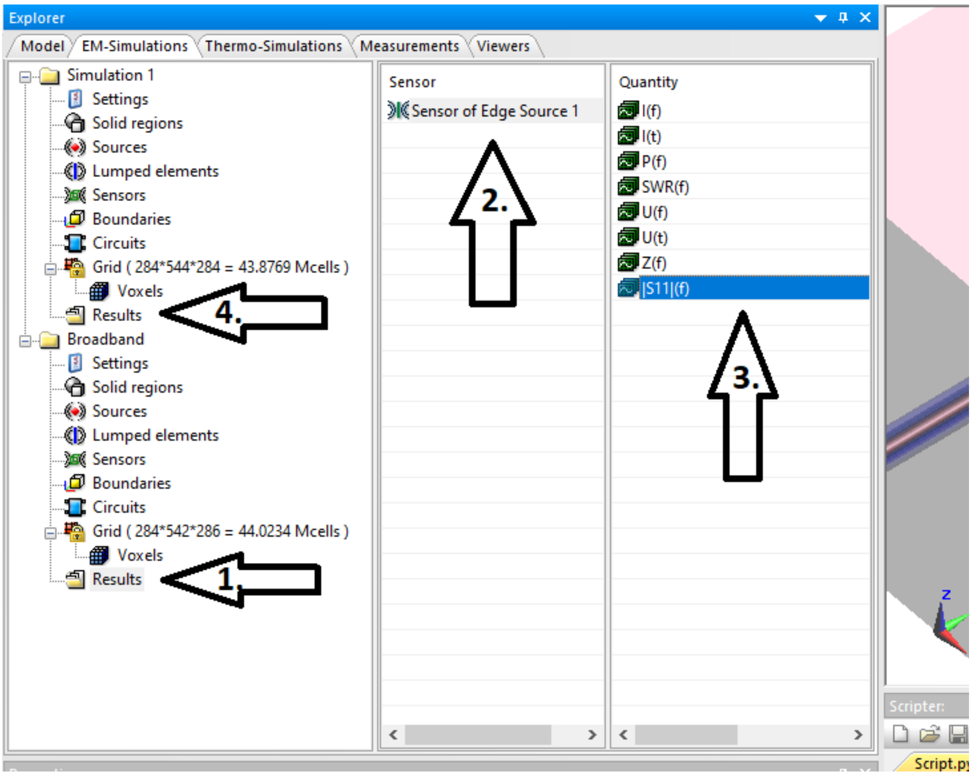

Fig. 8.: Results analysis.

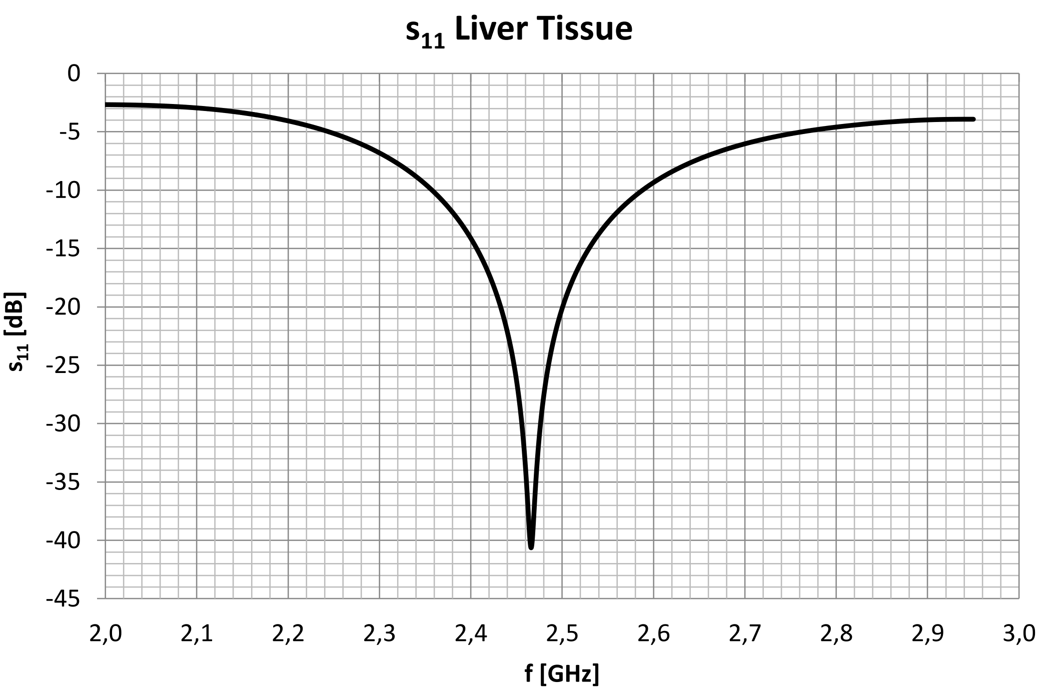

Fig. 9.: Resulted $|S_{11}|$ curve.

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Fig. 10.: SAR distribution of the applicator.

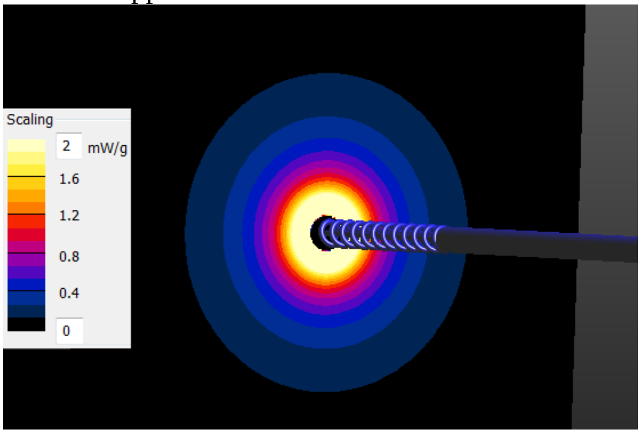

Fig. 11.: SAR distribution of the applicator.

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