Using transmission line theory to analyze RF induced tissue heating at implant lead tips

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INTRODUCTION:

RF induced currents in elongated electric conductors such as implant leads can give rise to serious burns during MRI examination. The heating essentially occurs in the tissue surrounding the lead tip. Several papers have investigated the amount of this heating by experiments and/or computational simulation methods considering specific leads under specific circumstances. To provide more general understanding of the heating mechanism, a method to analyze the tissue heating at lead tips is strongly desired. We use the theory of field-to-transmission line interaction [1] to calculate not only the induced current along an implant lead, but also the current density in the tissue at the lead tip. The results of the calculations are compared with results from finite-difference time-domain (FDTD) simulations.

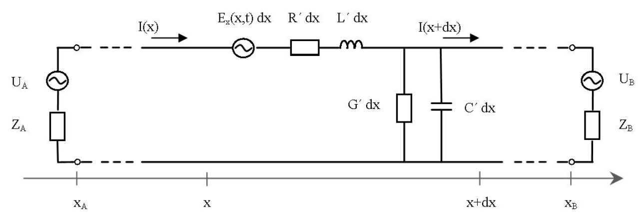

Figure 1: Model describing field-to-transmission line interaction.

THEORY:

The model of Agrawal et al. [2] is one of three different but mathematically equivalent transmission line models that describe the coupling of external electromagnetic fields to transmission lines (Figure 1). $Z'=R'+j\omega L'$ and $Y'=G'+j\omega C'$ are the well known complex distributed impedance and conductance, respectively. Z_A and Z_B are the impedances of the line terminations, U_A and U_B the voltage due to the external field at these terminations.

In our approach the Agrawal model is applied to a single insulated wire embedded in a tissue-like medium. Therefore the wire itself represents only the inner conductor, whereas the outer conductor is considered to be a hollow sphere with infinite radius. The termination impedances $Z_A=(R_A||C_A)$ and $Z_B=(R_B||C_B)$ are modeled as small half spheres with surface area A in contact with the tissue. To describe a wire with insulation an additional capacity has to be added to Y´. All the distributed impedances are estimated by geometric considerations.

RESULTS:

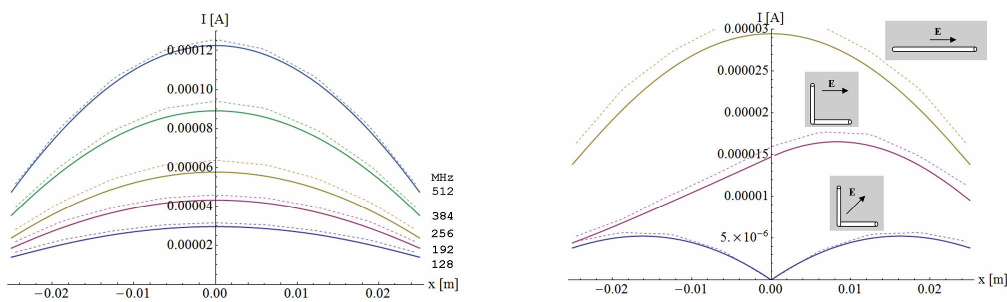

Figure 2: Comparison of calculations (solid lines) with FDTD simulations (dashed lines). Shown is the current distribution for short wires of 5cm length excited by a plane wave with electric field strength of 1 V/m parallel to the wire axis at (a) different frequencies. In (b) the current distribution at 128MHz of (a) is compared with that of a wire of the same length, but with a sharp bend of 90 degree in the middle (V shape) and the electric field aligned in two different angles as indicated in the figure.

The current densities giving rise to tissue heating at the tip, are the currents through R_A and R_B divided by the contact area A, which can be derived from the currents through the terminations Z_A and Z_B, given by $I(x_A)$ and $I(x_B)$. To make the model more accurate, the voltages U_A and U_B, which have been neglected in the presented results (Figure 2), have to be taken into account.

CONCLUSION:

We are aware that essential mathematical conditions for the legitimate use of the Agrawal model are not fulfilled in a transmission line whose outer conductor is shifted towards infinity. It is, for instance, obvious that the distance between inner and outer conductor becomes greater than the wavelength of the incident field. However, these conditions seem to be negligible due to the radial integration path. Other authors [3,4] have similarly used lumped element circuit models to describe coupling of implant wires with RF MRI fields. With our approach it is possible to analyze the effect of characteristic impedance (e.g. straight wires, solenoids or combinations of both), wire bending and/or electric field configuration on the current distribution of conducting leads (always a homogenous surrounding medium provided). Furthermore, it concentrates on being capable of estimating the current density at the lead tip responsible for tissue heating.

REFERENCES:

[1] Taylor et al., IEEE Transactions on Antennas and Propagation 13, 6 (1965), 987-989; [2] Agrawal et al., IEEE Transactions on Electromagnetic Compatibility 22, 2 (1980), 119-129; [3] Nitz et al., Journal of Magnetic Resonance Imaging 13, 1 (2001), 105-114; [4] Acikel and Atalar, Proceedings ISMRM 17 (2009), p. 4783.