Modeling of RF Induced Implant Lead Current for MRI

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INTRODUCTION:

During an MRI examination, induced radio frequency (RF) currents on electric conductors, such as implant leads may cause serious heating problems. This heating problem has been investigated with experimental studies. There exist solutions to this problem like adding transformers or RF chokes [1], however, all these solutions depend on experimental analysis and there is not a theoretical analysis method. Although, induced current can be calculated with computational methods, such as method of moments (MoM) or finite difference time domain (FDTD), it does not give full understanding of problem, they only provide solutions for a specific case. In this study implant leads, under RF field, are modeled in a similar way with the lumped element circuit model of transmission line and solve the current on this wire as two traveling wave.

THEORY:

In transmission line theory transmission lines are modeled as lumped element circuit, which contains a series impedance, Z, and a shunt admittance, Y, for an infinitesimal length. In our model there is an additional incident voltage source $\bar{E}\cdot dl$ due to the incident electric field as in Figure 1. The current on the wire can be solved by solving differential equation: $\ddot{I}/Y - IZ + E = 0$, where $\ddot{I}$ is the second derivative of current with respect to z. And solving the differential equation current can be found as $I = Ae^{-i\beta z} + Be^{i\beta z} + E/Z$ where $i = \sqrt{-1}$ and $\beta = \sqrt{-i\omega\mu_0\sigma'}$, $\sigma' = \sigma + i\omega\varepsilon$, μ_0 is permeability ε is permittivity and σ is the conductivity of medium. If a uniform electric field is applied on infinitely long lead, a uniform current on the lead would be observed. According to our model, differential equation reduces to $IZ = E$. Solution of the current can also be obtained using standard electromagnetic theory techniques and therefore Z, the series impedance, can be calculated as: $Z = -(\beta/\sigma')(H_0^2(\beta\rho)/H_1^2(\beta\rho))(1/(2\pi r_c))$. Since $\beta = \sqrt{ZY}$ (see [3]) then Y can be calculated. Remaining two unknown, A and B in the current equation can be calculated from the boundary conditions.

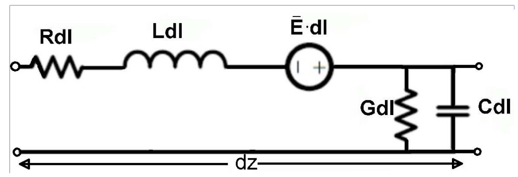
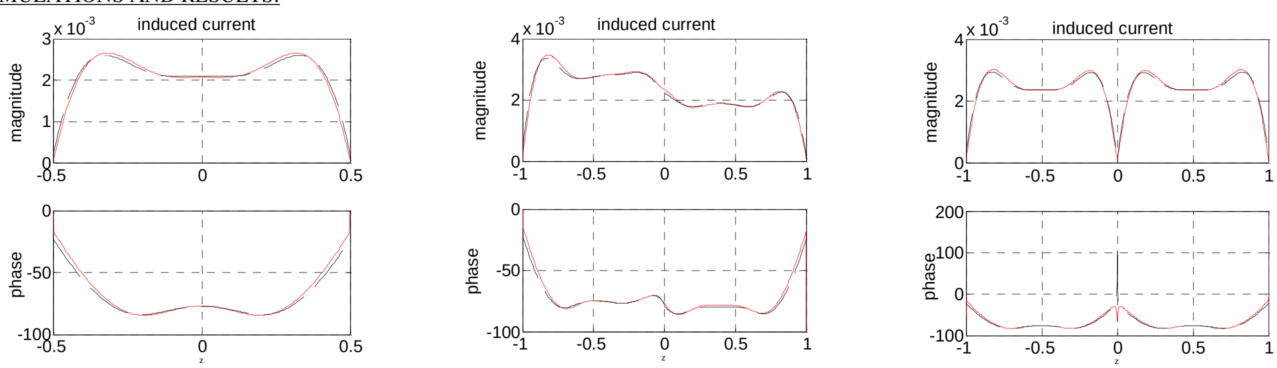


figure 1-model of implant leads

SIMULATIONS AND RESULTS:



(a) (b) (c)

Figure 2-comparison of computational method (MoM) with our model. In all graphs, the black dashed lines are obtained using MoM simulations and red solid lines are obtained using new analysis technique. Panel (a) is a bare wire with length 1m and radius 0.25mm. Conductivity, relative epsilon, frequency are:0.4 S/m, 80, 64MHz, respectively. Panel (b) shows current on two connected wires with different radiuses, 1mm and 0.1mm. Panel (c) displays the graph of current on a wire with radius 0.5mm bisected with a 1000Ω resistor.

Using the above mentioned theory, the current on the wire was calculated for different conditions and compared with MoM simulation results. Mean square error is between 3.2 and 4.2% (see Figure 2).

CONCLUSION:

In order to calculate induced current on implant leads due to the RF field leads modeled in a similar manner with transmission line lumped element circuit model. With this model it is easy to calculate induced current due to the RF field. Also, it gives understanding on behavior of induced current on leads and as heating is directly related to induced current on leads this model enables us to develop new solutions to heating problem due to implant leads and understand how the current solutions work.

REFERENCES:

[1]Vernickel P., Shulz V., Weiss S., Gleich B. A safe Transmission Line for MRI IEEE Trans. Biomed. Eng. 2005 [2] Yeung C. J., Susil R. C., and Atalar E, RF Safety of Wires in Interventional MRI: Using a Safety Index, Magn Reson Med 47(1):187-193, 2002. [3] D. M. Pozar, Microwave Engineering New York: Wiley, 1998