

Impedance Method for Calculation of Induced Voltage on Implanted Cardiac Leads due to MRI Gradient Magnetic Fields

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Introduction:

The time varying magnetic field produced by the gradient coils of an MRI system will induce an electric field in the conductive tissues within the body. This electric field can induce a voltage along an implanted lead connected to an active implantable medical device (AIMD) such as a pacemaker or cardioverter defibrillator. In the case of an implanted cardiac lead, the induced voltage could cause unintended cardiac stimulation which would be hazardous for a patient. If cardiac stimulation were to occur at a high rate of repetition, it could emulate ventricular tachycardia or fibrillation, leading to hemodynamic collapse. To characterize the risk of unintended cardiac stimulation the induced voltage along the lead needs to be determined. To aid in this risk assessment, a quasi static impedance method has been used to simulate the electric fields and determine the induced voltage along the path of an implanted lead. This work presents results of comparing induced lead voltage found using the impedance method with measurements made in an MRI scanner with a human body phantom.

Methods:

An impedance method [¹] which models conductive tissues as discrete elements and makes a quasi-static approximation has been implemented for the purpose of modeling the electric field within a phantom or a body exposed to the time varying magnetic fields of the MRI gradient coils. The modeling is a three step process consisting of the following: 1) calculation of the magnetic vector potential within the phantom or the body, 2) calculation of the electric field distribution within the phantom or the body, and 3) calculation of the induced voltage on a lead through integration of the tangential electric field component along the lead path.

As verification of this modeling effort, measurements were performed within an actual MRI system using an implantable lead routed in a phantom. The induced voltage produced by the slice select gradient for a coronal image plane was measured on a total of 50 lead paths. The induced voltage measurements are compared to simulated results to gauge the accuracy of the model. In addition, a time varying magnetic field map was measured in an actual MRI system using a 3-axis search coil. Magnetic field maps from measurement were compared with simulated field maps to verify that the gradient coil used in the simulations produces a field similar to the actual MRI gradient coils.

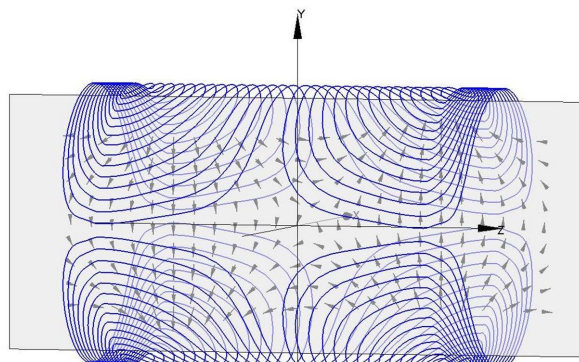


Figure 1. Gradient coil used in the model. The vector magnetic field is shown in the cross-section plane of the coil.

Results:

A simplistic gradient coil design (Figure 1) without active shielding was used in the modeling and matched a measured gradient field with an average dB/dt of 20T/s within +/- 1.5T/s. Results also show good correlation between induced voltages measured in a phantom using a clinical MRI scanner and the calculated voltages obtained from modeling (Figure 2).

Conclusion:

Results show good agreement between modeling and measurements and demonstrate that the impedance method is a viable method of calculating the induced voltage on implantable leads exposed to the time varying magnetic fields of the MRI gradient systems. This work will allow further modeling to be done using human body models to calculate induced voltages within a human, which will allow for accurate predictions of unintended cardiac stimulation for patients with implantable pacemakers or defibrillators.

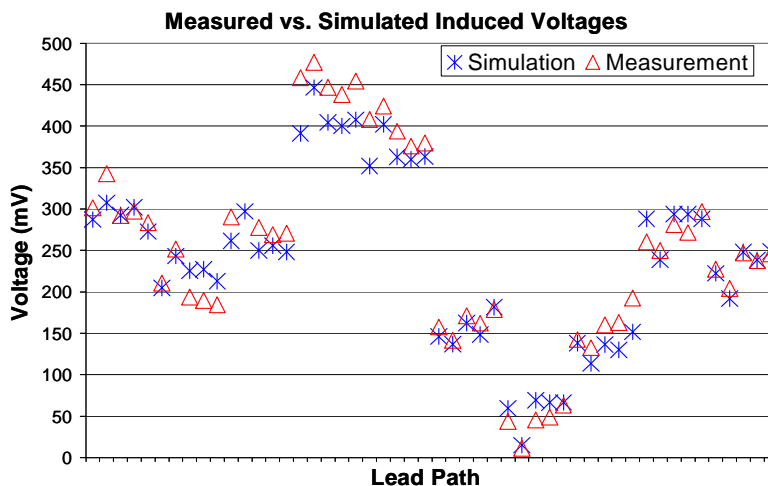


Figure 2. Comparison of the measured and simulated induced voltage of a cardiac lead routed in a human body phantom.

[¹]. N. Orcutt, and O. P. Gandhi, "A 3-D impedance method to calculate power deposition in biological bodies subjected to time varying magnetic fields", *IEEE Trans. Biomed. Eng.*, Vol. 35 No. 8, Aug. 1988, pp. 577-583.