Characterization of the Relationship between MR-Induced Distal Tip Heating in Cardiac Pacing Leads and the Electrical Performance of Novel Filtered Tip Assemblies

R. S. Johnson[1], H. Moschiano[1], R. Stevenson[1], S. Brainard[2], S. Ye[2], J. E. Spaulding[1], and W. Dabney[1]

[1]Cardiac & Neurology, Greatbatch, Inc., Clarence, NY, United States, [2]Cardiac & Neurology, Greatbatch, Inc., Plymouth, MN, United States

Purpose: It is well known that the B1 fields in MRI scanners induce significant heating at the distal ends of implanted active implantable medical device leads. Passive, two-component filters known as Band Stop Filters can be designed into the distal portion of leads such that this heating is reduced. The relationship between filter performance and measured temperature increase is developed and described.

Materials and Methods: Multiple combinations of parallel inductor-capacitor band stop filters (BSF) were constructed. The impedance frequency spectrum of the filters was characterized using an Agilent E4991A impedance analyzer (Figure 1). The impedance at 64MHz versus inductor value for each BSF is presented.

Prototype active fixation, extendable-retractable CRM leads were fabricated with varying 64MHz impedance BSF devices. The BSF device was attached immediately proximal to the 0.185 inch helical screw. The proximal ring was not filtered. The CRM leads were placed in a phantom containing a poly(acrylic acid) (PAA) gel, per ASTM F2182-02a. Two positional configurations were investigated: (i) parallel to the MRI bore z-axis and 23 cm from the isometric center and (ii) an approximate physiological configuration where an empty mock-up implantable pulse generator (IPG) was connected to the IS-1 connector, with the IPG placed in the “left pectoral pocket” and the lead routed to near the isometric center and towards the location of the “heart”.

A 1.5 Tesla MRI RF-intensive imaging protocol per ASTM F2182-2a was utilized. The whole body specific absorption rate (WB-SAR) as reported by the control software was not less than 3.8 W/kg. The temperatures of the distal end, proximal ring, PAA gel and the IS-1 connector were monitored with fluoroptic temperature probes. The temperature rise above the PAA gel reference temperature is presented as a function of the BSF device 64MHz impedance.

Results: The measured impedance of the BSF device can be systematically controlled by changing the component values and is empirically found to follow a linear relationship. Theoretical impedance calculations of ideal components corroborate this result, however with much larger impedance values. The impedance values at 64MHz ranged from 90 Ohms to 1,090 Ohms.

Heating of the distal helix was controlled with the impedance of the BSF device. The temperature at the distal helical screw demonstrated an inverse relationship to the impedance of the BSF device (Figure 2). In the straight lead configuration, the minimum heating was 9°C using a 1,090 Ohm BSF device and the maximum heating was 51°C using a control lead with no BSF device. Extrapolation of these results indicates a nonzero minimum heating value for increasing BSF device impedance. A physical model is developed relating electrical power to heating energy and correlated to the empirically found nonzero heating minimum.

Heating of the distal helix in the physiological configuration demonstrated similar trends to the straight lead configuration where the minimum heating was 0.5°C and the maximum heating was 4°C. The physiological heating was significantly reduced due to lower RF fields near the isometric center of the bore (1) and reduction in effective length of the CRM lead (2).

Conclusions: Control of BSF type devices for MRI heating reduction and lead impedance is possible. Due to the finite impedance values of passive filters, MRI heating of a CRM lead cannot be completely eliminated. Reduction of the local RF fields near the CRM lead, by either different scan protocols or location/orientation in the bore, can reduce the heating to levels at or near the detection limits of current hardware.

References:

(1) Nordbeck P, et. al. Spatial Distribution of RF-Induced E-Fields and Implant Heating in MRI. Magnetic Resonance in Medicine 2008;60:312-319.
(2) Mattei E, et al. Complexity of MRI induced heating on metallic leads: experimental measurements of 374 configurations. BioMedical Engineering OnLine 2008;7:11.

Figure 1: Typical impedance frequency spectra for BSF devices

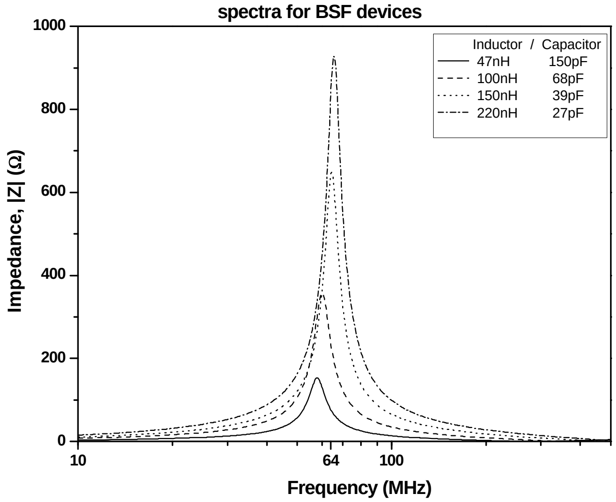

Figure 2: Heating of distal helical screw versus BSF device impedance at 64MHz