MRI Compatible Pacemaker Leads

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Introduction:

Radiofrequency (RF) heating at the tip of metallic wire-shaped devices, such as pacemakers and ICDs, has gained attention over the past several years. In this study, the simulation and implementation of a “safe wire” design is presented. This design is based on a previous work [1], concluding that wires smaller than a quarter wavelength and having adequate coating are safe in MR scanners. Considering this, RF chokes were placed at every quarter wavelength of the wire to ensure safety, similar to the safe coaxial cable design [2].

Methods:

Heating of half wavelength (22 cm) insulated wire was compared with the heating of a wire of the same length and inductor as an RF choke, as seen in Figure 1. A half wavelength is the resonant length, i.e., it is the lengh at which most heating occurs. First, a simulation was performed with an electromagnetic simulator, FEKO (EMSS, Stellenbosch,South Africa) to observe whether the RF choke could block the induced current so that the half wavelength wire acted as two separate quarter wavelength wires.

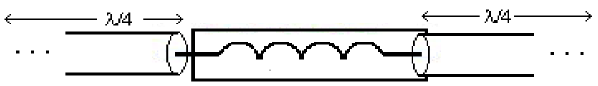

Fig1: Safe wire: An inductor is placed between every quarter wavelength to ensure RF safety. Shielding is used to ensure decoupling of the inductor with the field.

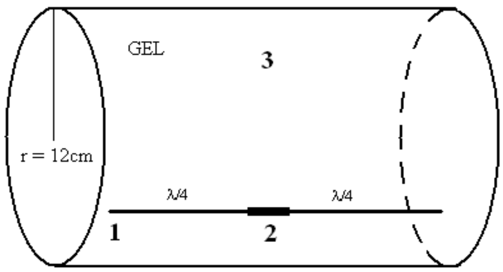

Fig2: Experimental setup: Gel-phantom experiment. 1 and 2 represent temperature probes located at the tip and the middle of the wire. 3 is the reference probe.All probes are equidistant from the origin.

Gel-phantom experiments were performed to verify the simulation results. The setup is shown in Figure2. The gel had a relative permittivity of 80 and a conductivity of 0.7S/m (3.6gr/lt NaCl), which is representative of human blood and heart tissue at 64 MHz [3]. A GE Signa 1.5T MR scanner was used, with all the gradients shut off, and a body coil was used to irradiate the phantom. An AWG 24 wire with a 0.25 mm radius and 0.2 mm insulation thickness were used and situated at a constant radial position, but placed longitudinally in the phantom. The temperature was recorded using custom-built fiberoptic temperature probes (FISO Technologies, Ste. Foy, Quebec, Canada).

Results:

The simulation results are depicted in Figure 3. Figure 3A shows the normalized induced current on the half wavelength wire and the safe wire. Figure 3B shows the Specific Absorbtion Rate (SAR) distribution on the surface of the half wavelength wire and safe wire. From these simulations, it is obvious that the safe wire is able to separate a resonant length wire into two quarter wavelength wires, ensuring safety.

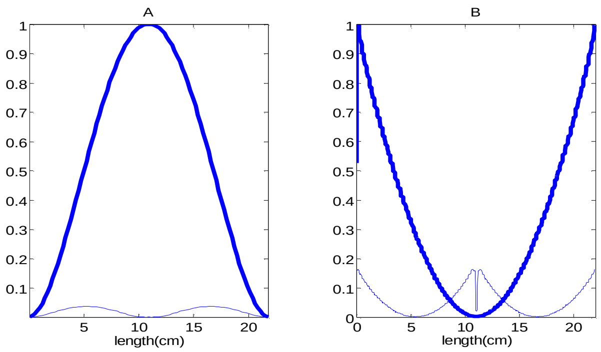

Fig3: Simulation results: (A) Induced current on regular wire (thick) and on safe wire (thin). (B) SAR tangent to regular wire (thick) and safe wire (thin). The values are normalized with respect to maximum values of regular wire.

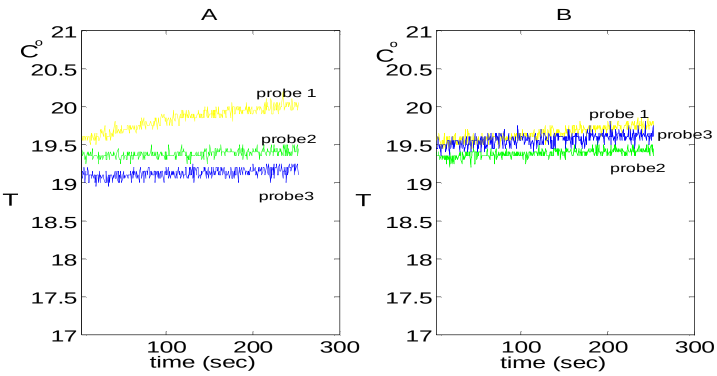

Fig4: Temperature profiles: (A) Regular wire. (B) Safe wire.

Temperature profiles of experiments with regular and safe resonant length wires are shown in Figure 4. Note that the temperature increases at the tip of the wires drop with the insertion of the inductor. SAR gain, i.e., the amplification in the SAR due to the presence of the wire, can be calculated by taking the ratios of temperature increase of the probe located at the tip of the wire to the reference probe. Experimentally, SAR gain was observed to be approximately 3 and 1 for regular and safe wire, whereas from the simulations, these values were found to be 2.35 and 1.33. These results lay within the error margin of the experiment. In vivo temperature increases can be calculated using the Green’s Function solution to the Bioheat equation [4]. Since the SAR gain in the safe wire was found to be around 1, without solving the Bioheat equation , intuitively it can be concluded that temperature increases will be same as for the case where no wire exists. For typical perfusion rates [4], the safety index, temperature increase per unit applied SAR is 0.02 C^0/W/kg in the heart, which is well below FDA limits.

Discussion and Conclusion:

A safe wire design implementation is demonstrated. Longer safe wires can be used in metallic implants for communication between the signal generator and the organ, if RF chokes are placed at every quarter wavelength. Patients using such metallic implants can be scanned with no additional RF heating.

Introducing RF chokes on the wire will lead into some degradation of the transmitted signal. Since almost no loss is observed on the cables, the same power will be transmitted to the organ. Rather than the shape of the transmitted pulse, it is the power of the pulse that creates an action potential on cell membranes; thus, this degradation can be tolerated. If a high inductance value is used, the RF choke becomes a better trap for the current, whereas signal degradation increases. This trade-off should be carefully investigated.

References: **[1]** Yeung CJ, Susil RC, Atalar E, *RF Safety of Wires in Interventional MRI*: *Using a Safety Index*, MRM. 47:187-193, 2002 **[2]** Atalar E. *Safe coaxial cables*. Proc. 7th ISMRM p.1006,1999. **[3]** www.brooks.af.mil/AFRL/HED/hedr **[4]** Yeung CJ et al. *A Green’s Function approach to local RF Heating in interventional MRI*. Med. Phys 28:826-832, 2001.

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