Energy Coupling between RF Electric Fields and Conductive Wires: Image Artifacts and Heating

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Introduction

RF electric fields can capacitively couple to conductive wires within the RF coil volume, resulting in a storage of electrical energy on the wire that is highly dependent on several environmental factors – principally the conductive length of the wire and wavelength of the penetrating electric fields. When resonance conditions are met, the high frequency wire currents can generate significant heat near the wire tip when placed in electrical contact with a resistive material, which can pose a serious threat when using intravascular guidewires **(1)**, pacemaker leads **(2)**, EEG/EKG wires, etc. in the MR environment. Furthermore, induced wire currents can produce sample excitation in addition to the primary B_1 fields, which can result in severe image artifacts **(3)**. With the use of high magnetic field scanners (≥ 3 T), there is an increased risk of these unwanted energy coupling effects, as the resulting shorter resonant lengths are more similar to the lengths of conductive wires used for many of the above mentioned applications. Consequently, for these techniques to be utilized, it is extremely important to determine which wire lengths can be safely and effectively used within the high field MR environment. *The purpose of this study was to investigate the resonance energy coupling between RF electric fields and conductive wires at 4 T, and to specifically determine the maximum conductive wire lengths that can be used for superficial physiological monitoring such as EEG and EKG at this field strength.*

Methods

Imaging experiments were performed on a 4 T Varian *UNITY*INOVA whole body scanner equipped with a quadrature hybrid birdcage RF head coil (rung length = 21 cm). A long, cylindrical 15% agarose gel phantom (diameter = 7.5 cm, length = 60 cm) with [NaCl] = 150 mM (salinity matched to human skin tissue) was centered with respect to the z-axis within the volume of the RF coil, and was positioned with a y-offset near the top coil wall to maximize electric field coupling. To model EEG and EKG applications, a multi-stranded (64/44, AWG = 26) copper wire was placed directly on the leveled surface of the agarose with its proximal tip aligned with the front of the RF coil rungs and its distal tip extending parallel to the static field. Images of the phantom were generated with a 3D gradient echo (GE) FLASH sequence (12 contiguous 2 cm thick slices, TR = 10.1 ms, TE = 5.5 ms), and image artifacts induced by the wire currents were quantified on a per slice basis after coil sensitivity corrections. Metrics for overall *hyper*-intense and *hypo*-intense signal artifacts for each slice were generated by summations of the absolute pixel-by-pixel intensity difference between the image and a reference image (no wire attached), where a minimum threshold of 30% intensity difference was stipulated for inclusion in the summations. This image analysis was performed for both a "grounded" wire (proximal tip in electrical contact with phantom) and a "free-floating" (no electrical contact) wire. Heating of the agarose gel at the proximal tip of the grounded wire during the application of a power intensive pulse sequence was monitored with a fiber-optic probe (FTI-10, FISO Technologies Inc.) and recorded by PowerLab (v5.2.1; ADInstruments). Image artifacts and heating measurements were made for a series of wire lengths (by truncating the wire at the distal end), and the maximum wire length that prevented these unwanted effects was determined for both the grounded and free-floating cases.

Results

Images displayed patterns of hyper- and hypo-intense artifacts that were specific to the wire length (**Fig. 1**), and as expected the severity of the artifacts showed a distinct resonance pattern with wire length (**Fig. 2**). Two resonant lengths were identified for both the free-floating wire (~35 cm, ~110 cm, **Fig. 2**) and grounded wire (~25 cm, ~110 cm, **Fig. 3**), and all of these lengths were shorter than the resonant lengths reported at 1.5 T (**4**). Furthermore, artifacts along the wire decreased towards the free-floating wire tip (**Fig. 2**) and increased towards the grounded tip. Agarose gel heating near the tip of the grounded wire followed a similar resonance pattern with wire length to that of the induced image artifacts (**Fig. 3**) – specifically to the hyper-intense artifacts. The maximum wire lengths that were shorter than a resonant length and avoided signal artifacts and heating were 20 cm and 10 cm for the free-floating and grounded wires, respectively.

Discussion

Contrary to previous reports at lower field strengths of a single "half-wavelength" resonant length, the secondary resonant length may describe the wire resonating more closely as a monopole antenna with resonant lengths at approximately $\lambda/4$ and $3\lambda/4$ than as dipole antenna. This result could be explained by capacitive coupling to the copper rungs of the RF coil. The image artifact pattern along the length of the free-floating wire at the shorter resonant length is similar to the theoretical current distribution over a $\lambda/4$ antenna. For EEG/EKG applications whose wires are in electrical contact with the skin, these results suggest that the wires should be kept ≤ 10 cm to avoid unwanted image artifacts and heating within the 4 T MRI environment. For applications those wire lengths cannot be easily minimized due to physiological constraints, the use of in-series low-pass filters (such as RF chokes) may be effective in conductively segmenting wires for RF driven currents, which could help avoid the unwanted effects.

References

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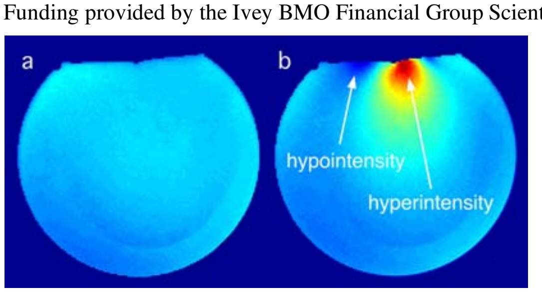

Fig. 1. GE images of a cylindrical agarose gel phantom underneath a free-floating copper wire: (a) non-resonating 10 cm wire length produces no signal artifacts; (b) 35 cm resonating wire length displays severe signal artifact due to secondary B1 field produced from wire currents.

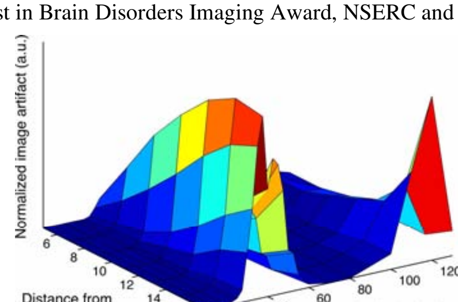

Fig. 2. Surface plot showing normalized total image artifact (hyper- plus hypo-intense) in an agarose gel phantom vs. length of wire and distance from wire tip for a free-floating copper wire.

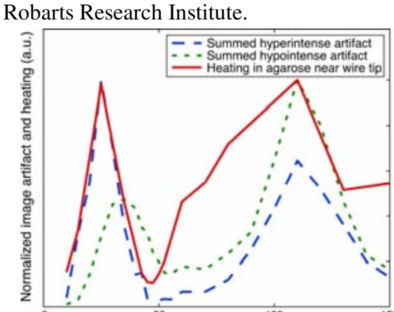

Fig. 3. Normalized patterns of image artifact and heating in an agarose gel phantom near the wire tip vs. length of wire for a grounded copper wire.