Reduction of RF Heating of Metallic Devices by Using a Two-Channel Transmit Array System : Application to Arbitrary Lead Geometries

Y. Eryaman[1], B. Akin[1], C. Oto[2], O. Algin[3], and E. Atalar[1]

[1]National Magnetic Resonance Research Center (UMRAM), Bilkent University, Ankara, Turkey, [2]Veterinary Medicine,Department of Anatomy, Ankara University, Ankara, Turkey, [3]Department of Radiology, Ataturk Training and Research Hospital, Ankara, Turkey

Introduction

The risks related to excessive heating of metallic devices under MRI became a major safety concern in the last decade. In general for all metallic devices with long wire shaped conductors, the SAR amplification at the tip of the device is a significant problem. In a previous work[1], a linearly polarized birdcage coil was proposed as an implant friendly coil which can improve the RF safety of MR procedures. In that work, the location of the metallic device was coincided with the zero electric field plane of the linear coil and the tip temperature of the device was reduced substantially. However this approach requires steering either the patient or the coil around their longitudinal axis. Furthermore it was assumed that the location of the device is known prior to the scan. In this work the above mentioned idea is developed further and adapted to a two-channel TX array technology. By doing so the zero electric field plane is steered inside the patient in order to make it coincide with the location of the metallic device. Additionally, the magnitude of the induced current artifact on the lead/wire is monitored. The excitation pattern that minimizes the induced current artifact is found. With this method the RF heating at the tip of the metallic leads are reduced substantially as demonstrated by phantom and animal experiments.
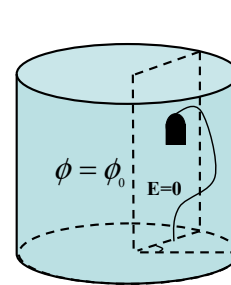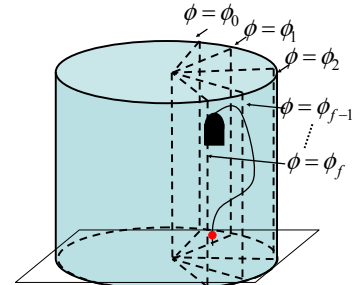

Figure 1 Leads that are not confined in cylindrical angular half- planes

Figure 2 Steering the location of the zero electric field plane as the artifact signal intensity near the lead tip is monitored
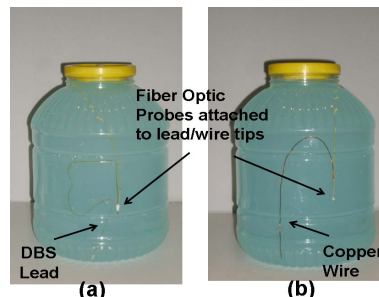
Theory

Linearly polarized electric field distribution inside a uniform object can be approximated as $E_z = -H_f j\omega\mu_0\rho\sin(\phi-\phi_0)$, $E_\phi = 0$, $E_\rho = 0$ where H_f is the sensitivity of the coil, ω is the Larmor frequency, μ_0 is the magnetic permeability, **j** is the imaginary number defined as $\sqrt{-1}$, ρ and ϕ are the radial and angular coordinates in the cylindrical coordinate system respectively. For this field distribution, the electric field is equal to zero at $\phi = \phi_0$ and $\phi = \phi_0 + \pi$ half planes. This field can be realized easily by using a birdcage coil as a two-channel transmit array system. The current at two orthogonal ports of the birdcage coil should be weighted with $\cos\phi_0$ and $\sin\phi_0$ for this purpose. In that case a metallic lead/wire which is confined in the $\phi = \phi_0$ plane would experience zero electric field and no current will flow on the conductor [1]. Similar principle can also be applied to devices with non-planar lead geometries.(Figure 1). Assume that the currents at two ports of the transmit array are weighted with $\cos\theta$ and $\sin\theta$. If the value of θ is changed to cover the range $[0,\pi]$ then the zero electric field plane will be steered within the same limits $\phi_0 \in [0,\pi]$. For a certain value of θ, the zero electric field plane will coincide with the location of the metallic device and the current on the device lead will be minimized. In this condition, the induced current artifacts near the lead tip will also be minimum. The signal intensity of these artifacts can be monitored for this purpose and a safer 2 channel excitation can be found (Figure2).

Methods and Results

In order to demonstrate the theory, phantom and animal experiments are performed. A commercial DBS lead (Medtronic 33877 DBS electrode (Medtronic Inc, Minneapolis,MN) and a copper wire is placed inside two identical phantoms (Figure 3) and are imaged with linear excitation by changing θ in the range $[0,\pi]$ with a step size of $\pi/36$ radians. A GRE sequence with flip angle= 5 deg and TR=200 msec is used to ensure that the sequence does not cause any RF heating. A swine experiment is also conducted with a similar procedure by using a copper wire placed under the skin and muscle tissues of the animal (Figure 4). The difference between the RF induced current artifact and the background signal in the image is measured and plotted with respect to θ (Figure 5). The different θ values that caused minimum artifact signal for each experiment can be noted in the Figure. Finally a GRE sequence with peak SAR of 4.4 W/kg is used to scan the phantoms/swine with quadrature and two channel linear excitation using angle θ. Maximum increase in the lead tip temperatures are measured by using fiber optic temperature probes (Neoptix Inc.Quebec, Canada). Temperature data can be seen in Table 1.

Figure 3 DBS lead and copper wire in phantoms
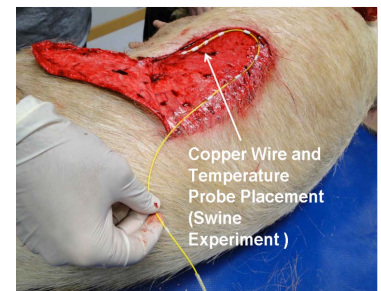

Figure 4 Copper wire placed under swine skin and muscle tissue

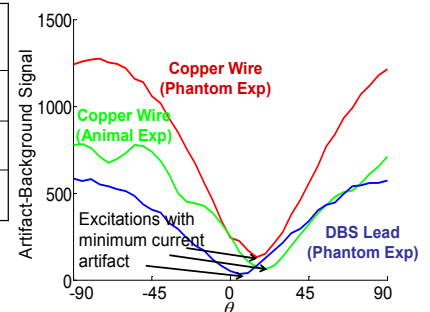| Maximum Lead Tip Temperature (C)	Quadrature	Linear Excitation
Copper Wire (Phantom Exp.)	13.8	0.3
DBS Lead (Phantom Exp.)	12.7	0.2
Copper Wire (Animal Exp.)	5.5	0.2

Table1 Maximum increase in tip temperature

Figure 5 Artifact-background signal difference plotted with respect to θ

Discussions and Conclusion

A method that reduces RF heating of metallic devices is explained. The method is based on finding a safer two channel transmit array excitation which minimizes the artifacts due to RF induced currents. The tip temperatures of a DBS lead and a copper wire are substantially reduced with the proposed method as shown by phantom and animal experiments.

Reference [1] Eryaman Y., Akin B. Atalar E. Reduction of Implant RF Heating Through Modification of Electric Field. Magn Reson Med *In Press*