Reduction of RF Heating of Metallic Devices Using Transmit Arrays

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Introduction

Radiofrequency (RF) field transmitted by MRI scanners can cause critical heating of metallic structures such as implant leads, catheters. Interaction of long metallic extensions of these devices with the electrical field is the main reason of heating. Heating of implant leads is an example of this situation. In a previous work [1] it was shown that modifying the electrical field distribution may reduce RF heating of implant leads. By using linear birdcage coils electric field inside the body was steered away from the implant. By matching the location of the zero electric field plane of the coil with the implant lead, the heating was minimized. This can easily be achieved by using 2 channel TX arrays in commercially available systems. However the whole body average SAR is doubled due to this modification. In this work it is shown that steering the electric field with TX (transmit) arrays possible by simply controlling the currents on separate channels. Furthermore whole body SAR can be decreased without sacrificing and homogeneity of the coil.

Theory

In TX arrays, the phase and magnitude of the currents on separate channels of a transmit coil can be chosen arbitrarily. Usually the excitation pattern of currents is adjusted in order to satisfy a given SAR or transmit field homogeneity constraint. In addition to SAR and homogeneity, the electric field distribution is another concern for reduction of RF heating. The main goal of this work is to obtain a homogenous transmit field distribution with minimum average SAR, with the condition that the metallic device inside the body experiences zero or minimal electric field. By choosing the excitation current patterns similar to the currents in the legs of a linear birdcage coil, this goal can easily be achieved. The excitation pattern for a linearly polarized field is given as $a_i = A\sin(2\pi i / N - \phi_0)$, where i is the index of the channel carrying the current α_i and 1<i<N and ϕ_0 denotes the angular position of the plane that the metallic device is located. N is the number of channels in the transmit array. Once the position of the device is found, ϕ_0 can be found. The heating extension of the device can have a shape of arbitrary geometry including loop structures. As long as the shape is bounded in a thin angular slice heating is minimized. The main concern with this approach is that the average SAR is doubled with respect to a quadrature excitation similar to the case with a linear birdcage coil. To solve this issue the current excitation pattern should be modified in order to minimize the average SAR. While doing so, the maximum electric field experienced by the implant should be kept bounded. Additionally the transmit field homogeneity should be preserved. Let α be a vector of size Nx1 whose elements are the complex currents on each channel of a TX array. E and B are the electric field and transmit sensitivity matrices where $E\alpha = c$, $B\alpha = d$ and c and d give the value of the electric field and the sensitivity at desired locations in the body. Average SAR is equal to $\alpha^* R\alpha$ [2] where R is the electric field cross correlation matrix. To minimize average SAR $\alpha^* R\alpha$ should be minimized. While doing so, the elements of c should be bounded around 1 with an amount of ∂ to ensure homogeneity. In addition, the elements of d should be bounded between 0 and ε to reduce RF heating.

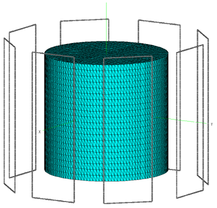

Figure 1 8 channel loop transmit array and uniform body model. A straight metallic wire is assumed to exist in the model at $\phi = \phi_0$ plane

To verify the theory, simulations of an 8 channel transmit coil array was performed by using FEKO simulation software.. The body is assumed as a homogenous cylinder and a straight metallic wire is assumed to exist in the body 2 cm away from the boundary (Figure1) First quadrature field is used to excite the body model by using the current expressions $\alpha_i = \exp(2\pi j \cdot i / N)$ where j is the imaginary number $\sqrt{-1}$ Then, a linear field is used to excite the model. The metallic wire is assumed to be located at the plane $\phi = \pi / 6$. The excitation pattern for the coils is chosen as $\alpha_i = 2\sin\left(2\pi i / 8 - \pi / 6\right)$ to ensure RF heating reduction. Finally optimized currents are calculated for SAR minimization. c is chosen such that z component of the electric field is sampled at 7 points separated by 3 cm along the wire. Similarly d is chosen such that the transmit sensitivity is sampled at 45 points distributed uniformly in a transverse imaging plane. The value of ε is chosen as $\varepsilon = 8.9$ to ensure that the maximum electric field experienced on the wire is 5 times less than quadrature case. Finally ∂ is chosen as 0.2 to ensure that the transmit sensitivity does not vary more than 20 percent in the imaging plane. The images of transmit sensitivity and the z component of electric field in the transverse plane can be seen in Figure2(a,b,c,d,e,f). In figure 2 (g,h,i) electric field is shown at the angular plane which the wire is assumed to exist. In order to compare the average SAR values of quadrature, linear, and optimum excitation currents the SAR values are normalized by the mean value of transmit sensitivity in the imaging plane. The linear coil had a SAR twice as the quadrature coil as expected. The SAR due to optimum currents was 1.4 times the SAR value of quadrature excitation. A reduction of 30% in SAR is achieved by the optimum excitation currents with respect to linear coil. Additionally as it can be seen from Figure 2 the homogeneity of the optimum current pattern is better than linear excitation.

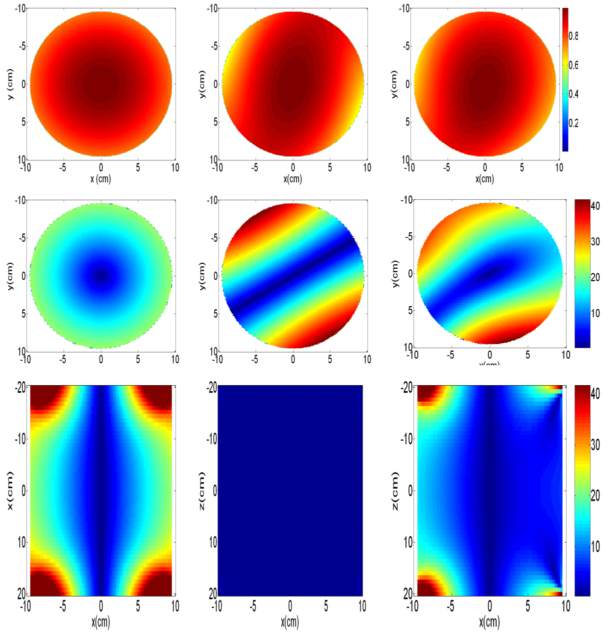

Figure 2 Sensitivity in transverse plane due to quadrature, linear and optimum excitation pattern is shown in (a,b,c). Electric field due to same excitations in transverse plane (d,e,f) and in $\phi = \pi / 6$ plane (g,h,i) is also shown.

Conclusion

In this work it is shown that heating of metallic devices can be reduced by using transmit array by steering the electric field distribution. By controlling currents on separate channels of the array local SAR reduction can be realized without sacrificing homogeneity and average SAR.

Reference [1]Eryaman et al “Reduction of Implant Rf Heating by Modification of Electrid Field”Proc.Int.Soc.mag.Reson.Med 17(2009) p304[2] Lattanzi, et al. (2009). "Electrodynamic Constraints on Homogeneity and Radiofrequency Power Deposition in Multiple Coil Excitations." Mag Reson Med 61(2): 315-334