OPTIMIZATION OF RADIATIVE SURFACE ANTENNA FOR HIGH FIELD MRI

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Introduction: The limited availability of RF power in high field MRI (>7 T) has resulted in the widespread usage of surface coils. In order to create large magnetic fields in the near zone, the coils are driven at resonance. This concept has been proven advantageous as long as body areas under investigation can be positioned in the near zone and high electric fields due to eddy currents can be prevented by sufficient low magnetic field frequencies. Here, we investigate by means of electromagnetic modeling the usage of radiative surface antenna for sites located at one or more wavelengths from the coil, i.e. beyond the near zone. Such antenna design requires that its Poynting vector is directed towards the target location and a dielectric substrate that ensures impedance matching at the antenna-body interface. Based on these demands, a radiative antenna design is investigated where two copper strips were placed on a high dielectric permittivity rectangular substrate (Figure 1). We optimized the antenna design with respect to the permittivity and the conductor dimensions in terms of impedance matching ability, effective B_1^+ delivery at depth and low local SAR (Specific Absorption Rate).

Materials and methods: To investigate the influence of the substrate materials and copper strip dimensions, we applied the finite difference time domain (FDTD) method to compute the corresponding impedances, B_1^+ and SAR profiles. The simulations were performed with SEMCAD[1] on a non-uniform grid with the maximum time step of 26 ps. A harmonic sinusoidal excitation at 300 MHz was done and a steady-state was reached after 10 periods of simulation time. The substrate (Morgan Technical Ceramics, 5x3x15.3 cm^3) (Figure 1) was placed on a rectangular phantom (22x15x22 cm^3) consisting of a material with the human equivalent dielectric properties (volumetric average of human pelvis: ε_r=34, σ=0.47). Different substrate materials (ε_r=20, 34, 50, 70, 90) were used, and the conductors were chosen as a PEC (perfect electrical conductor). By changing the substrate material with conductor dimensions (length and width), the values of impedance, B_1^+ field and spatial-average SAR are optimized. The B_1^+ values are normalized to 1 W input power. The spatial-average SAR (1 g) is normalized to the CW power to reach the B_1^+ value of 2.5 μT.

Results and Discussions:

Impedance: For the substrate materials having different dielectric constants than the phantom, matching and tuning is not possible (Figure 2a). This is caused by the dielectric mismatch at the substrate-phantom interface, which results in wave reflections. By changing the conductor dimensions, the antenna impedance can be altered (Figure 2b). However, only for a impedance of ε_r=34, the real impedance can be matched to 50 Ω for the conductor length of 6.25 cm and width of 0.8 cm (Figure 2a and 2b). In addition, when this tuned and matched antenna is placed on a human model at a pelvis region, it does not show a significant deviation in matched impedance values of ε_r=34.

B_1^+: The highest B_1^+ value per 1 W input power at 10 cm depth in the phantom (0.16 μT) is achieved by the substrate of ε_r=34 with the copper strips of 6.25x0.8 cm^2 (Figure 2c). This is explained by the minimized wave reflections in this case. Also, with these dimensions the antenna is matched to 50 Ω.

SAR: Although the differences in maximum SAR values are moderate for different substrate materials, the lowest maximum local SAR on the surface of the phantom (1.3 W/kg) is achieved by the substrate material of ε_r=90 for the conductor of 6.25 cm long and 0.8 cm wide (Figure 2d). As it is also seen in Figure 2c, with the high dielectric material of ε_r=90, the near zone is more confined to the substrate, exposing the phantom to lower electric fields, and thus less SAR deposition is expected.

Conclusion: This study illustrates that when the ε_r of the substrate is matched to that of the phantom, the radiative antenna can be matched to 50 Ω by modeling, thus its radiation efficiency is the highest. The high radiation efficiency of this antenna provides a high B_1^+ value at depth of the phantom as well as the low SAR values on the surface on the phantom.

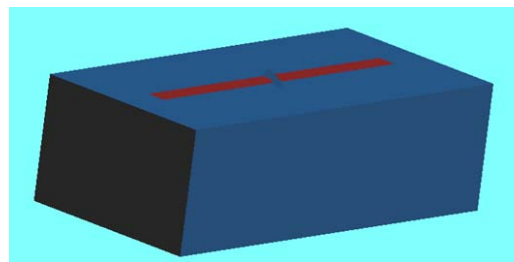

Figure 1- Schematic picture of radiative antenna.

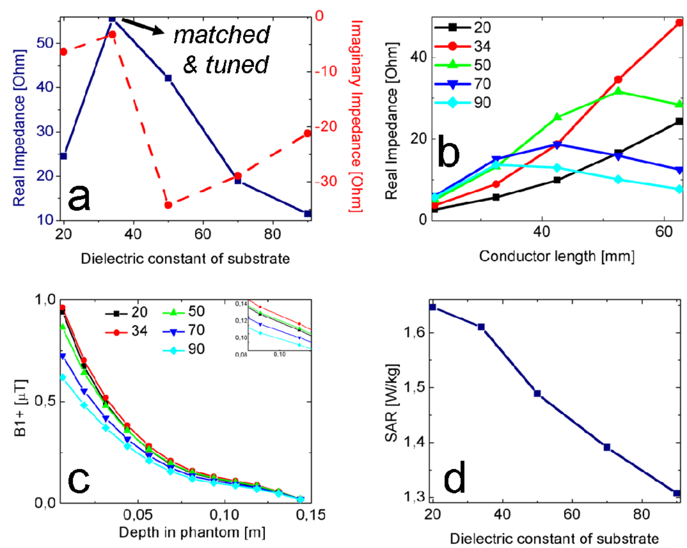

Figure 2- Real (solid) and imaginary (dashed) impedance vs. dielectric constant of substrate (a), real impedance vs. conductor length (b), normalized B_1^+ for 1W input power vs. depth of phantom (c), and maximum spatial-average SAR (1g) normalized for CW power to reach the B_1^+ value of 2.5 μT vs. dielectric constant of substrate (d) for the conductor length of 6.25 cm and width of 0.8 cm.