Boosting B_1^+ efficiency for RF transmit surface elements by a radiative antenna design

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Introduction

Conventional RF transmit coils in MR imaging are 'resonant' antennas. These antennas store magnetic (and electric) energy in the near-field region around the antenna, causing high levels of B_1^+. This region extends around the antenna for approximately a quarter of a wavelength ($\lambda/4$), which corresponds to ca. 20 cm for 1.5 T and 10 cm for 3 T imaging. However, at 7 Tesla, the near-field is extending only 4 cm into the patient. Many regions of interest for MR imaging are likely to be located outside the 'near-field' region. This work will show that resonant antennas are extremely inefficient in generating B_1^+ in the 'far-field' region. As an alternative, we present a different kind of antenna, which is known as a 'radiative antenna'. Instead of focussing the energy in the near-field region, the antenna is designed such that the energy will be radiated away from its source, resulting in more efficient B_1^+ generation at depths beyond half a wavelength.

Materials and methods

A comparison has been made between an optimised stripline design and a radiative antenna. Both antennas are meant to be part of a phased array where the elements are placed directly adjacent to the skin. In this study, the B_1^+ and SAR distributions of one element are evaluated to determine their performance.

FDTD simulations were performed on a 22 x 22 x 15 cm^3 phantom consisting of human tissue equivalent material (ε_r=34, σ=0.47). The stripline design consists of a teflon stripline, (dimensions 34 x 44 x 100 mm^3), with a 12 mm wide copper conductor and a ground plane extending over the lateral edges of the stripline. To avoid capacitive coupling, a 6 mm teflon spacer was placed between the conductor and the phantom (figure 1a). The radiative antenna consists of a 4 mm wide copper strip with a 5 mm gap over which the dipole source is excited. The strip is placed adjacent to a 3 cm thick layer of distilled water (in practice a ceramic material may be more suitable). The strip length equals $\lambda/4$ in water, figure 1b.

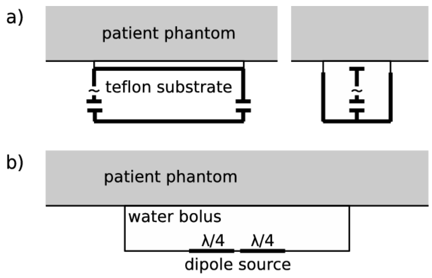

Figure 1: Coil geometries:
(a) stripline (b) radiative antenna

Results and Discussion

The in-depth B_1^+ profiles, for both antennas with equal power delivery, are plotted in figure 2a. For better comparison of the relative performance at large depths, the B_1^+ profile of the radiative antenna is plotted normalized to the profile of the stripline in figure 2b. For both designs the SAR_{max} occurs at the boundary of the phantom. However, in case of the radiative antenna the phantom is placed more into the far field with a lower electric field, resulting in a 2.5 times lower SAR_{max}. As this is the limiting factor at 7 T to obtain sufficient B_1^+ at a deeply located position, this will allow a $\sqrt{2.5}$ higher B_1^+ field without running into SAR constraints. To demonstrate this effect, we plotted in Figure 3a the B_1^+ profile, divided by the maximum SAR level for both antennas. Figure 3b shows this profile for the radiative antenna, normalized to the profile of the stripline antenna.

Conclusions

Radiative antennas are better RF coils for regions beyond $\lambda/4$. At a depth of 10 cm, the design presented in this abstract shows 20 % more B_1^+ in comparison to the stripline antenna for equal power delivery and additional 60 % more B_1^+ for equal SAR_{max}. The radiative antenna performs better, because the stripline antenna is wasting energy and high SAR levels in the near-field region. In near future, simulations with an array of elements on a phantom anatomy should demonstrate the expected increased performance in an MRI-measurement with phase-amplitude shimming.

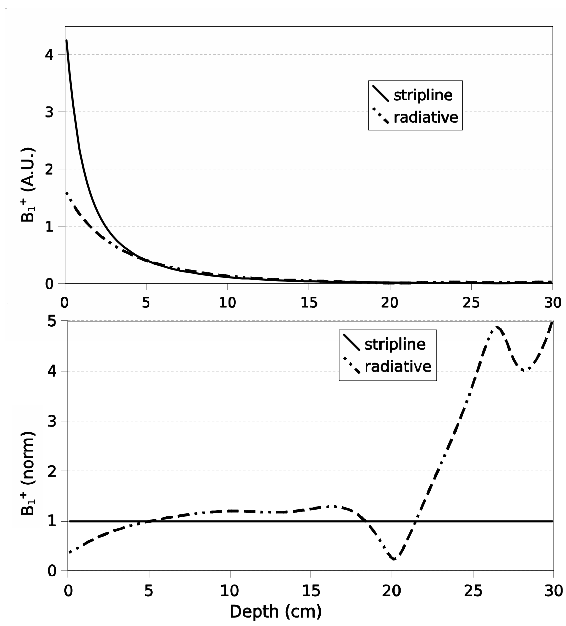

Figure 2: (a) In-depth B_1^+ profiles for stripline and radiative antenna with equal power delivery. (b) Profile of radiative antenna relative to the stripline profile

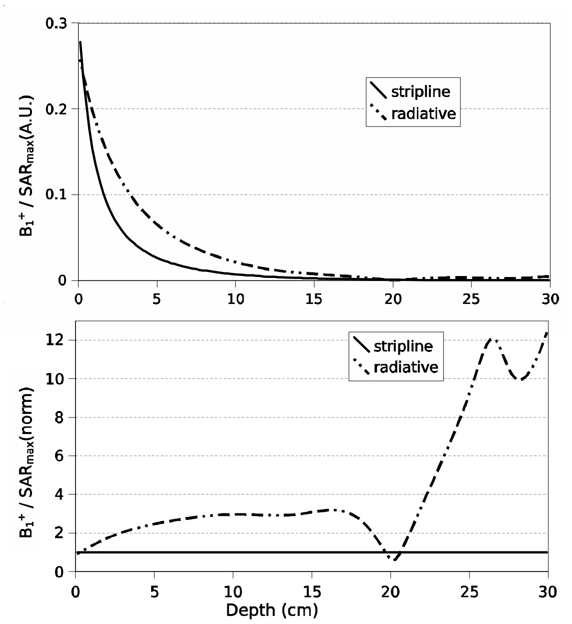

Figure 3: (a) In-depth B_1^+ profiles for stripline and radiative antenna divided by their maximum SAR level (b) Profile of radiative antenna relative to stripline profile