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A practical realization of an artificial magnetic shield for preclinical birdcage RF coils

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Abstract. In the most of magnetic resonance imaging (MRI) systems, a conventional radiofrequency (RF) electric shield is typically placed around an RF volume coil to avoid the interaction with the other components of the system. Disadvantageously metal shields reduce the transmit efficiency of the RF coil as well as its receive sensitivity due to out-of-phase reflection of electromagnetic waves. In contrast, an ideal magnetic shield having high surface impedance provides in-phase reflection, which can be promising for improvement of RF coil's performance. In this work, we propose an artificial magnetic shield based on a cylindrical miniaturized corrugated structure to improve characteristics of a small-animal birdcage coil at 7T. The coil was simulated in the presence of the metal and ideal magnetic shield as well as the proposed structure. The results demonstrate enhancement of the coil's performance in the presence of the proposed shield, which is comparable with an ideal one.

1. Introduction

Volume RF coils in MRI systems are used for transmitting RF signals to the object to be imaged and to receive the emitted signal the relaxation process if the coil is used in receive mode as well. These coils produce homogeneously distributed FR magnetic field over a relatively large region of interest. RF volume coils are usually equipped with a copper RF shield to reduce the interaction with the gradient system and electronics. On another hand, the presence of such shields limits power efficiency of the coil in the transmit mode, while reducing SNR provided by the same coil in the receive mode. This negative effect can be explained by a destructive interference between the primary RF field of the coil and the reflected field created by the currents induced on the shield. To solve the problem the concept of the artificial magnetic shield was introduced and demonstrated for shielded antennas in the microwave range and resonant artificial magnetic conductors were proposed[1]. Similar structures were proposed recently to improve the performance of surface [2] and volume [3] MR coils. However, the capabilities of the proposed structures were not studied in comparison to the effect of the ideal magnetic shield.

In this work, preclinical birdcage with an ideal magnetic shield with an infinite surface impedance boundary condition was numerically compared with the case of a conventional copper shield for the same birdcage. On the second step, the coil was simulated in the presence of the proposed artificial magnetic shield based on a cylindrical miniaturized corrugated structure and compared with the previous two cases in terms of the transmit efficiency and receive sensitivity on a homogeneous phantom.

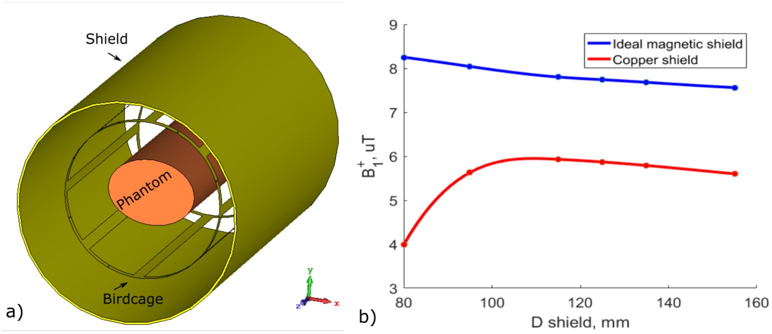

Figure 1. View of the simulation setup (a); B_1^+ in the center of the phantom depending on the outer diameter of the shield (for accepted power of 0.5 W) (b)

2. Methods

Numerical simulations were made in CST Microwave Studio 2017. Simulation model contained a homogeneous elliptical-cylinder phantom with the dimensions of 30x40x80 mm and material properties of $\sigma = 0.5$ S/m, $\varepsilon_r = 34$. The simulated high-pass birdcage had 8 legs and the diameter of 72 mm. The view of the simulation setup is depicted in Fig. 1(a). On the first step, the copper and the ideal magnetic shields both had the diameter of 82 mm, which is the standard diameter of the shield of commercial birdcage coil used in Bruker PharmaScan 70/16 US. To tune to the Larmor frequency of 300 MHz the end-ring capacitance of the birdcage was chosen as 12 pF and 4 pF in the presence of the copper and ideal magnetic shield respectively. Different shield diameters D were simulated for both cases for the fixed birdcage coil.

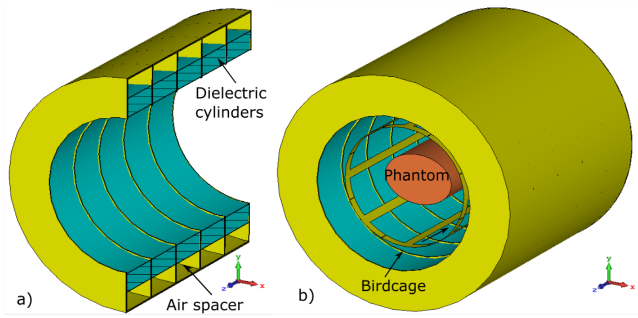

Figure 2. Sagittal cut view of the proposed corrugated structure (a), proposed corrugated structure with birdcage coil and phantom (b)

The proposed shield was implemented as a rotationally-symmetric array of metal corrugations periodic in the direction of the static magnetic field B_0 (Z-axis). Such structures refer to as corrugated surfaces [4] demonstrating high surface impedance at the resonance frequency. To tune the resonance frequency of the structure of 5 corrugations, they were filled with a high-permittivity dielectric material (tan $\delta = 0.001$ S/m, $\varepsilon_r = 160$). The corrugated surface was placed coaxially to the birdcage coil as depicted in Fig. 2. Each corrugation had the radial thickness of 22 mm and the length of 26.5 mm in z-direction. As a reference case for B_1^+

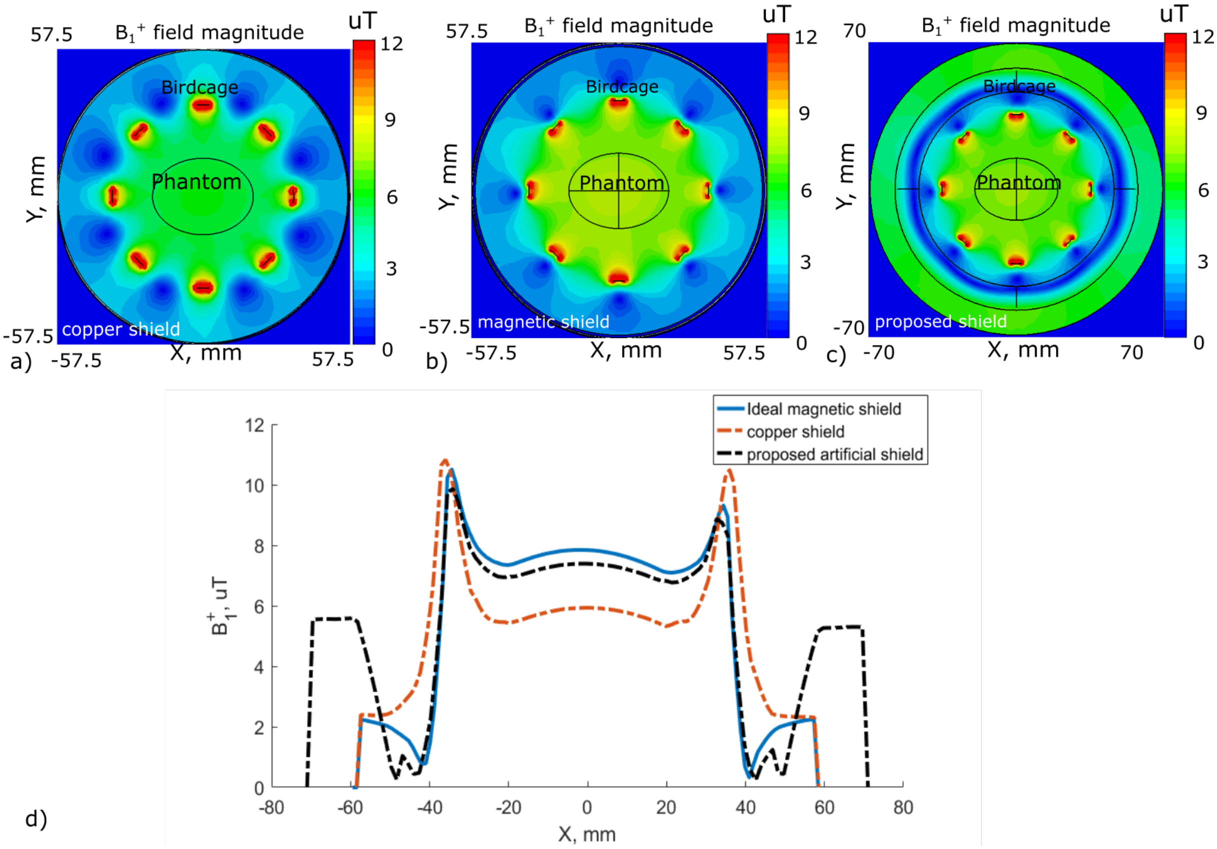

Figure 3. Simulated B_1^+ maps of the birdcage coil with copper shield (a), ideal magnetic shield (b) both with the diameter of 115 mm, proposed artificial magnetic shield (c); central transverse plane B_1^+ field distributions along X-axis (d) for the accepted power of 0.5W.

comparison the birdcage was calculated with the copper shield and the ideal magnetic shield both having the diameter equal to 115 mm which is corresponds to the optimal size of the copper shield 3 .

3. Results

The calculated dependence of B_1^+ on the shield diameter D shown in Fig 1. It demonstrates that the efficiency of the volume coil almost does not depend on the size of the RF magnetic shield, but for the case of the metal shield it drops down as D approaches the diameter of the coil. These results illustrate the effect of the magnetic shield manifesting itself reduction of intrinsic power losses in the shield and improvement of the coil's efficiency. The smaller the shield diameter, the stronger the efficiency gain due to replacing the metal shield with an ideal magnetic one. The magnetic shield also removes the strong localization of the magnetic field between the legs and the shield, typical for the case of the conventional copper shield one. This can be explained by in-phase reflection from the magnetic shield (constructive interference) instead of the out-of-phase reflection (destructive interference) from a metal shield. The ideal magnetic shield gives the improvement of the efficiency determined as B_1^+ for the given accepted power of 0.5 W of more than two (from 3.5 uT with the copper shield to 7.5 uT with the ideal magnetic one when the diameter of the shield is equal to 82 mm). Fig. 3 demonstrates the simulated B_1^+ maps of the birdcage coil in the presence of the copper (a) and the ideal magnetic shield with the diameter equal to 115 mm which corresponds to optimal size of the RF electric shield (b) and the proposed artificial magnetic shield (c). The transverse B_1^+ field pattern in the phantom holds homogeneous when replacing the copper shield with the ideal magnetic one and in the case of the proposed artificial shield, while the B_1^+ magnitude in the center of the phantom is higher in the last two cases as compared to the metal shield. Fig. 3 (d) illustrates the transverse plane B_1^+ distribution of the birdcage coil plotted along X axis. These results clearly shows that the proposed structure has a similar effect to the transmit field in the region of interest as the ideal magnetic shield and enhances the transmit efficiency of the birdcage coil. The coil also increase the E-field towards the subject, but as in the case of ideal electric shield, frequency shift of the birdcage resonance between the unloaded case and loaded with the phantom is much smaller than the frequency band, so that SAR issues are not relevant.

4. Conclusion

In this work the effect of a magnetic shield replacing a conventional copper one was studied, and the proposed artificial magnetic shield was shown to behave similarly as an ideal magnetic boundary condition. For a small-animal birdcage coil operating at 7 T it was shown by numerical calculation of B_1^+ for a given accepted power on a homogeneous phantom, that in the presence of the proposed artificial magnetic shield, the transmit efficiency, and therefore, the receive sensitivity of the same coils in the receive mode are improved while the B_1^+ pattern remains homogeneous in the phantom.

Acknowledgments

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