Improving the Sensitivity of Individually Shielded Elements of RF Transceiver Array Coils Using Dielectric Materials in MRI

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INTRODUCTION

Decoupling between the elements of RF transceiver array coils has been demonstrated to be extremely crucial in MRI [1-3]. Although several decoupling strategies have been proposed thus far, the decoupling remains a big challenge as existing strategies are beleaguered with either poor efficiency or impractical complexity [1, 4-9]. Of those proposed strategies, decoupling by individually shielding coil elements as well as capacitively interconnecting adjacent elements is capable of providing desirable decoupling between the coil elements (<-20dB). However, the sensitivity of the individually shielded coil elements are significantly degraded in this approach [8, 9]. We aim to improve the sensitivity of the shielded elements while maintaining the desirable isolations.

MATERIALS AND METHODS

In the individually shielding strategy, each loop element is shielded by a semi-cylindrical shield on the outer side of the element away from the object to be imaged as well as both gaps between the elements (Fig. 1). Because the space between each element and the shield is substantially constrained by the allowed gap-width between the elements, most magnetic fluxes are truncated at the shield. This flux truncation causes a significant reduction of the magnetic fluxes passing through the coil loops as well as the interferences between the signals from the objects and the reflections from the shields. Consequently, the sensitivity of the shielded elements is significantly degraded. Thus, the only way to improve the coil sensitivity is to increase the magnetic fluxes passing through the coil loops as well as to reduce the reflections. Considering that the travelling patterns of RF waves vary with both the dielectric constant and the dimensions of media, we can reshape the RF wave travelling patterns and reduce the reflections by inserting proper dielectric media between the coil elements and the shields, thereby improving the coil sensitivity while maintaining the desirable isolations between the elements. To identify the dielectric materials that would optimize the coil sensitivity, we first iteratively computed the sensitivity of a single-loop element using FDTD tools while varying both the dielectric constant and the dimensions of the dielectric media. The loop coil element was 200-mm-long and 50-mm-wide and was shielded with a 35-μm-thick arc copper sheet 8 mm off the element. We then constructed a loop coil with the optimized dielectric insert (Fig. 2a) and acquired images from a spherical phantom using the loop coil on a GE Signa® 3T MRI scanner with a typical GRE pulse sequence (TR=1000ms, TE=30ms, Matrix=256x256, Flip Angle=90^0). To examine the effects of the dielectric inserts on the isolations between the elements, we also constructed a four-element array coil mounted on a cylindrical former with a diameter of 200 mm (Fig. 2b). We then measured the decoupling between the coil elements. The sensitivity of the shielded element with and without the dielectric insert was measured and compared with that of the unshielded element.

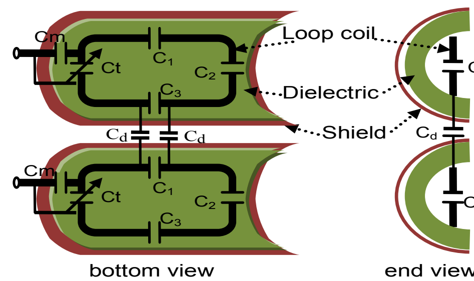

Fig.1. Decoupling strategy between adjacent elements.

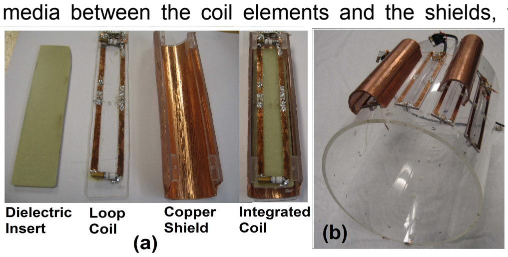

Fig. 2. Photos of (a) the single-loop element and (b) the four-element array coil under construction.

RESULTS AND DISCUSSION

The computed B_1-map of the single-loop element showed that, compared to the B_1 field of the unshielded coil element (Fig. 3a), the B_1 field of the shielded element without dielectric insert was significantly degenerated (Fig. 3b). The B_1 field of the shielded element with dielectric insert, however, was substantially improved (Fig. 3c). Further simulation results showed that the sensitivity of the shielded coil element dramatically varied with both the dielectric constant and the dimensions of the dielectric inserts. Without dielectric insert, the sensitivity of the shielded coil elements was degraded to as low as 32% of that of unshielded elements. With the dielectric insert, the sensitivity of the shielded element gradually increased with the increase of the dielectric constant before the dielectric constant reached a critical point. Beyond that point, however, the sensitivity began to decrease with the increase of the dielectric constant. We achieved an optimal sensitivity of 86% with a dielectric insert having a dielectric constant of about 700. The acquired images using the unshielded coil (Fig. 4a), the shielded coil without dielectric insert (Fig. 4b) and the shielded coil with dielectric insert (Fig. 4c) agreed with the simulation results. By measuring the transmission coefficients (S_{12}) between the elements of the four-element array coil, we obtained decoupling of -26.5dB between adjacent elements and -31 dB between non-adjacent elements, which was much better than the required level of -20dB, indicating the dielectric inserts did not downgrade the decoupling.

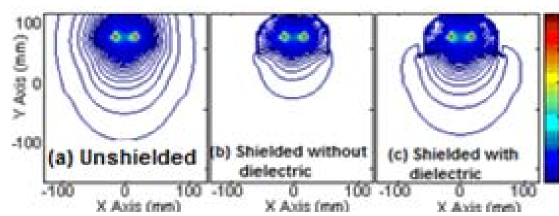

Fig. 3. Normalized computed B_1-mpas of a single-element coil.

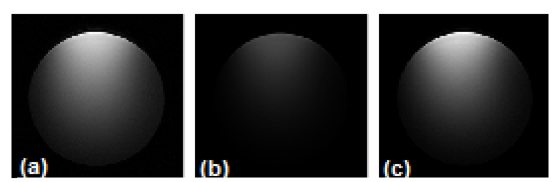

Fig. 4. Images acquired using a single element coil. (a) Unshielded; (b) Shielded without dielectric; (c) Shielded with dielectric.

CONCLUSIONS

We have demonstrated that the degradation of the sensitivity of individually shielded coil elements can be significantly improved by inserting proper dielectric media between the coil elements and the shields while maintaining desirable decoupling between the shielded elements. The coil sensitivity is closely dependent on both the dielectric constant and the dimensions of the dielectric medium. Our further preliminary study showed that the coil sensitivity is also affected by the geometry of the dielectric inserts. Thus, it is possible to achieve higher sensitivity close to those of unshielded coil elements when the dielectric inserts are selected with optimal parameters of dielectric constant, dimensions, and geometry. This optimization involves not only extremely huge computations but also too many experiments with various types of dielectric materials, which will be the future work of the study.

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