Loop T/R Coil for 7T MRI/MRS with Two Transmit/Receive channels

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Introduction

A loop T/R coil is simple to build and versatile to apply at different anatomies for various proton imaging or spectroscopy purposes. It has been widely used in both 1.5T and 3T MRI systems and provides reasonable B_1 field uniformity in the coil coverage area for those field strengths. However, at ultra-high fields such as 7T, B_1 field from a single loop coil is strongly disturbed and asymmetrical due to the increased tissue dielectric effect. It has a B_1 weak band in the middle of coil coverage area, thus produces relatively poor image quality. Here we propose a new coil structure topologically similar to the single loop coil but with distinctly different operational characteristics. It has two concentric flat rings which can be tuned to two orthogonal resonant modes at the same frequency. Combining with two independent transmit/receive (T/R) channels for B_1 shimming, a more uniform B_1-field coverage in the sensitive region of the coil is achieved. The proposed coil can easily be used for various imaging purposes at different anatomies such as head, torso and extremities at 7T.

Methods

The proposed coil structure has two concentric circular flat rings placed on one side of a 1cm-thick dielectric substrate. The mean diameters of the inner and outer rings are 13cm and 17cm. The two rings share the same RF shield placed on opposite side of the dielectric substrate (see Fig. 1). To tune the inner ring to a resonant mode at 298MHz, eight capacitors are used along the ring. Capacitor values are adjusted such that a uniform RF current distribution is established along the loop with B_1-field perpendicular to the ring plane (Y-direction). To tune the outer ring to a resonant mode at the same frequency, eight inductors are used evenly distributed along the ring. The inductor value is adjusted such that the current distribution along the ring is sinusoidal, which produces a B_1-field parallel to the ring plane (X-direction). The FDTD numerical method is used to model this coil structure and calculate B_1 (XFDTD software package, Remcom, Inc., State College, PA) [1,2]. Figure 1 shows the coil model placed 1cm above a uniform cylindrical phantom model (diameter = 30cm, height = 20cm, σ = 0.8S/m, ε_r = 80). Two RF excited sources are used to simulate two independent transmit channels, one source in each ring. B-field and E-field of steady-state solutions for each source are recorded separately. The combined $|B_1^+|$-field (B_1-field in the rotating frame) for two transmit channels is then calculated using the formula in [3], with the amplitude and phase for each source varied. $|B_1^+|$-field in the coil coverage area from the inner loop only, outer loop only, and from a 2-channel optimal transmit case are compared.

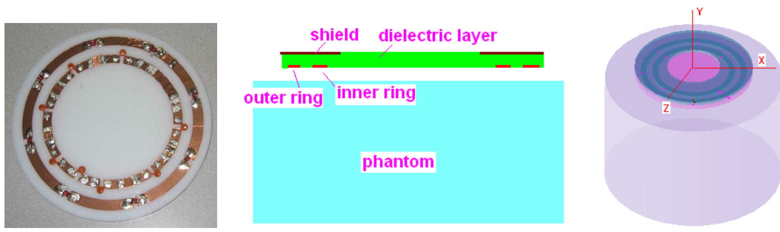

Figure 1. Two-ring coil prototype (left) and FDTD coil model placed 1cm-above a phantom (right).

Results

Bench testing of a coil prototype was performed. The inner ring (uniform current mode) had unloaded Q of ~ 220 and loaded Q, for a human arm, of ~ 25. For the outer ring (sinusoidal current mode) the like loaded to unloaded Q ratio is ~ 25:200, which is close to that of the inner ring. The two modes have good isolation. In Figure 2a, we show the calculated normalized $|B_1^+|/|B_1^+|_{center}$ distribution in the central transverse slice of the phantom from the uniform current mode, where $|B_1^+|_{center}$ is the $|B_1^+|$ at the center of the coil. As seen, at 7T, the $|B_1^+|$ uniformity/symmetry is different from that observed for field strengths of 1.5T and 3T. The existence of a weak $|B_1^+|$ band in the middle of coil coverage area makes a single loop coil less useful for imaging at 7T. Figure 2c shows the $|B_1^+|$ distribution in the 17cm-diameter coil coverage area from the outer ring alone with sinusoidal current distribution. The normalized $|B_1^+|$ standard deviation (no unit) in the plotted area is 0.4, which is better than 0.53 of the inner ring alone as shown in Figure 2b. When two transmit channels are used with optimal amplitude and phase difference, $|B_1^+|$-field uniformity in the coil coverage area is considerably improved, as shown in Figure 2d. In this case, the $|B_1^+|$ standard deviation is 0.34, about 15% better than the outer ring alone, and 36% better than the inner ring alone. The weak $|B_1^+|$ band in the middle of coil coverage area is substantially reduced.

Conclusions

A single loop T/R coil is easy to build and can be used for many purposes in practice. At 7T, the use of a single loop coil is less desired due to its severe non-uniform/asymmetric $|B_1^+|$-field in the transverses slice. With addition of a second concentric loop operating in a sinusoidal mode, combined with two channel transmit, the $|B_1^+|$-field uniformity/symmetry can be considerably improved. The two transmit channel configuration in this case is quite simple in approach, from a hardware perspective. This proposed loop coil could be conveniently used for both imaging and spectroscopy at different anatomies. With a third loop tuned to a different frequency, a double-tuned T/R coil can be built for multi-nuclear applications.

References

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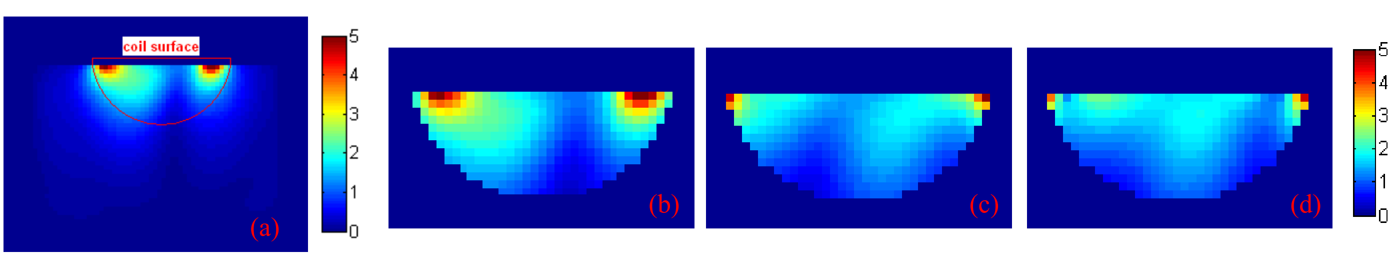

Figure 2. (a) Normalized $|B_1^+|/|B_1^+|_{center}$ in the central transverse slice of the phantom from the inner ring only; $|B_1^+|$ in a 17cm-diameter coil coverage area from inner ring only (b); from outer ring only (c); and from two-channel optimal driven (d).