Simulation Study of a 4-Channel Ladder-shaped Body Coil at 3T

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Introduction

Recently, the bore of MRI is increasing in order to improve patient comfort. A body coil, typically a birdcage coil [1], is placed in the inner side of the RF shield with gap from 2 to 3 cm as shown in Fig. 1. If this gap is decreased, the bore can be increased without any change in dimensions in a magnet and a gradient coil. However, the transmission efficiency of the body coil decreases as gaps shrink [2]. Therefore, we have designed a 4ch ladder-shaped body coil. As shown in Fig. 2, four ladder-shaped coils are placed along the inner side of the RF shield and there are wide gaps between nearest neighbor coils. Thus, the 4ch body coil increases spaces near the patient and the distance from the patient's face to the bore (D_f) and improves patient comfort. We also evaluated the characteristics of the designed coil at 3T using numerical simulation.

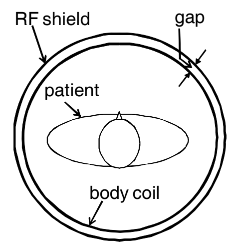

Fig. 1 Conventional setup of body coil and RF shield

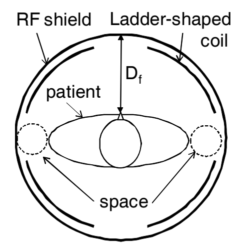

Fig. 2 Setup of 4ch ladder-shaped body coil

Method

Coil Design: The ladder-shaped coil is schematically shown in Fig. 3. This coil has five rungs and two arc conductors. Rungs are placed parallel to the direction of static magnetic field (B_0). Capacitors are inserted in the rungs (C_r) and arcs (C_a). Shunt capacitors (C_s) connect ends of rungs with an RF shield. A feeding port is connected to the shunt capacitor shown in Fig. 3. This coil has various resonant modes with changing values of C_r, C_s, and C_a. We found the mode in which all rung currents flow with identical phase and no current flows in the arc. We selected this mode as the resonant mode of the coil because this mode showed the highest transmission efficiency among the various resonant modes. The dimensions of the ladder-shaped coil used for numerical simulation were as follows. The RF shield had a diameter of 690 mm. The gap between the RF shield and the coil was set to 20 mm. The width and length of the rung were 60 mm and 400 mm. The width of the arc was 40 mm. The coil was tuned to 127.8 MHz (3.0T). The values of C_r, C_s, and C_a were 63, 32, and 300 pF, respectively. To construct the 4ch body coil, four ladder-shaped coils were placed along with the RF shield as shown in Fig. 2. The gap between nearest neighbor coils was 150 mm. Nearest neighbor coils were decoupled by means of a bridge with the decoupling capacitor. The bridge connected between the ends of arcs and was placed along the cylinder 680 mm in diameter. The value of the decoupling capacitor was 4 pF. This design increased the bore from 650 to 680 mm in the right-left (R-L) and anterior-posterior (A-P) directions. *Simulation:* Our own program, which was based on the method of moments and the impedance method [3], was used for numerical simulations. This program can calculate the sensitivity distributions of the coils with a load. A cylindrical phantom (300 mm in diameter and 500 mm long) was used for the load. The conductivity and relative permittivity of the phantom were 0.66 S/m and 78, respectively. The conductivity of the coil conductor was 5.8×10^6 S/m in view of degradation due to soldering and oxidation. The Q value of capacitors was 1000. The coil sensitivity was defined by the circularly polarized B_1 field generated by the coil when a signal of 1 W was fed to the coil. *Evaluation:* To confirm the resonant mode of the ladder-shaped coil, its current distribution was evaluated. To confirm the effect of decoupling, coupling between the coils in the 4ch body coil was evaluated. The amount of coupling between the two coils was calculated from the ratio of the current in the non-fed coil to that in the fed coil when one coil is fed. A B_1 map of the 4ch body coil with quadrature drive (QD) was calculated. Uniformity of B_1 distribution was evaluated with the NEMA standard [4]. A B_1 map of the 24-rung high-pass birdcage coil with an RF shield was also calculated for comparison. The dimensions of the RF shield and inner diameter of the birdcage coil were identical to those of the 4ch body coil.

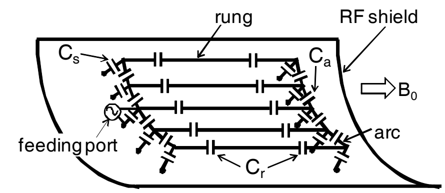

Fig. 3 Structure of ladder-shaped coil

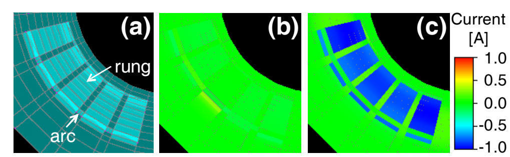

Fig. 4 Calculated current maps of a ladder-shaped coil ((a) Coil model, (b) Real part, (c) Imaginary part)

Results and Discussion

Figure 4 shows calculated current maps of a ladder-shaped coil. As shown in Fig. 4(b), the real part of the rung current was nearly zero. In contrast, the imaginary part of the rung current ranged from -0.8 to -1.0 A, as shown in Fig. 4(c). These results show that all rung currents flow with identical phases. The real and imaginary parts of current in the arcs were nearly zero. Thus, the ladder-shaped coil was confirmed to resonate in the designed mode. The unloaded Q value (Q_{UL}) of the coil was 440, and the loaded Q value (Q_L) was 192. The ratio of Q_{UL} to Q_L is 2.3. This means that the loss of the load is comparable to that of the coil. Figure 5 shows current map of the 4ch body coil when the only 1ch is driven. The current map showed the magnitude of the current. The maximum coupling of the designed coil was 7 %. This suggests that the four ladder-shaped coils were decoupled from each other. Figure 6 shows B_1 maps of each channel in the 4ch body coil. These B_1 maps had rotational symmetries through 90 degrees. There is a locally high B_1 region in the opposite side of driven coil in the B_1 maps. However, the influence of the region on the region of interest (ROI) is very small. These results suggest that each ladder-shaped coil in the 4ch body coil can operate independently. This means that RF shimming and the parallel transmission are possible using the body coil. Figure 7(a) shows the axial B_1 map of a 4ch body coil with QD drive in the unloaded condition, and Fig. 8 shows the B_1 profile in the R-L direction. The designed coil showed a uniform B_1 distribution. The uniformity of the coil was 3.5% in the ROI of 30 cm and 7.6% in the ROI of 40 cm. The averaged B_1 values of the 4ch body coil and the birdcage coil in the ROI of 30 cm were 0.33 and 0.38 $\mu T/W^{0.5}$. Figure 7(b) shows an axial B_1 map of the 4ch body coil in the loaded condition. The averaged B_1 value of the coil and the birdcage coil in the phantom showed the same value of 0.16 $\mu T/W^{0.5}$. These results suggest that the transmission efficiency and B_1 uniformity of the designed coil are comparable to those of the birdcage coil.

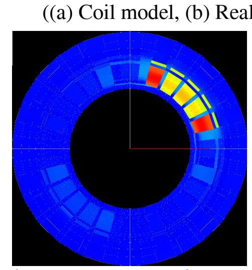

Fig. 5 Current map of 4ch body coil with 1ch drive

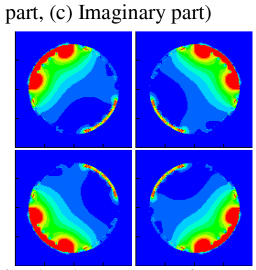

Fig. 6 Axial B_1 maps of each channel in 4ch body coil

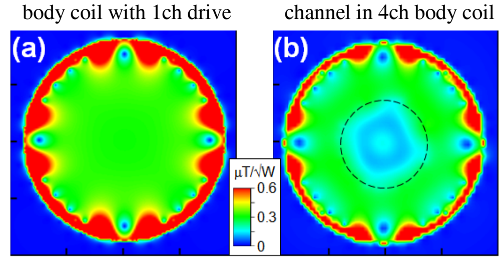

Fig. 7 Axial B_1 maps of 4ch body coil with QD drive in the unload (a) and loaded (b) condition

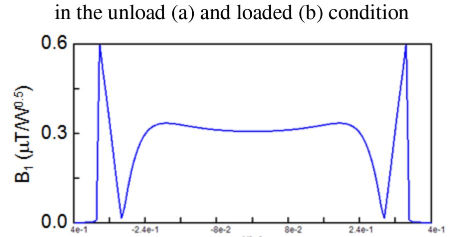

Fig. 8 B_1 profile of the 4ch body coil with QD drive in the R-L direction

Conclusion

We have designed a 4ch ladder-shaped body coil and demonstrated its characteristics at 3T using numerical simulations. The designed coil can increase bore size in the right-left and anterior-posterior directions. The simulation results suggest that the designed coil can be used as a multi-channel transmit body coil.

References [1] D. Weyers, et al., ISMRM 11th Annual Meeting, 1548 (2004) [2] T. K. F. Foo, et al., *Magn. Reson. Med.* 21, 165 (1991)
[3] H. Ochi, et al., SMRM 11th Annual Meeting, 4021 (1992) [4] NEMA Standard Publications. MS 1 (1988)