Combining cylindrically mounted dipoles with loops on a transverse plane for better head coverage in parallel transmission.

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Introduction: Parallel transmission (pTx) has been an expanding field of research in recent years, particularly for its ability to produce a more uniform excitation than standard volume coils at Ultra High Field. Various coil configurations have been developed for this purpose. In the case of coils dedicated to imaging the human head, these have mostly involved the placement of loop, stripline, or dipole elements on the surface of a cylinder. Such an arrangement positions the elements some distance from accessible parts of the head, particularly the superior surface. A limited number of geometries, however, do cover the surface of the head, for instance by using hexagonal, self-decoupled elements [1]. In this study, however, we attempt to combine a relatively standard cylindrical arrangement of dipoles with geometrically decoupled loops oriented with their axis parallel to the magnet axis.

Principle: Conventionally, a loop element is considered only to be effective if its axis is oriented transverse to the applied magnetic field. This is because the B1 field generated at the center of a loop is oriented co-axially. A loop placed with its axis parallel to the magnet axis will produce no transverse B1 field along the axis, and thus there is neither excitation nor reception sensitivity. However, this is only true along the loop axis. Off axis, the curving pattern of the B1 field around the conductor generates a circular area of transverse B1 field. The result is that, unlike in the transverse orientation where a loop element is most sensitive along its own axis, in the parallel orientation there is a null along the axis, surrounded by a circular area of sensitivity. As has been shown in multichannel receive helmets [2], a phased array of such parallel oriented loops can still generate a large area of sensitivity, as neighboring elements will fill in the central null from any individual element.

Unlike receive-only phased arrays, where next-neighbor elements can be relatively easily decoupled through the use of techniques such as preamplifier decoupling, transmit elements generally have to rely on geometric decoupling. For circular loops, it is reasonably easy to arrange two or three loops in such a way as to minimize their mutual coupling. Additionally, a loop oriented parallel to the main field will also have a large degree of geometric decoupling from dipoles that are oriented along the magnet axis. Thus, in principle, it should be possible to include the three loops inside of a cylindrical coil made from dipoles, without experiencing significant coupling.

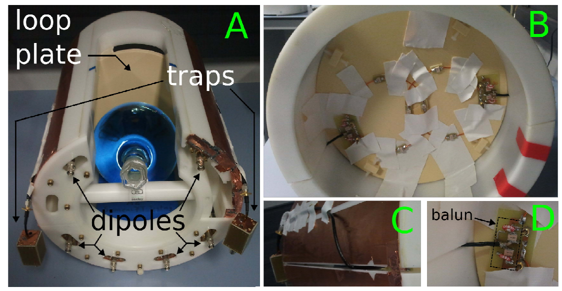

Figure 1: Images showing arrangement of dipoles and loops, as well as the baluns and cable traps used with the loops.

Methods: The cylindrical coil consisted of 6 dipoles, 4 arranged with an approximately 84 degree spacing around the surface of the cylinder and two located between the pairs at opposite sides. Inside of the cylinder, two loop elements of 10 cm diameter were mounted on a plate fixed. The placement of these elements was adjusted to minimize their mutual coupling, which was measured to be -15.5 dB. Since significant coupling to the dipoles could be observed if the cables of the loops were simply allowed to pass along the inside of the cylindrical coil, these cables were brought straight out the side of the coil and along the outer shield. Due to this arrangement, and the limited space within the head gradient set installed in the MRI system, the cable traps for the loop elements were introduced approximately 44 cm from the loops rather than the usual lamda/4 distance. To reduce common modes over this long cable, lattice baluns were added to the loop elements. With this arrangement the couplings to the neighboring dipoles ranged from -15.6 dB to -32.4 dB. The complete arrangement is shown in Figure 1.

The coil was tested in a 7 T MRI system equipped with a pTx extension (Siemens Medical Solutions, Erlangen, Germany). Two arrangements were tested, one utilizing four dipoles and the two loop elements, the other using six dipoles in an alternative geometry (an extra dipole added between the existing pairs on either side of the cylinder) with no loop elements. Relative transmit and receive sensitivities were measured using a combination of relative and absolute B1-maps [3,4]. Relative maps were obtained from spoiled Fast Low Angle Shot (FLASH) images (mean-FA: 3°, max-FA: 6°, sequence parameters: TR = 50 ms, 5-mm isotropic resolution with a 48x48x36 matrix). In order to increase the overall accuracy, this was implemented in the framework of the matrix-based B_1^+-mapping method [5]. Actual FA-maps were obtained for two approximately orthogonal phase combinations contained in the set of FLASH acquisitions. To this end, the AFI sequence [6] was used with TR1/TR2 = 40/200 ms, and the same acquisition matrix as for the FLASH sequence. Small non-linearities in the relative B1-mapping procedure were corrected, and receive maps were estimated as described in [7]. However, it should be noted that, for this exploratory experiment, a prototype dipole coil was used, which is known for having relatively poor efficiency. Of interest, however, is the different spatial patterns of excitation and reception, particularly in the areas that would correspond to the superior part of the head.

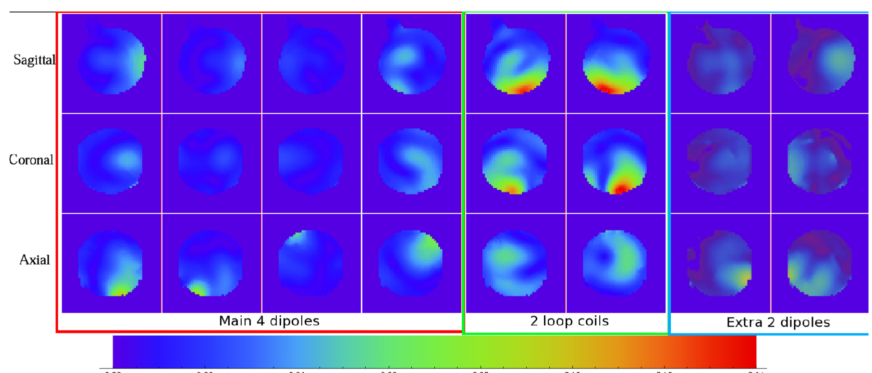

Figure 2: B1+ maps from the four dipoles used for both configurations (red box), the two loop coils (green box) and the additional two dipoles (blue box). Of particular note is the particularly high sensitivity of the loop coils in the lower region of the sagittal and coronal views, which, if placed at the other end of the coil, would be the superior part of the head.

Results: Shown in Figure 2 are the B1+ maps calculated for the various sets of elements. As expected, since the loop elements are situated relatively close to the edge of the phantom along the magnet axis, they show quite strong sensitivity in this region. The addition of two dipoles, with their position on the surface of the cylinder, does not add significant sensitivity in this area. Not shown are the receive sensitivities, which follow quite similar patterns.

Conclusion: It has been shown that it is possible to combine loop elements with their axes parallel to the main field to a cylindrical coil containing dipole elements. Low coupling was achieved through suitable geometric placement as well as careful attention to cable paths. The improved sensitivity in what would be the superior parts of the human brain suggests that more efficient use of RF power might be achieved. However careful modelling will be required to determine the SAR gains or penalties involved.

References: [1]Wiggins GC, Mareyam A, Setsompop K, Alagappan V, Potthast A, Wald LL, A Close-Fitting 7 Tesla 8 Channel Transmit/Receive Helmet Array with Dodecahedral Symmetry and B1 Variation Along Z. Proceedings of the 16th Annual Meeting International Society for Magnetic Resonance in Medicine 2008; Toronto Canada:, p. 148[2] Wiggins GC, Triantafyllou C, Potthast A, Reykowski A, Nittka M, Wald LL. 32-channel 3 Tesla receive-only phased-array head coil with soccer-ball element geometry. Magn Reson Med. 2006 Jul;56(1):216-23 [3] Setsompop, et al., MRM; 60:1422-1432 (2008).[4] van de Moortele ISMRM 2007; p1676.
[5] Brunner, et al., ISMRM 2008; p354. [6] Yarnykh, MRM 57:192-200 (2007) [7] Wang, et al. MRM 53:408–417 (2005).