A 6-Element Coil Array for Parallel Imaging in Arbitrary Directions

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Introduction

The increasing importance of parallel imaging poses further challenges for RF-coil design. In a coil array suitable for parallel imaging low mutual coupling and orthogonal sensitivity profiles are required. To meet these demands a large variety of different coil setups has been proposed [1]. In the loop-butterfly design [2] a loop coil together with a figure-of-eight shaped coil is used to provide orthogonal sensitivities and inherent geometric element decoupling. This principle can be extended by using coil elements with more than a single crossing such as the double twisted saddle train coil [3].

In this work an encoding coil array pattern is proposed for parallel imaging in arbitrary directions by using loop, butterfly and saddle train coil elements arranged side by side (Fig. 1(a)). In the direction across the three elements orthogonal sensitivity profiles is achieved by distance, while in the other direction by the phase inversion due to the crossings. Using two of these arrangements in a cylindrical placement (Fig, 1(b)) allows encoding in the third direction. A prototype of this design was developed for small animal imaging on a clinical 3T MRI system.

Materials and Methods

A 3-element coil consisting of a rectangular loop (50 mm×15 mm), a butterfly and a saddle-train element were etched on a copper coated foil. Two of these coils were fixed on the exterior of a 40mm-diameter acrylic-glass tube. The arrangement of the coils was chosen as a compromise between element decoupling and homogeneous sample illumination. The loaded and unloaded quality factors of the elements were determined by tuning of individual elements to 123.23 MHz with the other elements being open-circuited. As a load a syringe (l = 65 mm, d = 30 mm) filled with physiologic saline solution and 1% Gd-DTPA was used. The elements of the loaded coil array were iteratively matched to 50 Ω, and matching and mutual coupling of the elements were quantified in terms of the scattering parameters S_{nn} and S_{nm}, respectively. The mutual coupling between the elements was measured without connection to a preamplifier. Due to strongcoupling between loop elements 1 and 4 additional capacitors were inserted for active decoupling [4]. All MR experiments were performed on a 3 Tesla whole body MR system (Siemens TIM Trio, Erlangen, Germany), connecting each coil array (Fig. 2) to one of two 4-channel preamplifier interfaces (Flex Coil Interface). The array was placed orthogonal to the B_0-field, and a series of 100 2D gradient echo images (FLASH, TR = 40 ms, TE = 4 ms, α = 40°, matrix = 128², FOV = 50×50 mm²) was acquired with acceleration factors R between 1.7 and 2.6 (i.e., nominal acceleration factors PAT = 2, 3, and 4) and a SENSE [5] image reconstruction. From the image series g-factor maps were calculated.

Results and Discussion

The measured quality factors of the single element types are given in Tab.1. The loop element showed the highest Q_U and the highest load factor Q_U / Q_L. In general, the low load factors might be a consequence of the low filling factors. The input reflection factors S_{nn} of the matched elements are given as the diagonal elements in Tab. 2. No element reflected more than -28.5dB. The difference in matching for the two loops (S_{11} and S_{44}) results from the iterative matching process. Initially, the two opposing loops showed a high coupling of -9.4dB, which was reduced to -31.9dB by insertion of additional decoupling capacitors. The off-axis elements of Tab. 2 show the mutual element coupling S_{nm} of the final setup.

The average g-factors calculated from axial and sagittal images are listed in Tab. 3. At the edges of the phantom very high g-factors were found, so that for sagittal images the average values without the edges are presented. For an acceleration factor of 1.7 both phase encoding directions yield similar g-factors.

The proposed 6-element coil array design provides good imaging performance due to low mutual element coupling. The MR experiments showed that this coil setup can be used for parallel imaging in all spatial directions with nominal acceleration factors of 2 and more.

Acknowledgements

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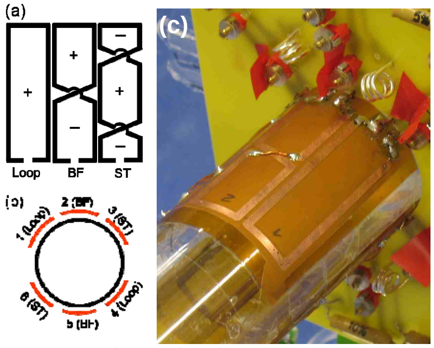

Fig. 1(a) Orthogonal coil concept: An array consisting of a loop, a butterfly shaped (BF) and a saddle train (ST) coil element. Mutual coupling of the elements is minimized since negative and positive fields cancel. (b,c) Arrangement of the elements on an acrylic glass tube. The element structure was etched on a copper coated foil.

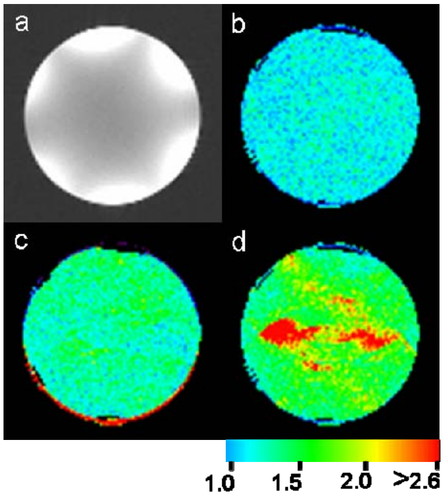

Fig. 2 (a) Non-accelerated 2D-FLASH image and g-factor maps for (b) R=1.7, (c) R=2.2 and (d) R=2.6.

		Axial		Sagittal	
PAT	R	A-P	L-R	A-P	H-F
2	1.7	1.1	1.1	1.1	1.2
3	2.2	1.4	1.4	1.2	1.5
4	2.6	1.7	1.7	1.3	1.9

Tab. 3 g-factors calculated from axial and sagittal images for phase encoding in anterior-posterior (ap), left-right (lr) and head-feet (hf) direction. Due to the scan of reference lines the real acceleration factor (R) is always less than the nominal (PAT).

References

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	Q_U	Q_L
Loop	189	132
Butterfly	179	148
Saddle Train	148	138

Tab. 1 Loaded and unloaded quality factors of the individual element types.

	1	2	3	4	5	6
1	-39.2	-15.6	-13.6	-31.9	-22.9	-14.9
2		-31.9	-29.9	-23.9	-19.1	-25.8
3			-29.1	-15.6	-24.6	-24.9
4				-31.7	-11.5	-16.4
5					-28.5	-13.0
6						-30.7

Tab. 2 Scatter-parameter S_{nm} of the coil elements in dB. For numeration refer to Fig. 1(b)