Experimental Verification of SNR and Parallel Imaging Improvements Using Complete Coil Arrays

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Introduction

Surface coil arrays [1] combine the high signal-to-noise ratio (SNR) obtained with single surface coils with the large field of view of volume coils. Standard arrays limit the conductive paths to a surface surrounding the imaging region [2], thus measuring only the normal components of the RF magnetic field and ignoring those that are tangential to the surface. Recent simulation results [3] confirm that limiting currents to a surface does not provide the mathematically complete measurement of the field that is required to approach the ultimate intrinsic SNR [4]. A mathematically complete coil array is capable of generating any basis vector field in the multi-pole expansion of the electromagnetic field, and consists of composite array elements made of three concentric orthogonal coils [3]. Orthogonal coils are electromagnetically decoupled and sensitive to mathematically orthogonal components of the electromagnetic field, thus ensuring that complementary signal information is captured by each of the three elements.

Materials and Methods

An array of three 7 × 7 cm^2 square surface coils separated by 3 mm gaps was built using 1-cm-wide copper tape on a polycarbonate sheet. A series-equivalent capacitance of 10.6 pF was distributed to resonate the loops at 128 MHz. Detuning and lattice matching networks similar to those of Ref. [5] and λ/2 coaxial cables were used to connect the coils to a box housing low-input-impedance, low-noise preamplifiers (Philips Healthcare, Cleveland, OH). Five additional 3.5 × 7 cm^2 composite elements were centered orthogonally above the planar elements (Figure 1), made resonant using 14.6 pF and similarly connected to the preamplifiers. A 36 × 26 × 11 cm^3 phantom filled with demineralised water, 3.6g/ℓ NaCl and 1.96g/ℓ $CuSO_4{\cdot}5H_2O$ was used for imaging and to load the coils for matching to 50 Ω. Unloaded-to-loaded Q ratios were 7.1 and 2.0 for surface and vertical coil elements, respectively. Gradient-echo imaging (TR/TE = 11/1.95 ms, pixel bandwidth = 727.2 Hz, acquisition matrix 256 × 256, FOV = 30 cm, 1 average) was performed and scans without RF excitation were also acquired to measure noise covariance. Image SNR maps were generated from all coils or only the surface elements by pixelwise combination using the covariance-weighted root-sum-of-squares [1,6,7]. Measurements were performed on a Philips 3T Achieva and all processing was performed in MATLAB (The MathWorks, Natick, MA, USA).

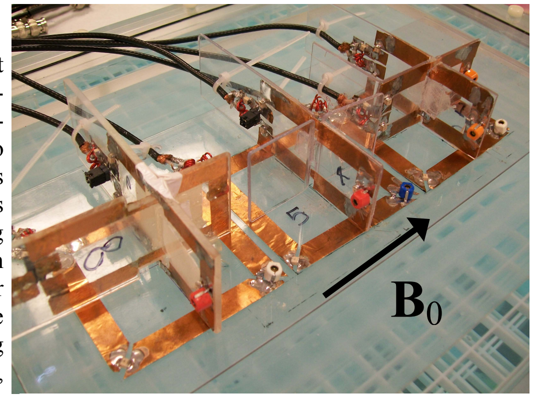

Figure 1: complete array and phantom

Results

Noise correlation within composite elements was found to be < 6.1% due to theoretically zero magnetic and electric coupling coefficients (electric field symmetries lead to zero mutual resistance), while between adjacent surface coils it was < 7.2 % and between all pairs the maximum was 22%.

SENSE acceleration	g factor mean/max	
	surface coils only	complete array
2	1.06/1.61	1.01/1.08
3	1.38/147	1.03/1.61
4	∞	1.15/3.25
6	∞	2.26/15.2
8	∞	9.76/808

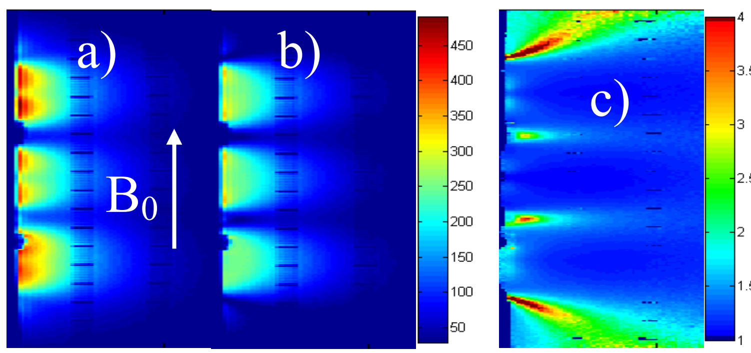

Figure 2: SNR maps for a) the complete array and b) only the surface elements; c) SNR of a) relative to that of b) indicates an overall increase in SNR especially where surface elements have sensitivity minima. Average SNR gain in this slice is 30%.

Results in Figure 2 show an overall improvement in SNR and SNR uniformity. Maximal increases greater than four-fold are seen where the surface coils alone have low sensitivity while minimal increases of approximately 5–10% occur in the region along the surface coils' centre axes. Ignoring regions in the combined image where SNR < 5 the average increase in SNR for ten images covering the array's FOV was 36%.

Geometry (g) factors for SENSE imaging [8] were calculated with acceleration parallel to B_0 for the complete array and for only the three surface elements. Mean and maximum g factors in the slice of Fig. 2 are given in the table for reductions from 2 to 8, showing substantial advantages of the complete array, approximately doubling the achievable parallel imaging reduction over the surface coils alone.

Discussion and Conclusion

The use of composite coils constructed of standard surface coils with additional orthogonal elements introduces new opportunities for parallel image encoding and enhanced SNR, confirming simulations and theoretical predictions. The construction of composite coils is simplified by the natural electromagnetic decoupling between orthogonal coils and provides an effective method to increase channel density without the difficulties of decreasing coil dimensions, which include increasing the proportion of noise due to the electronics [9] and shielding of the RF magnetic field [10].

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