Approaching Ultimate SNR: Comparison of Composite and Surface Coil Arrays

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Introduction

Arrays of composite coils, created by combining two upright coils with a standard surface coil [1], have the potential to provide higher performance than coil arrays consisting of only surface coils [2]. Many studies have reported that approaching the ultimate SNR (uSNR) requires array elements that provide different current patterns than those of surface coils (electric vs. magnetic dipole-like patterns) [3]; coils orthogonal to the surface coils can produce these patterns. We present a comparison of high-density arrays of composite coils and surface coils with equal numbers of elements (18, 36 and 54). The uSNR and parallel imaging performance (measured using geometry factors [4]) are compared along with the SNR including the noise added by matching networks, coil conductors and preamplifiers.

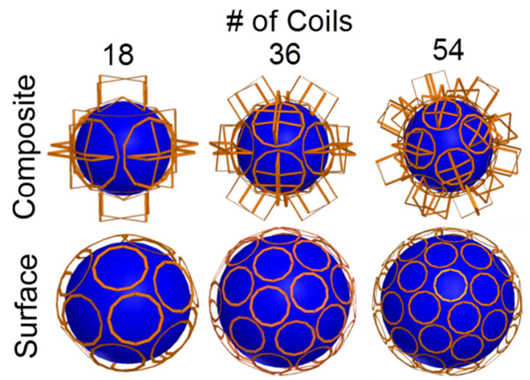

Figure 1: The composite and surface arrays. The position and diameter of coils in the 18 elements surface array are the same as those in the 54 element composite array

Materials and Methods

The arrays in Figure 1 are modeled in HFSS (Ansys)**.** Coils are distributed around the 18 cm diameter spherical phantom (ε_r=76, σ=0.8 S/m) and separated from the sphere by a 10±1 mm gap. The components of a lattice balun are chosen to match the individual input impedance of the coils to 50 Ω [5], while providing preamp decoupling with a preamp input impedance of 6 Ω [6]. The capacitors and inductors in the lattice balun have equivalent series resistances of 0.15 Ω and 0.36 Ω, respectively. The noise covariance matrix at the output of the matching networks, $\boldsymbol{\Psi_m}$, is calculated from Bosma's theorem [7] as

$$\boldsymbol{\Psi_m} = Bk_bT(\boldsymbol{I} - \boldsymbol{\Gamma_0}\boldsymbol{\Gamma_0}^{\mathcal{H}}), \quad (1)$$

where $\boldsymbol{\Gamma_0}$ is the reflection coefficient matrix seen looking into the matching networks at the preamp terminals, B is the acquisition bandwidth, k_b is Boltzmann's constant, $\boldsymbol{I}$ is the identity matrix, $\mathcal{H}$ indicates Hermitian transpose and T_0 is the noise temperature. The final noise covariance matrix is

$$\boldsymbol{\Psi} = \boldsymbol{Q}(\boldsymbol{\Psi_m})\boldsymbol{Q}^{\mathcal{H}} + \mathrm{diag}\big(\boldsymbol{Q}(\boldsymbol{\Psi_m})\boldsymbol{Q}^{\mathcal{H}}\big)\big(\boldsymbol{F}_{pre} - \boldsymbol{I}\big), \quad (2)$$

where $\boldsymbol{Q}$ and $\boldsymbol{F}_{pre}$ are diagonal matrices whose elements contain, respectively, the voltage gains between the preamp inputs and outputs [8], and the preamp noise factors (a noise figure of 0.5 dB is assumed throughout). The vector of signal voltages at the preamplifier outputs is proportional to

$$\boldsymbol{s} = \boldsymbol{Q}\boldsymbol{G_0}\widehat{\boldsymbol{B_1^-}}, \quad (3)$$

where $\widehat{\boldsymbol{B_1^-}}$ is a vector of coil sensitivities [9], the matrix $\boldsymbol{G_0}$ relates open circuit voltages at the coil terminals to the voltage at the preamplifier input [8]. The relative un-accelerated SNR is proportional to $B_0{}^2\sqrt{\boldsymbol{s}^H\boldsymbol{\Psi}^{-1}\boldsymbol{s}}$ [4,9,10].

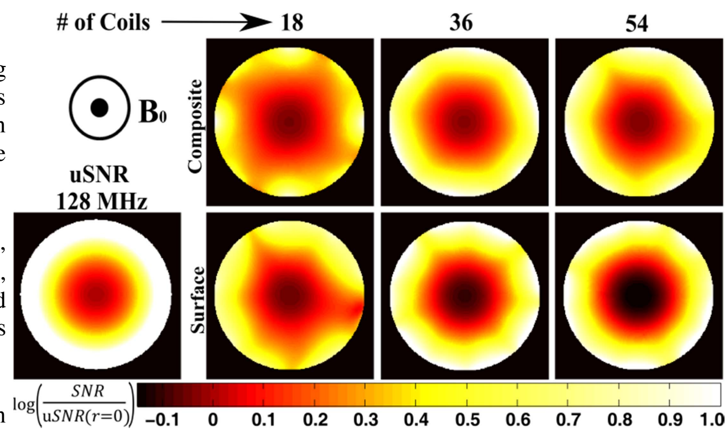

Figure 2: SNR (right) of the arrays and uSNR (left) at 128 MHz, relative to the uSNR at isocenter, in a transverse slice through the center of the sphere

Results and Discussion

The SNR performance in a transverse slice through the center of the spherical phantom is presented in Figure 2. The optimally-combined SNR was found to not depend at all on the preamplifier input impedance when the preamplifier contributes no noise, and to vary little when preamplifier noise is included. When composite arrays are compared to surface coil arrays with an equal number of elements, the composite arrays have lower overall coupling (not shown) and higher SNR in the inner two-thirds of the sphere, while having slightly lower SNR at the periphery. For the surface coil arrays the SNR at the center decreases as the channel density increases because of the higher coupling between elements than in the composite arrays, and because of the significant impact of the noise from the coils, matching networks and preamplifiers. This result agrees with the experimental comparisons of Ref. [11]. The average g-factors shown in Figure 3 for different accelerations in a transverse slice are lower for composite arrays despite the greater variety of sensitivity profiles, likely because of the smaller size and therefore more localized sensitivities of the surface coils. The same analysis repeated at 300 MHz shows an even greater benefit (36 and 54 element arrays) to using composite arrays in the inner two-thirds of the sphere because more of the losses of the upright coils are due to body losses at 300 MHz than at 128 MHz.

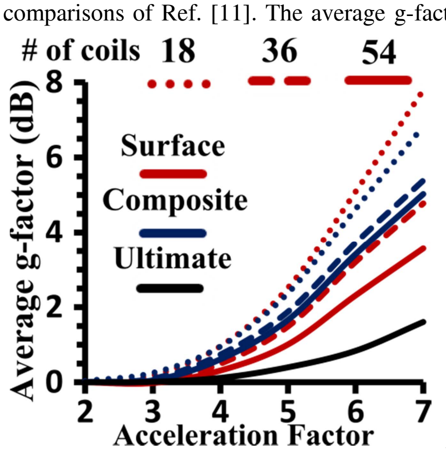

Figure 3: Average g-factor for a central transverse slice at 128 MHz.

Conclusion

Arrays of composite coils cover the same area as standard surface coils with larger coils and are therefore impacted less by noise due to copper, matching components and preamps. Composite coil arrays consequently achieve higher SNRs at depth than surface coil arrays, and are able to deliver SNR improvements more readily with realistic noise contributions from passive and active components when channel density increases.

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References: [1] W. Zhiyue J. *MR Imaging* 26:1310-1315 [2] Z. J. Wang. *NMR Biomed.* 22:952-959 [3] R. Lattanzi et al. *MRM* 68:286-304 [4] K. P. Pruessmann et al. *MRM* 42:952-962 [5] D. M. Peterson, "Impedance matching and baluns," *Encyclopedia of MR.* Sep 2011 [6] A. Reykowski et al. MRM 33:848-852 [7] S. W. Wedge et al. *IEEE Microw. Guided Wave Lett.* 1:117-119 [8] K. F. Warnick et al. *IEEE Trans. Antennas Propag.* 55:1726-1731 [9] F. Wiesingeret al. MRM 52: 376-390 [10] F. Wiesinger et al. *Proc. Intl. Soc. Mag. Reson. Med.,* 13:627. [11] G. C. Wiggins et al. MRM 62:754-762