Simulation of Coil Array Design: Optimizing the Signal Reception of Two Coils

P. Spincemaille[1], R. Brown[1], Y. Wang[1]

[1]Radiology, Weill Medical College of Cornell University, New York, NY, United States

Introduction Coil optimization is a complex computation problem. So far only one coil optimization is completely solved. Two coil optimization has been attempted previously with limited geometric consideration; a comprehensive solution remains to be elucidated. In this study, computer simulations are performed to investigate the maximal achievable SNR with a two-coil receiver system when the mutual inductance is assumed to be zero. Different designs are optimized and compared. SNR is not only measured in a single point at a certain depth but is also averaged along a longitudinal or transversal line at the same depth. The conducting medium containing these regions of interest is assumed to be an infinite half-space, an infinite cylinder or a finite sphere. Preliminary experimental data validated the calculated SNR increase of two coils with respect to the single coil.

Materials and Methods _Simulations_ The basic determinant of coil array SNR is the noise resistance matrix, as formulated by Roemer (1) or Wright (2), assuming the imaginary part of the mutual impedance is minimized by cancellation circuitry (3,4). Simulations are performed for a conducting infinite half-space, infinitely long cylinder (using bent coils as in (5)) and finite sphere (see Fig. 1), mimicking the larger body trunk, the leg and the head. In addition to considering the optimal SNR in a single point (here called SP), additional regions of interest (ROI) are investigated (Fig 2) : LR (a line running from left to right, with a length equal to the depth) and SI (superior to inferior). A single SNR value is obtained by averaging the SNR over the whole line. We consider symmetrical and asymmetric configurations (Fig. 2). In the asymmetric coil setup, the optimal coil size r_1 is determined for a single coil. Then a second coil is added (the position of the first coil remains unchanged.) The size r_2 and distance d is optimized to achieve maximal SNR. In the symmetric coil setup (Fig. 2 SYM), the coils are assumed to be identical (r_1=r_2=r). They are placed symmetrically on top of the ROI. The values for r and d are optimized to achieve maximal SNR. The half space calculations used an analytical expression for the mutual noise resistance. In the cylindrical and spherical case full volume integrations were performed numerically. The SP case for the infinite half-space was solved in (6) while the solution to the SYM problem was reported in (7).

Experiments Two identical coils (d=6.6 cm) for a 1.5T GE Signa CV/I scanner were constructed. A flux compensator was inserted into each coil loop to minimize coil coupling (3). The two coils were placed in a horizontal (coronal) plane on top of a large doped phantom (0.5% Gad solution). Noise measurement was performed by repeating the scan with the RF pulses turned off. SNR was averaged over a LR ROI located a depth equal to the coil diameter. The coil distance was changed several times.

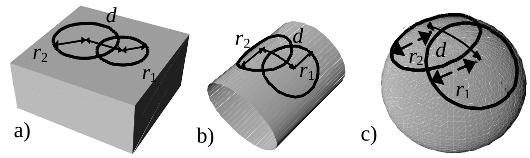

Fig. 1. Circular loops (radii r_1 and r_2) with a center-to-center distance d on top of a conducting a) infinite half space b) infinitely long cylinder (radius R) c) finite sphere (radius R)

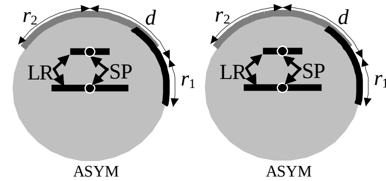

Fig. 2. Asymmetrical and symmetrical coil setup. LR (Left to Right) and SP (Single Point) at depth R and R/2.

	ROI	Depth	Radius	SNR
Half Space	SP	1.0	0.447	0.440
	LR	1.0	0.487	0.402
	SI	1.0	0.508	0.380
Cylinder (R=1)	SP	1.0	0.850	0.685
	LR	1.0	1.102	0.682
	SI	1.0	0.993	0.639
	SP	0.5	0.291	3.043
	LR	0.5	0.417	2.414
	SI	0.5	0.437	2.096
Sphere (R=1)	SP	1.0	1.000	1.448
	LR	1.0	1.000	1.554
	SI	1.0	1.000	1.554
	SP	0.5	0.369	3.783
	LR	0.5	0.536	3.307
	SI	0.5	0.611	3.030

Table 1 Optimal coil sizes for single coil receiver. SNR is measured in arbitrary units and R=1

# of coils	distance (in cm)	Measured SNR	Simulated SNR
1	N/A	14.1	14.1
2	7.0	17.9	17.7
2	9.8	17.9	17.5
2	13.2	17.1	16.7

Table 3 SNR in experiment vs simulation.SNR is normalized such that the single coil values coincide

	ROI	Depth	Setup	r_1	r_2	d	SNR
Half Space	SP	1.0	ASYM	0.447	0.5	0.379	0.509
	SP	1.0	SYM	0.502	0.502	0.4657	0.523
	LR	1.0	ASYM	0.487	0.516	0.560	0.487
	LR	1.0	SYM	0.534	0.534	0.559	0.505
	SI	1.0	ASYM	0.508	0.545	0.388	0.451
	SI	1.0	SYM	0.573	0.573	0.493	0.464
Infinitely Long Cylinder (R=1)	SP	1.0	ASYM	0.850	0.834	1.576	0.972
	SP	1.0	SYM	0.834	0.834	1.576	0.972
	LR	1.0	ASYM	1.102	0.443	1.556	1.164
	LR	1.0	SYM	0.419	0.419	3.141	1.409
	SI	1.0	ASYM	0.993	0.984	1.587	0.904
	SI	1.0	SYM	0.983	0.938	1.588	0.904
	SP	0.5	ASYM	0.291	0.331	0.289	3.610
	SP	0.5	SYM	0.318	0.318	0.378	3.739
	LR	0.5	ASYM	0.417	0.232	0.633	3.772
	LR	0.5	SYM	0.244	0.244	1.157	4.302
	SI	0.5	ASYM	0.437	0.441	0.295	2.658
	SI	0.5	SYM	0.473	0.473	0.433	2.744
Finite Sphere (R=1)	SP	1.0	ASYM	1.000	1.000	1.571	2.047
	SP	1.0	SYM	1.000	1.000	1.571	2.047
	LR	1.0	ASYM	1.000	0.673	1.571	2.080
	LR	1.0	SYM	1.000	1.000	0.830	2.089
	SI	1.0	ASYM	1.000	1.000	1.571	2.197
	SI	1.0	SYM	1.000	1.000	1.571	2.197
	SP	0.5	ASYM	0.369	0.414	0.337	4.540
	SP	0.5	SYM	0.404	0.404	0.429	4.703
	LR	0.5	ASYM	0.536	0.307	0.584	4.791
	LR	0.5	SYM	0.314	0.314	1.060	5.155
	SI	0.5	ASYM	0.611	0.543	0.375	3.892
	SI	0.5	SYM	0.629	0.629	0.579	3.976

Table 2. Optimal coil sizes for a two-coil receiver system.

Results Table 1 presents the result for a single coil with the two coil results shown in Table 2. The introduction of the second coil can increase the optimal SNR by as much as 42%. The optimal SNR varies with the ROI by as much as 62% and changes with the geometry of the medium by as much as four fold. The comparisons of the simulations with experiments are seen in Table 3.The maximal achievable SNR for both the symmetric (equal coil sizes) and asymmetric (one coil size fixed) was similar, suggesting that an approximate optimization can be achieved asymmetrically by sequentially adding coils into a coil set and optimizing the coil parameters one coil at a time. The optimal coil size for two coils is similar to the optimal single coil size for all ROIs and media, except the transverse LR line in the cylinder and the sphere. The optimal coil separation for the half space is approximately the coil radius; the optimal coil separation for the cylinder and sphere cases is dependent upon the location and orientation of the object and upon the symmetry. Except for the LR ROI, the overlap is again approximately equal to the coil radius.

Conclusion A comprehensive solution to the two coil optimization problem is presented. The optimal SNR varies substantially with the number of coils, the geometry of the region of interest and the geometry of the conducting medium that houses the region. This suggests that there is much to gain in SNR by tailoring phased coil arrays to a given imaging situation.

References (1) Roemer PB et al, Magn Reson Med 1990;16(2):192-225 (2) Wright SM et al NMR Biomed 1997;10(8):394-410 (3) Nabeshima T et al US patent 5,489,847, 1994 (4) Fox T Proc SMRM 1989:99 (5) Bottomley PA et al Magn Reson Med 1997;37(4):591-599 (6) Wang J et al, IEEE Trans Biomed Eng 1995;42(9):908-917 (7) Antoniadis Tet al Proc ISMRM 1996:1429. (8) Hadley R et al Proc ISMRM 2003:2375