Array SNR and coupling versus the input impedance of the preamplifiers

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INTRODUCTION

It is known that many factors affect Signal to Noise Ratio (SNR) in MR imaging. Array coil design related factors are coil loading, coil element diameter, array element separation and isolation, input impedance of decoupling preamplifier and system frequency. The purpose of this work was primarily to find the relation between SNR and perceived preamp input impedance and whether preamps need to be placed on the coil, or if they can be remote at the end of a lossy half wavelength transmission line, which would simplify the construction of large channel count arrays. We used four different methods: (1) FDTD simulation (2) Bench testing (3) Imaging (4) Circuit modeling.

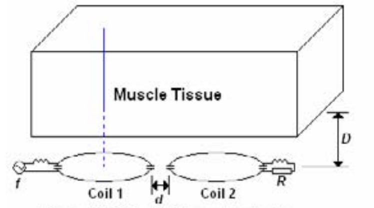

Fig 1. xFDTD Model & Image Exp Setup

METHODS

(1) A model was constructed in Remcom's xFDTD software, as shown in Fig. 1. Two 76.2 mm diameter loop shaped coils were constructed using 5.1 mm wide copper strip. A muscle tissue block of 15 by 15 by 38 cm was loading both coils. The muscle tissue had a conductivity of 0.7 S/m and a permittivity of 80. Coil 1 was matched to 50 ohms and excited by a sinusoidal RF source with frequency *f*, coil 2 was terminated with the same matching inductor and a resistor of *R* ohms to simulate the preamplifier input impedance, thus applying the well known preamplifier decoupling technique introduced by Roemer [1]. Coil to phantom distance *D* and coil to coil separation *d* were varied to study the effect of different conditions of coil loading and coil separation on SNR with different preamp resistances. Additionally *d* was set to infinity by removing coil 2 to obtain a SNR reference for comparison, referred to as "Baseline SNR". Different values of *f*, *R*, *d* and *D,* that were used, are tabulated in Table 1. SNR on the axis of coil 1 was simulated in xFDTD using following relation:

Frequency *f* [MHz]	63.86, 127.7
Preamp impedance *R* [ohm]	3, 9
Intercoil distance *d* [mm]	-20 to +30, step 5
Load distance *D* [mm]	8, 16, 24

Table 1: Parameter values

$$SNR = {}^{S}\!/_{N} = \frac{-\frac{\partial}{\partial t}\int \frac{\vec{B}_1}{I}\cdot\vec{M}\,dV}{\sqrt{4kTR\Delta f}} \propto \frac{{}^{B_1}\!/_{I}}{\sqrt{R}} = {}^{B_1}\!/_{\sqrt{P_{dis}}}$$

Where P_{dis} stands for dissipated power, and B_1 for B_1 field magnitude. The integral is assumed to be over a small volume, where B_1 can be assumed to be constant.

(2) Bench testing was done using a similar set up. Both coils were constructed and were loaded by a water phantom of 15 by 15 by 38 cm. The phantom contained 3.368 g/l $NiCl_2 \cdot 6H_2O$ and 2.4 g/l NaCl, consistent with the loading of the muscle block in the FDTD simulation. Channel 1 of the network analyzer was connected to coil 1 and channel 2 to a small flux probe placed at a distance of 25mm from the coil 1 along its axis. SNR degradation was measured by means of S21 between the flux probe and coil 1 while varying *d*, *D*, and *R*. Corrections were made for reflected power, by measuring the reflection coefficient.

(3) Images were taken in the MR scanner for verification of the simulation results. Parameters were kept the same as used in the simulation whenever possible. The experimental setup was the same as shown in Fig. 1, except that now excitation is done by the transmit body coil and coil 1 now has an actual preamp to detect the MR signal. The load phantom is the same as used in experiment 2.

(4) A simple model was developed in Agilent ADS circuit simulator for SNR degradation calculations. Each coil has its load resistance, which produces thermal noise $\sqrt{4kTR\Delta f}$. When two coils are coupled, noise from the secondary coil is coupled into the primary coil. Signal uniformity is also affected. Both effects work together to degrade SNR in the primary coil.

RESULTS and DISCUSSION

The plot on the left in Fig. 2 shows the SNR drop with increasing distance along the axis of coil 1 obtained from a FDTD simulation for a typical case (see plot title). On the right in Fig. 2 we see the drop in SNR in dB. The results show that SNR degradation is almost constant along the axis of coil 1. Therefore, each line was represented by a single value, and all FDTD results were plotted together, as shown in Fig. 3. Bench testing results are shown in Fig. 4. Results from MR images, shown in Fig. 5 have good agreement with results from FDTD simulation, except for a few bad data points. Calculation results from ADS are shown in Fig. 6.

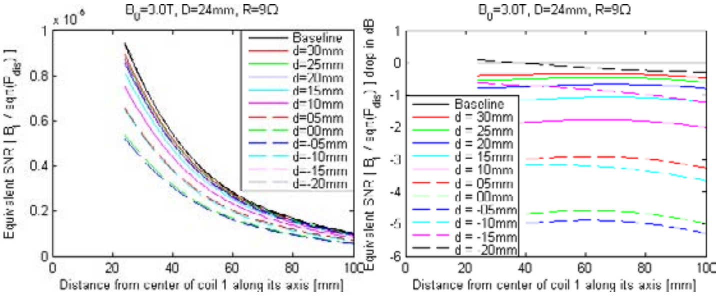

Fig 2 Typical FDTD results

CONCLUSIONS

Whereas a preamp impedance of 3 ohms represents a coil-integrated preamp, the 9 ohms represents a system preamp at the end of a lossy coaxial cable. For this coil element diameter of 3 inches we can conclude: (1) SNR loss due to coupling is much lower at 3T due to the heavier coil loading, (2) At 1.5T the SNR loss is more severe and it is likely that you will need to use preamps at the coils, (3) At 3T you can get away with moving the preamp to the end of a half wavelength cable in most cases. Cable management issues, manufacturability and flux shielding by the proximity of the preamp boxes also needs to be taken into consideration, but are not part of this study.

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REFERENCES

[1] P. Roemer, W. Edelstein, C. Hayes, S. Souza, O. Mueller, The NMR phased array, MRM 16, 192 (1990)

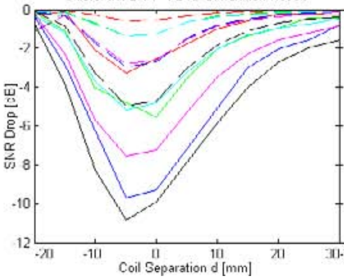

Fig. 3 FDTD Simulation Results

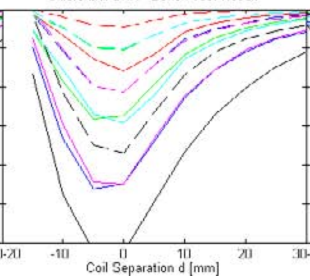

Fig. 4 Bench Test Results

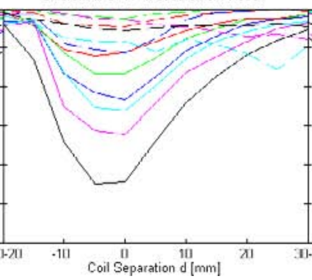

Fig. 5 Image Measurement Results

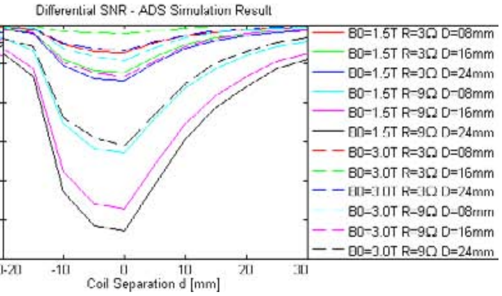

Fig. 6 ADS Simulation Results