Design Optimization for Phased Array Coil Decoupling and Tuning

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Introduction

Minimizing the coupling between coils is of significant importance in parallel MRI and is commonly addressed using techniques such as loop overlap, pre-amplifier decoupling, and capacitive decoupling [1-3]. Under transmit conditions, pre-amplifier decoupling cannot be used and the decoupling must be performed using the other techniques. These other methods typically implement and perform well in coil designs with relatively homogeneous loop topologies but tend to present significant design challenges as the number of coil channels increases and coil topologies become more complex. The capacitive decoupling approach offers numerous advantages, but the determination of capacitor values to sufficiently decouple coil loops involves numerous time-consuming iterations which diminish the benefits of this approach and can even render the approach unusable. New design methods are needed to facilitate the design of multi-channel coils with complex topologies. The method presented here provides a single iterative approach to predicting decoupling and tuning capacitors based on coil loop topology.

Methods

The procedure for determining decoupling and tuning capacitors based on the coil's topology follows the three major steps described below.

The process begins by using the concept of partial inductances to quantify the inductive coupling between all of the loop segments in a coil. This method eliminates the need to have a-priori knowledge of coil branch currents and removes geometry dependent sign ambiguities associated with mutual inductances between the coils. Instead of treating each coil as an independent loop, the coil assembly is broken down into smaller coil segments that begin and end at any geometric discontinuity, decoupling or tuning capacitor, or feed terminal. An inductance matrix of all the coil segments may be computed using closed form solutions for simple geometries, but a computational electromagnetic simulation is typically required for arbitrarily shaped geometries.

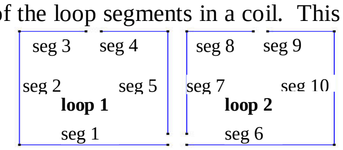

Fig 1. Partial inductance segment example of a two channel coil.

The partial inductance matrix of all the coil segments has little value of its own, and requires further reduction to obtain capacitor values. In the second step, the coil segment inductances are linked to the decoupling and tuning capacitors that will be soldered on to the coil. This linking creates a matrix, Z_t, that characterizes the impedances across the capacitors and feed terminals on the coil.

The partition of Z_t that corresponds to the feed terminals of the coil is of particular interest as it offers information used to decouple and tune the coil. The off diagonal terms of this partition indicate the amount of loop to loop coupling and are used to derive decoupling capacitor values. The diagonal entries represent the self impedance of the coil channels and are used to obtain tuning capacitor values.

In the third step, optimization procedures are used in conjunction with Z_t to obtain decoupling component values. An optimizing function is designed to minimize the off diagonal terms of Z_t for the coil feed ports using decoupling capacitor values as the unknown variables. Because numerous minima may exist, intelligent methods should be used to select the initial guesses used in the minimization routines. These methods may include calculated coupling coefficients and symmetry conditions. After decoupling capacitors are determined, tuning capacitor or inductors may be calculated from the optimized feed port impedances at the desired resonant frequency.

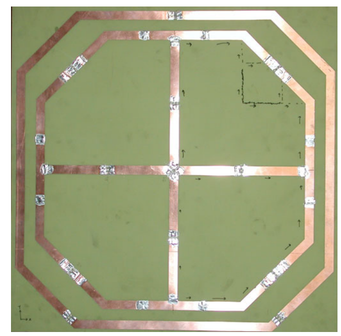
Fig 2. Four channel phased array coil.

Results

The methods described above were used to determine decoupling and tuning capacitors for a variety of phased array coil geometries. In the first example, the four channel phased array coil shown in Figure 2 is modeled according to the described process. Figure 3a illustrates the predicted inductance matrix for the feed terminals of the un-decoupled coil obtained from computed partial inductances. Coupling coefficients range from 5.7% to 25.3%. Figure 3b depicts the same information as Figure 3a, but decoupled using optimized capacitors. The zero valued off diagonal terms indicate successful decoupling between all four coil elements. Calculated capacitor values were then used to populate the coil in Figure 2. A coupling coefficient of 0.4% and a f_0 of 63.60 MHz were obtained from the physical coil using predicted capacitor values.

407.2	− 102.8	− 23.2	− 102.9
− 102.8	407.1	− 102.9	− 23.2
− 23.2	− 102.9	407.2	− 102.8
− 102.9	− 23.2	− 102.8	407.3

Fig 3a. Initial inductance matrix (ηH) of a four-channel coil

173.6	0.0	0.0	0.0
0.0	173.5	0.0	0.0
0.0	0.0	173.6	0.0
0.0	0.0	0.0	173.7

Fig 3b. Optimized inductance matrix (ηH) of a four-channel coil

In the second example, the model of a vertical field torso coil shown in Figure 4 produced the coupling coefficient profile illustrated in Figure 5. Maximum difference for this coil when compared to measured data was less than 1.3%.

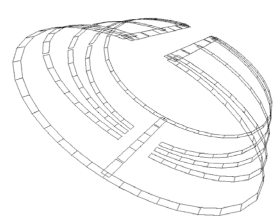
Fig 4. Electromagnetic model of an eight-channel phased array coil.

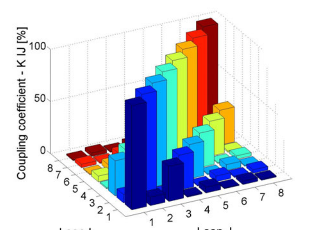

Fig 5. Coupling coefficient profile for the coil shown in Fig. 4.

Summary

A predictive engineering process has been presented that produces an accurate impedance characterization for arbitrary RF coil geometries. The impedance characterization can be used to successfully predict decoupling and tuning component values to obtain minimum decoupling and resonance at the desired frequency.

References

[1] Jevtic, J., Proc. ISMRM 9:17 (2001)
[2] Lee, R., et al., ISMRM 329 (2002)
[3] Gotshal, U., et al., ISMRM 165 (2002)