Analysis of imaged object's permittivity, conductivity, size and position effects on optimal Capacitive, Inductive and Transformer decoupling schemes in RF coil arrays

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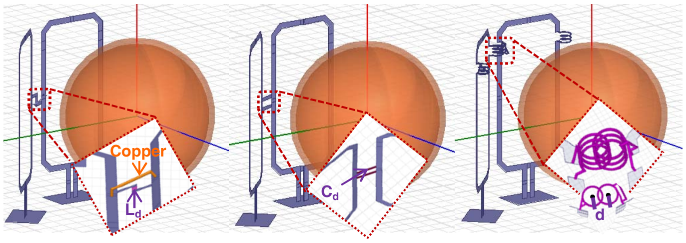
Target Audience: This abstract is intended for scientists who are interested in transmit or transmit-receive RF coil design for parallel imaging (PI).

Introduction: The quality of images in PI depends, to a large extent, on the signal to noise ratio and g-factor of the coil array, which are directly related to the coil design. Minimizing the coupling between coil elements is critical, but it was suggested that overlapping coil elements for decoupling might not be optimal for PI[1]. Zwart et al showed that partial overlapping would not provide the lowest possible g-factor and resulted in poorer image quality in PI. Therefore, alternative decoupling techniques would be preferred. Using low input impedance preamplifier for decoupling is effective, however, this can only be used for receive-only RF coil arrays and the challenge remains for transmit or transceiver arrays. Other popular methods for decoupling adjacent elements are transformer, capacitive and inductive decoupling, which can be used in both transmit and receive coils. Although these techniques have been widely used, a comparative analysis of their tolerances to load variances was not reported. We have previously reported the sensitivity of these decoupling techniques to variations in component values, which might arise from manufacturing tolerances as well as aging or heating[2]. In the study presented here, that framework was expanded to understand the robustness of each decoupling method to the variations in size and electrical properties of the loading object.



(a) (b) (c)

Fig. 1. (a) Inductive, (b) Capactive, and (c) Transformer decoupled coil elements.

Methods: The two-coil model previously reported in Arpinar *et al*[2] was used in this study. Full-wave electromagnetic solver (HFSS, ANSYS, Canonsburg, PA, US) was used to simulate the coils at resonance frequency (f_0) of 128MHz. To mimic the human head, the coil was loaded with a two-layer spherical phantom. For the initial calculations, the properties of the inner compartment was r_i:8.6cm, σ_i:0.57S/m, ε_i:63.4ε_0 and the outer compartment was r_o:9.3cm, σ_o:0.23S/m, ε_o:35.8ε_0. First a single coil and then two coils without decoupling were simulated and the admittance (Y) matrixes were found. From these Y matrixes initial capacitive and inductive and transformer decoupling values were estimated[2]. The locations of the decoupling elements are shown in Fig.1. Next, the two coils were simulated together with matching, tuning and decoupling circuit elements. The decoupling component's value was swept around the initial value to find the true optimal value where maximum decoupling was achieved (minimum S_{12} @ f_0). For transformer decoupling, the windings were modeled as solenoidal inductors and combined such that the windings combed each other (Fig.1(c)). The distance between their axes (d) was varied to control the amount of mutual coupling that would neutralize the coupling between the two imaging coil elements.

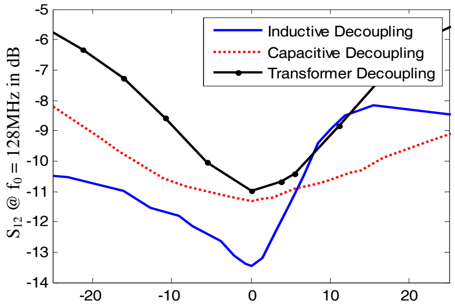


Fig. 2. S_{12} vs % change in decoupling element values.

To understand the effect of phantom size and shape on decoupling, the phantom's size is scaled to 85% (r_o:7.90cm, r_i:7.31cm) and 115% (r_o:10.70cm, r_i:9.89cm) of the original size, keeping the original electrical properties. Then, to study how coupling was affected by variations in electrical properties of phantom, the values were scaled to 75% (σ_i:0.428S/m, ε_i:47.6ε_0, σ_o:0.172S/m, ε_o:26.8ε_0) and 125% (σ_i:0.712S/m, ε_i:79.2ε_0, σ_o:0.288S/m, ε_o:44.8ε_0) of the original values, keeping the original size of the phantom.

Table 1. S_{12} vs decoupling technique and phantom variations

Decoupling	***S_{12}***					
	Initial		***σ&ε***		***Phantom Size***	
	optimum	***±5%***	***75%***	***125%***	***85%***	***115%***
Transformer	-10.90dB	0.65dB	-12.41dB	-10.57dB	-14.80dB	-10.42dB
Capacitive	-11.31dB	0.31dB	-10.64dB	-11.66dB	-10.66dB	-13.14dB
Inductive	-13.45dB	1.52dB	-8.07dB	-14.09dB	-10.51dB	-15.20dB

Results: In the absence of any decoupling element, the coupling factor *m* was found as $5.4 \cdot 10^{-2}$. With the original phantom, the optimal component values at f_0 were found to be 3.4mm, 9.0pF, and 280nH for the transformer, capacitive, and inductive decoupling, respectively. Fig.2 illustrates changes in S_{12} when components deviate from the optimal decoupling value. The first column of Table 1 lists S_{12} with original phantom and optimal component values. Changes in S_{12} with ±5% change in the values of decoupling components were given in the second column. The next two columns ($\sigma \& \varepsilon$) list S_{12} when electrical properties were changed by ±25%. The last columns show S_{12} for different phantom sizes (±15%).

Discussion and Conclusion: Full wave electromagnetic modeling was used to simulate a simple coil array to study the performances of transformer, capacitive and inductive decoupling schemes for different load sizes and electrical properties. Results show that decoupling improves for capacitive and inductive decoupling techniques when phantom size increases (which will decrease phantom-coil gap and increase coil loading). This is probably because the coil–phantom interactions becomes more pronounced than coil-coil interaction. Interestingly, the opposite was observed for the transformer case. It is possible that the decoupling transformer itself was also influenced more by the loading phantom nearby. Our findings also indicate that the variations in electrical properties of the phantom affect coupling significantly, especially for inductive decoupling. It was also observed that capacitive decoupling is less sensitive to variations in the phantom's electrical properties and size when compared to other techniques. We had observed a similar trend in our previous study, where capacitive decoupling was less sensitive to variations in component values. Although the capacitive decoupling may not yield the highest decoupling (minimum S_{12}) compared to other techniques, it is more robust against variations in component values as well as loading.

References: 1. JA Zwart et al, MRM. 2002, 47:1218–27   2. VE Arpinar et al, ISMRM 20 2012, 2775