Tunable Adjustable Inductive Decoupling (TAID) Board

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Introduction

In phased array coils for MRI applications, one of the major problems is coupling between receive elements. There are several ways to decouple the elements: inductive decoupling, capacitive decoupling and preamplifier decoupling [1]. One of the subsets of inductive decoupling is the so-called transformer decoupling, which in fact represents a remote inductive decoupling. It is used when overlapping between elements is not desired due to possible sensitivity overlap that affects the g-factor in accelerated imaging. The traditional transformer used in MRI coils is built out of inter-woven or adjacent inductors (Figure 1) sharing a common axis. One of the disadvantages of this type of transformer is the difficulty of adjustment of the coupling, dimensions and possible inductive coupling to other inductors in the MRI system. In this work we propose a transformer based on "RF Invisible" inductors shape [2] with adjustable inductive coupling strength and no self-inductance, which is very handy for MRI coil design and applications.

Theory

Let us consider a two-channel coil described by the matrix

$$\mathbf{Z}_{2element} = \begin{bmatrix} R_{11} + jX_{11} & R_{12} + jX_{12} \\ R_{21} + jX_{21} & R_{22} + jX_{22} \end{bmatrix} \quad (1)$$

where R_{11} and R_{22} represent the resistive losses in each channel, X_{11} and X_{22} are the reactances of the channels, $R_{12} = R_{21} = R_{2el}$ and $X_{12} = X_{21} = X_{2el}$ are the mutual resistances and reactances between channels. Ideally, in a tuned coil the self reactance is equal to zero $X_{11} = X_{22} = 0$. If the elements have strong coupling, $X_{2element}$ can be eliminated by using a transformer (Figure 1 or 2) that is also characterized by its own impedance matrix $\mathbf{Z}_{transformer}$

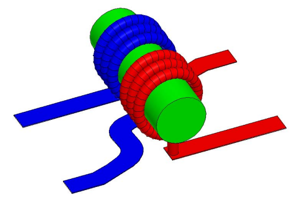

Figure 1. Traditional transformer used in MRI coils. "Red" and "Blue" sides are connected to coil elements with strong inductive coupling.

$$\mathbf{Z}_{transformer} = \begin{bmatrix} r_{11} + jx_{11} & r_{12} + jx_{12} \\ r_{21} + jx_{21} & r_{22} + jx_{22} \end{bmatrix} \quad (2)$$

where r_{11} and r_{22} represent the resistive losses in the transformer branches, $r_{12} = r_{21} = r_{tr}$ represents the mutual resistive losses, x_{11} and x_{22} represents the self-inductances of both branches of the transformer and $x_{12} = x_{21} = x_{tr}$ represents the mutual inductance of the transformer. When typical transformer decoupling is performed, mutual inductance of the transformer needs to be equal and opposite in sign with mutual inductance between the two channels $X_{2el} = -x_{tr}$. If the self-inductances of the transformer branches are canceled out by capacitors put in series, then by placing a transformer in between two independently tuned elements the impedance matrix will change to

$$\tilde{\mathbf{Z}}_{2elements} = \begin{bmatrix} R_{11} + r_{11} & R_{2el} + r_{tr} \\ R_{2el} + r_{tr} & R_{22} + r_{22} \end{bmatrix} \quad (3)$$

The transformer needs to be decoupled inductively and capacitively from other elements in the coil. This can be achieved through the double spiral shape utilized for building baluns and inductors [3,2]. Its flat topology is perfectly suitable for producing a printed circuit board (PCB) (Figure2 and Figure3).

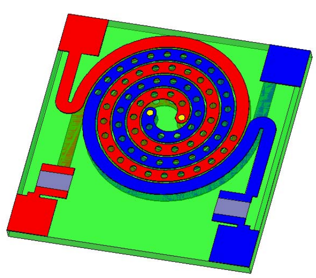

Figure 2. Tunable Adjustable Inductive Decoupling (TAID) Boards: the holes allow connection of the top and bottom spirals though a via. Vias positions are found for both branches of the transformer and the self-inductances are canceled out with in series placed capacitors.

Results

We have built several transformers in the new geometry, and used these transformers in coil arrays with strong coupling between elements. A spiral transformer was utilized for decoupling of the two 17x19 cm^2 loops with 3 cm gap between them (Figure 3). After inserting the transformer, isolation before preamplifier decoupling was turned on improved from –8dB to –20 dB for loaded coil and from –4dB to –22dB for unloaded coil.

Discussions and Conclusion

In a modern phased array coil, the coupling between elements can be removed utilizing transformers. The new transformer allowed flat geometry and adjustability of the mutual inductance, so the mutual inductance of the coil element can be exactly canceled. Its inductors have very well confined magnetic field been based on "RF Invisible" topology [2]. The transformer, however adds some resistive losses through its self-resistance and mutual resistance, but these losses are very small and do not affect the SNR. After individual coil elements are tuned, all capacitors preferably should stay fixed. However, when elements are turned on, the mutual coupling between elements will affect the performance considerably. It is convenient to add a transformer so that the tuning of the elements is not affected, but mutual inductance is removed. Having the transformer adjusted for necessary mutual inductance, previously measured from parasitic coupling between elements, and self-inductance cancelled out with series-placed capacitors, allows inserting the tuned transformer into the coil array without retuning the coil elements.

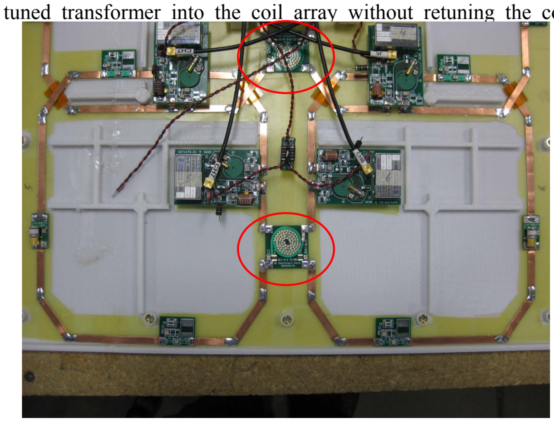

Figure 3. TAID board used for decoupling two elements with strong inductive coupling. It helped improve the isolation between elements from –8dB to –20dB when loaded and from –4dB to –22dB when unloaded.

References

1. Roemer et all, The NMR Phased Array, MRM 16, 192-225 (1990).
2. Taracila et all, RF-invisible inductors, ISMRM 2010.
3. Taracila et all, Six-layer stripline RF invisible balun, ISMRM 2010.