7T Coil Decoupling in Near-Magnet Power Amplifier

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Introduction: Mutual coupling between coil elements in parallel transmit array is considered a significant challenge in MRI applications. Induced current due to the interaction between elements disturbs the desirable independent control of current amplitude and phase in each coil element for RF-shimming purposes. In earlier studies on receive arrays, conventional decoupling techniques such as coil overlapping is used to minimize coupling between nearest-neighbor coils, and low input impedance preamplifiers are used to improve isolation between the non-nearest neighbors [1]. For Tx arrays, the concept of mismatched termination of coils by power amplifiers for coil isolation was proposed and a comparison was presented in [2]. This contribution presents an investigation of decoupling (isolation) performance by using the output impedance of the 1 kW power amplifier [3] designed for a 7 Tesla 32 channel near-magnet Tx array at the ELH Institute for Magnetic Resonance Imaging, Essen, Germany.

Methods and Construction:

The concept of decoupling by using a near-magnet power amplifier benefits from the close, "tuned" connection between the PA and the coil as shown in Fig.1, as a circulator in the transmit chain near the magnet is not feasible.

A meander coil with high-dielectric substrates [4] has been employed in our measurement as shown in Fig.2(a), which utilizes a quarter-wave transformer as the matching network with a planar balun as shown in Fig.2 (b). A measurement of coupling of a pair of pick-up coils close to the meander coil was made while terminating the coil with different types of load (open, short, 50 Ω) and in addition with the PA output (the PA powered but inactive).

The performance of PA decoupling has also been investigated by simulating two-coupled meander coils as seen in Fig.4, where the first element (on the left side) is fed by 1W accepted power while the second element (on the right side) is either matched terminated as in Fig.4(a) or terminated by the PA output reflection coefficient as in Fig.4(b). Numerical simulation was performed using a FDTD tool (CST Microwave Studio) by simulating two parallel aligned meander coils with 100 mm gap distance and 200 mm below a homogenous phantom ($\varepsilon_r = 45.3$, $\sigma = 0.8$ S/m).

The EM/Circuit Co-Simulation feature in Agilent ADS software which enables to combine results from EM simulation with large-signal circuit simulation, had served us in the design of the near-magnet power amplifier. This, in turn allowed us to study some properties of this power amplifier which are hard to study in lab, in particular the PA output large-signal reflection coefficient (Γ_{22}) by inserting an ideal coupler building block in the ADS amplifier schematic. In a first case the PA's input port is matched terminated (inactive mode) and a reverse power (P_{rev}) enters into the output port from an external source (emulating the coupling from a neighbor coil). In the second case the PA is activated and delivers power to load (P_{fwd}).

Results:

In Fig.3, we can see the coupling due to the PA termination to be close to the behavior of the open circuit termination. We can observe that the highest coupling occurs by short circuit (S.C.) termination as this permits the highest current to flow in the coil. The lowest coupling is seen by open circuit (O.C.) termination because infinite impedance in series with the coil impedance prohibits any current to flow. In Table.1, coupling results are normalized to the case of matched termination to produce a measure of "isolation" of coils from neighboring coils. As a result, we find the PA to allow an improvement of 18.7dB over the conventional 50Ω termination. Due to high coupling between the two meander coil elements (S_{21}=-9.61dB), in the case of 50Ω termination, strong induced current flows in the coupled element, producing strong magnetic field, as seen in Fig.4(a). Contrary, Fig.4 (b) shows a much smaller field around the coupled coil element when it is terminated by PA. Results of the PA circuit simulation in Fig.5 show the reflection coefficient (Γ_{22}) for PA remaining high, while the phase shifts when delivering power to a matched load or when receiving reverse power. Tables 2 & 3 show quantitative results of PA reflection coefficient for both cases where the output power of our PA is increased to its 1 dB saturation level of 1 kW while for the case of reverse power from the neighbor coils a lower power level of 200W is assumed as worst case.

Discussions

Results of measurements and simulations indicate that our PA can provide considerable isolation of coils in a Tx array when a tuned transmission line of quarter-wave plus N-times half-wave is used to feed the meander coil. However, the length of (lossy) cables should be limited in order to avoid reduction of the reflection coefficient which would lead to a reduction of the achieved isolation.

References: [1] Roemer et al, MRM (1990), pp.16:192-225, [2] N. Hollingsworth et al, Proc. Intl. Soc. MRM 22 (2014): 0547, [3] K. Solbach et al, Proc. Intl. Soc. MRM 22 (2014): 1287, [4] Z. Chen et al, EUCAP 7 (2013): 1716-1719.

Acknowledgement: The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. 291903 MRexcite.

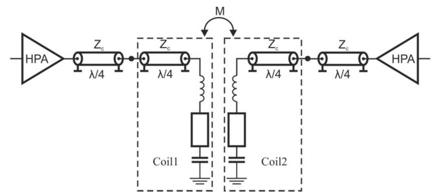

Fig.1: Schematic of two-coupled meander coils each connected to a near-magnet PA.

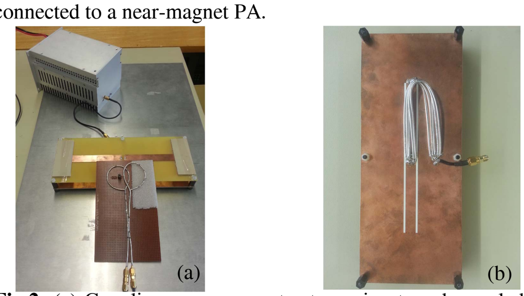

Fig.2: (a) Coupling measurement setup using two decoupled pick-up loops placed over a meander coil terminated by PA, (b) Planar balun and quarter-wave transmission line transformer.

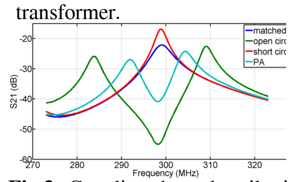

Fig.3: Coupling through coil with different coil terminations.

Termination	Isolation
O.C.	32.8 dB
PA.	18.7 dB
S.C.	-5.23 dB
50 Ω	0 dB

Table.1: Isolation measured for different types of termination.

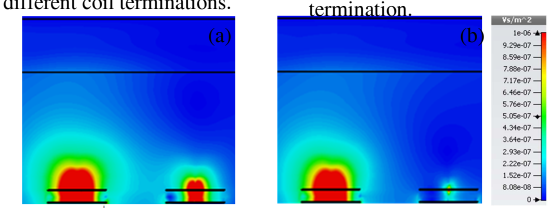

Fig.4: $|B_1^+|$ in mid-transversal section for coupled meander coils as seen in FDTD simulator. (a) The second element is matched terminated, (b)The second element is PA terminated.

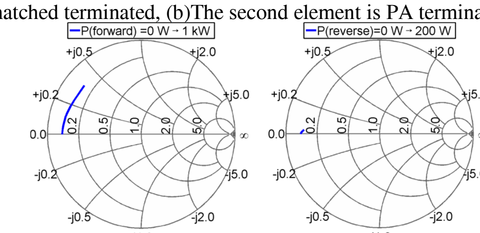

Fig.5: Simulated PA reflection coefficient (Γ_{22}) as function of (a) forward power, (b) reverse power.

P_{fwd}(W)	Γ_{22}
0	0.843/180°
100	0.840/176°
300	0.834/175°
500	0.827/167°
1000	0.797/140°

Table.2: Γ_{22} for active PA.

P_{rev}(W)	Γ_{22}
1	0.843/180°
50	0.839/180°
100	0.833/179°
150	0.823/178°
200	0.809/177°

Table.3: Γ_{22} for inactive PA.