Preliminary investigation on shielding-ring based decoupling technique for small monolithic RF coils

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Introduction: The use of small high temperature superconducting (HTS) coils based on monolithic design such as the Multi-turn Transmission Line Resonator (MTLR)[1] would be particularly attractive in a phased array configuration to achieve high SNR[2] over an extended FOV in high resolution MRI at intermediate field strength. However, decoupling small HTS coils still remains a challenge and limits the development of HTS arrays. Standard coil decoupling techniques such as geometric overlap or lumped capacitive decoupling are not suited for HTS MTLRs due to their monolithic double-sided design and the low intrinsic loss of HTS materials. Few decoupling techniques compatible with monolithic HTS coils have been proposed but all present some drawbacks such as a frequency dependent decoupling efficiency[3] due to the capacitive nature of the decoupling principle, a restricted range of application regarding the coil dimension[4] due to the limited decoupling flux amplitude achievable by decoupling annexes, a significant loss degradation[5] due to the use of solder joint, or the lack of a suitable model for decoupling optimization[6]. In this work, we further investigated the shielding ring based decoupling technique[6], which has been shown to be efficient for monolithic copper resonator but no studies on shielding ring configuration for optimal decoupling have been performed so far. We developed an analytical model based on magnetic flux compensation to determine the geometric configuration of two neighboring shielding rings to achieve optimal decoupling and we performed experimental validation of this model using a two-element array of copper MTLRs. Additionally, the effect of the shielding rings on the overall coil losses was evaluated using a standard two-coil array cooled at liquid nitrogen temperature.

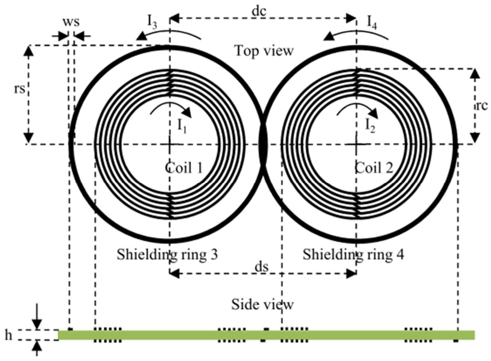

Figure 1 Shielded MTLRs geometric configuration

Methods: A MTLR consists of two conductive windings, each composed of N split rings connected in series, deposited on both sides of a dielectric substrate (thickness h) and works as transmission line with a differential mode current setting the resonance mode and a common mode current producing an external magnetic field. Fig.1 represents the schematic of two MTLRs (coils 1, 2) with external radius r_c, strip width w_c and inter-turn spacing a, separated by a center-to-center distance d_c. Both MTLRs are shielded by a conductive ring (rings 3, 4) with external radius w_s, strip width w_s and center-to-center distance d_s that are deposited on opposite sides of the dielectric substrate. For analysis, we consider I_1, in coil 1, to be the common mode current source, and I_2, I_3, I_4 represent the induced currents in each conductor with sign conventions defined as shown in the figure. Shielding ring 3 acts as a magnetic shield and current I_3 creates a flux (compensation flux) in coil 2 that is in opposite "sign" to the flux (coupling flux) in coil 2 created by currents I_1 in coil 1 and I_4 in shielding ring 4. The total flux through coil 2 is expressed as $\boldsymbol{\Phi_{total}} = |\boldsymbol{I_1} * |\boldsymbol{M_{21}}| + \boldsymbol{I_4} * |\boldsymbol{M_{24}}|| - |\boldsymbol{I_3} * |\boldsymbol{M_{23}}||$ with $\mathbf{M_{ij}}$: the mutual-inductance between conductors i and j. Optimal decoupling between coil 1 and coil 2 is achieved for $\boldsymbol{\Phi_{total}} = 0$. Investigation on shielding ring configuration for optimizing the decoupling performance was carried out using both numerical calculation to determine the fluxes through coil 2 and transmission scattering parameter (S_{21}) measurements to determine the achieved decoupling level. This was done by varying the distance d_s between centers of the shielding rings.

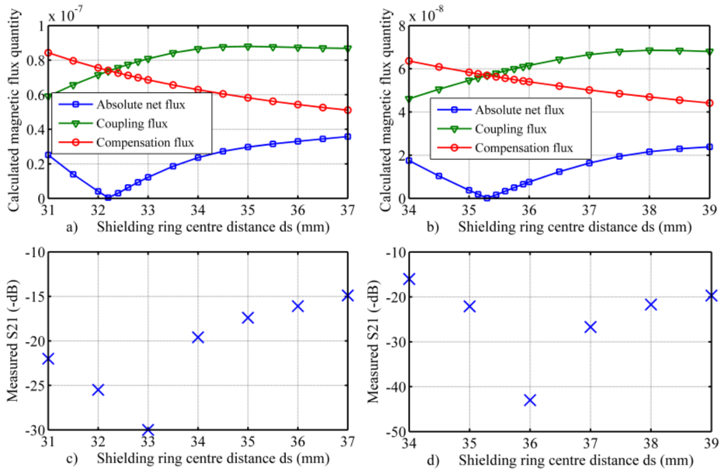

Figure 2 a, b) Calculated flux quantities as function of ds of configurations 1, 2; c, d) Measured transmission coefficient S21 as function of ds of configurations 1, 2.

Results: Results presented in Fig.2 were obtained for two different configurations of MTLR and shielding ring: (1) r_c = 15 mm, w_c = 0.5 mm, a = 0.5 mm, N = 6, h = 1.5 mm, d_c = 35 mm, r_s = 17.75 mm, w_s = 0.5 mm. (2) r_c = 15 mm, w_c = 0.5 mm, a = 0.5 mm, N = 6, h = 1.5 mm, d_c = 37.5 mm, r_s = 20 mm, w_s = 1 mm. Fig.2-a and b show the calculated magnetic fluxes for configurations 1 and 2 respectively. The calculated optimal decoupling is obtained for shielding ring distances close to the ones determined from the S_{21} measurements (Fig.2-c and d). A decoupling level of < -15 dB is achieved even for shielding ring distances strongly deviating from the calculated optima. Table 1 presents Q-factor values of a RLC coil either isolated or surrounded by a shielding ring both at ambient and liquid nitrogen temperatures. The presence of the shielding ring decreases the Q-factor by about 20% regardless of its initial value, while the decoupling performance is preserved in both two conditions.

Conclusion: The proposed model allows one to determine a shielding ring configuration that achieves near-optimal decoupling in agreement with experiments without the need for full wave EM simulation. The deviation between calculation and measurements may be related to the insufficient accuracy of inductance calculation and could be minimized by employing a more accurate inductance calculator, especially for non-standard coil geometries. The shielding ring based decoupling technique and the proposed model can be extended without restriction to MTLR arrays with an arbitrary number of elements. Since this decoupling technique does not introduce an absolute Q-factor limitation but only a relative one, employing HTS material for fabricating both the MTLRs and the shielding rings should allow for preserving the intrinsically high Q values of HTS coils and thus achieving high SNR performances in parallel imaging.

Table 1 Unshielded/shielded Q values of a RLC coil at ambient/liquid nitrogen temperatures with the corresponding S21 value.

330 K			77 K		
$Q_{unshielded}$	$Q_{shielded}$	S_{21} (dB)	$Q_{unshielded}$	$Q_{shielded}$	S_{21} (dB)
200	160	-25	485	390	-21

References: [1] Serfaty S et al., *Mag Reson Med*, 38(4), 1997. [2] Darrasse L et al., *Biochimie*, *85*(9), 2003. [3] Wosik. J et al., *Appl Phys Lett*, 91(18), 2007. [4] Kriegl. R et al., *Mag Reson Med*, *DOI 10.1002*, 2014. [5] Wosik. J et al., *ISMRM*, 2004. [6] Lanz. T et al., *ISMRM*, 2006.