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Design of optimal low-frequency NMR detection coils

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Introduction: The signal-to-noise ratio (SNR) in NMR measurements notoriously depends on the filling factor and Q-factor of the coil, and on the matching to the low-noise amplifier (LNA). At low frequency, the length of wire in multi-layered coils is not limited and impedance matching to 50Ω is not needed. Instead, noise matching to a high-impedance LNA is important.¹

Aim: We designed PU coils to optimise SNR while achieving sufficiently uniform sensitivity maps. The solenoid-like coils surround ~2-cm³ rectangular cells for diffusion measurements of hyperpolarized ³He gas in ordered Al₂O₃ aerogels² with different constraints on their maximum size.

Methods: The principle of reciprocity conveniently relates the average magnetic field per unit current B/I (computed using the Biot-Savart law) and the emf induced by the sample. At low frequency, the thermal noise is dominated by coil losses and scales as (R_{AC})^{1/2} with the AC coil resistance. A SNR factor B/I/(R_{AC})^{1/2} is therefore computed for arbitrary coil geometry and wire parameters.

Results: SNR factors and sensitivity maps only depend on coil dimensions, not on wire diameter. A broad optimum is found for coil length and winding thickness; moreover, the SNR decrease for more compact coils is easily evaluated (Fig. 1a). The coil sensitivity maps are fairly uniform over a wide range of dimensions (Fig. 1b). Two coils with the same bore and different outer dimensions were made, and tuned near 42 and 84 kHz (Q~100). With 1.4-mm-diameter and 0.75-mm-diameter litz wires the tank circuits were suitably noise-matched to a SR560 LNA.¹

Conclusion: The PU coils were used in different set-ups, with measured SNRs consistent with expectations. This generic low-frequency optimisation approach can be used for multi-coil systems as well, e.g. for rejection of interference noise.

¹ V.V. Kuzmin and P.-J. Nacher, *J. Magn. Reson.* 310 (2020) 106622.

² H. Loutfi et.al., this conference.

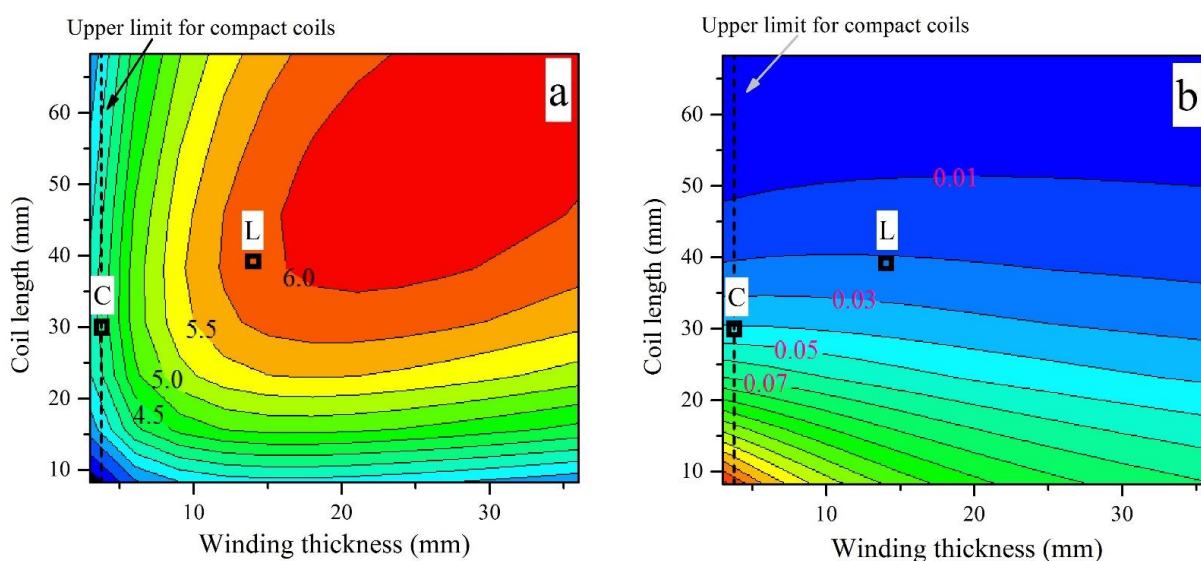


Fig. 1 2D maps of a: the coil SNR factor $B/I/R_{AC}^{1/2}$ and b: the standard deviation of coil sensitivity, for coils with rectangular bore $21.5 \times 24\text{mm}^2$. The symbols mark the parameters of the tested compact (C) and large (L) coils.