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Resonant and non-resonant coupled-wire coils for small-animal multinuclear imaging

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Synopsis

Metasurface coils coupled with an unmatched loop were suggested earlier as an alternative to classical surface and volume coils, with the aim to optimize volume and sensitivity. We developed a new approach combining a commercial surface coil and a non-resonant coupled-wire structure. With this approach, the signal contribution from the driving loop can be efficiently added to that of the wire surface. The configuration was simulated, built and tested for ^1H and ^{19}F at 7T. The results showed that this new strategy improves the coil's sensitive volume while simultaneously maintaining high SNR.

Introduction

Commercial MR coils can be divided in two categories: volume and surface coils. Volume coils such as birdcage coils [1,2] offer large sensitive volume, but low SNR [3]. In contrast, surface coils present higher sensitivity, resulting in high SNR [4]. Tradeoff between large FOV and sensitivity has been targeted in earlier works on metamaterial RF coils coupled with a non-matched loop [5,6,7]. This configuration presented so far the best compromise between SNR and sensitive volume [7]. Nevertheless, a small surface coil [8] still provided the highest SNR. Therefore, the aim of this work was to investigate if advantages can be obtained by combining both strategies. We propose an elementary structure consisting of two parallel wires with adjustable length to switch between resonant and non-resonant regimes. We hypothesized that beyond their use in resonant regime, such structures can be used off-resonance and driven by commercial coils.

Methods

Three cases of coils were analyzed as single channel transmit-receive antenna for proton and fluorine imaging. Numerical simulations were carried out (Figure 1) to study the current distribution in the coils and their spatial B_1 distribution.

Case (a): surface coil (loop with a matched circuit), case (b): resonant coupled-wire coil (non-matched loop with two wires of length L_0) and case (c): non-resonant coupled-wire coil (matched loop with two detuned wires of length $L < L_0$) were simulated.

Prototypes of the simulated combinations of coils were built and tested for proton and fluorine with a phantom and *in vivo* using a Bruker PharmaScan 7T MR system. A commercial ^1H birdcage coil was included in the experiments as additional reference for proton imaging.

Results

Figure 1D shows the maximum of the current amplitudes in the loop (red curve) and the coupled-wire structure (blue curve) in function of the wires length. Figure 1E shows the spatial B_1 distribution on the horizontal axis. It can be seen that the highest B_1 magnitude depends on the loop current while the enlargement of the sensitive volume depends on the wire current. Case (c) benefits from both contributions, resulting in a wide FOV and a high sensitivity.

SNR maps and profiles of the phantom are shown in Figure 2. As expected from the numerical predictions, case (c), featured a notable enlargement of the sensitive volume compared to the surface coil alone (case (a)) while keeping a high SNR.

According to Figure 3, the coils showed a similar SNR distribution for fluorine as for proton. Figures 4 and 5 show the results of the *in vivo* experiments for ^1H and ^{19}F , respectively and proved that the behavior of the coils remained consistent in *in vivo* situations.

Discussion

The numerical studies show that when using a case (b) coil, the contribution of the loop is reduced due to the extremely low current flowing in it, resulting in a low B_1 . On the contrary, the current in the wires is almost constant, leading to a wide FOV.

Note that an attempt to benefit from both contributions by combining a matched loop with a resonant coupled-wire structure would be impeded by the strong mutual coupling [9]. To mitigate this and still benefit from both contributions we proposed a new approach combining a detuned coupled-wire structure with a surface coil (case (c)). This strategy allowed us to increase the loop current without strongly modifying the current within the wires, resulting in a coil with higher sensitivity and large FOV.

The simulation results were validated experimentally on a phantom and on mice *in vivo* imaging. The obtained results perfectly corroborate the numerical predictions from Figure 1. As expected, case (b) has a homogeneous but low SNR. Case (c) preserves the high SNR of the surface coil, but a significant enlargement of the sensitive volume can be clearly seen, particularly *in vivo*.

Conclusion

Coupled-wire structures can be used as RF coils in both resonant and non-resonant regimes. The chosen regime will affect the current amplitude distribution within the coil and therefore the spatial distribution of the B_1 field. Experiments on phantom and *in vivo* confirmed the numerical predictions by coupling a carefully detuned coupled-wire structure with a commercial surface coil. It was further demonstrated that coupled-wire coils provide enough SNR to obtain ^{19}F images at low concentrations. We believe that such structures bring a new and flexible alternative to the design of versatile RF coils, with the aim to mitigate the conventional trade-off between FOV and SNR.

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Figures

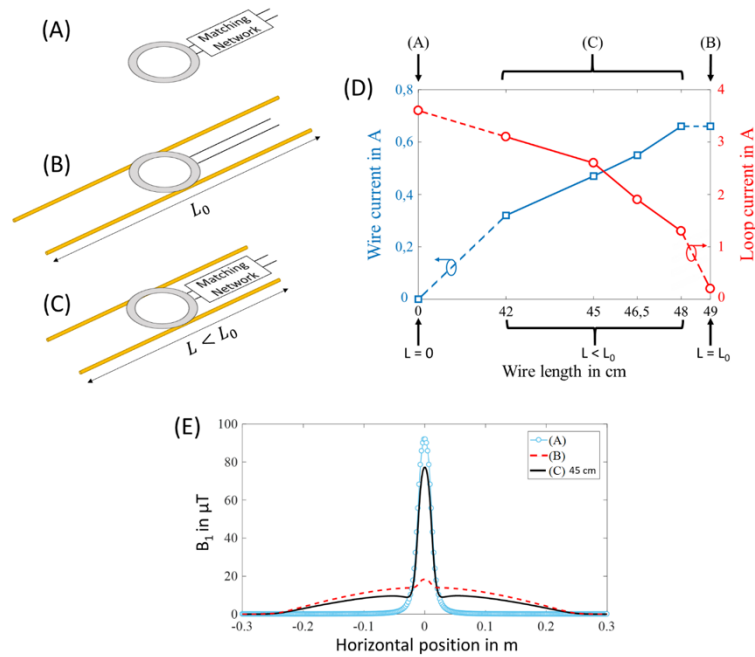


FIGURE 1: Numerical analysis of: (A) surface coil with a matching circuit, (B) resonant coupled-wire coil conformed by two wires with length L_0 coupled with an unmatched feed loop and (C) non-resonant coupled-wire coil that combines a matched surface coil with two wires of length $L < L_0$. Each configuration of the coil was tuned and matched to 300 MHz. (D) shows the plot of the current amplitudes in the loop (red) and in the wires (blue). (E) shows the B_1 profiles obtained along a horizontal line along the wires at 1 cm above the wire plane.

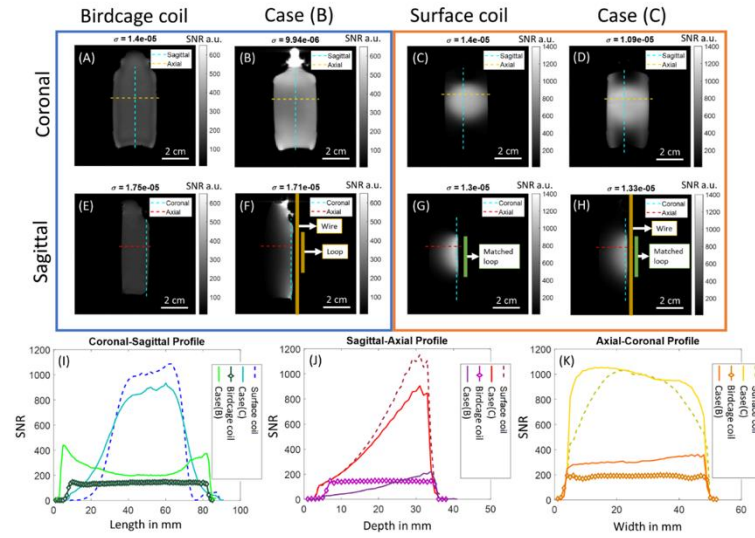


FIGURE 2: SNR maps in gray scale with coronal and sagittal orientation of the phantom. The dash lines locate the profile cuts. (A),(E) birdcage coil; (B),(F) case B; (C),(G) surface coil; (D),(H) case C. (I) Coronal-sagittal profiles obtained from the cyan line. (J) Sagittal-axial profiles obtained from the red line. (K) Axial-coronal profiles obtained from the yellow line. Noise standard deviation is given on top of each map.

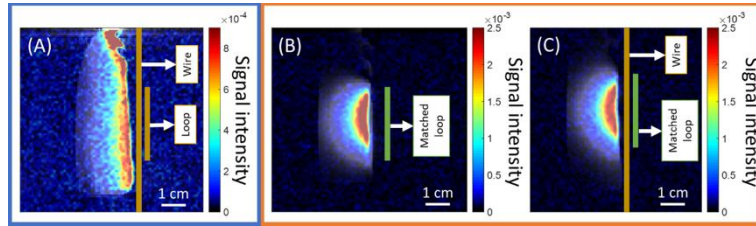


FIGURE 3: ^{19}F T₂-turboRARE-3D images of the phantom in jet color map acquired with: (A) case B ; (B) surface coil and (C) case C in sagittal orientation. The images were overlaid on top of ^1H FLASH images in gray scale.

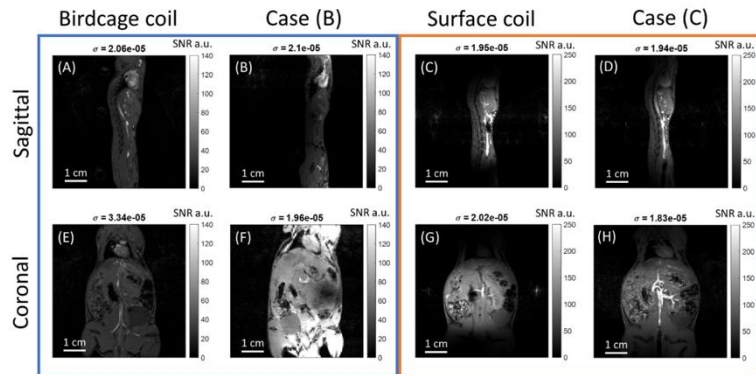


FIGURE 4: *In vivo* ^1H SNR maps. Sagittal and coronal-plane images with: (A), (E) birdcage coil; (B), (F) case B; (C), (G) surface coil and (D), (H) case C.

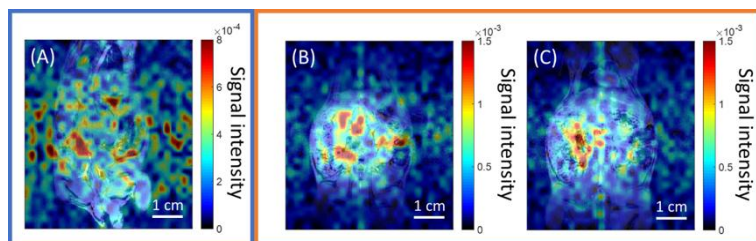


FIGURE 5: *In vivo* ^{19}F FLASH coronal-plane images in jet scale obtained with: (A) case B; (B) surface coil and (C) case C. The images were overlaid on top of ^1H FLASH images in gray scale.