

SNR and B1 Homogeneity Analysis of Intra-Vascular/Cavity RF Coil Designs

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Introduction

High spatial resolution vessel/cavity wall MRI requires a signal-to-noise ratio much higher than can be achieved using external phased array coils, so intravascular RF coils are used directly adjacent to the vessel of interest. Standard loop-style probes can achieve high SNR with suitable longitudinal coverage ($\sim 10\times$ coil diameter) but the B1 sensitivity falls off rapidly ($\sim 1/r^3$) with radial distance, r , from the loop [1]. More uniform designs have been proposed. The loopless antenna [2] has good SNR and longitudinal coverage, but still only moderate radial homogeneity ($1/r$), whereas the opposed solenoid design [3,4] has near ideal homogeneity, but very low SNR when it is designed for full longitudinal coverage. Here we investigate other intravascular coil designs using counter-rotating current concepts [5] and compare SNR as well as both radial and longitudinal homogeneity properties to existing designs.

Methods

B1 sensitivities were simulated quasistatically using Mathematica (Wolfram, IL) and experiments were performed on a Siemens 3T Trio-Tim MRI system. The receive-only probes were constructed at a 1.5cm diameter and 8 cm longitudinal coverage (MRI usable length) and inserted into an agar gel phantom. Image homogeneity was assessed using spin echo images (TR/TE=300/15 ms, 192x192 matrix, 5 mm slice thickness, 250 mm FOV).

Results and Discussion

We compared SNR and B1 homogeneity for the following designs (Fig. 1a): Birdcage (BC), Long and Short Opposed Solenoid (OS), Multi-Turn Crossed Loop (MCL), Concentric Birdcage (CBC). The region-of-interest is azimuthally symmetric, located a distance of 1-radius from the coil surface to a distance of 2-radii (53-61 in Fig. 1b,c), but with a longitudinal coverage of 10-radii. Fig. 1b compares simulated radial SNR for a transverse cross section of each coil design, matching experimental results. Although the opposed solenoid can be designed to achieve good radial and azimuthal homogeneity when the separation of the solenoid's are 4-radii (Short OS), the SNR is already lower than the Birdcage, and the longitudinal coverage is not adequate. When the opposed solenoid is designed to the specified longitudinal coverage, meaning that the solenoids are separated by 10-radii, the SNR is very low (Long OS). Based on the orthogonal solenoid design [6], we investigated an extended coverage version using a multi-turn crossed loop (MCL) (Fig. 1a), which has similar SNR and longitudinal coverage to the birdcage, but also enables forward-looking capability [6]. Fig. 1c compares transverse radial SNR for different birdcage modes. Mode $m=1$ produces the best overall SNR with good azimuthal symmetry, and better radial homogeneity than higher order modes ($m=2-4$). New concentric birdcage designs were investigated for improving B1 homogeneity while retaining high SNR. Concentric $m=1$ birdcages of different radii and opposed current shown in Fig. 1a (CBC), produce moderately high SNR and good longitudinal coverage, and radial B1 homogeneity (Fig. 2a,b) similar to the opposed solenoid (Fig. 2c,d) but not azimuthally symmetric (Fig. 2a), in fact homogenous B1 is only achieved along 6 narrow projections associated with 6 symmetric signal nulls (Fig. 2a). The $m=1$ birdcage mode falls off less rapidly than the higher order modes, so we investigated using a higher order mode as the opposed current smaller radius portion of the concentric birdcage design, but because different modes have different phase distributions, the azimuthal asymmetry was also not adequate (Fig. 2e).

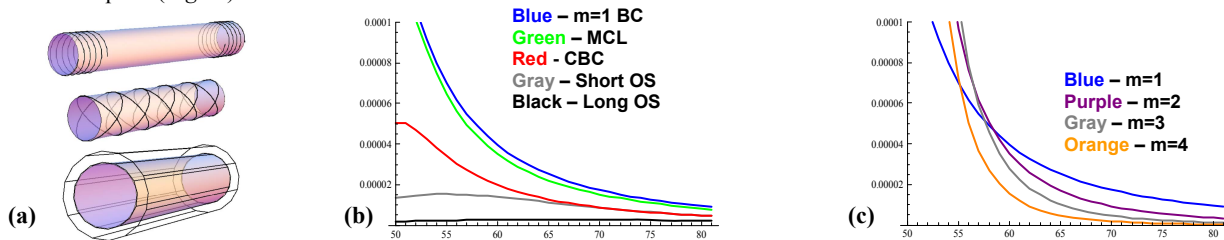


Fig. 1: (a) Long Opposed Solenoid (top), Multi-turn Crossed Loop (middle) Concentric BirdCage (bottom); (b) Radial B1 sensitivity; (c) Radial sensitivity of birdcage modes.

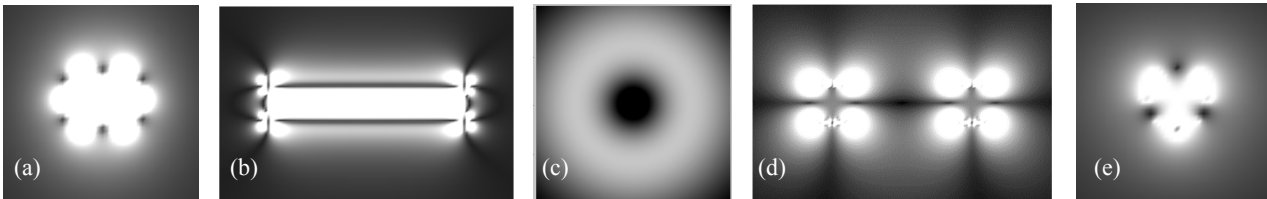


Fig. 2: 2D B1 sensitivity for: $m=1$ Concentric Birdcage (a) Transverse, (b) Sagittal; and Short Opposed Solenoid (c) Transverse and (d) Sagittal; (e) Transverse 2D B1 for $m1-m4$ Concentric Birdcage

Conclusions

Some new designs for intra-vascular/cavity style RF coils have been presented that have good SNR characteristics, and to varying degrees achieve good B1 homogeneity and longitudinal SNR coverage suitable for vessel wall or cavity MRI. Concentric birdcage designs are interesting in that they maintain the longitudinal SNR coverage, but also demonstrate some radial homogeneity albeit with azimuthal asymmetries that may not be ideal. Multi-turn crossed loops are another good design retaining the forward looking capability and orientation independence previously reported [6], but now with good longitudinal SNR coverage. These designs may offer alternatives to the low SNR opposed solenoid design.

References

- [1] Susil et al, MRM 50:383-390 (2003); [2] Ocali et al, MRM 37:112:118 (1997); [3] Martin et al, JMRI 2:421-429 (1992); [4] Hurst et al, MRM 24:343-357 (1992); [5] King et al, MRM 42:655-664 (1999); [6] Anderson et al, MRM 60:489-495 (2008).