A Microstrip Resonator Volume Coil Optimized for Full-Body Rat Imaging at 9.4T

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Introduction

The microstrip resonator volume coils have proven useful for imaging animals from rats to rhesus monkeys at fields from 3T to 4.7 T. These coils terminate the inner strips through capacitors directly to the cylindrical shield instead of an end-ring. The benefits of this design include good field homogeneity, especially in the transversal plane, good signal-to-noise ratio (SNR), and a field-of-view (FOV) extending beyond the edge of the coil. The rat-sized (72 mm ID, 105 mm shield diameter, 102 mm long) volume coils have been demonstrated by us to operate at frequencies as high as 500 MHz (^{1}H at 11.7 T) [1]. However, several issues limited the usability of these coils at these frequencies. The most prominent effect is excessive loading by the animal body, resulting in a large frequency shift from the unloaded to the loaded condition and the inability to properly tune and match the resonator for full-body imaging. Other issues included excessive coupling with the cable shield and inconvenient tuning rod attachment.

This paper presents a microstrip resonator design optimized for full-body rat imaging at 400 MHz (^{1}H at 9.4 T). The coil constitutes a complete mechanical and RF redesign that rectifies the shortcomings of previous generation of microstrip volume coils. The coil is simulated and optimized using a custom multi-conductor transmission line (MTL) model. Preliminary imaging results are presented.

Methods

For this work, the MTL model [2] is modified to include a lossy cylindrical load. The MTL model treats the strips and shield as a coupled transmission line system with wave propagation along the *z*-axis, and treats the remaining elements as lumped. It is possible to approximate the effects of a load, including eddy currents, by modifying the differential equations used to compute the transmission line parameter matrices **L**, **R**, **C** and **G**. The mathematical details of these modifications are relegated to a future publication.

Simulation

The previous generation microstrip coil was optimized for maximum SNR in transmit-receive configuration by maximizing the B_1 field produced by the unloaded coil. At 9.4 T, the heavy loading reduces the impact of unloaded coil efficiency, but presents a new challenge of achieving a clean resonance when loaded. Thus, the new coil was designed with a lower filling factor to help achieve good, tunable resonance. The number of strips was kept at 8 as in the previous design. The quadrature field homogeneity of an 8-strip coil is excellent when using optimized strip width, and SNR performance is predicted to drop slightly with additional strips. Table 1 lists the dimensions and parameters of the first and second generation microstrip coils and compares their performance at 9.4T using a cylindrical load that approximates a rat body. Figure 1 presents the simulated linear and quadrature field profiles for the new coil.

Construction

An entirely new microstrip coil construction method was developed to accommodate the additional capacitive breaks in the strips as well as solve several other problems. Figure 2 shows a rendering of the internal layout of the new coil. The strips are now placed on the outer surface of the inner cylinder (as opposed to the inner surface in the previous generation). Additional features made possible by this layout are integrated low-loss, balanced-to-unbalanced transformers (baluns that reduce stray cable shield currents) and a robust, stress-relieved tuning rod attachment.

Imaging Results

Initial imaging tests were performed on phantoms (polyethylene container filled with silicone oil, Aldrich # 290718; dimensions: OD = 70 mm, Length = 85 mm). Figure 3 presents axial and sagittal images (RARE sequence with TR=2s, TE=13.8ms, no averaging, 128x128 matrix, 10 cm [axial]/12 cm [sagittal] FOV, and 2 mm slice thickness) and compares the results with those of a stock volume coil (Bruker model Bio PRK 400 EPI Res 112/72). The measured SNR was 225 with the new coil and 184 with the stock coil. The transmitter attenuator settings were 18.4/12.4 dB (90°/180°) for the new coil and 14.1/8.1 dB for the stock coil. We note that the new coil operates in quadrature, while the stock coil is linear.

Conclusions

A new microstrip resonator volume coil was designed and optimized for full-body rat imaging at 9.4T (^{1}H). The new coil suffers a lower frequency drop when loaded and is much more robust in operation, but retains the performance of the previous generation microstrip coil. Initial imaging results reveal excellent field homogeneity, large FOV for full-body imaging and SNR above that of the stock volume coil.

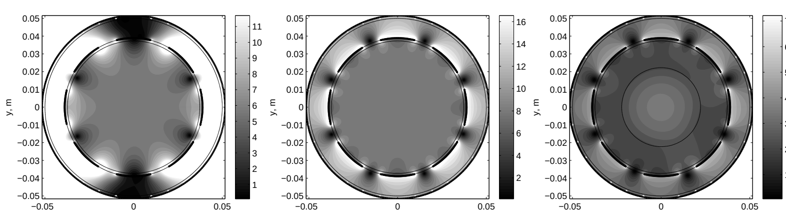
References

[1] Fisher T, Bogdanov G, Ludwig R. "An RF microstrip resonator for imaging at 11.7T." 11th ISMRM, 2003.

[2] Bogdanov G, Ludwig R. Magn Reson Med 2002; 47:579-593.

Table 1. Simulation of 1st and 2nd gen. microstrip coils at 400 MHz.

	1st gen. coil	**2nd gen. coil**
Parameters		
ID, mm	72.5	77.8
OD, mm	105.0	103.2
Length, mm	101.6	114.3
Strip width, mm	17.8 (62.4%)	20.0 (65.4%)
Simulation: unloaded		
C, pF	4.6 (2 breaks along strip)	12.7 (4 breaks along strip)
±1 dB B_1 (linear) ∅, mm	47.8	51.0
±1 dB B_1 (quad) ∅, mm	64.5	69.1
Q	323	454
B_1 (linear), $\mu T/\sqrt{W}$	6.32	5.90
B_1 (normalized), $\mu T/\sqrt{Q \cdot W}$	0.352	0.277
Simulation: 44.5 mm cylindrical load, $\varepsilon_r = 50 - 30j$		
Frequency shift, MHz	–8.83	–5.00
Q	27.0	37.1
B_1 (linear), $\mu T/\sqrt{W}$	2.79	2.52
B_1 (normalized), $\mu T/\sqrt{Q \cdot W}$	0.536	0.414



(a) (b) (c)

Figure 1. Simulated cross-sectional B_1 field: (a) linear, (b) quadrature, (c) loaded.

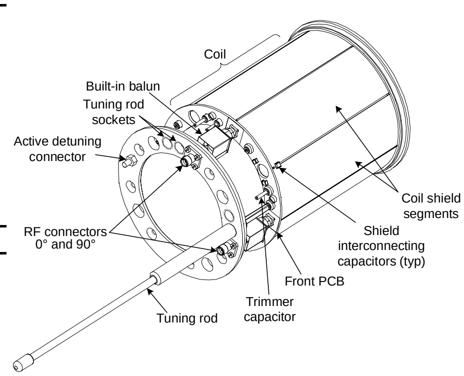


Figure 2. Layout of 2nd gen. microstrip coil.

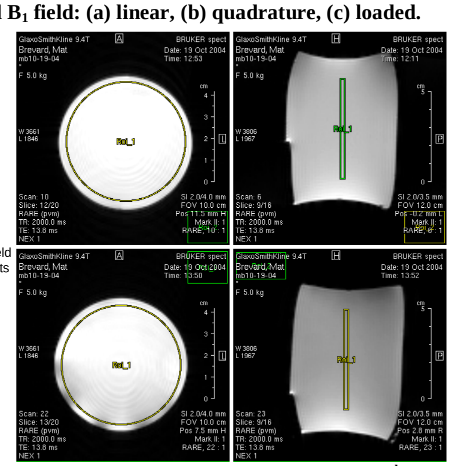


Figure 3. Initial imaging results: top – 2nd gen. microstrip coil, bottom – stock Bruker coil.