Frequency Limits and Radiation Resistance for Volume Coils

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Synopsis: To investigate the operational frequency and efficiency ranges for high field head coils, three unloaded RF volume coils were modeled by the Finite Difference Time Domain (XFDTD) method. Rung capacitance and radiation resistance were calculated versus the transverse mode resonant frequency for low pass configurations of a birdcage, a shielded birdcage, and a transmission line (TEM) resonator. Simulation results predict that practical birdcages are frequency limited to less than 200 MHz operation by radiation resistance and / or inductance, whereas the TEM resonator of the same size can achieve an operational frequency of 400 MHz.

Objective: To predict the practical frequency limits of three common head coil structures based on self resonance and efficiency calculations.

Background: Magnet technology now provides for human head MRI at 3T, 4T, 7T, and even 9.4T, and for unprecedented gains in SNR. Which coil designs will resonate, and perform most efficiently at these ultrahigh field strengths? A numerical approach toward answering this question is outlined below.

Methods: Unshielded birdcage [1], shielded birdcage [2], and TEM [3] structures were modeled, and the numerical Maxwell solutions were calculated for these models using a commercial XFDTD package (Remcom, State College, PA). All three coils had identical dimensions (27cm i.d. x 25cm long), and all were open on both ends. Lumped capacitive elements were centered on each of the four rungs for each model. These capacitances were changed to tune the resonant frequencies of the coils, as in realized coil circuits. To determine the point at which a coil reaches self resonance, rung capacitance versus the resonant frequency associated with the transverse B_1 field mode was calculated for each of the three low pass structures shown in Figure 1. The coil approaches self resonance as the series rung capacitance approaches zero. The results were plotted in Figure 2a. To quantify the amount of energy lost to radiated fields, the radiation resistance "$R_r = 2P_r / I_m^2$" versus resonant frequency was calculated for each coil structure. "P_r" is the radiated power and "I_m" is the maximum current in the coil.[4]

Figure 1. Coil Models

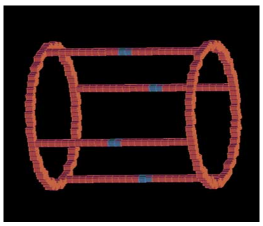

Fig. 1a: Unshielded Birdcage

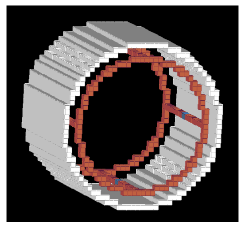

Fig. 1b: Shielded Birdcage

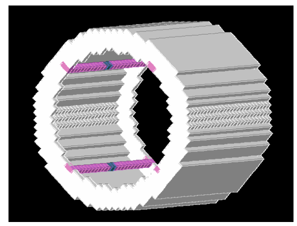

Fig. 1c: TEM Resonator

Results: By the results in Figure 2, the unshielded birdcage head coil as modeled reaches self resonance before 300MHz (7T). The same coil will not reach 200 MHz with the smallest practical capacitance of 1pf in each rung according to the model. If the unshielded birdcage were used at 200MHz, radiation losses of 70 ohms would severely degrade its efficiency. By shielding the birdcage however, the radiation losses are dramatically reduced, making the birdcage significantly more efficient. However, the high inductance of the birdcage shielded or unshielded, continues to limit its operational frequency. Because the TEM coil is shielded and is less inductive than the birdcage, its useful range as a full sized human head coil approaches 400MHz (9.4T). This prediction agrees with empirical results. [5] For the larger body coils, the curves plotted in Figure 2 will shift to the left, such that radiation resistance and self resonance will likely limit coil performance for birdcages at 3T and 4T proton frequencies. Future models will include high pass and band pass coil configurations, more rungs, larger dimensions (body coils), and human load conditions.

Figure 2. Model Results

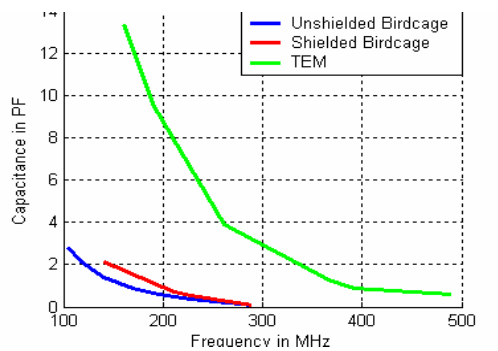

Fig. 2a: Capacitance vs. Frequency for 3 Coils

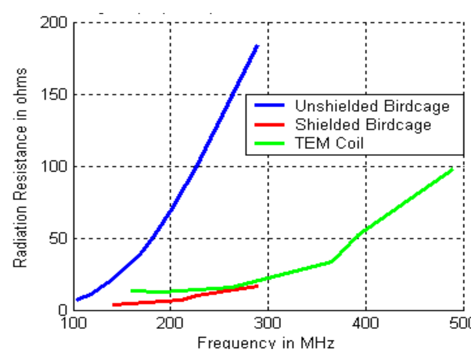

Fig. 2b: Radiation Resistance vs. Frequency

Conclusions: For the head coil structures modeled, the following predictions were concluded.

1. Unshielded birdcages are frequency limited to less than 200 MHz by inductance and radiation resistance.
2. Shielded birdcages are frequency limited by inductance to less than 200 MHz.
3. The TEM resonator is useful to approximately 400MHz.

References:

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2. Roemer PB and WA Edelstein, *Double-Sided RF Shield for RF Coil Contained within Gradient Coils of NMR Imaging Device.* US Patent Number 4, 879, 515, 1989.
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4 Vaughan, JT, G Adriany, M Garwood , et.al., *A detunable TEM volume coil for high field NMR.* Magn. Reson. Med., 2002. **47**(5): p. 990-1000.
5. Zhang, N, MS Roos, JT Vaughan, et. al. *Head coil B_1 field inhomogeneity and SNR performance at 8-10T. Proc. of the Fourth Annual Meeting of the ISMRM.* 1996.

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