3D Simulation Technique to Obtain Input Impedance and Frequency Response of Empty/Biologically Loaded RF Coils with Experimental Verifications

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Introduction: The ability to accurately predict the input impedance of an MRI RF coil, and therefore its frequency response, is crucial for implementing phased array excitation in high field MRI applications. This paper provides a new method utilizing the finite difference time domain (FDTD) technique and a numerical coaxial feed implementation to calculate these quantities. The provided results demonstrate the accuracy of the proposed method to predict the coil's characteristics, both empty and loaded, in a wide bandwidth that includes the coil's standard operating mode.

Methods: A model of an actual ultra-high field TEM head coil [1] was developed and simulated with FDTD. In the simulations, the coil was tuned by adjusting the gap between the tuning stubs, as done in experiment. Both the numerical and physical coils were tuned such that the mode of operation lied at approx. 330.5 MHz. The structures of both of these coils are shown in Figure 1. The transmission line coaxial feed was modeled using a proprietary algorithm and used to excite the sixteen ports that comprise the coil in the 3-D FDTD domain. After injecting the transmission line with an excitation source with sufficient frequency content within the coil's operational bandwidth, the resonator's transfer function (representative of its input impedances) was obtained by comparing the spectrum of the excite signal to that of the received signal from the coil during operation. These studies were performed numerically and experimentally (using a network analyzer) for an empty coil, a coil loaded with a live volunteer's head, and a coil loaded with a spherical phantom (approx. 18 cm in diameter) filled with saline that, using the Debye theory [2], provides constitutive properties equivalent to approx. 78 for the dielectric constant and 1.15 S/m for the conductivity at 330 MHz.

Results and Discussion: Figure 1 provides a comparison between the return loss of the TEM coil obtained from experiments (using a network analyzer) and simulations (using the transmission line/FDTD scheme). For the simulations, the coil was tuned to 330.5 MHz (mode 1) while loaded with the spherical phantom; the corresponding input impedance calculated at this mode was 54.87 Ohms. The actual impedance using the same spherical load at mode 1 was experimentally measured to be 58.79 Ohms. For the coil loaded with the head, while the results provide excellent agreement with experiment in terms of return loss, comparison of the calculated input impedance to measurements shows some variation. This is clearly expected due to 1) the difference between of the head model and the live subject head and 2) not including the shoulders in the head model. Finally, Figure 2 provides the calculated return loss and associated Smith chart corresponding to excitation from all 16 struts with the human head loaded at modes 0 and 1. Note that while mode 1 tunes to nearly the same frequency in all 16 struts, the load impedance as seen from each strut varies, verifying experimental measurements of ultra-high field MRI loaded coils.

Conclusions: The results presented verify the ability of the simulated coaxial transmission line feed with coil grids to accurately predict the frequency response and input impedance of an MRI coil, both empty and loaded. This creates new avenues that bridge numerical simulations and experimental phased array excitation techniques, and can lead to the use of numerical simulations in guiding RF shimming in 7 and 9.4 Tesla MRI.

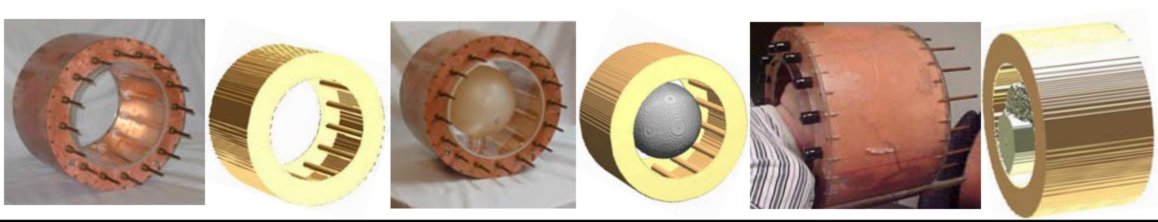

Fig. 1: Actual and simulated TEM coil, shown empty *(two left figures)*, loaded with a sphere *(two middle figures)*, and loaded with the human head *(two right figures)*.

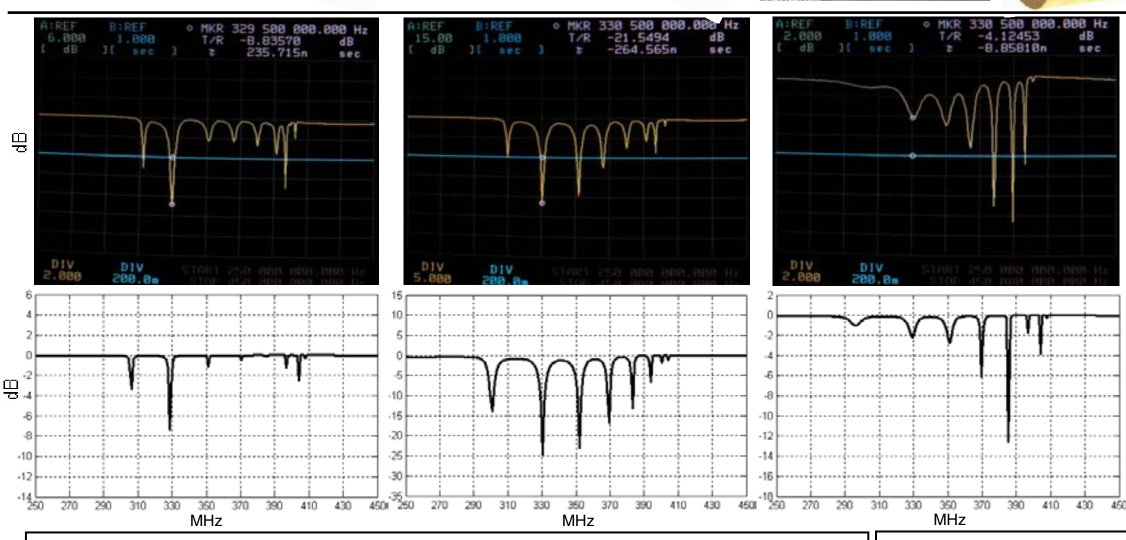

Fig. 2: *Top Row:* Experimental results showing the return loss of the TEM resonator obtained using a network analyzer. *Bottom Row:* Simulated results of the return loss obtained using the proposed transmission line/FDTD method. *Column 1:* Coil with no load; *Column 2:* Coil loaded with spherical phantom; *Column 3:* Coil loaded with human head (left-most strut excited).

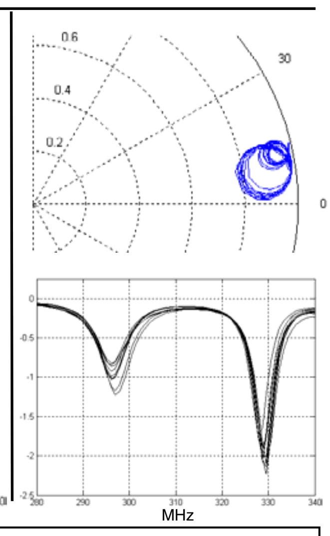

Fig. 3: Simulated Smith chart *(top)* and return loss *(bottom)* from 280 MHz – 340 MHz (containing modes 0 and 1) corresponding to excitation from all 16 ports, with the human head loaded in the coil.

References: [1] Vaughan, J.T., et al. *Magn .Reson. Med.,* vol 32, pp 206-218, 1994.

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