Analytical Analysis of the Nuclear Magnetic Resonance Signal with Experimental and Numerical Validation

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Ever since MRI was introduced as a medical diagnostic tool, there has been a constant drive towards operating at higher frequencies. There are many advantages to operating at higher frequencies, including the potential of exquisite resolution, reduced scan time, and increases in signal to noise ratio. At the same time, however, MRI at higher frequencies add significant technical complexities to the NMR experiment including difficulties in fabricating suitable RF coils. Understanding the source of the MR signal is a must in order to design a robust high-performance RF coil that can be utilized for high-field imaging. In this work, an analytical approach based on the principle of reciprocity for driving the NMR signal is presented with experimental and numerical validations at 8 Tesla (340 MHz).

An analytical model using the principle of reciprocity was developed to calculate the received signal in MRI. The analytical model was realized for general RF transmit and receive coils' geometries. To verify the analytical model, an experiment was conducted using an 8 Tesla clinical system. A 16-strut capped TEM resonator loaded with an 18.5 *cm* sphere filled with 0.5 *mM Gd DTPA* and 0.125 *M NaCl* was used. A nominal 90^o flip angle was defined for a 1 *cm* voxel near the isocenter of the phantom using *STEAM* voxel spectroscopy. Magnitude images for 18 flip angles were obtained and subsequently fit pixel by pixel such that the transmit and the receive fields were experimentally extracted.

For the numerical analysis, a 3D FDTD model was developed such that the RF coil (TEM resonator) and the phantom were modeled as a single system. This approach permits the electromagnetic interactions between excitation source and the sphere, which are easily observed form the results obtained in this study, to be rigorously included. The coil was numerically tuned by adjusting the gap between the TEM stubs until any of the modes of the TEM resonator is resonant at the desired frequency of operation.

An excellent agreement between the experiment and the simulated results was achieved. The results demonstrate the effectiveness of the developed FDTD model and the need for the rigorous modeling of the excitation source. It is concluded that optimizing both the transmit and the receive fields is necessary to achieve homogeneous and high signal to noise image. Therefore, it is imperative to design the transmitter and receiver coils accordingly.