Excitation of a TEM Mode in a Birdcage Resonator

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Introduction:

RF coils are an integral part of an MR-imaging system. The one of the most common types of RF coil used in MR is the birdcage resonator [1]. Another type of coil that has been gaining popularity is the so-called TEM resonator [2,3]. Though both birdcage and the TEM resonators produce uniform magnetic field inside the resonator, the operation and the design strategy for these resonators is very different. As the frequency of operation of MR has been increasing steadily over the years, the dimensions of the components of the birdcage resonator are becoming comparable to the wavelength of the electromagnetic waves inside the resonator. As a result the excitation of the TEM resonator modes in a shielded birdcage resonator becomes a more common occurrence. In this abstract we present such a case where an unwanted TEM mode is excited in a birdcage resonator. Fullwave simulation results to help identifying the problem and the remedy for the situation are also presented.

Methods:

The coil used in the experiment is the 7T Knee with a frequency of operation of approximately 300 MHz, designed by Invivo Corporation. The coil is a 16 rung birdcage with the end-rings placed outside of the shield. The shield near the rungs consists of 1/8″ diameter copper tubes, see figure 1. The one port reflection coefficient (S11) measurement using an HP8753 network analyzer, showed the expected mode distribution and the desired mode was tuned to the correct operating frequency. When an excitation was applied a uniform magnetic field was observed inside the coil as expected. But when a saline phantom was inserted in to the coil, the mode structure changed dramatically. The S11 measurement revealed that as the phantom was inserted into the coil an unknown mode with a lower quality factor (Q) moves in from higher frequency down to close to the frequency of operation of the coil. To gain insight into the problem a set of fullwave simulations were performed using Ansoft HFSS; a frequency domain simulation tool based on finite element method (FEM). We have chosen to use an FEM based simulator because of the extremes in length scales involved in the problem. The flexibility in grid sizing offered by the FEM simulator can be utilized, and thus an order of magnitude improvement in simulation time was achieved compared to the FDTD simulation.

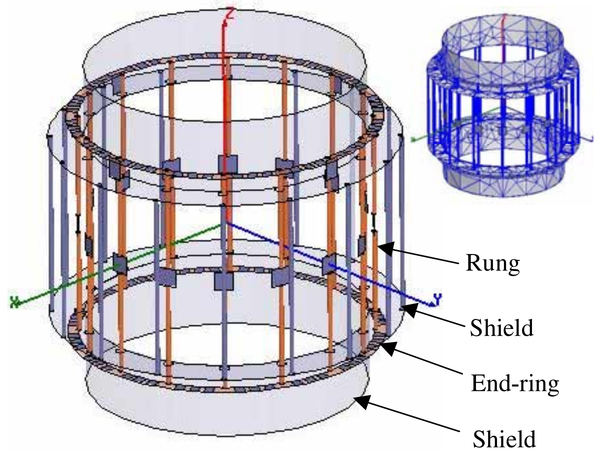

Figure 1) 7T Knee Coil (inset: mesh used in simulation).

Results:

The model of the coil and the mesh used in the simulation is shown in figure 1. The S11 without phantom (figure 2a) and the H-field profile (figure 2b) matched the measured data, thus establishing the validity of our model. The simulated S11 with phantom (figure 2a) also showed the unwanted lower Q mode. The fact that the unwanted mode appears when the phantom is inserted indicates suggest it to be a TEM mode, as the wavelength inside the phantom is smaller. The simulated H-field profile of the unwanted mode (figure 2c) confirms this fact and also identifies this mode to be the fundamental mode of the TEM resonator [3]. The reason this mode is excited is that the distance around the loop formed by the rung and the grounded copper rods outside the rung is comparable to a wavelength. This demonstrates the fact that it is easy to excite a TEM mode in a birdcage coil at high frequency. One must ensure not to excite this mode, because it disrupts the magnetic field homogeneity. Furthermore unlike the desired birdcage mode the electric field inside the coil does not fall off rather uniformly. As a result it may cause potential problems regarding power dissipation and SAR. To prevent the excitation of this mode, appropriate capacitors were added in the grounded copper rods thus pushing the resonant frequency of the unwanted mode to a sufficiently higher frequency so that there is no coupling in to this mode. In this mode the currents in all the rung are at the same phase, so a half wavelength coaxial cable was added between the diagonally opposite drive-points to force a quadrature drive which is the correct mode of driving for the desired birdcage mode but not for the unwanted mode. Both of these techniques when implemented in the coil prevented the excitation of the fundamental TEM mode with and without the phantom.

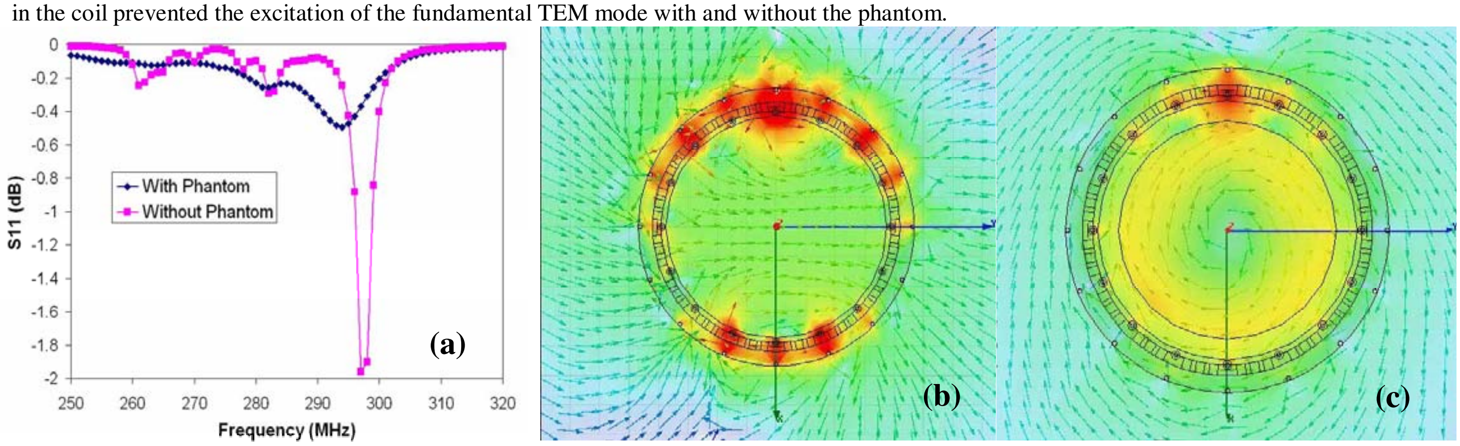

Figure 2. a) The simulated reflection coefficient, b) simulated H-field profile without phantom, and c) simulated H-field profile with phantom.

References:

[1] Hayes CE, et al. J Mag Res **63**, 622-628 (1985) [2] Vaughan JT, et al. MRM **32** (2): 206-218 [3] Bridges JF, U.S. Patent 4,751,464 (1988)