Current Distribution in a Large Volume Coil at 11.1 Tesla

B. L. Beck[1], R. T. Goldberg[2], J. R. Fitzsimmons[1,2]

[1]Brain Institute, University of Florida, Gainesville, FL, United States, [2]Radiology, University of Florida, Gainesville, FL, United States

Introduction

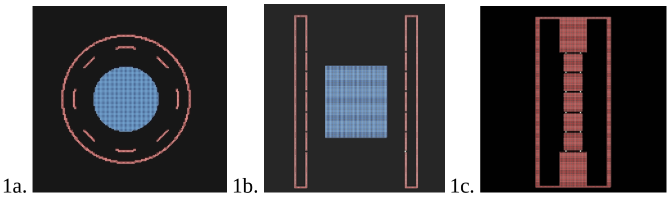
Severe B1 inhomogeneities have been observed in large samples at 11.1T[1]. These inhomogeneities may be caused by wave behavior within the sample, as well as, non-ideal current distribution in the coil. The ReCav[2] coil generates a homogeneous B1 field in its MR useful mode when a sinusoidal current distribution exists around the legs of the coil. Interaction between the coil and the sample may cause a disturbance to this sinusoidal distribution. If the disturbance is great enough, a homogeneous B1 field will not be generated. On the other hand, if a sinusoidal current distribution is maintained, but a severe B1 homogeneity is present, it can be concluded that the inhomogeneity is due to wave behavior in the phantom and not a disturbance of the currents in the coil. This work employs Finite Difference Time Domain (FDTD) simulation to study the current distribution in a large ReCav coil at 470MHz, loaded with a large cylindrical phantom. The electrical characteristics of the phantom are varied from low-dielectric/low-conductivity to high-dielectric/high-conductivity.

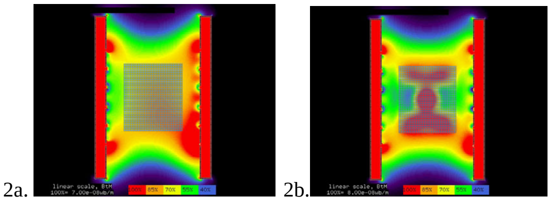
Methods

A ReCav volume coil for 11T was modeled using the XFDTD software package (Remcom Inc. State College, PA). Figure 1 shows the geometry of the coil and the cylindrical phantom. The conductivity and permittivity of the phantom were either $\sigma = 0.00016$ S/m and $\varepsilon_r = 2.0$ (oil) or $\sigma = 0.67$ S/m and $\varepsilon_r = 48.6$ (average brain at 470 MHz[3]). The coil has an inner diameter of 20.5 cm, outer diameter of 24.5 cm, and shield length of 35.5cm. The legs of the coil span a length of 24.5 cm, are 3.5 cm wide, and have two parallel capacitors at each of six breaks. A 2.5mm Yee-cell[4] size was used, and the simulation space was 200x200x240 cells. For the oil phantom, 160,000 time-steps of 4.81 ps were performed, and for the brain equivalent phantom, 35,000 time-steps. The coil was tuned by exciting the quad ports with a Gaussian pulse and observing the real and imaginary parts of the impedance versus time. At resonance, the real part of the impedance is high and the imaginary part is zero. Steady state field magnitudes and current densitites were sampled. Current densities around the coil legs were plotted for the last two cycles. In addition, the current densities in the legs at a single point in time were plotted. Spin echo images were acquired of a cylindrical phantom having electrical properties of average brain tissue at 470 MHz. The electrical characteristics of the phantom were verified with an HP85070C dielectric probe. The images were acquired in an 11.1T Magnex magnet with Bruker Biospec console.

Results

Figure 2 shows the magnitude of the magnetic field for different electrical properties of the cylindrical phantom. The phantom in Fig 2a. has the electrical properties of oil. The field is fairly homogeneous. In Fig 2b, the phantom electrical properties are those of average brain at 470 MHz and severe signal voids are seen with bright areas in the middle and ends of the phantom. Figure 3 is an image of the cylindrical phantom filled with the brain equivalent solution. The image shows a field pattern very similar to the simulation shown in Figure 2b. Figure 4 shows the current density in all eight legs of the ReCav for the last two cycles of the simulations. A 45˚ phase shift can be seen from leg to leg. Figures 5a and 5b show a sampling of the current density in all eight legs at one point in time. Figure 5a is for the oil phantom and 5b the brain equivalent phantom. A sinusoidal current distribution is seen in both plots. Interestingly, there is a 90˚ phase shift between the two phantom conditions.





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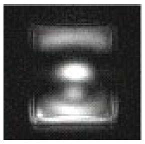

Fig 1 Geometry of ReCav; a)axial plane, b) sagittal plane, and c) leg geometry showing parallel capacitors at each break.

Fig 2 Magnitude of transmission field for, a) oil phantom, and b) tissue equivalent phantom.

Fig 3 MR image of tissue equivalent phantom acquired in 11T magnet using ReCav coil.

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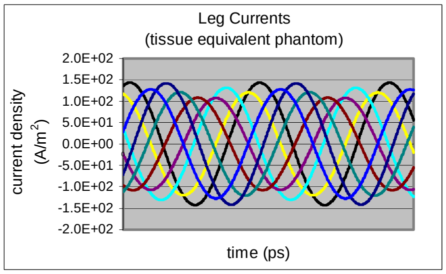

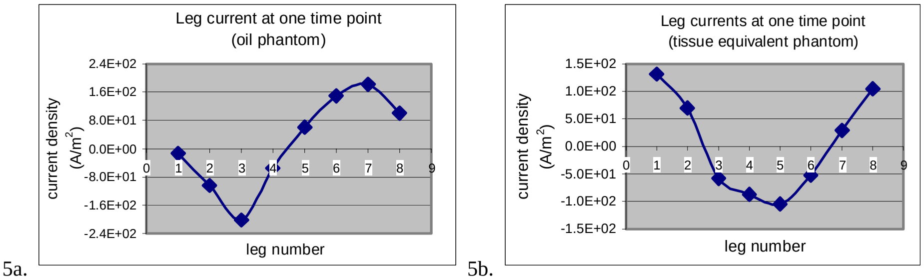

Fig 4 Current density of all eight legs of ReCav for last two cycles of simulation, showing 45˚ phase shift from leg to leg.

Fig 5 Current density (A/m^2) in legs of ReCav at one point in time for, a) oil phantom, and b) tissue equivalent phantom.

Conclusions

B1 inhomogeneities have been demonstrated on large phantoms at high frequency. It is possible that these inhomogeneities are due to a severe disturbance of the ideal current distribution of the coil. In the case of the ReCav, sinusoidal current distribution around the legs of the coil generates a homogeneous B1 field. We have demonstrated a sinusoidal current distribution and homogeneous B1 field in a ReCav loaded with a low dielectric, low conductivity phantom (oil). We have also demonstrated that a ReCav coil loaded with a large tissue equivalent phantom maintains a sinusoidal current distribution, but suffers severe B1 inhomogeneities. Therefore, the inhomogeneous B1field generated is due to wave behavior in the phantom and not a severe disturbance of the current distribution in the coil. These B1 inhomogeneities have been verified with magnet experiments. Generating homogeneous B1 fields in large structures at high frequencies is a current challenge for the rf coil engineer. Simulations, based on FDTD methods (and others, such as MoM), are a powerful ally to the rf coil engineer.

References

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