An 11 cm, 500 MHz, Hybrid Birdcage with Improved Tuning Range

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Abstract

RF Circuit Model

Since the low-pass capacitors C1 are quite large compared to the high-pass capacitors C.E, behavior shows an rf circuit model for the 8-section Hybrid BirdCage coil model is somewhat better than one previously used in that the runs are represented by a short transmission line at each end (TRL) with balanced couplings (L.B) between adjacent runs. Most of the losses are represented by appropriate attenuation coefficients in the TRLs and series reactances in the segments (L.E) and tuning capacitors (C.E).

For circular polarization (CP) operation, coil symmetry is quite critical especially for small loads and sample detuning often exceeds the tuning range of simple approaches.

Figure 2 shows an rf circuit model for the 8-section Hybrid BirdCage coil. A simple method of doing this is to connect a low-loss half-lambda transmission line between nodes 17 and 57 and another between nodes 37 and 77 (not shown here). This sometimes brings in additional complexity for the homogeneous mode, but small inductors from the center points (quarter-lambda points) to ground on these phasing lines generally solve this problem.

Figure 3(a) shows the coil geometry (sans external rf shield, sample, and matching elements) as simulated using full-wave EM software by Computer Simulation Technology (CST, Darmstadt, Germany), MWS 5.1. It consists of 8 sections with two parallel runs per section. The capacitors, represented in the figure by chamfered disks, are connected between sections and also in series with the runs to give a hybrid or bandpass configuration. At all locations, two parallel 1 kV ATC chip capacitors are used, one at each edge of the conductor foil, as shown. The sections in the rungs are centrally shorted. The coil is fabricated from 0.06 mm copper foil on teflon substrate 0.5 mm thick and mounted on the outside of a polycarbonate column which is 1.5 mm thick. The coil diameter is 110 mm and the external slotted rf shield diameter is 142 mm. The end-ring is 11.25 mm wide and the inside distance between the end rings is 90 mm.

The Software

We carried out preliminary evaluations of three commercial electromagnetic simulation tools about 18 months ago before concluding that CST MWS 5.1 had a number of advantages for our mix of rf problems, which includes small-animal MR rf coils, solids NMR spectroscopy rf coils, high-resolution NMR spectroscopy sample coils, and high-field MRI head coils. We also found its geometry construction tools and interface to be powerful and easy to use.

This CST code is based on a discretized solution of the integral formulation of Maxwell's equations; hence, the method is referred to as a Finite Integration Technique (FIT). To solve these equations, a finite calculation domain is defined enclosing the application problem. A structured Cartesian mesh is created for half of the field equations (R and D), and a second Cartesian mesh, offset by half the element size in each direction from the first mesh, is created for the other half of the field equations (H and D). The use of two offset meshes greatly reduces discretization errors.

Finally, we note that a weakness of the software is the quality of the documentation for applications such as these, which can lead to a longer learning curve than would initially be expected from simple test cases. However, when the essential settings, options, methods, nomenclature, and techniques are properly understood, the software displays impressive versatility, power, and accuracy. Another current weakness is the time required for some runs which involve high-Q structures containing small features. The subgridding feature is expected to be working more robustly within a few months, which should then permit much faster runs.

The Coil Structure

Table 1 shows some experimental data for the coil and also summarizes some simulated results for these cases, including central B1 in µT for 0.5 W excitation, from CST MWS 5.1. (Note that the NMR-effective B1, as listed, is one-half the peak field calculated for linear polarization, as linear polarization is equivalent to the sum of two oppositely rotating circular polarization fields, one of which is rotating in the wrong direction to induce NMR precession.) For consistency with recent trends we are reporting the simulated Q of the resonator (including the sample and all losses), Q.C, which is half the isolated Q, Q.I, that has more often been used in NMR SNR analyses. Interestingly the simulated B1 field with the small saline load is about 65% higher than that for the unloaded case, whereas with the large saline load it is 20% higher than that for the unloaded case. The simulations indicated the coil retained good symmetry over the tunable range, but experimental symmetry was, at least initially, less than expected.

Images were acquired from this coil at Washington University. Figure 5 shows the image of a baboon brain collected using a fast spin echo sequence. Central brightening due to dielectric resonance effects of clearly evident in this image.

Conclusions

The high accuracy of the CST MWS 5.1 code in predicting the applied node frequencies and B1 from a physically accurate model of the coil provides a very high level of confidence in its calculated fields and rf efficiencies – hence, S/N.

An improved tuning range is obtained with good channel isolation using this fraction hybrid design with 4-point drive. For heavy loads, the dielectric resonance effect dominates, resulting in central brightening in the image. The somewhat asymmetrical experimental intensity for the heavily loaded case is not yet understood, and the impedance transformations in the matching network also require further study.

REFERENCES


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