Session Title: RF modeling

Speaker Name: Bei Zhang, Translational & Molecular Imaging Institute, Icahn School of Medicine at Mount Sinai

Highlights

- RF modeling plays an important role in RF coil design for high-field MRI due to the interaction (which can be vividly illustrated through RF simulation) between the RF coil and the object
- RF modeling provides numerical analysis of full-wave behavior in the RF system; the typical numerical analysis methods are method of moments (MoM), finite element method (FEM) and finite difference time domain (FDTD), and there are commercial software packages based on these methods
- Accurate RF modeling helps bridge the gap between theory and reality, and allows the assessment of different coil designs prior to construction and can predict their performance in practice

Title: RF modeling for RF system in MRI

Audience: MR researchers and clinicians who want to learn RF modeling principles and methods for MR

Outcome/Objectives: Attendees will learn the basics RF modeling methods, be able to choose one suitable method according to their needs, and also learn how to set up conditions for accurate RF modeling.

INTRODUCTION: The basic set of equations describing the electromagnetic world is Maxwell's equations, and these have two forms: integral form and differential form. Combining them with appropriate boundary conditions and using numerical analysis methods to solve the Maxwell's equations for specific real-world problems is RF modeling. Some typical numerical methods are Method of Moments (MoM), Finite Difference Time Domain (FDTD) and Finite Element Method (FEM), and the relationships of these methods and Maxwell's equations and their advantages and disadvantages are shown in FIG. 1.

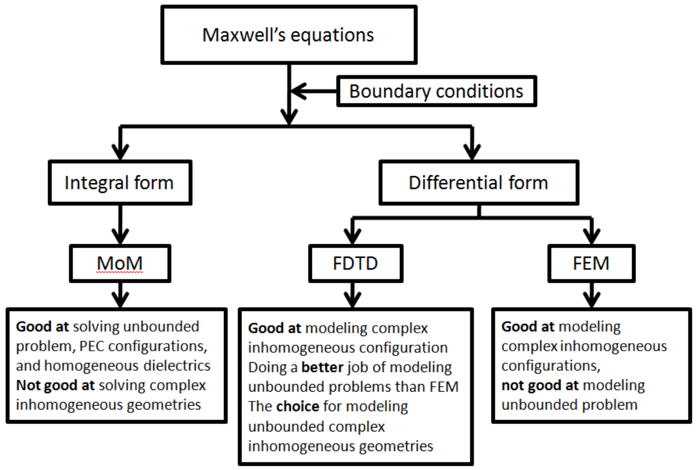

Figure 1 Flow chart of solving Maxwell's equations and the advantages and disadvantages of the numerical methods

Considering that the MRI RF system is an inhomogeneous system, and previous work shows that the radiated power is very small in the MRI system, usually FDTD and FEM method are used. A commercial package for the FEM method is Ansoft HFSS, and commercial packages for the FDTD method include CST Microwave Studio, Semcad and xFDTD. Previous work shows that HFSS and CST can provide comparable results for coil design and SAR estimation at 7T MRI. Therefore, the software selection also depends on user interface, software stability, affordability and personal preference.

No matter which method is used, numerical methods can closely approach but never exactly match physical reality. This is because the gridding methods of the numerical analysis cannot perfectly outline the shape of the system, and even if the gridding can be designed to be very close to the shape of the system, the cost is long simulation time and large storage space. Therefore, balancing the simulation accuracy, storage space and simulation time is important. In the course, we will discuss methods to balance these factors.

Moreover, most of these commercial packages provide RF circuit and electromagnetic co-simulation. The big advantage to co-simulation is that the system can be tuned and matched easily in the circuit simulator, and the tuning and matching can be directly applied into the 3D field simulation result, thus reducing the amount of simulation time needed. But usually the number of variables is more than the number of constraints. Therefore, the results can be different. In the course, we will show different results due to the change of different variables.

Furthermore, these commercial packages provide idealized voltage or current source driving methods, however, since the electrical field is usually high at the positions of ports and capacitors due to the electric potential different at these positions, accurate modeling is the key to bridge the gap between the simulation and experiment. In the course, we will show simulation results when using different driving sources. Normally, the packages are noise free environment; therefore, it is hard to acquire quality factor (Q factor) of a coil in simulation. In the course, we will compare the Q factor of an experimental loop with and without load and conductivity and resistance of the lumped elements as should be set in simulation in order to get a comparable Q-ratio in experiment.

At the end, an advanced MRI RF system modeling example will be provided, and simulation results, such as S-parameters, SAR distribution, system efficiency, Q-ratio, and the like, will be presented.

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