Application Sheet

FEKO

Comprehensive Electromagnetic Solutions

RF Design and Safety of MRI Systems

Introduction

Electromagnetic simulation software has become an indispensable tool in the development and analysis of magnetic resonance imaging (MRI) systems. The health industry's demand for higher image resolution, improved signal to noise ratio (SNR) and reduced scan times, motivates the challenge to design systems that operate at higher static (B_0) field strengths. The increase in static field strength implies a proportional increase in the B_1 field frequency. As the wavelength becomes comparable to the electrical size of the patient and the MRI geometry, it becomes increasingly more difficult to achieve a homogeneous field distribution required for good image quality.
The increase in operating frequency also has implications for patient safety. Since the conductivities of the tissues are proportional to the frequency, the tissue is more susceptible to absorbing electromagnetic energy at higher frequencies. The close proximity of transmit arrays to the body can result in higher absorption of the radio frequency (RF) energy in the body.

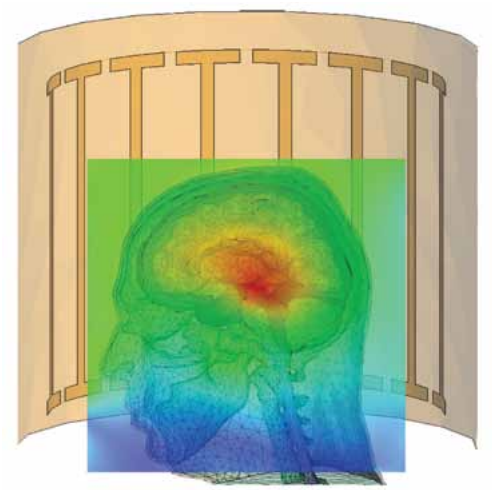
FEKO offers several ideal methods for the investigation into aspects of MRI system design and safety. By using FEKO, the researcher is provided with a virtual test bench to explore new concepts critical to the advancement of MRI technology.

RF Coil Design, Parallel Imaging Performance and RF Shimming

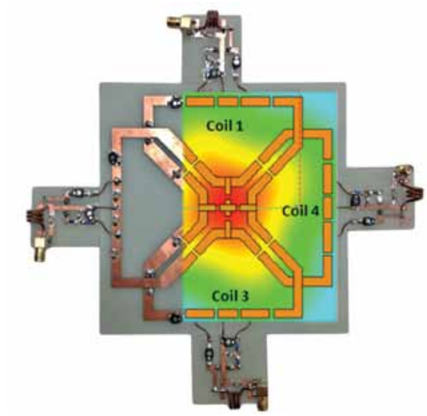
FEKO is used in the design of surface and volume coils to predict the field homogeneity, coil coupling, SNR and coil safety accurately. The integrated optimisation engine can be used to automatically adapt the coil geometry and tuning capacitors to achieve resonance frequency, specific absorption rate (SAR) and B_1 field goals. This can be especially useful for high Tesla systems where field and coupling interactions tend to be more complex and an automated optimisation is ideal as a design approach. For example, when designing surface array coils, FEKO can optimise the overlap distance to minimise mutual inductance between elements.

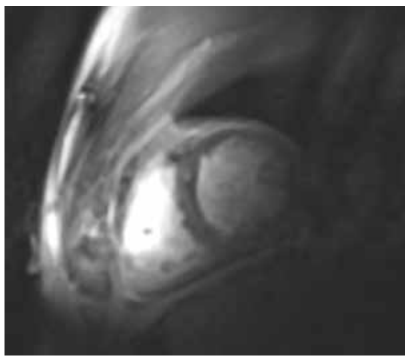
The fundamental resonance frequency for birdcage coils can be established by performing a frequency sweep. Tuning capacitor values are calculated accordingly to adjust the resonance to the desired Larmor frequency. A matching network can then be designed for the feed system using the direct interface with the Optenni Lab software. Optenni Lab offers automatic matching circuit generation for single and multiport systems with arbitrary topologies, as well as tolerance analysis of the circuit components.

Surface or volume coil arrays are commonly used to improve SNR. By reducing the area of a coil, less noise is received. Parallel imaging takes advantage of the spatial information offered by the array to reduce image acquisition time. FEKO can be used to evaluate the field distribution for the array to determine the SNR and applicable acceleration factor. The adjustment of the drive magnitude and phase of the different coils in

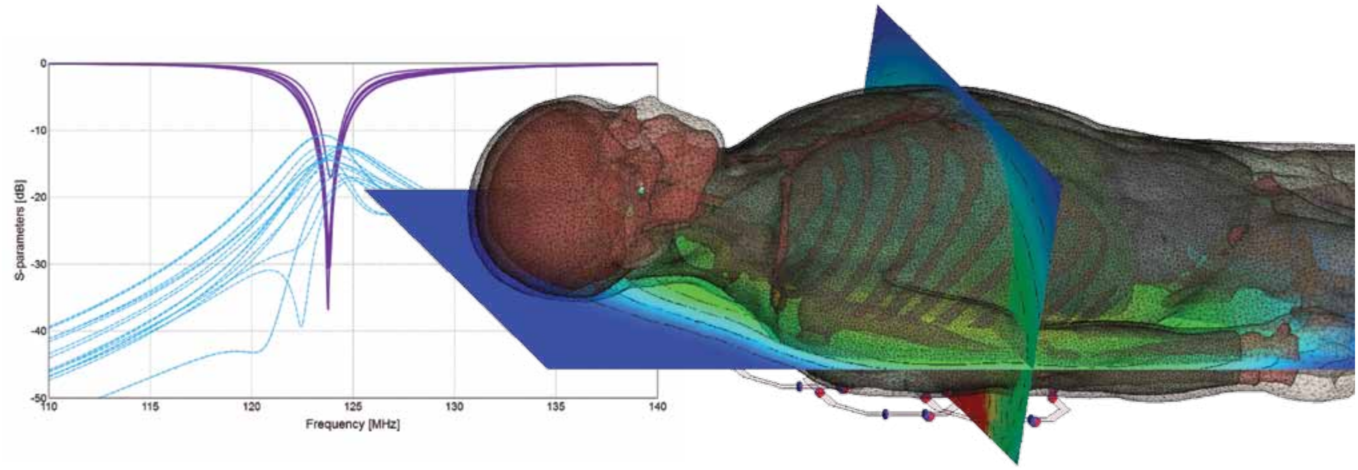


A low-pass MRI coil (7 T) and phantom showing B_1+ field distribution in the region of interest (ROI), simulated with hybrid MoM / FEM. The head phantom (provided by humanbodymodels.com, a Simpleware product) has an average tetrahedral size of 6.3 mm





A four-element cardiac transceiver designed with FEKO, with an overlay of the simulated magnetic field at 123 MHz (top). An image of a subject's heart that was acquired with this coil (bottom) [1]



A seven-element surface array coil for spinal imaging simulated with the hybrid MoM / FEM method. The array is tuned and matched at 3 T and the spacing is optimised to reduce coupling between elements. The anatomical phantom (provided by humanbodymodels.com, a Simpleware product) contains 13 different tissues and is meshed with 1.36 million elements with an average size of 8.3 mm

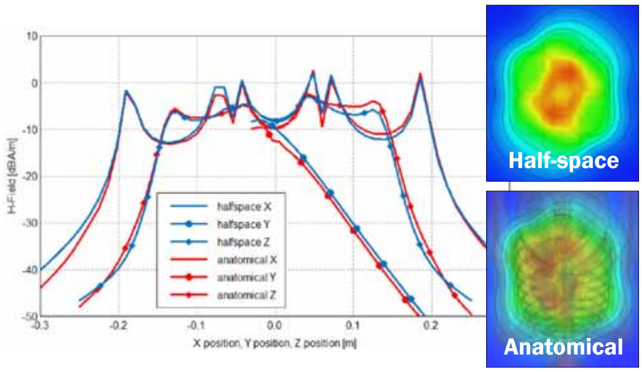
a transmit array to create a uniform B_1 field (RF shimming), can also be investigated.

Simulation Methods for MRI

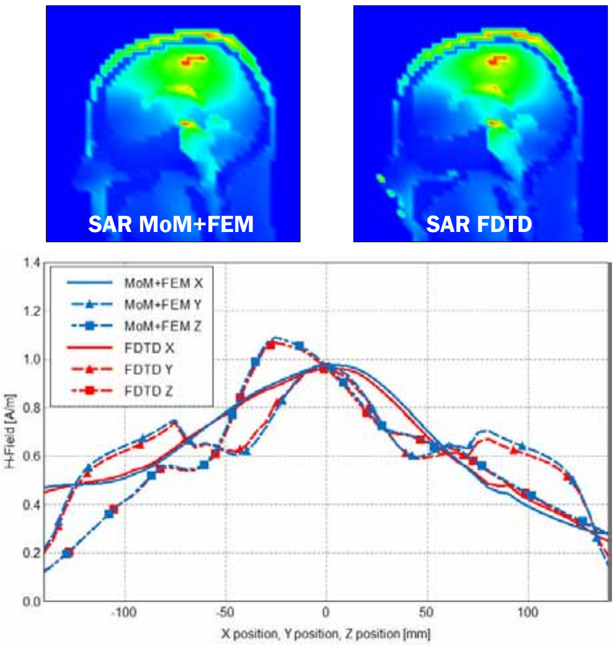
For the initial design of surface arrays, an efficient solution is to place the coil above a dielectric half-space and optimise the coil geometry using the method of moments (MoM). The inclusion of a half-space does not increase the number of unknowns. Similar results to those with a body present can be obtained by using this approach with minimal cost increase relative to simulating the arrays on their own. Such a design approach enables an automated optimisation strategy to be computationally feasible. Once the optimum array geometry is found, an anatomical model can be used to calculate the actual loaded coil performance.

While the MoM is efficient and accurate to solve the empty coil or coil with homogeneous phantoms, the hybrid MoM / FEM method offers an especially effective solution for accurate simulation of MRI systems with anatomical models. The MoM is well suited to solve the curved metallic geometries of the coil and the finite element method (FEM) to model the conductive tissue in human phantoms. The finite difference time domain (FDTD) method also offers efficient solutions to coils with anatomical models due to its straightforward approach to discretisation of the models. The FDTD solver lends itself to be more suitable for the cases where the FEM memory requirements become large.

Finally, applying different solvers to a problem build confidence in simulation results. Cross-validation enables comparison of design concepts and elimination of poor candidates to reduce the required number of prototype iterations.



Comparison of the magnetic field of a surface array simulated in turn with a dielectric half-space (blue) and an anatomical load (red)



Cross-validation of the SAR and magnetic field for a 7 T head coil using FEM / MoM and FDTD solvers

Phantom Models

Generic or homogeneous phantoms are well suited for efficient simulation, but more realistic anatomical phantoms are required for system verification and safety analysis. A range of phantoms, meshed for use with either MoM or FEM can be downloaded from the FEKO website. A phantom can also be easily remeshed as a voxel mesh for simulation with FDTD in FEKO. Additional high quality anatomical mesh models are also available through Simpleware.

References

[1] S. Wang, et al., A Four-Element Clover Transceiver Array for 3 Tesla Cardiac MRI, Microwave Journal,Vol.55, No.12, Dec. 2012

Altair
32 Techno Ave, Technopark, Stellenbosch, South Africa
Phone: 0027 21 831 1500 • Fax: 0027 21 880 1936
www.altair.com • info@altair.com