25) Modeling and Evaluation of High Impedance Surfaces Applied to Improve the Performance of RF Coils within High-field MRI

Benedikt Sievert(1), Andreas Rennings(1), and Daniel Erni(1)

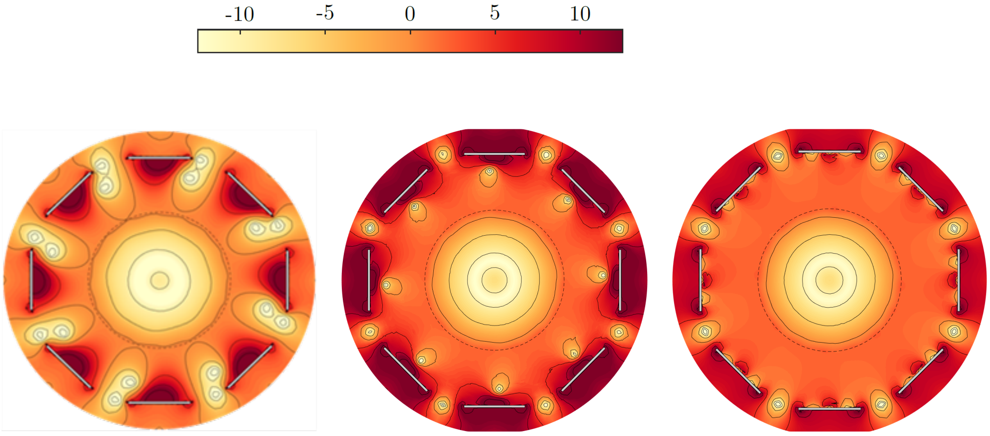
(1) Laboratory for General and Theoretical Electrical Engineering (ATE)
Faculty of Engineering, University of Duisburg-Essen,
D-47048 Duisburg, Germany

E-Mail: benedikt.sievert@stud.uni-duisburg-essen.de
Web: http://www.ate.uni-due.de/index.htm

Abstract – The use of High Impedance Surfaces (HIS) as an antenna reflector has proved beneficial for radiative applications [1], especially when compact solutions are desired [2]. With a focus on the MRI application, not only compact designs, but also improved B- to E-field ratio are goals of engineered solutions. In [3] it has been shown that, compared to conventional antenna shields, the use of a HIS supports a higher penetration depth in the body concerning the magnetic flux density. At its resonance, the HIS approaches the behavior of a Perfect Magnetic Conductor (PMC), a solely theoretical surface which forces the magnetic field to be normal to the surface. This behavior seems to enhance the penetration of the magnetic field [3]. The frequency of resonance is characterized by the surface impedance of the HIS reaching its maximum value, which results in a zero phase reflection coefficient.

Consisting of electrically small conducting patches, the HIS itself is a periodic structured surface with unit cells, which are smaller than the wavelength of the used EM-waves. In combination with high permittivity materials used for the HIS, small gaps between the patches and large shield surfaces in general, the computational effort for simulating these surfaces is high. Even simple MRI-setups using homogeneous phantoms challenge modern workstation PCs when using the FEM-method, if the HIS in included in the setup. A parallel LC circuit has been designed for describing the behavior of the HIS concerning its reflection behavior, used for gaining a deeper physical insight and applied for simplifying the domain in an accurate but effective manner. The equivalent circuit models the surface impedance of the HIS and is assigned to a so called Impedance Boundary Condition (IBC) in HFSS by Ansys [4]. This boundary condition is able to model the complex HIS structure within one surface boundary, which reduces the computational effort drastically. The resulting magnetic field for a symmetrical antenna setup is shown in Figure 1. The setup uses eight meandered dipole antennas, as they were presented in [5], which are modified based on the results from [6].

$$20\log_{10}\left(\frac{|{B_1}^{+}|}{\max SAR}\,\frac{\sqrt{\mathrm{Wkg}}}{\mu\mathrm{T}}\right)$$



a.) PEC *b.) HIS* *c.) IBC (modeling the HIS)*

Fig.1: Magnetic flux density $|{B_1}^{+}|$ normalized to the maximum of the SAR inside the homogeneous tissue for different shield types. a.) conventional PEC shield, b.) HIS shield and c.) Impedance boundary condition modeling the HIS. The tissue is denoted by the dotted line.

With the use of the HIS, the magnetic flux density increases in- and outside the tissue while the inhomogeneity decreases. The modeling of the HIS by the IBC shows a good compliance, especially inside the tissue. Deviations can be observed in the proximity of the antennas, nevertheless the characteristic field behavior of both approaches is comparable. As a next step a more complex setup, which should be measured in an MRI scanner, is investigated and optimized towards a strong and homogeneous ${B_1}^{+}$-field. With the advantage of reduced simulation time by use of the IBC, new optimization approaches are applicable.

References

[1] D. Sievenpiper, High-Impedance Electromangetic Surfaces. Dissertation, University of California, Los Angeles, 1999.

[2] G. Saleh, High Impedance Surface – Electromagnetic Band Gap (HIS-EBG) Structures for Magnetic Resonance Imaging (MRI) Applications. Dissertation, University of Duisburg-Essen, 2013.

[3] Z. Chen, Application of High Impedance Surfaces to Improve Radiofrequency Coil Performance for 7-Tesla Magnetic Resonance Imaging. Dissertation, University of Duisburg-Essen, 2016.

[4] HFSS is a solver for RF electromagnetics based on the FEM method. HFSS is a product by Ansys, Inc. http://www.ansys.com/Products/Electronics/ANSYS-HFSS (accessed March. 30, 2017)

[5] S. Orzada, A. Bahr, and T. Bolz. “A novel 7 T microstrip element using meanders to enhance decoupling”, 16th Proc. Intl. Soc. MRM, page 2979, 2008.

[6] Z. Chen, K. Solbach, D. Erni, and A. Rennings, "Dipole RF Element for 7 Tesla magnetic resonance imaging with minimized SAR", 7th European Conference on Antennas and Propagation (EuCAP 2013), April 8-12, Gothenburg, Sweden, Session CM1a.1, pp. 1716-1719, 2013, (invited paper).