Detailed investigations of a metamaterial transmit/receive coil element for 7 T MRI

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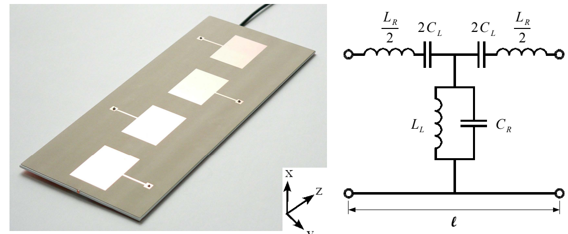
Introduction

The usage of composite right/left-handed (CRLH) [1] metamaterial transmission line resonators as basic elements for a 7T MRI transmit/receive coil was proposed, and the design and numerical results of a zeroth-order resonant coil (ZORC) element were presented in [2]. The purpose of the recent work was the physical build-up of this element and further numerical and experimental characterizations of this element.

Materials and Methods

The ZORC element is shown in Figure 1 a), and has a size of 250 mm x 100 mm x 2.25 mm. The periodic structure consists of four cascaded CRLH metamaterial unit cells. The equivalent circuit of one unit cell is shown in Figure 1 b), whereas the discrete elements are realized as distributed elements in the layout of the unit cell. Numerical investigations were done for different designs of the ZORC element, especially for a design with substrates and ground metallization extended in z-direction (Figure 2). Simulations for all elements were done using the commercially available software package Empire™. The element was investigated in air and with a flat phantom ($\varepsilon_r = 43.4$, $\sigma = 0.8$ 1/Ω/m) positioned 20 mm above the elements. Measurements of the B_1-Field were based on the dosimetric measurement system DASY and imaging experiments were performed with a phantom on a 7T whole-body MR system (Magnetom 7T, Siemens, Erlangen).



a) b)

Figure 1: A Prototype of the ZORC element with 4 unit cells (a), and the equivalent circuit for a unit cell (b)

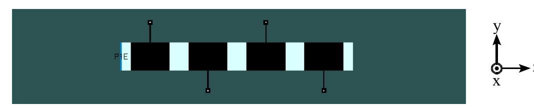
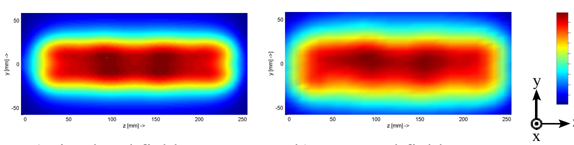


Figure 2: Layout of the in z-direction extended ZORC element

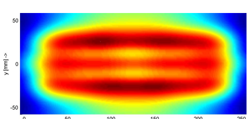
Results and Discussion

In Figure 3 the simulated and the measured B_1 field are shown. A good agreement between these two results can be observed, with a homogeneous B_1 field along the z-direction and above the metallization of the unit cells also along the y-direction. This homogeneous B_1 field along the y-direction is no longer existent in the circular polarized B_1^+ field and the $B_1^+ \times B_1^-$ field respectively, as it can be measured in the MR system. In Figure 4 b) the, with the MR System measured, $B_1^+ \times B_1^-$ field in a phantom is shown together with the numerical results (Figure 4 a)). Again there is a good agreement between the numerical and the measured results, but the two local minima around the center of the element would be a problem for MR imaging, as the SNR from these areas would be very small. Different designs of the unit cell were studied (all with a resonant frequency of 297 MHz), but no remarkable differences between the different layouts could be observed. A distinctive change in the field distribution can be realized, when the metamaterial structure doesn't reach the edges of the ground metallization in z-direction. In Figure 2 a modified element is shown, where the ground metallization and the substrates of the element are extended along the z-direction. For this setup an extension of 120mm at each end was chosen. This leads to the elimination of the local minima, and a concentration of the field in the y-direction**,** as it can be seen in Figure 4 c). Due to the extension of the ground metallization, the field also looses the constant distribution along the z-direction, and there is a local maximum at the center of the element. The changed field distribution results in a smaller volume that can be examined with the extended design of the metamaterial coil element. Further investigations about the dependency of the field distribution on the element design will follow.

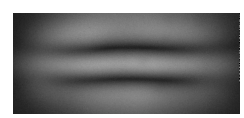


a) simulated field b) measured field

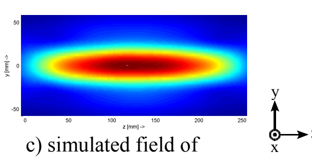
Figure 3: Absolute B_1 field in air at 297 MHz, 20mm above the elements in a yz-plane, and normalized to each maximum



a) simulated field



b) measured field from the MR system



c) simulated field of the extended element

Figure 4: $B_1^+ \times B_1^-$ field in a phantom, 30mm above the elements in a yz-plane

[1] Caloz, C & Itoh, T. Electromagnetic Metamaterials, Transmission Line Theory and Microwave Applications. Hoboken, NJ: Wiley Press (2005)
[2] Mosig, J et al. A novel metamaterial transmit/receive coil element for 7T MRI – Design and numerical results. In: Proc. Intl. Soc. MRM 17 (2009)