A novel metamaterial transmit/receive coil element for 7 T MRI – Design and numerical results

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Introduction

Microstrip transmission line (MTL) resonators can be used in high field MRI as basic elements for transmit/receive arrays (e.g. [1]). In contrast to a conventional MTL we describe in this work first studies of a composite right/left-handed (CRLH) [2] metamaterial transmission line resonator, with respect to the novel usage as a transmit/receive coil. On the basis of CRLH zeroth-order resonant antennas (ZORAs) [3], a CRLH zeroth-order resonant coil (ZORC) element [4], implemented in a multilayer configuration, was designed for usage at 7 T (297.2 MHz).

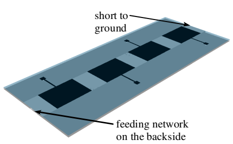


Figure 1: ZORC element

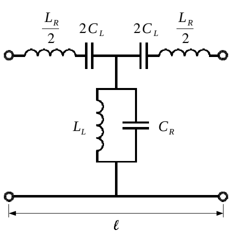
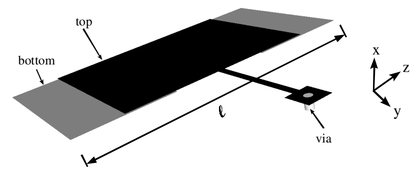


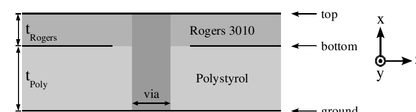
Figure 2: equivalent circuit of a T-symmetric CRLH unit cell

Materials and Methods

The 250 mm long and 100 mm wide ZORC element is implemented in a double-layer substrate assembly and consists of 4 metamaterial CRLH unit cells (Figure 1). The feeding is positioned at the left end on the backside of the element, while the right end is terminated by a short to the ground. In Figure 2 the equivalent circuit T-network for a unit cell is shown, and in Figure 3 the layout of one unit cell is depicted. Both the series inductances L_R and the shunt capacitor C_R arise parasitic from the whole unit cell topology, whereas the other elements of the equivalent circuit are explicit realised. The series capacitances C_L are implemented as metal-insulator-metal (MIM) capacitors, and the shunt inductance L_L is realised by a stub, shorted by a via to the ground. The top and bottom metallization together with the $t_{Rogers} = 250$ µm thick Rogers 3010 substrate ($\varepsilon_r \sim 10.2$, $\tan(\delta) \sim 0.0035$) compose a MIM Layer. The ground metallization is separated from this by a $t_{Poly} = 2$ mm thick Polystyrol layer ($\varepsilon_r \sim 2.7$, $\tan(\delta) \sim 0.0003$). The unit cell is 61.1 mm long and 30 mm wide. The stubs are 22.5 mm long and 1.5 mm wide. The via holes have a diameter of 1.5 mm. The element was designed to work in the series mode resonance at the resonant frequency $f_{se} = 1/\sqrt{L_R \cdot C_L}/(2\pi) = 297.2$ MHz.



a) layout of a unit cell



b) multilayer stack

Figure 3: CRLH unit cell

To investigate the characteristics of the ZORC element, this element is compared with a conventional MTL coil element similar to the element in [5], but with the same substrate configuration as the ZORC element and a 30 mm wide strip line on the top metallization. Simulations for all elements were done using the commercially available software package Empire™, with a flat phantom ($\varepsilon_r = 43.4$, $\sigma = 0.8$ 1/Ωm) positioned 20 mm above the elements. To determine the mutual coupling, two elements with a gap of 5 mm were investigated.

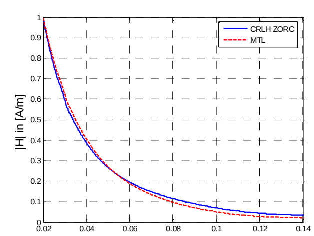
Results and Discussion

Both elements, the ZORC element and the MTL element, show a similar characteristic in the distribution of the magnetic field in the perpendicular x-direction, as shown in Figure 4 starting from 20 mm above the element (where the phantom is positioned). The calculated penetration depth into the phantom is about 22 mm for both elements.

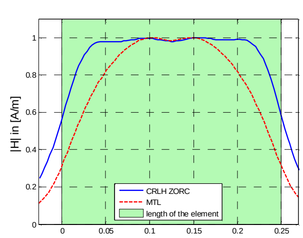
In Figure 4 b and c respectively, the magnetic field along the longitudinal, and the transverse direction, 30 mm above the element (10 mm inside the phantom) is shown. It can be seen that the magnetic field of the MTL element is much more concentrated around the center of the element (y = 0 mm, z = 125 mm) than the field of the ZORC element. This results in a larger field of view that can be examined with the ZORC element. The homogeneous magnetic field along the longitudinal z-direction is a special feature of the ZORC element, as the utilized zeroth-order resonance induces a constant current distribution along the element.

Altough the ZORC element can produce a homogeneous magnetic field in a larger field of view compared to the MTL element, the mutual coupling between two neighbouring coil elements increases only slightly from -14 dB for the MTL element to -13 dB for the ZORC element. Another advantage of the ZORC element is the independence of the zeroth order resonance from the number of unit cells. This leads to easy extensibility of the ZORC element, just by adding additional unit cells.

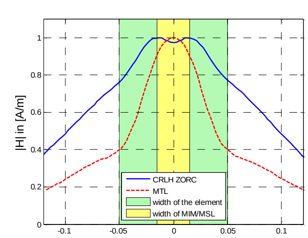
The next steps will be the physical build-up and characterisation of the ZORC element, as well as measurements on a Siemens 7 T whole body scanner.



a) perpendicular to the element



b) longitudinal, 30 mm above



c) transversal, 30 mm above

Figure 4: normalized absolute magnetic fields above the elements

[1] Zhang, X et al. An inverted-microstrip resonator for human head proton MR imaging at 7 Tesla. In: IEE Trans. Biomed. Eng. 49 (2005)

[2] Caloz, C & Itoh, T. Electromagnetic Metamaterials, Transmission Line Theory and Microwave Applications. Hoboken, NJ: Wiley Press (2005)

[3] Rennnings, A et al. Highly directive resonator antennas based on composite right/left handed (CRLH) transmission lines. In: Proc. 2nd Intl. ITG Conf. on Ant. (2007)

[4] Rennnings, A et al. A CRLH metamaterial based RF coil element for magnetic resonance imaging at 7 Tesla. Submitted to: 3rd Eu. Conf. on Ant.& Propag. (2009)

[5] Brunner, DO et al. A symmetrically fed micostrip coil array for 7 T. In: Proc. Intl. Soc. MRM 15 (2007)