serec newsletter

from the swiss electromagnetics research & engineering centre

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news

EMC in Power Supply and Distribution

The date of our next event has now been chosen, namely Friday 28 May 2009, and we warmly encourage you to immediately reserve this day in your diary! In an effort to better accommodate the needs of our membership in Central and Western Switzerland the event will take place at the Biel/Bienne campus of the Berne University of Applied Sciences rather than in Zurich.

The day's activities will be made up of a series of presentations from acknowledged experts on electromagnetic compatibility and interactions from academia, industry and utilities on such aspects as power electronics, lightning and transformers, etc.

We will soon be sending out personal invitations to a selection of carefully chosen individuals in commerce, representing relevant manufacturing and service industries, the power utilities and appropriate federal agencies. Once again please let us know the name and contact details of any companies or individuals active in this area that you would particularly like us to invite.

Our academic members are particularly encouraged to circulate details amongst their research groups, teams and students. Remember your participation is not limited to our contact person(s)!

The programme of talks will be found on our website where you should also register your attendance:

www.serec.ethz.ch/events

Please note that for administrative and catering reasons it is mandatory to register your attendance in advance. The event will be conducted in English. If you are not already a member of **serec** there is a small charge for participation.

Mobile telecommunications handset market resilient despite the recession

The number of handsets sold in 2009 fell by just 5.2% to 1,127 million – a fall that was 3% less than previously estimated. Market leader remains Nokia having sold almost 432 million handsets (-7.8%) which represents a 48.3% market share. Main competitors were Samsung (20% market share) and LG (10.5%).

Mobile working grows and grows in popularity

Mobile working (also known as remote or tele-working) encompasses the ability to work and access information from any location by use of mobile telecommunications technologies and increasingly with the identical functionality that can be provided in the classical office. This includes office-based, non-office based e.g. sales persons, and home-based employees. Such flexibility, particularly in the cases of non-office based and home-based employees, totally changes working practices, offers additional freedom to employees and avoids much of the necessity to commute daily to the working place. Nonetheless the risk of social isolation from working colleagues and the possible increased stress on traditional family life need to be considered.

It is now estimated that almost 1,200 million people, a third of the world's workforce, will be working, or able to work, in this manner by 2013. In Japan and the USA the percentage of mobile workers had probably already peaked at over 70% of the total workforce. In Western Europe growth is continuing at about 6% pa and is expected to total some 130 million persons by 2013 (50% of the workforce).

Metamaterial based RF coils for 7 Tesla MRI applications

Prof. Daniel Erni

One of the fast growing research fields in the Laboratory for General and Theoretical Electrical Engineering (ATE) at the University of Duisburg-Essen concerns the introduction of electromagnetic metamaterials in high-field Magnetic Resonance Imaging (MRI). Together with the Erwin L. Hahn Institute for Magnetic Resonance Imaging in Essen (ELH) and the *École Polytechnique de Montréal* in Quebec, Canada, preliminary experiments have been carried out confirming the applicability of novel coil topologies that are based on one-dimensional Composite Right/Left-Handed (CRLH) metamaterials (cf. Fig.1). The underlying structure – namely the periodic chain of unit cells – can be viewed as a macroscopic representation of a specific transmission line, although with a very unique dispersion characteristics that supports «exotic» resonant states when e.g. short-circuited at the far end. The emergent zeroth-order resonance has the attractive feature to yield a standing wave with a uniform current distribution (!) along the transmission line, virtually irrespective its length. This peculiarity makes the CRLH transmission line a promising candidate for providing intense uniform magnetic RF excitations (i.e. the B_1-field) and, hence, elongated fields of view in the context of MRI.

Under the guidance of Dr. Andreas Rennings and his colleagues Philipp Schneider (ATE), Stephan Orzada (ELH) and Prof. Christophe Caloz (École Polytechnique) a novel composite right/left-handed (CRLH) zeroth-order resonant coil (ZORC) has recently been validated within a 7 Tesla MRI using a homogeneous flat phantom for the emulation of the human body [1]. Large or rather long fields of view of approximately 30cm (corresponding to the length of the coil) have been achieved. Coils like this are thus particularly well suited to sagittal and coronal MRI sections, where the long field of view enables faster MRI processing by relaxing the necessity to move the body during diagnosis.

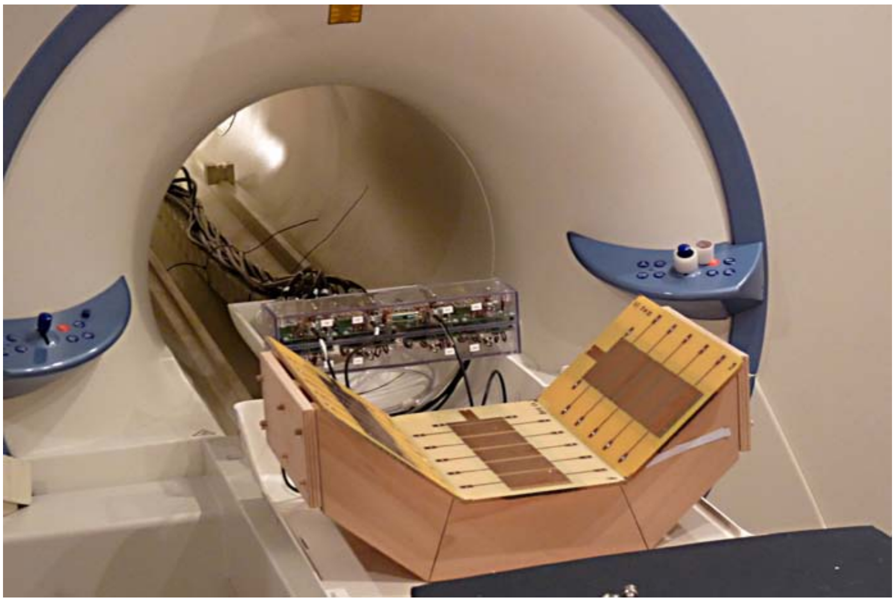


Fig.1: Prototype of the metamaterial coil system showing three elements of the overall coil topology. Each element consists of an artificial transmission line structure that is short-circuited at the far end (in front), and thus operating as a composite right/left-handed (CRLH) zeroth-order resonant coil (ZORC). The individual ZORCs encompass a concatenation of five corresponding unit cells.

ZORC element with longitudinally uniform fields

As the complete ZORC incorporates several identical ZORC elements to build a cylinder with a polygonal cross section, only one of these elements have to be considered first for analysis purposes, namely to inspect the uniformity of longitudinal distribution of the RF field. The design process usually starts with the proper engineering of the underlying unit cell [2], relying on both, advanced FDTD full-wave simulations of the proper cell implementation [Fig.2(b)] and the equivalent circuit model [Fig.2(a)], where the latter acts as a design guide. An operation frequency around 300MHz has to be chosen accordingly to match the Larmor frequency for the corresponding axial magnetostatic main field B_0 of 7T.

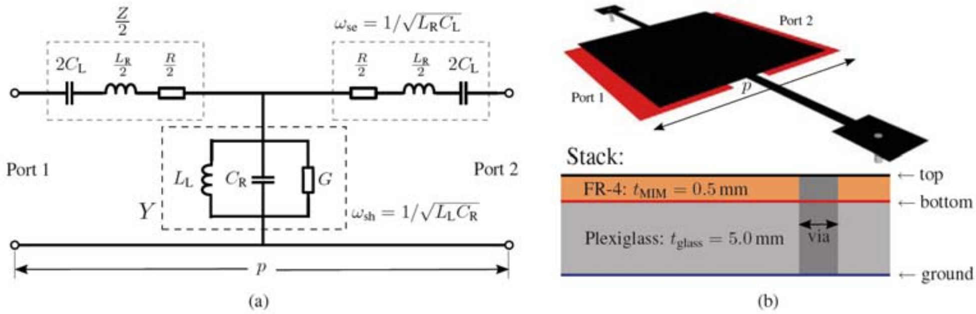


Fig.2: Unit cell of the ZORC element: (a) Lossy equivalent circuit in T-topology for the symmetric (with respect to the stubs) CRLH unit cell. (b) Perspective view periodic metal-insulator-metal (MIM) realization of the CRLH unit cell together with the involved multilayer profile with top/bottom metal layers for the upper/lower MIM plates and ground plane.

Within the design procedure the emergent series and shunt resonances among the reactive elements in the equivalent circuit (Fig.1) have to be chosen carefully to achieve the desired dispersion relation and the Bloch impedance, yielding a set of relations from which the circuit elements can be deduced. The proper shape of the unit cell is then extracted from corresponding full-wave simulations [2]. The equivalent circuit of a unit cell together with its realization in a metal-insulator-metal (MIM) technology are shown in Fig.2, whereas Fig.3 displays the complete 5-cell ZORC element and the associated numerical simulation of the resulting magnetic field distribution (H_y) on a parallel plane 2cm above the upper ZORC surface.

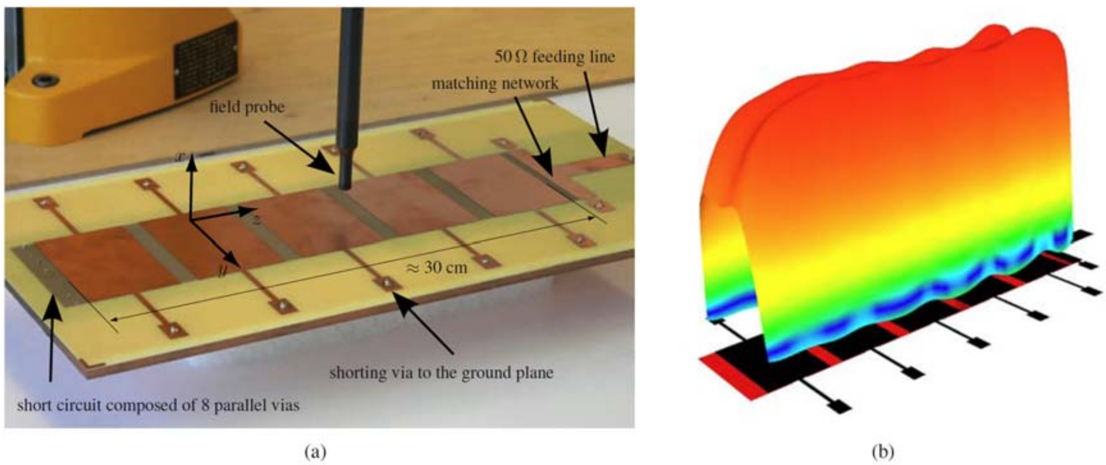
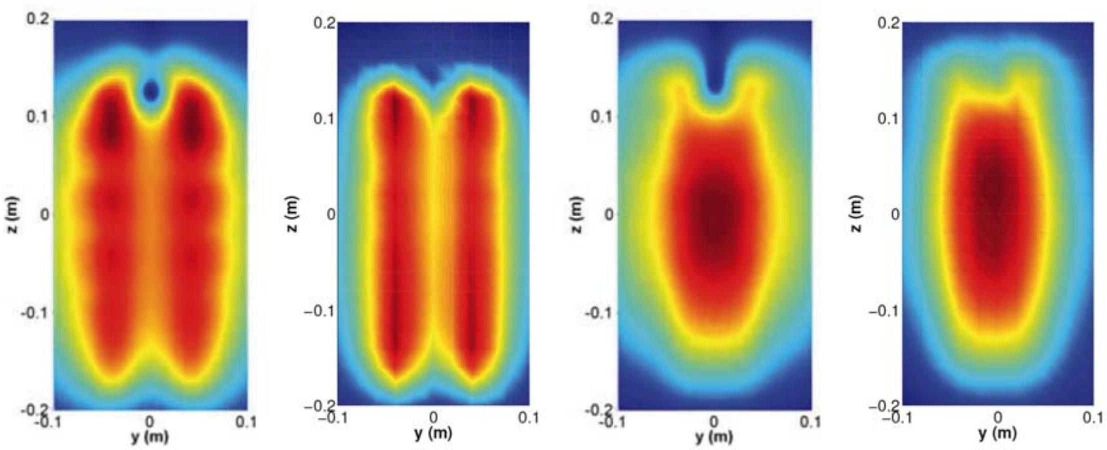


Fig.3: The fabricated ZORC structure: (a) Prototype and (b) FDTD simulation of the longitudinally uniform magnetic field component H_y on a parallel plane 2cm above the upper ZORC surface.

The ZORC is designed to operate in its series mode, which is achieved while terminating the structure by a short-circuit. In this mode, the energy is mainly concentrated in the series elements, i.e. along the axis of the structure, producing the intended (virtually uniform) current distribution along the ZORC topology. Two anti-parallel stubs are placed adjacent to each unit cell in order to minimize unwanted longitudinal magnetic field components caused by residual transverse currents. The electric and magnetic fields are polarized along and perpendicularly to the structure's axis, respectively. Since the ZORC structures are later complemented to form the overall coil system while adapting the cylindrical shape of the MRI bore as shown in Fig.1, the resulting magnetic RF field (i.e. the B_1-field) yields a polarization perpendicular to the magnetostatic main field B_0, and, hence, satisfying the requirements to induce the necessary angle flipping into the spinning protons of the various body tissues.

Experimental verification

To approach the realistic operating conditions a flat body phantom filled with tissue simulating liquid (cf. Fig.5) has been introduced. Fig.4 displays a comparison between simulated magnetic field distributions and the corresponding near field measurements on top of the ZORC element for both, the unloaded and loaded case, showing good longitudinal near-field uniformity for both scenarios. Uniformity in the longitudinal B_1-field distribution is prerequisite to high-quality MRI, since the entire body is completely immersed in the field energy produced in the MRI tube. Interestingly, the flux enhancement due to the introduction of the phantom tends to equalize the transverse field profile, which exhibits a valley in the unloaded case due to current crowding at the edges of the involved metal strips.



(a) $|\boldsymbol{H}_{\mathrm{unloaded}}|$ FDTD (b) $|\boldsymbol{H}_{\mathrm{unloaded}}|$ Meas. (c) $|\boldsymbol{H}_{\mathrm{loaded}}|$ FDTD (d) $|\boldsymbol{H}_{\mathrm{loaded}}|$ Meas.

Fig.4: Distribution of the magnetic field strength 25mm above the ZORC element for both, the unloaded and the loaded case, comparing the full-wave FDTD simulations [(a) and (c)] with the corresponding near field measurements [(b) and (d)].

Fig.5(b) shows two B_1-maps for different plane cuts representing the so-called flip angle associated to the corresponding voxel in the flat phantom volume leading to a picture that allows to indicate the maximal possible field of view. Preliminary MRI pictures are shown in Fig.6, where the bottom boundary of the flat phantom is clearly identified in the sagittal plane. The top boundary, namely the liquid surface is less pronounced, due to field attenuation. This latter imperfection becomes negligible in the overall ZORC coil system due to the radiating ZORC element at the opposite side.

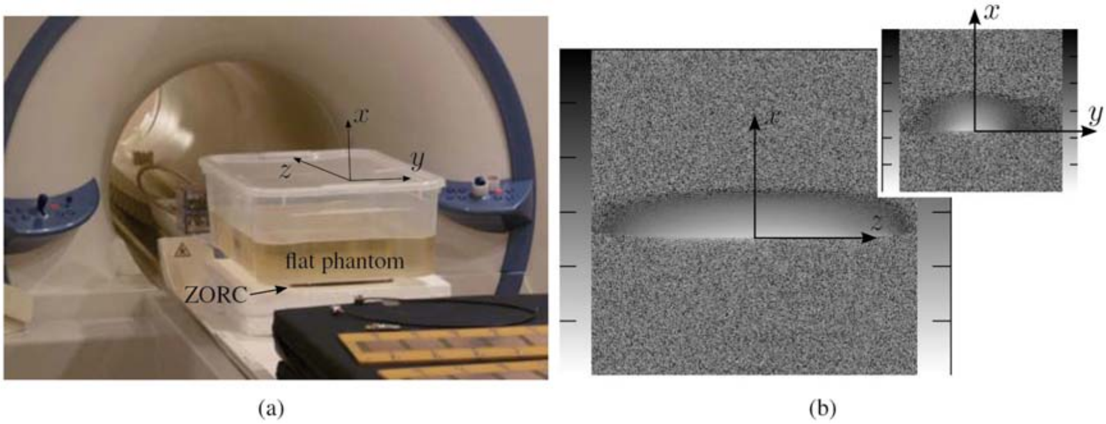


Fig.5: Experimental setup for the operating conditions: (a) ZORC element together with the body-emulating flat phantom in front of the 7-Tesla MRI tomography, and (b) B_1-sensitivity maps of the element for lateral and longitudinal cross-sections indicating a possible field of view.

Future steps in coil design

In our presented ZORC elements the CRLH metamaterials play the key role in supporting virtually uniform current distributions, and hence longitudinally homogeneous magnetic RF field profiles. Metamaterial-based transmission line structures have an admittedly pretty complex shape, which raises the question whether there is any simpler topology available (such as e.g. a series-fed patch array) that may fulfil the same task. Frankly speaking the answer is “yes”.

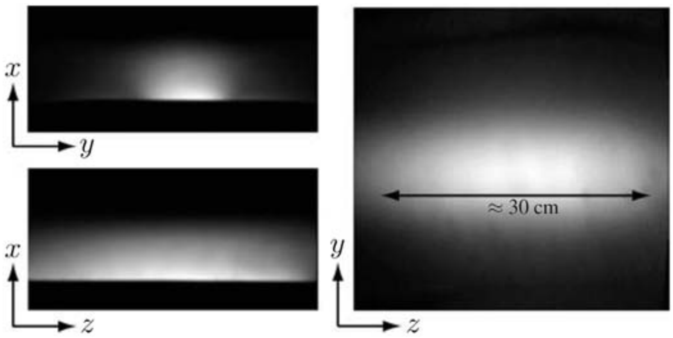


Fig.6: MRI pictures of the flat phantom setup (a) for sagittal (xz), transversal (xy) and coronal (yz) plane cuts.

In our research on electromagnetic metamaterials we have successfully demonstrated that CRLH transmission lines carries the attractive feature to offer a high degree of design freedom when tailoring dispersion characteristics at given (Bloch) impedance levels under the constraint of a predefined geometrical extent. In addition, the periodic nature of CRLH transmission lines supports very unique scaling properties: When properly designed, each interface between the unit cells is prone to provide a matched connection for an additional CRLH transmission line, leading to a very flexible scheme for resonant current distribution. Referring to our MRI application one of the most convincing features in favour of CRLH transmission lines is, however, the compact size that can be further reduced, when adding reactive lumped elements to the unit cell.

Our present research has already carried out a wide range of metamaterial-based ring topologies to support homogeneous illumination scenarios for the various tasks in current

MRI. Together with our colleagues from ETH Zurich (Prof. Klaas Prüssmann and Dr. Jürg Fröhlich) we are now reflecting on appropriate excitation schemes for next generation systems such as the travelling-wave MRI. We feel that the very obvious affinity between CRLH transmission lines and the travelling-wave concept offers a unique opportunity for exciting collaborative research.

For further information see also:

"Preliminary experiments on a CRLH metamaterial zeroth-order resonant coil (ZORC) element for 7 Tesla MRI applications with large field of view" by Andreas Rennings, Philipp Schneider, Christophe Caloz and Stephan Orzada, presented at *METAMATERIALS 2009*, in London; and "A CRLH metamaterial based RF coil element for magnetic resonance imaging at 7 Tesla," by Andreas Rennings, Juan Mosig, Achim Bahr, Christophe Caloz, Mark Ladd and Daniel Erni, presented at the *3rd European Conference on Antennas and Propagation (EuCAP 2009)*, in Berlin.

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