Stepped Impedance Resonators for High Field MRI

C. Akgun[1], L. DelaBarre[1], H. Yoo[2], C. J. Snyder[1], A. Gopinath[3], K. Ugurbil[1], and J. T. Vaughan[1]

[1]Center for Magnetic Resonance Imaging, University of MInnesota, Minneapolis, MN, United States, [2]Department of Biomedical Engineering, School of Electrical Engineering, University of Ulsan, Ulsan, Korea, Republic of, [3]Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, MN, United States

Objective:

Simulated and experimental investigation of RF multi-element volume head coils consisting of microstrip stepped impedance resonators.

Background:

The multi-element TEM volume coil can incorporate an array of microstrip transmission line elements that are mutually decoupled and operated as independent coils in typically multiple-element transmit and receive configuration[1-5]. Since its' inception in high field MRI volume coils, there have been very few modifications of the microstrip transmission line for optimal performance. In this study, two different microstrip designs with varying impedance lines referred to as stepped impedance resonators[6] (SIRs) are presented. The SIR can be designed to produce a peak B1+ in the center, while another SIR can be designed to limit SAR effects when compared to the traditional microstrip resonator. Imaging and simulation results for 8 element volume coils with these designs are obtained at 7T for the human head.

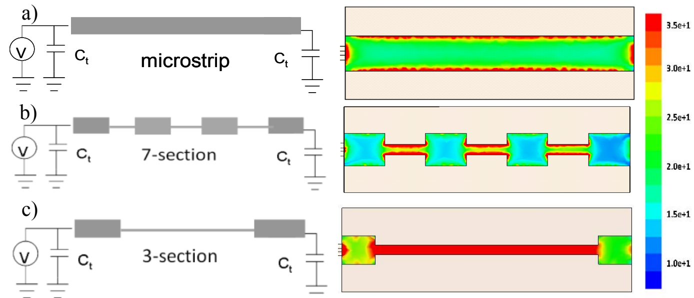

Figure 1) SIR elements and corresponding current density plots

Concept:

A microstrip transmission line with capacitive termination produces a standing wave with a current distribution peaking at the center of the line (Fig. 1a). Patterning the signal line into thick and thin sections can vary the impedances along the line and allows for control of the current density along the length of the transmission line. To produce greater peak B1+ at the center of the coil, the current can be locally increased with a 3-section SIR design (Fig. 1c) and, to limit E-field exposure to the load, a 7-section SIR (Fig. 1b) design can be implemented to vary the current distribution along the line.

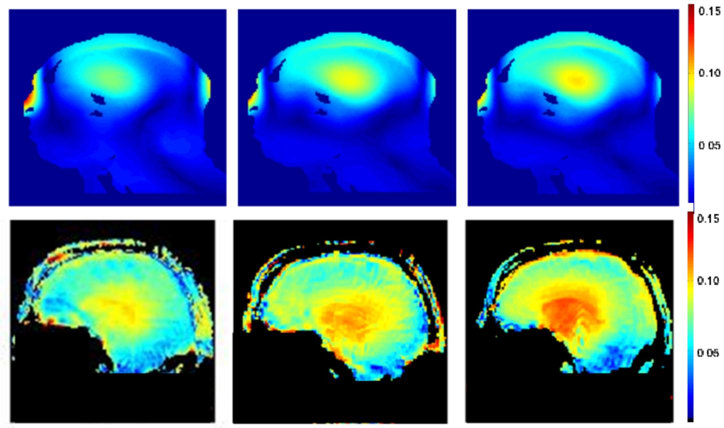

Figure 2) B1+ maps of 8-element a-d) microstrip b-e) 7-section SIR c-f) 3-section SIR volume coil volume coils (a-c experimental, d-f simulations)

Methods:

Three eight-channel transceiver arrays were built. Each element was comprised of a low loss Teflon substrate (ε_r = 2.08) with height and length of 1.90 cm and 14.0 cm, respectively. The elements were attached to a cylindrical plexi-glass shell 25.4 cm in diameter and 14.0 cm in length. The conductor widths were alternated with 1.2 cm copper foil and 16 gauge copper wire (0.127 cm diameter) for the *3-section SIR* (2 foil and 1 wire section) and *7-section SIR* (4 foil and 3 wire sections), while the standard straight microstrip element had a single 1.2 cm copper foil. Each element was individually tuned to 297 MHz (7 T) and matched to a 50-Ω, coaxial cable. No decoupling capacitors were used. Experiments were performed in a 7 T magnet (Magnex Scientific, UK) interfaced to a Siemens console (Siemens HealthCare, Germany).

Numerical Maxwell solutions of the 8-channel transceiver arrays were calculated about an anatomically correct human head using xFDTD version 6.5 (Remcom Inc., State College, PA). Each channel was simulated individually and combined in post-processing with B1+ geometric phases at the center of the brain to produce a circularly polarized B1+ field by Matlab (version 7.5). All the coils were normalized to 1W input power for comparison purposes.

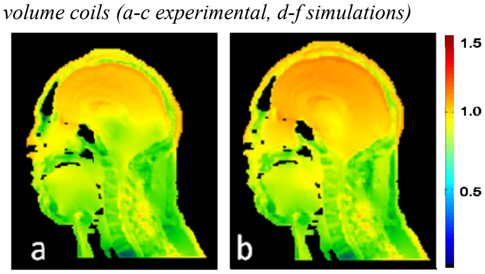

Figure 3) Sagittal SAR plots for 8-element a) microstrip b) 3-section SIR volume coil in (W/kg)

Results: Experimentally, when averaging B1+ values at the center of the brain, the *3-section SIR* shows 20% (Fig.2c) improvement in B1+ efficiency in the center of the head compared the microstrip while the *7-section SIR* shows 12% increase in the transaxial plane (Fig. 2b). The B1+ xFDTD simulations (Fig. 2a, b) show the 8-channel, *3-section SIR* with 25% more B1+ in the center of the head (Fig. 2f) while *7-section SIR* (Fig.3e) had 19% increase in the center of the head indicating strong correlation between experimental and theoretical results. The SAR results (Fig. 3) comparing all the coils for 1 W input power (Table 1) indicates that the 3-section SIR has larger Peak B1+ to maximum SAR ratio then the other two designs while the ratio of peak B1+ to the average SAR in the head indicates that 7-section SIR has a larger ratio compared to the other two designs.

8-element simulation	Peak $B1^+$(T)	Max.SAR (W/kg)	Peak $B1^+$(μT)/ Max. SAR	Ave.SAR head (W/kg)	Peak $B1^+$(μT)/ $(Ave.SAR)^{0.5}$
Microstrip	4.09E-7	**1.466**	0.279	**3.298E-2**	14.0
7-section	4.90E-7	1.791	0.274	4.249E-2	**15.2**
3-section	**5.14E-7**	1.573	**0.327**	4.548E-2	15.1

Table 1) Simulated B1+ and SAR data of SIRs for 1 W input power

Conclusions: Stepped impedance resonators are introduced for high field head imaging. The 3-section SIR demonstrated a much stronger peak B1+ profile in the center of the head compared to a standard, single-segment microstrip coil according to predictions and validating measurements. Simulations indicate that the 3-section SIR and 7-section SIR coils have B1 to SAR benefits compared to the traditional microstrip resonator. Stepped impedances in signal lines in multi-channel transceiver coils appear to be a good strategy for overcoming B1+ field inefficiencies and SAR limitations in high field MRI.

References:

[1] Roemer PB, et al. Magn Reson Med 1990;16: 192-225, [2] Vaughan J.T. et al. Magn Reson Med 1994;32: 206-218, [3] Vaughan, J. ISMRM 2004 [4] Lee RF, et al. *Magn Reson Med* 2001; 45: 673-683 [5] Adriany,G, et al. Magn Reson Med 2005; 53(2): 434-445 [6] Makimoto, IEEE Microwave Symposium, 1980.

Acknowledgements: This work was funded by WM Keck Foundation, NIH-NIBIB-EB000895, S10 RR026783 P30 NS057091, NIH NIBIB-EB006835, NIH-NIBIB-EB007327 and NIH-NCRR-P41-RR008079.