Tunable microstrip loop arrays for 3T and 7T MRI

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Introduction: Magnetic resonance imaging (MRI) coils have been dominated by tuned conductor loop designs. With the advent of whole body high magnetic field strength MRI systems, 3 T and specially 7 T, along with fast acquisition parallel techniques, the tuned conductor loop coil design does not easily extend to large antenna arrays without limitations due to inter-element coupling, cable interactions and the difficulty of tuning high frequency resonant circuits while maintaining good coupling to the load. Thus there is a need for innovative coil designs to handle high resonant frequencies. Due to its physical characteristics, microstrip loop coils solve these problems by reducing effective self-inductance, distributing capacitance and minimizing mutual inductance between coil elements [1,2,3]. In this work, microstrip loop arrays using 3 different substrates were constructed for operation at 3T and 7T for high resolution imaging of the head, knee and ankle. The arrays were evaluated both on the bench and in the MRI systems.

Methods

The 8-element receive coil arrays were built for use on a 3T clinical and a 7T research scanner (GE Healthcare, Waukesha, WI, USA). Double sided 35 μm thick copper laminates with substrates 1.5 and 2.5 mm thick made of FR-4, Rogers Ultralam and Sheldhal Comclad were used. The corresponding substrate relative permittivities were 4.4, 2.6, and 2.7. Hexagonal 7 cm inscribed tunable microstrips loops were milled from Rogers UL2.6 for the ankle receive array at 3T. Hexagonal 8.5 cm inscribed micro strip loops were cut from FR-4 for the head receive array at 3T. Finally, 6cm by 9cm micro strip loops were milled from the Comclad 2.5 mm thick material for the head and knee receive arrays at 7T. All micro strip loops shared trace dimensions of 3 mm wide on the top surface and 5mm wide concentric on the bottom surface. The hexagonal elements had on the top surface seven distributed gaps bridged with tuning capacitors. The rectangular elements had five distributed gaps bridged with tuning capacitors. The bottom copper surface was kept solid and connected to ground. Coil elements were tuned to 127.76 Mhz or 298.14 Mhz for 3T or 7T respectively. Pin-diode traps were built on all elements for coil detuning. Preamp decoupling was achieved by controlling coaxial cable length. Coupling between elements was measured by making transmission measurements (S12) as the spacing between elements was varied. At 3T the body coil was used for excitation while at 7T a de-tunable head coil was used. No cable traps were necessary at either frequency. Coil elements were placed on top of acrylic contoured sheets with fixed inter-element separation. Informed consent was obtained from volunteers.

Results

Bench top S12 measurements of coil coupling for the 6x9 cm coil elements, on the long side, are summarized in Figure 1 as a function of coil separation. Similar characteristics are observed for the hexagonal elements at 3T. Coil coupling response by resonance splitting [4] is weakly observed only when coil separation is less than 1 cm. Thus, coil sensitivity at f_o is not affected for larger separations. A minimum coupling value was reached when the traces exactly overlapped and a second one when the coil separation was -8 mm. Based on these results we chose a separation of 3.5 cm corresponding to an isolation of –17 dB. Typical coil element insertion loss was –40 dB and Q of 100 while loaded for 3T and 7T. Figure 2, shows the ankle and head arrays constructed for this study. Figure 3, depicts high resolution images acquired at 3T from the head and ankle arrays, note that there are no signal voids due to coupling at the 3.5 cm coil separation.

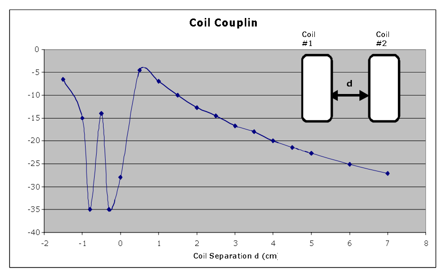

Figure 1. S12 measurement vs. coil separation (300 Mhz)

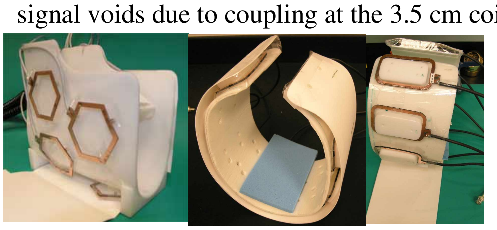

Figure 2. 3T ankle and 7T head arrays

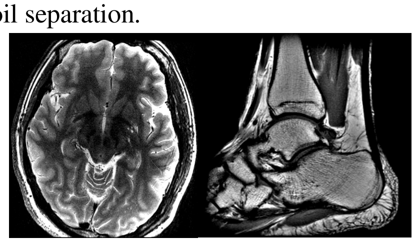

Figure 3. 3T images of head and ankle 512x512 FOV=20/14 cm respectively.

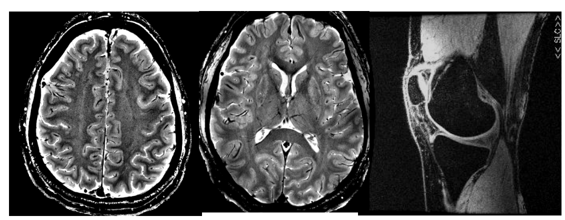

Figure 4. 7T images of head and knee. Matrix 512x512 and FOV=20 cm.

Conclusion

Microstrip loops are easily tuned to high frequencies (128 and 300 Mhz). The distributed capacitance of the trace with the ground prevents frequency shifts and minimizes coil coupling allowing easy construction of large array elements. Microstrip tunable loops are very frequency selective with narrow bandwidths of resonance (6 Mhz). Arrays provided good depth sensitivity and coverage.

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3. Becks B. et al., Proc ISMRM 13, 943 (2005), 4. Roemer et al., MRM 16, 192-225 (1990)