A novel design approach for planar local transmit/receive antennas in 3T spine imaging

Johanna Schöpfer[1], Klaus Huber[1], Stephan Biber[2], Sebastian Martius[1], and Helmut Greim[2]
[1]Corporate Technology, Siemens AG, Erlangen, Germany, [2]Healthcare Sector, Siemens AG, Erlangen, Germany

Introduction:
The human spine is one of the major examination areas in magnetic resonance imaging and, for instance, amounts to approximately 25% of overall scanned body parts in Germany [1]. Today's limitations like B_1^+ inhomogeneities, specified maximal B_1^+-field strengths or SAR figures can be overcome by local transmit coils adapted to the specific body area. Whereas in ultra-high field systems local transmit coils are well established to produce the required RF field, in commercially available 3T systems they are not that widely spread except for head and knee coils (cf. [2]). However, in research various approaches exist. In the following, a new antenna design of a local TX coil for spine imaging is presented which allows a simple integration in a current Siemens MAGNETOM Skyra 3T MRI-system and the promising perspective of low SAR figures and significantly reduced RF power. The design examines the balance between these potential benefits and the disadvantage of the inherent B_1^+ drop-off of a local TX coil.

Methods:
In multiple simulations and studies, different antenna designs and sizes were evaluated and compared for their suitability in spine imaging. Key figures were defined to be the local SAR value for 10g human tissue ([3]), B_1^+-field homogeneity, average B_1^+-field in a specific area around the spinal cord and the patient comfort. The latter was secured by the integration of the spine coil in the patient table, which requires planar antenna structures. All simulations were done in HFSS (Ansys).

The optimized antenna geometry was realized as a modification of a loop-butterfly antenna combination (cf. [4],[5]) and consists of three loop antennas. A single circular loop with a comparatively large radius of 10cm for sufficient penetration depth and reduced field drop and two antennas with an isosceles triangular profile (bases=25cm, height=18cm). The circular loop excites a magnetic field with a strong H-field component in perpendicular direction. The two triangular loops are oriented opposite to each other in a decoupled distance of 11cm (Figure 1*)*. Both triangles are fed simultaneously with opposed direction of current in order to create the corresponding orthogonal H-field component to the loop antenna in an area above the center. The main contributors for the excitation of the field component are the bases of the triangle; the other two legs build the current return path. In comparison to a quadratically designed loop, the reduced length of the triangle legs turned out to be advantageous. Both, the circular loop and the two-element structure are matched at 123.2 MHz to 50Ω. Furthermore, an adequate distance between the antenna and the skin of the human body model was evaluated in various simulation runs by supervising and comparing the SAR behavior, and was set to 3cm. The simulated antenna was built up with identical dimensions using copper strips on FR4 substrates and placed inside the housing of the spine coil (Figure 2). For integration in the MRI system the hardware was extended by a transmit/receive switch including a preamplifier. A feeding network was added in order to connect the two antenna elements to the single local transmit channel. It was designed to generate the required phase difference and a weighting of the two antenna channels and enables the possibility to balance the field strength and phase differences of both antenna elements. The ratio of the channels was set to be 1 (circular loop) to 2 (triangular loops) which could be verified by measurements of the H-field components with a pick up loop.

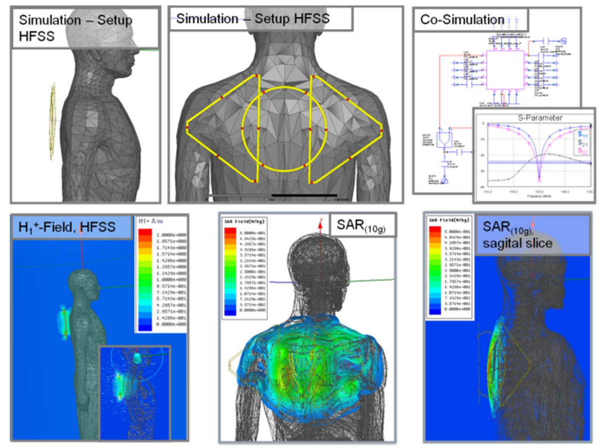

Figure 1: Top row, Simulation Setup HFSS (Ansys) and Co-simulation schematic including matching and coupling of both channels, Bottom row; H_1^+-distribution inside patient, SAR distribution inside the human body model and a sagittal slice

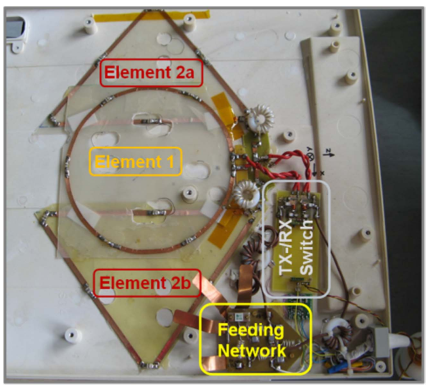

Figure 2: Hardware setup of the spine antenna, Loop Element (orange), triangular elements (red), Transmit-Receive switch (grey), Feeding network (yellow)

Results:
The simulations in HFSS with a human body model (Ansys) result in a local SAR value of 0.5 W/kg for an input power of 1W in a cube of 10g human tissue (Figure 1). In comparison, simulation with the traditional body coil showed enhanced power demands and consequently strongly increased SAR for an excitation of the corresponding area. The ratio of the resulting local SAR value of both, the designed antenna and the body coil, for a certain average field in the same areas varied between 5.8-9.2 depending on the location/size of the patient in various simulations. Concerning homogeneity, the presented antenna geometry showed a slight improvement compared to conventional loop-butterfly structures. For preliminary measurements, the spine hardware was tested to be power prove up to 6.5kW and was integrated in a Siemens MAGNETOM Skyra MRI. The imaged object was chosen to be a pork shoulder (2.5kg) including fat and muscle tissue. The reference amplitude for an average B_1^+-Field of 11.75 µT in the examined object resulted to 124V.

Figure 3 shows the images of spin-echo sequences with and without fat suppression. Furthermore discrete fibre-optic thermo sensors were placed inside the pork shoulder showing no considerable increase in temperature after 30min of heating.

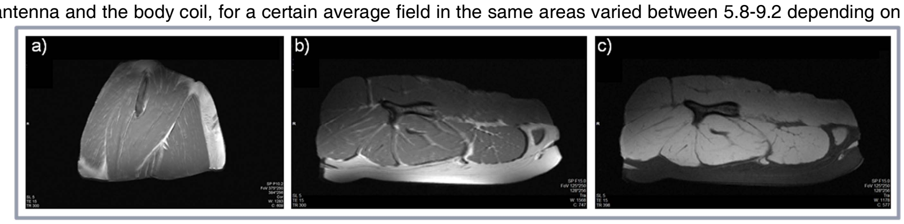

Figure 1: Spin-Echo Sequence, TE=15ms, TR=398ms, U_{ref}=124V/P_{in}=304W
a) coronal slice b) transversal slice c) transversal slice and fat suppression

Discussion / Conclusion:
The preliminary results show great potential for spine imaging with the optimized local transmit coil and will be further evaluated on in-vivo tests with volunteers. The developed antenna structure could also be extended to an array configuration and used as an addition to standard examinations with the body coil where high B_1^+-field strengths occurs to be the limiting part of the imaging process and SAR regulation restricts scanning time.

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