19-channel Rx array coil and 4-channel Tx loop array for cervical spinal cord imaging at 7T MRI

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Introduction: In this work, we developed a 19-channel receive array and a 4-channel parallel transmit loop array for imaging the cervical spinal cord at 7T. We addressed the challenge of obtaining uniform B1+ excitation by mounting a 4 channel degenerate-loop transmit array in the plane posterior to the subject similar to previous work [1,2]. The 4-channel transmit loop array had the sufficient decoupling <-16dB between each element and produced a relatively uniform excitation when driven with a single amplifier with a 45 degree phase increment in each element. The receive array loops closely contoured to the body and yielded high SNR performance as well as the ability to accelerated EPI imaging with R=3 in the cervical spinal cord.

Methods: Experiments were conducted on a Siemens 7T system (Siemens Healthcare) equipped with 8 transmit channels (1kW for each channel), 32 receive channels and SC72 gradient. *Receive coil*. The coil former was designed and then printed in ABS plastic using a 3D printer (Dimension SST 1200es, Dimension, Inc., Eden Prairie, MN, USA) (***Fig 1***). The former was populated with 19 overlapped loops of 7 cm diameter, made with 16 AWG tinned copper wire (Arcor Electronics, IL, US). A variable capacitor was used to fine-tune the loop resonance and a fuse was used for passive protection against large current, accidently induced during transmit. The input circuit board includes an active detuning circuit with a match capacitor, a handmade inductor and a PIN diode to provide a parallel resonant circuit to detune the receive loop when the diode is forward biased. A coaxial cable (23 cm length) was used to connect the coil and the preamplifier and to match the input impedance of the preamplifier. A cable trap was added in front of the preamplifier to block the cable current. *Transmit coil*. The transmit array was made with FR4 printed circuit board. All elements sit at a minimum distance of 65 cm from the subject. The dimension of each element is 14×7 cm (***Fig 2***). In the input circuit, the lattice circuit baluns were used to get the balanced RF signal about ground. A PIN diode was used for blocking current during receive. The array was simulated in HFSS 13.0. The circuit model of this loop array was simulated in Ansoft Designer 6.1. All the values of the capacitors of this circuit simulation were transferred to HFSS to generate the B1+ maps of each loop. To obtain a uniform B1+ field, each element was driven in the B1 shimming mode (45 degree phase increment and the same amplitude for each element). The ratio of local SAR to global SAR was 27.1 in this uniform mode excitation. *Acquisition*. We recruited a normal volunteer to run anatomical and functional sequences. Imaging protocol included an axial gradient echo FLASH sequence (0.3×0.3mm in-plane, 11 slices of 3mm thickness centered at C2-C3, TR/TE=100/4ms, R=2 acceleration, matrix=384×384, BW=290Hz/Pix, TA=20s, 4 averaging), a sagittal FLASH (0.5×0.5mm in-plane, 9 slices of 3mm thickness, TR/TE=100/4ms, R=2, matrix=320×320, BW=290Hz/Pix, TA=20s) and a gradient echo EPI sequence (0.7×0.7mm in-plane, 12 slices of 3mm thickness centered at C2-C3, TR/TE=2000/30ms, R=3, matrix=140×140, BW=1080Hz/Pix, echo spacing=0.92). Iterative shimming was conducted in a small box encompassing the spinal cord.

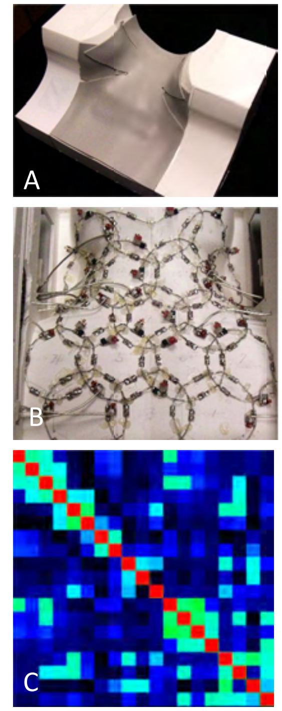

Fig1. *19ch Receive array coil.* ***A****: top view.* ***B****: rear view.* ***C****: Noise correlation matrix.*

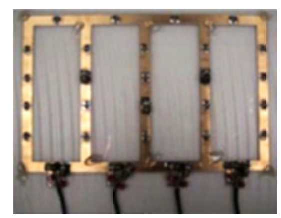

Fig2. *4ch transmit array.*

Results: The S_{12} coupling of the 4-channel Tx coil ranged from -22dB to -16dB, loaded with the Hugo-shaped water phantom. In the simulation, all the capacitors values were comparable with the physical coil and the input ports in the loop array provided a -20 dB decoupling. The B1 shimming mode of the sagittal plane (***Fig 3***) was used for SAR calculation for the *in vivo* scan. For the receive loop, the ratio of unloaded-to-loaded quality factor was 12 (Q_U/Q_L=180/15). The overall average noise correlation of the receive array was 18.2% (***Fig 1C***). *In vivo* imaging was successfully performed on the subject (***Fig4***). Sagittal FLASH image shows homogeneous signal along the cervical cord with good CSF/cord contrast. The axial FLASH at 0.3 mm in-plane resolution shows high details of the cord, with the butterfly-shaped gray matter. The SNR of the image could be further improved with longer acquisitions or 3D methods (TA was 1:20 min). The single shot EPI acquired at 0.7 mm in-plane resolution shows nice delineation of the cord and gray matter. More importantly, no ghosting was noticeable and susceptibility-related distortion and drop-out were minimum (***Fig4C***), thanks to acceleration factor of 3 (with GRAPPA reconstruction) and minimum echo spacing (0.92ms → 0.3ms effective echo spacing).

Discussion. The 19ch elements enabled parallel imaging with high acceleration factor, yielding short acquisition time at high resolution (0.3 mm in 1:20 min). Parallel acquisition was also beneficial for reducing susceptibility-distortions in EPI data (acquired with R=3). The quality of EPI suggests potential use for functional MRI experiments in the cervical spinal cord. Shimming was critical (especially for EPI).

Reference: [1] Kraff O. et al., Investigative Radiology, 44(11), 2009. [2] Duan Q. et al., Proc Intl. Soc. Mag. Reson. Med. 18 (2010), 51.

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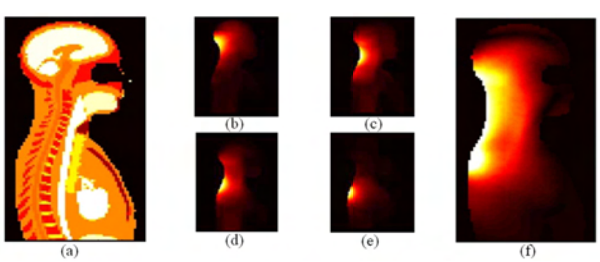

Fig 3. *$B1^+$ maps of the 4-channel transmit array in the sagittal plane of the HFSS human digital model, (a) HFSS human model; (b) $B1^+$ map of Tx1,(c) $B1^+$ map of Tx2,(d) $B1^+$ map of Tx3,(e) $B1^+$ map of Tx4, (f) The $B1^+$ map of B1 shimming mode in the sagittal plane*

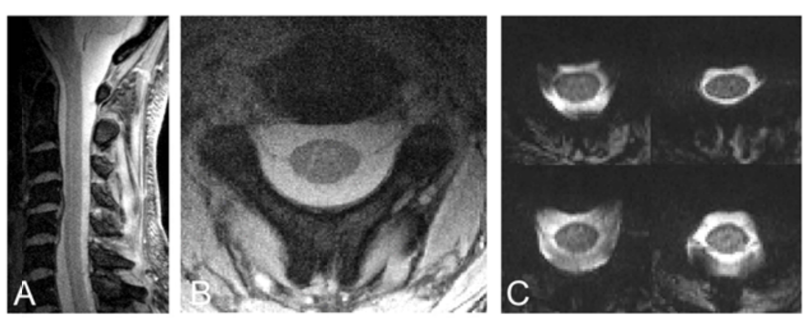

Fig4. ***A****: Sagittal FLASH at 0.5mm in-plane acquired in 20 s.* ***B****: Axial FLASH image at 0.3mm in-plane acquired in 1:20 min.* ***C****: Axial EPI at 0.7mm and R=3 (10 volumes averaged).*