Boosting ^{31}P signals by using a 7 channel Receive Array at 7T

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Target audience: researchers with interest in ^{31}P-nuclei spectroscopy and RF coil designers

Purpose: Direct insight in metabolic processes in the human brain, like energy or phospholipid metabolism, can be obtained by ^{31}P magnetic resonance spectroscopic imaging (MRSI). This nucleus has lower sensitivity than ^{1}H, but sensitivity can be increased by going to higher magnetic field strengths (≥7T) and the signals can be additionally be enhanced by exploiting the Nuclear Overhauser Effect (NOE). We already designed and constructed a ^{31}P birdcage coil (BC) [1] as an insert for an 8-channel, multi-transmit, octogonal shaped, ^{1}H coil [2]. This setup enabled homogeneous excitation and acquisition of ^{31}P signals, and could be used to enhance ^{31}P-signals using NOE. Sensitivity and signal-to-noise ratio (SNR) can be further increased by separating transmission (TX) and reception (RX) of the MR signal, which is why we constructed a 7-channel receive array ensuring an additional, but local, boost of the ^{31}P-signals.

Materials and methods: Each circular loop has a diameter of approximately 50mm and is made from copper wire (1.25mm^2). Each loop is tuned to 197.2MHz by 4 equidistantly positioned capacitors of 68pF and is matched to 50Ω by an additional capacitor of 162pF. This capacitor combined with a PIN-diode and series inductance (11nH) was used to actively detune each loop (Fig. 1). Loops were overlapped to minimize mutual inductance between adjacent elements and coupling between non-overlapping elements was further reduced by pre amplifier decoupling. The ^{31}P BC was made detunable (passive) by adding a series PIN-diode at both ends of each rung. All coils were connected to a 7T Siemens Magnetom system through home-built interfaces.

The unloaded-to-loaded Q-factors were determined in a bench test. A noise correlation matrix was acquired using a noise only scan to examine decoupling between the elements. A cylindrical phantom filled with inorganic phosphate (30mM) having a comparable load as an 'average' human head was used to investigate the SNR performance. This was done by obtaining two 3D MRSI data sets (TR/TE: 1500/0.1ms, flip: 45°, FOV: 200x200x200mm^3, matrix: 8x8x8, T_{acq}; 191s) where in one examination signal was acquired with the BC and in the other with the RX-array.

Possible features such as ^{1}H multi-transmit (imaging and RF shimming) & ^{31}P + NOE enhancement were tested on a healthy volunteer (M, 24y). We acquired 3D MRSI data (TR/TE: 1500/0.10ms, flip: 45°, hard pulse excitation bandwidth: ~3 kHz, FOV: 160x160x140 mm^3, matrix: 12x12x10 & T_{acq}: 15:55min) of the occipital lobe while using NOE-enhancement, after determining the reference ^{31}P B_1-amplitude and ^{1}H B_1-shimming. Enhancement was generated by saturating the water signals (γB_1=30Hz) using WALTZ-4 scheme during the full TR, except during the 204 ms of signal acquisition [3].

Results: The Q-factor ratio was 2.7 ± 0.3 and the average noise correlation was 10 ± 7%, with its maximum of 23% found between elements 3 & 6 (Fig. 2). A 7-fold increase in SNR was found when separating TX and RX (Fig. 3). High quality spectra of the full spectral range of interest could be obtained from 7.3cc voxels up to 5cm within the occipital lobe (Fig. 4).

Discussion and conclusion: We succesfully constructed a 7-channel receive array enabling a significant local increase (7-fold) in SNR. This increase combined with the limited field of view of the local receive coils enables higher resolution ^{31}P MRSI, or enables a reduction in scan time. This latter feature may be reduced even further especially when exploiting parallel imaging techniques. Optimally weighted signal addition from the different coil elements, using the correlation matrix can further improve spectral quality [4]. The complete coil setup can be used to excite ^{1}H and ^{31}P signals (within one sequence) at an ultra high field strength of 7T, and ^{31}P signals can be acquired with an increased signal-to-ratio by exploiting NOE-enhancement and by receiving the signals with a local receive array.

References: [1] Van de Bank *et al.* Proc. ISMRM 22 (2014) #4810 [2] Orzada *et al.* Proc. ISMRM 17 (2009) #3010 [3] Shaka *et al.* jMR 53(2):313-340 (1983) [4] Rodgers *et al.* MRM 63(4):881-891 (2010)

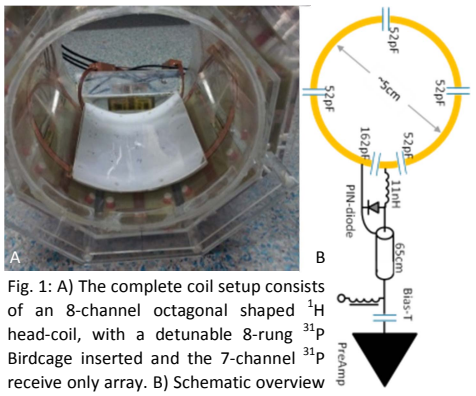

Fig. 1: A) The complete coil setup consists of an 8-channel octagonal shaped ^{1}H head-coil, with a detunable 8-rung ^{31}P Birdcage inserted and the 7-channel ^{31}P receive only array. B) Schematic overview of single detunable receive element.

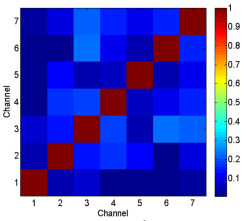

Fig. 2: Noise correlation matrix of the 7-channel receive-only array.

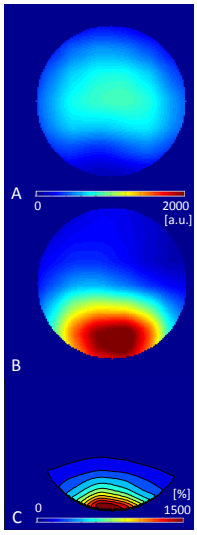

Fig. 3: Interpolated SNR images (a.u.) of a cylindrical phantom filled with 30mM in-organic phosphate. A) Acquired with the birdcage coil. B) Acquired with the local receive-only array. C) Percentual SNR increase $((B-A)/A \cdot 100\%)$, where a more than 7-fold SNR increase was achieved by separating transmission and acquisition of the signal.

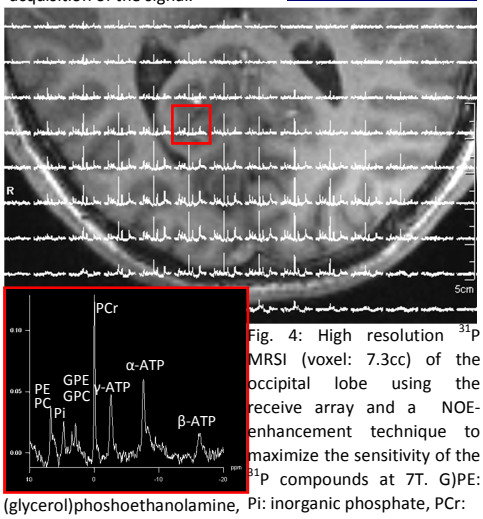

Fig. 4: High resolution ^{31}P MRSI (voxel: 7.3cc) of the occipital lobe using the receive array and a NOE-enhancement technique to maximize the sensitivity of the ^{31}P compounds at 7T. G)PE: (glycerol)phoshoethanolamine, Pi: inorganic phosphate, PCr: phosphocreatine, (G)PC: (glycerol)phosphocholine, ATP: adenosine triphosphate.