Human Brain Imaging at 7T With On-Coil Transceivers

Gudino N, Duan Q, de Zwart JA, Dodd SJ, Murphy-Boesch J, van Gelderen P, Duyn JH

Advanced MRI Section, LFMI, NINDS, National Institutes of Health, Bethesda, Maryland, USA

Advanced MRI

Introduction

On-coil current-source switch-mode amplification presents several advantages over conventional remote voltage-mode quasilinear amplification: high power efficiency, potential for fiber-optic control, more direct control of the transmit field (B_1), and decoupling of elements through the amplifier output impedance[1,2]. These advantages allow for more efficient and safer implementation of multi-channel transmit systems. Based on our previous amplifier design and pTx interface[2], we built a transceiver array for 300 MHz by adding a miniaturized transmit-receive (TR) switch and low-noise amplifier (LNA) to the on-coil configuration. This transceiver setup was chosen to facilitate safety assessment for imaging humans by eliminating the need of additional receiver hardware. This early application of on-coil transceivers for MRI of in-vivo human brain was performed at low transmit power.

Methods

Hardware Design: Optically controlled on-coil amplifiers for 7T imaging[2] were connected to 6-cm diameter loops through a 4.2 x 4.6 cm^2 5-layer double sided PCB that contains a miniaturized TR switch and an in-house LNA[3] (**Figure 1**). The switch provides a balanced connection from the amplifier to the coil trough a pair of low loss PIN diodes and a balanced to unbalanced connection to the LNA through a 50 Ω lattice balun. Additional isolation was achieved by a PIN diode in series with the LNA. During transmission a pin diode shorts the balun output and high impedance is seen from the coil into the RX due to the double parallel resonance formed by the C_c-L_b pair. During signal reception the impedance transformation of the balun results in optimum impedance seen from the LNA into the coil (around 50 Ω) and element decoupling is provided by the low preamplifier input impedance (< 2 Ω). Two channels were placed at an azimuthal angle of 45 degrees and separated by a 3.7 cm gap on the outside of a half cylindrical former that provided electrically insulation and support to the volunteer's head (**Figure 2**).

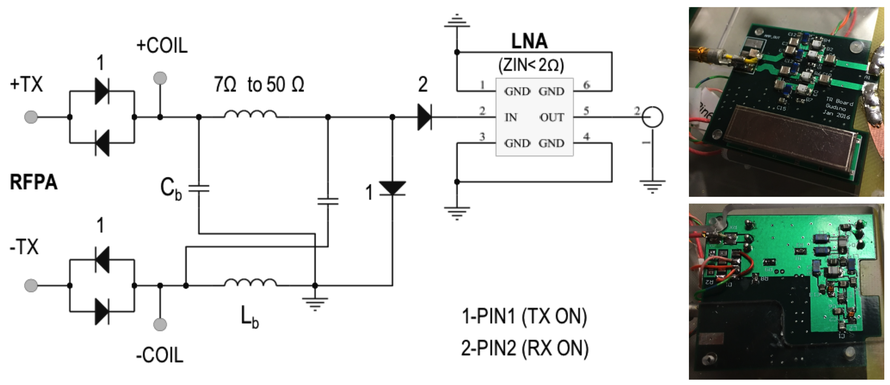

Figure 1: Simplified RF circuit diagram (DC blocking capacitors, RF chokes and PIN diodes bias circuits were omitted) and picture of TR switch and LNA double sided PCB.

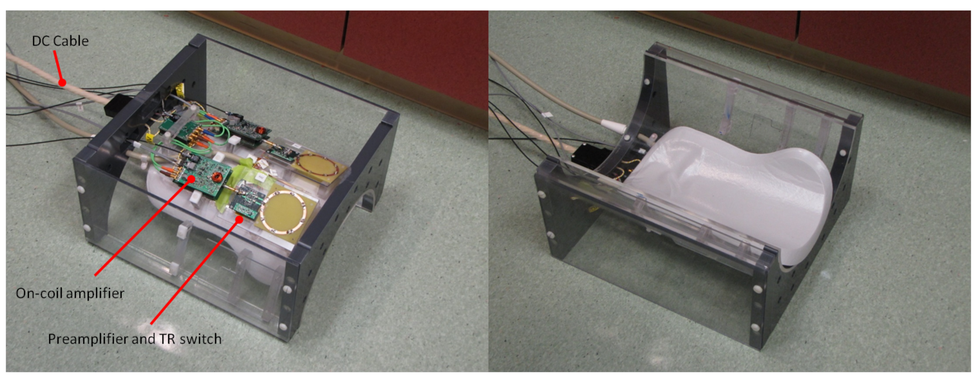

Figure 2: Preliminary 2-channel on-coil TX/RX head array.

Phantom Imaging: Axial images of an oil phantom were acquired with a single transceiver element using a GRE sequence with a rectangular RF pulse, TRF=4 ms, TR=2 s, TE= 3.18 ms, FOV=144 x 108 mm^2, resolution= 1.1 x 1.1 x 2 mm^3. SNR maps were calculated from these images.

SAR simulations: Electromagnetic simulations were performed with a cylindrical phantom with volume similar to human head and electrical properties similar to brain tissue (σ=0.55 S/m and ε=52)[4]. SAR10g was computed for total average delivered power of 0.4 W while the phase of one channel was incremented in 45-degree steps.

In-Vivo Brain Imaging: The setup is shown in **Figure 3**. The optical interface and amplifier design have been detailed in our previous work[2,5]. The RX signal is sent to the scanner console through the coil connection on the patient table, which provides the PIN diode signals and DC bias for the LNAs. In this initial experiment, peak power per amplifier was below 20 W by limiting the total input power to 40 W. Excitation duty cycle was limited to 1% to keep average total input power below 0.4 W based on the worst-case predictions from SAR simulations where 100 % power efficiency was assumed. Additional safety protections were added by monitoring DC input current and by placing slow fuses in the power line. Images of a volunteer brain were acquired with a GRE sequence under an IRB-approved protocol, with a flip angle=10 degrees, TE/TR=7/500 ms, slice thickness =5 mm, FOV= 195 X 240 mm^2 and matrix size= 286 X 352.

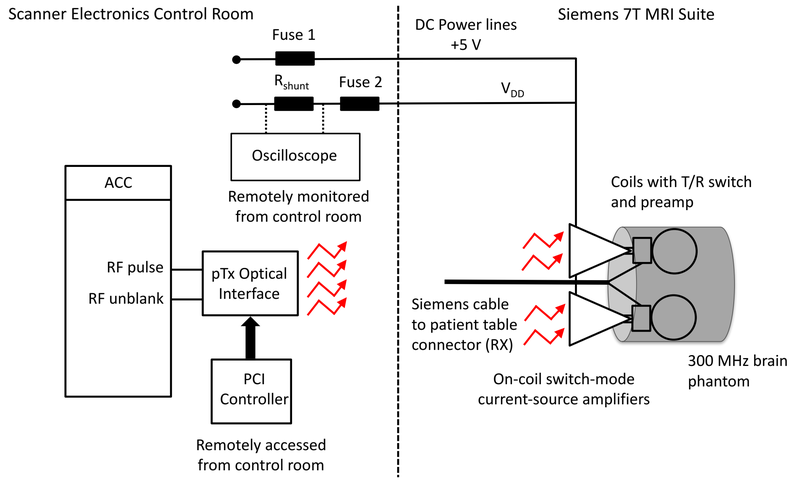

Figure 3: Hardware setup in scanner for human brain imaging.

Results

The TR switch provided ~50 dB isolation to protect the LNA during transmission. Maximum SNR was above 400 for 80-degree nominal flip angle as shown in **Figure 4a**. Noise images were acquired (RF amplitude =0) with and without the amplifier inside the bore. Less than 1% increase in the noise standard deviation was detected. The maximum local SAR10g obtained from simulations was at least 7 times lower than the FDA limit of 10 W/kg. **Figure 4b** shows an image of the volunteer's occipital brain region obtained by two-channel transmission and reception.

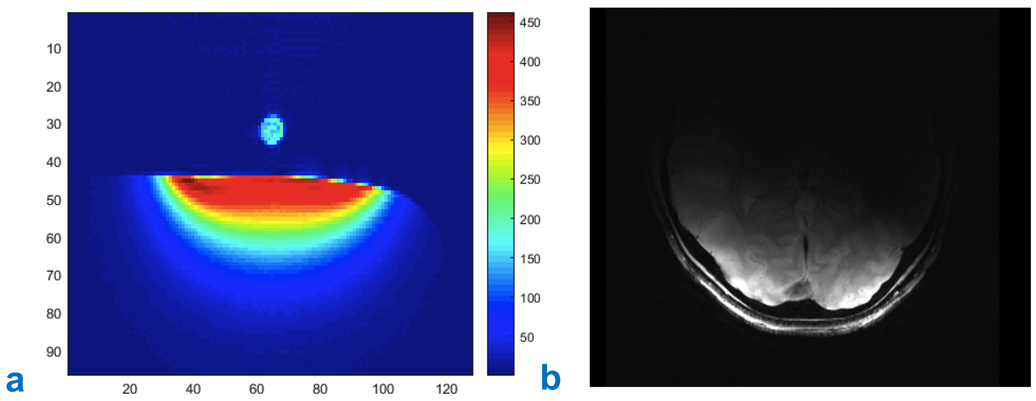

Figure 4: Test of new TX-RX hardware in the scanner. a) SNR map of oil phantom acquired with a single on-coil transceiver. b) Image of the occipital brain area from the combined signal of two RX channels.

Discussion

Successful high field implementation of on-coil transceiver technology was demonstrated for brain imaging on a human volunteer. Our on-coil transceiver setup simplifies the assessment of safety since no other coil hardware is required, and is easily extendable to a larger number of channels. We are currently working on a four-channel array that includes real-time monitoring of the transmit signal[6] (ISMRM 2017, Abstract 0758) to achieve larger brain coverage and higher B_1 amplitude, and ensure safety under high power operation.

References:
1- Gudino N, et al. Magn Reson Med. 2013 70:276-89 2- Gudino N, et al. Magn Reson Med. 2016 76:340-9
3- Dodd SJ, et al. ISMRM 2012 (Abstract 437) 4- Duan Q et al. Med Phys. 2014 41:102303
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