An on-coil current-source amplifier with integrated real-time optical monitoring of B1 amplitude and phase

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Purpose: B_1 shimming and SAR optimization at high field are possible through a parallel transmission (pTX) approach [1,2]. Commonly, optimization of the pTX excitation is based on prior information available from RF electromagnetic field simulations and MRI. Furthermore, it is possible to monitor the excitation per channel in real-time as a way to correct or confirm the target B_1 field excitation and to perform RF-safety monitoring [3-5]. To investigate a practical implementation, we exploit the integrated RF current sensor of an on-coil current-source amplifier with envelope feedback [6] to recover B_1 amplitude and phase information. Such information was digitally encoded through low power analog-to-digital converters (ADCs) to be sent optically to a controller located outside the MRI room. Here we show preliminary data by monitoring the field of a single channel in a two-channel transmission setup.

Methods: A rectangular loop (7.5 mm x 6.5 mm) was printed in an inner layer of a 300 MHz on-coil current-source amplifier prototype printed circuit board (PCB) [7]. This loop was magnetically coupled to the amplifier output traces on the top layer of the PCB, which are directly connected to the MRI coil by a short coaxial connection without any matching or tuning network (Fig 1). To obtain B_1 amplitude information, we measured the RMS voltage output of an envelope detector (ADL5511) located in the feedback loop of the RF amplitude modulation circuit (RF envelope amplifier) of the on-coil amplifier. Phase information was recovered using a pair of dual-logarithmic amplifier phase detectors (AD8302) in quadrature and located on a plug-in prototype PCB (Fig 3a). All voltage signals were digitized using 6-pin low power 10-bit ADCs and sent optically to remote digital-to-analog converters (DACs). Clock and Sync signals for the ADCs were transmitted optically into the scanner room and distributed through an in-bore circuit (Fig 3a). For a single channel, absolute voltages representing B_1 amplitude and relative phase (with respect to a second channel) were monitored in real-time by connecting the output of the DACs to an oscilloscope (2.5 GHz Infinium, Keysight Technologies). Inter-channel phase was set in a host computer that controls a custom-built pTX interface [8] while phase values were confirmed using a twin pair of pick-up loops positioned over each coil and connected to the oscilloscope. B_1 amplitude was controlled by changing the bias voltage of the amplifier power stage and measured through a calibrated probe. Images of an oil phantom were acquired in a 7 T scanner (Siemens, Erlangen) by transmitting with two on-coil amplifiers, receiving with a volume coil and acquiring signal with a gradient-echo sequence (1 ms RF pulse length, 5 ms echo time, 100 ms repetition time and 5 mm slice thickness). Control images of the phantom were acquired with same volume coil in TX/RX mode without any of the on-coil transmit hardware present. Additionally, signal was monitored with the patient table located in different positions (along z) in order to expose the setup to different field strengths (from ~0.5 T to 7 T).

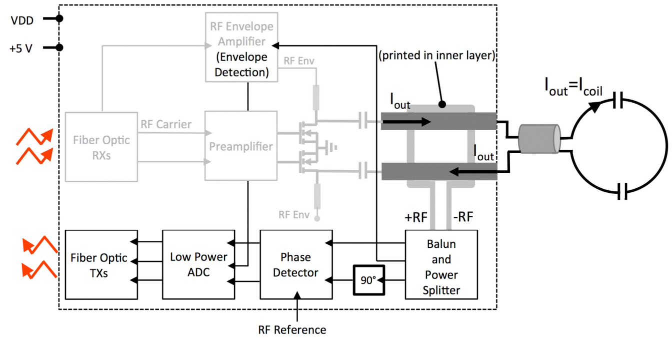

Figure 1: On-coil current-source amplifier with RF amplitude and phase detection. Signals were digitally encoded and optically transmitted to outside the MRI room.

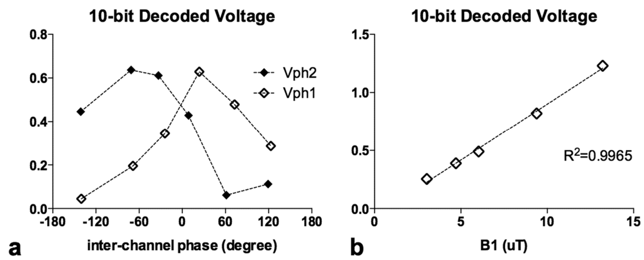

Figure 2: Decoded voltage after optical reception. Voltage per inter-channel phase (**a**) and voltage per B_1 amplitude (**b**).

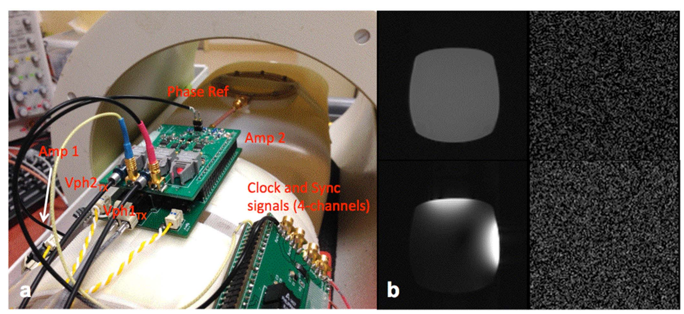

Figure 3: On-coil transmit setup in the scanner (**a**). Phantom (left) and noise (right) images obtained with a head TX/RX coil (top) and with the on-coil TX with phase and amplitude detection (bottom) (**b**)

Results: Decoded quadrature voltages (Vph1 and Vph2) versus inter-channel phase and decoded voltage versus B_1 amplitude are shown in Fig 2. Importantly, inter-channel phase could be obtained unambiguously from the voltage readings. On-coil two-channel transmission with the additional optical detection circuitry was successfully performed in the scanner. Background noise increased by 22 % compared to that of the control experiment (the low power +5 V line was disabled during RX mode) and no artifact was visible (Fig 3b). B_0 field dependence was checked for the B_1 amplitude measurement, none was detected.

Discussion: We performed direct measurements of B_1 amplitude and inter-channel phase by adding low power electronics to the on-coil amplifier, requiring a few additional optical fibers running into the scanner room. Even tough on-coil current source amplification allows implementation of well decoupled, load independent transmit arrays, real time monitoring of the excitation field will allow detection of unexpected failures of one or more TX channels which will be extremely important to assure patient safety. The design can be extended to more channels, and the optically monitored digital signals can be sent directly to the host computer that controls the pTX interface of the on-coil amplifiers, providing real-time feedback. In addition, this work shows feasibility of detection and use of the proposed electronics in the scanner environment which could be used for SAR monitoring by other transmit array configurations.

References: **1**-Mao W, Smith MB and Collings CM. Magn Reson Med. 2006 Oct;56(4):918-22 . **2**-Lee J et al. Magn Reson Med. 2012 Jun;67(6):1566-78. 3- Hoult DI, Kolansky G, Kripiakevich D. J Magn Reson. 2004 Nov;171(1):64-70.**4**-Stang P, Kerr A, Pauly J et al Proc. ISMRM 2008 (Abstract 0145). **5**-El-Sharkawy AM et al. Med Phys. 2012 May;39(5):2334-41. **6**-Gudino N , Heilman JA, Riffe MJ et al. Magn Reson Med. 2013 Jul;70(1):276-89. **7**-Gudino N, Duan Q, Murphy-Boesch J et al. Proc. ISMRM 2014 (Abstract 0320). **8**-Gudino N, de Zwart JA, Duan Q, et al. Proc. ISMRM 2014 (Abstract 0545)