Parallel transmission experiments using an extensible RF pulse generator

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Introduction: The use of parallel excitation (PEX) is a key to mitigate RF issues caused by wavelength shortening in high and ultrahigh field MR. An RF transmit chain usually consists of two main parts: the small signal chain that generates the pulses at powers in the mW range, which are subsequently boosted to usable levels by an RF power amplifier. Extending this to multiple channels yields additional challenges, since all chains need to be able to generate independent pulses but also have to be synchronized and maintain a stable phase relationship throughout the experiment. While transmit arrays are available from MR scanner manufacturers, they are usually limited in channel number and quite costly. If a parallel transmission system is to be used for transmit SENSE (txSENSE) [1] experiments, a high number of independent channels is especially important, since it directly relates to the achievable acceleration factor [2]. The design presented here, which builds upon a previous work [3], is intended as a replacement/extension of existing small signal chains and is currently capable of providing 14 independent channels. We used eight of the channels on our 3T Siemens Verio in conjunction with the power amplifier from its transmit array for static B_1 shimming and TxSENSE experiments to demonstrate the feasibility of the approach.

Methods: The system is based on a PC with one 32-Bit and three 64-Bit digital pattern generators (1x M2i.7020, 3xM2i.7021, Spectrum GmbH, Germany) and seven 16-Bit, 2-channel D/A converters (Texas Intruments DAC 5687 evaluation boards, 500 MHz sampling rate) housed in two 19" 4HE units (Fig. 1). The scanner/pulse generator interfacing is achieved through one M2i card which receives a 10 MHz reference clock from the scanner and a trigger signal that indicates the start of each pulse playback. The trigger was taken from the OscBit output of our Siemens scanner and sequences modified accordingly to switch the triggering signal. The clock and trigger signals are distributed to the other M2i cards through a so-called "StarHub" without phase delay, which ensures channel synchronicity. Since the sampling rate on the digital side is limited to 60 MHz, we use the frequency upconversion abilities of the DAC to shift the input signal to the desired 123.2 MHz. The digital signal is generated as an 8.8 MHz signal sampled at 44 MHz. After sample rate conversion and digital filtering, a 52.8 MHz signal sampled at 176 MHz and its Nyquist images, the first being at 123.2 MHz, are obtained. Applying an analogue bandpass filter at the end of the chain removes the unwanted components. Setting up the converters to the desired interpolation mode is achieved via an Arduino microcontroller (www.arduino.cc) that connects to the SPI interface of the DACs. The complete system is controlled through MATLAB (MathWorks, Natick, USA). Experiments done with the system included standard FLASH-based imaging, B_1- and B_0 –mapping and TxSENSE experiments, thus replacing the existing small signal chain for all steps of a parallel transmit experiment. Transmit SENSE pulses were calculated according to [4]. An eight channel coil (Rapid Biomed, Rimpar, Germany) was used with a 20 cm diameter cylindrical phantom load.

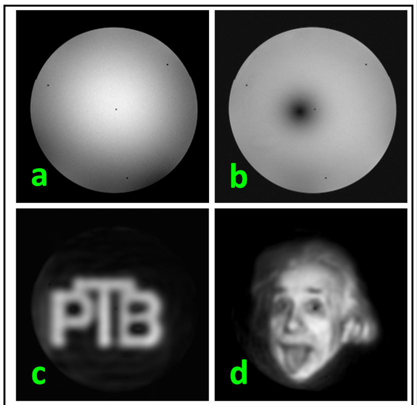

Fig. 2: Static phase shim (top) and TxSENSE (bottom) images. Image parameters : TR=50 ms, TE=2.5 ms (top); TR=100 ms, TE=5ms (bottom). TxSENSE parameters: 64² FOX matrix, 4x acceleration, 6.72 ms pulse

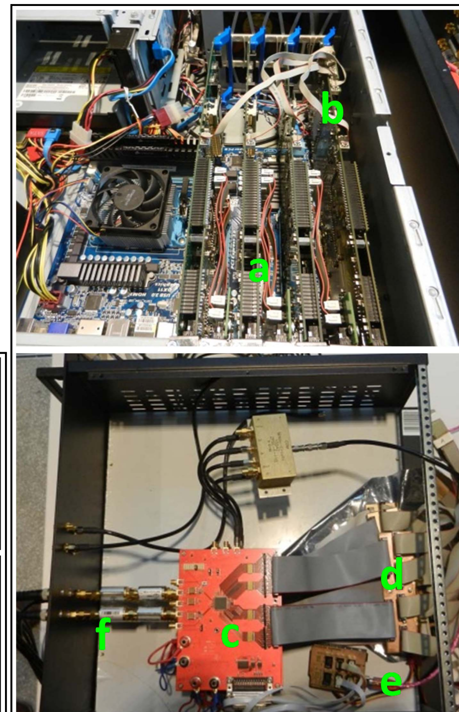

Fig. 1: Setup of the pulse generator. The digital cards (a), which are synchronized by the StarHub (b) transfer the digital signal to the stacked DACs (c) via the ribbon cables (d). The D/A setup is done via the Arduino (e). Bandpass filtering (f) of the analogue signal removes unwanted Nyquist images.

Results: Imaging results are shown in Fig. 2. Static phase shimming the coil to the equivalent of the first and second "Birdcage" mode confirms (Fig. 2 a and b) that phase relations can be adjusted and are constant throughout the imaging experiment. Transmit SENSE experiments (Fig. 2 c and d) yield a very good agreement with the calculated excitation shapes and are indistinguishable from images obtained by the Siemens array.

Conclusion: The results prove the feasibility of the proposed setup for full parallel transmission experiments. It can work with any system supplying a reference clock (usually, but not necessarily 10 MHz) and an appropriate trigger output; and was previously used on a Bruker MedSpec 30/100 3T system. It is easily adaptable to arbitrary frequencies by adjusting the frequency upconversion scheme and bandpass filters, making it usable for X-nuclei and/or different field strength proton experiments up to 300 MHz. In principle, 20 channels can be supported by one PC; and multiple PCs interlinked by larger hubs, making this a very extensible system with a comparatively low footprint and cost (~$1500/channel). Future work will include an additional four RFPAs for twelve-channel pTx experiments.

References:

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