An 8-Channel Parallel Transmit System For 7T MRI Based On Custom-Built I/Q Modulators

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Target Audience: Researchers working on parallel transmit (pTx) / ultra-high-field MRI.

Introduction:

Parallel transmission (pTx)[1,2] is a promising technique offering a variety of applications such as arbitrarily shaped excitation or reduced field of view imaging. Especially at ultra-high-field, pTx may be helpful to counter the inherent B_1 field inhomogeneities. In this work we present an add-on pTx system using custom-built modulators based on a Siemens 1-channel 7T MRI system.

Material and Methods:

The exciter channel of the 7T whole-body system (Magnetom 7T, Siemens, Erlangen, Germany) is split into 32 sub-channels by signal splitters utilizing microstrip circuit technology with industrial surface-mount power divider components. One I/Q modulator per channel is used to modulate the signal coming from the system's exciter, and 8 of these are fed into the 8 available standard power amplifiers of the 7T MR system.[4] The modulators are controlled via a 32-bit National Instruments Digital I/O Card and a customized GUI. All settings that are necessary for one sequence run, i.e. all modulator settings are loaded onto the card in advance, which then is synchronized to a trigger signal controlled by the MR sequence. The complete amplitude and phase sequences of the individual pTx RF pulse shapes are transformed into data words as needed for the communication with the modulators and downloaded onto the modulators within a few milliseconds before sequence begin.

A gradient echo sequence was modified to play out calculated pTx RF pulses and the corresponding gradient samples. As the modulators apply the individual RF pTx amplitude and phase values of each channel during the sequence to generate the desired pulse shape, a simple rect pulse with the pulse duration is played out by the exciter. As the total number of trigger events is restricted by the system architecture and the minimum trigger duration is 10 µs, the sequence can only play out trigger pulses every 20 µs. To enable 10 µs pulse sampling, the trigger events are duplicated by a custom-built hardware device consisting of two monostable multivibrators with one of these acting on the rising edge and one acting on the falling edge. This hardware thus forms a trigger pulse with 2.5 µs length every 10 µs. The first trigger is issued 20 µs before the start time of the RF / gradients.

During initial measurements an artifact was observed that appeared as concentric rings around the isocenter (Fig. 1a). The artifact was hypothesized to be caused by a constant amplitude offset of the modulators, a certain percentage of the actual RF amplitude. Bloch simulations confirmed this hypothesis: adding a constant value to a pTx pulse resulted in a similar pattern (Fig. 1b). To ameliorate the artifact, the modulation strategy was changed. Instead of a rect pulse, a modulated pTx pulse is used which always applies the maximum amplitude of all 8 individual RF pulses, thereby generating a variable dynamic range that minimizes the offset (Fig. 2).

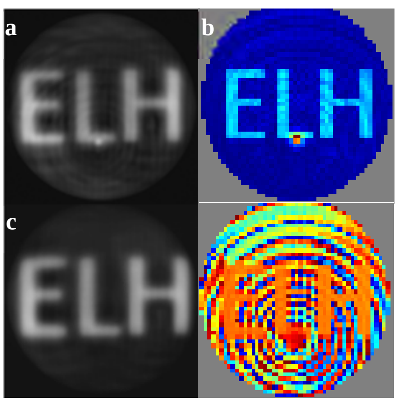

Fig. 1: *Selective excitation with offset error (a) and with modified modulation strategy (c). Simulation (b): Adding a 16% amplitude offset to a pTx pulse with spiral gradients results in an artifact consisting of concentric circles around the isocenter (top: magnitude / bottom: phase).*

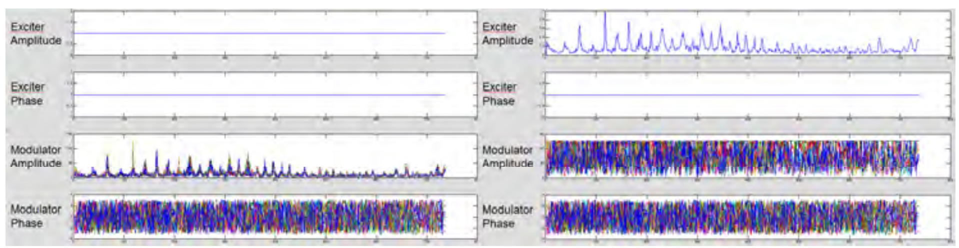

Fig. 2: *Initial modulation strategy (left) and applying dynamic ranging (right).*

Based on relative B_1 mapping with a turboFLASH sequence (resolution 64 x 64), a spiral gradient with variable density was used for pulse calculation leading to a pulse duration of 7 ms with a sample duration of 10 µs. To constrain the pulse duration, the RF pulse was non-selective in the slice direction. As a target magnetization, the letters "ELH" were used. A delay between gradient and RF system resulting in rotation of the excited magnetization was corrected by shifting the exciter RF pulse 4 µs relative to the gradients.

Imaging conditions: single slice with 5 mm thickness, TE = 7.3 ms, TR = 100 ms, FOV 24 cm x 24 cm, matrix 128 x 128, spherical oil phantom (polydimethylsiloxan) with a T_1 of approximately 1420 ms, and a custom-built 8-channel Tx/Rx head coil[3]. No SAR supervision was applied.

Results:

With this approach it was possible to successfully synchronize the gradients and modulators. The modified modulation strategy with variable dynamic range was able to suppress the artifact caused by the modulator offsets (Fig. 1c). The transition time of up to 3 µs required for the modulators to switch between states does not seem to severely influence the quality of the excited magnetization. Due to being limited to 8 amplifiers, only 8 channels were used. However, it could be verified that the modulator system is fast enough to switch the states of all 32 channels with 10 µs raster time.

Discussion and Conclusion:

Delays between gradient and RF hardware can be balanced by shifting either the RF pulse relative to the gradient raster or by manipulating the modulator setting rate. As the modulator system is fast enough to switch 32-channels, pTx functionality could be easily expanded to more channels given additional RF amplifiers. One possibility are custom-built amplifiers located inside the magnet room[5]. For in-vivo measurement, SAR supervision would have to be implemented.

References: 1. Katscher et al. MRM 49:144-150 (2003). 2. Grissom et al. MRM 56:620-629 (2006). 3. Orzada et al. ISMRM 2009, abstract 3010. 4. Shooshtary et al. ISMRM 2014, abstract 544. 5. Solbach et al. ISMRM 2014, abstract 1287.

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