Development of a Multi-Channel Transmit Extension for a Broadband RF-Electronics and its Evaluation on a 9.4 T Animal Scanner with 8 Transmit Channels

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Introduction

In the last years the concept of parallel RF transmission has gained considerable interest, especially in the domain of high field MRI. In essence two principal application domains have emerged from this concept: the field of static B_1-inhomogeneity compensation, also known as B_1-shimming [1,2,3], and the technique of accelerated spatially-selective excitation (SSE), also known as Parallel Excitation (PEX) or Transmit SENSE [4,5], for improving the performance of many useful applications of SSE such as inner-volume imaging or targeted spectroscopy.

In the field of B_1-shimming the demands on the RF system are moderate. The RF system must only be capable of generating the same RF pulse on different channels with individual, but time-constant amplitude scaling and phase offsets. This can be realized by RF splitters, amplitude modulators and phase shifters. In contrast, to perform PEX-experiments the RF system must be capable of generating different complex RF waveforms on multiple transmit channels with high accuracy. Recently, several experimental studies of PEX with 4 and 8 transmit channels have been performed [6,7,8] and it has been shown that for doing PEX with high spatial resolution and high acceleration factors, the RF system must be equipped with a sufficient number of transmit channels. Therefore, the aim of this work was to develop a multi-channel transmit extension for a broadband RF electronics with the potential of driving large numbers of transmit channels and to implement this electronics concept on a 9.4 T animal scanner with 8 transmit and receive channels.

Materials and Methods

The novel multi-channel transmit extension developed in this work is based on an Avance III spectrometer platform (Bruker BioSpin, Rheinstetten, Germany). This platform features in its standard MRI version up to 6 so-called frequency controllers. Each of these sequencer components drives via an LVDS interface one so-called signal generation unit (SGU), where by using the digital frequency, amplitude and phase information issued by the frequency controller an analogous RF signal is generated which is fed into a high power RF amplifier. With this basic configuration it is possible to operate up to 6 fully independent transmit channels which are capable of working at individual frequencies from 5 to 1072 MHz and which can generate RF pulse shapes with a minimum duration of only 25 ns per shape point. For this electronics setup which features the full flexibility of a high resolution NMR spectrometer, a so-called Parallel Excitation Multiplexing Component (PEXMUX) was developed in order to significantly increase the number of transmit channels for PEX applications in MRI. With its first version this PEXMUX-component enables each frequency controller to drive up to 8 SGUs by distributing the digital control signals from one frequency controller to multiple SGUs (see Figure 1). Apart from an increased minimum duration of the pulse shape points (now 200 ns) which still exceeds the needs of PEX-experiments, the performance concerning synchronization and temporal precision is fully maintained since the multiplexing is performed entirely on the digital side of the RF electronics. With this PEXMUX-component the limitation to 6 transmit channels is overcome and with the 6 available frequency controllers one could operate potentially up to 48 transmit channels.

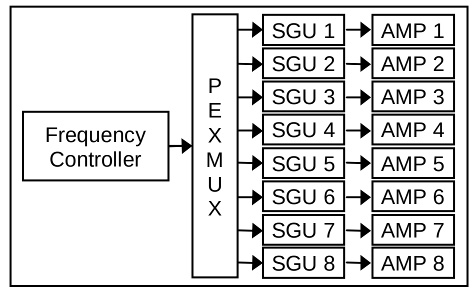

Fig. 1

On the software side the development of the PEXMUX-component was accompanied by the implementation of so-called multi-shape RF-pulses into the spectrometer control environment. With the help of this infrastructure all available transmit channels can be smoothly operated from one single pulse program executed on one single host computer. The usage of multi-channel RF-pulses for B_1-shimming or PEX can now be easily integrated into standard pulse programs by replacing normal RF pulses by such multi-shape pulses which specify the individual RF waveforms to be generated simultaneously by the multiple transmit channels.

Results

On the basis of this multi-transmit extension, a 9.4 T, 30 cm bore animal scanner was built up with 8 transmit and receive channels. Each transmit channel was equipped with a 1 kW RF-amplifier. The system was successfully tested in first experiments of B_1 shimming and PEX by using a novel 8-element TX/RX volume-array with an inner diameter of 72 mm (ITEE, University of Queensland, Brisbane, Australia). The images in Figure 2 show the transmit sensitivity distribution of the different array elements measured in a cylindrical bottle with T_1-doped saline water solution (∅=45 mm, ε=76, σ=0.2 S/m). Figure 3 shows the case where the transmit phases are adjusted to obtain a birdcage-like excitation mode. In Figures 4, 5 and 6 first results of 8-channel PEX with the new system are displayed. Figure 4 shows the parallel excitation of a checkerboard target pattern with a spiral k-space trajectory (8 turns) and an acceleration factor of 2. In Figure 5 the acceleration factor is increased to 4 corresponding to a reduction of the spiral to 4 turns. Figures 6 and 7 finally show the results when transmitting with the single array elements successively by using the factor-4-PEX-pulses (Fig. 7) as well as the complex numerical combination of these single-element images (Fig. 6). Here it can be nicely seen how the typical undersampling artefacts (Fig. 7) vanish when performing parallel transmission (Fig. 5). Furthermore, the numerical combination (Fig. 6) shows an excellent correspondence to the real PEX-experiment (Fig. 5), which is a convincing verification that the system is capable to synchronously generate individual RF waveforms on the different channels with high accuracy.

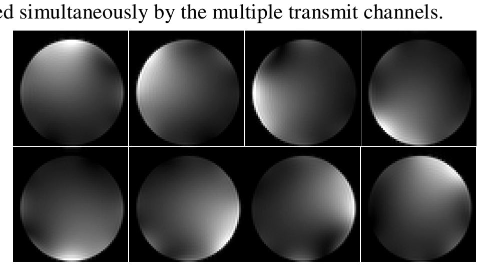

Fig. 2

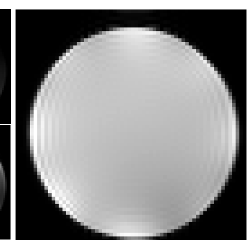

Fig. 3

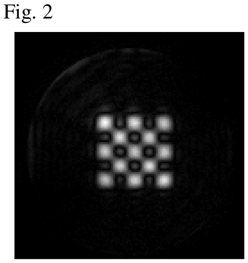

Fig. 4

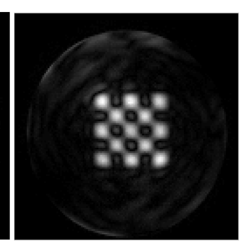

Fig. 5

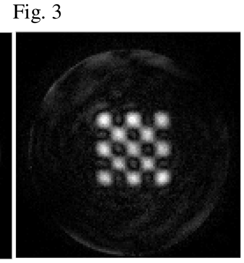

Fig. 6

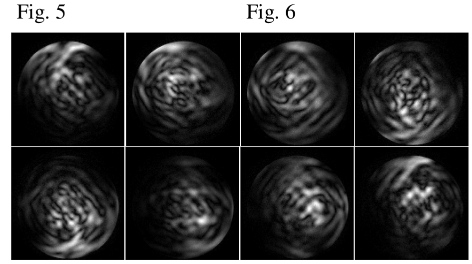

Fig. 7

Discussion and Conclusions

The results of the present study demonstrate the successful development of multi-channel transmit extension for a broadband RF-electronics and the implementation of this electronics design on an 8-TX/RX-channel animal scanner. By means of B_1-shimming and PEX experiments the full and proper functionality of the electronics has been validated. As next steps further experiments will be performed to compare systematically the performance of this 8-channel system to previously used 4-transmit-channel animal scanners.

References: [1] T. S. Ibrahim et al. MRI 18:733-742 (2000). [2] J. T. Vaughan et al., MRM 52:851-859 (2004). [3] F. Seifert et al., Proc. ISMRM 2004, p. 1569. [4] U. Katscher et al., MRM 49:144-150 (2003). [5] Y. Zhu, MRM 51:775-784 (2004). [6] P. Ullmann et al., MRM 54:994-1001 (2005). [7] I. Graesslin et al., Proc. ISMRM 2006, p. 129. [8] K. Setsompop et al., MRM 56:1163-1171 (2006).

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