

## High-Speed RF Modulation System for 32 Parallel Transmission Channels at 7T

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### Introduction:

Higher field strengths in MRI are well known for their potential to increase image resolution due to higher signal-to-noise ratio (SNR). However, due to the high dielectric permittivity of human tissue and higher resonance frequencies, and thus shorter wavelengths on the order of the human body size, RF interference artifacts are likely to occur. To overcome these constraints, parallel transmission concepts using multichannel transmit systems have gained significance throughout the past decade. An important part of such concepts is the modulation of the transmit signal using individual phases and amplitudes for each channel to adapt the resulting transmit field to restore the desired image homogeneity. Moreover, such systems facilitate applications in which only well-defined regions-of-interest in the body are excited for dedicated investigation. In earlier work [1], we gained experience with RF shimming using an 8-channel I/Q modulator system that allowed switching of shims at a rate of only about 1 kHz. In this work, we present a modular and extendable digitally controlled modulator system which is designed for high-speed and independent phase and magnitude control of 32 parallel transmission channels at 7T MRI for dynamic modulation during an MR sequence, thus allowing spoke trajectories and TX Sense in addition to static RF shimming.

### Concept:

Each of the 32 channels of the parallel transmit system consists of an individual modulator and power amplifier. The exciter channels of a commercial 8-channel pTx system (Step 2, Siemens Healthcare) are split into sub channels by 1:8 signal splitters utilizing microstrip circuit technology with industrial surface-mount power divider components. Two I/Q modulators, two selectors, and two variable-gain amplifier ICs are placed on a single PCB to provide two of 32 channels in one shielded package (cassette) with the RF output ports feeding the power amplifiers that are remotely placed near the magnet [2]. Fig.1 presents the RF feed network subdivided into two parts, with each half of the system providing one RF power splitter board, the DC power supply, and the control interface for 8 I/Q modulator cassettes (16 channels). Each modulator channel can be individually assigned to one of four channels of the MRI exciter by controlling the selector. A parallel digital interface is used to control the selectors and modulators to enable the adaptive combination of selected coil elements for optimization of the transmit sensitivity and to allow dynamic RF modulation.

### Realization:

**Hardware:** The power divider unit and one modulator cassette are shown in Fig.2. The I/Q modulator IC (AD8345) requires six inputs: a differential RF input is needed to minimize feed-through, which is achieved using a balun transformer; furthermore, differential in-phase (I) and quadrature (Q) control voltages which modulate the amplitude and phase of the applied RF signal. A D-Sub connector is used to supply digital lines and ground and DC voltages for the ICs from the backplane of the 19" RF feed network rack, Fig.3. Two MAX5100 Quad Digital-to-Analog Converter (DAC) ICs are used to create differential I and Q control voltage pairs, with each voltage at 8-bit resolution, resulting in an overall resolution in the complex I/Q plane equivalent to 2x9 bits. Two more DACs control two GSWA-4-30DR matched 1:4 selector ICs. Each channel includes a variable-gain amplifier with a 0-31 dB digital step attenuator and 1 dB resolution at the modulator output, which is set to achieve the desired power level for the input of the power amplifier.

#### Control of I/Q modulator selector board:

The board is controlled by a National Instruments Digital I/O card providing 32 digital lines using NI Labview software. 16 bits are used for data and addressing for each of the two half-systems. The data bits are used to control the DACs for setting the I/Q modulator and for assignment of the exciter channels to the desired output channel. Dip switches are used to set the local address. The address bits are used to ensure that the settings and input channel assignments are used for the respective channel only. While the DAC outputs are individually preset using a write-bit, the final application of the new setting for all channels is triggered by a common latch-bit (LDAC). To switch between different modulator settings for all channels as needed, e.g., for spoke trajectories, an external trigger from the MR sequence triggers the start of output of the requisite 32-bit patterns.

### Results and Discussion:

As the I/O card can send a single 32-bit word within 40 ns (25 MHz), an overall minimum of 8  $\mu$ s is needed to set new modulator settings with the required 194 words for all 32 channels. As shown in Fig.4, after latching, another 3  $\mu$ s is needed for the modulators to output the new voltage state. Comprehensive testing showed that these states are stable and reproducible and the reset cycle can start immediately after switching. This provides sufficient speed for experiments using e.g. spokes trajectories with great flexibility. Imperfections due to hardware tolerances in the output of the modulators can be calibrated out. Given the satisfactory output linearity, an easy visual online approach using specific patterns observed by a vector network analyzer can be used, Fig.5. Thus, offsets and gain imbalance of the I and Q channels can be compensated and the insertion phase equalized for all channels. Resulting phase variances are within two degrees, while mean amplitude deviations are in the order of five percent.

**References:** [1] Bitz A K et al.: Proc. Int. Soc. Mag. Reson. Med. 17 (2009) 4767, [2] Solbach K et al., "Near-magnet Power amplifier for 7 T MRI", abstract submitted to ISMRM2014.

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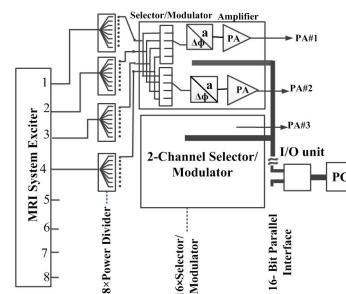


Fig.1: RF feed network for one half-system.



Fig. 2: Final design of the Power divider (left) and one of the modulator cassettes (right).



Fig.3: RF feed network components integrated into a 19" rack.

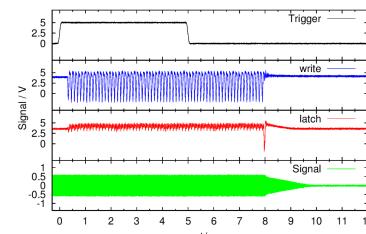


Fig. 4: A typical signal pattern as it is needed for setting the modulators on all 32 channels.

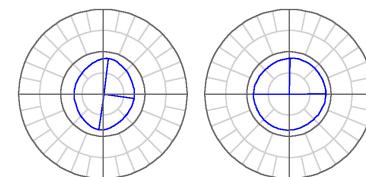


Fig.5: A calibration pattern on one channel before (left) and after calibration (right).