A fully digital RF pulse generator designed for multiple transmission channels

A. Kuehne[1], W. Hoffmann[1], and F. Seifert[1]
[1]Physikalisch-Technische Bundesanstalt, Berlin, Germany

Introduction and Motivation

Parallel excitation (PEX), in particular spatially selective excitation (transmit SENSE), is a key technique to tackle RF issues in high and ultra-field MR. Furthermore, new imaging and spectroscopic methods like inner-volume imaging and shaped-voxel spectroscopy might become feasible when using multi-channel transmit systems. Similar to parallel-receive experiments, the spatial information encoded in separate transmission coils is used to shorten the duration of the excitation pulse. The latter is necessary to overcome off-resonance effects and T2* issues. It has been shown, that the quality of the resulting excitation pattern is directly related to the acceleration factor, which itself is limited by the number of available independent RF-channels [1]. Since multi-channel transmit arrays are still rare and an upgrade of existing scanners using standard hardware, i.e. analogue quadrature modulators, is limited by cost and size of the equipment, a novel approach using direct digital signal generation is presented. Our set-up features four channels but the design is capable of supplying up to twenty independent RF channels for frequencies up to 300 MHz.

Materials and Methods

The system was designed to supplement a 3T Bruker Medspec30/100 whole body scanner but it can easily be adapted to other scanners. It is composed of a conventional PC with additional hardware, namely a digital I/O PCI board (M2i.7020, SPECTRUM GmbH, www.spec.de) for generating the digital waveform signal and 16 bit D/A-converters (Texas Instruments DAC 5687) for the subsequent analog signal generation. The M2i features sample rates up to 125 MHz at a resolution of 32 bit and extensive triggering possibilities for integration into the existing scanner hardware. The DAC 5687 offers two 16-Bit channels at a maximum sample rate of 500 MHz. Using 16 Bit per channel and channel multiplexing, the realized setup, using one M2i and two DAC 5687, provides four independent RF channels. The M2i's upper frequency limit of 62.5 MHz in multiplexed mode is countered by the D/A-converter's capabilities for digital signal up-conversion, interpolation and filtering. Using sampling-rate multiplication provided by the DAC 5687 and proper settings of the interpolation filters, a signal with a base frequency around 10 MHz sampled at 45 MHz is converted into the desired 125 MHz signal for the 3-T scanner. After simple wideband analog filtering and amplification the signal can be fed to the transmit coils. RF pulses with arbitrary sequences of both, amplitude and phase, can be set by the digital input and the digitally controlled output stage of the DAC 5687. Since there is no analog mixing stage there is also no leakage of the carrier frequency, in fact there is no carrier signal beyond the desired RF pulse. To ensure frequency and phase stability, all subsequent frequency generation is derived from the 10 MHz reference clock of the scanner (Fig.3). Pulse replay is initiated by a TTL signal from the scanner fed to the trigger input of the digital I/O-board. To determine the phase stability of the whole RF system, including the scanner's receiver system, we recorded a batch of 256 FID's and calculated standard deviation of the signal phase. To demonstrate the feasibility of the 4-channel RF pulse generation chain we performed static phase FLASH-type imaging using a four channel current-sheet antenna array [2,3] and a cylindrical head sized phantom (Fig.1).

Results

A single FID recorded after excitation with a 2ms Gauss pulse generated by the system is shown in Fig.2. From 256 sequential measurements we determined the standard deviation of the signal phase to be in the range of 0.03 – 0.06 radians (1.5° – 3.5°). These numbers incorporate the finite SNR, hence, they are upper bounds of the phase jitter. In Fig.4 images of 3 static 'B_1-shimming' experiments are shown. After calibration of the overall phase of the transmit channels the elements of the 4-channel CSA-array were fed with constant phase shifted pulses to generate static patterns as depicted in the figure. For demonstration purposes, we reproduced the 'birdcage', 'inverted birdcage' and 'donut' mode, all known from previous experiments with the original transmission chain of the scanner [2,3].

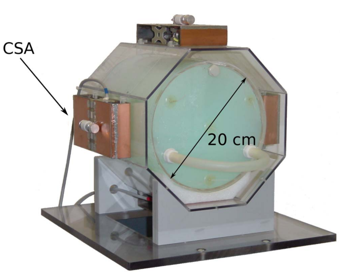

Fig.1: CSA coil array and phantom

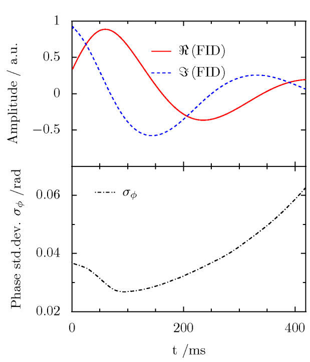

Fig.2: Single FID excited by the fully digitally MR pulse generation chain (top), standard deviation of the phase of 256 consecutively recorded FID's

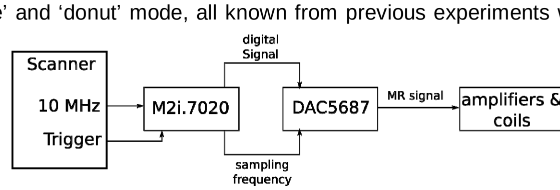

Fig.3: Block diagram of the fully digitally MR pulse generation chain

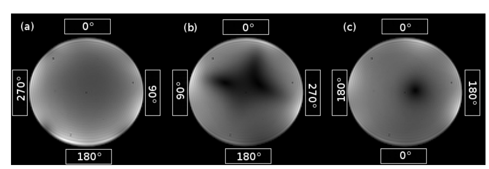

Fig.4: FLASH images with 4-channel static phases as depicted in the figure: 'birdcage' (a), 'inverted birdcage' (b), and 'donut'-mode (c).

Conclusions

We introduced a fully digital multi-channel MR pulse generation chain, inherently lacking many drawbacks of conventional designs. Measurements of phase jitter and first static phase images using a 4-channel transmit/receive coil array have demonstrated the feasibility of this approach. The system is intended as a low cost ($1000 per channel) complement to current controlled coil designs (^{2}CONTAR [4]), providing up to 20 channels controlled by a single PC.

References

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