An 8-channel add-on RF shimming system for whole-body 7 Tesla MRI including real-time SAR monitoring

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Introduction

In high-field MRI, transmit field (B_1^+) homogeneity inside the human body is often affected by destructive and constructive interference of the electromagnetic waves. Approaches such as Transmit SENSE [1, 2] or RF shimming [3, 4] can be utilized to mitigate effects on image quality provided that multiple transmit channels are available. In contrast to Transmit SENSE, the RF shimming approach transmits the same RF pulse envelope on each channel and, therefore, does not require individual exciters. Thus, a multiple transmit system adapted for RF shimming can be realized with moderate hardware and software modification by splitting the excitation signal of a conventional single-channel system into the desired number of channels. Subsequently, the channels can be weighted by amplitude and phase shifts optimized with respect to B_1^+ homogeneity. The benefits and limits of RF shimming are the subject of current research in high-field MRI, in particular for regions of interest outside the brain. Therefore, an add-on system for RF shimming was integrated into a 7 T whole-body MR scanner (Magnetom 7 T, Siemens Healthcare, Erlangen, Germany). To guarantee safe operation of the multi-channel system with respect to RF absorption in the human body, real-time monitoring of the transmitted RF power per channel was implemented.

Materials & Methods

The RF amplifier of the standard system consists of 8 individual modules providing 1 kW each (LPPA 13080W, Dressler, Germany), which are combined to provide 8kW of RF power in the single-channel configuration. Consequently, an 8-channel RF shimming setup could be designed and realized on the small-signal side of the system. Attenuators and phase shifters were inserted into the low-power RF chain directly at the output ports of the splitter (Fig. 1). Thus, these functions could be realized by inexpensive I/Q-modulators which enable computer-controlled adjustment of the transmit parameters of the individual channels. In the conventional single-channel mode, the modulators are bypassed with RF relays. The 8-channel mode is activated by coaxial relays (CX600N, Tohtsu, Japan) connected to the output ports of the RF amplifiers.

Optimized sets of amplitude and phase shifts are computed based on B_1^+ maps acquired in each subject for the individual channels of the coil array. The maps are automatically loaded into a graphical user interface which allows the selection of a region of interest over which the transmit field should be optimized using various shim algorithms. After the desired shim is chosen, the vector modulators are automatically programmed with the corresponding amplitude and phase settings by the control computer.

On-line RF supervision is performed by use of three logarithmic root-mean-square (rms) power meters which monitor forward and reflected power of up to three channels each via directional couplers with a sampling rate of 50 kHz per channel (TALES, Siemens Healthcare). A multiplexed, power-equivalent voltage is acquired and de-multiplexed by a real-time field programmable gate array (NI PXI 7852 R, National Instruments). The FPGA software performs time-averaging of the transmitted RF power according to the IEC safety guidelines. If safety limits are exceeded, the software immediately blanks the RF power by emergency relays located in the vector modulator circuit.

Various 8-channel Tx/Rx-coil arrays can be utilized with the shimming system, including dedicated coils for the head, the abdomen and thorax, the spine, and the carotids.

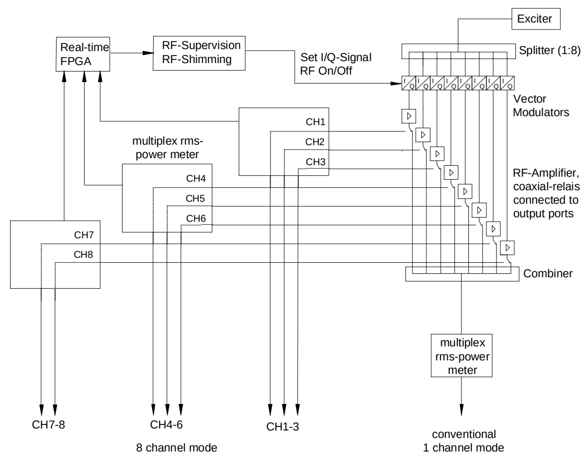

Fig. 1: Schematic of the 8-channel RF shimming system.

Results

Fig. 2 shows axial images obtained with a flexible body array in the trunk of a volunteer with 100 kg body mass. When driven in the circularly polarized mode, the overall image quality is quite good for 7 T; in the right image, the transmit field has been shimmed to achieve a uniform excitation of the right body region. In Fig. 3 a spine array was used to acquire FLASH-3D images in a volunteer with known scoliosis. Using RF shimming, the B_1^+ inhomogeneity (dark line to the right of spine) was shifted outside of the spine. The system has also been applied to improve signal uniformity in smaller regions of interest, e.g. in cardiac imaging (Fig. 4).

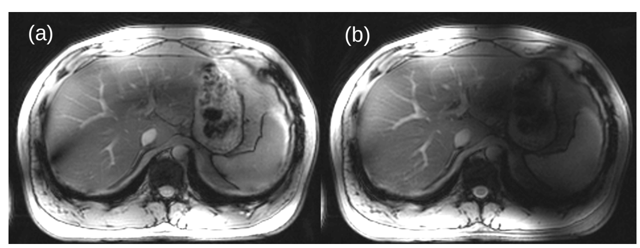

Fig. 2: T1-weighted FLASH image, in-phase, breath hold. (a) Circularly-polarized mode (phase shift 45°) of a flexible body array; (b) shim optimized for $B1^+$ homogeneity in the right body region.

Fig. 3: Coronal FLASH-3D image of a volunteer with known scoliosis.

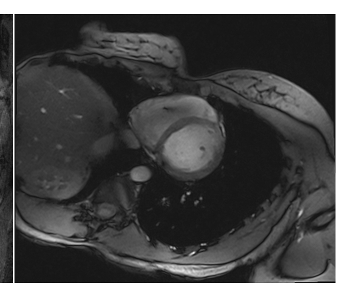

Fig. 4: Cardiac image: short axis, cine FLASH sequence, female volunteer (1.65 m, 60 kg).

Conclusion

An add-on system for RF shimming was integrated into a 7 T whole-body MR scanner. It was primarily realized on the small-signal side of the MR system, and enables computer-controlled setting of amplitude and phase of each transmit channel as well as on-line RF supervision. No significant modification of the existing MR system is necessary for integration, and the system can easily be switched between the conventional single-channel mode and multi-channel operation. The system enables research on the limits and benefits of RF shimming in various body regions. The setup has already been successfully utilized for MRI of the human head and trunk with dedicated coil arrays.

References

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