RF monitoring of the complex waveforms of an 8-channel multi-transmit system at 7T utilizing directional couplers and I/Q demodulators

I. Brote[1,2], K. Solbach[3], S. Orzada[1,2], O. Kraff[1,2], S. Maderwald[1,2], M. E. Ladd[1,2], and A. K. Bitz[1,2]
[1]Erwin L. Hahn Institute for Magnetic Resonance Imaging, Essen, Germany, [2]Department of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Essen, Germany, [3]High Frequency Engineering, University Duisburg-Essen, Duisburg, Germany

Introduction : SAR prediction and monitoring are essential for the safe operation of MR systems, especially at higher field strengths due to increased power absorption. With the application of multi-transmit approaches, e.g. RF shimming, RF monitoring becomes an even more challenging task, since several channels have to be supervised simultaneously. An approach to accomplish this task for multi-channel RF shimming systems has been presented in [1]. It is based on the supervision of the accepted power per channel by root-mean-square (RMS) power meters and online comparison of the actual amplitude ratios in the transmit channels to the target ratios of the applied RF shim. In the following, an extension of this approach is proposed which incorporates online monitoring of the RF phase by use of directional couplers and I/Q demodulators. In contrast to other monitoring systems [2, 3, 4], the proposed set-up is capable of measuring the phase and amplitude of the forward and reflected signals in each transmit channel. Furthermore, due to matched impedance conditions, the direct assessment of the complex scattering matrix of the coil array is possible.

Material and Methods: Experiments were performed on a 7T whole-body MR system (Magnetom 7T, Siemens Healthcare, Erlangen, Germany) which has been extended with a custom-built eight-channel RF shimming system [5]. The existing online RF power supervision utilizes logarithmic RMS power meters (TALES, Siemens Healthcare) equipped with built-in directional couplers and sample-and-hold circuits, which monitor the amplitude of the forward and reflected power for each transmit channel in conjunction with a FPGA acquisition card (NI PXI 7852R, National Instruments). In addition to this RF power supervision, a second independent supervision system has been implemented which allows for the simultaneous monitoring of the phase and amplitude envelopes of the forward and reflected signals. For this purpose, I/Q demodulators have been connected to independent directional couplers located at the output of each RF power amplifier.

To measure only the phase shifts of the actual RF shim as adjusted by phase shifters [5] which are connected to the input of the amplifier, the modulated MR signal at the input of the phase shifters can serve as the local oscillator for the I/Q demodulators; this approach implies that phase modulations of the RF pulse itself are disregarded. The 32 I/Q signals from the demodulators are processed with a sampling rate of 10 µs by a second FPGA card (NI PXI 7852R) equipped with additional analog input modules (NI 9222). The two FPGA cards are integrated into a PXI chassis, and both cards can be operated simultaneously by software programmed in LabView. The accuracy of the phase measurement with the described I/Q demodulators is within the range of ±10°. The correct operation of the phase monitoring system was verified by comparison of the RF amplitude envelope measured with the TALES and the RF amplitude envelope calculated from the I and Q signals of the demodulators. Furthermore, the measured phase difference of each channel was compared to the target phase shifts of the RF shim.

Since each amplifier is equipped with circulators and matched loads, reflected waves from the coil array are fully absorbed. This matched impedance condition enables the direct assessment of the complex scattering matrix of the coil array. This was tested with a configuration using an 8-channel head coil loaded with a phantom. To this end, a sequence was designed which plays out an RF pulse on each individual channel successively while simultaneously receiving the reflected waves from all coil channels. The full 8x8 scattering matrix can be acquired within 10 s.

Finally, a test was performed to check the suitability of the I/Q modulators for monitoring the amplitude and phase envelopes of the RF pulses themselves. A sinusoidal signal from an external generator adjusted to the transmitter frequency of the MR system was used to generate the local oscillator signal. Due to the missing phase lock between MR system and signal generator, a superimposed linear phase term and a beat frequency may be present. The latter is visible in the amplitude envelope.

Results: Fig. 1 shows a 10 ms BIR4 pulse monitored in real time. The comparison between amplitudes measured with the TALES and those measured from the I/Q signals shows a good correlation. The phase shift determined from the I/Q signals reveals the constant phase shift of the RF shim, points with undefined phase (zero amplitude) are ignored by the monitoring software. In Tab.1 the results of the phase monitoring of all 8 channels is shown for a phase increment of 45° between the channels. The maximum deviation from the target phase referenced to channel 0 is -10.5° in channel 5. The scattering matrix for the 8-channel head coil with phantom is given in Fig. 2, depicting the predominantly diagonal pattern of the scattering matrix. Fig. 3 shows the amplitude and phase envelope of an adiabatic BIR4 pulse calculated from the I/Q signals using the external sinusoidal local oscillator signal. The measured waveform reflects the BIR4 pulse but shows an superimposed phase term and small distortions of the amplitude envelope due to the nonexistent phase lock.

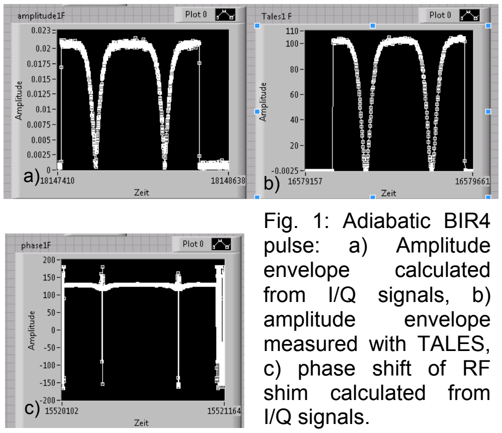

Fig. 1: Adiabatic BIR4 pulse: a) Amplitude envelope calculated from I/Q signals, b) amplitude envelope measured with TALES, c) phase shift of RF shim calculated from I/Q signals.

Channel	Target phase difference of RF shim	Measured absolute phase	Phase difference (reference channel 0)
0	0°	-135°	0°
1	45°	-91.5°	43.5°
2	90°	-46.5°	88.5°
3	135°	-3.5°	131.5°
4	180°	38°	173°
5	225°	79.5°	214.5°
6	270°	127°	262°
7	315°	179.5°	314.5°

Tab. 1: Comparison of the target phase difference for the applied RF shim and the phase difference measured by the I/Q demodulators.

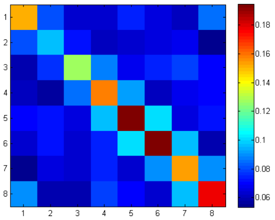

Fig. 2: Magnitude of the 8x8 scattering matrix.

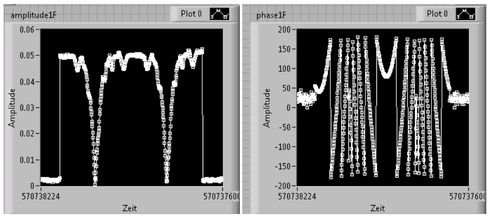

Fig. 3: Amplitude and phase envelope of an adiabatic BIR4 pulse calculated from the I/Q signals of the demodulators

Conclusion: A full RF monitoring setup for an RF shimming system has been successfully implemented which can simultaneously supervise both the phase and amplitude envelopes of the RF pulses in all channels. A good correlation between the TALES and the calculated amplitude from the I/Q signals was achieved. Since the factory-calibrated TALES units and the amplitude/phase monitoring units proposed here can be operated simultaneously, the calibration of the I/Q demodulators can be performed by comparison to the TALES data. The complex scattering matrix of the loaded coil array, which is of interest for computation of the power balance and as a constraint for pulse design, can be assessed in less than 10 s. The implemented system can also monitor the amplitude and phase envelopes of the RF pulses themselves, which would be of great interest for monitoring multi-dimensional pulses utilized for transmit SENSE applications.

References [1] Brote et.al. ISMRM Safety Workshop Oct. 2010 [2] Graesslin et.al. Proc. ISMRM 2009, 302 [3] Gagoski et.al. Proc. ISMRM 2010, 781 [4] Alon et.al Proc. ISMRM 2010, 780 [5] Bitz et.al. Proc. ISMRM 2009, 4767