A stand-alone system for concurrent gradient and RF sequence monitoring

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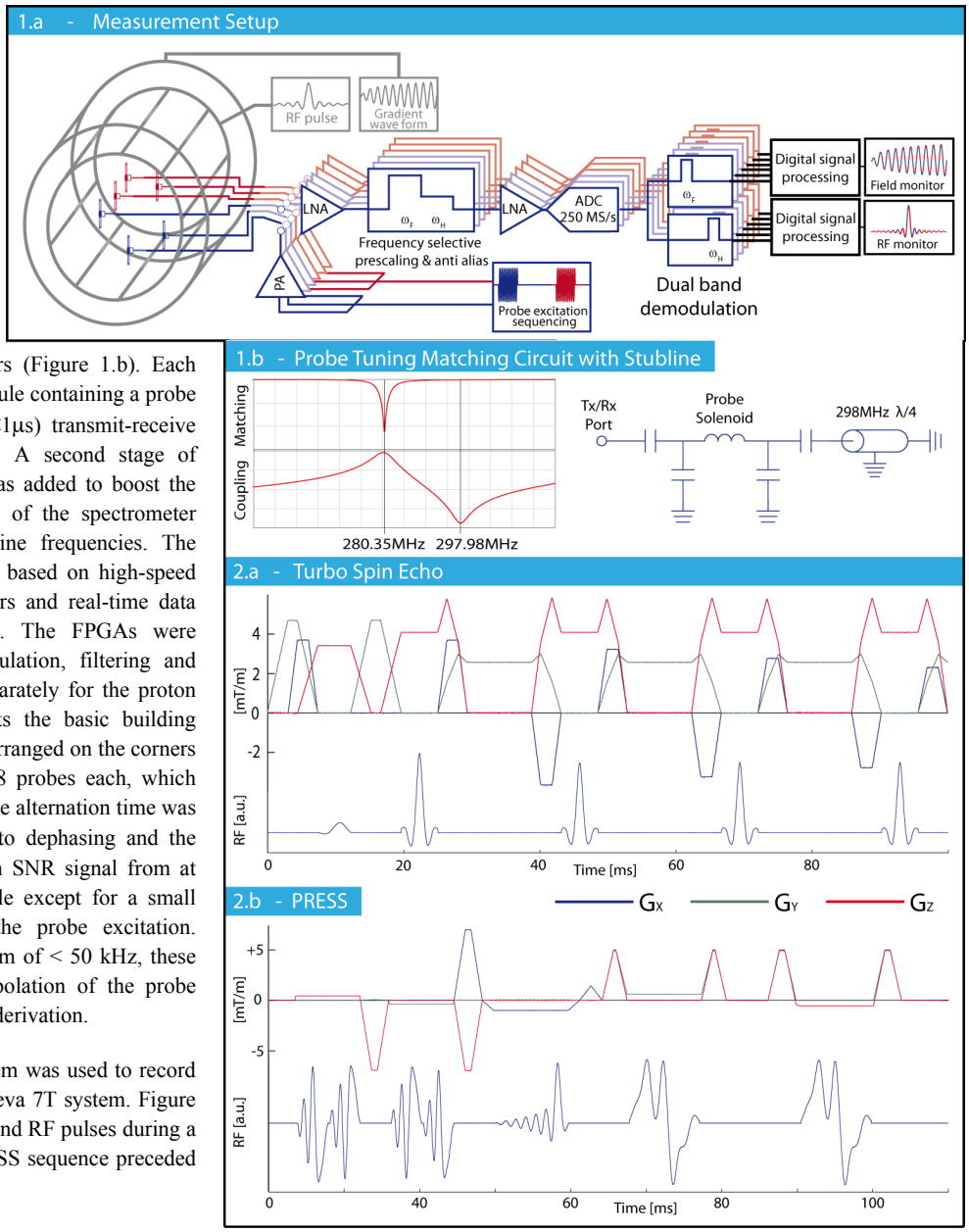
Introduction: Magnetic field monitoring using NMR probes allows the observation of the spatio-temporal field evolution during MR experiments [1,3,4,5] with high precision. However, the field sensor signal after each excitation is limited due to dephasing of the NMR sample by potentially strong gradients in the sequence. Therefore only a small continuous time interval can be robustly observed. Moreover, high-power RF transmission by the observed MR system may saturate or even destroy the probe receivers while, conversely, monitoring such transmission would add valuable information for system diagnostics and sequence development. The goal of the present work was to address these challenges, resulting in a system that permits the fully continuous observation of arbitrary gradient sequences concurrently with the recording of RF pulses played out at the same time.

Methods: The field camera head consisted of 16 field probes based on ^{19}F NMR for concurrent operation with proton MR sequences at 7T. The individual probes were built from a (2.3 mm inner diameter and approx. 4 cm length) glass capillary filled with a fluorine compound [6] doped to $T_2 \approx 280\mu s$. Six-turn solenoids (200 µm copper wire) served as transmit/receive coils. Each probe's tuning and matching circuit was equipped with a trap at the proton frequency preventing strong RF coupling to any external proton transmitters (Figure 1.b). Each probe was equipped with a custom-built module containing a probe excitation amplifier (2W), a high speed (<1µs) transmit-receive switch and a low-noise receive amplifier. A second stage of frequency selective filters and amplifiers was added to boost the receive signals to the required input level of the spectrometer concurrently for the 7T proton and fluorine frequencies. The custom made stand-alone spectrometer was based on high-speed (14Bit, 250MHz) analog-to-digital converters and real-time data processing FPGAs (National Instruments). The FPGAs were programmed to perform dual-band demodulation, filtering and decimation to 1 MHz output bandwidth separately for the proton and fluorine frequencies. Figure 1a depicts the basic building blocks of this setup. The field sensors were arranged on the corners of two nested cubes, forming two sets of 8 probes each, which were excited in an interleaved fashion [2]. The alternation time was set to 500µs to balance signal decay due to dephasing and the formation of spurious echoes. Thereby high SNR signal from at least one probe set is continuously available except for a small acquisition gap of 18µs introduced by the probe excitation. Assuming a bandwidth of the gradient system of < 50 kHz, these gaps were filled by finite-bandwidth interpolation of the probe phase data yielding field values by temporal derivation.



Results and Discussion: The resulting system was used to record sample imaging sequences in a Philips Achieva 7T system. Figure 2a shows the recorded sequence of gradient and RF pulses during a fast spin echo scan. Figure 2b shows a PRESS sequence preceded by outer volume suppression. .

Conclusion: By enabling continuous monitoring of RF and gradient pulses in arbitrary MR sequences, the presented system provides precise recordings of all NMR-relevant fields produced by a given MR system. It thus forms a useful, stand-alone tool for the calibration, verification and maintenance of MR systems and sequences and may also serve for image reconstruction purposes based on its capability of operating concurrently with imaging procedures.

[1] DeZanche et al. MRM 60:176–186 (2008) [2] Dietrich et al. ISMRM 2011, 1842, [3] Sipilä et al. ISMRM 2010, [4] C. Barmet et al, MRM 60:187-197 2008, [5] Barmet al. ISMRM 2008: 1152 p.781, [6] Barmet et al., ISMRM 2010: 216