Coil Ringdown Suppression by Broadband Forward Compensation

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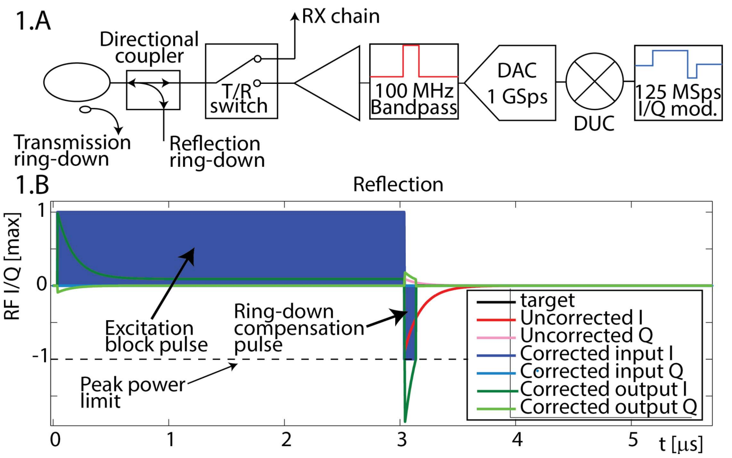

Figure 1: A setup used for the experiments. B simulations of the demodulated RF waveforms in-phase (I) and quadrature (Q) reflected from the coil for the corrected and the uncorrected pulse.

Introduction: MRI signals from high field systems (1T and more) are typically much narrower than the bandwidth of the involved digital and analogue RF components for transmission and reception. In the case of high power RF pulse transmission the RF component involved with the least bandwidth is the RF coil offering bandwidths of $BW = {}^{\omega_L}/_{2\pi\, Q} \approx 0.5 - 10\ MHz$. However with the advent of ultra-short T_2 sequences such as ZTE [1], SWIFT [2], UTE[3] requiring fast switching time, the bandwidth of the RF transmit chain becomes of critical interest, since the applied excitation pulses approach MHz scales and the ringdown time of typical coils settles in the regime of the required switching time to receive mode after transmission. The analogous problem is well known from solid state NMR, where typically active Q damping circuits [4] are applied to stop the RF power resonating in the coil to actually acquire the comparably very weak NMR signal after the pulse. Also feedback approaches [5] have been suggested to increase the bandwidth of the RF detector. However, all of these approaches require substantial changes to the existing RF coil hardware. We present in this work an approach to analytically design and generate broadband RF pulses that stop the ring-down at the end of the pulse to allow for fast switching with no excess peak RF power requirements.

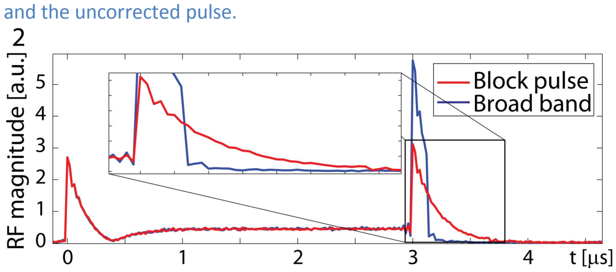

Figure 2: Bench measurements of the broadband pulse choking the ringdown of a strip line TR coil.

Theory: As shown in Fig.1.B a short block pulse (several µs) as used in ZTE causes reflections at the coil port because its bandwidth is substantially higher than that of matched coil. These reflections appear as ringdown signal propagating back towards the TR switch (trace "uncorrected I&Q"), which can consequently not be thrown to reception in such a "hot state" until the RF decayed. However, the crucial ringdown emanates from the falling flank of the pulse. Adding a 180° phase shifted block pulse of equal peak power (trace "corrected input I&Q") initially doubles the ringdown transient, but if the falling edge of this compensation pulse is timed with this transient crossing at half level, the transient emanating from the compensation pulse just cancels the one from the excitation pulse (trace "corrected output I&Q"). The duration of this compensation pulse is analytically given by $\tau = \ln\left({}^{Q}/_{\omega_L}\left(2 - 1.5\, S_{11}(\omega_L)\right)\right)$, taking the *Q* of the coil and the remnant coil mismatch (S_{11}) into account.

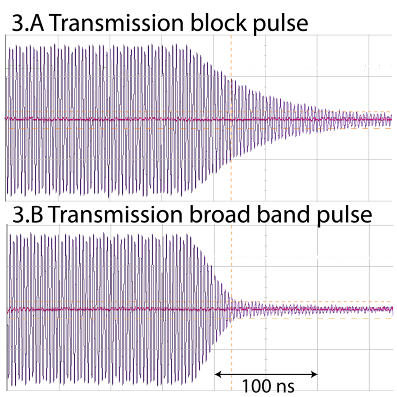

Figure 3: Measurements of the ringdown of a volume resonator TR coil in the scanner without correction pulse (A) and with (B).

Methods: The pulse design has been applied at 7T (f_0=298 MHz) driving a single strip-line element (Q~300). Bench measurements have been performed by directly driving the element using a custom built 1GSps direct digital synthesizer (DDS) with 125 MHz AM/PM modulation bandwidth. The reflected wave from the coil has been measured using a 50 MHz I/Q BW receiver (PXIe-5622, National Instruments, Austin, USA) connected via a -20dB directional coupler. Measurements on the scanner have been performed via a pick up loop whose signal was acquired with a 4GSps mixed signal oscilloscope (Agilent, Santa Clara USA). The pulse was generated by the same DDS and amplified by to 1kW peak by an NMR power amplifier (BLA-1000, Bruker, Wissembourg, France) before being transmitted by a TR volume resonator. All pulses were digitally bandpassed to 30 MHz in order to stay within the bandwidth of the rest of the transmit chain and to avoid potential issues with the power amplifiers rise time limitations.

Results: As seen in Fig.2 the 135 ns long correction pulse was found to be effective to choke the ringdown after the pulse and resulted in a 20 dB suppression at equal time points. The same applies to the ringdown behaviour seen in the scanner which allowed switching the TR switch 50 ns after the end of the pulse as opposed to 150-200 ns.

Discussion & Conclusion: The presented approach is comparably easy to implement, provides a robust calculation scheme, requires no additional coil hardware (and its inflicting losses) and most importantly no excess peak power is requested from the power amplifier. Further it does not run the risk of potential instability as active feedback schemes. Although a slightly longer pulse is sent by the wave former, no additional SAR is deposited in the subject since the power is dissipated in the power amplifier quenching the ringing. The ringdown of the coil was demonstrated to be suppressed by about 20 dB which proved sufficient to allow for 200 ns earlier switching of the TR switch and saves about 3 ringdown periods (${}^{2\pi Q}/_{\omega_L}$). Although the remaining power in the coil's resonance can still cause measureable transient signals after the pulse of a few microseconds, its dynamic range was found even 1 µs after the pulse to be comparable of that of the NMR signal, which in principle would allow for removing the disturbing signal by subtraction schemes in post processing without loss of signal-to-noise and resolution during RF signal digitization.

References: [1] Weiger, MRM (2011), [2] Bergin, Radiology (1991), [3] Idiyatullin, JMR (2006) [4] A.S. Peshkovsky, JMR (2005), [5] D. I. Hoult, Magn Reson Mater Phys (2008)