Sideband Excitation for Concurrent RF Transmission and Reception

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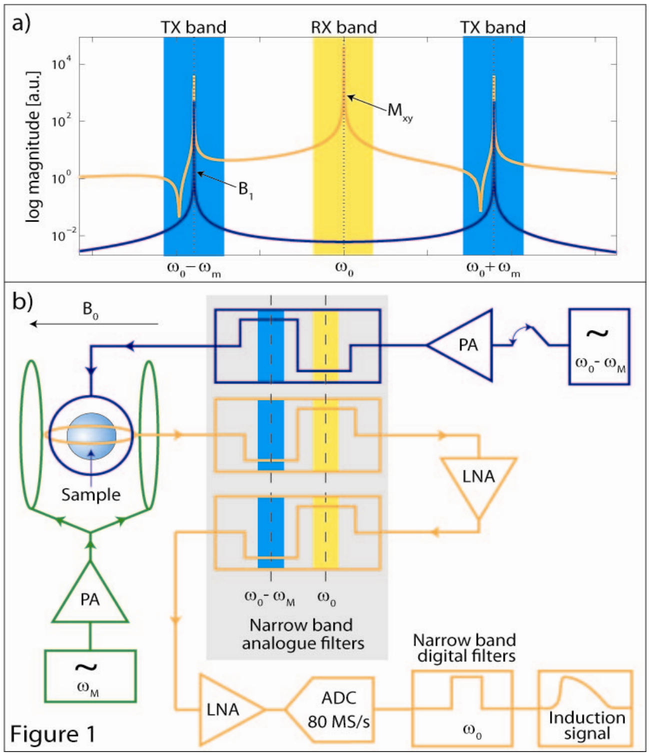

Figure 1

a) spectral separation of transmission and reception by modulation sidebands.
b) schematic of the implemented setup.

Introduction: Most NMR and MRI methods have in common that RF transmission (TX) and NMR signal reception (RX) cannot be performed concomitantly. This is mostly due to the large difference in power levels that does not allow to reliably and robustly isolate the two signal paths from each other. Nevertheless in many cases it would be useful to observe nuclear magnetization also during RF transmission, yielding immediate information about spin dynamics in the presence of the B_1 field. Important examples include stochastic resonance [1], acquisitions of ultra-short-T_2 samples and nuclei [2], measurements of relaxation parameters under RF irradiation [3], and re-excitation of NMR magnetic field sensors [4]. Concurrent TX and RX is performed in classic continuous-wave (CW) NMR. However, the isolation and stability that can be achieved with bridge measurements are limited, especially with live samples. Lock-in measurements [5] are relatively slow and limited to steady-state observations. As a more generic alternative, in the present work it is proposed to use the principle of sideband modulation [6] to separate the TX and RX bands and thus permit isolation by analog and digital filtering. Unlike original sideband *reception* concepts, high receive sensitivity can be achieved by *exciting* magnetization via its sidebands while observing it at the same time in its centre band.

Theory: Fast modulation (ω_m>$1/T_1$,$1/T_2$, line width) by a time harmonic magnetic field B_m along the main field direction produces sideband copies of the NMR lines at $\omega_0 \pm n\omega_m$ (see Fig. 1a) whose amplitudes depend on the modulation depth factor $\beta=\gamma B_m/\omega_m$. Interestingly, an RF magnetic field (B_1) transmitted at any of these frequencies (B_1) fulfils resonance condition for the sideband and induces spin nutation with an effective field of $\beta \cdot B_1$. If ω_m is chosen larger than the TX and RX bandwidths, the two bands are effectively separated. Such spectral separation readily permits isolating the high-power transmit signal from the receive chain by analogue and digital filtering.

Materials: An initial setup for operation at 7T (schematically shown in Fig. 1b) was built on a 2 cm Helmholtz modulation coil that was driven at ω_m = 2.25 MHz with a power of 10 W using a CB transceiver (YAESU FT-100). Crossed loop coils (ø = 1 cm) with a mutual coupling of -15 dB were used for transmission and detection. For simplicity only the first lower sideband was irradiated by maximally 250 mW. Each gain stage of the receive chain was equipped with a stopband filter (-55 dB in the TX band, 0.7 dB insertion loss in the RX band). The output noise of the RF power amplifier in the RX band was rejected by another stopband filter. The sample was a 5 mm PTFE tube filled with tap water.

Results: Fig. 2: The light blue plot shows a common FID that was obtained without modulation, using a TR switch in the receive chain and a 100 µs on-resonant block excitation pulse. The green plot shows an excitation induced via sideband modulation. Arrow a) indicates noise injected when switching on the modulation field, which was kept on until the end of the acquisition. At point b) the RF power was switched on for a 1ms block pulse. Concurrent acquisition shows the resulting build-up of transverse magnetization. After switching off the RF power at t=0, an FID is observed again. The black curve shows the signal magnitude acquired during a 20 ms block pulse with sideband modulation. It directly reflects the initial build-up and approaches a plateau. Since the pulse is much longer than the dephasing time of less than 2 ms seen in the FID, it effectively performs spin locking, which can be observed directly in the sideband approach.

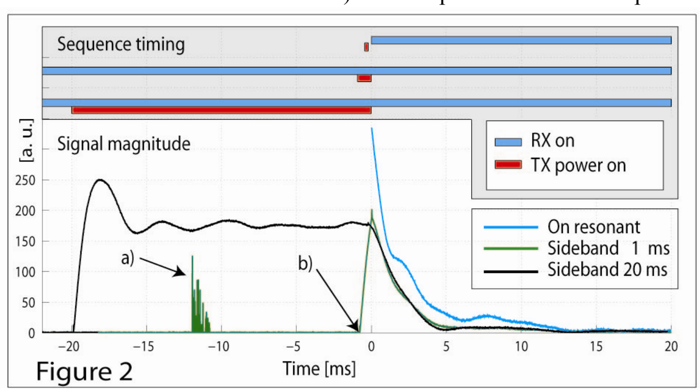

Figure 2

Pulsed FID (blue) and signal acquisitions from concurrent excitation and detection (green & black).

Conclusions: The proposed technique permits concurrent NMR excitation and detection by spectral separation of transmit and receive signals, which obviates excessive isolation requirements. As long as it does not saturate the receiver, the transmit signal can be readily removed from the spin signal by filtering. Unlike subtraction approaches, filtering does not require any knowledge about the exact waveform and phase of the transmit signal nor about its coupling to the receive line, rendering this method very robust. The ability to observe transverse magnetization during RF transmission is particularly promising for short-T_2 imaging with frequency sweeps [2], stochastic imaging, and relaxometry. The main challenges of the proposed approach relate to its power demands. For small sideband amplitudes the RF transmit power needs to be suitably scaled up to reach a given effective B_1 level. Furthermore, the modulation field adds power deposition in the sample, which needs to be considered for potential in-vivo applications. Means of addressing these issues include the use of both first modulation bands for transmission, circularly polarized T/R probes, as well as filter optimization and working at moderate B_0 to reduce the modulation and RF frequencies.

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