

An integrated CMOS detector for MR image guided interventions

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Objective: In this work, standard CMOS technology is used to miniaturize highly integrated active tracking devices in MR image guided interventions. Previous attempts at such active tracking systems [1], [2] used rather bulky custom made detection coils with external electronics, increasing the minimum size of usable catheters. The presented microsystem is an extension of the work presented in [3]. Further on-chip electronics increase the robustness of the output signals. An on-chip mixer reduces the output frequency to a few kilohertz, significantly reducing losses in the cables and thereby facilitating the use of the system in small catheters. The feasibility of the approach is demonstrated with phantom experiments in a standard 1.5 T clinical scanner.

Materials and Methods: The use of modern CMOS technologies allows us to cointegrate a complete RF receiver underneath the detection coil, resulting in a very compact microsystem (1 mm by 2 mm by 0.74 mm) that not only detects an NMR signal, but amplifies

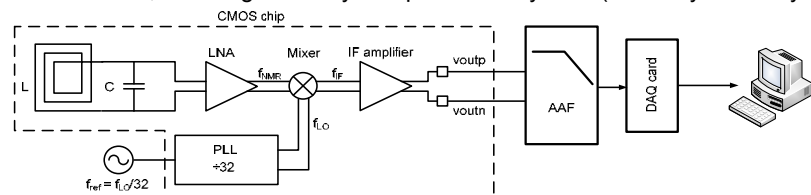


Figure 1 Test setup and circuit block diagram

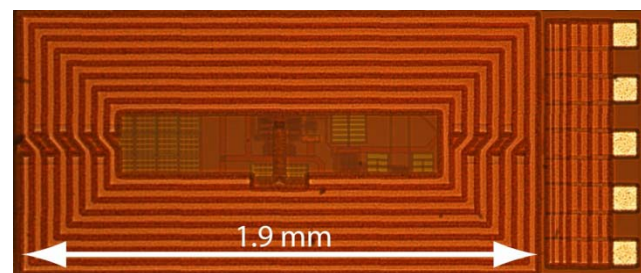


Figure 2 Chip microphotograph

the small NMR-induced voltage (tens of microvolts) to robust signal levels (hundreds of millivolts) and downconverts it to low frequencies (DC to several kilohertz) at the same time. At these low frequencies, small cables are less lossy compared to higher frequencies and miniaturized twisted pair cables can be used to directly connect the device to an external analog-to-digital converter (ADC) for further signal processing. A block diagram of the integrated circuit is shown in the dashed box in Fig.1. A microphotograph of the chip is displayed in Fig. 2. The detection coil has a rectangular shape to maximize the signal-to-noise ratio (SNR) while keeping one dimension small enough to enable the use of reasonably-sized catheters. An on-chip tuning capacitor allows a noise-free, although relatively weak, preamplification of the induced voltage by the coil's Q-factor ($Q \approx 4$ at 63 MHz). The on-chip low-noise amplifier (LNA) amplifies the detected signal at high-frequencies (around 63 MHz). The on-chip mixer downconverts the signal to a low frequency f_{IF} , which is determined by the difference between the Larmor frequency f_{NMR} and the local oscillator frequency f_{LO} , i.e. $f_{IF} = f_{NMR} - f_{LO}$. A low-frequency gain stage further amplifies the signal to enable direct A/D-conversion of the chip's output signal. The local oscillator signal is generated from a low-frequency reference at a frequency of $f_{LO}/32$ using an on-chip phase-locked loop. Therefore no high-frequency signals have to be transferred through cables into the catheter. All signals except the reference frequency for the PLL are differential to enhance their robustness against interference.

The complete test setup is shown in Fig. 1. The reference frequency for the PLL is generated using a standard signal generator (HP 33120A) that is phase-locked to the 10 MHz reference frequency of the MRI scanner. The output of the chip is low-pass filtered using a custom-made fourth order Butterworth filter to prevent aliasing. The same circuit performs a differential-to-single-ended conversion to facilitate the read-in using a standard data acquisition (DAQ) card from National Instruments. All measurements were performed on a Siemens Espree 1.5 T scanner. The goal of these preliminaries tests is to demonstrate the chip's capability of accurately recording free-induction decays (FIDs) using the MRI scanner's excitation coil. To this end, rectangular 90°-pulses ($T_{pulse} = 1$ ms, $T_R = 1$ s) were applied and the corresponding FIDs were recorded using the DAQ card.

Results: Fig. 3 shows the real part of the FFT of the recorded FID for a glycerol nitrate capsule ($T_1 = 135$ ms, $T_2 = 90$ ms, 5 mm diameter). Before taking the FFT, an exponential time-domain filter with $T_{fit} = 10$ ms was applied. The obtained magnetic field resolution is better than 30 nT/ \sqrt{Hz} .

Conclusion: The preliminary results indicate that the microsystem is suitable as a tracking device in MR image guided interventions. It can be connected to a standard clinical scanner in a relatively simple manner. The next step will be to mount the chip on a catheter and to develop optimized pulse sequences for the tracking application.

References: [1] M. Bock et al., JMRI 19:580-589, 2004, [2] D.R. Elgort et al., JMRI 18: 621-626, 2003 [3] S. Patil et al., Proc. ISMRM 2009

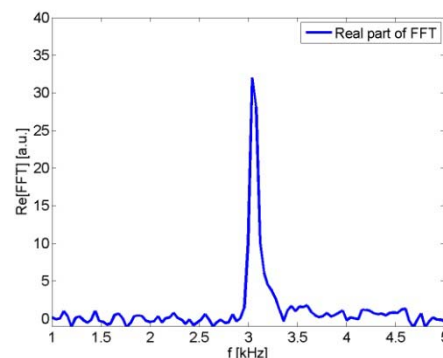


Figure 3 Real part of FFT after a 90°-pulse