FREQUENCY-DIVISION MULTIPLEXING FOR CONCURRENT IMAGING AND FIELD MONITORING

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Introduction: Spatial encoding in MRI relies on the use of linear gradient fields. Imperfections in the dynamics of these fields can be monitored by NMR probes [2], relying on the field history recorded in the phase of their signals [1]. First-order field monitoring requires the use of four probes positioned around the object be imaged. Higher-order monitoring requires more probes, e.g., 16 for 3rd–order monitoring in spherical harmonic terms. The additional receiver channels thus needed are not available on many standard MRI systems and they are costly to add. To address this issue, in the present work we propose a frequency-division multiplexing (FDM) approach in which the signal of each monitoring probe is combined with that of one imaging coil such as to jointly use only a single receiver channel, enabling concurrent field monitoring without the need for additional spectrometer hardware.

Materials and Methods: Two different and independent experiments have been performed concurrently on a 7T Philips Achieva system (Philips Healthcare, Best, NL). The first one involves a phantom (an apple, diameter=8cm) whose proton signal (Larmor frequency=298MHz) is detected in a standard way through a 16-channel head receive coil connected directly to the system spectrometer (Fig. 1). The second experiment involves four fluorine field probes (Larmor frequency=280MHz) spaced around the phantom in a tetrahedral fashion. These probes are similar to those described in Ref. [3], except that they are not shielded and that the NMR compound is a fluorinated crown ether (15-crown-5) doped with 1.9 mM of $Gd(fod)_3$. To receive the fluorine signals, four T/R switches (tuned to the fluorine frequency, isolation in transmission better than 50 dB, insertion loss in reception=0.6dB), four low-noise preamplifiers (*Agilent* MGA-53543, noise figure including the insertion loss of the T/R switch=2.58dB) and four high-gain amplifiers (two-stage amplification, *Agilent* MGA-62563, gain=44.8 dB) were built. The two experiments are independent in the sense that the precession frequencies of fluorine and water are separated by almost 20MHz. Outside the MR room the fluorine signals are mixed up to a frequency close to that of the protons (roughly 330 kHz above the proton frequency, c.f. Fig. 2) and are then added through a resistive power combiner into the first four proton receive channels. The mixers used were *Analog Devices* AD8342 (local oscillator frequency=578.707 MHz), their output were filtered by very narrow passband filters. The mixers' measured noise figure is 11.3 dB at a conversion gain of 5.5 dB, which proved sufficient in the proposed setup. The remaining 12 channels acquired only proton signal. As long as the combined proton and fluorine signals do not overlap in frequency their content can be fully recovered with digital filtering and the phase information of the fluorine signal can be used to monitor the gradient field evolution.
The digital filter was a standard equiripple filter designed with the Matlab FIRPM function (passband ripple = 0.001, stopband attenuation = 10^{-5}, order = 91) and was applied to all the 16 channels to have the same amplitude and phase transformation. Due to the digital filtering the first 10usec of all signals are corrupted. To still monitor the gradient field evolution completely the signal acquisition was started 0.2msec before the first gradient lobe.

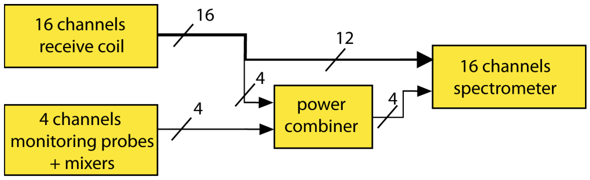

Figure 1: Schematic of the FDM experiment

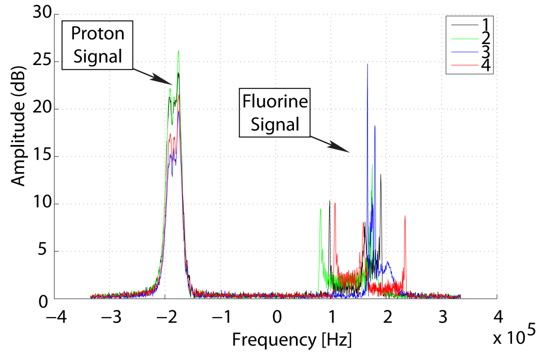

Figure 2: Frequency separation between the mixed fluorine and proton signal (first 4 channels) in one interleave of a FFE sequence

Results: For a basic demonstration of this system a gradient echo sequence (TE=3ms, TR=200ms, FOV=150x150x6 mm, voxel size = 0.7x0.7 mm, flip angle=10°, NSA=8) was performed with a total acquisition bandwidth of 670 kHz. Figure 2 illustrates the joint occupation of this bandwidth by proton and fluorine signals with sufficient frequency separation. The fluorine signals were digitally extracted and processed in the way described in Ref. (3) to yield the exact k-space trajectories under which the proton signals evolved. Standard gridding reconstruction based on the measured trajectories yielded the perfectly artifact-free image shown in Fig. 3. One concern with the multiplexing approach is the superposition of noise from two inputs along with the desired signal combination. To assess this issue an imaging experiment on a water phantom (gradient echo, TE=4.93, TR=11ms) was performed twice, once in the fashion described above and once with the monitoring setup completely disconnected. SNR analysis of the resulting images yielded an SNR loss due to the presence of the field probes of approximately 30%.

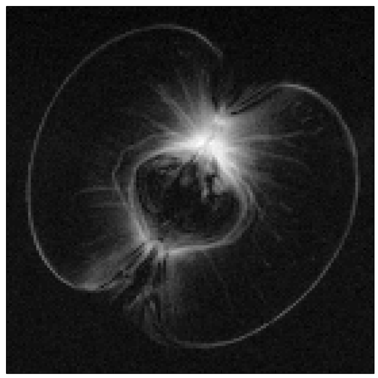

Figure 3: Phantom image reconstructed based

Discussion and Conclusion: Field monitoring is a versatile approach for MRI in the presence of imperfection of the net field response such as gradient amplifier defects, gradient chain delays, or eddy currents. A basic monitoring setup requires at least an additional four receiver channels. For situations in which such channels are not available frequency division multiplexing s been shown to offer an effective, inexpensive alternative. In this approach, great attention generally must be paid to strictly avoid spectral overlap of the combined signals. The residual SNR degradation observed in this work remains to be suitably addressed. The generic solution of this issue is band-pass filtering before combining signals, which however may require mixing to higher intermediate frequencies to achieve the necessary filter characteristics.

References [1] Barmet et al., MRM 60:187 (2008) [2] De Zanche et al., MRM 60:176 (2008) [3] Barmet et al., MRM 60:187 (2008)