Noise Power Reduction Strategy by Matching Receiver Bandwidth to the Coil Sensitivity Profile of the Phased Array Coil

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Introduction

With the introduction of the phased array in early 1990s the dominating strategy to reduce noise power in MRI images has been through the reduction of the coil size. By combining a large number of coils to cover anatomies of interest with many smaller elements the phased array coils have seen increases in SNR and greatly contributed to the development of sparse sampling technology in order to accelerate image acquisition. With the growth of MR as a gold standard of diagnostic imaging, the current state of the art systems from major OEMs are starting to offer systems able to acquiring data with up to 128 channels simultaneously. However each of the 128 receiver channels is optimized to work with just a single channel RF coil. Thus, the optimization of perfect SNR reconstruction is possible through a *priori* knowledge of noise cross correlation coefficients and the coil B_1 sensitivity profile [1].

The purpose of this work is to investigate how developments in commercial digital communication technology may be used to modify MR receiver chains such that each receive channel is optimized to acquire data from an individual coil in the phased array. This would ideally be performed in real time by designing custom full bandwidth digital filters that will match each receiver to its connected coil.

Materials and Methods

Theory: Once MRI signal is generated and passes through the receive chain the realized magnitude image will have noise contribution from various sources. It is common to describe raw MR data in time domain as Gaussian distribution with the noise power $<V^2>$:

$$< V^2 >= 4k_B T_c \Delta\nu (R_c + R_e + R_d)$$

where, T_c is coil temperature, $\Delta\nu$ receiver bandwidth, R_c is resistance of the coil and R_e and R_d are effective resistances contributed by sample and dielectric losses [2]. By reducing receiver bandwidth $\Delta\nu$ it is thus possible to reduce the noise power.

Simulations: Simulations were performed using a simulated digital receive chain using MATLAB Simulink (The Mathworks, Natick, MA, USA). A SINC function with BW of 40 kHz and Gaussian noise source was used to simulate the MR time domain signal.

Experimental: Scanning was performed using a GE Signa Excite 3T MR (GE Healthcare, Milwaukee, WI) simultaneously using the OEMs receiver as well as a parallel digital receiver system (Tornado Medical Systems Toronto, ON Canada). The digital receiver system running a Linux OS has an ability to program a Graychip 4016 (Texas Instruments) in real time for modifying data filtering and decimation parameters. Custom filters were designed according to the scan prescription and measured B_1 profile. The filters were uploaded to the hardware during prescan. A spine coil array was used for data acquisition. The coil layout allowed the acquisition of only 3 channels in the frequency direction which were subsequentlyreconstructed. MR acquisition was performed using 2D Fast Spin Echo with matrix size 512x512, TE=12ms, TR=400ms, ETL=6, NEX=1, BW=162.7Hz/pixel. Images from individual coils were weighted using the equation:

$$M(x,y) = \frac{\sum_{n=1}^{3} I_n(f) * C_n(f)}{\sqrt{\sum_{n=1}^{3} C_n(f)^2}}$$

I_n is the image from the coil and C_n is the FIR filters frequency response profile. The OEM system was allowed to calculate its best scan parameters and amplifier settings.

Results

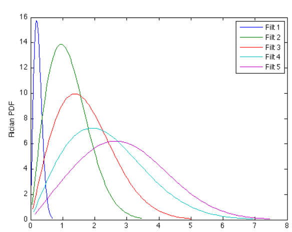

Figure 1: Simulated digital receiver data showing the PDF of data measured from the noise floor after the data was filtered using 63 TAP FIR filter with various BW 102 -- 375 kHz.

PFIR Filter BW (kHz)	Signal Mean	Signal Variance
102	447.9816	0.8876
146	448.0169	0.9129
179	448.0311	0.9194
250	447.9861	0.9146
375	448.0107	0.9111

Table 1: The signal mean and the signal variance of the data measured by varying filter BW.

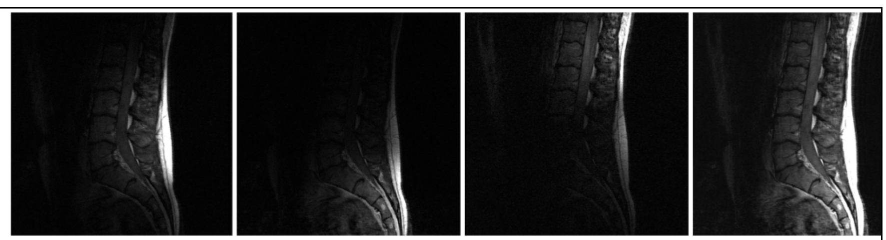

Figure 2: FSE images showing MRI data acquired using a spine array using a digital receiver, data from each coil was filtered using a narrow band FIR filter with 63 TAPS.

Table 2: SNR calculations from 6 ROIs each placed at the center of the individual coil.

	OEM	Digital Receiver BW 375 kHz	Digital Receiver BW 105 kHz
SNR	42.5±1.29	94.83±1.91	96.18±1.93

Discussion: The digital receiver has performed better in general than the OEM counterpart, although we only see a marginal improvement with the narrow BW approach. We expect the improvement to follow the simulations and increase the SNR as the number of coils in the frequency direction increases. Both simulations and experimental results showed that magnitude images followed Rician distribution and the observed noise power was reduced with narrowing of filter BW. The coil sensitivity profile is three dimensional in nature thus this technique will only address the data read out in the frequency direction, limiting this approach to certain prescriptions and coil geometries.

References: 1) Roemer, et.al. (1990), The NMR phased array. Magnetic Resonance in Medicine, 16: 192–225. 2) Hoult, D. I. (2007). Sensitivity of the NMR Experiment. Encyclopedia of Magnetic Resonance. 3) Bodurka (2003) MRM 51(1), 165–171, 2004