A High Dynamic Range Receiver for Improved Diffusion Tensor Imaging

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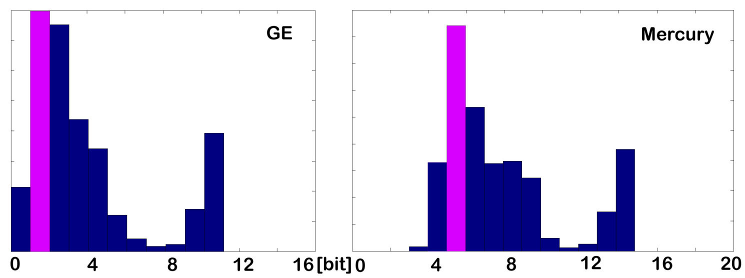
Introduction

Diffusion Tensor Imaging (DTI) [1] is an imaging modality that analyzes the difference between a spin-echo MR image without diffusion gradients and another image that is diffusion sensitized by application of diffusion weighting imaging gradients. The diffusion-weighted image has a substantially lower signal-to-noise ratio (SNR) than the unweighted image and often needs to be recovered from the background noise by averaging data points. Even smaller signals need to be recovered from the noise floor with Q–ball imaging (QBI) [2] or modalities that seek to quantify non-Gaussian water diffusion like Diffusion Kurtosis Imaging (DKI) [3]. Also, because of the small size of neuronal fiber bundles that are of interest it is desirable to increase resolution (especially for fiber tracking), which in turn decreases signal amplitude. While the utility of higher field strengths has lead to improved signal amplitudes [4], very short relaxation times at such field strengths combined with long echo times that are necessary to achieve high diffusion weighting result in low signals which occupy only the last few bits of RF analog-digital converters (ADC). The need for high dynamic range and sufficient SNR asks for ADCs with more than the typically used 16 bits. Here, we use a high-speed direct-conversion RF receiver system that was developed by the Medical College of Wisconsin and Mercury Computer Systems (Chelmsford, MA) to record the RF signal at 100MHz - oversampling the signal by a factor of 200 to 1600 (for receiver bandwidths of 250kHz to 31.25kHz respectively). The result is a gain of up to 5.5 bits in dynamic range, stored as signed 24bit values.

Methods

A spherical saline phantom was scanned on a GE Signa 3T MRI using a 64x64 echo-planar diffusion-weighted spin-echo sequence (voxel size 5x5x5mm). We simultaneously recorded from the 16 bit GE receiver and the 24 bit Mercury receiver, applying several diffusion weightings, b=0 (unweighted), 1000, 2000, and 3000 s/mm^2. The 100MHz signal from the Mercury receiver was downsampled by a factor of 800 to the 125kHz receiver bandwidth using the Graychip 4016 (Texas Instruments). On the GE receiver the amplitude gain was set automatically through the GE software, on the Mercury receiver the gain was set to 60%. The difference between the unweighted and diffusion-weighted image was assessed by calculating the diffusion-to-noise ratio (DNR) [5].

Results



The Figure shows the histogram of the Fourier reconstructed phantom image for the GE (left) and Mercury (right) receivers (values $\log_2$ transformed to demonstrate ADC bits, only b=0 shown in the abstract). The reconstructed Mercury images have more than 4 bit higher dynamic range (4.8 theoretically with downsampling by 800) and show an undisturbed Rician magnitude distribution (Gaussian for real and imaginary channels) around the background and phantom image values, while images from the GE receiver are cut of at the lowest bit. The image histogram for the GE receiver peaks at bit 1 while for the Mercury receiver it peaks at bit 5. The Table displays the differences of SNR and DNR in percent between the images reconstructed from the Mercury and the GE receiver; demonstrating the advantage of the Mercury receiver, especially for higher b-values.

b-Value	Diff.DNR%	Diff.SNR%
1000	41.5	17.5
2000	50.2	21.5
3000	50.3	23.2

Conclusions

Our wide dynamic range receiver performed better than the GE receiver for diffusion imaging experiments with high b-weightings. In such experiments the signal differences between unweighted and diffusion-weighted images become large and require a wide dynamic range to provide sufficient signal resolution after analog-digital conversion. Current 16 bit receiver technology will use only 8 bits at best for the diffusion-weighed image with b=3000, and only 4 bit with b=6000 (typical with Q-ball imaging) making it difficult to extract the diffusion-weighted image from the background noise. The Mercury receiver however demonstrated a dynamic range that is about 20 bits (with downsampling from 100MHz to a typical receiver bandwidth) and showed superior SNR and DNR compared to the GE receiver. Importantly, the 50 percent increase in DNR (with b-value ≥ 2000) requires twice the scanning time with the GE receiver for an MR sequence that is already very long.

References

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