Direct MRI Detection at 3T and 9.4 T Using 16-bit High-Speed Digital Receiver

A. Jesmanowicz[1], and J. S. Hyde[1]
[1]Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States

INTRODUCTION: The purpose of this work was to evaluate a new high-speed digital receiver ECDR-GC316-PCI-FS made by Mercury (Chelmsford, MA) that incorporates three Linear (Milpitas, CA) 130 MSPS LTC2208 A/D converters with an input bandwidth of 700 MHz. In particular, we tested dynamic range and management of the reference frequency in 3T and 9.4T MRI scanners. In a 2006 ISMRM abstract (1), we described an MRI detection system based on 14-bit converters and an input bandwidth of 200 MHz. The new unit operates similarly, decimating and filtering data in a pipe-line using three Graychip GC4016 quad digital receivers.

METHODS: The study was performed on GE Signa EXCITE 3T MR and Bruker BioSpec 94/30 9.4T MR scanners. Acquisition was done off-line using a computer equipped with Mercury ECDR-GC316-PCI-FS cards running Linux OS. The configuration was described in (1). After initial preamplification, the signal is split and fed to the off-line system and to the standard MR scanner acquisition track. The second stage amplifier, part of the off-line systems, was developed at MCW. The goal was to reduce noise and increase dynamic range linearity. Tests were carried out using Gradient Echo and EPI sequences. 2D images were obtained at BW 31.25 kHz on 3T and 50 kHz on 9.4T; 32 cm FOV on the 3T and 3.2 cm on the 9.4T; 256×256 resolution; 3 mm slice on 3T and 2 mm on 9.4T; 50 ms TR and minimum TE. EPI images were acquired at a resolution of 64x64 with different BWs - up to 1 MHz at 9.4T and 125 kHz at 3T.

RESULTS: ● *Dynamic range*: First, at 3T all scanning parameters were set to maximize the MR signal. The resulting images from the GE scanner and the off-line system were the same and had similar noise patterns. Nevertheless, the off-line images had up to a 10% better S/N ratio. We attribute this to the absence of hardware down converters (mixers) that are used in factory scanners. In our system, mixing is done in software, avoiding hardware insertion losses. Second, we added a 40 dB attenuator after the preamplifier, leaving all other scanning parameters the same. This reduced both signal and thermal noise from the phantom. Images were noisier, but the off-line pictures had better S/N ratio by a factor of four (12 dB). This result means that the ECDR-GC316 receiver had better dynamic range by two bits. One would expect at least a 17 dB (2.8 bit) improvement when comparing sampling clock rates, 2 MHz on GE vs. 100 MHz on the Mercury A/D card. We attribute the lower value to the higher 700 MHz bandwidth of the ECDR-GC316 receiver. Converter noise cannot be reduced even by an anti-alias filter, which was used on all A/D inputs.

● *Increased bandwidth*: The converter was tested and worked at input frequencies up to 2 GHz. A 100 MHz sampling rate was used. At 1.5 GHz the output amplitude was reduced only by 12 dB, making it equivalent to a 14-bit converter. In MRI applications, it can be used up to 35T. In our lab, it is used off-line routinely on the Bruker 9.4T scanner at a resonance frequency of 400.3 MHz. It occurred to us that we cannot use a 100 MHz clock at this scanner for the following reason: the DC offset at the output of LTC2208 A/D converter is warranted to be below 0.2% only and is not adjustable. The converter is built for AC signals only. At 100 MSMP, a 400 MHz signal is transformed, by undersampling, to the digital DC level and is supplied to the input of a Graychip GC4016 digital receiver. At resonance, the Graychip NCO sine/cosine generator is set to 0.3 MHz (400.3 modulo 100), and at bandwidths above 0.6 MHz, the DC level cannot be filtered out. The DC level appears as a zipper on the side of the image. For this reason, we changed the clock to 120 MHz, well within the AD converter range but on the edge of the GC4016 chip, which has worked for a year and also reduces the noise level by 1 dB due to the required increase in decimation ratio.

● *Elimination of intermediate frequency*: The test was made at 3T using our own synthesizer, an RF pulse modulator, and a Dressler LPPA-14020 2 KW transmitter. First, we used a reference signal at the resonance frequency. In the past, scanners were plagued by DC offset of A/D converters using this approach. We chose a central slice (0 Hz offset) and acquired a scan. Artifacts were not apparent, especially at the center. RF pulse chopping was not used. The GE scanner that acquired the image also shifted it up by half in the phase encoding direction. This image also showed no artifacts even in the central empty space. These results were obtained when using double shielded 50 ohm cables in the entire receiver track. We tried single shielded cables such as RG58/U, but they were insufficient. Signal leak from a synthesizer appeared in the image as a single, central spot of a different brightness. Second, we tried imaging slices offset from the center without returning a reference signal to the resonance frequency at a readout time. In scanners that use this approach, images are shifted sideways in the frequency-encoding direction. In our experiment, we programmed a Graychip GC4016 NCO sine/cosine generator to the slice offset frequency. As a result, the reconstructed image was centered automatically, and artifacts were not apparent, similar to the first approach. This confirms our assumption that mixing MRI and reference signals in the software, after digitizing, does not produce spur frequencies. To further improve the process, we used only the phase information of the reference signal. Variations in amplitude were reduced by creating sine and cosine waveforms from the phase and keeping amplitude at a value of one.

DISCUSSION: The new converter increases the range of magnetic fields of MRI applications beyond today's practical values, up to 17T at its specified bandwidth. The increased dynamic range improves 3D imaging as described in (2). The elimination of a frequency switching point between slice selection and a readout time removes phase errors. This is important because the error in coherency at a switching point is proportional to the frequency shift and the amount of jitter at this point.

REFERENCES:

1. Jesmanowicz A., Hyde J.S., *Proceedings of ISMRM*, Seattle, p. 2027, 2006.
2. Jesmanowicz A., Hyde J.S., *Proceedings of ISMRM*, Sydney, p. 2019, 1998.