Direct MRI Detection at 3T Using an FPGA-Controlled High-Speed Digital Receiver

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INTRODUCTION: The purpose of this work was to develop a new MRI receiver using a modern A/D converter with high sampling rate and high dynamic range. In a 1998 ISMRM abstract (1) we described a system for 3D imaging containing 4 A/D converters, each fed with the same signal but at a different gain ranging from 0 to 36 dB. The conclusion was that for 3D imaging using a single A/D converter a dynamic range of 19 bits is required. Today such a unit is available from Echotek (Huntsville, AL) as a single-board digital receiver ECDR-GC314. Basically, it contains three 14-bit 200 MHz Analog Devices AD6645 converters clocked at 100 MSPS and three Graychip GC4016 quad digital receivers. At least two of the receiving channels are required for the method described here. The unit is controlled by FPGA logic. When the initial bandwidth (BW) of 50 MHz is reduced to 49 kHz by decimation of 1024, the dynamic range is increased by 5 bits, making it a 19-bit converter. To realize this advantage, the entire spectrum of 50 MHz BW noise is required according to the rule that for every factor of 4 reduction in BW, one bit of dynamic range is gained by signal averaging in decimation filters.

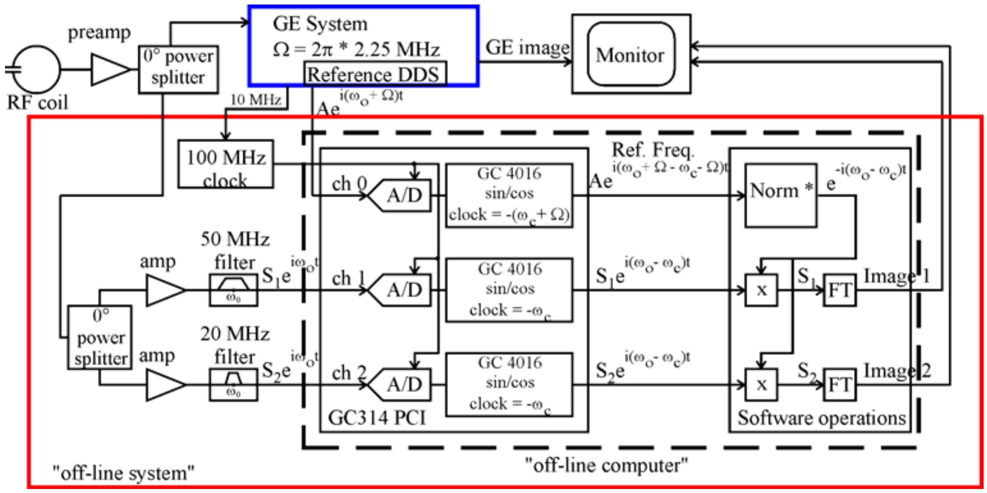

***Fig. 1**. Configuration of the off-line acquisition system.* $\omega_c \approx \omega_0$, $\Omega = 2\pi \cdot 2.25$ MHz

METHODS: The study was performed on a GE Signa EXCITE 3T MR scanner. Acquisition was done off-line using a computer equipped with an Echotek ECDR-GC314 card running Linux OS. The configuration is shown in Figure 1. After preamplification, the signal is split and fed to the off-line system in addition to the standard GE acquisition track. The off-line signal (either channel 1 or 2) is digitized directly at 100 MSPS, decimated, filtered and processed digitally. One A/D channel (labeled "ch 0" in Fig. 1) is used exclusively to digitize the GE digital synthesizer (DDS) internal reference waveform to establish an RF phase reference. The ω_c of sin/cos clocks in the GC4016 chip was set close to the MRI resonance ω_0. It does not have to be precisely at ω_0 because both ω_0 and ω_c drop out as shown in the "software operations" block of Fig. 1. Complex arithmetic was used, making signal mixing in a computer equivalent to the use of an ideal hardware mirror rejection mixer. Basically the off-line system eliminated the need for all hardware except for initial signal broadband amplifiers and anti-alias filters. 3D images were scanned using the SPGR sequence: BW = 31.25 kHz (15.6 kHz in GE notation); 256×256×124 resolution; 1 NEX; FOV = 24 cm; slice = 1 mm; TR = 20 ms; TE = 6.9 ms; 11 minutes total acquisition time.

RESULTS: The off-line system using channel 1 created 3D images that were the same as the GE scanner but with reduced background noise. The noise reduction was up to 1.6 in phantom images, and about 1.25 in the head. Because the peak signal from the head was 4 dB lower, the advantage of high dynamic range is reduced, which explains the difference between the 1.6 and 1.25 factors. The second channel contains a narrower 20-MHz filter intended for an older A/D board clocked at 40 MHz. This filter looks much better than the 50-MHz one (Fig. 2.), but in every case, including 2D slices, the noise level for this channel was higher by 5–15%, which is because a narrower anti-alias filter decreases the dynamic range of a digital receiver.

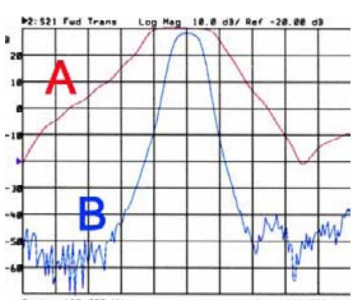

***Fig. 2.** Anti-alias filters.*
BW: a) 50 MHz b) 20 MHz

DISCUSSION: Signal and thermal noise were amplified by 35 dB in the first stage and were the same in all three detection tracks. The noise difference in the resulting images shows once more, as in (1), the importance of high dynamic range A/D converters. There is a second, even more important conclusion from this work. What once was only possible in hardware can be done now in software, not only simplifying the data acquisition track, but also improving the phase stability. There is no longer any need to shift the reference clock (by 2.25 MHz as in the GE scanner), noting that for sub-sampling, this leads to slight phase errors. There is also no longer a need to shift back to ω_0 after slice selection as was done in early scanners that were plagued by DC offset of A/D converters. Everything can be done now in software with unprecedented accuracy.

REFERENCES: Jesmanowicz A, Hyde JS. *Proceedings of ISMRM 6*, Sydney, p. 2019, 1998.