Comparison of analog and digital transceiver systems for magnetic resonance imaging

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INTRODUCTION

The advantages of digital transceivers over analog transceivers are widely believed to include better gain balance and orthogonality between two receiver channels, a wider receiver dynamic range (DR), freedom from DC or low-frequency artifacts, and better stability and reproducibility of reference phases. However, to our knowledge, no report has yet confirmed these advantages experimentally. In this study, analog and digital transceivers developed by the same manufacturer were compared critically under the identical experimental conditions.

MATERIALS AND METHODS

The analog transceiver was a direct-conversion transceiver developed with active mixers (AD8343) for a 200 MHz Larmor frequency. It was controlled by a pulse programmer using a DSP board running at 40 MHz. The resolution and maximum sampling interval of the ADC board for the baseband sampling were 14-bits and 1 μs. The digital transceiver was developed with a 16-bit ADC (AD9460-105), a 14-bit DAC (DAC904), and an FPGA (Cyclone III) (Fig.1). The sampling frequency for the ADC and DAC was 60 MHz and the intermediated frequency (IF) of the transceiver was 12 MHz. Because the digital transceiver was originally designed for Larmor frequencies lower than 15 MHz, an up-down frequency converter unit between a 202 MHz RF signal and a 12 MHz IF signal was developed. The transceiver was controlled by a PC-MRI pulse programmer of which time resolution and data length were 1 μs and 128 (16×8) bits [1]. The MRI experiments were performed using an MRI system including a 4.74 T vertical bore SC magnet and a gradient-coil probe with a solenoid RF coil (40 mm ID). MR images of a kumquat were acquired with a 3DSE sequence, of which parameters were: FOV = $(40.96\ \text{mm})^3$, image matrix = 512 × 512 × 64, TR = 800 ms, TE = 20 ms, NEX = 1. To extend the receiver DR, a gain stepping (GS) scan technique with 30 dB gain difference between low and high frequencies in the k-space was used for both transceivers.

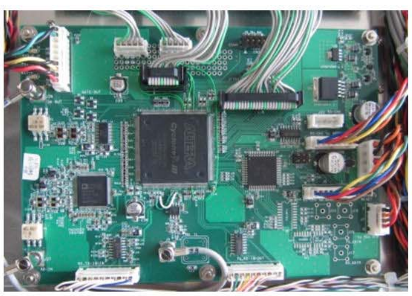
RESULTS AND DISCUSSION

Figure 2 shows the relative average signal power in the k-space plotted against the wavenumber of the MR signal (k-power plot) obtained with and without the GS scan. For the analog transceiver, the DR for the constant gain scan (single scan) was about 64 dB, but by using the GS scan (dual scan) the DR was extended to about 80 dB. For the digital transceiver, the DR seemed larger for the single scan than that for the dual scan. The k-power plot for the dual scan in Fig.2 is almost identical to that for the analog receiver.

Figures 3 show identical cross sections selected from 3D image datasets acquired with the 3D SE sequence. As shown in Figs. 3(a) and (b), the SNR of the image was drastically improved using the GS scan for the analog transceiver. As shown in Figs. 3(c) and (d), although the SNRs of the cross-sectional images seem nearly identical, the spatial resolution is clearly improved using the GS scan for the digital transceiver. For both transceivers, the GS scan achieved a similarly high image quality for both in SNR and spatial resolution. As shown in Figs.3(b), the presence of the DC artifact in the image acquired with the analog receiver is clearly observed. However, no other low frequency noise is observed. In Figs.3(b) and (d), background noise-amplitudes normalized by the mean values of the image intensity of the cross-sections were calculated both in the signal-readout and phase-encoding directions. Their mean values were 2.6 %and 4.1 % for the analog transceiver and 3.2 % and 3.3 % for the digital transceiver. This result indicated reference phase instability and stability in the analog and digital transceivers, respectively.

As shown in Fig. 2, the DR of the MR signal acquired from the sample was about 80 dB. For correct sampling of this signal, more than 15-bit resolution was required. However, in the single-scan experiment using the digital receiver, the maximum number of the signals was 5667, which was caused by an incorrect amplitude setting. Therefore, the loss of the high spatial-frequency components was caused by the inadequate gain setting for the digital transceiver. However, because the dual scan technique recovered the high spatial-frequency components, the correct MR image was obtained, as shown in Fig. 3(d). In conclusion, the digital transceiver has several advantages over the analog transceiver, but a careful gain setting is indispensable, if the benefit of the wide receiver dynamic range is to be utilized.

REFERENCES: [1] S. Hashimoto, K. Kose, and T. Haishi, Rev. Sci. Instrum. **83**, 053702 (2012).



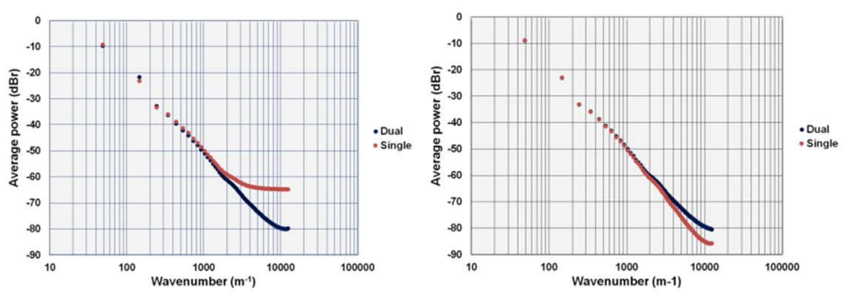


Fig.1 Mainboard of the digital transceiver. Fig.2 "k-power plot" for the analog (left) and digital (right) transceivers

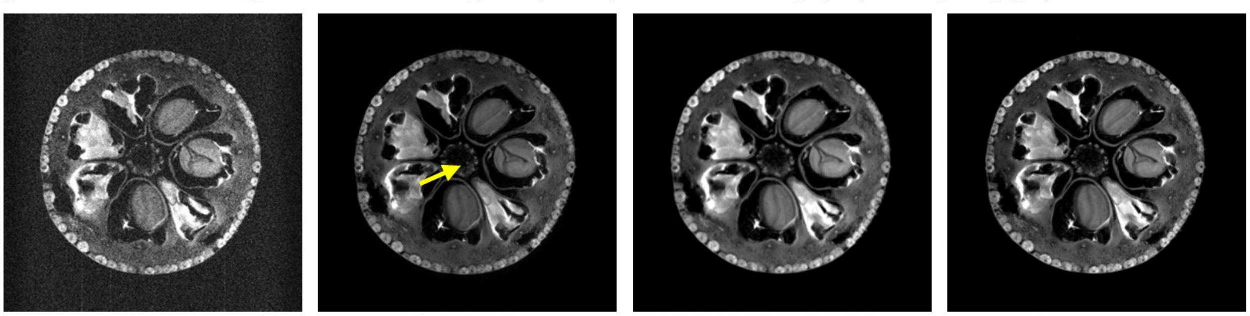


Fig.3 (a) analog, single (b) analog, dual (c) digital, single (d) digital, dual