AN INEXPENSIVE IMPLEMENTATION OF A SCALABLE MR RECEIVER WITH DIGITAL OPTICAL TRANSMISSION

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Introduction: Parallel reception makes high demands on MR receivers in terms of scalability, SNR, high speed, and cost. The analog optical transmission of RF signals may address these challenges yet suffers a degradation of the dynamic range [1-3]. Recently, digital optical transmission has been utilized in some commercial receiver where signals are digitized and transmitted from coils to the reconstruction engine [4]. Since the analog signal path of the overall receiver chain is greatly shortened, the external noise can be eliminated and the dynamic rage is maintained. In this work, we suggest some ideas for an inexpensive, scalable implementation of a MR receiver with digital optical transmission. A four channel prototype has been built based on off-the-shelf components, and demonstrated with a home-built MRI system.

Methods: The prototype consists of a RF front end at the magnet housing and a control interface at the electronics room. In the front end, RF signals from the preamplifiers are directly sampled on a mezzanine card that complies with FPGA Mezzanine Card (FMC) standard known as ANSI/VITA 57. One processing FPGA (XC5VSX35T, Xilinx Inc.) on the carrier board performs digital down conversion, and implements a serializer/deserializer (SERDES) that communicates with a small factor pluggable (SFP) short wavelength transceiver. To operate a bi-directional optical data link, a pair of SFP transceivers (FTLF8519P2, Finisar Inc.) are used coupling with a 50/125 µm multimode fiber cable passing through the penetration panel. Since the optical link is in a duplex configuration, the synchronization and control signals for the front end can also be sent via the same fiber. The SERDES units are Virtex-5 FPGA multi-gigabit transceivers (MGT) that allow high speed transportation for data rate up to 3.75 Gb/s over the Aurora core. As a lightweight communication protocol, the Aurora supports 8B/10B encoding, clock correction, bonded lanes, and provides transparent user application interface to physical layer. Additionally, it is totally free of charge and open for development. This significantly reduces the system cost and simplifies the serial connectivity design. The MR data carried from the fiber are stored in a one-gigabyte buffer under the management of a communication FPGA (XC5VLX30T, Xilinx Inc.) within the control interface. The integrated Endpoint block and Direct Memory Access (DMA) engine are implemented inside the FPGA that allows the receiver to communicate with a reconstruction computer via an 8-lane Peripheral Component Interconnect Express (PCIE) bus. The operations of the receiver are coordinated by a digital signal controller (TMS320F28335, TI Inc.) that works as a pulse sequence generator.

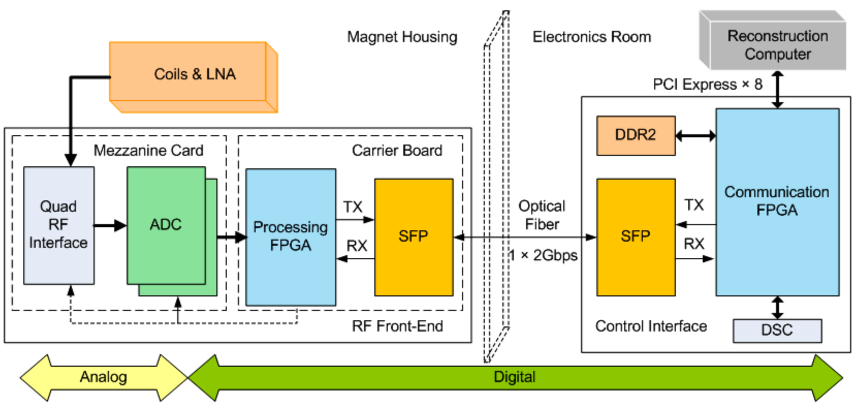

Figure1: The block diagram of the receiver with digital optical link.

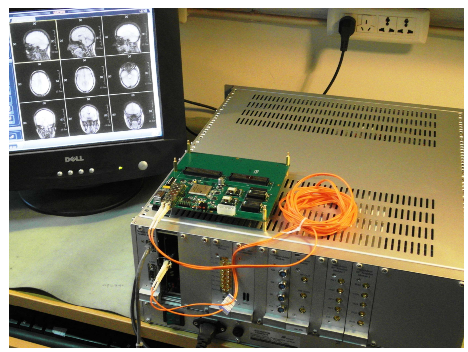

Figure 2: The snapshot of the RF carrier having a compact size of 160×160mm. It is coupled with a PKspec console via an optical fiber.

Results: The prototype receiver is incorporated with a digital MR console (PKspec, Peking University) and verified using a series of standard imaging protocols. The front end is carefully designed, and allowed to be placed at the magnet housing without adversely affecting imaging in the field of view. The digital optical link is tested with a bit error rate (BER) less than 1×10^{-12}. Figure 3 shows a sagittal T2-weighted imaging of a volunteer's brain (matrix size of 256×242) obtained by a 0.36T permanent magnet system. The sequence parameters include: FOV=250×225mm, TR=4250ms, TE=139ms, NEX=3, THK=7mm. The signal-to-noise ratio (SNR) of T1-weighted images is measured as about 20% higher than that acquired without digital optical transmission. Total hardware cost for the prototype is approximately $400 per channel.

Figure 3: In-vivo image

Discussion/Conclusions: The data throughput of the digital optical link is depending on the capability of the SERDES and the optical transceiver. In this work, the line rate is specified as 2 Gb/s using a single Aurora lane, and effective bandwidth is 1.6 Gb/s due to an 8B/10B encoding overhead. The protocol has a deterministic latency as little as 30 MGT clock cycles. Since MR signals are decimated into a low bandwidth (<1MHz) before being transmitted, the receiver is allowed to accommodate more channels using one fiber cable. The dynamic range is also increased by 4 to 5 bits according to the processing gain achieved by oversampling and decimation. Owing to modular hardware architecture, the receiver can scale easily by adding I/O mezzanine cards and fiber cables. Currently, we are managing additional receive modules involved in the system and making it available for experiments in higher field (>1.5T).

References: [1] S. Biber et al, Analog optical transmission of 4 MRI receive channels with high dynamic range over one single optical fiber. [2] T. Demir et al, Optical transmission system for high field systems. [3] R. E. Gabr et al, Journal of Magnetic Resonance 198 (2009) 137-145. [4] C. Possanzini et al, Scalability and channel independency of the digital broadband dStream architecture.