A Distributed Multichannel MRI Console Using Digital Optical Transmission

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Target Audience: Researchers and hardware engineers involved in console electronics innovations.

Purpose: Modern electronic technologies enable MRI researchers to develop custom-built consoles feasible for parallel imaging and high-bandwidth EPI acquisitions. With modular system design concept, easy extension to an arbitrary number of channels allows to be implemented with flexibility and efficiency.[1,2] However, the trend towards higher channel counts conventionally requires additional long coaxial cables between coils and receiver electronics. These analog cables have resulted in an increased complexity of reception path, and introduced losses and interference to RF signals. At ISMRM 2012,[3] we described an inexpensive digital optical transmission approach to MRI receiver design which addressed the issues mentioned above. The application of such a receive system at high magnetic fields invites a redesign of an original PKU-built console. Considering the demanding challenges such as data transfer rate, synchronization, and cost-effectiveness, we proposed a new multichannel console based on high-speed serial interfaces, separate pulse sequencers, direct RF synthesizers/receivers, and high-precision gradient controllers. Some of the experimental results acquired at 1.5T were presented to verify its performance.

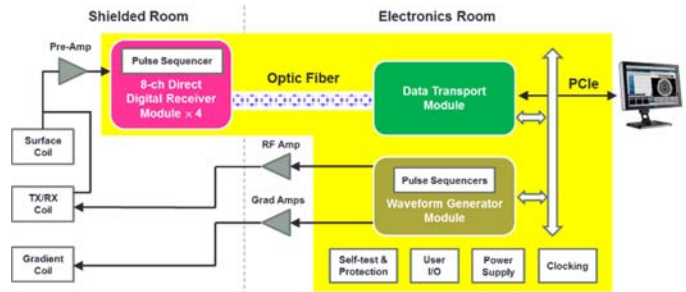

Figure 1: Block diagram of the distributed multichannel MRI console

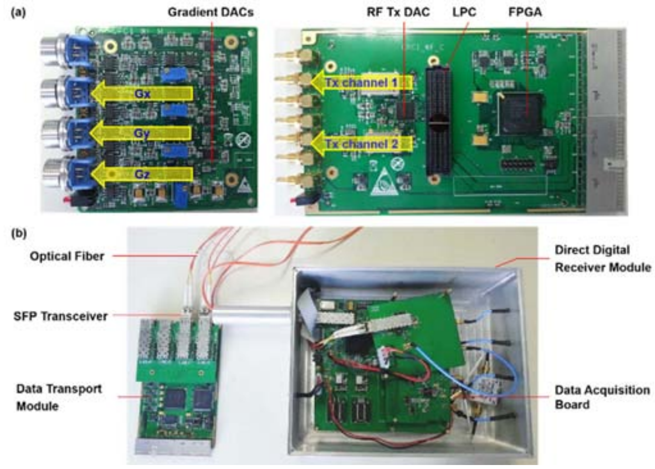

Figure 2: Photos of (a) a waveform generation module and (b) a direct digital receiver module in a basic 4-channel configuration linked to a data transport module over an optical fiber pair.

Methods: The console (Fig. 1) is built in a distributed manner with a set of remote receiver (Rx) modules and one rack-mount chassis. Each Rx module, located inside the shielded room, is scalable in 4-channel increments to a maximum of 8 parallel acquisition channels. The detected signals for each Rx channel are directly digitized and collected under control of an independent pulse sequencer. The data created during this phase are decimated into a low bandwidth (<1 MHz) and then transferred via a fiber-optic link to the electronics room. The chassis contains self-constructed modules that perform system functions such as RF excitation (Tx), gradient generation/shimming, and data distribution. Herein two RF Tx channels are realized on a highly-integrated waveform generation module together with gradient blocks. The RF pulses are synthesized based upon an Analog Devices AD9122 16-bit high-speed dual digital-to-analog converter (DAC) and reconfigurable numerically controlled oscillators. For gradient generation, 4 Analog Devices AD5791 20-bit DACs are utilized for accurate manipulation of the Gx, Gy, and Gz gradient outputs as well as B0 compensation. An on-module field programmable gate array implements the same sequence control logic as the Rx module and provides the digital data required for producing the RF and gradient waveforms. The chassis connects to a host PC with a data transport module through a peripheral component interconnect express (PCIe) cable. This module also handles the data flow from/to the optical link and coordinates external subsystems. All console electronics are operated with a low-level jitter (<1 ps) system clock and strictly synchronized for timing requirement. The completed modules are depicted in Fig. 2.

Results: Imaging experiments have been carried out on a 1.5T MRI system with in-house RF assemblies to evaluate the multichannel capabilities of the hardware. Fig. 3 shows initial results of abdominal images obtained with each of 8 individual body coil elements and EPI-DWI images acquired from an 8-channel surface coil. The Rx module achieves a typical dynamic range of ~96 dB at a bandwidth of 100 KHz; the exciter produces a spur-free dynamic range over 80 dBc; and each of four gradient channels offers a fastest response time of 1 µs and precise waveform control on the order of 1 ppm. The useful data throughput of the digital optical link is 6.4 Gb/s on aggregate and the PCIe bus supports 800 MB/s transfer speed.

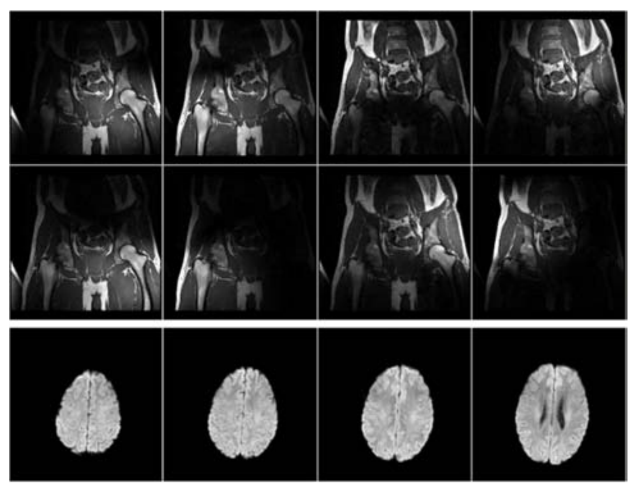

Figure 3: Abdominal images (top) and multi-slice EPI-DWI images (bottom) acquired from different 8-channel receive coils

Discussion: Typically up to 4 Rx modules are available in the current prototype. Assuming each Rx module in a maximum of 8-channel configuration, a total of 32 receive channels can be implemented, in which case the hardware cost is approximately $650 per channel. With a distributed system architecture and high-speed serial connectivity, the console can expand easily by adding modules. For the demand of larger channel counts, a PCIe switch may be used as well as extra data transport modules and RF electronics.

Conclusion: A low-cost, multichannel MRI console was developed and built to exploit the potential of coil arrays and high-bandwidth EPI acquisitions such as BOLD-fMRI. The distributed, modular system infrastructure not only delivers improved scalability and signal fidelity, but also simplifies hardware design. The performance of the resulting console has been demonstrated with substantial imaging protocols at 1.5T as well as low permanent magnetic fields. Future work will focus on the miniaturization of remote Rx modules for more compact channel migration to coil systems.

References: **1**. Jerzy Bodurka et al. Scalable multichannel MRI data acquisition system. Magn. Reson. Med. 2004; 51:165-171. **2**. Pascal P. Stang et al. Medusa: A scalable MR console using USB. IEEE Trans. Med. Imag. 2012; 30(2):370-379. **3**. Weinan Tang et al. An inexpensive implementation of a scalable MR receiver with digital optical transmission. Proc 20th ISMRM p2758, 2012.