A USB Approach to Scalable Design of MRI Systems

P. Stang[1], S. Conolly[1], J. Pauly[1], G. Scott[1]
[1]Electrical Engineering, Stanford University, Stanford, California, United States

Introduction: Parallel imaging in MRI makes new demands on system architecture and data flow. At many levels, system integration is dependent on proprietary hardware and interfaces which suffer from a lack of scalability and modularity. Meanwhile, the communication and instrumentation industries are harnessing modular programmable RF components generally known as "synthetic instrumentation"[1]. We are investigating this approach to creating a highly scalable MR system based on direct digital synthesizer and receiver blocks operating as Universal Serial Bus peripherals in a USB peripheral tree. We wish to determine bandwidth and scalability limits of an MR console designed using this distributed USB data transport, as well as exploring the advantages and issues of nearly all-digital RF transmission and reception in parallel scalable MRI systems.

Methods: Our prototype system is built as a distributed set of intelligent Universal Serial Bus devices each with a USB interface module and an embedded controller. The RF module is an exciter and receiver based on Analog Devices components. For the exciter, we are using the AD9854 quadrature-output direct digital synthesizer (DDS). The digital receiver (DR) is based upon the AD6644 14-bit ADC and AD6620 digital receiver and down-converter. We plan a seperate USB gradient module to provide gradient coil outputs. In each module, operations are coordinated by a Philips LPC2106 32-bit ARM-based embedded controller at 60MHz, or an Atmel 8-bit AVR controller. USB 1.1 connectivity is provided by an FTDI FT245BM interface IC. The PC host control software and user GUI is written in C++ with the QT widget set making it cross-compilable to Linux, Microsoft and Mac operating systems. To attain the full USB 2.0 High-Speed bandwidth, we must link the USB 1.1 devices via a USB hub that incorporates a separate transaction translater for each port. Cypress Semiconductor' tetrahub technology provides this.

Results: We have successfully performed loop-back tests on the RF module with the DDS transmitting a sync pulse train while demodulating on the digital receiver. The RF module can operate from DC to 66MHz (1.5T) without external RF mixers. Our initial data through-put was 1.3Mbit/s per node - well below the expected 8Mbit/s for the FT245 device. The gradient module is currently under development.

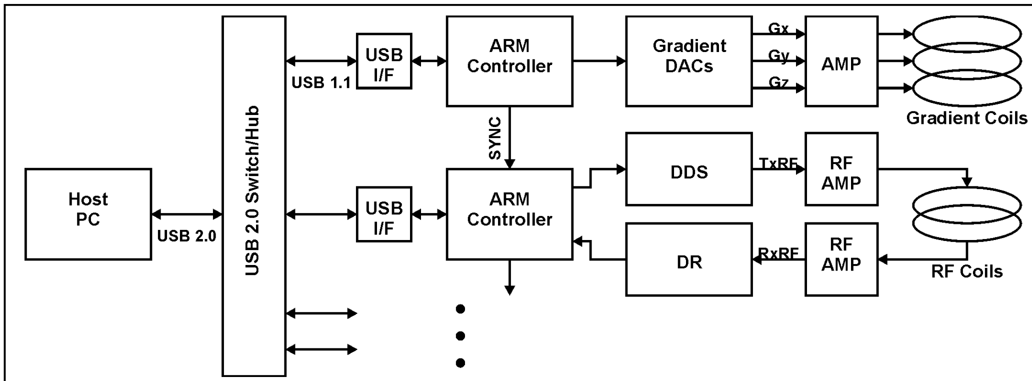

Figure 1: Parallel MRI System Architecture using USB

Discussion: To achieve the full potential of this approach as a parallel MRI system, multiple RF and/or gradient modules must be connected to one host PC. The USB 2.0 standard allows up to 128 devices and bit rates of 480Mbit/s in High-Speed mode. Overhead and host-side inefficiencies typically reduce the usable continuous bandwidth to 200Mbit/s. Nonetheless, in the context of MRI, this amounts to 6 Million complex words/s of total system capacity, with each USB 1.1 module allowing up to 250K complex words/s. Thus USB1.1 should suffice for most single-channel MRI needs, and USB 2.0 enables support for multiple channels. For expediency, we chose the FT245 USB interface IC because its hardware USB stack required almost no extra USB software development, but we found that this device did not achieve the full USB 1.1 bandwidth. This may be due to the manufacturer's host side device driver, hence, we are considering other USB devices and interfaces that can achieve full bandwidth. For MRI, modules must be synchronized via a signal separate from USB. Given the modular approach to code and hardware, other data transport mechanisms can also be used such as Firewire or Ethernet.

Conclusions: Our approach to scalable MR system design depends upon generic RF and data interfacing blocks. We have demonstrated our design approach with a USB exciter- receiver block. With proper device selection we expect to achieve full USB data bandwidth. Scaling the number of receiver channels for parallel reception, or the number of exciters for parallel transmission should then be no more complicated than adding a peripheral to a USB hub.

References:
[1] M. Granieri, RF Design, p16 Feb 2004.