A Scaleable Multi-Channel MR Data Acquisition System

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Synopsis: In order to perform high sensitivity brain MRI, a 16-channel, high speed, high dynamic range digital receiver system for use with a General Electric (GE) scanner was developed. Commercially available, PCI-based digital receiver boards were used in a Linux PC. The system was designed to sustain data throughput that allows continuous high bandwidth EPI acquisition, e.g. fMRI applications. It was evaluated at 3 T using a custom built 16-element gapped coil array, designed to achieve optimal image signal-to-noise ratio (SNR) and SENSE performance.

Purpose: Arrays of surface coils[1] have been shown to deliver a high SNR without the field of view restrictions of single surface coils. With appropriately designed array coils, the SNR of volume coils can be matched or exceeded in any location in the object[2]. Surface coil arrays also allow the use of parallel imaging techniques such as SMASH[3] and SENSE[4]. Recently, it has become evident that for many applications, the number of receive coils (i.e. receive channels) required for optimal sensitivity and parallel imaging performance is likely to be substantially higher than 8 and might exceed 16-20, even for the study of small objects such as the human brain. These considerations invite a re-design of the MRI receive system. In the following, we present a design that provides a flexible choice in the number of the receive channels and show initial results obtained with a 16-channel receive coil.

Method: The scaleable MRI receiver was designed to perform the entire MRI acquisition process, including signal reception, digitization, image reconstruction and display. The analog electronics (Fig. 1), developed by Nova Medical Inc., include the MRI receive coil, pin-diode drivers (including fault detection circuitry) for detuning the receive coils during RF transmit, pre-amplifiers, signal combiners, and anti-aliasing filters. Multi-element pre-amp decoupled surface coil arrays[2] are used for signal reception. The pre-amps, located in the magnet bore, provided less than 1 Ohm effective input impedance and 35 dB of gain at 127.8 MHz.

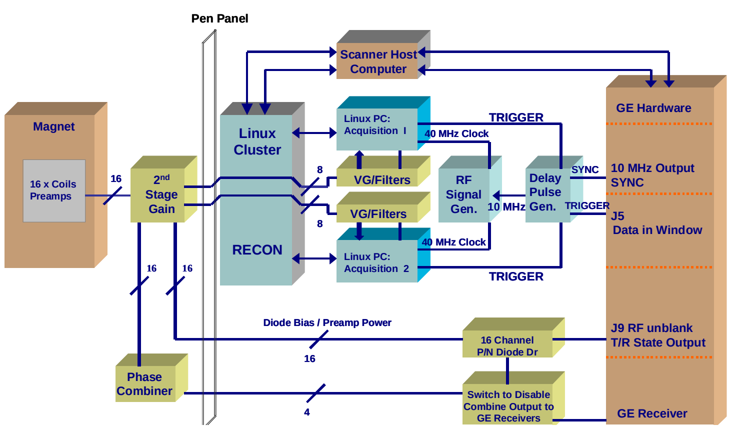

Fig 1: Schematic 16 channel MR data acquisition system

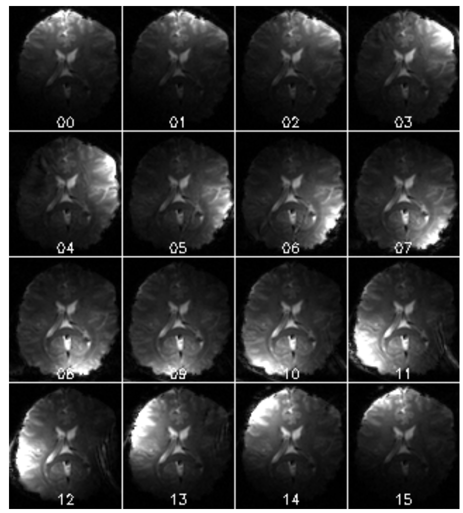

Fig. 2: 16 channel single-shot 128x96 EPI results

Outside the magnet bore, the signal was amplified 13 dB by a second gain stage, after which the signal of each channel was split two ways, one half going into the GE receiver and the other into the custom-built 16-channel system. The signals for the GE receivers were analog combined to feed into the four channels that are part of the standard hardware. The GE input was used for transmitter gain optimization and frequency adjustment. Before going into the digitizers, the 16 signals for the custom receiver were bandpass-filtered and additionally amplified with a gain that is adjusted by computer-controlled attenuators. Overall analog bandwidth was approximately 8 MHz and overall gain was adjustable from 52 to 68 dB. Digital electronics for the custom receiver were designed around PCI-based receiver boards, placed in rack-mount PCs. The digital electronics for the custom receiver were designed around PCI-based digital receiver boards (ECDR-GC214-PCI/TS, Echotek Corporation), placed in rack-mount Linux based PCs. Each board allowed digitization of 2 independent wideband analog input signals using 14-bit ADCs (AD6644AST-65, Analog Devices) which were operated at 40 MHz. Digital down-conversion and filtering were performed with on-board DSP chips (Graychip GC4016, Texas Instruments) resulting in greater than 16 bit output dynamic range. With 4 cards (8 channels) per computer, 100% duty-cycle with an output bandwidth of 1 MHz was realized. Linux based software was developed (device driver, acquisition, communication and data transmission software) together with a master graphic user interface program with real-time scanner control capabilities. Acquired data were locally stored in real-time onto hard drives and simultaneously send over 1 Gb Ethernet to a Linux-based reconstruction cluster (master + 8 nodes). All software was written in C and Perl with Tcl/Tk module extension, reconstruction software was written in C and IDL.

Results and Discussion: The overall system noise figure was less than 1 dB at a 1 MHz imaging bandwidth. Comparison of MRI data acquired with a single channel (birdcage) coil shows equivalent (within 10%) SNR for the custom and GE receiver under a variety of conditions. EPI images of human brain (Fig. 2) were acquired with 500 kHz bandwidth. SNR for the 16-channel array was 6-fold increased in cortex and 1.8-fold in central brain compared to the GE birdcage.

Conclusions: The practical feasibility of a receiver with 16 independent wideband channels has been demonstrated. The system design allows for easy increase of the number of receive channels by addition of extra acquisition and reconstruction PCs. The availability of systems with a large number of channels will greatly improve image quality, in particular for fMRI applications.

References: [1] PB Roemer, et al., Magn Reson Med 1990, 16:192-225. [2] JA de Zwart, et al., Magn Reson Med 2002, 47:1218-1227. [3] DK Sodickson and WJ Manning, Magn Reson Med 1997, 38: 591-603. [4] KP Pruessmann, et al., Magn Reson Med 1999, 42:952-962.