# Design and Implementation of a Real Time Multi-Coil Amplifier System

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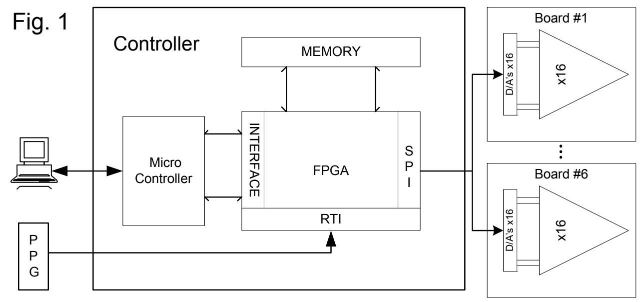
**Introduction –** An exciting new field of research has recently developed using multiple electrical coils which are independent of the scanner's main shim and gradient coils. This has led to applications for static shimming as well as gradient and higher order field term generation [1,2,3]. While commercial shim amplifiers can, in principle, be used to drive these coils, they have a higher cost, and have difficulty matching loads with small inductances and resistances. They furthermore, have limited updating speeds of both the amplifier and the controller. Here we present the design and implementation of a modular Multi Coil Amplifier System (MCAS) that has up to 96, independent +/- 1A constant current channels. Each channel is equipped with its own memory and can be controlled in real time from the scanner's pulse programmer (PPG).

**Methods –** Figure 1 shows a block diagram of the MCAS. The system consists of a controller and a number of amplifier boards. Each amplifier board contains 16 Digital to Analog converters (D/A) along with 16 constant current power amplifiers. The modular design allows the combination of up to 6 boards to reach a total of 96 channels. The amplifiers were designed using a standard constant current topology where the demand current generated by the D/A was compared to that of the sampled current through the coil via a precision shut resistor. A significant costs saving was realized by using a power device which had multiple amplifiers in each package. Power dissipation was also minimized by choosing the optimum voltage rail needed to support the required amplifier rise time. Current amplitude settings for the individual channels were sent via a slow serial interface from a PC to the microcontroller. A FPGA controller was developed that could take the current settings and load them into local memory ahead of the experiment. When called upon by the PPG, the FPGA could rapidly read out the current settings from the memory and apply them to the individual D/A's via it's Real Time Interface (RTI). A single TTL pulse from the PPG was all that was required to read out up to 96 channels. Experimental data with this set up was obtained with an array of 24 circular electrical coils on a Varian 9.4T animal system.

Fig. 1




**Results –** The switching time of the system is dependent upon two parameters: Firstly, the time taken to read current settings from memory and to apply them to all channels simultaneously. The use of a custom designed FPGA allowed a time of less than 1μS to read a single channels' current setting from memory and its application to the corresponding D/A. Once all 24 channels had been loaded, a trigger command was sent to apply all 24 channels simultaneously. This meant that current settings of all 24 channels could be updated in as little as 25uS. Secondly, the rise time of the amplifier which was governed by the voltage rail and the bandwidth of the amplifier. The bandwidth was set by matching the amplifiers loop gain to the load. Carefully matching the load allowed an amplifier rise time of 50μS for all channels to be achieved using a 10V voltage rail. Figure 2 demonstrates the flexibility of the multi-coil approach by allowing the generation of a linear, oblique XY gradient (2KHz/cm) as well as a second-order X2-Y2 (1 kHz/cm$^2$) field. By running all 24 channels independently, a wide range of magnetic field distributions can be created, the complexity of which is only limited by the coil array. In addition, the availability of independent channels allows a flexible trade-off between strength and accuracy of the field over a given volume. Figure 3 shows an image of a mouse brain that was acquired using the MCAS to generate the encoding gradients. The image is essentially identical to that obtained with conventional X,Y and Z gradients

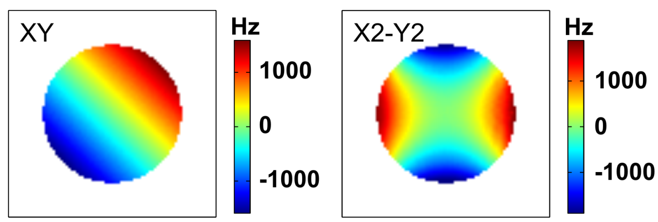
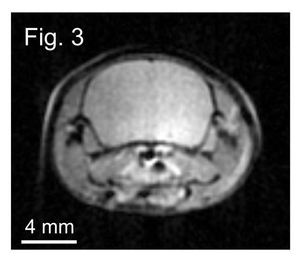



Fig. 2

**Discussion –** In its first realization, a modular amplifier and controller system has been implemented using 24 channels. Due to its modular design, the MCAS's number of channels can be customized in future systems by choosing the appropriate number of boards. The full capacity of 96 channels will be essential for human applications; however space limitations in animal systems might require a reduction of the coil matrix which is easily achieved with the presented MCAS. The amplifiers have been matched to the individual coils allowing for a relatively fast rise time. Each amplifier can have its amplitude value updated within 1μS so that amplitude changes of all 96 channels can be realized every 100μS or less depending upon the number of boards. The design and construction of the MCAS, to allow the independent control of up to 96 channels, is an essential step towards the generation of complex magnetic fields that can find application in MRI, parallel MRI, diffusion MRI and spatial localization in MRS.

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[1-3] Proc. ISMRM (2009), 3079-3081;