A High Speed Vector Modulation Array System

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Introduction: Transmit arrays represent a significant advance in MRI technology owing to the reduced SAR deposition [1], RF pulse acceleration [2,3], and ability to minimize RF coupling to interventional devices by localizing excitation[4]. However, the technology requires sophisticated and expensive engineering for commercial implementations. We demonstrate a complete transmit array system that can be retrofitted to virtually any MRI scanner and requires access only to the small signal RF output, a logic trigger, and a 10 MHz system reference.

Figure 1: Left: An array of 4 vector modulators provide 4 output channels. Center: A 4 channel high speed digital output system with USB interface, controller and single channel digital synthesizer and digital receiver. Right: Dual channel 300W RF amplifier stage.

Methods: Our system incorporates a ganged array of four vector modulators that share a common small signal RF input from the scanner. Each modulator uses RC weights to tune on board internal quadrature polyphase networks for 64 MHz, and high speed serial DACs to amplitude weight and combine for arbitrary phase shifts. Originally, all DAC channels were daisy chained through a single SPI serial line which prevented fast updates. We have now added a 60 MHz 32 bit ARM controller with USB 1 and 2 interfaces that streams data to 4 modulators simultaneously. Multiple banks can be stacked to increase the number of outputs in groups of 4. The vector modulators can now be updated at 375 KSPS but will attain over 500 KSPS with a minor rewiring. In addition, we also included a single channel 100 MHz direct digital synthesizer and a 66 MHz direct digital receiver. This unit allows us to perform a system calibration prior to connecting to the MRI RF input, and can quantify pulse nonlinearity. This unit also provides the capability to monitor transmitted and reflected power on a coil via directional couplers, or via coil current by use of on-coil current transducers (Fig 2). We constructed dual channel amplifiers using AN779H 20W predrivers and AR313 300W output stages sold by Communication Concepts Inc. RF gating of the output stage was achieved by disabling the MOSFET gate bias voltage. Waveform generation and control are provided via MATLAB.

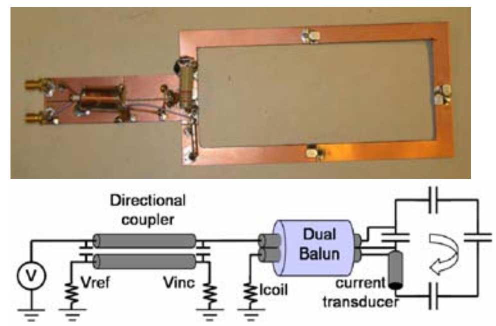

Figure 2: Array coil element incorporating a current transducer. A directional coupler can be placed between the coil and amplifier.

Results: Figure 3 shows the waveform generation interface, and a scope shot demonstrating how a rect pulse can be wave-shaped by the vector modulators to bow-tie and sinc waveforms. Figure 4 demonstrates imaging with a transmit only array composed of three 22x14 cm elements on a GE Signa 1.5T scanner. In the top row, coils were individually activated by PIN switches. In the second row, all coils are active with different amplitude and phase weightings. The plot shows MRI phase errors vs desired phase shift. The image errors deviated by less than 1.5 degrees throughout the entire transmit system chain.

Discussion & Conclusions: The component costs are approximately $1000 per channel and require minimum interfacing. All printed circuits were designed in house and are easily fabricated with inexpensive CAD tools. However, one should be aware that vector modulation acts similarly to updating a phase offset register in DDS systems. Hence, aliasing can be expected at the sampling rate. This motivates future development to use interpolating high speed DACs in future designs. Second, although vector modulators use the scanner's phase synchronous RF signal, some degree of clock synchronization is needed to prevent minor clock jitter causing phase errors in regions at the FOV edge with high gradients. Our hardware incorporates this ability. This platform will enable low cost development of Transmit SENSE and RF safe interventional systems.

References:[1]Y. Zhu, 14th ISMRM p599, 2006. [2]U. Katscher, MRM, 49:144, 2003, [3]Y. Zhu, MRM, 51:775-784, 2004. [4]G Scott, 14th ISMRM p128,2006.

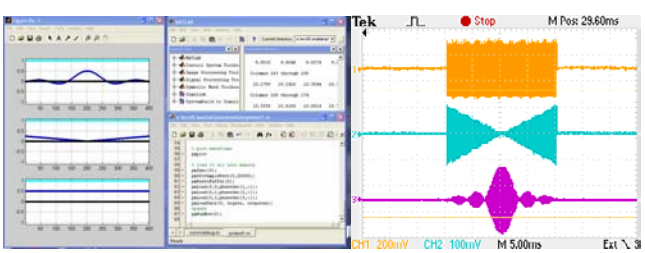

Figure 3: Matlab interface and scope shot show signal modulation.

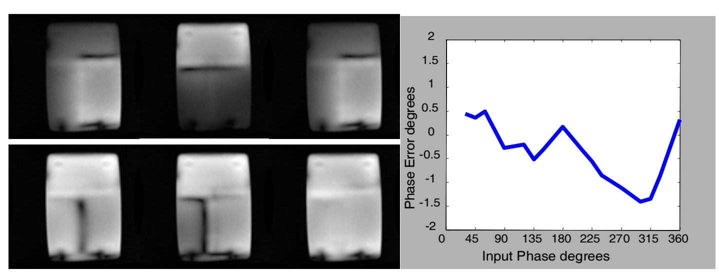

Figure 4: Coil array elements excited individually (top row) and simultaneously (bottom row). Output image phase errors deviated by less than 1.5 degrees.