A Vector Modulation Transmit Array System

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Introduction: In interventional MRI, RF safety and the elimination of guidewire heating are major concerns. The fundamental problem is that body coil excitation couples over large volumes to conducting structures such as guide wires. Some form of safe RF excitation is needed [1]. The best approach to eliminate RF coupling is the use of coil structures that have a small excitation volume and that generate electric and magnetic fields that are generally orthogonal to those of guidewire structures. Single surface coil excitation can greatly reduce wire heating[2], but has a very limited field of view. We propose a transmit surface coil array system that will adjust the excitation region but keep coupling to conducting structures to a minimum. Our goal is to create an affordable system for adding transmitter channels without significant re-design of the MR scanner.

Methods: We base our method on vector modulation. Our prototype system incorporates three subsystems: (1) parallel vector modulator blocks for amplitude and phase control, (2) low cost 200-300W RF amplifier modules, and (3) transmit only surface coil arrays.

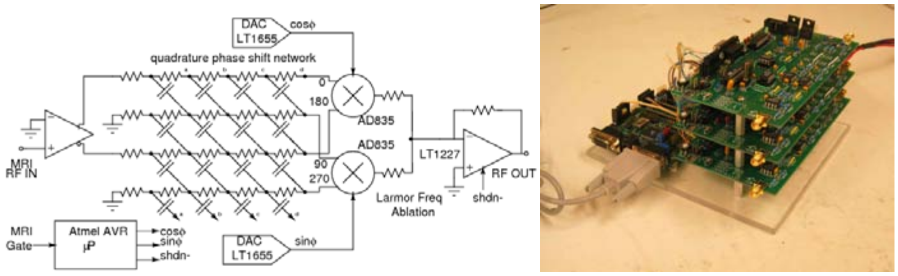

Figure 1: A broadband analog vector modulator is tuned for 64 MHz with RC weightings. When $\cos(\omega\tau)$ is input, the output is $A(\tau)\cos(\omega\tau+\phi(\tau)+\varphi)$. Three channels have been constructed.

Vector Modulator System: We have constructed a ganged array of analog vector modulators. The modulators are all connected to the same small signal RF output of the MRI scanner much like the transmit micro-coil technique[3]. Each modulator incorporates a 2 stage polyphase filter to generate differential precision phase shifts in 90 degree increments. The RC time cross-over frequencies are chosen to bracket 64 MHz +/- 2 MHz to provide broadband phase shift precision The quadrature signals are then multiplied (AD835) with two 16 bit serial DACs (LT1655) representing the cosine and sine weightings to synthesize the signal $A\sin(\omega\tau+\phi)$ as $A\sin(\phi)\cos(\omega\tau)+A\cos(\phi)\sin(\omega\tau)$. The amplitude and phase weightings are clocked in via an Atmel ATMega128 microcontroller with 512K waveform memory. Waveform generation and control are provided via MATLAB. The scanner simply transmits a hard pulse and a logic gate signal. Each modulator can individually shape the waveform eg for transmit SENSE[4,5], or provide simple RF signal weightings to perform B1 shimming.

RF Amplifier Blocks: At present, we have two AR Kalmus KAA2040M2 0.5-100MHz 200 W amplifiers ($11,000 each) available. For large array implementations, these components would be cost prohibitive. Instead, we are prototyping a third RF amplifier block using an AN779H 20W predriver and an AR313 300W power amplifier sold by Communication Concepts Inc for about $500. These devices do not incorporate RF gating so these components must be modified to perform programmable shutdown. We verified that the AN779H, although specified for 2 to 30MHz, could provide 20W drive at 64 MHz.

Figure 2: AN779H 20W predriver (left) and AR313 300W RF amplifier module (right).

Surface Coil Array: We constructed a three channel transmit-only array composed of 22x14 cm elements. Elements are arranged in a triangular pattern and overlapped to minimize mutual coupling. Blocking networks composed of PIN diode RF traps keep each coil in a normally off state. A forward DC bias activates the coils for transmit. Each coil has 2 blocking networks: one at the input port, and the second in any of the remaining 5 tuning capacitors. Any receive surface coil can be overlaid.

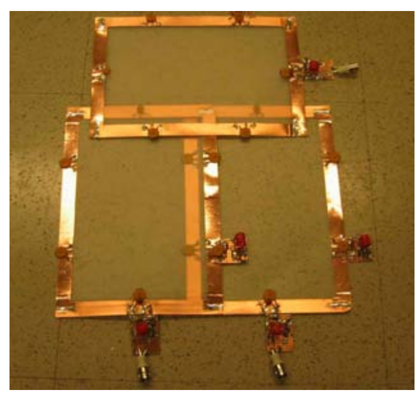

Figure 3: A three element transmit coil array. Each coil needs DC bias to become active.

Results: At present, we have completed 3 vector modulator channels, and the coil arrays. Modification of the low cost RF amplifier block is still in progress. In initial phase accuracy tests, the modulator quadrature precision is less than 1 degree and 1% amplitude error at 64 MHz. The residual error can be easily calibrated. For feasibility tests, all 3 modulator DACs are serially streamed by a single AVR microcontroller which limits update rates to 30 kHz. In future, each modulator will be assigned its own ARM controller to increase the sample rates to the DAC limit of 300 kHz. For coil testing, coil arrays were matched to 50Ω under typical chest loading. In the off state, we found that a chest loaded 5 inch receive surface coil suffered about a 20% loading increase due to transmit coil interaction. Therefore, future transmit arrays will require more blocking stages.

Discussion & Conclusions: For MR guided interventions, one really needs only locally uniform excitation, so why create RF heating dangers with a whole body excitation? Array transmitters appear to be an ideal solution. In this context, assigning one power amplifier per coil may be excessive. In future arrays, an RF power switch matrix could steer power to a select few coils with vector modulation providing the local B1 shim and waveform modulation. Using modified RF modules, we expect material costs per channel to be about $1000. We believe our approach is sufficiently cost-effective to allow adoption on most conventional MRI scanners.

References:

[1] C. Yeung et al, MRM, 48:1096-8, 2002. [2] R. Venook, ENC Proceedings, p31, 2005.[3] W. Overall et al, Proc 13th ISMRM, p2655, 2005. [4] U. Katscher et al, MRM, 49:144-150, 2003,[5] Y. Zhu, MRM, 51:775-784, 2004.