Parallel Excitation on a 3T Human MRI Scanner using Current Source Amplifiers and Iterative RF Pulse Design

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INTRODUCTION: Parallel excitation is an emerging technology with the potential to solve several problems in high-field MRI, such as B1+ homogeneity compensation, SAR control, and the acceleration of multi-dimensional RF pulses. In this work, we demonstrate an implementation of parallel excitation on a 3T GE MRI scanner using active rung/current source technology (1,2) and the RF pulse design method of (3).

METHODS: In our experiment, we used a modified version of an 8-channel active rung/current source transmit array (2) with two independent channels. The current source amplifiers use Philips Semiconductor BLF245 MOSFETS, and have a maximum output power of 30W, with 17dB gain. Waveforms were generated using the two exciter channels available on a GE 3T Signa Excite MRI scanner. We built two RF preamplifier chains for driving the current sources, consisting of a Minicircuits ZX-60-3018G small-signal amplifier, and a Minicircuits ZHL-03-5WF large-signal amplifier, which together provided 52dB gain. The current source amplifiers were blanked during receive. Our configuration used 4 of the 8 channels in the transmit array, wired in pairs on the left and right side of the coil. A quadrature receive-only coil was used for signal reception. Figure 1 shows the absolute value of transmit B1 maps produced by the each of the two RF channels. The maps were obtained with the unused coil connected but biased at zero.

We designed the 2D RF pulses for each channel using the iterative pulse design method described in (3). In this method, the pulses are designed as:

$$\hat{\mathbf{b}}_{full} = \underset{\mathbf{b}_{full}}{\operatorname{argmin}} \left\{ \|\mathbf{A}_{full}\mathbf{b}_{full} - \phi_{des}\|^2_{\mathbf{W}} + \beta\|\mathbf{b}_{full}\|^2 \right\}, \qquad [1]$$

where $\mathbf{b}_{full}$ is a vector containing the pulses for each coil, $\mathbf{A}_{full}$ is a system matrix containing Fourier matrices that are weighted in the spatial dimension by each coil's transmit B1 map, $\mathbf{W}$ is a diagonal matrix that specifies a region of interest, and β is a Tikhonov regularization parameter. The solution is computed using conjugate gradient with non-uniform fast Fourier transforms to compute products involving $\mathbf{A}_{full}$ (4). The pulses were designed using 3.6 ms gradient waveforms to produce a spiral-in trajectory with an excitation FOV of 5 cm. We used an 8 cm diameter gelatin disk phantom, leading to a speed-up factor of $R = 8/5 = 1.6$. The target excitation pattern was a uniform square, and Fig. 2 shows the magnitude of the resultant waveforms. The resulting excitation patterns were imaged using a single-shot spiral-out trajectory.

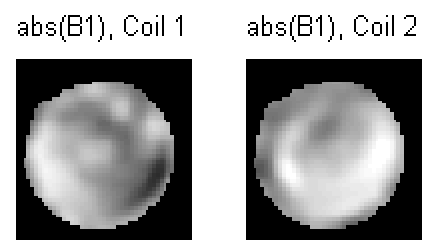

Fig. 1. B1 Maps for two RF channels using current source technology. These maps have been calibrated in gauss/waveform units.

Fig. 3 shows resulting images for excitation with each individual RF coil and for both coils transmitting simultaneously. These figures show that coil 2 does the bulk of the work for this particular arrangement of coil and target excitation pattern. With parallel excitation with both coils, it is clear that there is cancellation of aliasing artifact outside the target pattern and constructive addition within it (see arrows). When compared to the simulated excitation pattern, we see some left-right asymmetry and some incomplete aliasing cancellation. We ascribe most of these differences to artifacts or miscalibration of our B1 maps as seen in Fig 1.

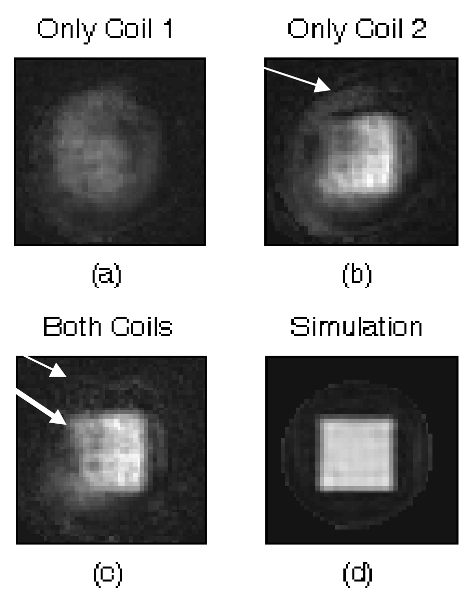

Fig. 3. (a-b) excited image for coils 1 and 2 individually, (c) excited image for both waveforms applied simultaneously showing cancellation of excitation aliases (thin arrow) and filling of the desired pattern (thick arrow), and (d) the ideal simulated pattern.

CONCLUSION: In this work, we demonstrated the ability of current source technology to produce high fidelity multidimensional RF waveforms for parallel excitation. We successfully interfaced two-channel parallel excitation hardware to the GE 3T system. We have demonstrated a processing protocol stream that integrates B1 mapping, iterative RF pulse design, and the MRI scanner. Additionally, we have experimentally verified the RF pulse design method of (3).

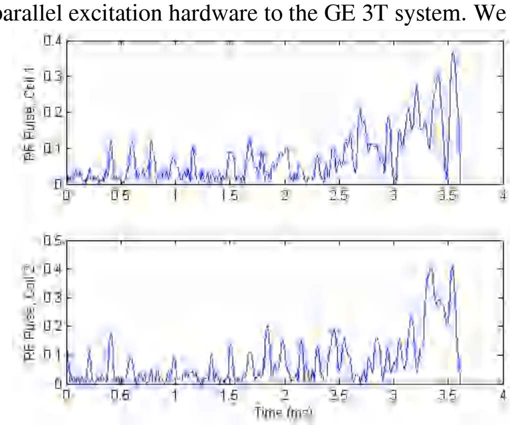

Fig. 2. RF waveforms for the two RF channels to produce a square excitation pattern with a speed-up factor of 1.6.

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