Real Time RF Power Prediction of Parallel Transmission RF Pulse Design at 7T

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Introduction

Current MRI systems are capable of measuring power dissipated into a patient by employing parallel transmission RF pulses. It was shown by Zhu [1] that predicting real power dissipation to a patient can be obtained using the E-field covariance matrix, $\mathbf{\Phi}$, calibration, before employing the RF pulses on a patient. In this work, we used the real time calibration system to predict the global SAR consequence of the parallel transmission RF pulse design [2]. Results showed that the flip angle distribution and the power deposition of the parallel transmission RF pulses can be predicted and they match with actual measurements.

Methods

Experiments were performed on a Siemens whole body 7T Magnetom scanner (Erlangen, Germany) equipped with an 8 channel parallel transmit system. An 8-channel stripline coil array was used for RF excitation and reception (Figure 1A). Measurements were performed on 7300mL cylindrical water phantom with 15cm diameter containing 1.25mg/L nickel sulfate and 4mg/L sodium chloride. Forward and reflected power readings of 8 channels were obtained with a power sensor (Rhodes&Schwarz NRP-Z11) connected to directional couplers at the output of each RF amplifier via an RF switch (National Instrument Dual 16x1 MUX).

B1 calibration was performed following the outline provided in Ref. 3. In order to obtain individual transmit channel B1+ profiles, pre-saturation pulses were employed on a reference image obtained with CP mode excitation. Axial B1 maps at the isocenter were obtained using 2ms rectangular pulse. Parameters used were: FOV=250x250mm^2 , TE=5.10ms, TR=500ms, acquisition matrix=128x128.

The target excitation flip angle distribution $\boldsymbol{\theta}_{des}$ was a 90° homogenous 4x2cm^2 rectangle 2D profile (Figure 1C). An inward spiral trajectory was used to cover the excitation *k*-space with the following imaging parameters: FOV=250x250mm^2, sampling interval=10µs and duration= 7 ms, resolution=7.875mm, gradient slew rate=150mT/m/s, and gradient amplitude=40mT/m.

The linear class large-tip-angle (LCLTA) method [4] was used to design 90° excitation pulses by solving $\underset{\mathbf{b}_{full}}{\arg\min}\left\{\left\|\mathbf{S}_{full}\mathbf{b}_{full}-\boldsymbol{\theta}_{des}\right\|_{\mathbf{W}}^{2}+R\left(\mathbf{b}_{full}\right)\right\}$ where $\mathbf{b}_{full}$ is the RF pulse waveform of all coils, $\mathbf{W}$ is the weighting matrix (equal to unity inside the phantom and zero elsewhere), $R\left(\mathbf{b}_{full}\right)$ is the regularization term, and S_{full} is the system matrix. We used $R\left(\mathbf{b}_{full}\right)=\beta\mathbf{b}_{full}^{H}\mathbf{b}_{full}$ to penalize integrated RF waveform where β is the regularization parameter. Calculated RF pulses were fed into a Bloch equation simulator [4] to predict the flip angle distribution of the excitation profile.

Expected power deposition into the phantom was predicted by $\mathbf{b}_{full}^{H}\mathbf{\Phi}\mathbf{b}_{full}$ and compared with the real time net power measurements. The $\mathbf{\Phi}$-matrix (Figure 1B) was measured using a real time calibration method described in [5]. Linearity of the calculated parallel transmission RF pulses and system was analyzed by stepping through a range of transmit voltages (60-100V) and acquiring flip angle maps by subtracting the effect of the pre-saturation pulses from reference image [3]. Average flip angle values are calculated masking the flip angle maps with a threshold of 50°.

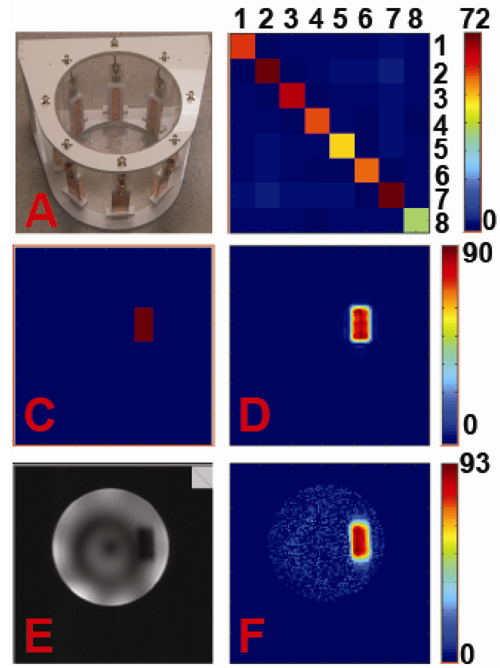

Figure 1 A) 8 Channel transmit receive coil, B) Calibrated $\mathbf{\Phi}$ matrix, C) Desired excitation profile, D) Bloch simulation result of the calculated RF pulses, E) CP mode reference excitation and the designed RF pulses played as pre-saturation, F) Flip angle distribution of the designed pulses.

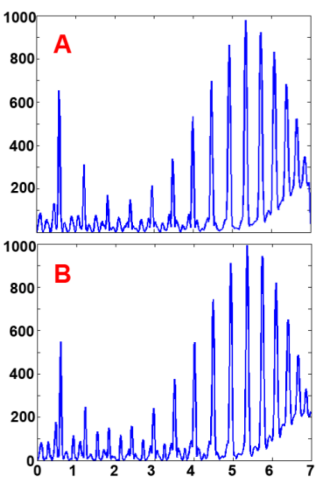

Figure 3 Measured(A) and predicted (B) net power (in watts) of the transmit array with 7ms LCLTA RF pulse.

Results

Figure 1D-F shows that the Bloch simulation results are well matched to the desired flip angle distribution. CP mode excitation in the reference image and pre-saturation effects of the calculated RF pulses can be seen in Figure 1E for 70V input transmit voltage.

LCLTA parallel transmit RF pulse design resulted in a linear response of the system for the given input voltages (Figure 2). This validates the linear class assumption used in the pulse calculation and linearity of the system with the given input voltage.

Figure 3 shows the net power measurements and predictions of the RF pulses. Predicted average net power for the designed RF pulse was 115.19W, compared to measured average net power of 116.29W. Smoother actual experimental power readings were observed because net power measurements were obtained with lower temporal resolution (twice the raster time of the system).

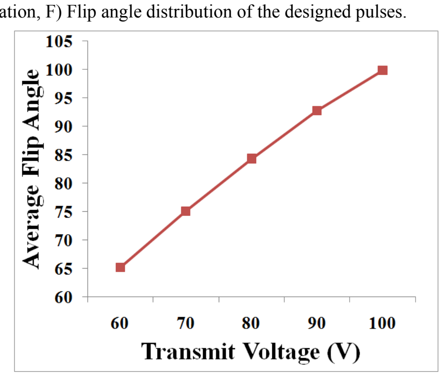

Figure 2 Linearity of the system and RF pulse design process with respect to transmit voltage

Discussion

In this work, preliminary results of using power calibration system with parallel transmission RF pulse design to predict the energy deposited to patient was shown. Flip angle profile and power predictions of designed RF pulse were demonstrated. Results showed that there is a good agreement between simulations and actual measurements.

References: [1] Zhu, Y. ISMRM 2009, 2585. [2] Alon L. et al. (2009), Automated In Vivo Global SAR prediction and monitoring for Parallel Transmission. ISMRM Parallel Workshop. [3] Fautz, H-P et al. (2008) ISMRM: 1247. [4] Xu, D, et al.(2007) MRM 58: 326-34. [5] Pauly, J, et al. (1991) IEEE TMI 10: 53-65