SAR Monitoring and Pulse Design Workflow in Parallel Transmission at 7 Tesla

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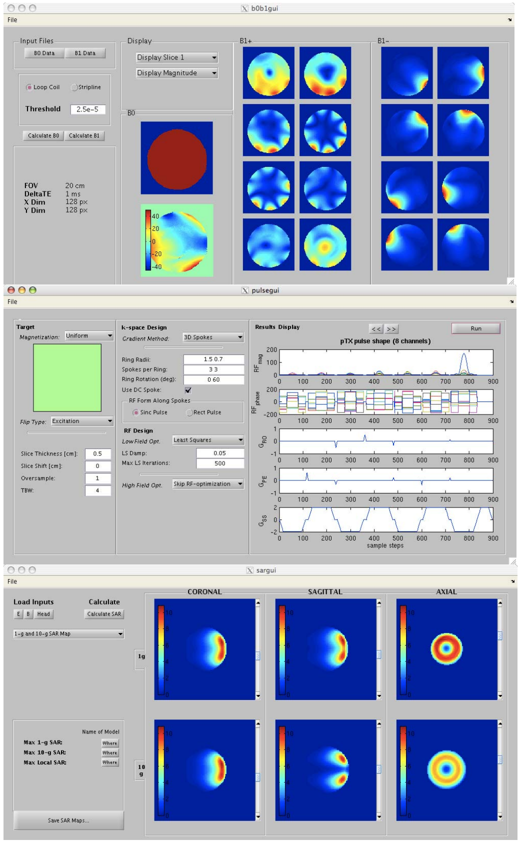
Introduction: At B_0 field strengths of 7T and above, B_1^+ inhomogeneity severely limits MR imaging applications. Parallel transmission (pTx) makes it practical to perform B_1^+ mitigation to overcome this limitation [1]. However, pTx is still limited in several applications by the need to restrict power deposition in patient tissue. Strict regulatory limits are imposed on the allowed local and global specific absorption rate (SAR [W/kg]), to avoid excessive heating. Since the scanner can only monitor total power absorbed by the coil/body, calculations are needed to ensure that local SAR limits are not exceeded before global SAR limits. For standard single channel systems, it is sufficient to model the E and B fields produced by the coil and then the global and local SAR deposition in the body model. Knowing the local-to-global SAR ratio for a coil allows the system to derate the global power limit to ensure the local SAR limits are not exceeded. Since the global power is measured in real time, the system can be shut down if a local SAR limit is exceeded.

The use of pTx requires additional care to avoid exceeding these limits. In the pTx case, the amplitude and phase of the RF pulses on different channels is calculated on a patient-by-patient case and the local-to-global SAR ratio changes significantly for different pTx phase and amplitude combinations. This forces the local-to-global SAR calculation to be done for each RF pulse designed while the subject is in the scanner. A full workflow for pTx imaging requires integrated B_1^+ field mapping followed by RF pulse design. The SAR distribution must then be calculated for the pulse based on pre-calculated B_1 and E_1 fields in the appropriate body and coil model. Once the local maximum SAR is found, the local-to-global SAR ratio can be examined and the global power limit derated so that the scanner will shut down if the local SAR limit is expected to be exceeded based on the measured global power. In this abstract, we describe a workflow environment for efficiently implementing pTx pulses, checking their local SAR properties, and passing this information to the MR scanner.



Display Slice 1
Display Magnitude
● Loop Coil ○ Stripline
Threshold 2.5e-5
FOV 20 cm
DeltaTE 1 ms
X Dim 128 px
Y Dim 128 px

Target
Magnetization: Uniform
Flip Type: Excitation
Slice Thickness [cm]: 0.5
Slice Shift [cm]: 0
Oversample: 1
TBW: 4

k-space Design
Gradient Method: 3D Spokes
Ring Radii: 1.5 0.7
Spokes per Ring: 3 3
Ring Rotation (deg): 0 60
Use DC Spoke: ☑
RF Form Along Spokes: ● Sinc Pulse ○ Rect Pulse
RF Design
Low Field Opt. Least Squares
LS Damp: 0.05
Max LS Iterations: 500
High Field Opt. Skip RF-optimization

1-g and 10-g SAR Map
Max 1-g SAR:
Max 10-g SAR:
Max Local SAR:

Fig 1. Interface for integrated B_1^+ mapping, pulse design and SAR monitoring. Results for a water phantom and an 8-channel coil driven by a Butler matrix, uniform excitation, and SAR map for one channel.

Methods: <u>Numerical computation of E_1 fields</u>. We pre-calculate the steady-state E-fields arising from a 1 V sinusoidal voltage source applied to each coil channel using the finite difference time domain solver XFDTD 7.0.3.3 (Remcom, State College, PA). We model an 8-channel loop coil and perform tuning and matching to 297 MHz in the simulation prior to evaluation of the steady-state E and B fields. The calculation is performed with the HUGO body model, resolution = 3 mm.

<u>B_1 mapping (top figure)</u>. We use 8 multi-shot turbo-flash scans (one for each channel) to map the B_1 field both the subject. The B_1^+ mapping results can be compared to the B_1^+ fields from the simulation to check the consistency between the experimental environment and the SAR model.

<u>Pulse Design (middle figure)</u>. The user then designs the pTx pulse based on a variety of methods (e.g. spokes, spiral trajectory, etc) and the user's requirements. A Bloch simulator shows the expected magnetization pattern as well as metrics comparing the magnetization to the target pattern.

<u>SAR calculation (bottom figure)</u>. After a pTx pulse is calculated, it is passed to the SAR calculation tool. The instantaneous local power is equal to $P_{local}(t)= \sigma_x |\Sigma U_k E_{k,x}(t)|^2 + \sigma_y |\Sigma U_k E_{k,y}(t)|^2 + \sigma_z |\Sigma U_k E_{k,z}(t)|^2$, where the sums are taken over the channel index k, σ_i is the electrical conductivity of the tissue in direction i, U_k is the voltage in channel k, and $E_{k,i}$ is the steady-state E-field generated by channel k per unit applied Volt. Local instantaneous SAR is equal to $P_{local}/(2\rho)$ where ρ is the mass density. The temporal average SAR is the integral over the pulse duration. We perform 10g and 1g spatial averaging of the local SAR by adding voxels using a cubic region growth, and interpolating where necessary. The SAR calculation is implemented on an inexpensive Nvidia GPU card in the Cuda programming language and requires 2 minutes of computation time.

Results: All calculations are performed through a unified interface written using Matlab (The MathWorks, Natick, MA) to provide an integrated workflow. Fig. 1 shows the three steps involved: B_1^+ mapping, pulse design, and SAR evaluation. A SAR-checked pulse is sent to the scanner with the SAR limits stored in a header file which is examined by the pulse sequence and used to set the global power limits monitored in real time. The system also uses small pickup loops on each transmit channel which are monitored in real time by the receiver and compared to the theoretical pulse.

Conclusion and Discussion: An integrated software tool for SAR monitoring provides a means of performing pulse design and SAR checking in a simple workflow which examines local SAR for every pTx pulse implemented.

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References: [1] Grissom W. et al., MRM, 56, p. 620-629, 2006.