Minimum SAR for RF Shimming by Allowing Spatial Phase Variation

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Introduction
Specific Absorption Rate (SAR) is a patient safety parameter that should be seriously considered in MRI. There are studies in the literature that minimized average SAR, for a given target transmit sensitivity. In one of these studies SAR due to a given multi-channel transmit coil was minimized with respect to the phase and the magnitude of the excitation currents on the individual channels [1]. In another work the ultimate value of SAR for RF shimming and transmit sense was calculated by the optimization of the field inside a homogenous body model [2]. In these studies target transmit sensitivities were chosen in order to obtain a uniform magnitude field distribution. However SAR change due to the phase variation among the individual points on the target profile was not investigated. In this study by keeping the magnitude distribution of the target transmit profile constant, the phase distribution is optimized to obtain true ultimate SAR for MRI coils. It was shown that with this method it is possible to reduce whole body SAR by orders up to 30, while realizing a desired magnitude distribution for target sensitivity.

Theory
Average whole body SAR inside a homogenous body model is given as $SAR = \sigma / M \int_{body} |E|^2 dv$ where σ is the conductivity and M is the total body mass. On the other hand, for a certain point of interest (ρ_0, ϕ_0), the forward polarized field component H_f is expressed as $H_f = (H_\rho - jH_\phi)e^{-j\phi_0}$ where H_ρ and H_ϕ are the magnetic field components in radial and angular directions respectively. H_f can be set to desired values at an array of points that forms the target transmit profile. Let the vector α denote the weighting coefficients for the cylindrical basis functions for an arbitrary EM field expansion. Then the SAR minimization problem is equivalent to minimizing $\alpha^* R\alpha$ where the constraint on H_f can be expressed as $B\alpha = c$ The solution for this problem can easily be found by Lagrange optimizer method as, $SAR_{avg} = c^*(BR^{-1}B^*)^{-1}c$ Let S be defined as $S = BR^{-1}B^*$ where R is a conjugate symmetric, positive definite, block diagonal matrix and contains the power deposition integrals due to each separate mode of cylindrical basis expansion. On the other hand B matrix contains the value of each cylindrical expansion modes of H_f evaluated at different points of the target profile. c contains the value of the transmit target profile at different sample points. In MRI usually a magnitudewise uniform transmit profile is desirable. However this condition does not set a constraint on the phase variation. In other words keeping the absolute value of H_f equal to unity at each location, an optimization involving the target profile phase distribution can be performed. For this purpose $SAR_{avg} = c^* Sc$ must be minimized with the constraint, $1 - \delta < |c_i| < 1 + \delta \;\; for \;\; i = 1, 2....N$,where N is the number of points in the target profile and δ is the maximum tolerance value for the magnitude of H_f

Methods and Results
In order to solve the above optimization problem "particle swarm opptimization"[3] algorithm is used. A MATLAB (version 7.0,MathworksInc., Natick, MA) program is used to implement the algorithm. A circular target transmit profile of radius 8 cm is used for calculations in a body model of radius 10 cm (Figure1). 45 points was distributed homogenously inside the target profile in order to obtain a uniform field. Phase distribution of the target profile is optimized for different δ Homogenity coefficient for H_f is calculated for δ=0 at 3 field strengths. The square of the difference between magnitude of each pixel in the target profile and the center pixel is summed and averaged. Table 1 shows the results. Table 2 shows the improvement in SAR with respect to zero phase H_f distribution, for different values of δ at 1.5T,3T and 4.7T. Figure 2 shows the optimum phase and magnitude variation of H_f inside the body model at z=0 plane for 3 different main magnetic field strengths.

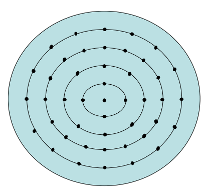

Figure 1 Target transmit profile for H_f

HOMOGENITY COEFFICIENT	
1.5 T	0.013
3.0 T	0.043
4.7 T	0.055

Table 1 Homogenity coefficients

SAR REDUCTION	δ=0	$\delta = 0.03$	$\delta = 0.1$
1.5 T	2.62	2.67	2.67
3.0 T	5.86	10.97	12.66
4.7 T	12.95	35.06	37.8

Table 2 SAR reduction with respect to zero phase target transmit profile

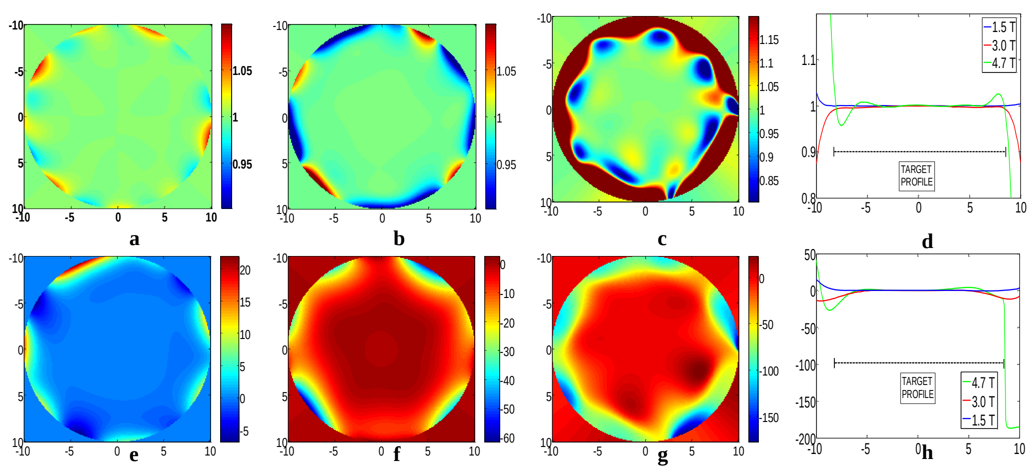

Figure 2 Forward polarized magnetic field map magnitude for 1.5T(a),3T(b) and 4.7T(c),and radial variation for 3 field strengths(d) Forward polarized magnetic field phase variation (in degrees) for 1.5T(e),3T(f) and 4.7T(g). and radial variation for 3 field strengths(h)

Discussion
For 1.5 T and 3.0 T transmit target profile guaranteed the forward polarized magnetic field to behave smoothly in the entire slice. In 4.7 T some inhomogenity effects are visible.

Conclusion
The effect of target transmit profile phase optimization on the average SAR is demonstrated. The optimum phase distribution and the coresponding ultimate SAR is calculated. A maximum SAR reduction factor of 37.8 is feasible with the optimum phase distribution in 4.7 Tesla. The optimum field distribution that gives the minimum SAR is calculated.

References [1] Zhu Y, (2004) MRM 51:775-784 [2]Lattanzi, ISMRM 2008 p 614 [3]Robinson, IEEE Transactions on Antennas and Propagation 2004;52(3)397-407