INTRODUCTION: In the design of multi dimensional spatially selective RF pulses particular attention must be paid to the local 1 gram Specific Absorption Rate (1g-SAR). Employing multi-transmit RF systems allows an additional degree of freedom which can be exploited to design RF pulses with lowest maximal 1g-SAR over the whole spatial domain. While the problem of total (global) SAR minimization can be solved quite easily[1], here we present a new method which solves the problem of local SAR optimization in a limited amount of time. For this purpose innovative mathematical techniques are applied to this problem.

METHODS AND MATERIALS: After the discretizing the solution of the Bloch Equation under the small flip angle approximation, the problem is to find an optimal numerical solution to the least squares problem argmin{||Ax-b||^2 } (1) where the matrix A is the discretization of the integral operator as in [2]. x and b are vectors corresponding to the requested RF pulses and desired magnetization, respectively. Due to the typically high condition number of A, a regularization term must be added to obtain a reliable solution of (1) and the problem becomes argmin{||Ax-b||^2+λ||x||^2} (2). The weight on ||x||^2 has a beneficial effect also for SAR optimized solutions, since the total SAR is proportional to the squared solution norm (see [3]). However, the local 1 gram SAR is of importance, since the following constraint must be fulfilled: max_{r} 1g-SAR(r) ≤ SAR_{lim}, with r ∈ ROI (the 3D spatial domain). We aim to lower the max_{r} 1g-SAR(r) for x (denoted by max_{1g-SAR(x)}) while maintaining a good accuracy of the Bloch verified magnetization profile (denoted by b_{Bloch}(x)). Analogously to [4] we construct local SAR operators Sr, such that (Sr)x(3)=1g and σ(r)=||Sr||^2. To construct a 1g-SAR operator we must average SAR(r) over a 1 gram cube around r. This is done by computing c_{0}(3)=1g and c_{0}1 the function returning the cholesky factor of a matrix. Then we have: 1g-SAR(r)=c_{0} ||x||^2. We are interested in the solutions of (2) which minimize max_{r} ||x||^2. The approach we follow is to compute first an optimal solution x^0 to (2). To solve (2) we apply the multi-shift mCGLS algorithm derived in [5]. After choosing a set of values λ∈A, mCGLS computes each solution x simultaneously. The optimal solution can then be found by plotting the L-curve. This solution has a lowest norm and thus optimal w.r.t total SAR. We then compute the highest local values of 1g-SAR(r) obtained by x^0. The strategy is to lower those high values of 1g-SAR(r) and to better distribute the 1g-SAR. We add an extra weighting term to (2) and we obtain the following modified problem: argmin_{x} {||Ax-b||^2+λ||x||^2+β(α_1||Sr||^2+α_2||S_r||^2+...+α_n||Sr||^2)} (3) where r denotes a voxel from the R top values of 1g-SAR(x^0) required for each iteration step in mCGLS, can be carried out in an efficient way due to the sparse structure of the matrices: this fact, together with the speed up achieved by mCGLS determine a fast computation of the whole procedure. The computations and simulations are carried out with MATLAB 7.4.0 on an Intel Core 2 Duo processor T3400 2.16 GHz.

RESULTS: We want to find the RF pulses for the desired magnetization (flip angle 15°) on a 2D domain corresponding to the central slice of human head (see figures 1 and 2). We employ the E-field and P. Börnert and Gerard L.G. Sleijpen Average gradient methods for families of shifted systems Applied Numerical Mathematics, 49,17-37 (2004);