SAR Reduction in Parallel Transmission by k-Space Dependent RF Pulse Selection

P. Börnert[1], J. Weller[2], and I. Graesslin[1]
[1]Philips Research Europe, Hamburg, Germany, [2]University Hamburg, Hamburg, Germany

Parallel transmission has gained considerable interest during the last few years [1,2]. The use of multiple individual RF transmit coils have been introduced to overcome B_1 homogeneity limitations and to improve multi-dimensional RF pulses by shortening their duration. Of special concern in all these transmit applications is the specific absorption rate (SAR), which has to be kept below certain limits to avoid excessive patient heating. Different approaches have been discussed to reduce SAR in parallel transmission. Thus, the degree of freedom in RF pulse design allows selecting solutions with minimal SAR [2] e.g. via regularization techniques that help to enforce low SAR [1,3]. Furthermore, the interplay between k-space trajectory and RF waveform can be used (VERSE [4]) for SAR reduction. The optimal RF pulse thus obtained is then used for the corresponding MR experiment. In that respect the parallel transmission RF pulse is optimized almost independently from the MR signal sampling process.

Methods

In this work an alternative concept is proposed. Obviously, there is a very strong relationship between the SAR of an RF pulse and its performance / overall accuracy. This relation is schematically given in Fig.1. Now RF pulse design should also be considered in relation to the signal sampling process. Core element of this approach is the idea that different areas in k-space show different sensitivities to signal imperfections [5-7], which is known from key-hole imaging [6] or motion adapted gating [7]. Thus, instead of using a single and fixed RF pulse for the entire MR experiment, a couple of different RF pulses could be employed in a single scan. Each of these RF pulses might show a different performance / accuracy resulting in different RF pulse specific SAR values (c.f. Fig.1). Thus, the RF pulses might differ slightly in the actual excitation pattern, the B_1 waveform and/or the k-space trajectory etc. The average SAR over such a single scan can potentially be reduced this way compared to the use of a fixed and highly optimized RF pulses without scarifying significant image quality.

This concept is demonstrated for local excitation using a 2D spatially selective RF pulse (Fig.2). For sake of simplicity a Cartesian spin-warp sampling scheme as shown in Fig.2 is considered. A 2D RF excitation pulse is used for localized MR, restricting the area the signal comes from. Sampling is performed in a FOV smaller than the FOX (field of excitation) of the employed RF pulse. Signal excitation for the individual lines in k-space is performed using a class of RF pulses differing in their spatial definition (Fig.3). Those have been realized simply by filtering the RF pulse target magnetization by a Gaussian kernel (0.1 – 4.0 pixel FWHM with respect to the sampling FOV) and calculating the parallel transmit RF pulses according to [8], while estimating their corresponding SAR [3]. A disk-shaped RF pulse target was considered on a 32×32 matrix (see Fig.3) for an 8-channel Tx array using a reduction factor of 4 and employing a spiral RF pulse k-space trajectory using 8 revolutions. MR signal sampling was performed assuming a 128×128 matrix. The question, which RF pulse is used to generate the signal for a given phase encoding step k_y, was subject of a very simple trial and error search, taking also the energy of the k-space representation of the excitation pattern in account. The use of different RF pulses in a single experiment will result in data inconsistencies. The question is, whether the resulting error is dominated by normal image noise or by artifacts peaking out of the noise floor. Therefore, an SNR of 15 was assumed for the simulations. To judge the performance of the different variable RF pulse acquisition schemes, the normalized root mean square error (NRMSE) was calculated with respect to an experiment using a fixed and optimal RF pulse at infinite SNR.

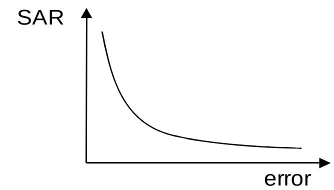

Fig.1. Schematic relation between SAR and RF performance. High definition RF pulse performance corresponds to high SAR.

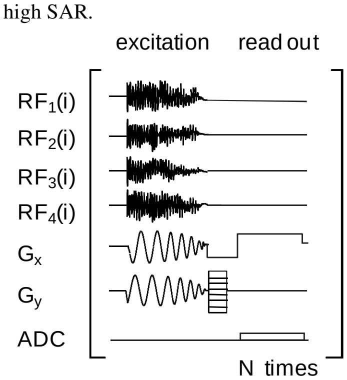

Fig.2. Scheme of 2D zoomed spin-warp imaging sampling using four individual transmit RF channels. Note, for each k_y an individual RF pulse RF(i) can be used to optimize the average SAR of the entire scan.

Results and Discussion

The simulations performed proofed the basic concept. The results given in Tab.1 illustrate the compromise between potential SAR reductions at the cost of a slightly increased excitation error (NRMSE). For a given error (NRMSE) the average SAR values are compared for the mode using different RF pulses in a scan (SAR_v) versus a fixed RF pulse mode (SAR_f). SAR reduction is achieved especially if higher errors are tolerated. However, the scenario chosen is not optimal because frequency encoding is involved, which can obscure the results. Pure 2D phase encoding would be more appropriate, making these kinds of approaches more appropriate. This concept can be applied also to refocusing RF pulses and to all kinds of magnetization preparation RF pulses.

Further studies are needed to exploit the full advantage of this concept and to judge the benefits versus the extra efforts (like extra RF pulse calculation, memory issues, etc.).

Set	NRMSE	SAR_v (%)	SAR_f (%)
#0	0.18	/	100
#1	0.20	84	91
#2	0.23	79	82
#3	0.24	61	76
#4	0.25	52	69

Tab.1. Variable vs. fixed RF pulse approach. For a given error (NRMSE) the SAR is given (index v: variable, f: fixed) Set #0 illustrates the pure noise level.

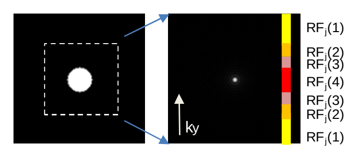

Fig.3. RF pulse pattern given in the FOX with sampling FOV (dotted square) included (left). Imaging k-space (right). The color bar indicates that different RF pulses are used for k_y sampling.

References:
[1] Katscher U et al. MRM 2003; 49: 144-150.
[2] Zhu Y. MRM 2004; 51: 775-84.
[3] Graesslin I, et al. 2008; ISMRM 621.
[4] Conolly S, et al. JMR 1988; 78:440-58.
[5] Fuderer M. IEEE TMI 1988;7:368-80.
[6] van Vaals J. et al. JMRI 1993;3:671-75.
[7] Weiger M et al. MRM 1997;38:322-33.
[8] Grissom et al. MRM 2006;56:620-29.