# SAR Reduction for Parallel Transmission using VERSE and k-space Filtering

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## Introduction

With increasing field strength, the deposition of SAR becomes a serious concern in MR imaging, in particular when short spatially selective RF excitation is applied. The RF power deposition scales roughly with the square of the B0 field. Variable-rate selective excitation (VERSE) [1] is an RF pulse design approach, which reduces the RF power deposition by adjusting the time-varying gradient waveform and the RF waveform simultaneously. The use of parallel transmission [2] offers additional degrees of freedom that can be exploited during the RF pulse design to reduce SAR [3]. In this work, the VERSE approach was adopted to parallel transmission, which has so far only been used for the design of (non-accelerated) spatially selective 1D pulses [4-5]. A significant reduction of SAR can be achieved using VERSE for accelerated RF pulses in combination with k-space filtering.

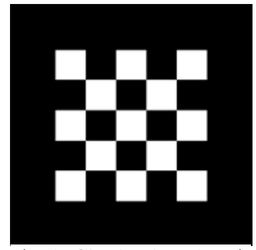

Fig. 1: Checker board excitation pattern (32×32)

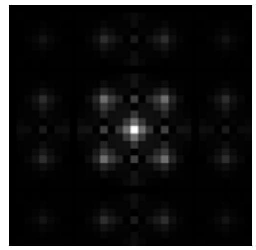

Fig. 2: FFT of checker board excitation pattern (~$B_1$(k))

## Methods

In ref. [6], an algorithm for the iterative calculation of Transmit SENSE pulses, based on (non-)Cartesian trajectories, was presented. The algorithm was implemented in analogy with the non-Cartesian SENSE reconstruction [7]. This calculation of multidimensional RF excitation pulses for parallel transmission was extended for the VERSE approach. Initially, in a first step, the excitation pattern (Fig. 1) is filtered by a filter "F" and subsequently intensity corrected (step "I"), before the conjugate-gradient iteration is started. In this study, the filtering step "F" was replaced by an enhanced filtering procedure consisting of the following three steps: 1) applying a filter to the FFT of the excitation pattern (Fig. 2) to remove all locations that cannot be covered by the chosen k-space trajectory, 2) applying the VERSE algorithm to the k-space trajectory based on the FFT of the excitation pattern [8] (see Fig. 3b), and finally 3) applying a trajectory based k-space filtering using a Gaussian weighting function based on the calculated VERSE trajectory (see Fig. 3c).

RF coil sensitivities were derived from finite-difference time-domain simulations ("XFDTD", Remcom, Inc., USA) of an eight-channel Tx/Rx body coil [9]. The sensitivities of the transmit elements were calculated on a 5mm grid using the bio-mesh model (Philips Medical Systems, Cleveland) of the "Visible Human Male" [10]. The SAR was calculated based on the computed E-fields derived from the FDTD simulations. As an example for a desired excitation pattern, the checkerboard excitation pattern is shown in Fig. 1. Its periodic structure is better suited for illustrative purposes than other irregular patterns. A spiral k-space trajectory with uniform sampling density in radial direction was used. The numerical resolution of the field-of-excitation varied between 32×32 and 128×128 pixels, and reduction factors of up to four were used for Transmit SENSE pulse calculations for eight transmit channels. Initial experiments were realized on a whole body 3T MRI system (Achieva, Philips Medical Systems, The Netherlands) that was extended to eight parallel RF transmit channels [11]. For these experiments, the real gradient strength *G* and slew rate *S* have to be considered ($G_{max}$=40mT/m, $S_{max}$=140mT/m/s). A 3D FFE sequence ($T_R/T_E$=5/2.4ms, voxel size 1.7×1.7×20mm) and a cylindrical oil phantom (diameter: 16cm, length: 37cm) were used for experimental verification.

## Results and Discussion

In the original VERSE approach [1], the trajectory adaptation is based on the calculated pulse shape. This principle cannot directly be transferred to parallel transmission due to the very high amplitude and phase variations of consecutive RF samples. Therefore, this study applies VERSE to the trajectory before the calculation of the pulse to stabilize the Transmit SENSE calculation.

Fig. 3 shows (a) the initial trajectory of a 2D spatially selective RF pulse, (b) the trajectory optimized via k-space filtering and VERSE as well as (c) limited by gradient amplitude and slew rate. The density of the optimized trajectory (Fig. 3b) clearly correlates with the Fourier-transformed excitation pattern (Fig. 2). In the trajectory shown in Fig. 3c), slew rate limitations have been considered. The degree of change of the k-space trajectory depends very much on the slew rate reserve to be exploited by the VERSE algorithm. Fig. 4 shows the amplitudes corresponding to the RF amplitudes for the three k-space trajectories (Fig. 3a-c). For an unlimited slew rate, a peak suppression of a factor of 11.8 was achieved, which is reduced to a factor of 4.2 for the trajectory with limited gradient amplitude and slew rate. The peak suppression is a very desirable effect besides the pulse power reduction, since the peak amplitude of the RF amplifier is limited. Fig. 5 shows the effects of the VERSE algorithm on the gradient amplitude and slew rate. For a reduction factor of *R*=2 and a fixed gradient amplitude and slew rate reserve of 25%, the pulse power was reduced by a factor of 1.49, the global SAR by 1.51, and the local SAR by 1.59. Initial results have shown that also a small gradient amplitude and a slew rate reserve already lead to significant peak suppression and reduction of global and local SAR.

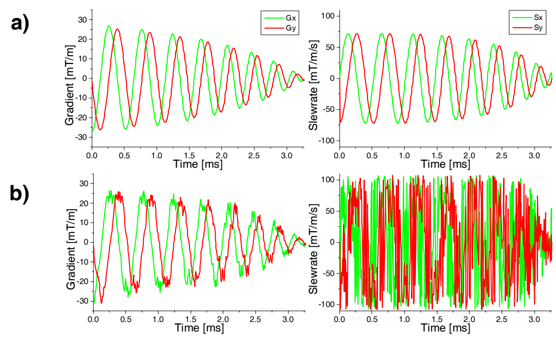


Fig. 5: Comparison of (a)standard gradient amplitude and slew rate and (b) the corresponding VERSE adapted gradient and slew rate for a 25% added reserve of amplitude and slew rate.

## Conclusion

In this work, the potential of the VERSE approach was demonstrated for multi-dimensional RF pulse calculations for parallel transmission. The combination of pre-k-space filtering in combination with the VERSE techniques has proven to be a very interesting concept for reducing the SAR for parallel transmission. Further investigations of the parameters influencing the achievable SAR reduction are required.

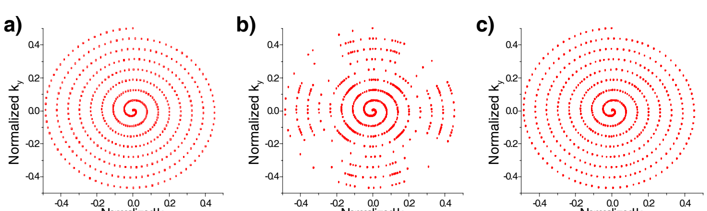


Fig. 3: Comparison of a) the standard trajectory for a 2D spatially selective RF pulse for *R*=2, b) the corresponding k-space filtered and VERSE adapted trajectory, and c) the VERSE trajectory with limited gradient and slew rate.

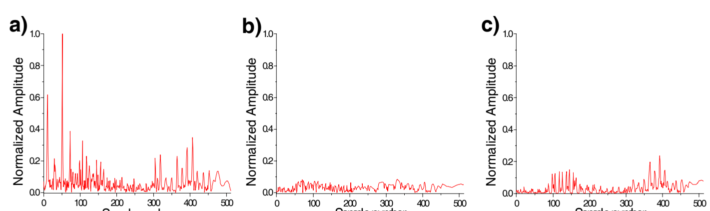


Fig. 4: Comparison of the RF amplitude for a 2D spatially selective RF pulse for *R*=2. a) The ideal trajectory, b) the corresponding k-space filtered and VERSE adapted trajectory, and c) VERSE trajectory with limited gradient amplitude and slew rate.

## References

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