# VERSE Optimized Multi-Channel Transmission

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**Introduction:** Magnetic Resonance Imaging (MRI) at high static magnetic field is favorable mainly due to its high signal to noise ratio (SNR). However, imaging at high magnetic field has its own drawbacks e.g. severe $B_1^+$ inhomonegeity in axial plane and increased Specific Absorption Rate (SAR). Methods like Variable Rate Selective Excitation (VERSE) (2) have been used to reduce the SAR. In this work a multidimensional RF pulse design method is proposed for multi-channel transmit systems which realize the maximum possible SAR reduction with the VERSE operation while assuring the maximum $B_1^+$ inhomogeneity mitigation.

**Theory:** For the multi-channel transmit systems the relation between the desired transversal magnetization profile ( $\boldsymbol{M_{xy}}$ ) and the RF waveforms ( $\boldsymbol{b_{1,p}}$ ) given in Eq.[1]. This relation includes the position dependent sensitivity information of each channel ( $\boldsymbol{S_p(r)}$ ) and which is necessary for $B_1^+$ inhomogeneity mitigation.

$$\boldsymbol{M_{xy}(r)} = \sum_{p=1}^{P} diag\left\{\boldsymbol{S_p(r)}\right\} \boldsymbol{A b_{1,p}} = \boldsymbol{A_{full} b_{full}} = M_{\boldsymbol{full}} \qquad [1]$$

where i-j'th element of matrix $\boldsymbol{A}$ is defined as: $a_{ij} = i\gamma M_0 \Delta t \exp\left(i\gamma \Delta \boldsymbol{B_0}(\boldsymbol{r_i})\left(t_j - T\right)\right)\exp\left(i r_i \bullet \boldsymbol{k}\left(\boldsymbol{t_j}\right)\right)$ , $\boldsymbol{M_{xy}} = \boldsymbol{M_x} + i\boldsymbol{M_y}$ , $\gamma$ is the gyromagnetic ratio, $M_0$ is the steady-state magnetization, r is the spatial variable, $\Delta \boldsymbol{B_0(r)}$ is the inhomogeneity distribution of the main static magnetic field and **k(t)** is the k-space trajectory.

The whole body SAR for multi-channel transmit systems is given as follows (1):

$$SAR_{\text{ave}} = \sum_{i=1}^{N_t} b_i^H \boldsymbol{S_{\text{sub}}} b_i = \boldsymbol{b_{\text{full}}^H S b_{\text{full}}} \qquad [2]$$

where $\boldsymbol{b_i}$ is i'th current sample, $\boldsymbol{b_{full}}$ is the same as $\boldsymbol{b_{full}}$ in Eq.[1], **S** is a diagonal matrix where each block of it is $\boldsymbol{S_{\text{sub}}}$ and $\boldsymbol{S_{\text{sub}}}$ is a positive definitive matrix, the p-k'th elemnt of $\boldsymbol{S_{\text{sub}}}$ is defined as: $s_{sub}^{p,k} = \frac{\Delta t}{T_R N_t m} \int \sigma(r) \boldsymbol{E_p}\left(\boldsymbol{r}\right) \bullet \boldsymbol{E_k}\left(\boldsymbol{r}\right) \boldsymbol{dv}$ **,** $\Delta t$ is the temporal resolution, $T_R$ is the repetition time, m is the mass of the object, $N_t$ is the total number of time samples, $\boldsymbol{\sigma(r)}$ is the position dependent conductivity of the object and $\boldsymbol{E}\left(\boldsymbol{r,t_i}\right)$ is the position and time dependent E-field vector.

Eq. [1] can be solved using different methods. In 2004, Zhu et.al.(1) proposed to solve Eq. [1] by defining an optimization problem which minimizes the $SAR_{\text{ave}}$ . For convenience this method mentioned as SAR Optimized Parallel-Transmission (SOP). The $SAR_{\text{ave}}$ can still be reduced if the VERSE algorithm is applied to the RF waveforms that are calculated with the SOP method. However, maximum SAR reduction efficiency is not guaranteed. Therefore, instead of minimizing $SAR_{\text{ave}}$ before the VERSE operation it is proposed to reformulate the optimization problem such that the RF waveforms which have the minimum SAR after VERSE operation are calculated. This method called as VERSE Optimized Parallel Transmission (VOP). In design step hardware constraints such as maximum RF amplitude, maximum gradient slew rate were not imposed but in application step these limitations were considered.

| **SAR Optimized Parallel-Transmission (SOP)** | **VERSE Optimized Parallel Transmission (VOP)** | |
|---|---|---|
| $minimize\ SAR_{\text{ave}} = \boldsymbol{b_{\text{full}}^H S b_{\text{full}}}$ | $minimize\ \ SAR_{\text{UC\_VERSE}} = \frac{\left(\sum_{i=1}^{N_t} \sqrt{\boldsymbol{b_i^H S_{\text{sub}} b_i}}\right)^2}{N_t}$ | [3] |
| $subjected\ to\ \boldsymbol{M_{\text{full}}} = \boldsymbol{A_{\text{full}} b_{\text{full}}}$ | $subjected\ to\ \ \boldsymbol{M_{\text{full}}} = \boldsymbol{A_{\text{full}} b_{\text{full}}}$ | [4] |

**Methods:** A Siemens TIM Trio 3T MR Scanner with an 8-channel Transmit Array System (Siemens Medical Solutions, Erlangen, Germany) was used in all our experiments. **.** A circularly shaped water phantom with 1.25 g/liter nickel sulfate ( $T_1 \sim 330$ ms and $T_2 \sim 220$ ms) was used as an object. 3D GRE sequence was preferred with 2D spiral excitation pattern. The spiral trajectory was chosen such that number of turns remained above 8.

**Results:** Imaging experiments with spherical phantoms are conducted. The B1 inhomogeneity mitigation and SAR reduction performance of the VOP is observed. In addition to unconstrained VERSE, constrained VERSE results displayed because it is not possible to apply unconstrained waveforms because of the hardware limitations.

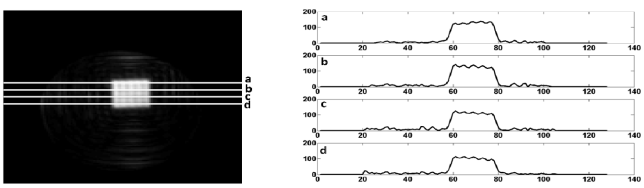


**Figure 1: Selective Excitation and Corresponding Profiles for Image Quality Assessment.**

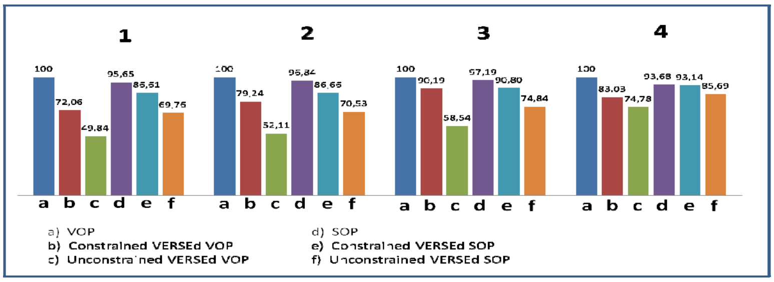


**Figure 2: SAR Comparison for Different Methods.**

As it is seen in Fig. 1 the image quality and the B1 inhomogeneity correction is satisfying with the sequence prepared using VOP. In Fig. 2 it is seen VOP outperforms SOP in term of SAR reduction.

**Discussions and Conclusion:** VOP is a useful method for multi-channel transmission applications where inhomogeneity and SAR problems arise. Considerable SAR reduction is obtained with the VOP method therefore it is managed to increase SAR reduction performance of the VERSE algorithm. It should be noted that we only considered whole body SAR because we worked at 3T but for ultra high field MRI the local SAR should also be considered.

**References:** 1. Zhu YD. Parallel excitation with an array of transmit coils. Magn Reson Med 2004;51(4):775-784.

2. Conolly S, Nishimura D, Macovski A, Glover G. Variable-Rate Selective Excitation. J Magn Reson 1988;78(3):440-458.