Basics of RF power behaviour in parallel transmission

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Introduction: Parallel transmission [1,2,3] allows the reduction of the duration of spatially selective RF pulses by the use of multiple RF transmit coils. One particular application of parallel transmission is the compensation of B1 field inhomogeneities occurring at high fields caused by, e.g., dielectric resonances. In this framework, the dependence of the RF pulse power on the parameters of parallel transmission has not been addressed up to now. In this study, a simple model for the RF pulse power required in parallel transmission is developed. Predictions from this model are compared with results from simulations of a cylindrical head coil with up to 32 elements and Transmit SENSE [1] for $B_0 = 3$ T.

Theory: The RF power P_{mod} required in parallel transmission is derived via a simple model to roughly sketch its dependence on the time reduction factor R and the number of transmit elements N. To this goal, a model inductivity $L_{mod} \sim N^2$ is assumed supposing roughly the same current amplitude in the different elements. Furthermore, a model current $I_{mod} \sim R / N$ is assumed, which follows from the assumption, that the flip angle α should be the same with and without parallel transmission $\alpha = \gamma B_1^{R=N=1} T = \gamma N B_1^{R,N} T / R$. Using these model inductivity L_{mod} and model current I_{mod}, the model RF power P_{mod} is proportional to

$$P_{mod} \sim L_{mod} I_{mod}^2 \sim N^2 I_{mod}^2 \sim R^2 \tag{1}$$

assuming a constant coil quality factor and patient dominated coil loading. Now, the corresponding RF power P_{TS} using Transmit SENSE [1] is estimated. To this goal, first the time-dependent currents $I_i(t)$ of element i are calculated via Transmit SENSE [1]. Then, the mean square $\left\langle I_i^2(t) \right\rangle$ of the currents I_i are derived by taking the average over the pulse duration T / R and over the N transmit elements

$$\left\langle I_i^2(t) \right\rangle = \frac{R}{NT} \sum_{i=1}^{N} \int_{t=0}^{T/R} I_i^2(t) \mathrm{d}t \ . \tag{2}$$

Finally, the resulting RF power P_{TS} for Transmit SENSE is estimated by replacing I_{mod}^2 in Eq. (1) with $\left\langle I_i^2(t) \right\rangle$

$$P_{TS} \sim N^2 \left\langle I_i^2(t) \right\rangle . \tag{3}$$

Methods: Using the software package FEKO [4], a transmit TEM resonator array of up to $N = 32$ equidistant, independent elements is simulated in a cylindrical RF screen (diameter = 30 cm, length = 30 cm, see Fig. 1). The elements are assumed to be fully decoupled. As a head model, a sphere is placed in the coil with diameter 0.16 m, permittivity $\varepsilon_r = 81$, and conductivity $\sigma = 0.5$ S/m. The sensitivities of these elements are calculated in the central plane perpendicular to B_0. Then, independent RF waveforms are derived for the different elements using Transmit SENSE [1], assuming a Cartesian trajectory in the excitation *k*-space. The desired excitation pattern is defined to be constant within the field of excitation (FOX) on a 32×32 grid, i.e., the simultaneous transmission of the RF waveforms should yield a homogeneous transverse magnetization in spite of dielectric resonances and the inhomogeneous sensitivities of the individual elements. Simulations were performed for cases $1 < R < 32$ and $1 < N < 32$ with $N > R$. Finally, the corresponding P_{mod} and P_{TS} were calculated using Eqs. (1,3).

Results: The results in Figs. 2,3 show, that the RF power model presented is applicable especially for large ratios N / R, i.e. roughly $N / R > 4$. For smaller ratios N / R, the required RF power derived via Transmit SENSE reveals a more complex behaviour. For instance, for small ratios N / R, the RF power decreases with increasing N (Fig. 2) and increases slower than R^2 (Fig. 3) as predicted by the model. For $N = R$, this leads to a maximum of P_{TS} for the investigated scenario for an intermediate range of $N = R = 4$ (see Fig. 2).

Discussion: The above presented simple RF power model does not require spatially independent coil sensitivities, but would be optimally fulfilled by using identical coils. Spatially independent coil sensitivities introduce additional information into the system. With this additional information, the resulting RF pulses are able to act as complements rather than just splitting the required RF power. Vice versa, an agreement of P_{mod} and P_{TS} indicates spatially dependent coil sensitivities. Thus, the model sketches the worst case of the required RF power, which will usually be more benign using real coils.

Conclusion: The RF power required in parallel transmission can be estimated via a simple model, especially for high ratios of N / R. For small ratios N / R, simulations reveal a complex RF power behaviour, showing that parallel transmission does not necessarily increase the required RF power. Due to the close relationship of the different parallel transmission approaches [1,2,3] it is expected, that the simulation results derived in this study via Transmit SENSE [1] are also valid using different parallel transmission approaches [2,3]. The results might serve as input for further studies investigating the SAR occurring in parallel transmission, or the specification of amplifier requirements.

References: [1] Katscher U et al., MRM 49 (2003) 144-50 [2] Zhu Y, MRM 51 (2004) 775-84 [3] Grissom W, Proc. 2. Int Workshop on Parallel MRI, Zürich (2004) 95 [4] Jakobus U, IEEE Antennas & Prop. Conf. 436 (1997) 182-5

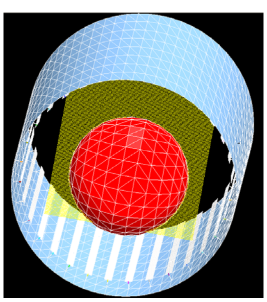

Fig. 1: Sketch of the simulation scenario. A transmit array of up to 32 independent elements (white) is arranged in a cylindrical RF screen (blue), loaded with a spherical head model (red). Furthermore, the central plane (yellow) is indicated as field of excitation (FOX).

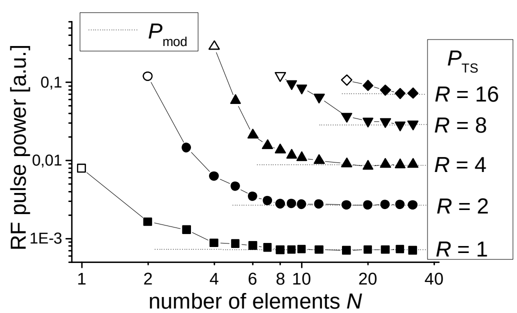

Fig. 2: The required RF power for different number of elements and reduction factors. For small values of N / R, the RF power decreases with increasing N. The open symbols indicate results for $N = R$. Here, a maximum can be found for $N = R = 4$.

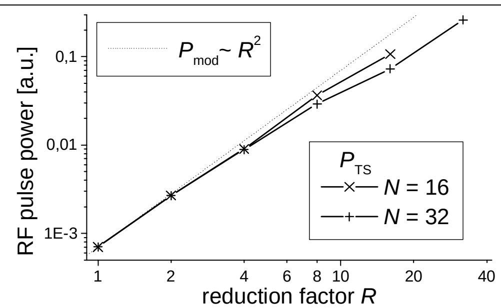

Fig. 3: The required RF power for different reduction factors and number of elements. For large values N / R, the RF power follows a simple R^2 behaviour according to the presented model. For small values N / R, the RF power increases slower than R^2.