Safety considerations concerning SAR during RF amplifier malfunctions in parallel transmission

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Introduction

Parallel transmission [1,2] has gained increased interest, e.g., for B1-shimming [3] or local excitation [4]. Recently, first MR system prototypes have been presented, which are capable of parallel transmission [5,6,7]. Thus far, these experiments were focused primarily on phantom studies due to safety concerns. This study investigates consequences of RF amplifier malfunctions on the occurring specific absorption rate (SAR). It was investigated, if – in opposite to intuitive expectations – a malfunction of a transmit channel or erroneous shutdown of an amplifier might increase local SAR.

Methods

A multi-channel body coil (MBC) with eight ideally decoupled TEM transmit elements (Fig. 1) for operation at 3T (128MHz) was simulated using the finite difference time domain (FDTD) method ("XFDTD", Remcom, Inc., USA). The generated coil sensitivities were calculated on a 5mm grid using a 5mm resolution bio-mesh model of the "Visible Human Male" [8]. The SAR was calculated by superposition of the electric fields of the individual coil elements as $SAR = \sigma\ |E|^2/\rho$, where σ is the electrical conductivity and ρ is the mass density of the tissue. The local SAR is obtained from averaging SAR over $1cm^3$. Two different cases were studied for a transversal slice in the center of the MBC (Fig. 2): first, the usual quadrature driven body coil (QBC mode) with a positive circularly polarized component of $\underline{B}_1$ defined as $|\underline{B}_1^{(+)}| = |B_{1x} + i\ B_{1y}|$, secondly, the multi transmission (MTX) mode with the individually driven channels of the MBC having sets of selected phases and constant amplitudes.

Within this simulation scenario of a slice in the pelvis area, the distribution of the SAR was evaluated for different sets of phases in the transmit channels. The effect of the failure of a single transmit channel was investigated by setting the respective excitation amplitude to zero for that channel. A worst-case analysis for the local SAR was carried out for three different excitation setups of the MBC in Fig. 2 using either four or eight coil elements. Setup A (coils 1 – 8), setup B (coils 2, 3, 6, 7), and setup C (coils 1, 4, 5, 8). For the MTX mode, the phases were varied for all coil elements in steps of 60° and 72°, in order to simulate asymmetric cases.

Failing coil	Setup A	Setup B	Setup C
1	1.35	-	**1.73**
2	**1.79**	2.16	-
3	1.62	1.80	-
4	1.17	-	1.31
5	1.18	-	1.43
6	1.62	2.18	-
7	1.57	**2.31**	-
8	1.17	-	1.10

Table 1: Ratio of SAR increase for the MBC driven in QBC Mode

	MTX mode	QBC mode
Setup A	2.85 (failing coil 7)	1.79 (failing coil 2)
Setup B	2.87 (failing coil 7)	2.31 (failing coil 7)
Setup C	2.94 (failing coil 1)	1.73 (failing coil 1)

Table 2: Ratio of SAR increase: worst-case scenarios for MTX and QBC mode

Results and Discussion

The increase of the local SAR depends on the position of the coil element having zero amplitude. For the QBC mode, Table 1 presents the increase in SAR for different coil elements failing. The maximum ratio of local SAR increase amounts to 1.79 in Setup A, 2.31 in Setup B, and 1.73 in Setup C. For the MTX mode, the local SAR can increase significantly under unfavorable superposition of the different phases in the channels. When the total input power is kept constant, variations of the amplitudes lead to only minor changes. For this reason, only variations of the phases were considered. For the MBC coil driven in MTX mode, this ratio increases much stronger up to 2.85 in Setup A, 2.87 in Setup B and 2.89 in Setup C as shown in Table 2. Therefore, the failure of a single transmit channel may have an impact on the local SAR. Results of the SAR simulation are shown in Fig. 3 for the worst-case scenario of Setup A driven in MTX mode.

Conclusion

Safety considerations are very important for multi-channel transmit systems, where the failure of a single RF transmit channel can lead to increased local SAR. The worst-case ratios of Table 2 indicate that the local SAR increases, although the total input power decreases by a factor of 1/4 or 1/8. Thus, in order to prevent safety hazards in a multi-element transmit MR system, suitable channel control is needed. Such a mechanism must ensure the immediate shutdown of a running scan in case that malfunctioning occurs in one of the RF transmit channels.

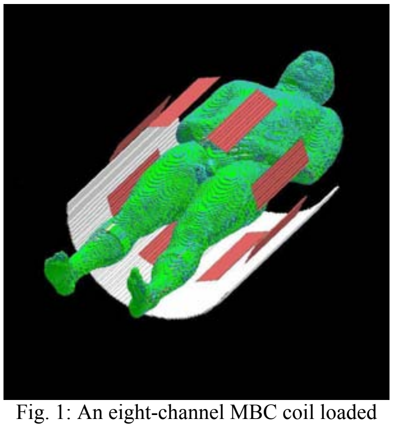

Fig. 1: An eight-channel MBC coil loaded with the NLM "Visible human Male" bio-mesh

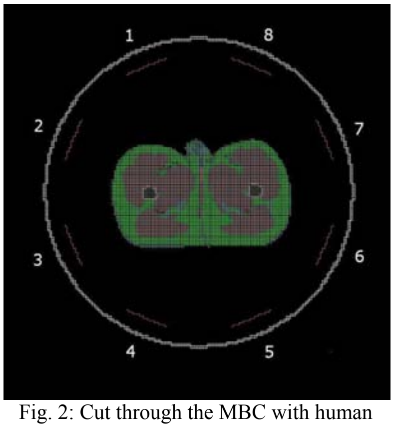

Fig. 2: Cut through the MBC with human model at the location of the investigated (center) transverse slice

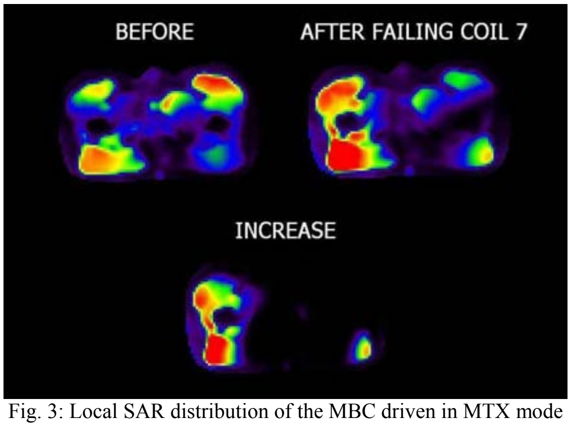

Fig. 3: Local SAR distribution of the MBC driven in MTX mode (upper left), after the failing of coil 7 (upper right) and the resulting increase of local SAR (lower middle)

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