Safety evaluation of a multiple-channel travelling-wave system at 7T

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Introduction

The travelling wave concept [1] was recently extended to multiple channels showing promising results in phantoms [2]. For in vivo imaging a reliable SAR evaluation is necessary considering all uncertainties particular to this RF system. Methods were developed to calculate an input power limit, such that the local SAR limits are not exceeded [3], in any case of operation and within the uncertainties given.

Figure 1: Travelling wave multiple channel RF system.

Methods

RF array system

The RF system consists of a 2m long, dielectrically loaded waveguide section entering the bore whose modes are excited by seven stubs and one loop at the distant end from the sample, see Fig. 1. 52 cylindrical water filled rods, the waveguide is able to support 17 modes.

EM field simulations

The RF system including bore, waveguide, dielectric filling, feed structure and a human body model (Duke, Virtual Family, IT'IS, Zurich, Switzerland) was modeled using an FDTD-based commercial simulation platform (SEMCAD, SPEAG, Zurich, Switzerland).

Safety validation based on modal field distribution

The main problem to be solved was that the uncertainties of the coupling coefficients of the individual ports to the propagating modes could not be reliably assessed whether numerically nor experimentally. To ensure compliance it was necessary to find a conservative estimate of the maximum SAR induced in the human body independently of those coupling coefficients. This was achieved by taking all field patterns into account that are able to propagate to the sample and deriving the worst case SAR deposition resulting from all of them.

The number of all possible field distributions and their field patterns were calculated by addition of further exciters until a principal component analysis (PCA) of the field distributions inside the human body model indicated that the variance of the further field distributions is already explained by the previously calculated ones. This convergence was safely achieved by 20 ports.

The worst case SAR possibly induced by those 20 field patterns in any RF shimming configuration was calculated independently of their individual coupling efficiency by normalizing the local SAR deposition to the total power dissipated in the human body. This was achieved by maximizing the ratio of local SAR and whole body power absorption, in each 10g portion of the body, by the following approach [4]:

$$SAR = \frac{\boldsymbol{V}^H[P]\boldsymbol{V}}{\boldsymbol{V}^H[P]_L\boldsymbol{V}} = \frac{\boldsymbol{V}'^H[P']\boldsymbol{V}'}{\|\boldsymbol{V}'\|^2} \quad \text{with} \quad \boldsymbol{V}' = R\boldsymbol{V},\ [P'] = R^{-1H}[P]R^{-1}$$

where [P] is the SAR matrix, $[P]_L$ the power loss matrix inside the human, and R the lower triangular matrix of the Cholesky factorization of the power loss matrix, $R^H{*}R=[P]_L$. In order to define a conservative maximum input power for the actual physical system from the worst case SAR derived before, it was assumed that all power sent to the ports is entirely dissipated in the human body.

Results safety assessment

The worst-case SAR analysis yielded a maximal local 10g average SAR of 3.2W/kg for 1W input power. This analysis allowed in-vivo images with a total input power averaged over 6 minutes of 30W into the RF system for a maximal 10g average SAR of 20 W/kg.

In-vivo imaging

Spoiled gradient echo images of the transversal, sagittal and coronal planes were acquired on a 7T Philips Achieva scanner with MultiX system with 8 independent transmit/receive channels (Philips Healthcare, Cleveland, OH). In lack of a power monitoring system, the average forward power delivered to the exciters was limited by the RF duty cycle of the sequence under the assumption the RF pulse could reach the full peak power for the duration of the excitation pulse. This estimation allowed a sequence timing of 0.5ms for the main excitation lobe and a minimal TR of 150ms with maximimum duration of 6 minutes. Examples of RF shimmed images of several planes are shown in Figs 2 and 3. For the three images in Fig. 2 the travelling wave system was used in transceive mode. For the image In Fig. 3 the travelling wave system was used in transmit mode only and a 16 channel array coil, Nova Medical (Wilmington, MA, USA) was used for reception.

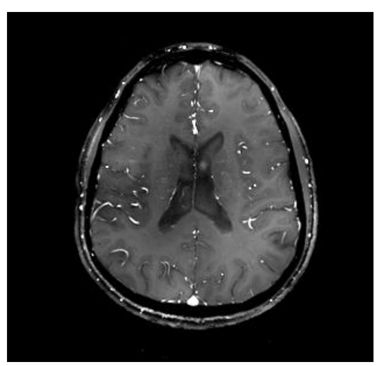

Figure 3: Multichannel travelling wave transmit, local array receive.

Figure 2: Multichannel travelling wave transmit and receive.

Discussion & Outlook

A conservative safety evaluation of the multi-channel travelling wave system was developed taking all the uncertainties into account. This is achieved by considering the finite number of excitable modes within the bore extension. This allowed a safe operation of the 7T scanner for in-vivo imaging using parallel transmission with 8 channels. Initial experiments showed that uniform images in all three orthogonal slices over the whole brain including the brainstem are possible. An increase in SNR was achieved with a local receive coil array. Further work includes the reduction of the uncertainties in order to further raise the power limits for better contrast.

References

[1] Brunner, Nature 457,pp. 994-998, 2009; [2] Paska, ISMRM, p1879, 2010, 2010, [3] IEC 60601-2-33 ed3.0; [4] Brunner, ISMRM, p1320,2008