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RF B^{1+} field homogenization over the whole brain in 7T MRI

Kyoungsub Yoon*[(1)], Hansol Noh[(1)], Sunkyu Yu[(1)], and Namkyoo Park[(1)]
(1) Seoul National University, Seoul, Korea; yqs1122@snu.ac.kr; nkpark@snu.ac.kr

Ultra-High-Field (UHF) MRIs, with the static B_0 magnetic field > 7 Tesla, offer enhanced SNR and better images, thus enabling patients to get scanned faster at reduced exposure to EM radiation. Nonetheless, at the same time, this very use of higher static B_0 also makes the effective Lamour wavelength of the transmit RF magnetic field B_1^+ to be smaller than the feature size of the B_1^+ field resonator - the human head in the case of brain MRI - therefore significantly increasing the inhomogeneity of RF B_1^+ field inside the region of interest (ROI), such as the brain.

In this work, we propose and present a strategy that suppresses the inhomogeneity of the RF B_1^+ field, over the 3D ROI of the whole brain. To start, without a loss in generality, we take a sample of spherical phantom (radius = 10cm, ϵ_r = 64, and σ = 0.51 S/m) mimicking the properties of humans, and then numerically derive the linear combination of quasi-eigenmodes ψ_i - providing the homogenization over the whole 3D volume of target ROI.

$$\underset{c_i}{argmin}\left(\varphi - \left|\sum c_i \psi_i\right|\right)^2 \tag{1}$$

In detail, first, we identify the best scenario 3D B^{1+} mode profile - which offers the global homogenization in the whole brain above the axial palatal plane - with the minimum number ($i = 1 \sim N$) of participating quasi-eigenmodes, yet offering clinically acceptable and practically achievable B^{1+} field coefficient of variation (CV) < 0.2. Then by assuming a set of non-contact cylindrical high permittivity materials (HPMs), we further show that it is possible to control the wavefront of the RF B^{1+} field, to achieve the best scenario calculated limit of $\sum c_i \psi_i$ inside ROI.

The proposed idea has been verified under 7T MRI environments, employing a realistic human head model of MIDA within *Sim4Life*, the commercial FDTD tool for biomedical study. Over the whole *brain* of MIDA, excellent B^{1+} field homogeneity improvement and reduced exposure to EM radiation have been achieved with our approach - over 40% reduction in B^{1+} field variation (CV) and 20% reduction in EM exposure (SAR: specific absorption rate). Our approach's robustness is also verified in terms of the movement or size variation of the head. Our B^{1+} homogenization proposal paves the first step in the successful application of electromagnetic metasurface for the UHF MRI 3D volume homogenization problem, which has persisted over the past 20 years, and further constitutes the first application of metasurface for the mode shaping of the magnetic field inside 3D volume of heterogeneous media.

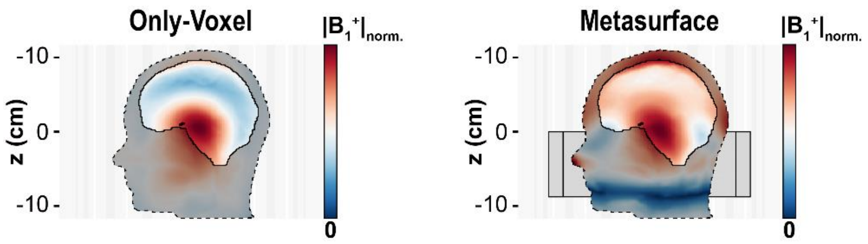

Figure 1. Comparion of the RF B^{1+} field distribution: (left: control without mitigation) vs. (right: with the application of metasurface).