Ultimate Intrinsic Signal-to-Noise Ratio of the Human Head at 9.4T

J. Felder[1], and N. J. Shah[1,2]

[1]Institute of Neuroscience and Medicine-4, Forschungszentrum Juelich GmbH, Juelich, NRW, Germany, [2]Department of Neurology, Faculty of Medicine, JARA, RWTH Aachen University, Aachen, Germany

Introduction Ultimate intrinsic signal-to-noise ratio (SNR) has been introduced to establish an upper limit for physically achievable SNR in magnetic resonance experiments [1, 2] when taking only sample noise into consideration. The extension of the theory for parallel imaging proved that for high field systems operation with high acceleration factors is feasible without significantly sacrificing geometry factor performance [3, 4]. However, up to now, due to its computational complexity, ultimate intrinsic SNR solutions have only been presented for highly symmetric and homogeneous phantoms. Using 3D field simulations, we have evaluated ultimate intrinsic SNR for the human head at 9.4T. This allows comparison of novel conductor arrangements for high field, parallel imaging coils and evaluating experimental performance in an absolute measure.

Methods Ultimate intrinsic SNR is the maximum SNR obtainable for one voxel of 1 cm^3 under the single constraint that Maxwell's equations are fulfilled. This can be achieved by selecting a set of basis functions, each of which satisfies the conditions imposed by Maxwell's equations, and superimposing a growing number of modes until convergence is reached. We simulated plane waves incident on a human head (Ella [5]) using the finite integration method (CST GmbH, Darmstadt, Germany) and material parameters as given in [6]. The plane waves were equally distributed on a sphere and used two orthogonally polarised modes each. The field distribution for each mode was stored and postprocessing was carried out using MATLAB (The Mathworks Inc., Massachusetts, USA). Postprocessing consisted of computing the sensitivity H_1^- for each mode as well as the noise covariance matrix, $\boldsymbol{\psi}$. Assembling the sensitivities in the vector $\mathbf{b}$, the optimum SNR is given by

$$SNR_{max} = \frac{\sqrt{2}\,\omega\mu M_0 V H_1^-(\mathbf{r}_0)}{\sqrt{4 k_B T R_{min} / 2}} \quad \text{with} \quad R_{min} = \frac{1}{\mathbf{b}\,\boldsymbol{\Psi}^{-1}\mathbf{b}^H}$$

where V=1 cm^3 and H_1^-=1 as a result of the constraint optimisation and division of the minimum noise resistance R_{min} by the factor 2 stems from the formula for time average power loss $P_{loss} = ½ \int \sigma\, \mathbf{E}\, \mathbf{E}^* \, dV = I_{eff}^2 R$.

Results Ultimate intrinsic SNR for the human head at 9.4T is shown in Fig. 1 for a small number of incidents waves and in Fig. 2 for a set of 500 basis functions (each having two polarizations) in a logarithmic scale for improved visualisation. Convergence of the algorithm has been verified by monitoring ultimate intrinsic SNR in two pixels (see Fig. 3) – one at the top of the head and one at the brain stem of the model. The MATLAB implementation was also verified against the results given in [2].

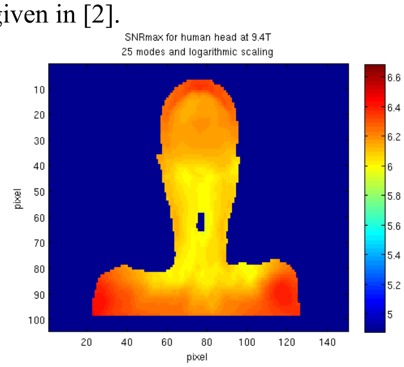

Figure 1

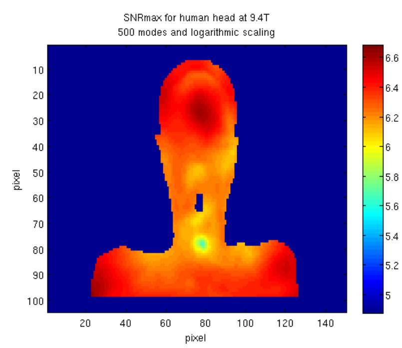

Figure 2

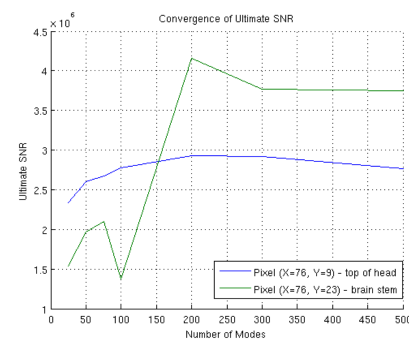

Figure 3

Discussion When one compares Figures 1 and 2, it is obvious that the peripheral regions of the human body can easily be imaged with a high SNR. This is consistent with the widespread use of surface coil arrays. For optimum SNR from deeper regions, a more complex field distribution is required. In the brain – which has a more homogeneous distribution of dielectric properties – focussing the field distribution for optimum SNR is realisable, while regions with cavities and large distances in dielectric properties suffer from reflections of the incident waves. Again, this effect can be easily observed when imaging regions with high susceptibility differences.

In contrast to the approach taken in [2, 3], we have chosen to have the plane waves incident from outside the sample (except for the region where the human model has been cut off to reduce simulation effort). In this way, bending and reflections at the air tissue interface are taken into account. This is deemed to be a more realistic approach since any conductor arrangement intended to produce the desired field pattern has to be placed around the head.

Outlook In the next step we plan to remove the plane waves incident from inside the human body and use a complete model of the human anatomy. This will put into perspective the high SNR observed at the bottom of Figures 1 and 2, but is not expected to change the SNR in the head. It is also intended to include computations for ultimate geometry factor in order to investigate favourable sampling strategies and to investigate the field distributions obtained for approaches of reverse coil design, e. g. by target field approaches.

Literature [1] W. A. Edelstein et. al., MRM 3:604-618 (1986) [2] O. Ocali et. al., MRM 39:462-473 (1998) [3] M. A. Ohliger et. al., MRM 50:1018-1030 (2003) [4] P. M. Robson et. al., MRM 60:895-907 (2008) [5] A. Christ et. al., Phys. Med. Biol. 55:N23-N38 (2010) [6] S. Gabriel et. al., Phys. Med. Biol. 41:2271-2293 (1996)