

Calibration of electromagnetic field simulations of MR coil arrays for accurate quantitative comparison with the measured image SNR

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Introduction: Electromagnetic field simulation can be a very powerful tool for optimizing MR receiving coils in terms of the maximum achievable SNR of the MR image. However, field simulation results alone like magnetic field distribution can only be qualitatively compared to measured image SNR of a given MR system. This is due to system and sequence specific properties like magnetization M and voxel volume V of the probe and effective system noise bandwidth Δf . In [1] it is shown that the SNR of an MR image depends on factors like inspected volume size and its magnetization. These factors can hardly be simulated by electromagnetic field simulations alone. In this contribution a method for obtaining a calibration factor for a direct quantitative comparison of field simulations and system MR images is deduced. Further it will be explained how to perform such a calibration measurement and for a 4-channel RX array simulation and measurement results will be discussed.

Theory of MR calibration factor: The maximum available SNR of an antenna array is given by $\text{SNR} = \frac{\omega VM \cdot B(r)}{\sqrt{16kT\Delta f P_V}}$ [2] $\rightarrow \text{SNR} = K \cdot \frac{B(r)}{\sqrt{P_V}} \rightarrow K = \text{SNR} \cdot \frac{\sqrt{P_V}}{B(r)}$. Here the factor K is a constant for a certain MR sequence in a given MR system for a specific object. To compare a measured SNR image to a simulation, the factor K needs to be determined by a calibration measurement. The calibration can be done by taking a MR image with the body coil and using a small phantom with homogeneous SNR image. With knowledge of the value of the magnetic field distribution $B(r)$ in the phantom generated by the body coil and measuring the dissipated power P_V in the system for this field, the ratio $B(r)/\sqrt{P_V}$ can be calculated. This ratio is a property of the MR system especially depending on the antenna geometry and system losses. Due to reciprocity of antennas this ratio describes the antenna in case of transmit and receive. In case of transmit the ratio provides how much power is dissipated in the system to achieve a certain field strength in a spot. In case of receive it describes how much noise power is received by the system while detecting a certain field strength. Comparing the value of $B(r)/\sqrt{P_V}$ to the measured SNR value inside a voxel returns the factor K . This factor is valid for any measurement with any local coil geometries with the restriction that the same MR system, the same MR sequence and the same phantom liquid as for the calibration measurement has to be used. We also assume that the preamplifier noise figure in the receive path is the same for the calibration measurement as for any other measurements.

Measurement and simulation setup: For the calibration measurement a cylindrical phantom filled with one litre of NaCl water solution was used. The SNR image was generated with a gradient echo sequence (GRE) at a 3T Magnetom Skyra MRI system (Siemens Healthcare, Erlangen, Germany). The magnetic field $B(r)$ for a 180° pulse of 1 ms length is $B = 11.75 \mu\text{T}$ and the dissipated power for this pulse was $P_V = 1917 \text{ W}$. The measured SNR value was 62.87 in the phantom center, which is representative for a 180° pulse. For this value the factor K results in $234.3 \frac{\sqrt{\text{W}}}{\mu\text{T}}$. To verify this calibration method, another experimental setup with a 4-element RX antenna array and a phantom with larger volume were used for measurements. With an electromagnetic field simulation tool the antenna array, the phantom and the RF shield of the system were modelled and the circularly polarized magnetic field $B_{\text{circ}}(r)$ in the phantom was calculated resulting from a given RF transmit power P_V . In the simulation the antenna is considered as a transmit antenna. The results can be applied to the case of receiving with this antenna. The dissipated power in the system can be obtained by using the calculated 4x4 scattering matrix for the four ports of the coil array. By using a maximum ratio combined algorithm for combining the magnetic field contribution of each individual coil, the ratio $\frac{B_1(r)}{\sqrt{P_V}}$ can be maximized for every voxel in the phantom. This ratio multiplied by K gives the simulated optimal SNR in each voxel, which is shown in Fig.1 together with the measured maximum available SNR [1] of the system. The acquired factor K implies that e.g. for a SNR value of 100 a ratio of $\frac{B(r)}{\sqrt{P_V}} = 0.42 \frac{\mu\text{T}}{\sqrt{\text{W}}}$ is required. In Fig.2 a cross section along the x- and y-direction of both measured and simulated SNR is compared.

Results and discussion: Calculating the maximum deviation of the cross sections in Fig.2 leads to a maximum relative error of 18% in x-direction and 15% in y-direction, whereas the mean deviation is much lower. The examined phantom is considered as a worst case scenario because of the large water volume and therefore inhomogeneous SNR image. Due to the large continuous water volume with high $\epsilon_r > 80$ resonances in the phantom affect the transmitted field strength significantly. This effect leads to deviations from the adjusted flip angle which causes errors for the comparison to simulated results. These errors could be further reduced by recording a B_1 field map and compensating for the flip angle error. Comparing the two images of Fig.1 one can see a very good agreement between measured and simulated SNR. The results show that not only the relative shape but also absolute quantitative values of SNR can be compared to measurements.

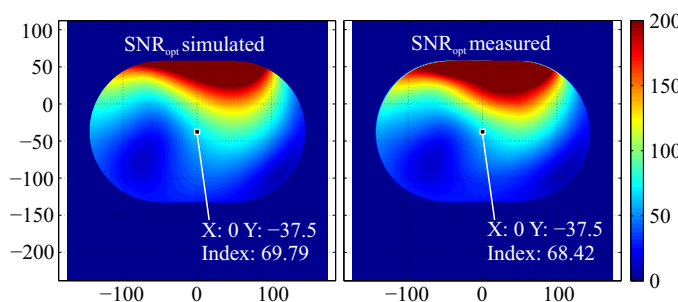


Fig. 1. SNR_{opt}; left: simulated and calibrated; right: measured

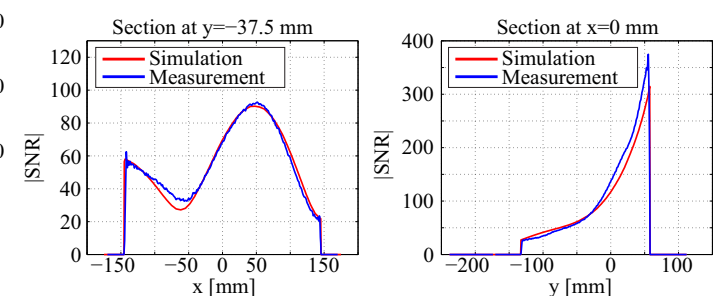


Fig. 2. Cross sections through SNR images at phantom's center position

Conclusion: A new method to compare simulated magnetic fields of antenna arrays to measured SNR images of MR systems recorded with such an array was shown. This method can be used for any possible antenna configuration of local coils and leads to accurate results.

References:

- [1] Roemer, P.B., Edelstein, W.A., Hayes, C.E., Souza, S.P., Mueller, O.M., "The NMR phased array", Magn. Res. Med., 16 (2), pp. 192-225, 1990.
- [2] Schnell, W., Renz, W., Vester, M., Ermert, H., "Ultimate signal-to-noise-ratio of surface and body antennas for magnetic resonance imaging", IEEE Trans Ant Prop 2000, 48:418-428.