

Numerical Determination of SNR using an Anatomic Pixel Rat Brain Model

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Introduction. The signal-to-noise ratio (SNR) is an accepted measure of the coil performance and at the same time SNR is an accepted standard for measurement of image quality in MRI, as the quality of the reconstructed image depends strongly on the SNR of the acquired MR signals. Analytical expressions based on the Maxwell equations, can be derived for the simplest cases of surface coils [1], but it is very difficult to derive expressions for more complex geometries due to the complicated mathematical framework involved. The numerical study of the electromagnetic behavior for MRI coils and biological tissues is a good alternative. A numerical method based on the Finite Element Method (FEM) to compute the SNR in a circular-shaped coil is presented here, and this was compared with the SNR calculated by a Varian algorithm from a real rat brain phantom image obtained with a 7T MRI system in our laboratory

Theoretical Background. The image quality depends on the SNR, which is a function of the coil geometry and the sample noise. The SNR is defined in [2], and expressed by (1), where V is the sample volume, ω is the Larmor frequency, B_1 is the magnetic field of the RF signal and R is the effective resistance. The thermally activated motions of the charge carriers in dissipative media produce random electric and magnetic fields, which can be detected as noise. A resistance R produces an RMS noise voltage V (2), where k is Boltzmann's constant, T is absolute temperature, Δf is the receiver bandwidth [3]. The SNR is proportional to the MR signal. The voltage of the thermal noise of the coil is approximately (3), where the power losses are P_A (circular-shaped coil) and P_B (biological sample). Power losses in the form of Joule heating within the specimen will arise from eddy currents induced [4]. The energy dissipation per unit volume is given approximately by (4) where σ is the effective conductivity, and $|E|$ is the amplitude of the electric field produced by the sample. Then a good approximation to SNR is (5). Rojas and Rodríguez [5] proposed a matrix scheme based on FEM to compute the electric and magnetic fields using a commercial software tool.

$$SNR \propto \frac{V \omega^2 B_1}{R} \quad (1) \quad V = \sqrt{4kT\Delta f R} \quad (2) \quad SNR \propto \frac{V \omega^2 B_1}{\sqrt{8kT\Delta f (P_A + P_B)}} \quad (3)$$

$$P = \frac{1}{2} \rho |E|^2 \quad (4) \quad SNR \propto \frac{\text{Magnetic field}}{\text{Electric field}} = \frac{B_1}{E} \quad (5)$$

for all matrix calculations. For validation, we used a rat brain encapsulated in a cylindrical tube and formaldehyde solution-fixed. Brain phantom images were acquired with a 7T/21cm Varian MRI system equipped with DirectDrive™ technology (Varian, Inc, Palo Alto, CA). A gradient echo sequence was used for all imaging experiments with the following acquisition parameters: TR/TE = 32.76/3.22 ms, FOV= 22x22 mm, matrix size=128x128, slice thickness=2mm, NEX=5.

Results and Discussion. Electromagnetic fields were numerically computed and coronal sections are shown in Fig. 2 a) and b) and the computed SNR is in c). A photo of the formaldehyde solution-fixed brain phantom is depicted in Fig. 3a) and a T1 image is in b). The SNR calculated with the software provided by the Varian company is in Fig. c). This procedure is based on the computation of an image histogram, which is used to separate the signal from noise. The noise level is calculated as average intensity in 4 regions outside the object, then the input image is filtered and the signal level is determined as maximum signal. The SNR is finally calculated as the maximum signal divided by the noise [7]. To compare the validity of our method, a comparison plot was calculated and shown in Fig. 4. The profiles were computed from Figs. 2.c) and Fig. 3c) and the data was taken as indicated by the red line in Fig. 3c). There is a good similarity taking into account that a rough pixel model of the rat brain was used. A precise study will require a more detailed model of the rat brain. This consequently implies that numerical computations will require the used of more powerful computers. A surface coil was chosen for simplicity, however it can also be extended to more complex coil configurations such as the birdcage or coil arrays. Other pixel anatomical models now for human organs can be constructed and numerically simulated with this method. This numerical method can offer a graphical tool to illustrate the behaviour of the SNR. The use of solution-fixed brain phantoms provides a more realistically anatomical method to compare with. These ex vivo experiments can be easily extended to in vivo experiments for more accurate studies. It can be particularly useful for those students and researchers starting to familiarise themselves with the development of RF coil for MRI, since the simulation method is easy to implement on standard computers. This simple numerical method to assess the SNR can be a good tool to study the performance of RF coils.

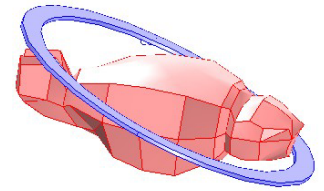


Fig.1. Brain model with RF single loop coil.

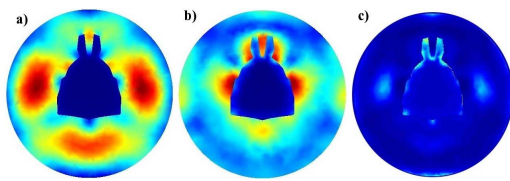


Fig.2. Electric (a) and magnetic (b) fields obtained from Fig. 1 setup. c) SNR calculated from a) & b) data.

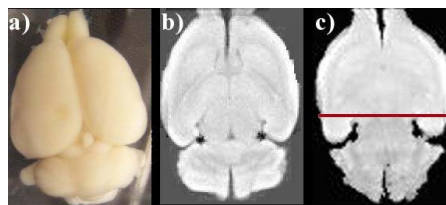


Fig.3. a) Brain phantom photo, b) Rat's brain MR image, c) SNR calculated with Varian algorithm.

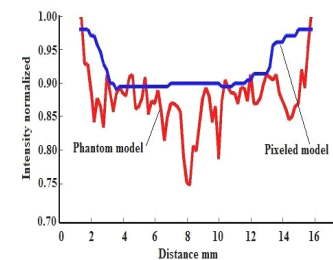


Fig.4. Comparison plot of SNR intensities of Figs. 2.c) and Fig. 3.c).

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References

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