Intensity Correction at 7T using Bloch-Siegert B_1^+ Mapping

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Purpose: Receive sensitivity characterization is needed for image reconstruction using parallel imaging such as ASSET or SENSE from data acquired with phased array coils. It is also beneficial for accurate image intensity correction, which is necessary for segmentation and quantitative analysis of MRI images. In high field MRI the image intensity is affected by both transmit sensitivity (B_1^+) and receive sensitivity (B_1^-). A number of methods have been proposed for intensity correction [1], which do not distinguish between transmit and receive B_1 field inhomogeneity. This will complicate the intensity correction at high field MRI due to large B_1^+ inhomogeneity across the image. Here we use the Bloch-Siegert (B-S) B_1^+ mapping method [2] to compute both transmit and receive sensitivities. The receive sensitivity is then used for image intensity correction of subsequent scans.

Theory: The parameters of B-S B_1^+ mapping sequences are selected to generate a proton density weighted (PD) image. The signal equation for spoiled gradient echo sequence is give by Eq. 1 where S_n is the signal from the n-th coil, R_n is the receive sensitivity of the n-th coil, M_0 is the proton density,

$$S_n = R_n M_0 \sin(\alpha)\frac{1-E_1}{1-E_1\cos(\alpha)} \quad (1)$$

α is the flip angle and $E_1=\exp(-TR/T_1)$. Assuming relatively long TR and small flip angle, we could write $S_n \cong R_n M_0 \sin(\alpha)$. The transmit sensitivity or $\sin(\alpha)$ term can be measured by the B-S B_1^+ mapping method. We assume that the receive sensitivity R_n and proton density M_0 are separable in the spatial frequency domain with R_n dominating the low spatial frequency range and M_0 dominating the high spatial frequency range. Therefore, a heavily low-pass-filtered version of $R_n M_0$ will be a good approximation to the pure receive sensitivity, R_n.

Methods: A 4ms optimized B-S pulse [3] was added to a conventional gradient echo sequence after the slice-select gradient and before the readout gradient for B-S B_1^+ mapping. Brain images of 4 volunteers were acquired on a 7T scanner (GE Healthcare, Waukesha, WI) using a quadrature transmit and 16ch receive Nova Head coil (Nova Inc, Boston, MA) in coronal planes with FOV=22cm, 16 slices, slice thickness=5mm, spacing=5mm, matrix=64×64, BW=31.25 kHz, FA=20 deg, TE=7.7ms and TR=850ms. The B_1^+ map is obtained by conventional B-S processing and then the Tx sensitivity is derived from the B_1^+ map for each slice. The B-S image magnitudes, which are proton density weighted, are averaged together to increase the SNR. The transmit sensitivity is then divided out, and a low pass filter applied (σ=0.4cm^{-1}) to remove proton density contrast, leaving the receive sensitivity map behind. The final receive sensitivity of the combined image is produced by a sum-of-squares over all channels, which is then interpolated over a 3D volume and used for intensity correction of the target CUBE images, acquired with FOV=22cm, 0.1mm isotropic resolution, TR=3500ms, TE=89ms.

Results: Fig 1-a shows the B_1^+ maps of a volunteer brain using the B-S B_1^+ mapping method. These maps were used to create the transmit sensitivity maps shown in Fig 1-b. Fig 2 shows the block diagram of the proposed method. For simplicity of presentation, the sum-of-square image is shown at each step instead of showing individual channels. Fig 3 shows the original mid slab coronal image along with the intensity corrected image using the proposed method. The T2-CUBE images before correction demonstrated a significant asymmetry with higher signal on the right side due largely to the receive sensitivity. After correction, the images were more homogeneous.

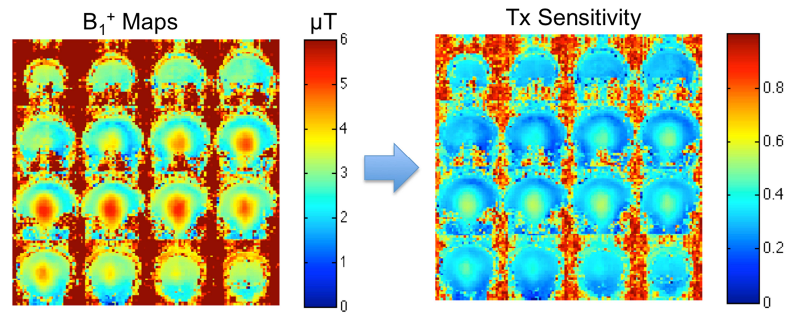

Fig 1: B_1^+ maps with B-S method are used to create the Tx sensitivity for each slice.

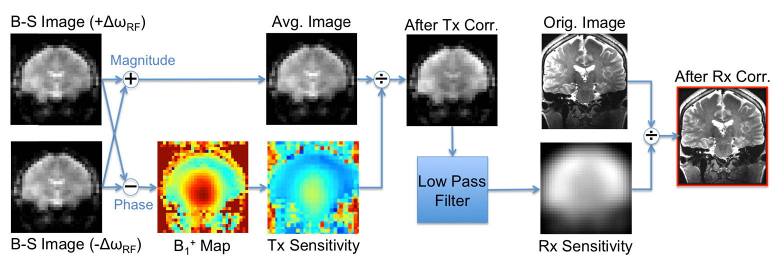

Fig 2:The block diagram of receive sensitivity estimation using B-S method.

Discussion: In this work, we have shown how B-S method can be used for measuring both transmit and receive sensitivities. The imaging parameters of the B-S method are selected to generate a proton density image. It is assumed that the proton density contrast contains only high spatial frequencies and can be separated from the receive sensitivity by low-pass filtering. While this assumption likely holds in brain, further investigation is needed for body images. The receive sensitivities, which are obtained for each individual channel can be used for image reconstruction in parallel imaging in addition to intensity correction. A simple low pass filter which is sometimes used for intensity correction cannot be used for receive sensitivity measurement especially in high field MRI because it cannot separate the transmit sensitivity from the receive sensitivity. The proposed method will achieve receive sensitivity correction but the transmit inhomogeneity will remain in the final image. If the signal equation of the final image is known, the transmit sensitivity could be obtained from the B_1^+ maps and consequently corrected, but in most cases the signal equation is dependant on tissue properties such as T1 or T2 which are not often available. Alternatively, parallel transmit or B1-insensitive sequences can be used to create a uniform transmit field.

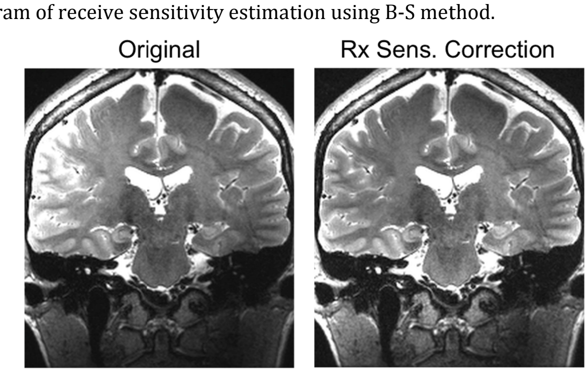

Fig 3: Receive sensitivity correction on CUBE images at 7T

References: [1] Milles et al., Comp. Med. Imag. & Graph. 31:81-90, 2007 [2] Sacolick et al., MRM 63:1315-1322, 2010 [3] Khalighi et al., MRM in press, 2011.

Acknowledgement: Research support from GE Healthcare.