

B1 Mapping Near Metallic Implants

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Introduction: Spatial distribution of flip angles provided by transmit B1 field (B1) maps is relevant in areas of RF safety, quantitative MRI, qualitative evaluation of electric field distribution and RF coil quality control. Existing B1 mapping techniques have not yet been successfully implemented near metallic implants because of artifacts caused by B0 variations from susceptibility variations of these metallic implants. With the development of SEMAC [1] and MAVRIC [2], these artifacts have been significantly reduced, thus allowing for further advancements in B1 mapping. This study aims to demonstrate B1 mapping near a metallic implant through the combination of SEMAC and the existing double angle method [3] (DAM).

Theory: For this study, we focused on a magnitude ratio-based DAM method with the prescribed flip angles of α and 2α . The B1 map is computed by taking the arccosine of the ratio of the second image (I_2) over the first image (I_1), as follows:

$$\text{DAM (Gradient Echo): } \alpha = \arccos(I_2/(2I_1)) - \text{Eq. 1}$$

The pulse theory proposed combines SEMAC with DAM. Two images are acquired using a spin echo sequence with extra z-phase encode lines/slice and VAT [1]. These additional parameters help to correct for in-plane and through-plane distortions. I_1 is acquired using a 45° - 180° flip angle sequence while I_2 is acquired using a 90° - 180° flip angle sequence. The B1 map is then calculated using Eq. 1.

Method: Three experiments were performed: (A) comparison of the SEMAC DAM to a GRE DAM, (B) simulations of the sensitivity of SEMAC DAM, and (C) acquisition of B1 maps of a shoulder implant phantom at 1.5T and 3T.

(A) Acquisitions were made of a spherical phantom on a 1.5T MR scanner (Signa, GE Healthcare). Two images were obtained using a 2D single-slice SPGR sequence (GRE DAM) with TR/TE of 3s/3.9ms, 32cm FOV, 10mm slice thickness, 256x160 matrix and a scan time of 8:12min. The prescribed flip angles were 60° and 120° and they were used to calculate the magnitude ratio B1 map using Eq. 1. The proposed 3D Fast Spin Echo sequence (SEMAC DAM) with TR/TE of 3s/5.6ms, 32cm FOV, 10mm slice thickness, 256x160 matrix and a scan time of 8:03min was also applied to the same spherical phantom. The first image for this method was acquired using a 45° - 180° flip angle sequence while the second image was obtained using a 90° - 180° flip angle sequence. We developed a B1 mapping plug-in in OsiriX (Open source imaging viewer) [5] and used it to calculate the magnitude ratio map.

(B) MATLAB simulations incorporating the Bloch simulator, SEMAC imaging technique and GRE DAM were run to evaluate the error between the measured and expected flip angles. Simulations over a frequency range of ± 8 kHz with $<2\%$ variation as a function of frequency were performed. This models the B0/frequency variation present.

(C) Subsequent scans were carried out on a metallic shoulder implant phantom at both 1.5T and 3T. A SEMAC pulse sequence of TR/TE = 1.6s/5.9ms, 256x128 matrix, 25cm FOV, 3mm slice thickness, 10 z-phase encode lines/slice and a scan time of 12:26min was used at 1.5T. At 3T, a similar SEMAC pulse sequence was used with TR/TE = 1.8s/6.2ms, 2mm slice thickness and 20 z-phase encodes per slice. The scan time at 3T was 15:56min.

Results: B1 maps of the spherical phantom obtained using SEMAC DAM agreed well with the standard GRE DAM. This is evident through a near zero mean difference map (Fig. 1). Figure 2 plots the results from the simulations of the SEMAC flip angle errors. When using a nominal flip angle of 45 degrees, the expected error is less than 12% for actual flip angles in the range 27° - 77° . Figure 3 shows the B1 maps of the metal phantom acquired at 1.5T and 3T. Poorer B1 homogeneity was observed at 3T.

Discussion: A good agreement of the SEMAC and GRE DAM B1 maps show that SEMAC DAM provides an accurate B1 mapping technique. Increased B1 variation at 3T (Fig.3) is expected due to increased hardware demands at higher field strengths. However, there are factors that require consideration before a claim of successful B1 mapping near metallic implants can be made. Due to significant B0/frequency variations in the presence of metallic implants, being able to precisely map a large flip angle range is an important factor. The gradient echo DAM offers a larger flip angle dynamic range due to its $\sin(\theta)$ relationship. It is however, less sensitive to variations. Also, there is a spin echo DAM [4] that demonstrates a $\sin^3(\theta)$ relationship and provides more sensitive maps at the cost of a more limited dynamic range. Therefore, more work needs to be conducted to determine the ideal nominal flip angle for the proposed SEMAC DAM. From our validation tests on the spherical phantom, an optimal nominal flip angle of 60° was used for the GRE DAM. This optimal nominal flip angle changes when using SEMAC DAM when a metallic implant is present. This is due to slice profile-related artifacts that accompany an applied flip angle sequence of 120° - 240° .

Conclusion: Preliminary results indicate that the SEMAC DAM can map flip angle variation near a metallic implant and is a valid approach for tackling the issue of B1 mapping near metallic implants.

References: [1] Lu W et al. Magn Reson Med 2009; 62:66-76. [2] Koch K et al. Magn Reson Med 2009; 61: 381-390. [3] Cunningham CH et al. Magn Reson Med 2006; 55:1326-1333. [4] Insko EK et al. J Magn. Reson 1993; 103:82-85. [5] Rosset et al. J Digit Imaging 2004; 17(3):205-16. **Acknowledgements:** Funding by GE Healthcare, NIH EB008190, and NIH EB002524.

Validating proposed method

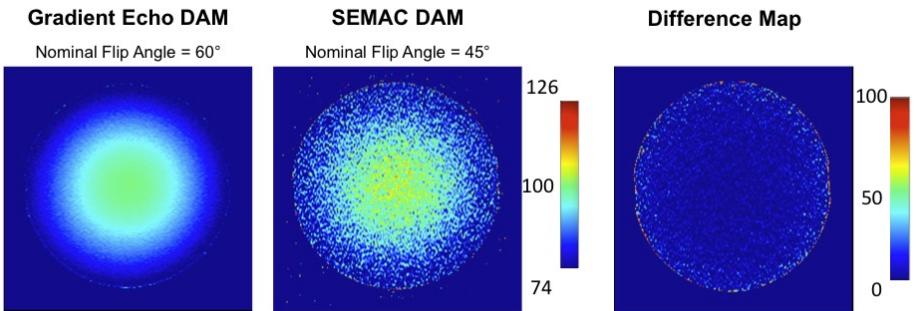


Figure 1: B1 maps (scale = % of the nominal flip angle) acquired from a spherical phantom (diameter \approx 30cm) using the gradient echo and SEMAC double angle methods (left). Both maps show that B1 is highest in the middle. A noise threshold value of 8% was applied to both maps (right).

Flip angle range simulation

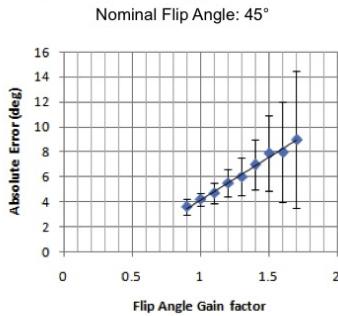


Figure 2: Matlab simulations used to determine the relative error between the expected and measured flip angle

Metal Phantom

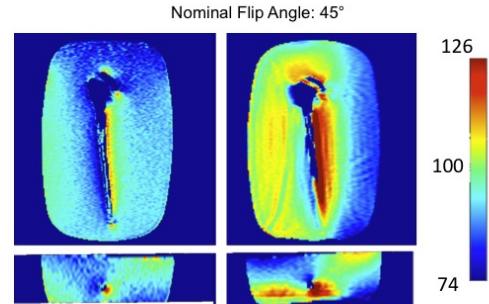


Figure 3: Coronal (top) and axial-reformatted (bottom) B1 maps (scale = % of nominal flip angle) of the shoulder implant acquired using the SEMAC double angle method at 1.5T (left) and 3T (right). As expected, the magnitude of the map is larger at 3T than at 1.5T.