Simultaneous B1+ magnitude and phase mapping using multi-echo AFI

Narae Choi[1], Joonsung Lee[1], and Dong-Hyun Kim[1]

[1]*Electrical and Electronic Engineering, Yonsei University, Sinchon dong, Seoul, Korea, Republic of*

Introduction: The measurement of the transmit radiofrequency (RF) field is useful for many MR applications such as RF pulse designs, electric property mapping, quality control of RF coils, and correction of $B1^+$ inhomogeneity in various quantitative studies. Conventionally, the amplitude of the $B1^+$ is measured by $B1^+$ mapping methods [1-5] and the phase of the $B1^+$ can be estimated using spin echo (SE) sequence [6]. For phase mapping, when near field is considered (Biot-Savart law) and the electrical parameters of the sample are isotropic, the phase of the clock-wise circularly polarized RF field of the exciting coil is approximately half of the phase at TE = 0 or the phase of a spin-echo image. In this work, a multi-echo gradient echo sequence is proposed to estimate the phase at TE = 0. Furthermore, for simultaneous acquisition of the magnitude and the phase of the $B1^+$, we integrated the multi-echo gradient echo sequence to a actual flip-angle imaging (AFI) [5] sequence. This approach is validated with phantom and in-vivo experiments.

Methods: Sequence: In MRI, many methods were proposed to measure images at very short echo times but no methods are available for acquisition at TE = 0. To estimate the phase at TE = 0, SE sequences were applied to remove the effect of B0 inhomogeneity from the phase image. In this work, we developed an approach using gradient echo sequence, based on AFI approach. AFI wes originally developed to measure the magnitude of $B1^+$ by interleaving two different TRs. A multi-echo gradient echo readout was integrated to every other TR of AFI sequence to simultaneously measure the phase at the TE = 0. In other words, the first gradient echo were acquired at both TRs to estimate the magnitude of $B1^+$, but the other echoes were acquired only at the second TRs as shown in Fig. 1. We assume that in the GRE sequence the phase of the image varies linearly with respect to echo time with the slope of B0 inhomogeneity. By linearly extrapolating the phase, the phase at TE = 0 was determined. We used the multiple echoes to complement the reliability of the phase information from the noise.

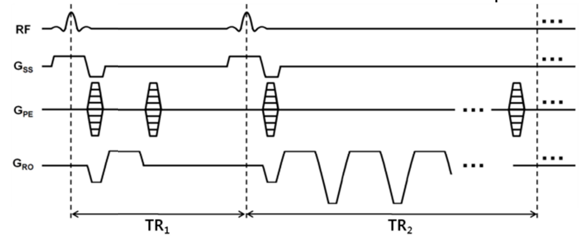

Figure 1. Sequence diagram of the AFI based multi-echo gradient echo

Validation by Experiments: To demonstrate the performance of our proposed methods, a phantom with three cylindrical anomalies as shown in Fig. 2 was made. Three cylindrical anomalies were filled with the various concentrations of NaCl (0.12%, 0.36%, 0.60%) to generate different patterns of the phase at TE = 0. Agarose gel was placed inside a thin plastic bottle to prevent conductivity changes by ion diffusion. Coronal images of a phantom were acquired on a 3.0T Siemens Tim Trio MRI scanner using a transmit-receive head coil. Forty four slices were obtained in 3D acquisition mode with resolution = 2.0x2.0x2.0 mm^3, TR_1 = 30 ms, TR_2 = 150 ms, first echo time = 4.15 ms, echo spacing = 3.55 ms, FA = 60°, FOV = 256x256 mm^2, number of echoes = 6, leading to a total scan time of 17 minutes. In addition, to compare with the conventional $B1^+$ mapping methods (DAM), two SE images were scanned with FA = 60°, 120°. Other scan parameters were TR/TE = 7000/10 ms, 22 slices in 2D multi-slice mode, and same voxel size, slice locations, and FOV were used with the proposed sequence. Each scan took 15 minutes. The in-vivo data were acquired with same TR_1,TR_2, TE, voxel size and number of echoes. Eighty eight slices in sagittal view were obtained in 3D acquisition mode for 34 minutes. Two SE data sets were also acquired in 2D multi-slice mode with the following parameters: TR/TE = 6500/10 ms, FA: 60°, 120°, and scan time = 14 minutes, respectively. Since 3D acquisition in SE would require several hours of scan time, we scanned SE using multi-slice 2D acquisition

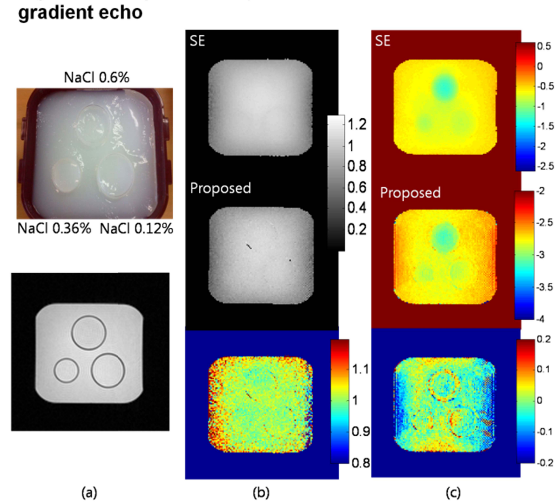

Figure 2. The results of the phantom test. (a) Phantom design and a magnitude image (SE), (b) B1⁺ magnitude map (scale: [0 1.3]) and the ratio of the B1⁺ map (last row), (c) B1⁺ phase map and difference of phase (last row) (The mean value of the difference image was set to zero by adding a constant value to the original difference image, scale: [-0.2, 0.2] rad)

Result: The approximated magnitude of $B1^+$ and phase at TE = 0 using the proposed method are shown in Fig. 2. and Fig. 3. Comparing the results with SE data, the ratio of the $B1^+$ map ($B1^+$ of SE/Proposed method) was measured. Phases acquired from both methods were of same range in radian. The ratio of $B1^+$ magnitude map and the phase difference is in the reasonable range except at the boundaries of anomalies and the air/phantom. To estimate the phase of $B1^+$ in multi-echo acquisition, phase at TE = 0 was approximated using six different TE datasets from proposed sequence.

Discussion: Using the proposed AFI based multi-echo gradient echo sequence, the magnitude and the phase of $B1^+$ can be measured simultaneously within a reasonable scan time. We have evaluated its performance with phantom and in-vivo studies. However, accurate measurement of phases at areas such as air-tissue interfaces were hampered by signal loss due to strong B0 inhomogeneity since the proposed method was based on GRE sequence. Although SNR can be increased by using data from multiple echoes, this may not be beneficial since B0 inhomogeneity also increases with TE. Also, since the proposed method uses T1-weighted images, the estimated phase at TE = 0 has larges errors at CSF.

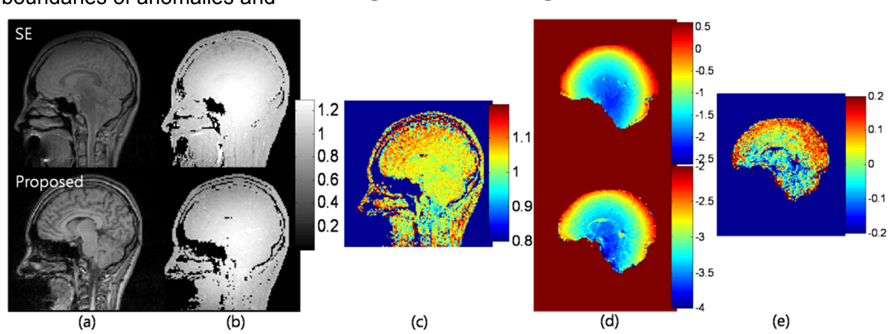

Figure 3. The results of the in-vivo experiments. (a) Magnitude image (b) B1⁺ magnitude map (scale: [0 1.3]) (c) The ratio of the B1⁺ map (d) B1 phase map (e) Difference of phase map (The mean value of the difference image was set to zero by adding a constant value to the original difference image, scale: [-0.2, 0.2] rad)

References: [1] S. Rudolf, et al., MRM, 35:246-251, 1996. [2] C. H. Cunningham, et al., MRM, 55:1326-1333, 2006. [3] G. R. Morrell., MRM, 60:889–894, 2008. [4] L. I. Sacolick, et al., MRM, 63:1315–1322, 2010. [5] V. L. Yarnykh., MRM, 57:192–200, 2007. [6] H. Wen, et al., SPIE, 5030, 2003.

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