Validation strategies for NMR probes in field measurement applications

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INTRODUCTION

Nuclear magnetic resonance (NMR) probes can provide real time, location specific, measurements of signal phase and magnitude variations. They have been utilized successfully in a variety of applications, including catheter tracking [1], motion correction [2], magnetic field monitoring [3] and compensation of higher order field perturbations [4]. Here, we propose and demonstrate three different approaches to test the performance of NMR probes in the scanner and their ability to measure varying external fields. The approaches are, (a) motion simulation, (b) spectrometer frequency offsets and (c) higher order field perturbations using a real time shim-switching module (RTS, Resonance Research Inc, MA, USA).

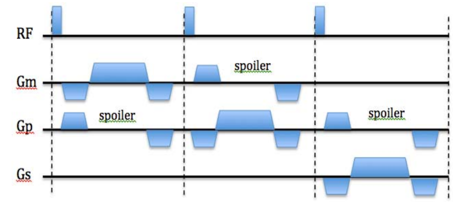

Figure 1: Probe data gathering module

EXPERIMENTS AND RESULTS

Three receive only ^{1}H probes with 1 mm diameter capillary tube sample of water, doped with 2.5mM gadolinium were built for experiments on a whole-body 7 Tesla MR scanner (Philips Healthcare, Cleveland, OH, USA). The probes were fixed on a bottle phantom ($CuSO_4$ + NaCl) and connected to spare channels of the scanner's RF interface module.

Motion Simulation: Known motion was synthetically applied on a stationary setup by updating the gradient matrix for rotation and demodulation frequency for translation about the foot-head axis for every TR in two gradient recalled echo (GRE) experiments. (64 matrix, FOV 300 mm, TR/TE = 20/5 ms). A probe data acquisition module performed every TR consisted of non-selective low flip angle (5^o) excitations and projections in the X, Y and Z directions for position encoding (Figure 1). Figure 2 shows image space projection data of the probes in three directions. Probe data reflected the applied real time rotations and translations and matched the input motion parameters in both the cases demonstrating good probe performance.

0^{th} order field offsets: The ability of the probes to detect zeroth order field changes was tested in a dynamic f0 experiment. The spectrometer frequency was switched in a predefined slice-wise manner in a 7-slice GRE scan. The phase ramps observed in the probe data after reference subtraction were fit to the sampling times to calculate the f0 changes. Figure 3a shows the reference-subtracted phase from one probe in one direction for the seven slices. The obtained f0 offsets matched the applied slice-to-slice frequency offsets as shown in Figure 3b.

Higher order field variations: The ability of the probes to detect higher order field changes was tested in a GRE experiment using the RTS. The shielded Z2 shim was switched dynamically in a slice-wise pattern of [-1.2, -1.8, -0.9, 0, 0.9, 1.8, 0.6] Amps in a 7-slice scan with a 7 s TR to allow eddy current field settling. The reference subtracted phase of the probe signals was unwrapped and fit according to

$$\phi_p(t) = K_0(t) + K_{Z2}(t).\, r_{Z2P}$$

where P is the probe index, $K_0(t)$ and $K_{Z2}(t)$ are the time integrals of the $B_0(t)$ field induced by the Z2 shim and the Z2(t) respectively. r_{Z2P} is the P^{th} probe distance. Figure 4 shows K_{Z2} values for a single time point in arbitrary units obtained from fitting the probe data, which match the slice-wise Z2 shim pattern that is applied.

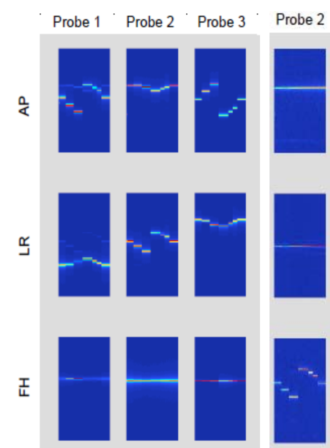

Figure 2. Image space probe data with simulated rotation (left) and translation (right).

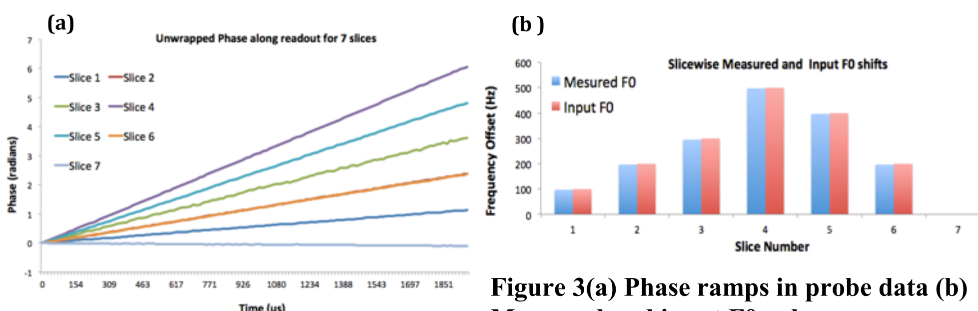

Figure 3(a) Phase ramps in probe data (b) Measured and input F0 values.

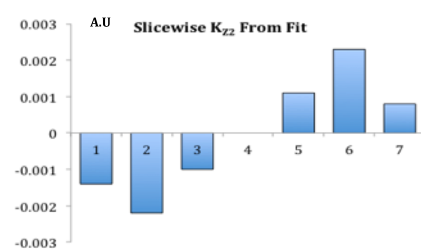

Figure 4: K_{Z2} values for a single time point obtained from the fit.

DISCUSSION

Interrogating NMR probes in a controlled setting with precise knowledge of the expected signal perturbations is a valuable tool for characterizing probe performance. Repeatability studies carried out with the approaches described here can measure the precision of the probes. These tests, performed against calibrated 0^{th}, 1^{st} and higher order field adjustment systems, combined with the signal to noise analysis presented in [5] can therefore provide a complete characterization of an NMR probe system and provide a basis for comparison of different probe designs.

REFERENCES

[1] Krueger S, et al. IEEE TMI, (2007) 26: 385. [2] Ooi MB, et al. MRM, (2009) 62: 943. [3] Barmet C, et al. MRM, (2008) 60: 187. [4] Wilm BJ et al. MRM, (2011) 65:1690 [5] De Zanche N et al. MRM, (2008) 60: 176.