# High resolution GRE at 9.4T using spokes pulses

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**Target Audience**: MR physicists, engineers and clinicians who are interested in imaging at UHF and applications.

**Purpose:** The increased SNR at ultra high field opens up opportunities for high resolution imaging. It has been shown previously that it is possible to acquire ultra high resolution images with a voxel size of 0.13mm x 0.13mm x 0.8mm at 9.4T [1]. However, at this field strength MR images are often hampered by RF inhomogeneity as the RF wavelength becomes smaller or comparable to the dimensions of a typical adult head [2]. In this study, we demonstrate improved high resolution GRE imaging at 9.4T with RF inhomogeneity mitigated using spokes pulses [3,4].

**Methods:** All experiments were performed on a 9.4T human MR scanner (Magnetom 9.4T, Siemens Medical Solutions, Erlangen, Germany) with a dual-row 8-channel transmit and 31-channel receive array coil [5]. B1+ maps for each transmit channels were acquired with a T2* compensated version of DREAM [6] ($TE_{ste}$ = 2.22ms, $TE_{fid}$ = 4.44ms, TR = 7.5s, 4mm x 4mm voxel size, 4 mm slice thickness) using a transmit channel phase encoding scheme [7], B0 maps were estimated using two 3D GRE with different echo times (TE1 = 1ms, TE2 = 3.21ms, TR = 30ms, FA = $8^o$, 5 mm isotropic voxel size). Monopolar slice-selective spokes pulses were designed in a slice-specific fashion using the spatial domain method [8] with magnitude least square optimisation [9,10]. The B0 map was included in the spokes design problem as shown in ref. [8]. The amplitudes of the spokes pulses were constrained to a maximum of 75V during the design to avoid overshooting the SAR limits. The spokes pulses were incorporated into a 2D GRE sequence (TE = 14ms, TR = 500ms, FA = $40^o$) for the acquisition of high resolution (0.25 mm x 0.25 mm in plane, 1 mm slice thickness, FOV 160mm x 131mm) images of the brain. The flip angles of the spokes pulses were mapped using Presat-TFL [11] (TE = 2.85 ms, TR = 7.4 ms, 4mm x 4mm voxel size, 0.5 x spokes pulse slice thickness) to check against the prediction. The imaging experiments were repeated with a global (i.e. non-slice-specific) CP-mode-like phase-only RF shim setting for comparison. In vivo images were acquired from a 30-year-old male volunteer who gave written, informed consent and the study was approved by the local ethics committee.

**Results:**

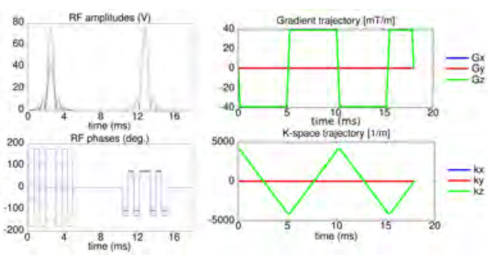


***Figure 1:*** *An example of amplitude and phase of a 8-channel 2-spoke pulse, and the corresponding gradient and k-space trajectory monopolar spokes design [10].*

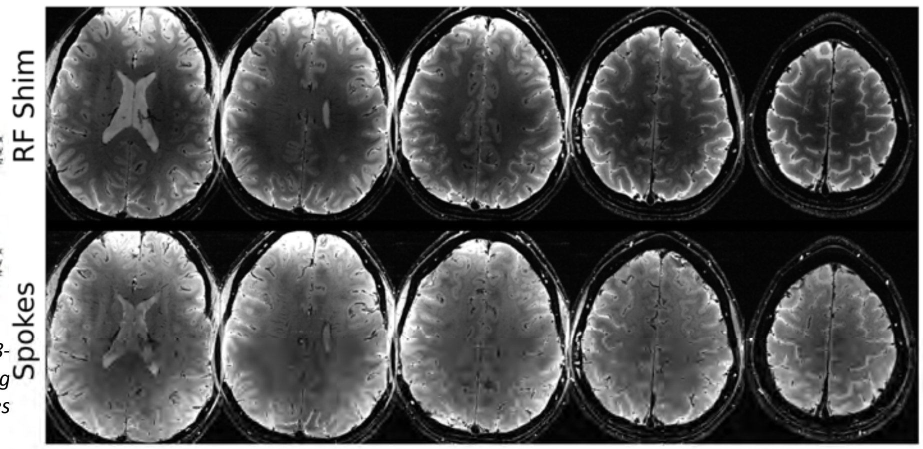


***Figure 2:*** *High resolution 2D GRE images obtained using RF shim (top) and slice-specific 2-spoke pulse (bottom).*

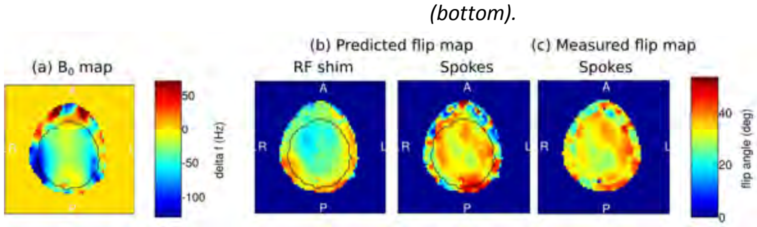


***Figure 3:*** *(a) B0 map; (b) Predicted flip angle map of RF shim and a spokes pulse for one of the slices. The black contour indicates the brain mask used in the optimisation; (c) Presat-TFL measured flip angle map of the same spokes pulse.*

**Discussion and conclusion:** A flip angle drop out was observed in the phase-only RF shim excitation at the centre of the brain as shown in Fig. 3 (b). In contrast, the spokes pulses provided a more uniform flip throughout the brain at the desired angle of 40 degrees. When designing 2-spoke pulses, we found that it was beneficial to traverse kz in the same direction for both spokes (monopolar). Indeed, as B0 deforms the slice profile, the slice distortions for both spoke do not match if the kz traversal is performed in opposite directions for spoke 1 and spoke 2. By rewinding every spoke (Fig. 1), slice distortions between spoke 1 and spoke 2 are guaranteed to match which improves robustness. Because of the lower flip angle at the centre of the brain when using RF shim, the GRE images have reduced SNR and non-physiological contrast variation in this area. The use of 2-spoke pulses largely resolved these issues because of the more uniform flip angle profile. As a result, fine details of veins in both the grey and white matters can be observed in these images.

**References:** [1] Budde J, et al. Neuroimage 86 (2014) 592. [2] Van de Moortele P, et al. MRM 54 (2005) 1503. [3] Setsompop K, et al. MRM 60 (2008) 1422. [4]Wu X, et al. Plos ONE 8 (2013) e78078. [5] Shajan G, et al. MRM 71 (2014) 870. [6] Nehrke K, et al. MRM 71 (2014) 246. [7] Tse DHY, et al. JMR 245 (2014) 125. [8] Grissom W, et al. MRM 56 (2006) 620. [9] Setsompop K, et al. MRM 59 (2008) 908. [10] Guerin B, et al. MRM in press (2014). [11] Chung S, et al. MRM 64 (2010) 439.