

# A Dual-Band Three-Dimensional Tailored RF Pulse for Simultaneous Susceptibility Artifact and B1+ Inhomogeneity Reduction

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**Introduction:** Susceptibility artifacts and B1+ inhomogeneity are major limitations in high field MRI. Three-dimensional (3D) RF pulses have been shown to be useful for reducing B1+ inhomogeneity (1) and spectral spatial pulses have been shown to reduce the through-plane signal loss susceptibility artifact (2). We present a dual-band “fast- $k_z$ ” 3D RF pulse (3-5) trajectory for simultaneously reducing susceptibility induced signal loss and B1+ inhomogeneity. The method is demonstrated in T2\* weighted brain images at 3T using an RF body coil.

**Theory:** Assuming small tip angles, the fast- $k_z$  trajectory consists of a series of 1D slice-select pulses “blipped” through the  $k_x$ - $k_y$  plane that can compensate for a smooth in-plane B1+ inhomogeneity. A dual-band pulse  $b(t)$  of length  $T$  at off-resonance frequencies of 0 and  $\Delta f$  can be created using a fly-back trajectory  $\mathbf{k}(t)$  where each point is sampled by two 1D pulses (6). This can be cast as a matrix equation that can be solved using least squares approaches:

$$\begin{bmatrix} m(\mathbf{r}) \\ m(\mathbf{r})e^{-i\phi(z)} \end{bmatrix} = \begin{bmatrix} e^{-i2\pi\mathbf{k}(t)\mathbf{r}} \\ e^{-i2\pi\mathbf{k}(t)\mathbf{r}-i2\pi\Delta f(t-T)} \end{bmatrix} \times b(t)$$

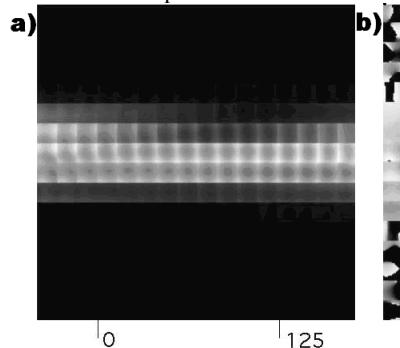
In order to correct for a body coil B1+ inhomogeneity, characterized by a bright center, an approximation for the magnetization profile  $m(\mathbf{r})$  is

$$m(\mathbf{r}) = \text{rect}(z/\Delta z) \left[ 1 - ae^{-\pi(x^2+y^2)/b^2} \right].$$

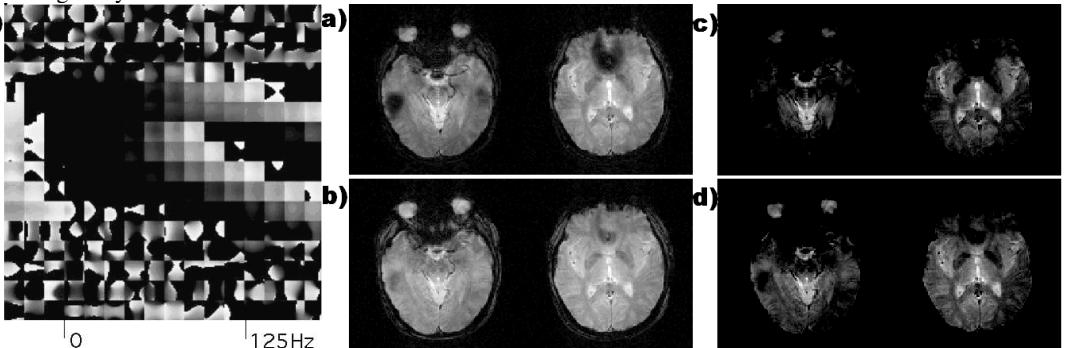
This is a slice of thickness  $\Delta z$  with an in-plane profile of one minus a 2D Gaussian parameterized by  $a$  and  $b$ . The through-plane phase due to susceptibility variations is corrected by pre-phasing the magnetization at  $\Delta f$  by  $\phi(z)$ . The assumption is that regions with signal loss will also be off-resonance by  $\Delta f$ , which has been well demonstrated in Ref. (2).

**Methods:** Human brain studies were performed on a Siemens 3T (Erlangen, Germany) whole body scanner using the RF body coil in TR mode with body gradients (150 T/m/s slew rate, 4 mT/m peak). The pulses were calculated using Matlab (Natick, MA) and inserted into a FLASH sequence (TE/TR=30/500ms, 22cm FOV, 128x128, 30° flip). Pulse parameters of  $\Delta f=125\text{Hz}$ ,  $\phi(z)=2\pi$ ,  $\Delta z=5\text{mm}$ ,  $a=.5$ , and  $b=1\text{cm}$  were determined by *post-hoc* visual inspection of corrected brain images. Figure 1 shows the trajectory and pulse designed with these parameters. Figure 2 shows Bloch equation simulations of  $m(\mathbf{r})$  as a function of frequency from the same pulse.

**Results:** Figure 3 shows example brain slices from one of the human volunteers using a standard slice-select pulse and the dual band 3D RF pulse. The signal recovery in the orbital frontal (sinus) area as well as above the ear canals can be easily seen. Windowed images of the same slices are also shown. Clear improvement in the B1+ homogeneity can be observed.



**Figure 2.** Bloch simulations of the pulse in Fig. 1(b) in the  $z$ - $f$  plane of the (a) magnitude and (b) phase of  $m(\mathbf{r})$  displayed as 2D images in  $x$ - $y$ . Note the “bowl” shaped magnitude needed for B1+ reduction and the through-plane compensatory phase at 125Hz.



**Figure 3.** T2\* weighted brain image measured with (a) a standard pulse and (b) the dual band 3D RF pulse. Note the recovered signal in the sinus and auditory areas. Windowed images of the same slices for the (c) standard and (d) dual band pulses. Note the improved B1+ homogeneity in (d) from the dual band pulse.

**Conclusions:** We have presented a dual band 3D RF pulse for the simultaneous reduction of the through-plane signal loss susceptibility artifact and B1+ field inhomogeneity. The method was shown to be successful at 3T in T2\* weighted brain images. The empirically determined pulse parameters terms were observed to work well in multiple slices and several volunteers, which facilitates implementation. The method can easily be extended to parallel transmission applications or more complex B1+ profiles.

**References:** (1) S. Saekho *et al.* MRM 2006;55:719-724. (2) C-Y Yip *et al.* Proc of 16<sup>th</sup> ISMRM 2008, p. 2453. (3) D. O. Brunner and K. P. Pruessmann Proc of 16<sup>th</sup> ISMRM 2008, p. 615 (4) K. Setsompop *et al.* Proc of 16<sup>th</sup> ISMRM 2008, p. 616. (5) A. B. Kerr *et al.* Proc of 16<sup>th</sup> ISMRM 2008, p. 617. (6) J. M. Pauly *et al.* Proc of 11<sup>th</sup> ISMRM 2003 p. 966.

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