Correction of 2D RF Pulses

Yuval Zur[1]
[1]GE Healthcare, Tirat Carmel, Israel

Introduction: Two dimensional (2D) RF pulses with EPI excitation trajectory are widely used as spectral-spatial (spsp) pulses in EPI (1) or for rectangular FOV excitation in DWI sequences (2). The correction method described below is valid for all 2D RF pulses where sub-pulses are applied in conjunction with an oscillating gradient (Fig. 1).

To excite an off center volume, a frequency waveform (Omega waveform) is played out in concert with the gradient. As shown in Figure 1, there is a mismatch between the gradient and omega waveform due to eddy currents and gradient-RF delay, which creates a phase Φ between even and odd sub-pulses. If $\Phi \neq 0$ the stop band (fat) is excited and the pass band (water) is partially suppressed (1). In practice these artifacts cannot be suppressed because Φ is extremely sensitive to system imperfections (1). In a recent publication (3) we have shown how to measure Φ accurately and quickly. During a scan the phase –Φ is added to even sub-pulses thereby eliminating these artifacts. As shown in (3) the phase Φ for a slice located z cm off-center is

$$\Phi = G_0A + G_0b \cdot z + 2\gamma G_0 z \cdot T_{del} \equiv G_0A + G_0Bz \qquad [1]$$

Where Tdel is the RF-gradient delay and G_0 is the amplitude of the oscillating gradient in Fig. 1. A and B are constants. Each physical gradient has different A and B: Ax, Bx for gradient x; Ay, By for gradient y; Az, Bz for gradient z. All the A and B terms are determined once with a calibration scan during system installation. Φ is calculated during scan prescription using [1] when z and G_0 are known. Finally Φ is added to even sub-pulses and the pulse is corrected. The assumption in (3) is that Φ within the excited volume or slice is the same, so a position-independent Φ is OK. This assumption is not true for an oblique slice. It is even not true for non-oblique slices as in Eq. [1], because Φ varies in z due to the finite width of the slice. In this work we describe a new method to correct a 2D RF pulse accurately using gradient blips.

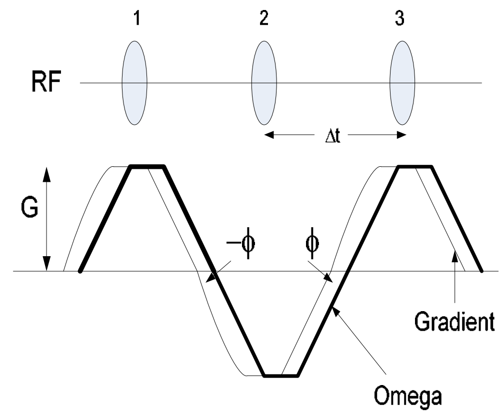

Figure 1

Method: In oblique scans the oscillating gradient with amplitude G_0 is rotated by a rotation matrix **R** from z to the desired direction. The phase error Φ in [1] becomes:

$$\Phi = G_0 \cdot \left(A_xR_{13} + A_yR_{23} + A_zR_{33} + B_xR_{13}x + B_yR_{23}y + B_zR_{33}z\right) \qquad [2]$$

Where **R** is the rotation matrix and Rij is element ij of **R**. The A and B terms are defined in [1]. To correct the RF pulse we add a phase –Φ to all the even sub-pulses. The first 3 terms on the right hand side in Eq. [2] are position independent. Therefore they are added to the phase of each even sub-pulse. The last 3 terms in [2] must be corrected with gradient blips on the x, y and z axes respectively. From Eq. [2], the areas of the gradient blips **S**x, **S**y and **S**z in vector notation are given by Eq. [3]. The blips areas in Eq. [3] are the areas after rotation by **R**. However the scan software calculates the area before the rotation is applied. Hence the areas **SC**x, **SC**y and **SC**z calculated by the software are given by Eq. [4].

$$\gamma\begin{pmatrix}\boldsymbol{S}_x\\ \boldsymbol{S}_y\\ \boldsymbol{S}_z\end{pmatrix} = -G_0 \cdot \begin{pmatrix}B_xR_{13}\\ B_yR_{23}\\ B_zR_{33}\end{pmatrix} \qquad [3]$$

$$\gamma\begin{pmatrix}\boldsymbol{SC}_x\\ \boldsymbol{SC}_y\\ \boldsymbol{SC}_z\end{pmatrix} = \gamma\boldsymbol{R}^{-1}\begin{pmatrix}S_x\\ S_y\\ S_z\end{pmatrix} = -G_0 \cdot \boldsymbol{R}^{-1}\begin{pmatrix}B_xR_{13}\\ B_yR_{23}\\ B_zR_{33}\end{pmatrix} \qquad [4]$$

Results: The corrected 2D RF pulse is shown in Fig. 2. The amplitudes of the correction blips alternate. The position-independent phase in Eq. [2] is added to the phase of even sub-pulses as shown in Fig.2. Fig. 3 shows results of water fat phantom scanned with a spsp RF pulse at a double oblique orientation. Excellent stop band suppression (fat) without pass band saturation (water) is achieved.

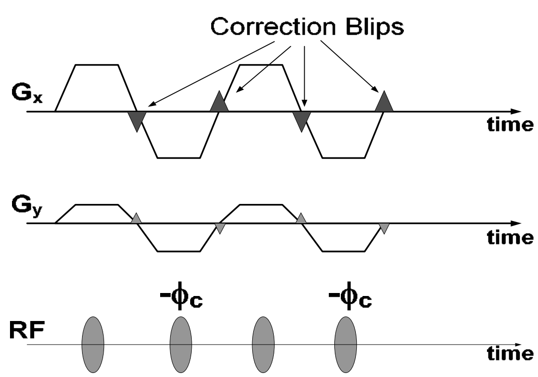

Figure 2

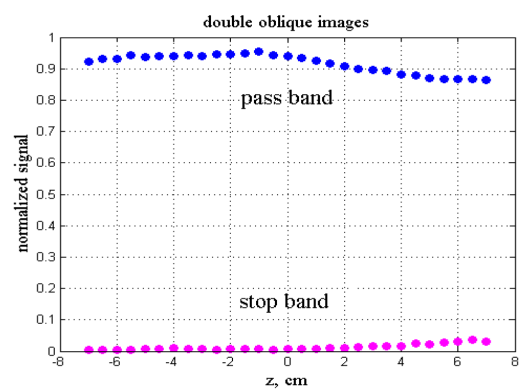

Figure 3

References: (1) Y. Zur, Mag. Res. Med. 43, 410 – 420 (2000).
(2) E. Ulku Saritas et.al. Mag. Res.Med. 60, 468 – 473 (2008). (3) Y. Zur, Proceedings ISMRM 2013 abstract 3778.