Spatial phase encoding using a Bloch-Siegert Shift gradient

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Introduction: Conventional MR-scanners use B_0-gradients for spatial encoding. In this work we introduce a robust RF only spatial encoding method, which is mimicking conventional phase encoding using B_0-gradients by exploiting the properties of spatially dependent Bloch-Siegert(BS) [1, 2 , 3] phase shifts induced by a RF gradient coil.

Theory: Applying far off-resonant RF pulses to a magnetization induces a BS phase shift in the transverse component without significantly tipping the magnetization, given the magnetization has been flipped far away enough from the z-axis. The application of a coil with an inhomogeneous B_1 field leads to a spatially dependent phase shift and therefore offers the possibility of spatial encoding using the same spatial encoding paradigm as conventional MR system. The induced phase shift reads $\phi(x,y) = [\gamma B_1\,(x,y)]^2\tau/(2\Delta\omega_{off}\,)$, where $\Delta\omega_{off}$ denotes the off-resonance, $B_1(x,y)$ the spatially dependent field strength and τ the BS-pulse duration. Hence applying a BS-pulse with a certain duration and fixed amplitude is equivalent to applying a conventional B_0-g-radient with a particular gradient moment. Since the phase shift is proportional to B_1^2 a constant gradient in the RF field leads to a quadratic phase encoding.

Material and methods: A conventional 0.5 T scanner with a 3D gradient system has been equipped with an additional 10 loop RF-transmit coil and a 12 mm inner diameter. Outside of the coil the B_1-transmit coil has a profile which follows an approximately constant gradient of 400 mT/m. 2D BS encoded spin echo (SE) measurements were carried out. The conventional phase encoding via B_0-gradients was replaced by 500 kHz off-resonant rectangular pulses with systematically increasing durations and a constant power of 40W. A linear reconstruction by a Fourier transform yields an image distorted by the non linear encoding. To obtain the undistorted image a non linear reconstruction based on the spatial dependence of the previously measured 2D B_1-field was applied. Alternatively a RF-gradient with a profile following a square-root function would be needed for a linear phase encoding.

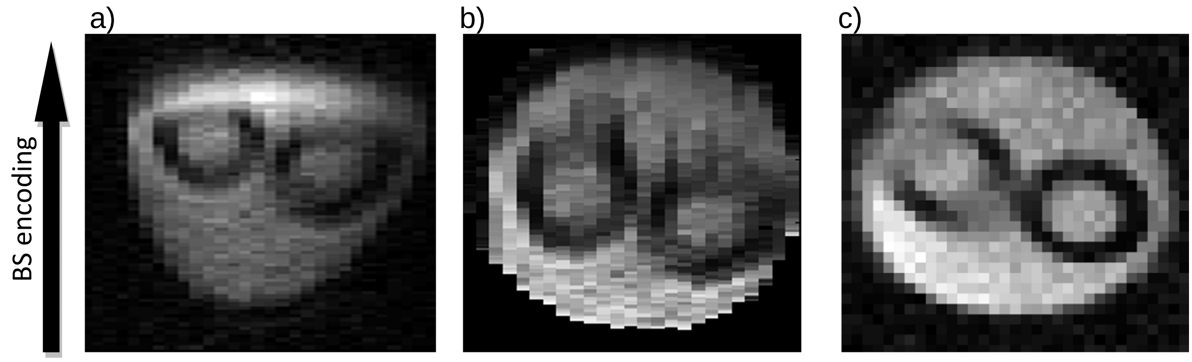

Figure 1: BS SE 2D image of 4mm diameter oil sample with 2 tubes. 50x80 matrix; BS-encoding 500 kHz off resonance rectangular pulses with a maximum length of 4 ms; AVG 20; TE 18 ms.

a) Fourier transformation results in a distorted image along BS encoding direction. Please note the low resolution far away from the BS coil (top of image a) and increasing resolution towards BS coil (bottom)
b) Non linear reconstruction along BS-encoding dimension leads to an undistorted image.
c) Result of a standard SE 2D sequence without BS encoding (Matrix 50x80).

Results: The results of the BS 2D SE sequence are shown in figure 1. A structured oil sample with a diameter of 4 mm was measured. The vertical direction was encoded using the BS-shift, the horizontal direction was encoded by a conventional B_0 read gradient. Panel (a) shows the distorted BS-image with the Fourier transform reconstruction. The same data was reconstructed by taking into account the spatial dependence of the B_1-field. This results in an undistorted BS-image shown in panel (b). The result of a conventional 2D SE sequence is shown in panel (c).

Discussion: In this work the proof of concept for spatial phase encoding using a B_1-gradient in combination with BS RF pulses is demonstrated. Compared to B_0-gradient phase encoding, BS-gradient imaging has evident restrictions. Thus one drawback is the very high SAR given in high field experiments. However, being a RF only encoding technique it has an increased immunity against eddy currents and a very short switching time. In principle, the application of BS-gradients mimicking B_0 gradients are not restricted to spatial phase encoding and could for example be applied to flow or diffusion measurements.

Reference:

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