# Design of flyback echo-planar readout gradients for MR spectroscopic imaging

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**INTRODUCTION** The spatial resolution of magnetic resonance spectroscopic imaging (MRSI) is typically coarse (e.g., 1 cm^3 voxels), mainly due to SNR limitations. However, the increased signal available with higher field scanners and new array coils now permits higher spatial resolution than is feasible with conventional chemical shift imaging (phase encoding) within the time available in a clinical MRSI exam. More efficient data acquisition methods are required. The use of time varying gradients during the readout window is a well known method for reducing the scan time, with some of the spatial encoding done at the same time as the spectral readout [1]. While some of these methods are sensitive to conditions encountered in practice (timing errors, eddy currents etc.) or require a sophisticated data reconstruction, the "flyback" echo-planar trajectory [2] is particularly insensitive to errors and provides data that are simple to process. Recent advances in gradient hardware have made flyback trajectories feasible with the higher spatial resolutions and larger spectral bandwidth of high-field MRSI. In this abstract we present the design of flyback echo-planar trajectories that make full use of the gradient performance available with a modern, whole-body MRI system.

**THEORY** The readout gradient for a flyback echo-planar trajectory consists of a flat section during which data are acquired, followed by a rewind lobe that retraces across the desired portion of k-space as quickly as possible. The most efficient form of such a gradient consists of rewind lobes using the maximum slew rate of the gradient hardware, interleaved with flat portions that exactly cover the desired extent in k-space. The duration (and thus amplitude) of this flat part is determined by the desired spectral bandwidth (SBW), with SBW = 1/(T_flat + T_rewind).

Since data are not acquired during the rewind lobe of the flyback gradient, a penalty in SNR is incurred relative to the usual continuous sampling during the readout window. This penalty, expressed as the fraction of the full SNR that could be achieved during the same readout time, is given by SNRf = $(\mathrm{T\_flat}/(\mathrm{T\_flat} + \mathrm{T\_rewind}))^{1/2}$. Higher spatial resolution (longer T_rewind) and higher spectral bandwidth (shorter T_flat) both imply a reduction in the SNRf.

For high spatial resolution scans, where signal averaging is often used to increase the SNR, interleaving of k-space trajectories can be used to boost the SNR fraction [3]. For example, if two signal averages are to be used, then the flyback trajectory can be designed for half of the desired SBW, boosting the SNR fraction. Then, during the second of the two data acquisitions, the readout gradient is shifted by 1/(SBW), and the two acquisitions can be combined to regain the full SBW. For higher spatial resolution waveforms (Fig. 1(a)), this can have a significant benefit (Fig. 1(c)).

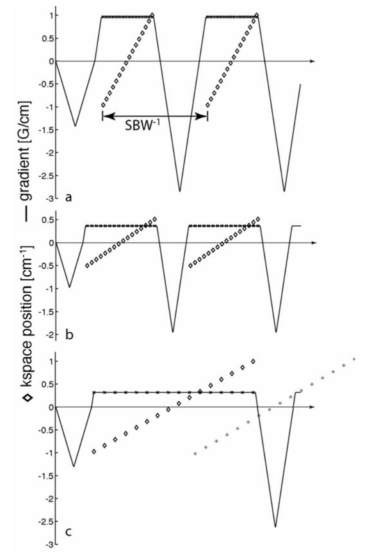

**Figure 1**: Flyback echo-planar trajectories designed to use the full performance of the gradients. The first 2.4 ms of each gradient waveform is shown, as well as the kspace position at each sample point. (a) Gradient waveform designed for 5 mm spatial resolution and 977 Hz spectral bandwidth (SNRf = 71%). The spectral bandwidth (SBW) is defined by the time between kspace traversals. (b) Gradient waveform designed for 10 mm spatial resolution and 988 Hz spectral bandwidth (SNRf = 83%). (c) Reduced SBW waveform (506 Hz) achieves 5 mm spatial resolution with much higher efficiency than (a) (SNRf = 92%), and with temporal interleaving (* in (c), see Theory) would give 1012 Hz SBW.

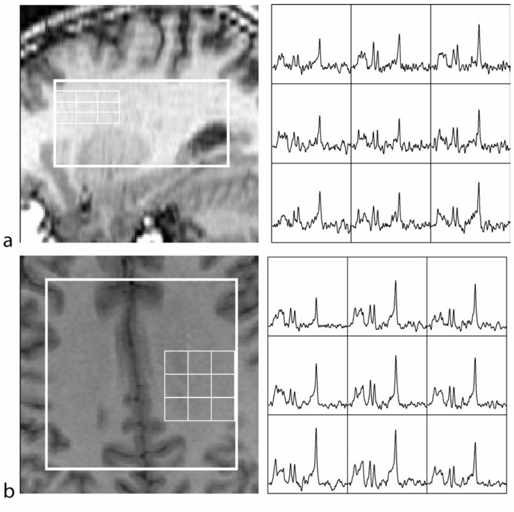

**Figure 2:** MRSI data acquired using the new trajectories. The white box shown on the T2 weighted image denotes the region excited/refocused by the RF pulses in the PRESS sequence. The grid shows the phase-encoded voxels from which spectra are shown on the right. (a) Spectra acquired using the gradient shown in Fig. 1(a). (b) Spectra acquired using the gradient in Fig. 1(b).

**METHODS** Gradient waveforms were designed in MATLAB (The Mathworks, Natick MA) using custom software. The design inputs were the spatial resolution and spectral bandwidth. The gradient waveforms were designed to be optimal in the sense that the gradient is either flat (time during which data are acquired) or ramping at the maximum slew rate, 150 mT/m/ms (see Fig. 1). Trajectories were designed for the spatial resolutions desired for brain MRSI (1 cm) and prostate MRSI (5 mm) at 3 T.

To test these flyback echo-planar trajectories, phantom experiments were performed and brain spectra were acquired from normal volunteers. The readout gradients were implemented in a PRESS pulse sequence on a GE Signa 3T scanner (GE Healthcare Technologies, Waukeshaw WI). Signal was received using an 8-channel phased array head coil, and the whole-body birdcage coil was used for RF transmission. The parameters for the data acquisitions were 16384 data samples per readout, TR = 2 s and 16x16x16 encoding (8.5 m scan time). The voxel dimensions were 10 mm in the two non-echo-planar dimensions. The resolution was set to the minimum for the echo-planar dimension (5 mm for Fig. 1(a) and 10mm for Fig. 1(b)), and the echo times were 35 ms and 30 ms, respectively. The echo-planar gradient was applied in the superior/inferior direction.

**CONCLUSIONS**

High efficiency gradient waveforms for flyback echo-planar MRSI were designed and implemented. Data from normal volunteers showed good spectral quality, with large coverage (16 x 16 x 16 voxels) and reasonable scan time (8.5 minutes).

**REFERENCES**

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