

# Accurate Measurement of MRI Gradient Characteristics

Gerald B Matson<sup>1,2</sup> and Hui Liu<sup>1</sup>

<sup>1</sup>Center for Imaging of Neurodegenerative Diseases, Department of Veterans Affairs, San Francisco, California, United States, <sup>2</sup>Pharmaceutical Chemistry, University of California, San Francisco, San Francisco, California, United States

## Purpose

The purpose of this study is to demonstrate a simple approach for accurately measuring the characteristics of an MRI gradient system. One approach to alleviate gradient non-fidelity is to measure the actual k-space trajectory, and use this information for reconstruction of the image. Alternatively, the gradient system may be considered as a linear, time invariant system and the gradient impulse response functions measured. This has the advantage that the actual gradient output for any requested gradient waveform can be predicted. The gradient output,  $out(t)$ , is related to the requested gradient,  $input(t)$ , according to the impulse response  $h(t)$ <sup>1</sup>:

$$out(t) = \int_{-\infty}^{\infty} in(\tau) \cdot h(t - \tau) d\tau . \quad 1$$

Taking the Fourier transform (FT), such that  $H(\omega) = FT\{h(t)\}$  and  $IN(\omega) = FT\{in(t)\}$ , the relationship can be expressed as:

$$OUT(\omega) = IN(\omega) \cdot H(\omega) . \quad 2$$

Vannesjo et al.<sup>1</sup> labeled  $H(\omega)$  as the GIRF. Their approach involved the elaborate construction of an array of multiple, small samples (on the order of 1 mm diameter), each with their own transmit coil and receive circuit, and mounted as a single phantom. Through signal averaging, they have demonstrated the ability to measure the gradient system GIRFs with unprecedented accuracy.

## Methods

To alleviate the construction difficulties of the Vannesjo et al. phantom, we used a single, small 110  $\mu$ l spherical bulb phantom, with its own transmit/receive coil wound around an 8mm NMR tube. As the phantom size was several mm in diameter and not susceptibility matched, the construction was relatively straightforward. The phantom has its T1 reduced to approximately 100 ms to enable fairly rapid pulsing. To determine the GIRFs on our Siemens Skyra system, we followed the Vannesjo et al. approach and used a series of nine triangular gradient waveforms for mapping the frequency response of the gradients, along with their suggested method for combining the results for obtaining the GIRFs. For the most part, we used a bandwidth of 100 kHz, and 200 repetitions (TR of 500 ms) of alternating gradient-on / gradient-off acquisitions. As the GIRF measurements became noisy and unreliable at high frequency, the logarithm of a portion of the measured GIRFs (from 16 to 27 kHz) was fitted to a quadratic and extrapolated out to higher frequencies.

## Results

Magnitude GIRF results are shown in Fig. 1, while zoomed regions are shown in Fig. 2. The sharp features seen in the zoomed plot are presumed due to mechanical vibrations. To demonstrate the predictive capabilities of the GIRFs, Fig. 3 shows a requested x-gradient trapezoidal waveform (green) with 100  $\mu$ s rise, top and fall times, with a slew of 180 mT/m/ms. The experimentally measured gradient (blue) is shown along with the GIRF predicted waveform (red). The insets in this figure show zoomed portions from the top and end of the gradient waveform. As shown, the predicted gradient waveform closely follows the experimentally measured waveform.

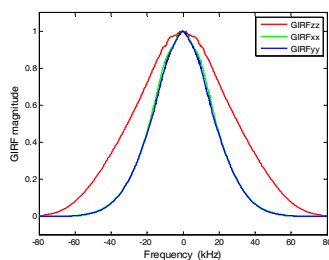


Fig. 1. Magnitude GIRFs. Fig.

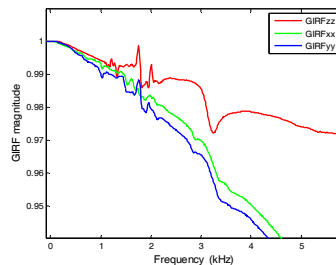


Fig. 2. Zoomed region of Fig. 1.

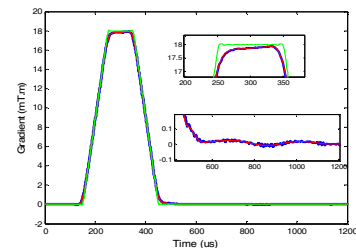


Fig. 3. Requested (green), experimental (blue) and predicted (red) gradient waveforms.

## Discussion

An advantage of this approach is that it is independent of models of eddy current behavior, and intrinsically includes effects due to gradient mechanical vibrations. Our simple approach still produces GIRFs of high accuracy with excellent predictive capabilities, with the capability to predict actual k-space trajectories for improved fidelity of image reconstruction.

**References:** 1. Vannesjo SJ, Haeberlin M, Kasper I, et al. Magn Reson Med 2013, 69, 583-593.