Imaging Based Gradient Pre-emphasis

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Introduction
Characterizing the spatiotemporal gradient eddy current impulse response is important in MR imaging as it helps correct for errors in the gradient moments caused due to eddy currents (a.k.a. pre-emphasis). Errors in pre-emphasis settings could result in image distortions in k-space, and inaccuracies in q-space imaging especially while measuring very low diffusivities and flow velocities which often require strong gradients. Current methods to measure gradient response typically involve mapping of the eddy current magnetic field by the phase of the FID acquired following a test gradient pulse [1]. Localization of eddy currents is achieved by either moving the sample in space or using multiple solvents with differing chemical shift placed in different known locations. Pre-emphasis parameters are obtained by fitting the time-varying eddy current magnetic field with a multi-exponential decaying curve in time assuming three time constants (short, medium and long) [2]. We propose a new imaging based method to adjust gradient pre-emphasis, which is easy to implement and doesn’t assume any apriori information on the number of time constants.

Method
MR measurements were performed using a Magnex Scientific 11.1T magnet connected to Agilent Direct Drive console, running VmrJ 3.1A software, with shielded gradients (Model BFG-240/120-S6, Resonance Research, Inc. Billerica, MA). A 3D fast low angle shot (FLASH) gradient echo imaging sequence was modified by adding a test gradient pulse with a variable delay time before RF excitation. Zeroing the pre-emphasis unit and using a 40 mm DSV sample filled with water, the sequence was used to characterize the Z-gradient with the following imaging parameters; TR/TE: 1400/0.55 ms, flip angle: 4°, matrix size: 32 x 16 x 16, field of view: 50 mm x 50 mm x 50 mm, test gradient amplitude/duration: 300 mT/m & 500 ms, and delay times: 0.90, 1.00, 1.25, 1.50, 1.75, 2.00, 5.00, 20.00, 50.00, 200.00 and 500.00 ms. For a given delay time, two measurements were acquired with opposite test gradient polarities to account for non-eddy current related phase changes. A 3D time varying eddy current magnetic field map was obtained from the phase resulting from complex dividing the two opposite gradient-polarity images acquired at each delay time. The resulting magnetic field was fit to a trilinear equation in space whose slopes were then fit to a decaying multi-exponential model in time to obtain the required pre-emphasis amplitudes and time constants. The time constants were successively added to the multi-exponential model until the statistical significance of the added parameters is negligible as determined by the statistical F-test.

Results & Discussion
In Figure 1, the modeled time-dependence eddy current fields, after pulsing the Z-gradient, are plotted as a percentage of the applied test gradient amplitude versus the delay time. The large amplitude eddy current fields have smaller time constants and vice-versa (see Table 1 and Figure 1). The maximum eddy current field was less than 15% of the applied gradient strength. Such a low field distortion could result from eddy current in the gradient shield.

<table>
<thead>
<tr>
<th>Distortion</th>
<th>a1</th>
<th>τ1 (ms)</th>
<th>a2</th>
<th>τ2 (ms)</th>
<th>a3</th>
<th>τ3 (ms)</th>
<th>R² fit</th>
</tr>
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<tbody>
<tr>
<td>B0 (%)</td>
<td>0.002</td>
<td>0.2371</td>
<td>-0.005</td>
<td>8.6139</td>
<td>0.005</td>
<td>9.8227</td>
<td>0.998</td>
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<td>Gx (%)</td>
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<td>-0.006</td>
<td>8.6139</td>
<td>0.005</td>
<td>9.8227</td>
<td>0.997</td>
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<td>Gy (%)</td>
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<td>0.1071</td>
<td>0.0026</td>
<td>31.7223</td>
<td>-0.003</td>
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<td>0.901</td>
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<tr>
<td>Gz (%)</td>
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<td>-0.1357</td>
<td>2.0228</td>
<td>-0.003</td>
<td>9.8227</td>
<td>1.000</td>
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</tbody>
</table>

Table 1: Gradient pre-emphasis constants for Z-gradient. Gx refers to gradient in the i^th axis, a_i, are the multi-exponential parameters and τ_i is the time constant respectively. R² fit is the goodness of fit measure for the multi-exponential temporal model fitting.

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References