Characterization of PatLoc Gradient with a Field Camera

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$$o(t) = \int i(\tau)h(t-\tau)d\tau$$

$\updownarrow$ Fourier Transform

$$O(\omega) = I(\omega)H(\omega) \quad (1)$$

$$H_{n,m}(\omega) = \frac{\sum_j I^*_{n,j}(\omega)O_{n,j,m}(\omega)}{\sum_j |I_{n,j}(\omega)|^2} \quad (2)$$

Introduction: Parallel Acquisition Technique with Localised gradients (PatLoc)[1] is a new MR imaging strategy using localized gradients tailored to better match the imaging geometry of interest and with the potential to reduce peripheral nerve stimulation. Higher order field dynamics can be recorded by magnetic field monitoring (MFM) [3] using a field camera. The field camera can be used additionally to measure the gradient impulse response functions (GIRF) [4] for every gradient channel, incorporating therefore all sources of error, such as eddy currents, gradient coil vibrations, etc. which are influencing the effective encoding trajecory. In the present work a field camera with 16 ^{1}H field probes is used to characterize the PatLoc gradient coil [5] by testing the linearity of its performance in combination with standard linear gradients and to measure and compare the GIRFs of the linear and the PatLoc gradient systems.

Fig.1:Field camera setup

Theory: The phase of the acquired signals of the field probes reflects the magnetic field evolution at their respective positions. The field evolution, modeled as real spherical harmonics ($k_0(t)$, $k_x(t)$, $k_y(t)$, $k_z(t)$, $k_{xz}(t)$,…), can then be estimated in a least square sense from the unwrapped field probe phases, taking into account their position and their off-resonance frequency. The field evolution describes the effective k-space trajectory which can be used in the image reconstruction [3] in order to take into account effects such as eddy currents, field drifts, gradient delays, which are affecting the image quality.
The GIRFs of the gradient coils can be calculated from the measured field evolution based on linear system theory. The measured output gradient o(t) and the nominal input gradient *i(t)* are then linked together with the impulse function *h(t)* by the convolution described by Eq.(1) (see top right). A Dirac delta function as *i(t)* would cover an infinite frequency bandwidth which needs to be approximated as a short triangle because of the discretisation of the gradient waveform, amplitude and slew rate limitations of the gradient coil. Several triangular shaped gradient intputs $i_j(t)$ with different amplitudes are used to fill in zeros of the Fourier Transform $I_j(w)$. The input and the measured output functions can be combined in a least square sense, Eq.(2), to estimate the Fourier Transform of the GIRF $H_{n,m}(w)$. The index *j* denotes the input gradients, *n* the gradient channel used (3 linear and 2 PatLoc gradients) and *m* the component of the gradient *o(t)* calculated by differentiating the reconstructed trajectories.

Experiments: Measurements were performed on a 3T Tim TRIO MR scanner (Siemens Healthcare, Erlangen, Germany). The PatLoc fields are produced by a head gradient coil insert [5] producing quadratic magnetic fields of the type XY and X^2-Y^2 denoted here as A and B, respectively. The field camera consisted of 16 field probes [3] approximatively distributed on a 18cm sphere placed inside the Tx\Rx head coil (Fig.1). The field probes are operated in transmit/receive mode and connected to the spectrometer of the scanner. The separate transmit chain is controlled via trigger signals from the scanner and allowed to excite the field probes with short RF-pulses (5µs). Image reconstruction and data analysis are performed offline in MATLAB (The Mathworks, Natick, AM, USA).
A single shot 4D radial-in radial-out trajectory (4D-RIO)[6] is used to test the linearity of the system when linear and quadratic gradients are used. In experiment E1 only the linear part of the 4D-RIO trajectory, in experiment E2 only the PatLoc part and in experiment E3 the complete trajectory is applied.
The GIRFs are calculated from the field evolutions of 16 triangular shaped gradients (slew rate = 153T/m/s, amplitudes varying from 7.65 to 30.6mT/m in steps of 1.53 mT/m) in order to cover the gradient coils bandwidth. The acquisition and excitation bandwidths are 400kHz and 200kHz, respectively. 60 repetitions are acquired with a repetition time of TR=2s.

Results: The trajectory components from E1-E3 are normalized to the maximum phase evolution on a 20 cm sphere. The observed fields in the case of linear only and PatLoc only can be added together (Fig.2 (a)) to obtain the observed field in case of linear and PatLoc gradients switched on simultaneously (Fig.2 (b)). The maximum root mean square deviation for all 16 components is 1.6 rad, showing a linear behavior of the two gradient coils. In Fig.3 (a) details of the GIRF of the x,y and z and in Fig.3 (b) of A and B gradients are shown. The GIRFs of gradients A and B show strong harmonics of ~220Hz which are also visible in the linear terms and in the XYZ and Z(X²-Y²). This behavior might be due to mechanical or electromagnetic coupling with the scanner gradient and shim system.
Conclusion: A field camera with 16 ^{1}H field probes is used to characterize the scanner system consisting of linear and non-linear gradients. Higher order field dynamics are recorded of a 4D-RIO trajectory and GIRFs of the linear and the PatLoc gradient system are presented.

Acknowledgments: This work has been supported by the INUMAC project supported by the German Federal Ministry of Education and Research, grants #01EQ0605 & #13N9208. **References:** [1] Hennig J. et al., MAGMA 21(1-2):5–14, 2008 ; [2] Duyn J. et al. JMR, 132 :150-3,1998 ; [3] Wilm B. et al., MRM 65:1690, 2011 ; [4] Vannesjö J. et al., 18th ISMRM 2010, p1536 ; [5] Welz A. et al., 17th ISMRM 2009, p3073 ; [6] Gallichan D. et al. MRM 65:702 ,2011

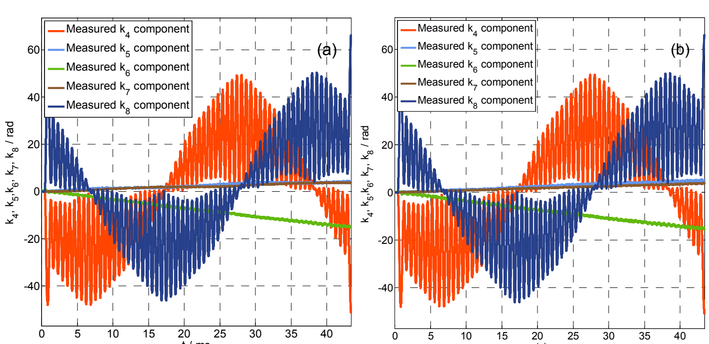

Fig.2 (a) quadratic component from 4D-RIO; (b) sum of the quadratic components from separate measurements of the linear and the PatLoc gradients

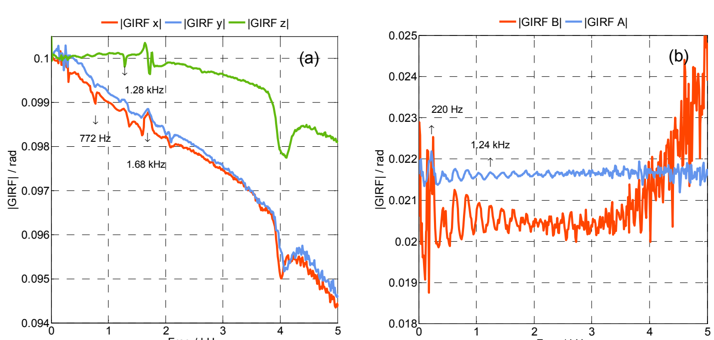

Fig.3:(a) Absolute GIRF of the linear gradients; (b) Absolute GIRF of the PatLoc gradients A and B