Monoplanar gradient system for imaging with nonlinear gradients

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Introduction: Non-linear local gradients for MRI have been introduced [1,2] with the aim to overcome present limitations of gradient performance due to safety limitations from peripheral nerve stimulation (PNS) and to investigate novel non-linear encoding strategies. The PatLoc (parallel imaging technique using localized gradients) fields used so far have been quadrupolar spherical harmonics [3]. Here we present a design and show the process of building a nonlinear monoplanar PatLoc gradient system (FlatLoc). Three nonlinear fields have been optimized to achieve orthogonal voxels over the whole FOV [4]. This hand built system is dedicated for imaging the heart, abdomen and pelvis and was interfaced to our 3T whole-body scanner, equipped with 6 individually controlled gradient channels.

Materials and Methods: The size of the nonlinear encoding system was chosen to fit into the patient table of a Siemens 3T Trio Tim (Siemens Healthcare, Erlangen, Germany) and is therefore limited to 0.49 x 1.69 m. Each channel of the encoding system is built up of 2 to 4 coil elements and is wound of 3.0 mm insulated copper wire. These three layers are separated by two layers of water cooling, which were made of 6mm copper tubes, shielding fluid artifacts from the cooling cycle. For mechanical stability glass reinforced plastic (GRP) was used as top and bottom layers and between cooling tubes. The entire encoding system was cast in epoxy resin. Figure 1 shows different layers of the FlatLoc coil during manufacturing. For all acquired images a standard gradient echo sequence (GRE) was used.

Fig. 1: Coil elements for each channel and one layer of water cooling tubes with grooves for temperature sensors and connectors.

Results and Discussion: The electrical values have been optimized during the design process to match the available gradient power amplifiers for fast switching rates. The following values were measured including connection cables:

Channel	Inductance [µH]	Resistance [mΩ]
1	380	130
2	413	170
3	432	245

Performance tests have been passed successfully with currents up to 282 A showing a very good performance of the implemented water cooling. Further tests confirmed the high performance for a hand built gradient system with duty cycles up to 98%. Thereafter the FlatLoc coil was integrated into our 6-gradient channel 3T system. Fieldmaps have been measured for all three channels using a GRE and can bee seen in Fig. 2. Only a coronal slice is shown, but the field gradients are approximately locally orthogonal in three dimensions throughout the whole VOI. To demonstrate feasibility, an image approximating a coronal slice was acquired using all three nonlinear channels, entirely without standard linear gradients. Fig. 3 left shows an image acquired with channel 1 for slice-selective excitation and channels 2 and 3 for readout and frequency encoding. The resulting image acquired with all three nonlinear channels, demonstrates good orthogonality and similar sensitivities of the channels. Geometric distortions are expected with a monoplanar coil arrangement. Those distortions are planned to be corrected for by using a conjugate gradient reconstruction method and advanced encoding strategies. The large field of view in Fig. 3 shows that it is possible to encode in a volume comparable to that one covered by linear gradients. Vibrational and acoustic effects generated by the FlatLoc coil are compatible with human imaging. IRB approval for in vivo measurements has been obtained, however, due to RF-transmitter limitations in vivo measurements could not be performed to date.

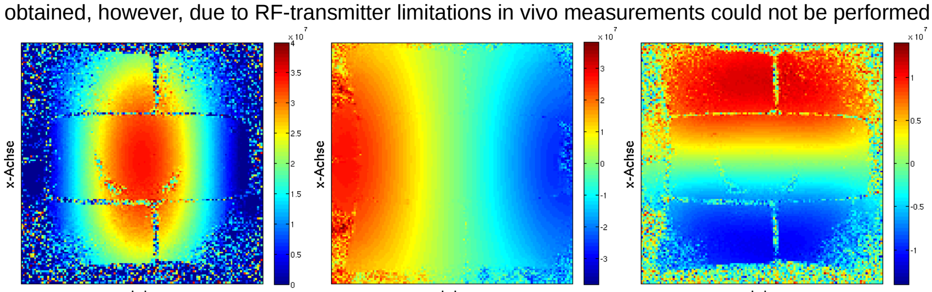

Fig. 2: Fieldmaps in Hz/(100 A) of all three channels in a coronal view 12 cm above the top of the nonlinear encoding system.

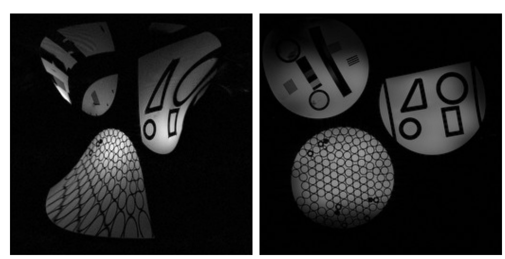

Fig. 3: Images acquired using three nonlinear encoding fields entirely without the conventional linear gradients (left). As a reference images acquired with linear gradients (right).

Conclusions: A balanced monoplanar high performance gradient system has been implemented. Feasibility of imaging was demonstrated through phantom experiments. This gradient system opens new perspectives for flexible region-specific encoding in different body regions. New encoding systems and strategies may help to push back existing physiological limits, enable faster imaging and open up new possibilities in methodological developments.

[1] J. Hennig et al , MAGMA 21(1-2):5-14(2008) [2] S. Littin et al, ISMRM 2011, p.1837 [3] A.M. Welz et al, ISMRM 2009, p.3073
[4] S. Littin et al, ESMRMB 2011, p.529

Acknowledgment: This work is a part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208