A 50-channel matrix gradient system: a feasibility study

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INTRODUCTION

MRI-scanners typically have two independently acting systems to manipulate the B0-field. The gradient system generates a linear field profile and is used for signal encoding. The shim system, consisting of many different coils, generates multiple higher order field profiles which are used for correcting field distortions. As several orders are required to achieve good homogeneity a specific coil has to be designed for each field order.

In this study a novel gradient/shim design is presented, which combines both systems. The new design is capable of generating both linear gradient fields for imaging and at the same time high order shim fields. The simultaneous generation of several orders can be achieved by using an array of individually driven coils. The complete magnetic field results from the superposition of all these individual fields. This provides the possibility of creating a large variety of field profiles by driving each coil with a different current.

This matrix gradient approach can not only provide strong linear gradients used for imaging but at the same time allows generating shim fields in order to compensate inhomogeneities in the main field. Driving the coils separately grants the advantage of switching shim and gradient fields very fast due to the low inductivity of each single coil.

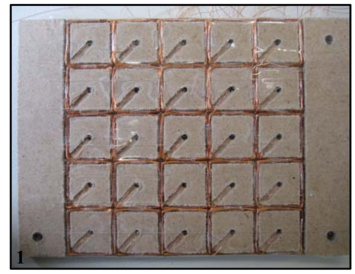

Fig. 1: One gradient plane with 25 coils arranged in a 5x5 matrix. Each coil is driven with an individual current.

METHODS

In order to demonstrate the principle of the matrix gradients, a biplanar gradient system was simulated and built. It consists of 50 individual rectangular coils, each with 40 turns, arranged in two opposite planes. The distance between the planes is 4 cm and outer dimensions are 10 cm * 10 cm. The coils are arranged in two 5x5 matrices (figure 1). Each coil C_x is driven with an individual current I_x. Multiple field profiles have been simulated and measured. The simulations were done using biot-savart's law. The field measurements were made in a 1.5 T whole body scanner.

RESULTS

Each coil has a low inductance of 60µH which makes very fast switching times of about 18µs possible. This short time applies to any arbitrary field profile, gradient as well as shim fields. Exemplarily a simulation of the linear gradient field in x-direction is shown in figure 2. The gradient strength is about 27,3 mT/m/A in a field of view of 3 cm. To demonstrate the capability of creating higher field orders a simulated spherical harmonic of the 3rd order, $3x^2y-y^3$, is shown in figure 3. A measured quadratic shim field in y direction is shown in figure 4a. The field profile corresponds to the simulations (figure 4b).

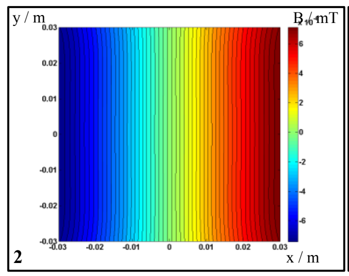

Fig. 2: Simulation of linear gradient field, exemplarily shown for the x-direction.

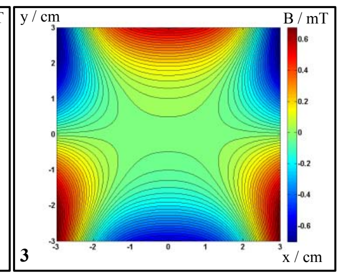

Fig. 3: Simulation a 3rd order y gradient - $3x^2y-y^3$

DISCUSSION

Preliminary results are encouraging, since the novel design is able to create strong and linear gradient fields for imaging and at the same time generates shim fields of multiple orders to homogenize the B0-field. The simulated field profiles have been verified by the experiments.

Moreover it is possible to build an arbitrary matrix gradient system for almost every given geometry. The geometry is not restricted to planar gradient systems and the number of coils and their arrangement is free of choice. The major drawback, however, is that for each coil a separate gradient amplifier is required.

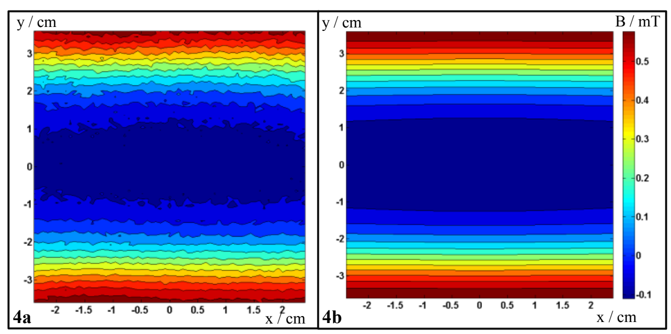

Fig. 4: a: Measurement of a quadratic field profile in y direction
b: Simulated quadratic field profile in y direction

CONCLUSION

The proposed gradient system is able to create strong linear gradient fields as well as higher order shims simultaneously with fast switching times. Furthermore, the possibility to switch high order shims as fast as linear gradients is advantageous e.g. for individual slice shim in multislice experiments.

The next step to unleash the full possibilities of the matrix gradient system is to build a 50 channel gradient amplifier. Such an amplifier is already in development.

REFERENCES

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