Fast phase-modulated B1+ mapping in the low flip-angle regime

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Introduction and purpose: In high-field MRI phased transmit arrays are used to mitigate RF issues, e.g. optimizing the inhomogeneous B_1^+ field using spatially tailored RF pulses played out by such an array. In order to design the RF pulses that produce the desired excitation field, the B_1^+ field per coil must be mapped. Ideally, these B1 mapping techniques are fast and have a low SAR deposition. However, most of the contemporary B1 mapping techniques require large flip angles [1,2] and are therefore accompanied by relatively high SAR values. As a consequence, lengthy acquisition times are needed to stay within SAR limits. In this abstract we describe a fast method to measure the B_1^+ field per coil in the low flip-angle regime, using phase modulated 3D low flip angle (PMLF) GRE images.

Theory: In GRE images for low flip angles, the signal amplitude is directly proportional to the product of the proton density, the receive sensitivity (B_1^-) and the transmit sensitivity (B_1^+) [equation 1], where the B_1^+ field is the superposition of the individual coil fields [equation 2]. The relation in equation 1 invokes that in order to disentangle B_1^+ from the other two factors, a non-linear manipulation of the transmit sensitivity is needed. Here we propose to achieve this by electronically phase modulating one of the coil input signals with angle ϕ_e. The resulting B_1^+ field, the superposition of all individual coil B1+ fields, can be expressed by the law of cosines, a non-linear function [equation 3, figure 1]. This makes it possible to obtain the value of the B_1^+ of the phase-modulated channel relative to the fixed channel. By weighting this relative value by an absolute B_1^+ map obtained in the high-flip (HF) angle regime, we obtain the B1+ map of the phase-modulated coil.

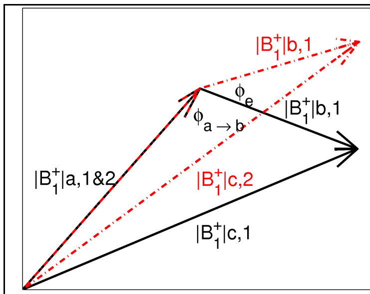

Figure 1: Visualization of the effect of phase modulation by an angle of ϕ_e on the total B_1^+ amplitude $|B_{1,}^+|_c$

$$S_{GRE} \propto \rho B_1^- B_1^+ \quad [1]$$

$$\left|B_{1,total}^+\right| = \left|\sum_{N=n} B_{1,n}^+\right| \quad [2]$$

$$\left|B_{1,total,e}^+\right|^2 = \underbrace{\left|\sum_{n=M} B_{1,n}^+\right|^2 + \left|B_{1,c}^+\right|^2}_{DC} + 2\underbrace{\left|\sum_{n=M} B_{1,n}^+\right|\left|B_{1,c}^+\right|}_{AC}\cos(\phi_{N\to c} + \phi_e) \text{ with } M \neq c \quad [3]$$

Method: The relative B_1^+ value was extracted from the data using the Fourier series. It is readily seen that decomposition of equation 4 in these series results in the DC and AC component being the a_0 and a_1 Fourier coefficient, respectively. From these coefficients we can calculate the relative B_1^+. This relative value is weighted using the earlier obtained absolute HF B_1^+ map steered in quadrature mode, to obtain the absolute B_1^+ map per channel. This algorithm was tested using a 7T (Achieva, Philips Medical Systems, Best, the Netherlands) scanner. *In vivo* measurements were performed using a high-pass birdcage with two ports. In each GRE measurement (FA = 10deg, TR = 50ms, t = 90s) the phase of 1 port was fixed and one was modulated between 0^0 and 360^o in 20 steps. For each separate port and for quadrature steering a HF B1+ map (t = 300s) [1] was obtained.

Results: In figure 2A the HF B_1^+ map in quadrature mode is shown. In 2B and 2D the relative B_1^+ amplitudes of the two ports are shown, which are based on HF and PMLF measurements respectively. In figure 2C and 2D an FDTD simulated and PMLF measured B_1^+ map respectively are shown. This demonstrates that the pattern is similar; although an error is seen in the ventricles. This can be caused by long T1 of CSF, which prevents the spins to reach the steady state before the measurement starts.

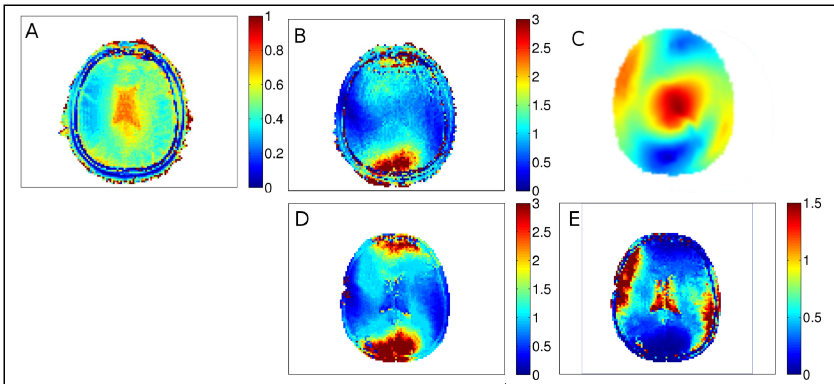

Figure 2: 2 channel high-pass head coil. A) HF B_1^+ map for quadrature excitation. B) Relative B_1^+ based on HF B_1^+ map. C) FDTD simulated B_1^+ field for one port. D) Relative B_1^+ based on PMLF GRE images. E) PMLF B_1^+ map of one port based on 2A and 2D.

Discussion and conclusion: We showed a new technique to measure the B1+ field fast and at low SAR cost, which was validated by FDTD simulations and HF B_1^+ measurements. This method does not require assumptions on the symmetry between B1+ and B1- as is needed in similar low flip angle methods [3]. The shown technique can be expanded to measure the individual B_1^+ maps of N-coil arrays. Especially for larger arrays, its speed will be an advantage. A disadvantage of the technique can be the lack of interference between the fixed and modulated channels at distant locations from the phase modulated coil. By working with other coil interference sets (e.g. phase modulating more coils simultaneously), the interference amplitude can be improved, which will improve the B1+ measurement [1].

[1] Brunner et *al.* MRM (2009) 61:1480-1488
[2] Yarnikh, MRM (2007) 57:192-200
[3] Van de Moortele, Proc. ISMRM (2009) 367