A multiple element probe and sequential pulse sequence for ultra high field imaging - an improvement in B_1 homogeneity

A. W. Magill[1], B. Wilton[1], A. Jones[1], D. McKirdy[2], P. Glover[1]
[1]Sir Peter Mansfield Magnetic Resonance Centre, Nottingham University, Nottingham, United Kingdom, [2]George Green Institute for Electromagnetic Research, Nottingham University, Nottingham, United Kingdom

Introduction

At high frequency (>128MHz), conventional volume coils produce inhomogeneous B_1 fields inside the human head (1). Improvements may be made by RF shimming (2,3) but multiple coherent current sources will always produce interference as length scales approach a wavelength. To overcome this difficulty we present an alternative strategy using multiple strip-line transmit/receive elements, excited in sequence rather than simultaneously. The B_1 field produced by a conventional volume coil can be considered as the superposition of the fields generated by each coil element. At high frequencies, these fields will have a significant phase shift across the VOI, leading to interference when they are superimposed. We propose using a BURST style sequence (4) to excite coil elements in sequence (figure 1) to generate a net 90° pulse. We are then able to separate signals due to excitation by different coil elements within the same slice (i.e. without interference). Received signals can then be combined using a well developed parallel reconstruction method such as SENSE (5), to maintain SNR for a same acquisition time. This sequence requires only one RF transmit channel and power amplifier, which can be switched between coil elements using a demultiplexer (figure 2). This leads to a more cost effective method than parallel transmit approaches, which require multiple RF power amplifiers.

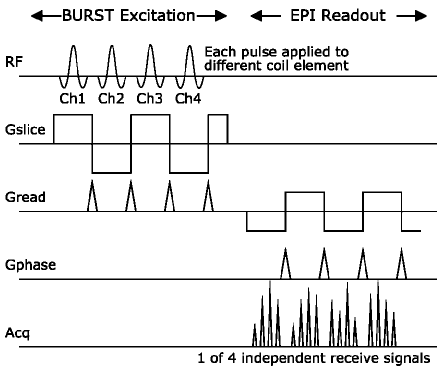

Figure 1: Pulse sequence

Methods

In order to justify the proposed method, both simulations and experiments have been carried out. The Transmission Line Matrix (TLM) method (6) was used to simulate the B_1 fields generated in the HUGO head model. A four strip element coil was simulated, each element driven by a 300MHz current source at its centre. Simulations were run to generate rotating B_1^+ field maps produced by each element. These spatial maps of amplitude and phase were then incorporated into a Bloch simulation of the proposed sequence and used to generate final simulated images. The proposed imaging sequence has been implemented on a 3T scanner using a TEM volume coil in order to justify the approach.

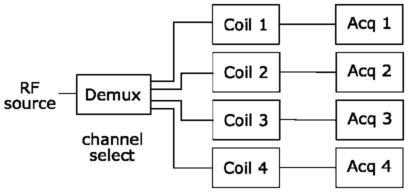

Figure 2: RF demultiplexer. One RF amplifier is used to drive multiple coil elements in sequence.

Results

Figure 3 shows the B_1^+ field generated by (a) a single coil element, (b) combining these fields in quadrature, showing clear interference effects expected from volume probes and (c) combining the magnitude of individual B_1^+ fields. By ignoring the effect of phase, a more uniform B_1^+ field is produced, reducing the standard deviation over this slice from 62% to 34%.

Figure 4 (a) and (b) show the results from the Bloch simulation of a spherical tissue-like phantom ($\varepsilon_r = 78$, $\sigma = 0.5$ S/m). Figure 4(a) shows a simulated EPI sequence, generated by transmitting and receiving with all coil elements in parallel, showing a clear central brightening. Figure 4(b) shows a simulated image generated using the new sequence. Both images used the signal received by all four strip-line elements, reconstructed using sum-of-squares. The second image shows a clear improvement in uniformity with no central brightening. Figure 4(c) shows a phantom image acquired on a 3T system using a TEM coil.

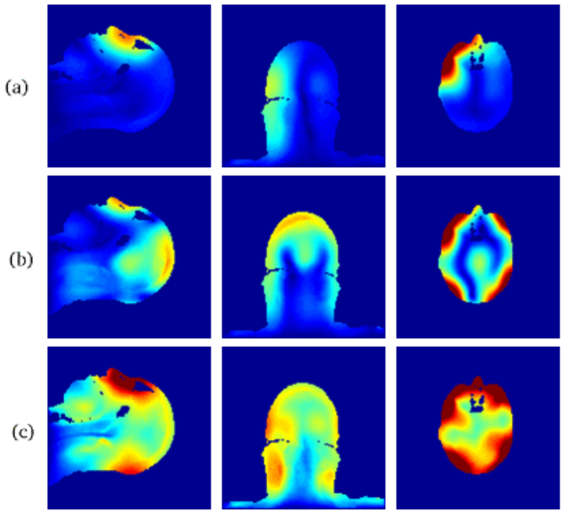

Figure 3: Simulated B_1^+ field generated in the head by (a) a single stripline element, (b) combining fields in quadrature and (c) combining field magnitudes without phase.

Discussion

Using a BURST style sequence allows excitation of the sample from each coil element individually, with no additional time penalty. The BURST sequence also gives a more uniform overall excitation at high field. A more uniform or reduced SAR is also predicted. Following excitation, any GE readout sequence can be used, such as EPI. This does mean that 180º pulses are not possible. However, the main application will be in gradient echo fMRI at 7T, so this is not seen as an overall disadvantage.

Bloch simulation results show a clear improvement in image homogeneity at 7T. The strong Nyquist ghosting artifact seen in both images is a product of the simulation, rather than the imaging method. Images acquired on the 3T scanner demonstrate that it is possible to acquire multiple images using this imaging sequence.

These initial results suggest this approach is feasible at 7T, and could offer significant improvements in B_1 homogeneity. A four element head coil and RF demultiplexer are now being assembled ready for the arrival of the 7T scanner.

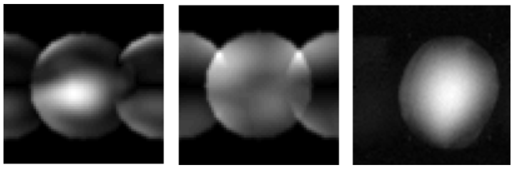

Figure 4:(a) simulated EPI image at 7T (b) simulated image generated by the new sequence at 7T and (c) image acquired on a 3T scanner using a TEM coil

References

1) Collins CM, et al [2003] ISMRM 11:2391
2) Ibrahim TS, et al, [2001] MRI 19:1339-1347
3) Ledden P [2003] ISMRM 11:2390
4) Hennig J, Hodapp M [1993] MAGMA 1:39-48
5) Pruessmann K, et al [1999] MRM 42:952:962
6) Christopoulos, C [1995] Transmission-Line Modeling Method, IEEE Press