A Close-Fitting 7 Tesla 8 Channel Transmit/Receive Helmet Array with Dodecahedral Symmetry and B1 Variation Along Z

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Introduction: MR systems for whole-body at 3T and for body or head imaging at fields of 7T or higher suffer from significant B_1^+ inhomogeneity when conventional birdcage-like volume coils are used for excitation. Through the use of transmit arrays, and techniques such as RF shimming[1] or accelerated spatially tailored RF pulses[2,3], it is possible to mitigate high field B_1^+ inhomogeneity, or indeed to prescribe almost any pattern of excitation that is desired. For full control of the excitation profile through the volume of the head it is necessary to have transmit element profiles which vary along the Z-direction, as well as in the axial plane. With most multichannel transmit systems having only 8 separate channels it is a challenge to arrange coils such that there is good brain coverage and variation along the Z direction. While many transmit array designs are built on large cylindrical formers which keep the coil elements a significant distance away from the subject, in part motivated by the desire to avoid creating SAR hotspots, such designs can not be expected to have comparable receive sensitivity compared to a close fitting receive array. It is possible to create a large detunable transmit array and place inside of it a close-fitting receive array, but this entails a high degree of complexity. We propose a design with 8 loop elements tightly coupled to the head, good decoupling between elements during transmit, B_1^+ variation along Z, and good receive sensitivity with whole-brain coverage.

Methods: The coil array was tested on a prototype 7T scanner (Siemens Medical Solutions, Erlangen Germany) with 32 receive channels and 8 transmit channels, but only a single TX channel system was used to perform these initial experiments. The coil was constructed from 12.5mm thick Teflon, cut into regular pentagons with beveled edges (Fig. 1). The outer edges of the pentagon sections were 95mm long, and the inner edges inside the structure, where the antenna conductors were placed, were 85mm long. The antenna structure was formed with 6mm wide adhesive copper tape (3M, St. Paul MN), and consists of capacitively decoupled loops whose conductors trace out the edges of 8 of the 12 pentagonal faces of a dodecahedron (Fig 2). To provide greater distributed capacitance and allow for a tuning capacitor in each loop, the conductors "cut the corners" and form a slightly truncated pentagon, with a capacitor in each corner position. Fixed capacitors of 10pF were used throughout, except in the decoupling and tuning positions where a high voltage variable capacitor (Tronser, Engelsbrand Germany) was used. Neighboring loops are capacitively decoupled by having an adjustable capacitor in each shared edge. A lattice balun is attached to a free edge to match the elements to 50 Ohms. There is a complete ring of 5 coils around the top of the head, and three more in a lower row around the back of the head. For testing as a conventional receive coil, and for assessment of B_1^+ transmit profiles of the individual elements using a separate detunable T/R loop coil, diodes were added to the lattice baluns to provide detuning. Cable length was chosen to provide preamp decoupling when the coils were in receive mode. Tuning, match and decoupling of neighboring elements was optimized on the bench with a human head and assessed with a network analyzer (HP 8712ES). The B1 transmit profiles of the individual elements were assessed by using a separate detunable T/R loop coil with 14cm diameter mounted on a 17cm spherical loading water phantom inside the T/R array. The full transmit and receive profiles of this separate coil were determined from a series of scans stepping through various RF pulse voltages. The B_1^+ transmit profiles of the individual elements were determined by transmitting on one element at a time, while all the other elements were terminated with a 50 Ohm load, while receiving the signal with the separate T/R loop coil. The receive sensitivity of the T/R array was determined by placing the T/R array in a detunable birdcage transmit coil and using it in a standard receive array configuration. SNR was compared to an in-house built 8 channel wrap around array with 85mm diameter elements [4] and to the SNR of the 28cm birdcage coil in T/R mode. SNR comparisons were made using gradient echo images (TR/TE/flip/slice = 30ms/6ms/10deg/3mm, 384x384, FoV=200x200mm) obtained in human scans.

Results:

S12 coupling between neighboring elements, measured with a head load and with all other coils tuned and terminated with 50 Ohms, ranged from -13.3 to -25dB and averaged -16.9dB. S12 coupling between non-adjacent coils averaged -16.4dB. S11 match for a human head load was -15dB or better for each element for several different subject heads.

B_1^+ transmit profiles for the individual elements are shown in Fig. 3. Because of the presence of a null in the receive profile of the T/R loop used to receive the image data, B1 information was lost in the center of the phantom and this area is masked in gray. The B_1^+ transmit efficiency of this coil was compared to an array of stripline elements arranged on a 28cm cylinder, and the closely coupled loop coils in the dodecahedral coil were found to produce approximately twice the B_1^+ field per volt. When used as a conventional detunable receive array, the coil shows good brain coverage, with peak SNR significantly lower than the most sensitive regions of the wrap-around 8 channel coil, but with much better homogeneity through the brain (Fig. 4).

Conclusions: Before this T/R array is used for transmit and receive on a human subject it will be necessary to understand the SAR characteristics of the coil and establish safe limits. The double row of coils offers variation in Z, which should offer better control of the full excitation profile throughout the head compared to designs with a single row of coils. The transmit efficiency, receive sensitivity and brain coverage offer the possibility of using a single coil for both B1 control through parallel transmission techniques and high sensitivity in receive, simplifying the equipment needed for high field brain imaging.

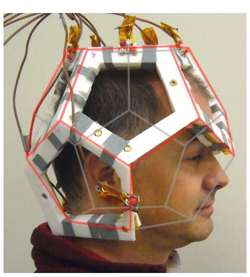

Fig. 1 T/R Array with super-imposed sketch in red and gray showing dodecahedral structure

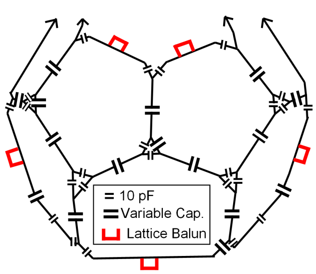

Fig. 2. Electrical design of antenna, showing 5 loops which form the back of the helmet.

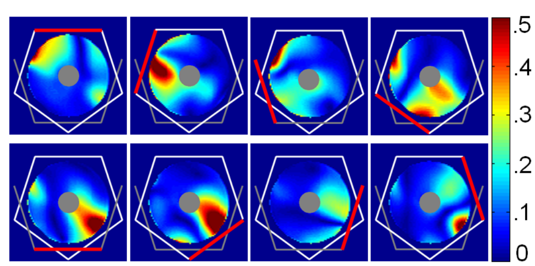

Fig. 3. B_1^+ transmit profiles (Arb. Units) for the individual elements in an axial plane at isocenter. The active coil is shown in red, five coils at the top of the helmet are represented in white and the three lower coils in gray. The central region is masked in gray because of the presence of a null in the receive profile of the separate T/R loop used to receive the images.

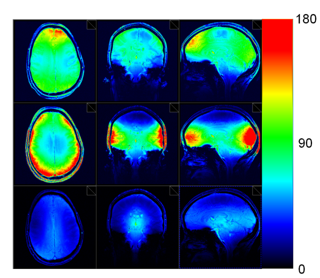

Fig. 4. SNR Maps for Birdcage TX, Array Rx. Top row: Dodecahedral Coil, Middle: 8 Ch Wrap-around Array, Bottom: 28cm Tx Birdcage in T/R mode

[1] Adriany G, et.al. Magn. Reson Med. 2005 **53** (2) p434-45 [2] Katscher U et.al. Magn. Reson Med. 2003 **49** (1) p144-50 [3] Zhu Y et.al. Magn. Reson Med. 2004 **51** 42) p775-84 [4] Wiggins G, et.al. Magn. Reson. Med, 2005 **54** p.235-240