A Degenerate Birdcage Coil for Parallel Excitation

V. Alagappan[1], J. Nistler[2], E. Adalsteinsson[3], K. Setsompop[3], U. Fontius[2], A. Zelinski[3], M. Vester[2], G. Wiggins[4], F. Hebrank[5], W. Renz[2], F. Schmitt[2], and L. Wald[4]

[1]Athinoula A. Martinos Center for Biomedical Imaging, MGH, Charlestown, MA, United States, [2]Siemens Medical Solutions, Erlangen, Germany, [3]Massachusetts Institute
Technology, Cambridge, MA, United States, [4]Athinoula A. Martinos Center for Biomedical Imaging, MGH, charlestown, MA, United States, [5]Siemens Medical Solutions,
Charlestown, MA, United States

Introduction:

The many positive benefits of high field MRI are accompanied by destructive interference of the transmit RF fields within a typical volume excitation coil[1]. This effect arises when the wavelength of the electromagnetic fields in the body approaches the dimension of the human head or body. It has been shown that 2D and 3D spatially tailored excitation pulses can be designed to provide an arbitrary spatial pattern to the amplitude and phase of the transverse magnetization, subject to gradient performance and RF power constraints. Thus, if the B_1 map of the excitation coil is known, a compensating excitation pattern can be designed that results in a uniform transverse magnetization after the excitation. The principle practical limitation of this method is the RF pulse length of the 2D or 3D excitation pulse. By using a multi-channel transmit coil, the differing spatial B_1 patterns of each coil can be used to accelerate the excitation *k*-space trajectory[2, 3]. In this work we evaluate the use of the varying spatial modes of a Degenerate Birdcage Coil (DBC) for parallel excitation using either the eight "loop mode" basis set, or the orthogonal birdcage modes as driven by a Butler matrix.

Methods:

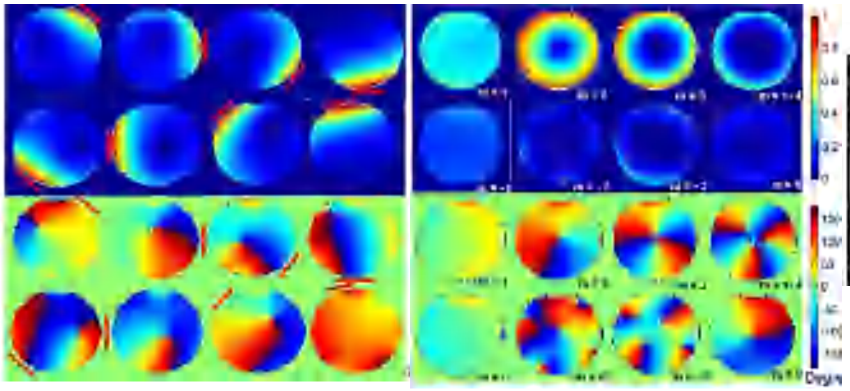
The coil was tested on a prototype 3T MAGNETOM Trio, A Tim System (Siemens Medical Solutions, Erlangen, Germany) with 8 independent transmit channels. All the modes of a birdcage coil were made to resonate at the same frequency (123.25 MHz) by varying the ratio of the capacitance on the end ring to that of the rung. Fig 1 shows the constructed coil with the Butler matrix and the S parameter matrix. The "loop modes" were accessed by coupling into each independent loop in the birdcage structure. The orthogonal birdcage modes were tapped by exciting the rungs with the phase relationship corresponding to that mode. This was done using a 8x8 Butler matrix[4], which has 8 coaxial inputs and outputs and constructed from 90 degree hybrids and phase shifters. A signal at any of the input ports produces equal amplitudes at all the output ports and a linear phase progression from port to port. The phase increment depends on which input port is used. So in a 8 rung birdcage coil all the 8 modes (the 3 CP modes (+1,+2,+3), 3 anti-CP modes (-1,-2,-3), 1 linear mode(4) and 1 coaxial mode(0)) could be excited simultaneously using the Butler matrix. The excitation B1 amplitude and phase profiles of the various modes were measured by exciting the modes one at a time using a low flip GRE sequence and receiving with the homogenous RF body coil. Figure 2 shows the B1 profiles excitation for the DBC coil in both the configurations.

Fig 1: The constructed DBC coil and Butler matrix

These B1 profiles were used to design 2D and 3D spatially tailored RF pulses[5]. In theory the anti CP mode and coaxial mode do not excite any spins, but due to the loading and other imperfections in the coil, they were found to produce some excitations. A 4X accelerated spatial pattern was excited on a 17cm dia oil phantom in two different coil configurations. In the first case parallel excitation was done with the 4 alternate loops of the DBC coil, while in the second configurations only the 4 orthogonal bright modes (3 CP modes and 1 linear modes) were used with 4 independent transmit channels.

Results & Conclusion:

The coil was tuned to degeneracy with average S_{12} coupling between the loop basis set of -20.17 dB and average decoupling between the orthogonal BC modes of -34.8 dB. When all eight modes were used for parallel TX, 4 and 6 fold accelerated patterns had similar artifact burdens for the two basis sets. If a reduced number of TX channels were used, the 4 "brightest" modes of the orthogonal basis set were found to produce fewer artifacts when compared to the 4 loops excitation. Fig 3 compares the excitation obtained by transmitting with the 4 loops of the DBC coil (12, 3, 6, and 9 o'clock positions) with that of the 4 bright modes. The correlation factor between the target profile and the obtained profile in the case of the loop array was 91.68% and that with the orthogonal birdcage array was 95.24%. In addition to being naturally orthogonal, the birdcage modes have a convenient spatial B_1 magnitude patterns. The lowest mode is uniform in the long wavelength regime and thus is expected to have a good B1 efficiency in the center. The higher order modes have center magnitude nulls and azimuthal phase variation.



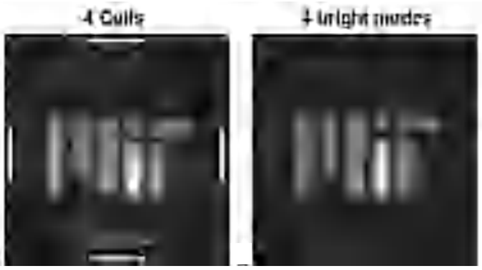


Fig 3: 4x accelerated 2D RF excitation with the 4 loop coils and the 4 bright modes

Fig 2: The excitation amplitude (B1) and phase of the loop coils basis set and the birdcage modes of the DBC

1. Collins, C.M., et al., *Central brightening due to constructive interference with, without, and despite dielectric resonance.* JMRI, 2005. **21**(2): p. 192-6.
2. Katscher, U., et al., *Transmit SENSE.* Magn Reson Med, 2003. **49**(1): p. 144-50.
3. Zhu, Y., *Parallel excitation with an array of transmit coils.* Magn Reson Med, 2004. **51**(4): p. 775-84.
4. Butler J and Lowe R, *Beamforming matrix simplifies design of electronically scanned antennas.* Electron. Design, , 1961. **9**: p. 170 -173.
5. Setsompop, K., et al., *Parallel RF Transmission with Eight Channels at 3 Tesla.* Magn Reson Med, 2006. **56**(5): p. 1163-1171.

Acknowledgement: Funding support from P41RR14075 and the MIND institute, Siemens Medical Solutions, Erlangen, Germany.