A Simplified 16-channel Butler Matrix for Parallel Excitation with the Birdcage Modes at 7T.

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Introduction: Multi-channel transmit/receive coils can overcome B_1^+ inhomogeniety caused by high field wavelength effects. Given the high cost of additional transmit channels, it is critical to use them effectively. Arrays formed from the orthogonal modes of a Degenerate Birdcage Coil (DBC) have been shown to have beneficial properties (1,2). In order to access these modes simultaneously, a Butler matrix (3) is used to drive the individual rungs of the DBC in linear combinations to form the well know uniform birdcage mode as well as higher gradient modes. An important practical benefit is access to a near uniform mode in one channel (enabling e.g. a "prescan" in effectively a single-channel TX configuration). Although the two basis sets of equal number of modes should have identical performance when viewed in their entirety, a linear combination which distributes these attributes unequally among the modes is advantageous when modes are omitted based on their contribution to sensitivity and encoding. While the individual rung modes are identical up to a rotation, the orthogonal modes of the DBC are very heterogeneous (with both Circularly Polarized (CP) and Anti-CP (ACP) modes) suggesting they are more amenable to mode compression. To achieve these goals, robust, high power, inexpensive, Butler matrices must be constructed. In this work we develop and test a simplified 16-channel high-power Butler matrix at 300 MHz. Unlike the conventional design, this device can be easily reconfigured into two 8x8 Butler matrices.

Methods and Construction: The Butler matrix (Fig. 1) is the analog of the Fast Fourier Transform (FFT) algorithm. It can also be thought of as a generalization of a quadrature hybrid. 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 the input port used. If *m* indexes the input port (connected to the power amplifier) and *i* indexes the output ports (connected to the coils), The RF signal voltage (S_i) driving a coil rung is related to the input waveforms (amplitude A_m and phase Φ_m) by Eq. 1. The phase shifters were determined with simulation (Advanced Design Systems, Agilent Tech.) and implemented with 50Ω semi rigid coaxial cables. The Butler matrix was formed by these phase shifters together with stripline based quad-hybrids rated for 420W continuous power (1Z0263-3, Anaren Microwave).

The 16 BC modes produced include seven CP modes (m = 1 to 7) seven anti-ACP modes (m = 9 to 15), mode m= 16 which is the in-phase, or coaxial mode with no phase variation between the rungs and finally mode m=8 the linear mode with a π phase shift between adjacent rungs. In theory, only modes 1-8 have efficient excitation capability (i.e. correct CP). The Butler matrix and coil was tested in phantom and human imaging using a 7T prototype system with 8 transmit channels (Siemens Medical Solutions, Erlangen).

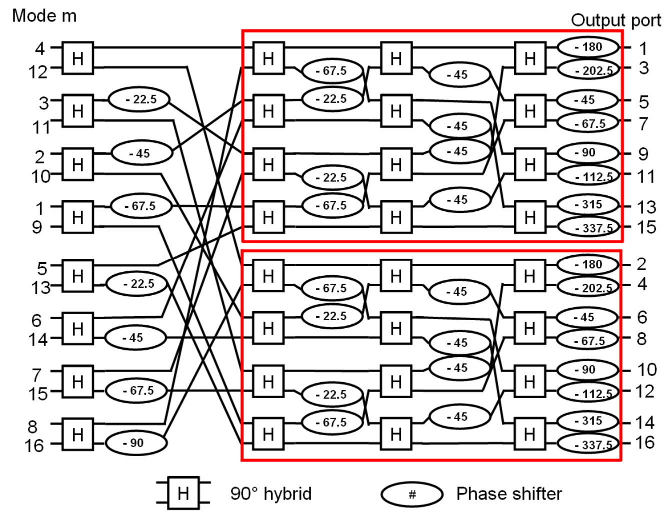

Fig 1: Schematics of a 16-channel high-power Butler Matrix. The red box shows the two independent 8x8 butler matrices.

Results & Conclusion: Like the quadrature hybrid where a reflected wave is cancelled if the mismatched load is symmetric, the Butler matrix has been found to provide reflection coefficients that are insensitive to the load. The 16-channel Butler matrix had an average phase error of ± 5° and an amplitude error of ±0.5 dB. Fig 2 shows the constructed coil and the Butler matrix. Fig. 3 shows the excitation profiles on a spherical oil phantom and water phantom using the Butler matrix and a 16-element cylindrical stripline array (Fig. 3). The ACP modes do not excite any spins in the oil phantom. In the water phantom, however, the deviations in polarization (4) allow excitation by the ACP modes. Fig 4 shows the B_1^+ profiles of the 8 modes with highest excitation efficiency on a human head.

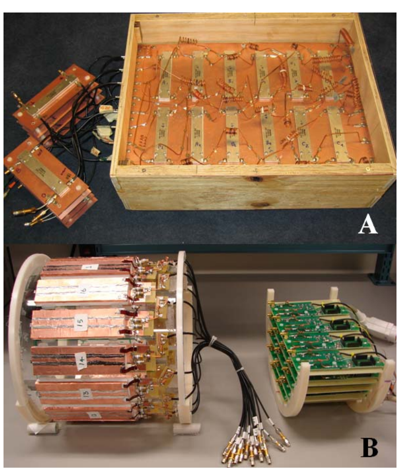

Fig 2: A) The two 8x8 Butler matrices with the interface to drive them as a single 16x16 butler matrix, B) 16 channel T/R stripline array coil.

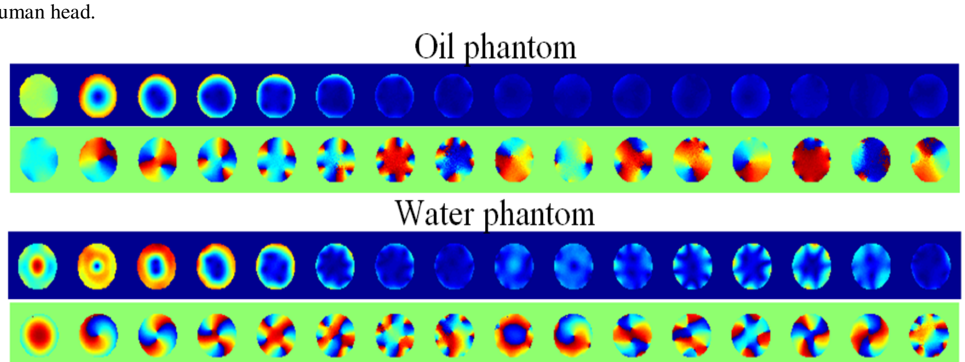

Fig 3: The B1+ mag and phase maps on a spherical oil and water phantom

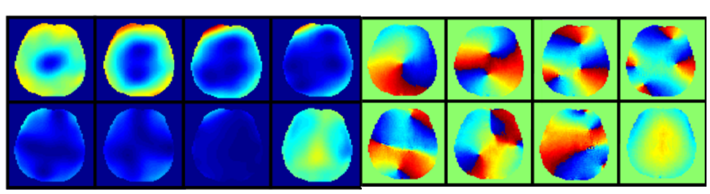

Fig 4: The B_1^+ profiles, Mag and Phase of the optimal 8 modes on a human head.

References: 1) Vester M et al ISMRM 2006, P 2024 2) Alagappan V et al, MRM 2007 57(6), P 1148, 3) Butler J et al, Electron Design (9) 1961 p 170 4) Ibrahim et al High field workshop 2007, Asilomar.