Mode Compression of Transmit and Receive Arrays for Parallel Imaging at 7T

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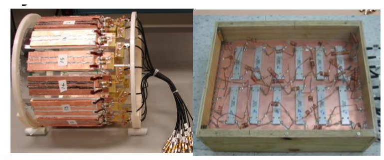
Introduction: While increasing the number of array elements appears beneficial for both parallel transmission and reception, this approach is limited in practice, especially in the parallel transmit (pTX) case. Forming linear combinations of array elements can transform the spatial modes of the array into a different basis set, potentially capturing a majority of the sensitivity (1) and acceleration capabilities in a valuable subset of the channels. We develop a mode transformation of a 16 element 7T T/R strip-line array and analyze both the Strip-Line (SL) and orthogonal BirdCage mode (BC) basis sets when truncated from 16 modes to 8. We compare the covariance matrix of the transmit profiles and the Rx g-factor maps, and evaluate the strategy in pTX experiments for flip angle inhomogeneity mitigation. The compressed BC basis set was found to reduce the mean signal covariance among the B_1 profiles compared to the SL basis set. In pTX, the BC modes achieved improved flip angle uniformity at a lower input power. In parallel receive, the truncated BC modes achieved a higher SNR and better g-factor for high acceleration.

Methods: The experiments were performed on a prototype Siemens 7T system equipped with 8 transmit and 32 receive channels. A 16ch SL array coil (length 15cm, dia. 28cm) was constructed with a strip width of 2.54cm, shield width 5cm, and 1.3cm of Teflon spacing. Adjacent elements were capacitively decoupled. The 16 channel coil could be driven by the 8 independent TX channels in either of two modes. The SL basis set was formed by directly exciting every other element of the 16ch coil. The BC set was formed by combining the coil elements using a 16x16 Butler matrix (2). The Butler matrix distributes the power to the different coils with the appropriate phase to excite the modes associated with a birdcage coil (3). The 16 BC modes include seven Circularly Polarized (CP) modes (m = 1 to 7) seven Anti-Circularly Polarized (ACP) modes (m = 9 to 15), a coaxial mode (m= 16), and a linear mode (m=8). In theory, only modes 1-8 have efficient excitation capability (correct CP).

The B_1^+ and B_1^- mode profiles were obtained by imaging using separate channels with multiple excitation voltages and using the theoretical relationship between signal and transmit voltage for gradient echo images. The B_1^+ profiles were used to design 3D spatially-tailored, slice-selective RF pulses (4) producing a spatially uniform excitation with an echo-volumar trajectory with only two "spokes" in *kx-ky* plane. The B_1^- profiles were taken by transmitting with the uniform BC mode, receiving with all channels then dividing by the fitted B_1^+ profile.

The signal covariance matrix was calculated for the two basis sets from the spatial B_1^+ maps. This is similar to the noise covariance but it is performed on the signal data to reveal the spatial orthogonality of the basis sets. The 8 BC modes with the highest covariance (transmit or receive efficiency) were used. For the SL array, each element had the same (covariance) energy, and thus every other element was used in the 8ch case. The mean of the off-diagonal elements of the covariance estimates the orthogonality of the modes.



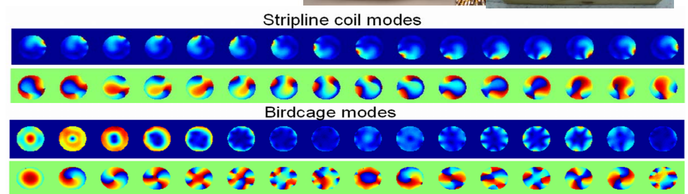


Fig 1: The constructed 16 channel stripline array coil, 16x16 Butler matrix and the fitted B_1^+ maps in a spherical saline phantom.

Results & Conclusion: The S_{12} coupling between adjacent elements of the SL array coil was -18 dB and that between the next nearest neighbor was -12 dB. Figure 1 shows the constructed coil, Butler matrix, and the fitted B_1^+ profiles for both the basis sets. Fig 2 shows the 16x16 B_1^+ covariance matrices. The compressed BC basis was found to reduce the mean off-diagonal value of the correlation matrix by 32%. Figure 3 shows the measured excitation profile for the BC and SL basis sets using a Tikhonov regularization parameter β=0.02. The SD as percent of mean in the flip angle map reduced from 6.5% to 3.9% using the truncated BC modes. Figure 4 shows the plot of the experimental RMS error in excitation against the L2-norm (pulse voltage) at measured for pulses designed with different β. On average, the error in the profile achieved with the BC basis was reduced by 42.46% with a 16.57% lower voltage compared to the SL basis. Figure 5 plots the maximum g-factors against acceleration rate (R) for the truncated BC basis and the truncated SL basis set. The compressed BC basis set provided lower g-factors for high acceleration rates. Fig 6 shows the mean SNR of the optimal SNR combination in the phantom computed from the B_1^- profiles and noise correlation as a function of the number of receive channels used. As expected, if all modes are kept, the two basis sets are equivalent. If the array is truncated to fewer than 12 channels there is a significant SNR benefit to the BC basis set.

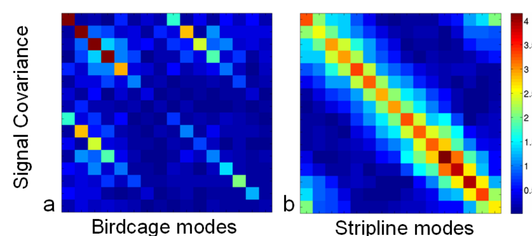


Fig 2: The B_1^+ covariance matrices.

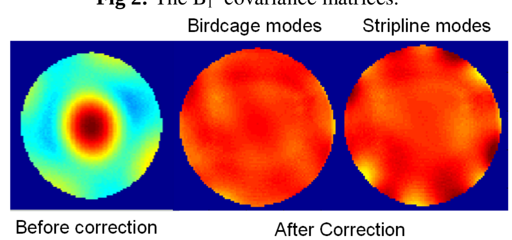


Fig 3: TX maps for two-spoke excitation. Standard deviation across the phantom, $\sigma_{uncorr} = 28.3\%$, $\sigma_{SL} = 6.5\%$, $\sigma_{BC} = 3.9\%$

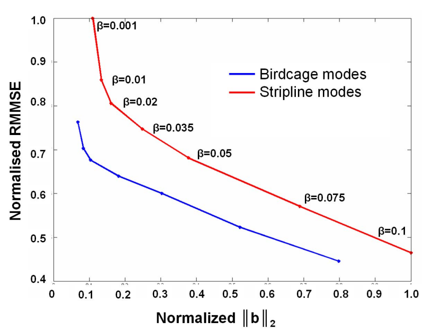


Fig 4: Regularization curves, RMS error against the L2 norm of the pulse.

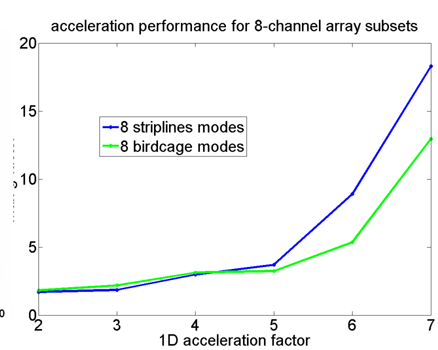


Fig 5: Maximum g-factor for R=2 to 7.

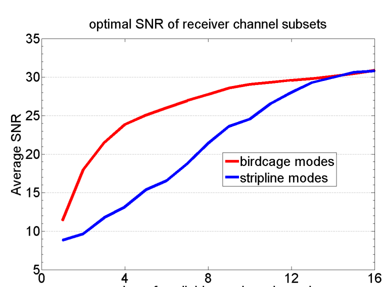


Fig. 6: Average cumulative SNR as a function of receive channels.

References : (1) King et al Concepts in MR 2006 29B(1) 42. (2) Butler et al 1961 Electron design 9 p 170. (3) Alagappan et al 2007, MRM 57 p1148. (4) Setsompop et al 2006 MRM 56 p 1163.