The Linear EIGENCOIL®

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Introduction

In recent years, the need for higher SNR over large FOV has driven the development of MRI systems with 8 and more receiver channels. Furthermore, the use of parallel imaging techniques has greatly increased the demand for multiple coil elements and system channels. However, such multiple channel systems are not always available, therefore optimal use of existing channels is beneficial. For this purpose, the EIGENCOIL® was presented [1], where the optimal SNR of an 8-channel coil is achieved in as few as 3 receiver channels. In that case channel reduction is possible mainly due to the circular symmetry of the coil element system. This work explores the behavior of the well-known planar linear array and its eigenmodes, and investigates the opportunity for reduction of channel number in the case of planar arrays.

Theory/Methods

The principle of eigenmodes for the linear phased array may be understood by first looking at the simple case of two adjacent loops with a shared conductor. It is well known that this coil system may be excited by either driving the two loops, or alternatively, by driving the external loop and butterfly modes. This concept may be extended for a higher number of loops, as shown in Figure 1 for 4 loops. The shaded lines represent the linear phased array elements, and the 4 eigenmodes are: (a) large loop – obtained by co-rotating currents in all elements (eigenvector is $V_1 =[1\ 1\ 1\ 1]$), (b) butterfly mode – obtained by 2 pairs of co-rotating currents, where the pairs are opposite to each other (eigenvector is $V_2 = [1\ 1\ {-1}\ {-1}]$), (c) triple butterfly, where $V_3 = [-1\ 1\ 1\ {-1}]$, and (d) quadruple butterfly, where $V_4 = [-1\ 1\ {-1}\ 1]$. Exciting these eigenmodes is not necessarily easy or practical. However, obtaining these modes by proper combination of the original signals of the individual loops is a straightforward operation, once the eigenmodes are known. For mathematical accuracy it should be added that these are approximate eigenmodes of the system. The true eigenmodes are slightly different, but for practical purposes this will be ignored. The experiment was performed using the MRI Devices 4 channel linear EIGENCOIL® consisting of a 4-element linear array and the eigen combiner, which generates the 4 eigenmodes of the coil system. Phantom images were acquired on the GE Excite 1.5T scanner at the Health Central Hospital, Ocoee FL. The array was positioned along both S-I (sagittal image) and L-R (axial image) directions.

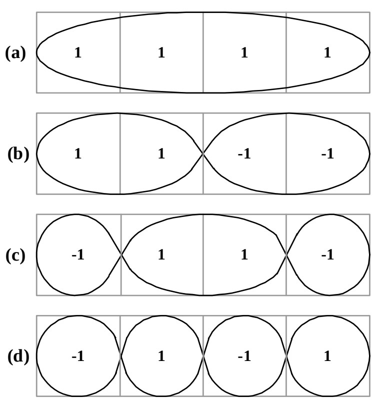

Figure 1. The eigenmodes of the 4 elements linear array

Results

Figure 2 shows phantom images of the original 4 elements (top row), and those of the 4 eigenmodes obtain by the eigen combiner (center and bottom rows). Also shown are sum-of-squares SNR values for each case (right column). The dark stripes in the eigenmodes images of the center row (array in the S-I direction) occur because the different butterfly modes have field components in the z-axis, therefore they do not contribute any NMR signal. This clearly shows that the required modes were achieved by the combiner. The same modes in the L-R direction (bottom row) do not show the null areas because the horizontal field of the butterfly modes does generate NMR signal in this case. The right column (numbers in the boxes are average SNR) shows that equal or higher (optimal [2]) SNR is obtained with the combiner. G-factor maps for SENSE reconstruction with x3 reduction are shown in Figure 3 (S-I direction), indicating that parallel imaging capability is improved with the eigen combiner vs. the original signals. This is a direct result of the distinguishable profiles of the eigenmodes as shown in the center row of Figure 2.

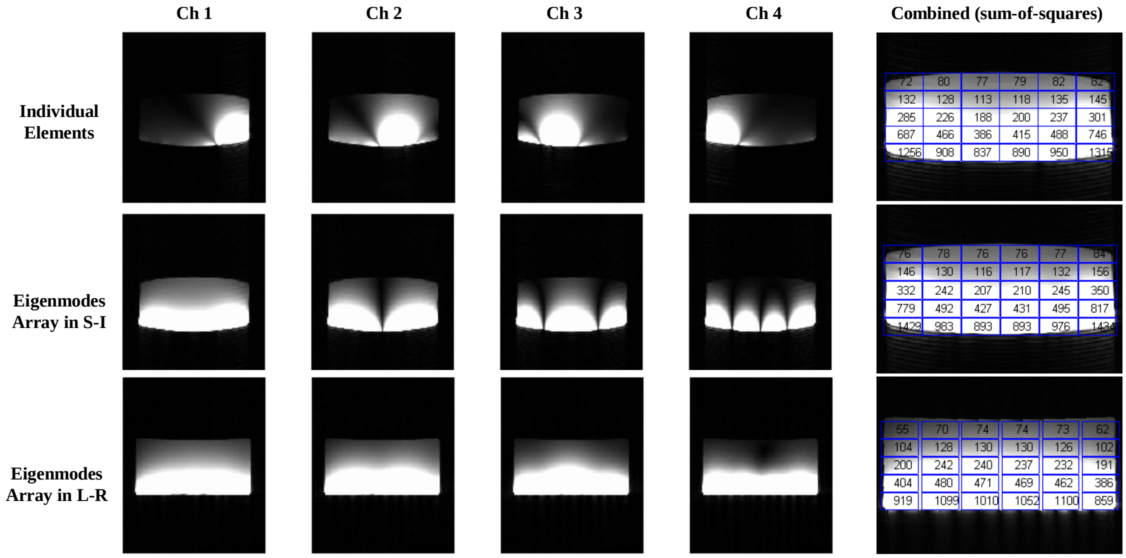

Figure 2. Phantom images of individual elements, eigenmode channels, and sum-of-squares SNR

Discussion

The lower eigenmodes – the uniform mode (ch1) and the first butterfly mode (ch2) – are orthogonal, therefore candidates for a quad combination. In addition, the highest eigenmode (ch4) has relatively poor penetration. This allows for the reduction of the number of receiving channels from 4 to 2 by quad combining channels 1 and 2 after the eigen combiner, and simply eliminating channel 4. The SNR of the resultant 2-channels reconstruction (sum-of-squares) is shown in Figure 4. The SNR in the center at 15cm depth (top of phantom) is almost not changed, which makes this channel reduction useful for applications such as spine and cardiac imaging, where specific areas are of interest. This concept of eigenmodes and channel reduction can be extrapolated to a larger number of linear elements and also to a 2 dimensional planar array, thus reducing data flow rates and computational time.

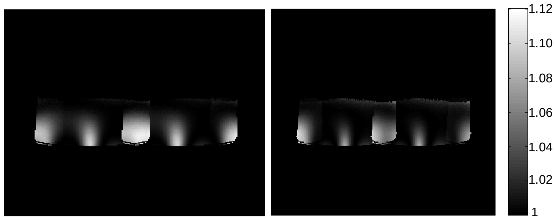

Figure 3. g-factor maps for R=3 without combiner (left) and with (right)

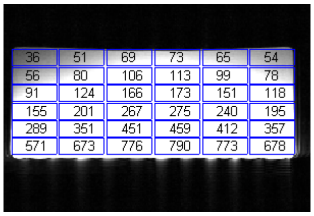

Figure 4. SNR of 2 ch. reconstruction

References

[1] King, S.B., et al. ISMRM Proc. p. 712, 2003.
[2] Roemer, P.B., et al., Mag Res Med 16:192-225, 1990.