A 24-channel quadrature surface coil array for high-resolution human temporal lobe fMRI at 3T

Pu-Yeh Wu[1], Ying-Hua Chu[1], Shang-Yueh Tsai[2], Wen-Jui Kuo[3], and Fa-Hsuan Lin[1]

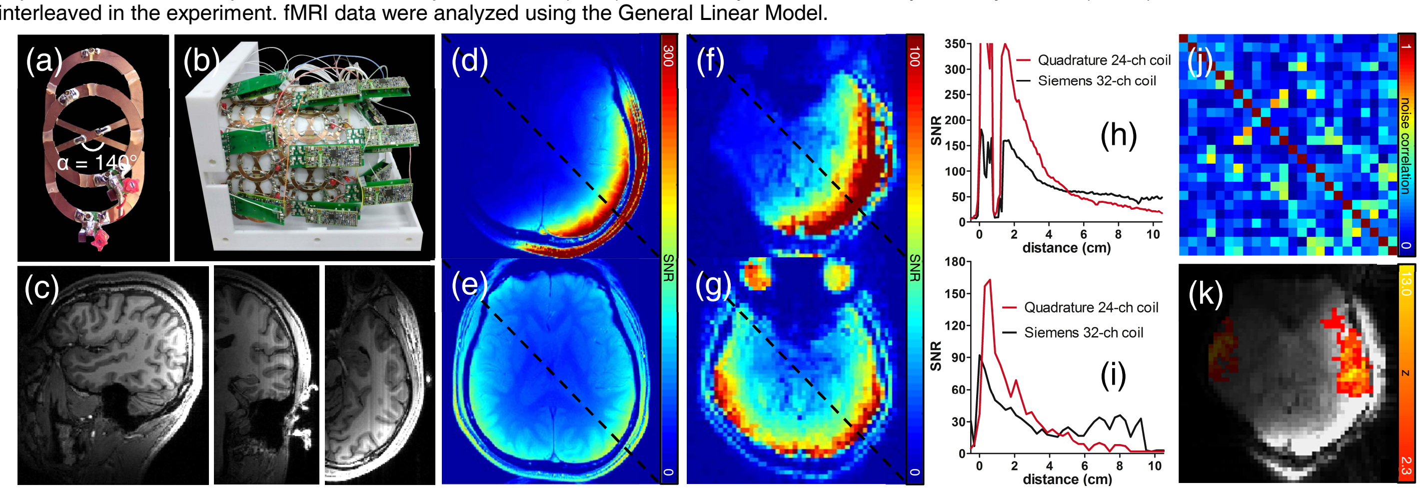
[1]*Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan,* [2]*Institute of Applied Physics, National Chengchi University, Taipei, Taiwan,* [3]*Institute of Neuroscience, National Yang Ming University, Taipei, Taiwan*

TARGET AUDIENCE: Scientists interested in quadrature surface coil design and high-resolution temporal lobe fMRI.

PURPOSE: A coil array with many small elements has been demonstrated to be an effective experimental setup to obtain high signal-to-noise ratio (SNR) images with large field-of-view (FoV) [1]. These advantages can also be traded-off for spatiotemporal resolution enhancement using parallel imaging methods [2]. While there have been head coil arrays using 32, 64, and 96 channels, they are all designed for the whole-head coverage. When interested in a specific anatomical region and limited by the number of RF channels in an MRI system, it is possible to tailor the array design, including the number, geometry, and locations of coils in the array, in order to achieve sufficient sensitivity depth and FOV. Quadrature MR receiver pairs comprised of elements with orthogonal RF magnetic field components and can provide high SNR NMR detection [3]. Here we developed a dedicated 24-channel coil array for human brain temporal lobe imaging. Specifically, we used 12 pairs of quadrature surface coil to optimize the SNR around the auditory cortex. Compared to a coil array consisting of loop coils, quadrature surface coil arrays can improve the SNR by 22%. Anatomical images acquired from our array show detailed brain structure of the temporal lobe. Compared to a 32-channel whole head coil array, our array shows SNR advantage at region no deeper than 5 cm from the scalp. Functional MRI experiment using our array shows strong hemodynamic responses at the auditory cortex elicited by music.

METHOD: A 24-channel quadrature coil array was designed for a 3T MR system (Skyra, Siemens). A quadrature coil pair consisted of a loop coil with 5 cm diameter and a figure-8 coil (Figure (a)). All loop coils and figure-8 coils were tuned to 123.25 MHz and connected to a low noise pre-amplifier (LNA) integrated with a mixer (Siemens, Erlangen, Germany) through a 3 cm coaxial cable and a matching circuit, which had a balanced circuit design and transformed the impedance to 50 Ω in order to obtain the lowest noise figure. An active detuning circuit was formed using a variable inductor and a PIN diode. The angle α (Figure (a)) in the figure-8 coil was experimentally tested and optimized to 140°. Twelve quadrature coil pairs were hexagonally arranged on a mechanical housing (Fortus, 400mc, Stratasys, Mn, USA) fitted to the shape of a human head (Figure (b)). To mutually decouple between neighboring coils in the array, coils were critically overlapped. The matching circuit transforming the LNA's input impedance to a serial high impedance at the coil loop provided further decoupling between coils.

Data were acquired on a 3T MRI (Skyra, Siemens). Structural images were measured with a MPRAGE pulse sequence (FoV: 256x256 mm^2, slice thickness: 1 mm, TR: 2530 ms, TE: 3.3 ms, Flip angle: 7^o). SNR maps were measured with a gradient echo (GRE) sequence (FoV: 178x178 mm^2, slice thickness: 5 mm, TR: 462 ms, TE: 10 ms, Flip angle: 25^o) and an EPI pulse sequence (FoV: 224x224 mm^2, slice thickness: 3.5 mm, TR: 2000 ms, TE: 30 ms, Flip angle: 90^o, 120 measurements). Oversampled data of GRE were used to calculate the noise correlation matrix between RF coils. In the fMRI experiment, music was presented to the subject for 30 s ("ON"), followed by 30 s without any auditory stimuli ("OFF"). Six "ON" and 6 "OFF" were interleaved in the experiment. fMRI data were analyzed using the General Linear Model.



RESULTS: Our quadrature coil pairs provides 22% improvement in SNR compared with a pair of circular loop coils (5 cm diamter; data not shown). The mutual coupling between adjacent RF coils was below -15 dB for all coils. LNAs brought additional -20 dB coupling between coils. The sagittal, coronal, and transverse structural images show detailed brain structure of the temporal lobe (Figure (c)). Figure (d) and (e) are SNR maps measured by the 24-channel quadrature coil array and the commercial 32-channel head coil array using a GRE pulse sequence, respectively. Figure (f) and (g) are SNR maps measured by an EPI pulse sequence. Comparing between SNR maps, relatively higher sensitivity around the temporal lobe was found in images acquired from the quadrature coil array. Figure (h) shows the SNR profiles through the black diagonal line of two SNR maps using a GRE pulse sequence. Overall, the average SNR of quadrature coil array is 70% better than the commercial 32-channel array within the 5 cm depth. Figure (i) shows the SNR profiles through the black diagonal line of two SNR maps using an EPI pulse sequence. Overall, the average SNR of quadrature coil array is 71% better than the commercial 32-channel array within the 5 cm depth. Figure (j) shows the noise correlation matrix: the average and the maximum of off-diagonal entries were 0.19 and 0.72, respectively. Functional maps show strong auditory responses elicited by music (Figure (k)).

DISCUSSION: Our empirical data suggests that our 24-channel head coil array can provide high SNR images at the temporal lobe for both structural and functional images. Although the SNR advantage of our array is limited to superficial cortex, such 5 cm depth limit can be sufficient for experiments focusing on auditory cortex. With tailored mechanical housing, we expect that our coil array can also be used for occipital lobe imaging to provide high quality images at the visual cortex. In the future, we may further develop this quadrature array to cover bi-hemispheric temporal lobe by adding another 12 quadrature coil pairs. Our coil array can be useful in high spatial resolution anatomical and functional imaging experiments.

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