Parallel Traveling-wave MRI: Antenna Array Approach to Traveling-wave MRI for Parallel Transmission and Acquisition

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Introduction: Recently the traveling-wave [1] has been applied to excite and receive MR signals using patch antenna and waveguide. By utilizing the far field of a single piece patch antenna, homogeneous RF field can be generated to cover samples whose size is larger than the wave length, which is very useful for high field MRI. In this work, we propose a novel design of traveling-wave array which uses patch array to implement multi-source traveling-wave to make parallel transmission and acquisition possible. A 4-element single-feed quadrature transceiver patch array is built as the RF source for 298 MHz and a copper bore acts as waveguide. FDTD simulation is performed to evaluate the isolation among array elements, and the RF field distributions on both axial and sagittal planes. G-factor maps for 1D SENSE [2] are calculated on axial planes from 85cm to 135cm away from patch array.

Material and method: As shown in Figure 1a, a copper cylinder bore with 63 cm ID, 65 cm OD and 150 cm length acted as waveguide. On one end of the cylinder bore the 4-element antenna array was built as the source of RF field, as shown in Figure 1b. Each array element was a nearly square ring microstrip patch antenna made from copper foil [3]. The outer dimension of the ring was 12.2 cm by 12 cm, while the inner dimension was a square with 4.4 cm side length. This square slot was carefully cut to reduce resonance frequency of the antenna to 298 MHz. The coaxial feed point was along the diagonal and very close to the square of slot, which was able to generate a quadrature RF field [3]. These 4 elements were equipped (neighboring distance was 8 cm) placed on a piece of TMM 13I material with permittivity of 13.1 and diameter of 63 cm. On the back of the substrate the antenna ground was made from a single piece copper foil. The simulation model of this traveling-wave array, the parameters S11 and S21, and the evaluation of RF field distributions were achieved as shown in Figure 3, illustrating “traveling-wave” behavior. Figure 4 shows B₁ profile (combination of x- and y-components) of 4 elements when fed individually. This axial plane the g-factor for 1D SENSE at reduction factor R=2 can reach 1.1. Table 1 shows the g-factor average values at R=2 and 3 for 6 different axial planes from 85cm to 135cm away from the patch array. On each axial plane the FOV is 61cm. Figure 5 shows their corresponding g-factor maps. These data and figures illustrate that parallel imaging can be performed within a large range using the traveling-wave. Furthermore, we also demonstrated that by rotating the element 2 and 3 clockwise 90°, the decoupling can be further improved and the B₁ profiles of the elements are changed, as shown in Figure 6. This provided a simple way to switch patch array to implement the decoupling by changing the orientation and shape of the patch antenna.

Conclusion and discussion: In this preliminary work a novel design of parallel traveling-wave MRI using single-feed quadrature microstrip patch array antenna has been demonstrated. The transmission coefficients and the conduction current density of each element have demonstrated excellent isolation between array elements. The different sensitivity distributions on both axial and sagittal planes. G-factor maps for 1D SENSE [2] are calculated using Matlab7.6 (Mathworks Co.). G-factors for 1D SENSE were calculated using AFDTD6.4 (Remcom Inc.).

Results: At 298 MHz the simulated S21, S31 and S41 are all better than -40dB while the S11 is nearly -8 dB. Figure 2 shows the conduction current density (J) on the array surface: when element 1 was fed individually, the currents induced on the other 3 elements are limited, indicating excellent decoupling performance among the elements. When all 4 elements are fed simultaneously, homogeneous B₁ distribution along sagittal plane can be achieved as shown in Figure 3, illustrating “traveling-wave” behavior. Figure 4 shows B₁ profile of each element. Different B₁ profile, making it possible to perform parallel transmission and acquisition. At this axial plane the g-factor for 1D SENSE at reduction factor R=2 can reach 1.1. Table 1 shows the g-factor average values at R=2 and 3 for 6 different axial planes from 85cm to 135cm away from the patch array. On each axial plane the FOV is 61cm. Figure 5 shows their corresponding g-factor maps. These data and figures illustrate that parallel imaging can be performed within a large range using the traveling-wave. Furthermore, we also demonstrated that by rotating the element 2 and 3 clockwise 90°, the decoupling can be further improved and the B₁ profiles of the elements are changed, as shown in Figure 6. This provided a simple way to switch patch array to implement the decoupling by changing the orientation and shape of the patch antenna.


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Table 1 G-factors for 1D SENSE at 6 different axial planes (85cm to 135cm away from patch array), with reduction factor of 2 and 3.

<table>
<thead>
<tr>
<th>Position z (cm)</th>
<th>85</th>
<th>95</th>
<th>105</th>
<th>115</th>
<th>125</th>
<th>135</th>
</tr>
</thead>
<tbody>
<tr>
<td>g-factor at R=2</td>
<td>1.25</td>
<td>1.15</td>
<td>1.10</td>
<td>1.13</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>g-factor at R=3</td>
<td>2.80</td>
<td>2.81</td>
<td>2.59</td>
<td>2.52</td>
<td>2.82</td>
<td>2.71</td>
</tr>
</tbody>
</table>

Fig. 1 Traveling-wave array model: (a) copper waveguide; (b) 4-element nearly square ring microstrip patch array acts as RF source.

Fig. 2 Conduction current on array surface when only CH1 is fed.

Fig. 3 Homogeneous B₁ distribution at 105cm away from the patch array. FOV is 61cm. The number denotes channel number.

Fig. 4 B₁ profiles of each element of axial plane at 105cm away from the patch array. FOV is 61cm. The number denotes channel number.

Fig. 5 Corresponding to Table 1, G-factor maps for 1D SENSE at different transverse slices (85cm to 135cm away from patch array), with reduction factor of 2 and 3.

Fig. 6 After rotating the element 2 and 3 clockwise 90°, B₁ profiles of each element at the same axial plane as Fig.4 changes.