FDTD Simulation of Receiver-Only Array Inserts for 7Tesla Transmit-Only Head Coil: Influence on $B_1^+$ Field and Specific Absorption Rate (SAR)

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Overview:

• Evaluate the Influence of Different Receiver Array Geometry on Transmit Field viz. scatter parameters, $B_1^+$ field and RF absorption or SAR

• Issues with current receiver design & receiver built by our RF group

• Simulation Results
Motivation: Issues with Current Receiver Array

- Smaller loop arrays produce higher SNR images
  - Massively parallel receive systems have been built for high field MRI

- Loops of array constructed with wire

Issues:
- Although wires are an improvement over 5mm copper tape (reduced coverage)
- Close conforming loops of receiver array could cause an increase in RF absorption?
- Current receiver helmets do not account for different head shapes and sizes
Four Piece Helmet Design

The assembly was designed to fit 90 percentile of heads*
L 7.5 ± 0.6” W 5.9 ± 0.6”

Grid localizes array geometry

<table>
<thead>
<tr>
<th>Heads USA</th>
<th>Length (inches) (min,mean,max)</th>
<th>Width (inches) (min,mean,max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>7.1, 7.7, 8.4</td>
<td>5.6, 6.1, 6.7</td>
</tr>
<tr>
<td>Female</td>
<td>6.4, 7.1, 7.8</td>
<td>5.2, 5.7, 6.3</td>
</tr>
</tbody>
</table>

*The measure of man and woman, human factors in design A. R. Tilley, John Wiley & Sons 2002 p27
PEC Wire Model of 32 Channel Overlapped Array

- Created from CAD model using Matlab
- 3d Spline discretized to 1.6mm resolution
Overview:

- Evaluate the Influence of Different Receiver Array Geometry on Transmit Field viz. scatter parameters, $B_1^+$ field and RF absorption or SAR

- Issues with current receiver design & receiver built by our RF group
Different Receiver only designs in TEM coil

Receive Array Geometry:

- Cylindrical overlap, staggered overlap and close fitting helmet array of varying copper trace widths modeled

- Detuning of loops modeled as open circuit

- Two anatomically detailed head models of 1.6mm resolution (Head2 18 tissues & 3.6Kg, Head3 22 tissues & 4.7Kg) were used
Transverse electromagnetic (TEM) Resonator

TEM coil Schematic: The coil was tuned and matched to 50Ω at 300 MHz

• Four ports of coil were connected in quadrature excitation.
• Voltage per port was scaled by $\sqrt{1 - \text{reflection}_{\text{port}}^2}$ to ensure equal transmission
Results: Effect on Scatter Parameters

Bottom: Change in coupling with different receiver inserts is < 6%. Right: Match between scatter parameters using a network analyzer and FDTD simulation.

- The coupling between ports of TEM coil do not change with different receiver inserts

<table>
<thead>
<tr>
<th>Table1</th>
<th>Scatter Parameters Head2 dB</th>
<th>Scatter Parameters Head3 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8Loop</td>
<td>16Loop</td>
</tr>
<tr>
<td></td>
<td>Honly</td>
<td>H+.125”</td>
</tr>
</tbody>
</table>

Percent change in coupling Head2  Percent change in coupling Head3

|        |        |        |        |        |        |        |        |        |        |        |        |
| S12    | -5.4   | -3.8   | 1.9    | 2.6    | 1.9    |        | -5.6   | -3.9   | 2.0    | 2.0    |
| S13    | -5.9   | -4.6   | -0.1   | -0.5   | -3.8   |        | 0.2    | 1.6    | 5.6    | 5.6    |
Results: Effect on RF Absorption & Coil Radiation

Could copper of receiver array scatter RF and increase TEM coil radiation?

Total absorption = 0.5 \( \sigma E^2 \)

Global absorption in the two heads increased 9-18%

Input Power = Power Absorbed + Radiated

Radiated power from TEM coil decreased

| Absorbed Power in head for equal transmission of four ports in quadrature excitation |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Table 2                         | Power (Watt)    | Percent Change  |
|                                | Head2 | Head3 | Head2 | Head3 |
| Head only                       | 2.57  | 2.65  |       |       |
| H+8 loop array 0.125” copper    | 3.02  | 3.09  | 17.77 | 16.59 |
| H+8 loop array 0.25” copper     | 2.97  | 3.05  | 15.87 | 14.78 |
| H+16 loop array 0.125” copper   | 2.95  | 2.98  | 14.94 | 12.34 |
| H+16 loop array 0.25” copper    | 3.02  | 2.98  | 17.79 | 12.34 |
| H+32 array 0.063” copper        | 2.80  |       | 9.01  |       |
Results: Effect on B₁⁺ Field

Bottom: Axial, coronal & sagittal slice of B₁⁺ in brain of heads2&3 for 1 Watt of absorption

Right: % change in B₁⁺ with different receiver array is <4%

The existing receiver array design do not alter mean B₁⁺ of TEM coil

Table 3

<table>
<thead>
<tr>
<th></th>
<th>B₁p per 1 Watt absorbed power (Micro Tesla) Mean</th>
<th>Percent change B₁p Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head2</td>
<td>Head3</td>
</tr>
<tr>
<td>Head only</td>
<td>0.77</td>
<td>0.60</td>
</tr>
<tr>
<td>H+8 loop array 0.125” copper</td>
<td>0.76</td>
<td>0.59</td>
</tr>
<tr>
<td>H+8 loop array 0.25” copper</td>
<td>0.76</td>
<td>0.59</td>
</tr>
<tr>
<td>H+16 loop array 0.125” copper</td>
<td>0.79</td>
<td>0.61</td>
</tr>
<tr>
<td>H+16 loop array 0.25” copper</td>
<td>0.79</td>
<td>0.61</td>
</tr>
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<td>0.77</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Results: Effect on local SAR W/kg per 10gm

Bottom: Axial, coronal & sagittal slice of SAR in heads 2&3 averaged over 10gm of tissue, for mean $B_1^+$ in brain of 1 micro Tesla

Right: % change in peak SAR

Peak Local SAR increased 2-15% with different receiver array

Table 4

<table>
<thead>
<tr>
<th>Array Configuration</th>
<th>Peak SAR (W/Kg Per 10gm) for mean B1p (1Micro Tesla in Brain)</th>
<th>Percent change In Peak SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head only</td>
<td>6.72 8.99</td>
<td>Head2</td>
</tr>
<tr>
<td>H+8 loop array</td>
<td></td>
<td>7.20 9.68</td>
</tr>
<tr>
<td>0.125” copper</td>
<td></td>
<td>7.17 9.65</td>
</tr>
<tr>
<td>H+8 loop array</td>
<td></td>
<td>6.83 8.95</td>
</tr>
<tr>
<td>0.25” copper</td>
<td></td>
<td>6.85 8.95</td>
</tr>
<tr>
<td>H+16 loop array</td>
<td></td>
<td>7.71 14.69</td>
</tr>
</tbody>
</table>
Results: Effect of Copper Trace Width on RF absorption

Copper width of 8 & 16 loop array varied & absorption over 9 tissues analyzed

Absorption increased with trace width for 16 Loop array while it decreased for the 8 Loop array

Overall effect of trace width on RF absorption was inconclusive
Results: Percent Change in SAR with Receiver Inserts

SAR increased at regions with very different RF properties; e.g. at boundaries of Sinuses, Bone, CSF, GM & Eyes

Conductivity @ 300MHz:

2.2 CSF, 1.54 Eye, 0.97 CBE, 0.77 Muscle, 0.69 GM, 0.64 Skin, 0.41 WM, 0.08 Bone, 0.0 Sinus, 0.03 FAT
Results: Changes in Peak Local SAR

- Peak SAR (hot-spot) intensity increased with different receiver inserts
- Hot-spot location in some tissues changed when receiver array inserts are used for head2
- Close conforming helmet array caused greatest change in peak SAR distribution when compared to cylindrical arrays
Conclusion: Influence of Different Receive Array Inserts on Transmit Field

- Receiver inserts do not change coupling of the TEM coil (<6 %)
- Mean $B_{1}^+$ in brain per Watt of absorption did not change (<3%).
- For same input power: SAR increased with # of receive channels with corresponding decrease in radiation from the coil.

Tissue specific analysis
- A global increase in absorption (9-18%)
- Vulnerable structures like Eyes and tissue adjoining sinuses showed a notable increase in absorption
- Peak SAR location and intensity in tissues changed when different receiver inserts were used
  - Close conforming helmet array affected peak SAR distribution more than the cylindrical arrays
- Overall effect of copper trace width on RF absorption was inconclusive
Acknowledgements

RF Group
Tamer S Ibrahim

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