Transmit array with novel shield and fabrication technique for reducing losses at UHF

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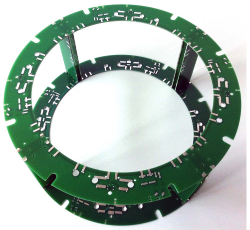

Figure 1 Printed circuit boards of a 4-element array.

Purpose: Design constraints for ultra high field (UHF) transmit arrays differ from those of conventional coils. Eddy-current power-losses increase with the square of the frequency, and radiation losses increase more than exponentially. As such, common-mode current suppression through baluns, cable-traps, and symmetrical placement of conductors requires more attention at high frequency than merited at lower field strength. Accurate power budget simulation is critical for translating established MR protocols to high field without violating limits for deposited power in humans. In simulations, common-mode currents are not modeled. Coil engineers must eliminate common-mode currents, and in general minimize deviations in coil specifications between simulations and devices. At UHF, the need for motion-tracking and correction systems increases due to the enhanced spatial-resolution. Coil designs that allow line-of-sight to markers placed on top of imaging targets reduce tracking errors. Here we present a transmit array for head imaging at 7T, with special consideration for baluns, shielding, and coil symmetry and a novel fabrication technique (Fig 1).

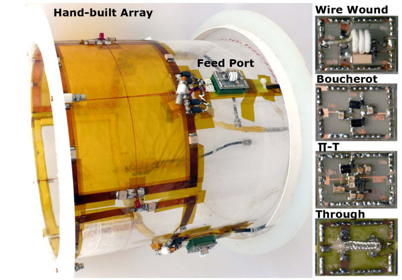

Figure 2 At the feed port of each element, motherboards allow insertion of different baluns.

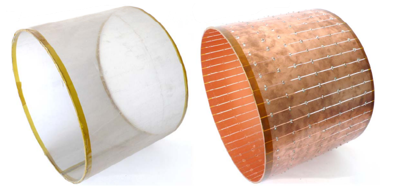

Figure 3 Transparent shield, comprising a polyimide mesh coated with less than a skin depth of silver (left), and 48 pieces of 25-mm-wide 35-micron-thick copper, with 94 nF lumped capacitance spanning each gap (right).

Methods: Each array is 300-mm in diameter, with 4 rectangular loops, 222.5 mm in width and 150 mm in length. The first prototype was hand built with 1-cm-wide copper tape with 8 distributed capacitors and 4 diodes in path (Fig 2). Inductive decoupling of the array elements was achieved with intertwined inductors[1] (<-12 dB). The array used a parallel matching configuration, and each element was fit with a motherboard for switching balun design at the feed port. For these tests the array was used as a transceiver. The second prototype was made of 2-mm-thick FR4 printed circuit boards fitted together to form the 3-dimensional structure, and is hence referred to as the PCB array (Fig 1). The 5-mm-wide copper traces are perpendicular to the surface of the optional acrylic former mounted within the array. The PCB array was tuned for minimum reflected power[2]. Matching was achieved with symmetric series capacitors. A 400-mm-diameter 300-mm-long acrylic former was used to support two different kinds of shields (Fig 3). A receive array with 8 overlapping 160-mm-diameter loops on a 220-mm-cylinder was built at Gachon University and modified with coil-mounted preamps. For all tests we used a 400-mm-diameter shield and a 180-mm-diameter phantom to load the coil (7.3 L with 1.24g/L $NiSO_4 \times 6 H_2O$ and 2.62 g/L NaCl; T1 300 ms, 0.52 S/m, rel. permittivity 78). **Bench-top metrics:** All elements were first tuned and matched in isolation (Sxx ≤ -20 dB). Loaded *Q* was measured as the ratio of the center frequency and the 7-dB bandwidth of the matched coil through the cable (Sxx). The coupling factor *k* was measured by activating pairs of neighboring elements, and calculated as the ratio of the distance between peaks and the operating frequency. **Scanner metrics:** Maps of $|B_1^+|$ were obtained by Actual Flip Angle Imaging (AFI), solving the steady-state AFI equation analytically to correct for T1 measured previously for the phantom (TR2/TR1=5, TR1=75 ms, TE=3.2 ms, 60 coronal slices with 3-mm-isotropic resolution, flip angles of 50° with 2 averages, as well as 45° with 3 averages). Histograms of the alpha ratio in each voxel were obtained by normalizing flip angle maps by the reference angle. Transmit efficiency is defined as $|B_1^+|$ normalized by the square-root of the applied power. Peak voltage reported by the scanner was used without correcting for attenuation between the power-monitoring hardware of the scanner and the coil. We evaluate the transmit efficiency from the central peak, average, and volume integral of the $|B_1^+|$. The metric for the homogeneity of the excitation profile is the coefficient of variation for the $|B_1^+|$ (population standard deviation normalized by the mean). The defined regions of interest are the signal containing voxels of the phantom, and a region within 9-cm of the top of the phantom (to approximate the brain).

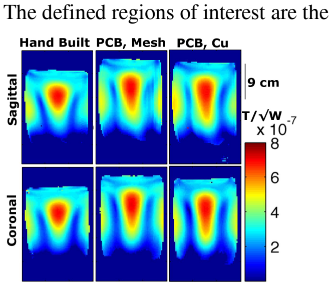

Figure 4 PCB array (center) delivers B_1 to phantom more efficiently than the hand-built array (left; 10% B_1) and the copper shield (right; 10% power). Local peak-transmit-efficiency near coils is only symmetric for PCB array with transparent mesh shield.

Results: The wire-wound balun was the most efficient, and was therefore implemented in the second-generation device. The hand-built coil showed greater variation across the elements than the PCB array for bench-top metrics (loaded *Q*: 8% vs. 2%; *k*: 6% vs. 2%), and the peak transmit efficiency near the elements (10% vs. 0%; Fig 4). However, the loaded *Q* of the PCB array varies more when used with the copper shield (5% variation), as do peak transmit-efficiencies adjacent to each element (6% variation). Coupling between nearest neighbors is negligibly worse for the transparent shield, although it varies less than the standard deviation of the elements with the copper shield (mesh: -6.4+/-0.1 dB, copper: -6.7+/- 0.4 dB). The loaded *Q* of the elements decreases from 42 (mesh) to 33 with the copper shield. The summed $|B_1^+|$ per square root power for the entire phantom was consistently more efficient with the mesh shield than with the split copper shield (10% power difference). The reflected power was 0.2% for the PCB arrays and 0.7% for the hand-built, conventionally tuned array. The transmit efficiency of the hand-built array over the 9-cm region is comparable to the PCB arrays, but it is 10% lower for the entire phantom. The $|B_1^+|$ homogeneity for the arrays were as follows (9-cm region/entire phantom): hand-built array 30% / 49%, PCB with copper shield 34% / 48%, and PCB with transparent shield 32% / 41%. The peak transmit efficiency was in the range of 0.69–0.71 μT/ √W, and the average over the 9-cm region was in the range of 0.30-0.31 μT/ √W for the arrays described.

Discussion: The presented values for transmit efficiency are similar to values for loop coil transceiver arrays in 7T literature, for maximum: 0.54 μT/ √W [1], 0.84 μT/ √W (attenuation corrected; 0.45 S/m phantom)[2], and average values[3]: 0.276 μT/ √W. All of these examples have shields that are in close proximity to the elements, and would therefore likely benefit from using shields that are a fraction of the skin-depth to dampen mirror currents that in such close proximity reduce coil inductance and increase effective resistance. Shields that interact strongly with elements can generate asymmetry. Asymmetries in coil construction are difficult to simulate, and can coincide with anatomical features that can worsen local hotspots. Array performance with the copper shield is more dependent on tuning, and has a higher peak alpha ratio (Fig 5). We present an array fabrication technique and a transparent shield that minimize the asymmetries of a coil array, and improve array performance for a cylindrical phantom. Further study is needed to determine array performance in the context of an anatomically correct phantom or brain. Such data is projected to be available at the time of the conference.

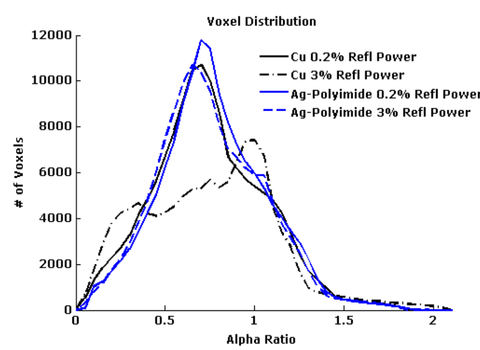

Figure 5 the distribution of the alpha ratio of voxels in the phantom is shown for both shields with optimal tuning/matching <1% reflected power) and 3% reflected power – dashed lines).

1) Avdievich et al, JMRI 2009 (29): 461-465; 2) Kozlov and Turner, JMR 2009 (200): 14-152; 3) Gilbert et al, MRM 2012 (67):1487-1496