An 8 Channel Phased Array Coil and Detunable TEM Transmit Coil for 7 T Brain Imaging

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Introduction   The advantages of an array of small surface coils placed close to the body are well established in MR imaging [1]. These advantages are expected to become greater at higher frequency due to increases in tissue loading and radiative losses. There are however various challenges in their design and use at fields of 7 Telsa and higher, including coil to coil and cable interactions. Also, the absence of an RF body coil on current 7 Tesla systems requires the construction of detunable volume coils for efficient uniform transmit excitation. We describe a flexible 8 channel phased array head coil and detunable TEM transmit coil, and evaluate their sensitivity in phantom and human studies.

Methods   The system was developed and tested on a prototype 7T human scanner (Siemens Medical Solutions, Erlangen, Germany). A linear array of 8 circular surface coils was designed on a flexible former to wrap tightly around the human head. Each coil element has 85 mm inner diameter, conductor width of 5 mm, 9 gaps bridged by 10 pF and 13pF capacitors, and is matched to 50 Ω coax cable with a 50Ω to 50Ω lattice balun. Several measures were required to reduce coil-to-coil and cable-to-cable interactions. The dimensions of the balun were reduced (all components fit within a 7 mm X 19 mm area) by use of 2.1mm diameter semi-rigid coax, and the amount of exposed coax central conductor was minimized. A cable trap was required near each surface coil to reduce shield currents. Each trap was created with two loops of the semi-rigid coax bridged with a 12 pF capacitor, and was tuned to approximately 303 MHz in order to avoid coupling too strongly to the main coil resonance at 298.2 MHz. The small coax was then joined to RG223 cable to connect to the preamps. Diode detuning was provided on each surface coil by bridging the lattice balun with a PIN diode (Macom 4006B). To minimize the inductive coupling, the surface coil elements were overlapped [1] and preamplifier decoupling was employed by transforming the input impedance of the 8 modified Siemens preamplifiers preamps to a low impedance at the coil.

A detunable TEM volume coil [2, 3] was constructed with an inner diameter large enough (256 mm) to accommodate the human head and phased array coil. The outer diameter of the TEM was 316 mm. The coil utilized 24 distributed capacitance rungs made from 0.7 mm thick low-loss dielectric circuit board (Rogers Corp.), with rungs of 24.5 mm width spaced by 10 mm gaps. The outer TEM shield was made from 1 mil copper foil, separated into 24 strips to reduce eddy currents, and linked with numerous 10 nF capacitors to provide RF continuity. Each rung was connected directly to the shield at one end, and via a trim capacitor to the shield at the other end. We placed PIN diodes between every third rung and its associated trim capacitor. Bias voltages for the diodes were brought in via 4 coax leads, each biasing 2 diodes in series. The 4 driving rungs were matched to 50Ω coax and driven with phases of 0, 90, 180, and 270 degrees.

For SNR comparison, images were made with identical parameters using the phased array and also with a separate dedicated Transmit/Receive end-capped TEM coil. SNR maps were generated by dividing the smoothed image intensity by the standard deviation of the noise in a ROI outside the head using a proton density gradient echo image (TR/TE/flip = 75ms / 3.9ms / 20 deg, 256x256, FOV = 200mm).

Results   The S12 coupling between 2 probes lightly coupled to the transmit coil was measured with the PIN diodes in the forward (transmit) and reverse (receive) biased states. Detuning provides 25dB of decoupling between transmit and receive modes. The resonant frequency of the surface coil elements changes with loading, decreasing by 2.4 MHz when loaded with the hand, but increasing by only 0.4 MHz when placed against the head. Placing the surface coil elements inside the detuned TEM coil causes their resonant frequency to drop by about 0.5 MHz. S12 coupling between nearest neighbor coil elements was –18 dB when loaded. Figure 1 shows gradient echo images from the individual receive coils as well as the sum-of-squares combination in a human subject, demonstrating good isolation between the phased array coil elements. Figure 2 shows SNR profiles through the center of the head for the phased array system and the T/R TEM. The SNR gain provided by the phased array compared to a standard TEM volume coil ranged from 6 fold in the outer parts of the brain to 1.2 fold in the center of the head. MPRAGE scans with the phased array (Figure 3) demonstrate the receive and transmit coverage over the brain volume. Figure 4 shows the use of the increased sensitivity provided by the phased array for high resolution imaging of fine anatomic details.

Conclusions   A 7 Tesla 8 channel phased array coil and detunable TEM transmit coil have been constructed and used successfully in human brain imaging. The phased array provides significant SNR improvements over the TEM volume coils which have become the standard for high field brain imaging. The observed gains are consistent with what has been observed with phased array receivers at 1.5T and 3T. Although the array sensitivity is highest near the surface of the brain, significant improvements are observed thoughout the brain, including the center of the head.
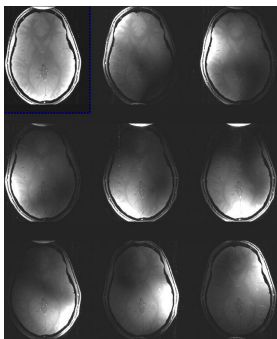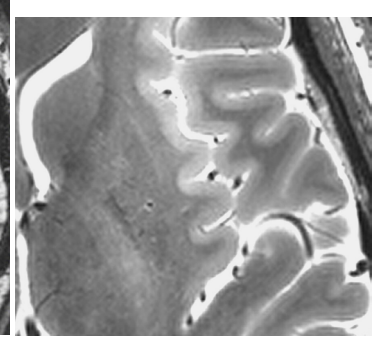

Figure 1. Combined (upper left) and uncombined brain images with phased array. Gradient Echo TR/TE/flip = 200/3.9/ 20[0]
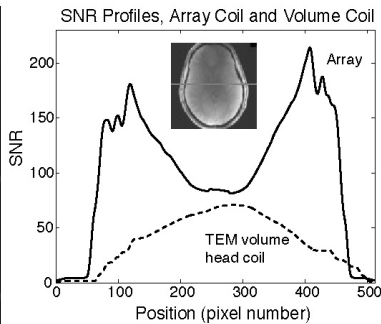
Figure 2.   SNR profiles through the center of the head for phased array (solid line) and T/R TEM (dotted line)
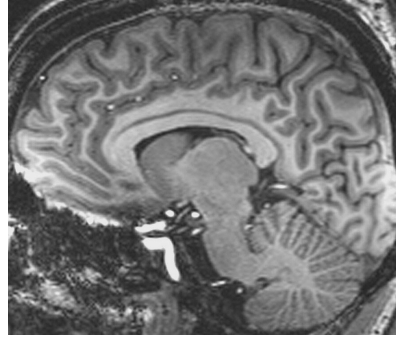
Figure 3. Normalized slices from an 8 minute 3D MPRAGE whole head volume acquisition, TR/TE/TI/flip = 2530 / 3.4 / 1100 / 7[0] 192x256x128, FOV 256x256mm

Figure 4. Detail from T2 weighted TSE scan, image intensity spatially normalized. TR/TE/TA/flip = 5000 / 80 / 4:50 / 137[0], resolution = 312x382, slice = 2mm

[1] Roemer PB et al Magnetic Resonance in Medicine **16**, 192-225 (1990)
[2] Vaughan JT et al Magnetic Resonance in Medicine **47**, 990-1000 (2002)
[3] Ledden PJ, Wald LL, Vaughan JT, Proc. ISMRM, p.168(1999)