Feasibility of constructing receive-only arrays for human imaging at 11.7T and 14T

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Introduction: Surface coil arrays are indispensible for ultra-high field imaging, and brain arrays consisting of approximately 6cm to 9cm diameter loop elements have become the most common choice for high-sensitivity 7T brain imaging. With 11.7T human systems in the construction stage and even higher field systems under consideration, it is worthwhile evaluating the loop array design above 7T. In this work, we test the feasibility of loop-coil brain array designs for proton imaging at 11.7T and 14.1T (500 and 600MHz). At these frequencies, the lumped capacitance approach becomes increasingly difficult since the size of the discrete capacitances becomes comparable to stray capacitances and losses within discrete components increase. We compare performance metrics such as loaded to unloaded Q, shift on loading, and matching for 500 and 600MHz 8cm diameter loop elements with completely distributed capacitance to highly distributed discrete capacitance loops. We also test the performance of geometric decoupling and preamplifier decoupling in arrays formed from the distributed capacitance loops.

Fig. 1: Photographs of distributed capacitance elements (left) and final 4-channel arrays (right).

Methods: Each distributed capacitance coil element was fabricated from overlapping the two copper plates in double-sided microwave circuit board material following.[1] The 0.8 mm thick material (Rogers Corp, RO3003 12X18 R2 0300) was milled to form a loop 8 cm in outer diameter. On the 11.7T coil, the trace width was 1.2 cm with five gaps defining the overlapping sections, and the 14T coil trace width was 1.5 cm with six gaps. All coil elements were tuned and matched to the back of the head with a standard lattice balun design (Z=50 Ohm, L=15 nH, and C=6.8 pF for 11.7T; Z=50 Ohm, L=13 nH, and C=4.8 pF for 14T). A simple PIN diode in the lattice balun detunes the elements during transmit. Custom-tuned preamps were obtained for the 14T coil based on 3T Siemens preamplifiers and the preamp decoupling was achieved with a cable length of 8 cm.

For comparison, lumped-circuit coil elements were constructed at the same two frequencies with equivalent dimensions that consisted of 12 distributed series capacitors used to increase the total capacitance, and tuned and matched for the same target load using the same lattice balun with a PIN diode for detuning.

Results: Photographs of individual distributed capacitance coil elements and the resulting arrays are shown in Fig. 1. The bench measurements comparing the distributed capacitance elements and lumped capacitance elements are provided in Table 1 and the plots in Fig. 2. The fully distributed coils showed little change in resonance frequency with loading and had loaded to unloaded Q ratios of ~5. Active detuning (S12 with diode off compared to with diode on, Fig. 2e) was about 40dB and the characteristic dip in the S12 response to two lightly coupled probes showed that preamplifier decoupling was working well (Fig. 2f).
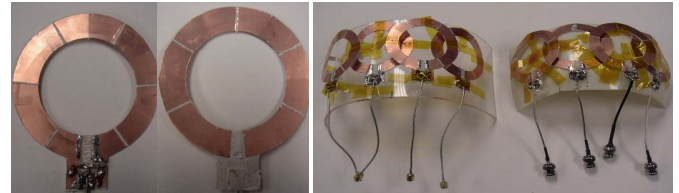
	Distributed Cap.		Discrete Cap.	
	11.7 T	**14 T**	**11.7 T**	**14 T**
Q$_U$/Q$_l$-ratio	101/20	70/15	55/20	40/13
S11 Unloaded	-3.5dB	-4.7dB	-6.8dB	-7.9dB
S11 Loaded	-30dB	-30dB	-40dB	-38dB
S21 Unloaded	-18dB	-16dB	*n.a.*	*n.a.*
S21 Loaded	-15dB	-12dB	*n.a.*	*n.a.*
Active Detuning	40dB	40dB	40dB	40dB

Table 1: Bench measurements and comparisons of two coil designs. S21 measures are between two overlapped elements.

Conclusions: The distributed capacitance method outperformed the lumped element design in Q$_U$/Q$_L$ ratio likely due to losses in the lumped element capacitors and solder joints [2]. The distributed capacitance array is straightforward to construct and work with and appears to be a plausible method for constructing extremely high field strength human arrays.

References: [1] Sullenberger *et al.* (1988) *Proc SMRM* 7:864. [2] Kumar *et al.* (2009) MRM 61:1201-9.
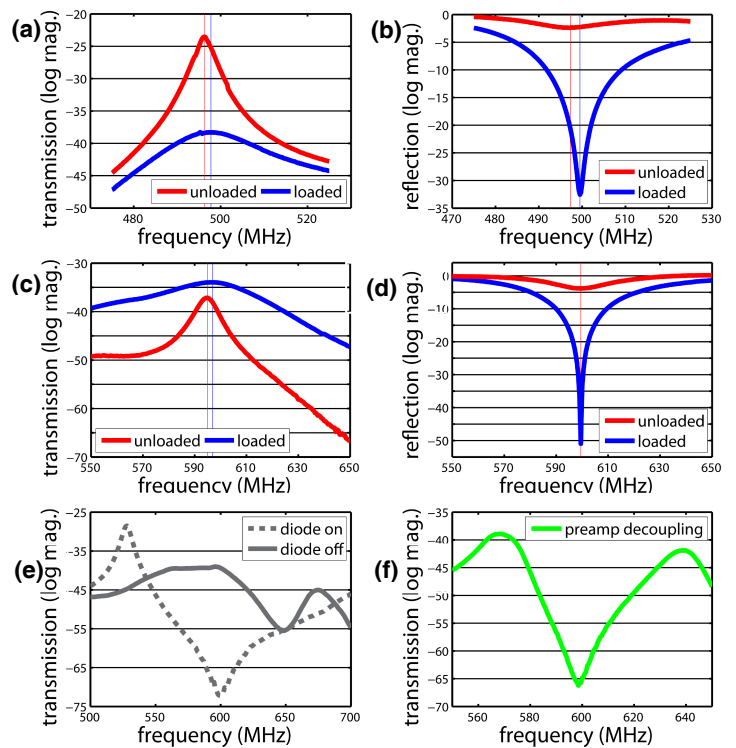
Fig. 2: Transmission and reflection plots. (a) Q$_U$/Q$_L$, 500MHz coil. (b) S11$_U$/S11$_L$, 500MHz coil. (c) Q$_U$/Q$_L$, 600MHz coil. (d) S11$_U$/S11$_L$, 600MHz coil. (e) Active detuning, 600MHz coil. (e) Preamp decoupling, 600MHz array.