Bespoke Coils: Screen-Printed, Tailored Flexible MRI Receiver Coils

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Introduction We present a new technique for designing and fabricating flexible MRI receiver coils. Our approach is based on printed electronics on cloth-like mesh substrates using screen-printing with all components and material processed from solution. Our aim is to fabricate custom-made (e.g. bespoke) tailored flexible coils that can fit to a wide variety of patients and anatomy, thus improving sensitivity and signal-to-noise. Recently, the field of printed electronics has made breakthroughs in fabricating high-precision electronic components directly on a variety of flexible substrates by using ink-based printing techniques. These include ink-jet, gravure, and screen printing. In previous work by Mager *et.al,* [1] a technique to fabricate 400MHz MRI coils using inkjet printing was shown. In that work, they were able to take advantage of printing on both sides of a Kapton substrate and use it as the dielectric for the capacitors that were printed (balancing inflexible capacitors were connected via a traditional PCB board). Although promising, this approach is constrained by inkjet printing limitations, such as thickness of printed layers and scalability. These make inkjet printing not well suited to larger area devices, such as clinical sized coils and coil arrays. Our approach utilized fabrication via screen printing (Fig. 1). We print the entire coil and balancing capacitors on a flexible mesh substrate using materials with high dielectric constants. These were high enough to achieve the capacitance required for resonances as low as 57 MHz, which makes them suitable for 1.5T as well as 3T. Our approach takes advantage of multiple layers of printed materials on a single side to create the flexible components needed for optimized function.

Merriam-Webster: be·spoke (*adj* \bi-ˈspōk\)
a: Custom-Made <a bespoke suit>

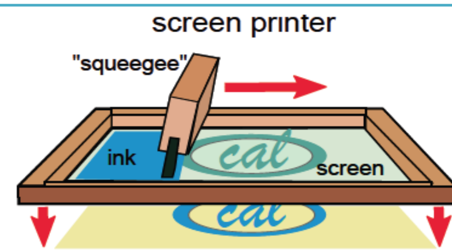

Fig (1): Ink is distributed by the squeegee and pushed into the screen and onto the substrate through openings in an emulsion. The emulsion covers the screen except where the pattern is desired. Screen printing can use a wide variety of inks, has good yield, and good thickness control.

Methods Flexible receiver coils were fabricated by printing several patterned layers of conductive and dielectric ink together to form the coil and capacitor structures (i.e. repeating the process in Fig. 1 for each layer with an anneal in between). The initial coil was designed to be 8.7 cm in diameter, 0.5 cm in width, with 4 parallel plate capacitors spaced evenly throughout (Fig. 2). Ink containing silver nanoparticles encapsulated in an organic barrier was used for the conductor loop. Printing onto the substrate is followed by an annealing step in which the ink becomes conductive. The achievable conductivity is directly proportional to the annealing temperature and duration. The main limitation on temperature is the heat resistance of the substrate. As a result, several substrates were examined: Polyethylene terephthalate (PET), Nylon, and Polyetheretherketone (PEEK). While PEEK possesses the highest melting (260 °C), our specific ink did not print well on it. The specific ink is more optimized for printing on PET (melting point 120 °C), which gave the best print. To achieve a high quality factor, we aim for a low resistance. With 60 minutes at 120°C annealing, the silver ink has lower conductivity than bulk copper. Therefore we compensate by using thicker films for adequate conductivity. In order to support these thicker films and prevent cracking during bending, a novel woven mesh substrate was chosen. The mesh substrate provides better mechanical stability for thicker films by giving more surface area for the inks to adhere to. Additionally, using a mesh allows materials to be more flexible than they would be in a sheet. During processing a PET sheet was adhered to the back of the mesh to serve as supporting layer and allow the use of vacuum restraining during processing. The capacitors on the coil were formed by printing silver ink, followed by dielectric ink containing ceramic nanoparticles, followed with a top layer of silver ink. This stack was repeated to get multiple 'fingers' to further increase capacitance. Tuning of the capacitors was done by first under sizing the top plate then adding silver ink to increase the area. Analysis was performed on a network analyzer.

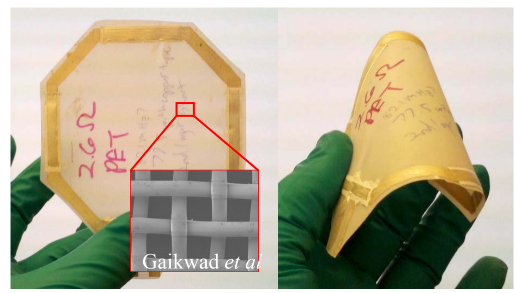

Fig (2): Prototype coil fabricated with screen printing with printed capacitors fabricated on PET

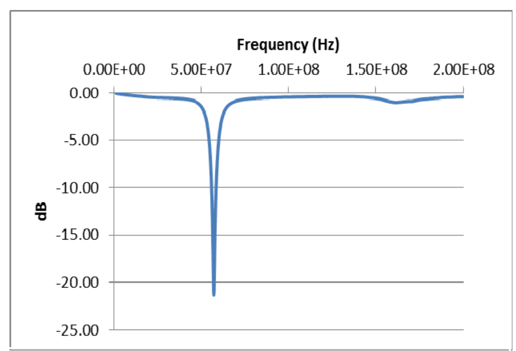

Fig (3): Bode plot from coil with lowest resonant frequency (57 MHz)

Conclusions and outlook The coils fabricated in this experiment have been designed to show resonant frequencies between 57 and 168 MHz, allowing them to be used in 1.5 and 3T systems (Fig. 3). The coils have also shown impedances of 20-100 ohms to allowing them to be tuned for to 50 ohms, a requirement for most preamplifiers. The quality factor of the coils have shown to be up to 25.5 unloaded, which while not excellent, is still enough to maintain body noise dominance (same coil loaded is 10).

References [1] D. Mager et. al, IEEE TMI 2010; 29(2):pp 482-7 **[2]** Gaikwad, A. M., *et al*, Advanced Materials, 2001;23: 3251–3255.