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Printed frequency selective surfaces on textiles

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This letter introduces a novel technique for inkjet printing frequency selective surfaces (FSS) on textiles. The challenge of printing an inkjet layer of three micron thickness on polyester cotton with a surface roughness of the order of 150 microns is achieved with a screen printed interface layer. The conducting inkjet layer is then printed directly on top of the interface layer. A screen mask was used so that the interface layer was only printed directly below the conducting ink. A square FSS structure has been fabricated and the measured shielding has been compared to simulations.

Introduction: The modern world is dependent on wireless communications. Frequency Selective Surfaces (FSS) are a subset of metamaterials and have been widely studied [1]. Many applications which include the medical and military sectors can benefit from shielding electromagnetic fields at specific frequencies. FSS can also be applied to stop unwanted mobile phone communication. This paper explores FSS structures that are printed on textiles. Inkjet printing allows a fine resolution of printing and design flexibility and is comprehensively reviewed in [2]. Weaving and screen printed textile FSS have been recently reported [3]. Textile FSS have also been created with highly conducting knitted fibres [4]. The potential effect of printing errors in an FSS array was investigated by etching arrays with different numbers of deliberately mis-printed squares [5]. As the number of incomplete squares increased, the frequency of the FSS increased and the shielding effectiveness decreased.

Fabrication of the FSS: The first stage is screen printing an interface layer onto standard 65/35 polyester cotton fabric supplied by Klopman International (www.klopman.com). The screen printer used in this research work is a DEK 248 (www.dek.com). The purpose of the interface layer is to reduce the surface roughness of the fabric and present a smooth layer for subsequent inkjet printed layers. The ultraviolet (UV) curable interface ink, Fabink-IF-UV4 (www.fabinks.com), was screen printed using a pre-designed mesh screen with 250 threads/inch. The screen design ensures the interface layer is printed only where required thereby maintaining the fabric's flexibility and breathability compared to commercial pre-coated fabrics. The printer squeegee pressure setting was set to 6 kg and the printing gap was 0.8 to 1 mm. Three layers are required to obtain a smooth interface surface with an average thickness of 150 µm. The film is cured with a UV dose of between 500 to 1500 mJ/cm^2.

Inkjet printing was used to deposit the silver on to the interface layer with the desired pattern. The inkjet printer used in this research is a Dimatix DMP 2831 (www.fujifilmusa.com) used specifically for printed electronics. The inkjet printable silver nanoparticle ink U5714 is supplied by SunChemical (www.sunchemical.com). The drop spacing was set to 15 µm and a droplet velocity of 8 m/s was chosen for printing the silver to provide good conductivity and line edge definition. Two deposits are required to form a layer which maintains good conductivity during bending of the fabric [6]. The silver ink layer was thermally cured for 10 minutes at 150° C in a box oven. The selected curing condition provides a good conductivity of 0.3×10^6 S/m as calculated from measurements with a four point probe and a profilemeter to accurately measure the conducting ink thickness. No observable degradation occurred to the fabric during the curing process. Fig. 1 shows an overview of each stage of the printing process.

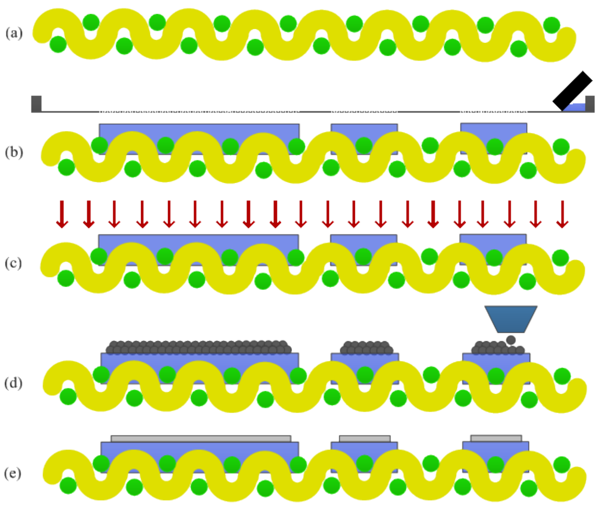

Fig. 1 *Cross sectional view flow diagram for the inkjet printed FSS on fabric fabrication process comprising two deposition stages: (a) cross sectional view of the standard 65/35 polyester cotton fabric; (b) screen printing stage to deposit the interface layers on top of the fabric; (c) UV curing stage to solidify the printed interface paste layer; (d) inkjet printing stage to pattern the silver layer on top of the interface layer and (e) thermal curing stage to evaporate the organic solvent and sinter the silver nanoparticles to form a conductive film.*

FSS Geometry: The geometry of the inkjet printed structure is shown in Fig. 2. The exterior dimensions of the squares are 28 mm; the line thickness is 0.5mm and the unit cell is 40mm. Four sets of 3 × 3 arrays were printed and then attached to a block of Rohacell to form a 6 × 6 array of squares using paper tape at the edges and the middle.

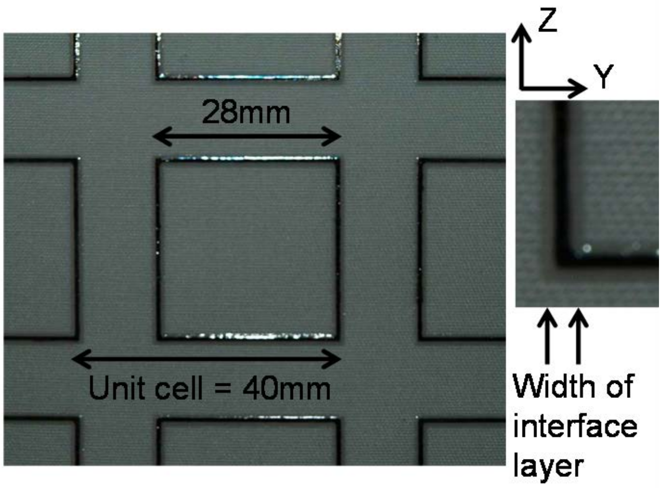

Fig. 2 *Geometry of printed layers. Inset is a zoomed in view of the interface layer (1.5 mm wide) with silver conductor layer on top (0.5 mm wide).*

Simulated and measured results: The structure was simulated in EMPIRE XCcel finite difference time domain (FDTD) software. A single unit cell was simulated with a vertically (Z axis in Fig.2) polarised plane wave source. The structure was mirrored to be infinite in two dimensions by using perfect magnetic walls on the side boundaries and perfect electric walls at the top and bottom of the unit cell. The FSS was placed on a 0.5 mm thick fabric substrate with a relative permittivity of 1.4. Scanning electron microscope (SEM) images indicated that the silver layer varied between two and four microns thick. The FSS layer was therefore simulated as three microns thick.

The measurement setup is shown in the inset picture in Fig. 3. The 6 × 6 array of inkjet printed squares was placed between two horn antennas in a semi-anechoic chamber. The results are shown in Fig. 4 and indicate that the S21 has a stop band at approximately 3 GHz compared to the theoretical value of 3.169GHz. The conductivity of the printed silver ink layer was varied in the simulations to compare to the measured results. Fig. 4 indicates that the simulated shielding effectiveness of the FSS increased with higher conductivities. These results indicate that the conductivity of the ink layer is approximately 0.3 to 0.5 $\times 10^6$ S/m which agree with the four point probe results. As a comparison, a simulated conductivity of 1×10^7 S/m had an S21 of -30 dB while an infinite conductivity resulted in an S21 of -40 dB. Further simulations with an ink thickness of 10 microns and a conductivity of 1×10^6 S/m improved shielding effectiveness to better than -20 dB. This indicates the level of shielding is related to the skin depth. Note, the simulated results use an infinite array and hence will have improved shielding compared to the finite sized measured results.

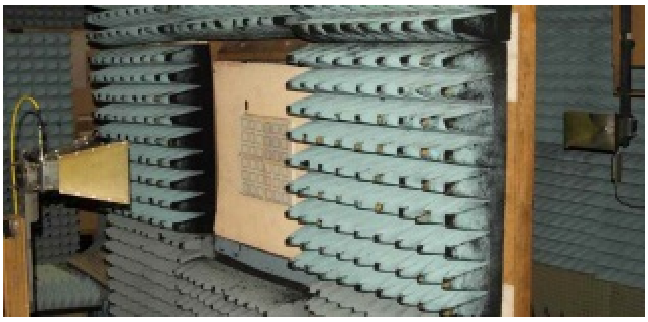

Fig. 3 *Measurement setup with 6 × 6 array of printed squares.*

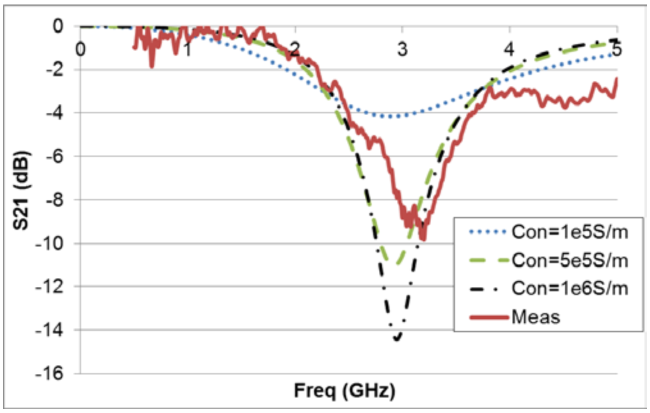

Fig. 4 *Measured and simulated S21. The simulated S21 results indicate better shielding with higher conductivities*

Conclusions: This paper has introduced fabric FSS structures using inkjet printing. This has been achieved by screen printing an interface layer on fabric to reduce the surface roughness. The interface layer can be selectively printed only under the conductive tracks and hence the fabric maintains the look, feel, flexibility and breathability of polyester cotton. Inkjet printing provides a very high degree of accuracy and hence this technique could be extended to higher frequencies. At spectra where the skin depth is smaller, a better degree of shielding would be expected with the same metallisation thickness.

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