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**Study of Printing Errors in Digitally Fabricated FSS**

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# Study of Printing Errors in Digitally Fabricated FSS

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**Abstract**—Low cost fabrication techniques might give rise to defects in electromagnetic structures. This paper investigates the detrimental effect of producing frequency selective screens with differing percentages of absent square loop elements. It is shown that as many as one in five elements can be incomplete before the array transmission response is considered unusable.

**Keywords;** Frequency selective surfaces; Indoor radio propagation; Inkjet printing.

## I. INTRODUCTION

Inkjet technology is considered to be a promising means for economically manufacturing electromagnetic structures on inexpensive substrates such as paper, with a process that reduces the waste associated with chemical etching [1]. Inkjet drop-on-demand (DoD) technology [2] can deposit precise and repeatable drop sizes achieving the resolutions required for UHF printed circuits. Frequency Selective Surfaces (FSS) are well-known periodic structures with applications in reflector antennas, radome design, and satellite communications. They are filters of electromagnetic waves and printed FSS have been shown to be capable of achieving transmission nulls (signal attenuation) comparable in depth with those of conventionally etched bulk copper [3].

Particularly in the built environment, wireless communication system performance is limited by factors such as co-channel interference as the radio spectrum is heavily utilized in certain bands. Also user privacy may be compromised by eavesdropping with close-by receivers. These problems are pronounced in indoor wireless systems owing to the concentration of users sharing a limited number of unlicensed bands. The introduction of FSS into the building structure has been considered as a possible way to improve the situation [4],[5],[6].

In printed mass produced FSS, such as might be required in application to the built environment for electromagnetic architecture modification, imperfections might be expected from blockage of printer nozzles, poor surface quality, and non-uniformity in any conducting ink sintering process that might be adopted. To assess the consequences of this effect, some results from a study of the impact on transmission properties arising from randomly missing elements in a simple square loop FSS are presented here. Arrays of square loop

elements [7] were used as demonstrators, as they are a commonly encountered FSS configuration. Square loop arrays can provide a common reflection band of about 25% over incident angles ranging from 0 to 50°. This paper provides some insight into how the reflection band is affected by the loss of elements.

## II. DESIGN METHODOLOGY

The complete arrays contained 1080 patch square loops arranged in a square lattice format with length  $L$  and periodicity  $P$  equal to 6 and 7mm respectively, as shown in Fig.1. The element width  $w$  was 0.4mm and conductor thickness was 0.01mm.

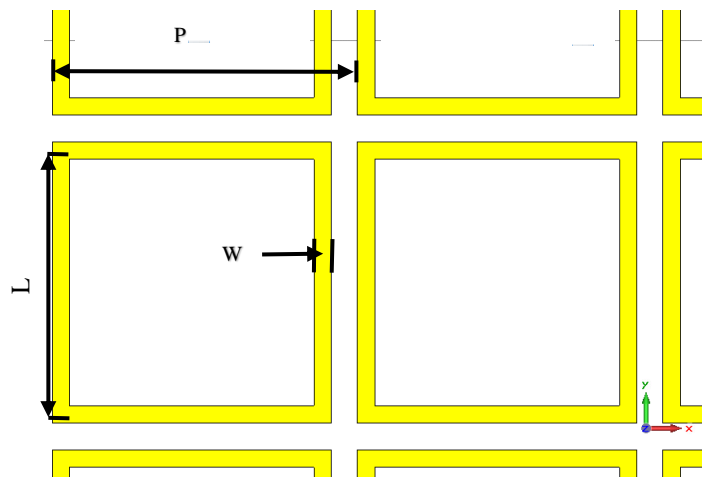


Fig.1 Finite square loop FSS

The FSS was etched onto a 0.045mm thick polyester substrate with relative permittivity  $\epsilon_r = 3.5$  and loss tangent = 0.02. The physical size of the array was  $280 \times 190 \text{ mm}^2$ .

Four additional FSS were fabricated, with 10, 20, 30 and 40% of the elements missing from random positions in the lattice. The numbers of the absent elements were 108, 216, 324, and 432 respectively. All arrays were placed in an aperture in an absorbing screen 1.18m away from the illuminating horn antennas.

The five arrays were also simulated using CST Microwave Studio™ (CST MWS) for comparison with measurement. Figs. 2 (a) & (b) show the modelled complete array and also that with 40% absent elements.

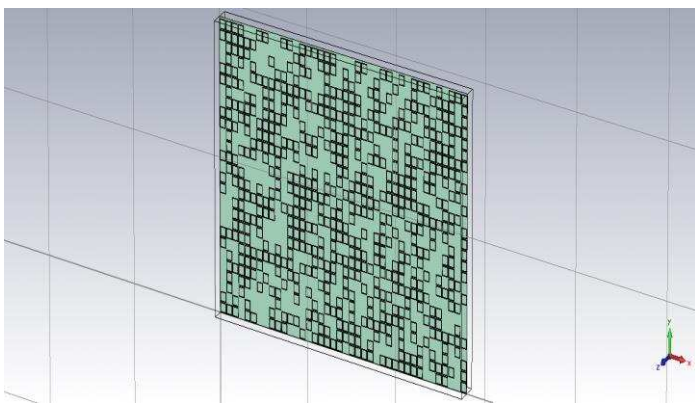
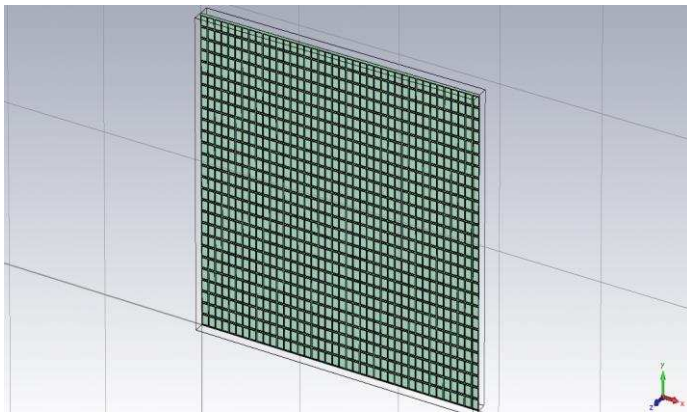


Fig.2 Modelled Square loop FSS arrays

### III. RESULTS

#### A. Transmission response ( $S_{21}$ )

The measured and simulated transmission responses ( $S_{21}$ ) are shown in Fig.3(a) and Fig.3(b). As the number of missing elements increases, the transmission null degrades.

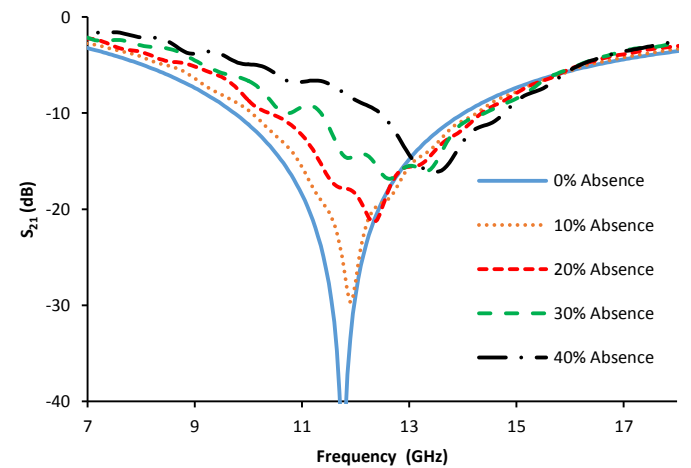
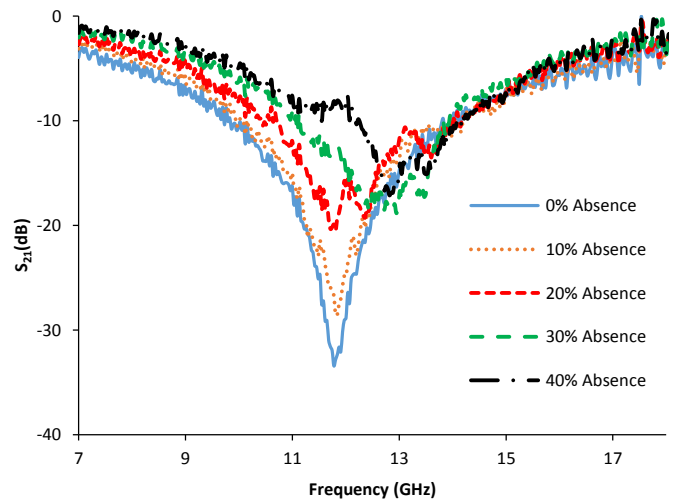


Fig.3 Transmission response ( $S_{21}$ )

The absence of 10% and 20% of the elements causes a reduction of about 6dB and 16dB, respectively, in the measured transmission null depths. The depths in the simulated cases are broadly similar. Fig.4 summarises the results.

There is also a small shift in the resonant frequency which becomes more pronounced as the number of missing elements increases, as illustrated in Fig. 5.

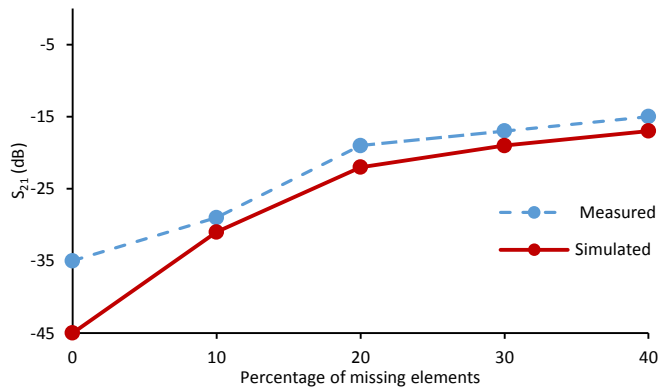


Fig.4 Depth of transmission null (S<sub>21</sub>)

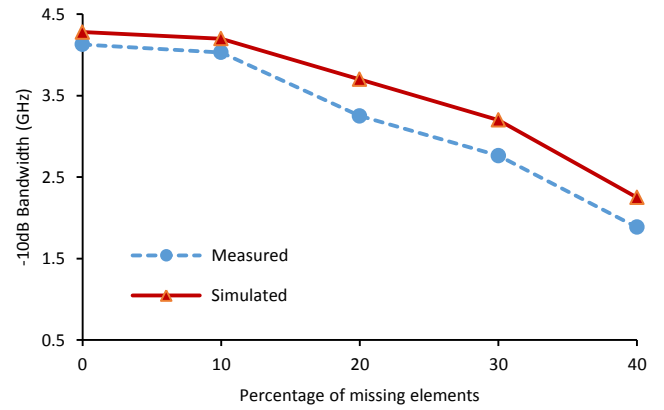


Fig.6 Reflection Bandwidth.

The resonance frequency  $f_r$  increases by about 300MHz when 10% of the elements are absent, while 20% absent elements lead to a 450-500MHz increase. As then might be deduced, a large increase, of about 1GHz, occurs when 30 and 40% of the elements are absent.

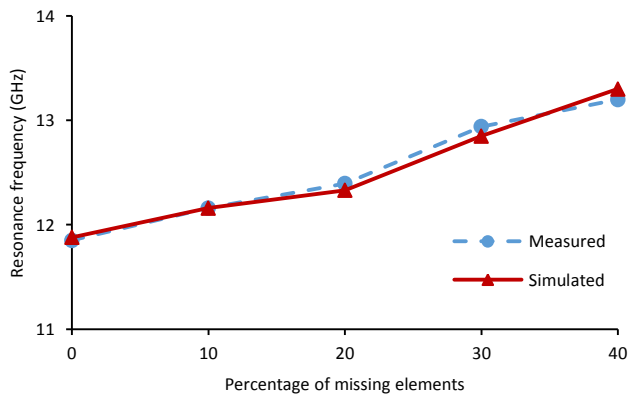


Fig.5 Resonance frequency

TABLE 1 SUMMARY OF RESULTS

% Absent elements	$f_r$ (GHz)		S <sub>21</sub> (dB)		BW (GHz)	
	S	M	S	M	S	M
0	11.9	11.9	-45	-35	4.3	4.1
10	12.2	12.2	-31	-29	4.2	4.0
20	12.3	12.3	-22	-19	3.7	3.3
30	12.8	12.9	-19	-17	3.2	2.8
40	13.3	13.2	-17	-15	2.3	1.2

IV. DISCUSSION AND CONCLUSIONS

In a parallel study on the influence of defects in arrays of linear dipoles on squared and skewed lattices [8] it was again found that errors in 15-20% of the elements at random locations could be tolerated if a null depth of 20dB was taken as a benchmark, although those FSS were slightly more sensitive to faults.

As an indication of the improvement that might be obtained through the use of FSS in buildings, suppressing the external interference by 15dB can reduce the outage probability in mobile communications by more than a factor of 20 [9]. Furthermore, in square law propagation conditions a 10dB attenuation of the co-channel interference level shortens the co-channel separation required, and therefore the cell size, by a factor of about three. The results presented here demonstrate that meeting such performance requirements should be readily achievable using manufacturing methods that do not meet the quality standards demanded for applications such as, for example, might be found in multiband satellite communication systems.

B. 10 dB Reflection Bandwidth

In addition to frequency drift, the available reflection bandwidth is also affected by element absence. The measured -10dB width for the complete FSS is about 4GHz and this is reduced by about 2% (50 MHz) and 20% (900 MHz), respectively for 10 and 20% missing elements (Fig.6). Larger bandwidth reductions of 30% and 70% are experienced when 30 and 40% of the elements are missing, a situation expected to be out of specification for any system.

The measured and simulated resonant frequencies, transmission null depths, and 10dB bandwidth of the five square loop arrays are summarized in Table 1.

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