Influence of defective elements on the performance of frequency selective surfaces

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This letter describes the performance of FSS arrays in which some of the conducting elements at randomly chosen locations were absent or defective. The aim was to assess the proportion of defects that can be tolerated when low-cost fabrication techniques are employed.

Introduction **:** Frequency Selective surfaces (FSS) are well known electromagnetic structures; they have been used in such applications as multiband reflectors in the form of curved secondary mirrors, in multiband feed systems, and as spatial filters used in side lobe suppression and beam forming [1-2].

Suitable screening in buildings can reduce co-channel interference and increase the signal to interference ratio, thereby decreasing the outage probability [3-4]. Recently FSS panels have been proposed for use in buildings to improve wireless communications at long wavelength mobile bands, where the limited available frequency spectrum demands frequency reuse, and suppression of interference from adjacent buildings or users [5- 6]. The electromagnetic architecture is modified by suitably incorporating those panels in wall structures.

In their simplest form, FSS consist of periodic arrays of conducting elements bonded to suitable supporting dielectric substrates. They are typically fabricated by chemical etching, a subtractive technique where unwanted metal is removed and lost from the substrate surface. An alternative is to use an additive printing technique. Unlike standard etching processes, printers deposit single droplets from a nozzle at the desired positions. Less waste is created, resulting in principle in an economical fabrication process [7]. Drop-on-demand (DOD) print head technology can produce precise and repeatable ink droplets, allowing inkjets to create track dimensions with sufficient resolution to satisfy RF design requirements with realistic manufacturing costs, number of processing steps and fabrication time [8]. The performance of inkjet printed FSS on porous and non-porous substrates has been reported previously [9].

The degree to which fabrication errors can be tolerated is an important issue. In the building industry, low-cost manufacture of acceptable performance components is required, in contrast to, for example, aerospace systems where the high precision fabrication of critical components is essential and often involves the use of expensive specialised materials. This paper summarises the results of an investigation of imperfectly fabricated FSS arrays in which defects were introduced intentionally in two sequential processes. In the first, array elements were removed entirely from random locations, while in the second sequence, small discontinuities were introduced in the conductors of randomly chosen elements. It is important to note that the defective elements were not strongly clustered in this study. The fabricated designs were arrays of linear dipoles on skewed lattices [10] and all structures were also modelled using CST Microwave Studio™ (CST MWS™). In order to quantify the impact of print error discontinuities, 20 dB null-depth was taken as the limit of acceptable band stop performance, corresponding to 1% signal transmission through the structure.

Configuration of the FSS: The structure consisted of 374 patch dipoles set on a skewed lattice, as shown in Fig 1. The dipoles were 9.4mm in length, with horizontal spacing $Dx = 1$mm, and vertical spacing $Dy = 2$mm. All dipoles had width $w = 0.4$mm and thickness $= 0.01$mm. They were etched on a 0.045mm thick copper clad polyester substrate with relative permittivity $\epsilon_r = 3.5$ and loss tangent $\sigma = 0.02$. The physical size of the FSS was 222×194 mm^2. To obtain the transmission response, they were placed in an aperture in an absorbing screen and 20 dBi waveguide horns were used as signal source and receiver over a frequency range of 10-20 GHz.

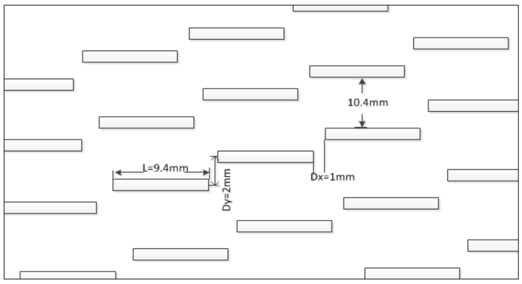

Fig. 1 *The linear dipole FSS*

An initial set of five FSS were made, one was complete, while in each of the others, 20, 30, and 40% proportions of the elements were absent. The missing element locations were chosen using a random number generator in Matlab™.

In the second set, instead of removing the random elements completely, a gap, g of 0.4mm was introduced at the centres of the defective dipoles as shown in Fig.2.

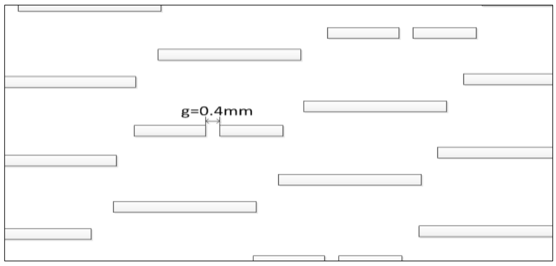

Fig.2 *Skewed lattice dipole arrays with discontinuity in some elements*

Results and discussion: The measured transmission responses of the first set are shown in Fig 3. As the number of missing elements increased, the null depth decreased and a small change in the resonant frequency could be seen as well.

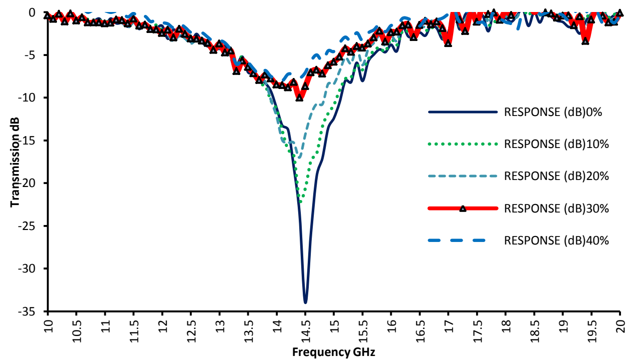

Fig.3 *Measured transmission response (S_{21}) of arrays with missing elements.*

Defects in 10% of the elements (37 dipoles) resulted in a measured depth of 22 dB (dotted curve), and for both simulations and measurements there was a deterioration of about 11 dB relative to the complete perfect array, as illustrated in Table 1.

Table 1: Measured (M) and simulated (S) null depths.

% Defective elements	Missing elements		Broken elements	
	S	**M**	**S**	**M**
0	-38	-33	-38	-33
10	-27	-22	-29	-22
20	-21	-17	-24	-18
30	-15	-10	-16	-10
40	-11	-8	-13	-9

Similarly, defects in 20% of the elements (75 dipoles) degraded the measured performance by a further 4-5 dB and the 20dB depth requirement was not met.

To establish whether or not the trend in Table 1 for dipoles on skewed lattices also applies for FSS of different configurations, elements were randomly removed in the same proportions from other arrays including square loops, dipoles and rings arranged on square lattices. The measured and simulated transmission null depths are given in Table 2.

Table 2 S_{21} (dB) for 3 square lattice FSS arrays with missing elements (S: Simulations, M: Measurements).

% Absent elements	Square lattice dipoles		Square loops		Ring loops	
	S	**M**	**S**	**M**	**S**	**M**
0	-39	-31	-45	-35	-37	-35
10	-23	-23	-31	-29	-27	-26
20	-16	-16	-22	-19	-21	-19
30	-11	-10	-19	-17	-15	-16
40	-8	-9	-17	-15	-13	-14

The measured performance of the square lattice dipole arrays corresponds closely with that of the skewed lattice versions as elements were removed. In this investigation, the square loops and rings had marginally deeper (about 2dB) nulls than the dipole arrays at the 20% missing element level and more clearly deeper at 10%.

*Conclusions***:** A useful benchmark for acceptable performance is indicated by the study reported in [3]. An improvement of 15dB in the carrier to interference ratio in indoor wireless communications can reduce the outage probability by more than a factor of 20. Also a 10dB decrease of co-channel interference enables the cell size in square law propagation conditions to be reduced by about 3. In the absence of strong clustering, which in the extreme case would imply an aperture in the array, the results presented in Tables 1&2 suggest FSS screens can suffer defects in as many as 20 % of the elements and still provide an interference attenuation of about 20dB. This would provide adequate shielding from external interference to reduce the outage probability to the order reported in [3].

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