GA optimisation of crossed dipole FSS array geometry

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Abstract— Crossed dipoles are used as dual polarised elements in frequency selective surface arrays but the transmission response is angle of incidence dependent. A genetic algorithm has been used to minimise the drift of the reflection band, stabilising it for a wide range of angles, to beyond 60°, even on thin substrates.

1. Introduction

An issue in the design of frequency selective surfaces (FSS) is the dependence of the frequency response on the wave incidence angles (θ and ϕ) and polarisation state. Sensitivity to variations in the azimuth angle ϕ is reduced by choosing element geometries with dual axial symmetry, e.g. square loops and crossed dipoles. Invariance to the state of wave polarisation is difficult to achieve [1], but with careful design can often be brought within acceptable bounds over a limited range of angles of incidence. For TM-polarised waves incident on patch elements the reflection bandwidth varies, but for TE-incidence the resonance usually drifts in frequency (Fig. 1*a*).

The aim of the study outlined in this Letter was to improve the angular stability of the frequency response of FSS composed of crossed dipole arrays [2] by optimising the lattice geometry (Fig. 2). Crossed dipoles were chosen as interleaving them enables moderately dense lattices to be used, with the element dimension L being larger than the lattice distances d1 and d2. A genetic algorithm (GA) was chosen as the optimisation tool due to its natural ability to solve problems with a relatively large number of parameters. In this case there were five: d1, d2, a1, a2, and L. Their values were coded into binary genes, reserving 10 bits for each. Gray code representation was used to smooth the optimisation procedure, so neighbouring quantisation levels values then always differ by only one bit, whereas standard binary coding can require several bits to change in order to reach the neighbouring value. Additional geometric constraints were imposed on the lattice parameters to avoid overlapping the crossed dipole elements. A standard widely available GA package PGAPACK [3, 4] was combined with an FSS solver based on Floquet modal analysis and using roof-top functions to represent the induced currents. The population size was chosen to be 100, with the five most fit strings from each generation being retained. Other main optimisation parameters (mutation rate, crossover type, population replacement type) took default values provided by PGAPACK.

The fitness function for the problem was chosen to be:

$$FF = \sum_{i,j,k} \left| T(\phi_i, \sigma_j, \theta_k) \right| \qquad (1)$$

where T is the plane wave transmission coefficient amplitude. The GA routine sought to minimise this function, at a prescribed frequency.

Results illustrating the improvement in performance have been obtained for the case of a crossed dipole array with a reflection band near 30 GHz, and supported on a dielectric substrate 0.03 mm thick with εr = 3.0 and tan δ = 0.021. The aim was to stabilise the frequency of resonance. The polarisation angle σ (Fig. 2) took two values, 0° and 90°, corresponding to the main incidence states, TE and TM, for linearly polarised waves. The elevation angles θ chosen were 1° and 45°. In one example illustrated here, the angle ϕ had only a single value 0°, while in the second it took three values: 0°, 30° and 60°. Almost perfect independence to variations in θ was observed for the case of constant ϕ (Fig. 1b). It should be noted that although only two values of the angle θ had been involved in the fitness function (eqn. 1), the solver showed that the resonance frequency for this design was highly stable for values of θ up to at least 85°. The drift seen in Fig. 1a has been virtually eliminated. In applications where the FSS is illuminated by non-collimated beams the angle ϕ varies across the array. For this more general case, with three values of ϕ taken into account in the fitness function, results are presented in Fig. 3. There is now slightly more drift for TE polarisation compared with the previous case but this is still significantly smaller than in Fig. 1a. The diagrams also show the resulting geometries of the FSS lattice. The optimised unit cells are not rectangular, and the lattice spacings d1 and d2 are smaller than the crossed dipole dimension L.

Conclusion: The arrays located by the GA are all closely spaced: closer packing of the crosses increases the capacitive coupling between neighbouring elements, which is linked with the improved stability of the frequency response. An additional advantage of using these denser lattices is a further separation of the reflection band from the frequency of onset of grating responses.

Acknowledgments: This work was supported by the UK Engineering and Physical Sciences Research Council and by the UK Defence Evaluation and Research Agency.

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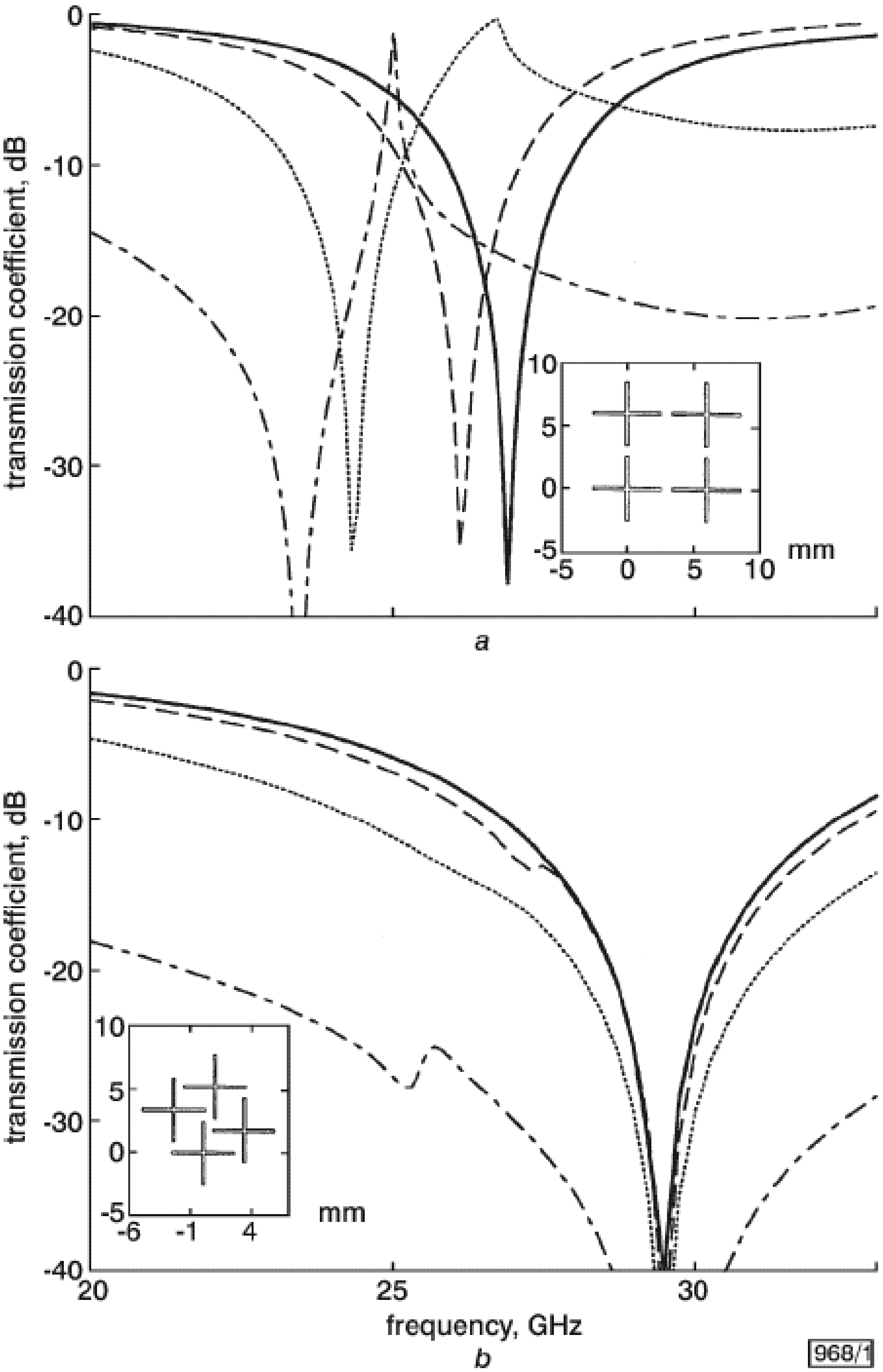

Fig. 1 *Computed plane wave transmission responses*

TE incidence, $\phi = 0°$
———— normal
– – – – – $\theta = 30°$
··········· $\theta = 60°$
— - — - $\theta = 85°$
a Square lattice, $d_1 = d_2 = 6.0$ mm
b Optimised lattice, $d_1 = 3.9$, $d_2 = 4.2$ mm, $\alpha_1 = 29°$, $\alpha_2 = 125°$, $L = 5.1$ mm

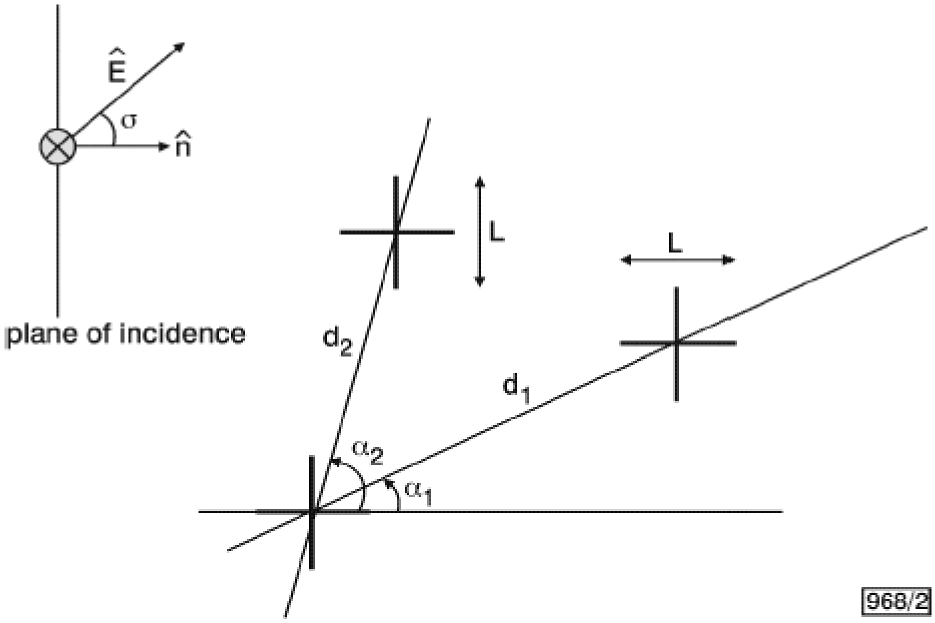

Fig. 2 *Orientation of incident E field relative to plane of incidence and geometry of dipole FSS arrays*

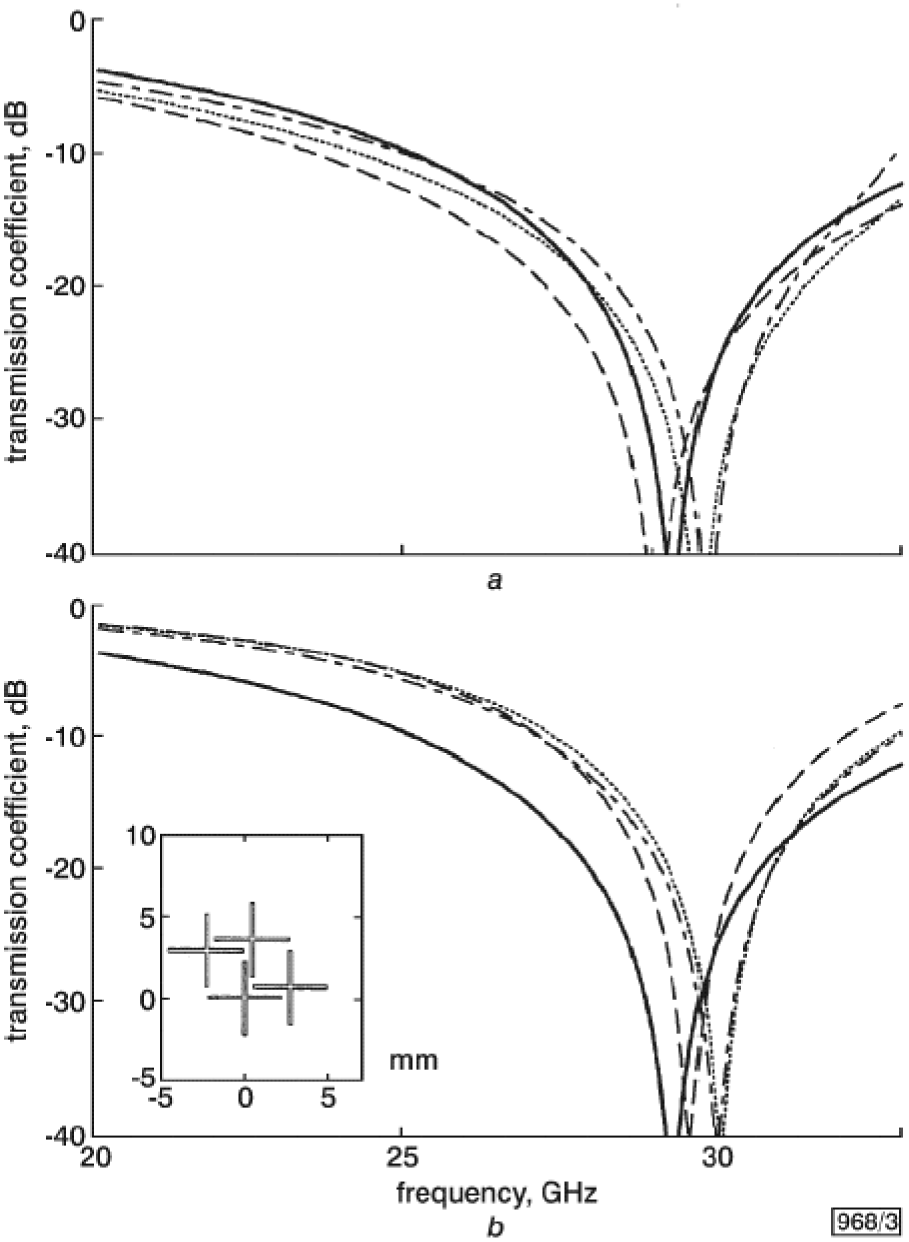

Fig. 3 *Transmission responses optimised for* ϕ *= 0, 30 and 60°*

$d_1 = 2.9$ mm, $d_2 = 3.7$ mm, $\alpha_1 = 14°$, $\alpha_2 = 129°$, $L = 4.5$ mm
a TE
b TM
——— normal
– – – – – $\phi = 0°$, $\theta = 45°$
- - - - - - $\phi = 30°$, $\theta = 45°$
— - — - $\phi = 60°$, $\theta = 45°$