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Enquiries

Resonant frequencies of open and closed loop frequency selective surface arrays

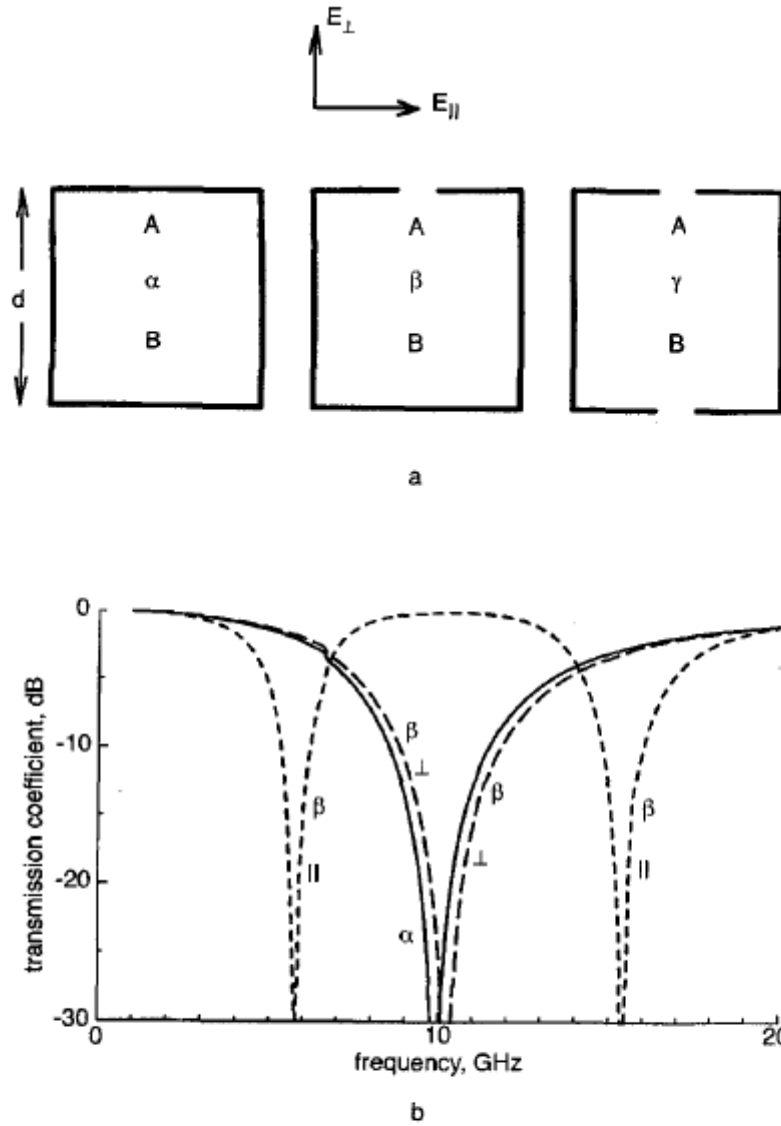**A.D. Chuprin, E.A. Parker and J.C. Batchelor**

Resonant frequencies of open and closed loop frequency selective surface arrays

A.D. Chuprin, E.A. Parker and J.C. Batchelor

Abstract:

The effects on the transmission responses of loop element frequency selective surface arrays of breaking the conductor at suitable locations are described for simple squares and for highly convoluted geometries based on Peano curves. This simple modifcation generates a large reduction in the reflection band frequency for a fixed unit cell size.

The square loop, either in single or double form, has been used as an element for frequency selective surface (FSS) arrays over a wide range of frequencies, from microwave to submillimetre wavelengths [l]. Single loop FSS have a simple transmission frequency response, in the patch version consisting of a reflection resonance, with a transmission band at low frequencies. There is also usually an upper transmission band, which has a width determined by the proximity of the reflection band to grating frequency, set by the array periodicity p. Fig. la shows a single square loop element of side d. In Fig. lb the computed transmission response of an array of these elements with $p = 8.0°$ and $d = 7.0°$ is plotted for normal plane wave incidence. The array was supported on a dielectric substrate 0.03mm thick, with $\varepsilon_r = 3.0$. The solid curve shows the resonance occurring at $f_r = 10$GHz.

$E_\perp$

$E_\parallel$

d

A
α
B

A
β
B

A
γ
B

a

transmission coefficient, dB

β
⊥
β
⊥
β
∥
α
β
∥

0   10   20
frequency, GHz

b

**Fig. 1** *Geometry of square elements and transmission responses*

a Geometry of square elements
b Computed plane wave transmission responses of arrays of elements
α and β, normal incidence

Table 1: Resonant frequencies (GHz) for the three square elements in Fig. 1a

poln.	$f_{r\alpha}$	$f_{r\beta}$	$f_{r\gamma}$	$f_{r\beta}/f_{r\alpha}$	$f_{r\gamma}/f_{r\alpha}$	$f_{r\alpha}^\uparrow/f_{r\alpha}^\rightarrow$	$f_{r\beta}^\uparrow/f_{r\beta}^\rightarrow$	$f_{r\gamma}^\uparrow/f_{r\gamma}^\rightarrow$
↑	10	10	11	1.0	1.1	1.0	1.8	0.46
→	10	5.8	23	0.58	2.3			

3

The element is symmetrical and so this response is unaltered when the orientation of the incident E field vector is switched between the two directions ∥ and ⊥. At this resonance, the distribution of the induced current around the element is approximately sinusoidal, and for the ⊥ incidence direction has nulls at the points A and B in diagram α, with maxima on the other two sides of the square. Consequently, breaking the conductor at A in diagram *p* or at A and B in *y* has almost no effect on the transmission response, as shown by comparing the solid curve and the broken curve labelled ⊥.

An important change occurs in the response of β however when the incident E field is parallel to the gap A. The element resonates in a mode with a current null at A only, increasing the resonant wavelength by almost a factor of 2, as shown by the curve labelled ∥ in Fig. 1b. A second resonance appears at about 16GHz. These results are summarised in Table 1, where it can be seen that element *y* resonates at a much higher frequency, at 23GHz. For linear polarisation, opening the loop is therefore a way of increasing the resonant wavelength λ_r, of a square element FSS, increasing the separation of the reflection band from the grating frequency since the periodicity *p* is unaltered. Alternatively, for a given reflection frequency the array unit cell becomes smaller, an advantage when designing small dichroic screens for use at long wavelengths. A parameter which indicates the performance of these FSS is the figure of merit h)p, the resonant wavelength normalised by the unit cell size. For the closed square the value is ~4, and for the open case it is 6.5.
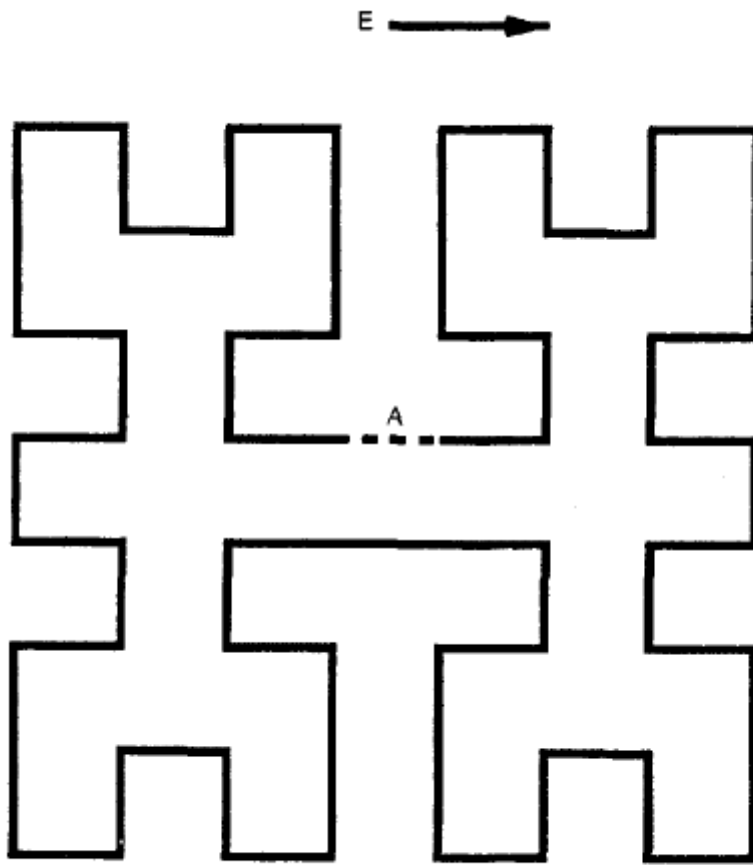
Fig. 2 *Geometry of Peano curve element*

An alternative means of lowering the reflection band frequency for a unit cell of futed size, by folding the element conductor, has been studied in earlier work [2]. Several highly convoluted conductor configurations were described, including some based on Peano space filling curves. One such curve is illustrated in Fig. 2. It is interesting to discover whether or not a similar increase in the resonant wavelengths occurs when this much more complicated loop is opened in an array of these elements. Fig. 3 shows the transmission response computed for normal incidence, and for TE and TM incidence at 45°. The overall size of the element d is again 7.0° and the periodicity p is the same dimensions as for the simple square element FSS. The gap at *A* in Fig. 2 is closed, and the resonant frequency5 is 6GHz, compared with l0GHz for the closed

5

square. λ_r /p is about 6, similar to the value for the open square. Note that f, is very stable when the angle of incidence is altered. In Fig. 3 the component of the incident E field that is in the plane of the array remains parallel to the conductor segment A. Interrupting the conductor at A does reduce 5, as shown in Fig. 4. It remains very stable to the angle of incidence. λ_r /p has increased to almost 12, more than six times the value available from simple dipole element FSS. There is also a second stable reflection band at about 9GHz. Between the two there is a useful transmission band, with a width of about 40% between the 4.5dB points. In the TM case though, (the broken curves), a crosspolar component is generated in the reflection band: the plane of incidence is parallel to the gap and relative to that plane the open element is asymmetrical.

We conclude that altering the current distribution on loop element FSS by the simple process of breaking the conductor at suitable locations is an effective method for generating a large reduction in the reflection band frequency for a fixed unit cell size.

A.D. Chuprin, E.A. Parker and J.C. Batchelor (Electronic Engineering Department, University of Kent, Canterbury CT2 7NT, United Kingdom)

E-mail: E.A.Parker@ukc.ac.uk

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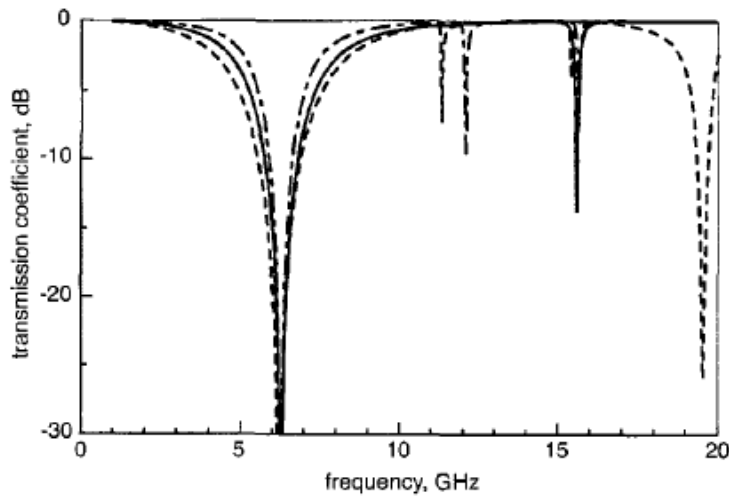
Fig. 3 *Computed transmission response of array of elements in Fig. 2, gap A closed*

——— normal incidence
– – – – TE incidence at 45°
— · — · TM incidence at 45°
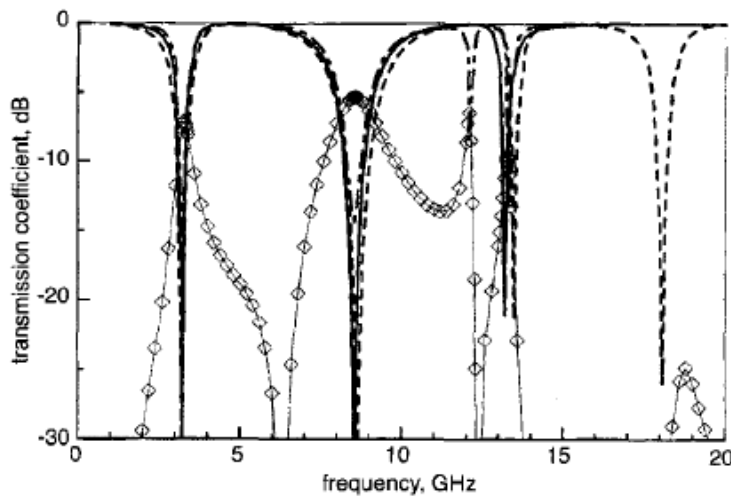
Fig. 4 *Transmission response with gap at A*

——— normal incidence
– – – – TE incidence at 45°
— · — · TM incidence at 45°
◇ TM incidence at 45°, cross-polar