Multi-Band Frequency Selective Surface Design Based on Idea of Clusters in Cellular Communication Systems

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Abstract **─** A frequency selective surface which can provide up to 4 passbands will be proposed. The passbands are nearly independent so it simplifies the design procedure. The base of the design is according to frequency reuse in cellular communications which there are N different frequencies in one cluster. The array cells in this FSS are hexagons and the resonators on top and bottom of each cell are aperture loops. As the elements and cells are in the most geometrical symmetry, stability about polarization and angle of incidence is in the good state. As some examples, a dual-band, a triple-band and a quad-band FSS are simulated with CST software. The results are in good agreement with theoretical calculations.

Index Terms **─** Aperture loop, cluster size, dual-band FSS, frequency selective surface (FSS), quad-band FSS, triple-band FSS.

I. INTRODUCTION

In many communicational systems we need to design frequency selective surfaces with more than one passband [1] such as dual-band, triple-band [1]-[2] and even quad-band [3] structures. In these multiband FSSs, it is hard to design the whole structure entirely and it is valuable to have a procedure which passbands can be designed independently and separately in it [4], after that whole structure is constructed by adding these independent designs [1].

To have the most stable frequency response for a bandpass FSS, the best choice is circular aperture, for its geometrical symmetry [5]. Also, to select the array cells, a good choice is hexagon because it is nearly similar to a circle and compatible with aperture loop and it can cover surface perfectly. By using hexagonal array cells, a honeycomb structure is raised which can be related to cellular communications. Keep in mind that in those systems, for frequency reuse, it is routine that the centre frequencies are selected deferent from each other and some clusters are constructed [6]. In the next section, a short introduction of this concept is proposed; however, one of the possible cases is the cluster size of 4. The configuration of cells in this cluster size is shown in Fig. 1.

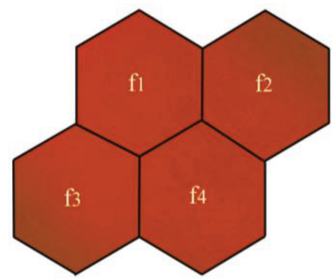

Fig. 1. Cluster size of 4.

If the resonant frequency of circular aperture available in each cluster is selected according to Fig. 2, a multiband FSS with four passbands can be implemented. If two or three passbands are needed, three or two apertures can be selected the same, respectively. So by this configuration, a FSS with 2, 3 or 4 passbands is designed. Modularity of passbands cause to simplify multiband designing, so preliminary design is simple to do. Then final optimization will be completed by some tuning of the geometrical parameters.

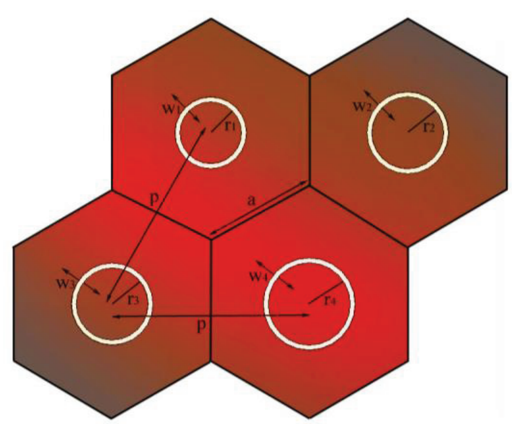

Fig. 2. Geometry of a multiband FSS.

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II. DESIGN

The resonant frequency of a circular aperture can be estimated by the approximate equation in (1), which was only suitable for the calculating the resonant frequency of conventional aperture type FSS [7]:

$$f_r = \frac{c}{\sqrt{\varepsilon_{eff}}} \frac{1.2}{2\pi(r + w/2)}, \tag{1}$$

c is speed of light in free space. ε_{eff} for thin substrate, can be calculated from equation (2) [8]:

$$\varepsilon_{eff} = \varepsilon_r + (1-\varepsilon_r)e^{-Nx}. \tag{2}$$

N is an exponential factor, this parameter varies for different cell shapes, here, it is 2.2, x is:

$$x = \frac{10t}{\lambda_0}, \tag{3}$$

where λ_0 is free space wavelength and t is thickness of substrate.

Which c is the speed of light in free space, r is the inner radius and w is the width of aperture. For the design of multiband FSS, the centre frequency of each band is independently designed with a circular resonator with f_r according to equation (1). This aperture exists on top and bottom of substrate. There are some coupling effects that vary a little resonant frequency that in the final tuning frequency response can be optimized.

In cellular communication, cluster size, N, is selected according to how many frequencies are needed. This number is equal to (4) [6]:

$$N = i^2 + j^2 + ij. \tag{4}$$

Here i and j are positive integers or zero and $i \geq j$. According to Fig. 3, i and j are shift parameters, means move i cells from centre of a reference cell along any of the sides of hexagons, turn anticlockwise by 60° and then move j cells along this direction, leads to the same frequency as the reference [6]. Any value of N given by this relationship produce clusters which cover the whole surface with N independent f_r. Some examples of different N are shown in Fig. 4.

In cellular system $N=7$ is the preferable number to design. In our purpose for multiband FSS, $N=4$ is sufficient and good choice.

For FSS with rectangular cells periodicity is along two perpendicular axes but for a FSS with honeycomb structure elements arranged periodically along coordinates that enclose the 60° angle [9]. To prevent making grating lobes, the distance between elements along two coordinates should be smaller than $\lambda/2$ [10].

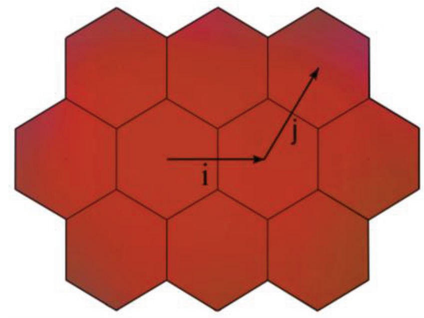

Fig. 3. Geometry of a multi-band FSS.

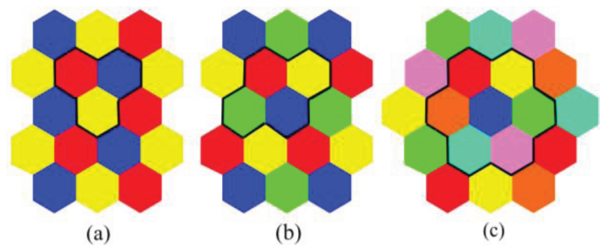

Fig. 4. Some cluster sizes: (a) N=3, (b) N=4, and (c) N=7.

III. SIMULATED RESULTS

In the previous section it is shown that 2, 3 or 4 passbands with the proposed FSS can be achieved. In this section, three examples proposed for dual-band, triple-band and quad-band FSS.

A. Design for dual-band FSS

According to the notes and relationship mentioned in the previous section, and for the geometry of Fig. 2, the geometrical parameters of a dual-band FSS are described in Table 1. As it is mentioned in the previous section to achieve two passbands, two resonators should be selected similar. The dielectric constant and height for substrate is 2.65 and 1.5 *mm*.

Table 1: Geometrical parameters for dual-band FSS

Parameter	Value (mm)	Parameter	Value (mm)
r_1	3	w_2	0.55
r_2	3.25	w_3	0.55
r_3	3.25	w_4	0.44
r_4	3	a	9.5
w_1	0.44	p	16.45

According to r_i and w_i ($i=1,4$) and equation (1), the resonant frequencies can be listed as Table 2.

Table 2: Calculated resonant frequencies for dual-band FSS

Resonant Frequency	Value (GHz)
f_1	11.06
f_2	12.11

The transmission and reflection coefficient of simulated FSS is shown in Fig. 5. There are two passbands in frequencies which are calculated with equation (1).

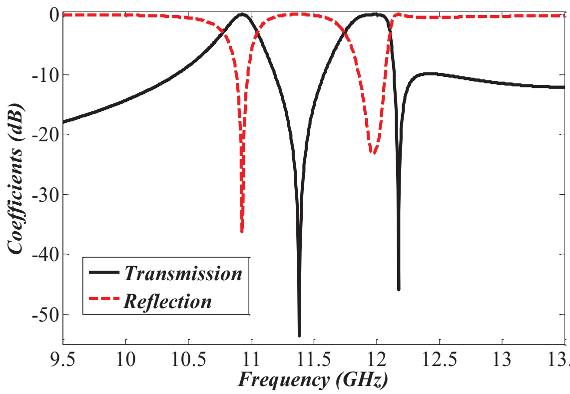

Fig. 5. Transmission and reflection coefficient for dual-band FSS.

B. Design for triple-band FSS

The geometrical parameters of a triple-band FSS are described in Table 3. In addition, dielectric constant and height for substrate is fixed in all three examples. Again, two resonators are selected the same.

Table 3: Geometrical parameters for triple-band FSS

Parameter	Value (mm)	Parameter	Value (mm)
r_1	2.7	w_2	0.44
r_2	3.15	w_3	0.44
r_3	3.15	w_4	0.44
r_4	3.6	a	10
w_1	0.44	p	17.3

Again with these new r_i and w_i, three resonant frequencies are calculated according to Table 4.

Table 4: Calculated resonant frequencies for triple-band FSS

Resonant Frequency	Value (GHz)
f_1	10.21
f_2	11.57
f_3	13.35

The transmission and reflection coefficient of simulated triple-band FSS is shown in Fig. 6. As it is clear from this figure, three passbands which are obtained from simulation are compatible with calculated ones.

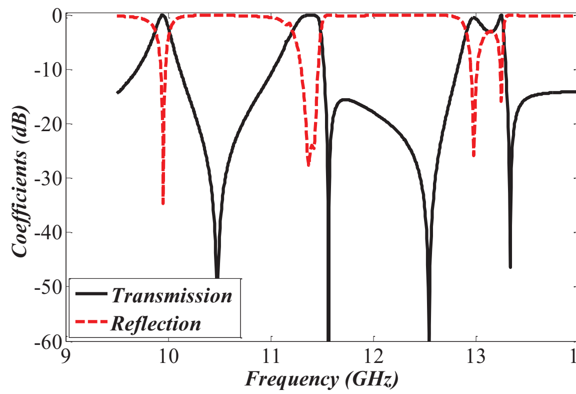

Fig. 6. Transmission and reflection coefficient for triple-band FSS.

C. Design for quad-band FSS

The geometrical parameters for a quad-band FSS are listed in Table 5.

Table 5: Geometrical parameters for quad-band FSS

Parameter	Value (mm)	Parameter	Value (mm)
r_1	2.7	w_2	0.49
r_2	3.0	w_3	0.5
r_3	3.3	w_4	0.44
r_4	3.6	a	10
w_1	0.4	p	17.32

For this new configuration, four resonant frequencies are calculated with equation (1). Table 6 shows these resonances.

Table 6: Calculated resonant frequencies for quad-band FSS

Resonant Frequency	Value (GHz)
f_1	10.21
f_2	10.98
f_3	12.01
f_4	13.45

In Fig. 7, the transmission and reflection coefficient of simulated FSS is represented. Four separate passbands are obtained in this figure, which except for third resonance, the others are in good agreement with calculations.

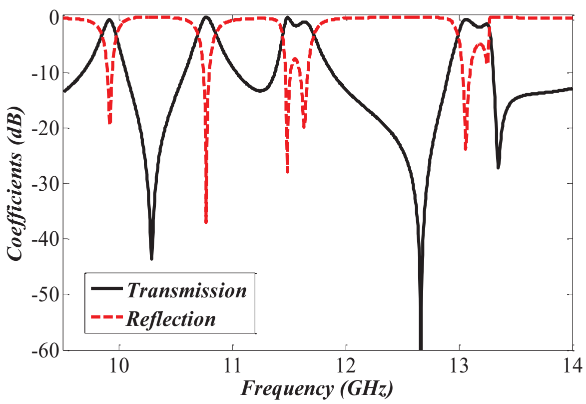

Fig. 7. Transmission and reflection coefficient for quad-band FSS.

IV. CONCLUSION

Multiband FSS based on aperture loop and hexagonal cells was proposed, which can produce up to four passbands. The transmission bands are designed separately and independently, so the design procedure can be simple to do. Three examples, dual-band, triple-band and quad-band FSS, were simulated to show how this passbands can be achieved.

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