EIGHT-LEGGED RESONANT ELEMENT FOR MULTIBAND FSS AND ITS EXPERIMENTAL VERIFICATION

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1. Introduction

Recently, single-layer frequency selective surfaces (FSSs) for multiband operation of spatial filters have been realized by developing the geometry of resonant elements. To archive the purpose, dual-resonant patch elements such as a double square loop (DSL), [1] a convoluted double square (CDS) [2] and Fractal shapes [3] have been reported so far. The Fractal FSSs have the limitation in the separation of two reflection bands, whereas the DSL and the CDS can control it by varying the relative sizes of the two square components [2]. On the other hand, we have already developed a multiband single-layer FSS by optimizing an element shape using a genetic algorithm (GA) [4], [5], so that the reflection bands broader than the previous FSSs can be realized. The GA-designed FSSs also have two resonant frequencies, but the two reflection bands can not be easily changed since the element shapes are complicated. To understand the resonant property, we have investigated the mechanism in details [6].

On the basis of the resonant currents, this paper proposes a new simple element that has two resonant frequencies for full reflection at dual bands. The geometry is drastically simplified, compared with the GA-designed elements. The proposed patch element is called hereafter eight-legged element from the view point of the geometry. To prove the effectiveness of the eight-legged element, the transmission responses at normal plane-wave incidence are shown for various geometrical parameters. And it is confirmed from the results that the FSS has the high flexibility in the reflection-band separation. Furthermore, to realize the broader reflection bandwidth, we add the resonant grid into the eight-legged element [7]. The verification of the simulated results is performed by the experiments.

2. Resonant Characteristics

Fig. 1 shows the two-dimensional infinite periodic structure consisting of the proposed eight-legged resonant elements, and their unit cell. The x and y directed periodic spacing are represented by p_x and p_y, respectively, and the angle of incidence is denoted by θ. The eight-legged element is the conductor patch with the eight legs (length l and width w). For simplicity, the geometry is symmetrical with respect to both x and y axes to work for dual polarizations.

To investigate the resonant characteristics, Fig. 2 shows the transmission responses at the normal plane-wave incidence for various geometrical parameters. The characteristics are simulated by a Floquet modal analysis. The FSS is backed by a dielectric substrate of 1.6 mm thick with $\varepsilon_r = 4.3$. The periodic spacing is set to be $p_x = p_y = 11.0$ [mm]. It is observed from Fig. 2(a) that the first resonant frequency f_{r1} shifts to lower frequency with the length d increased, while the second one f_{r2} does not almost change. In this case, the unit cell is not required to change its size, unlike the DSL and the CDS. As a result, the bandwidth reduction due to the grating lobe can be avoided at higher reflection band at f_{r2}. Fig. 2(b) shows that the second resonant frequency f_{r2} can be made higher by widening the leg width w and keeping the gap g. Also, f_{r1} and f_{r2} shift to higher frequency simultaneously as the leg length l becomes longer, as shown in Fig. 2(c). In above results, the reflection-band ratio f_{r2}/f_{r1} is in the range from 1.3 to 2.0. In Fig. 2(d), the close reflection-band separation $f_{r2}/f_{r1} = 1.3$ can be realized by making the gap g narrower. Consequently, the eight-legged resonant element can easily control the band ratio of two reflection bands for a fixed unit cell.

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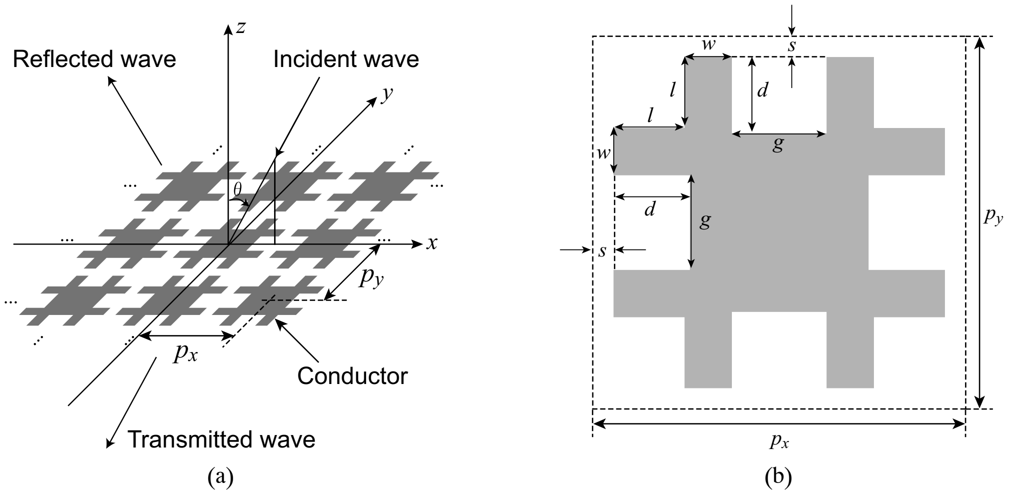


Fig. 1. FSS with eight-legged elements. (a) Two-dimensional periodic structure and (b) the unit cell.

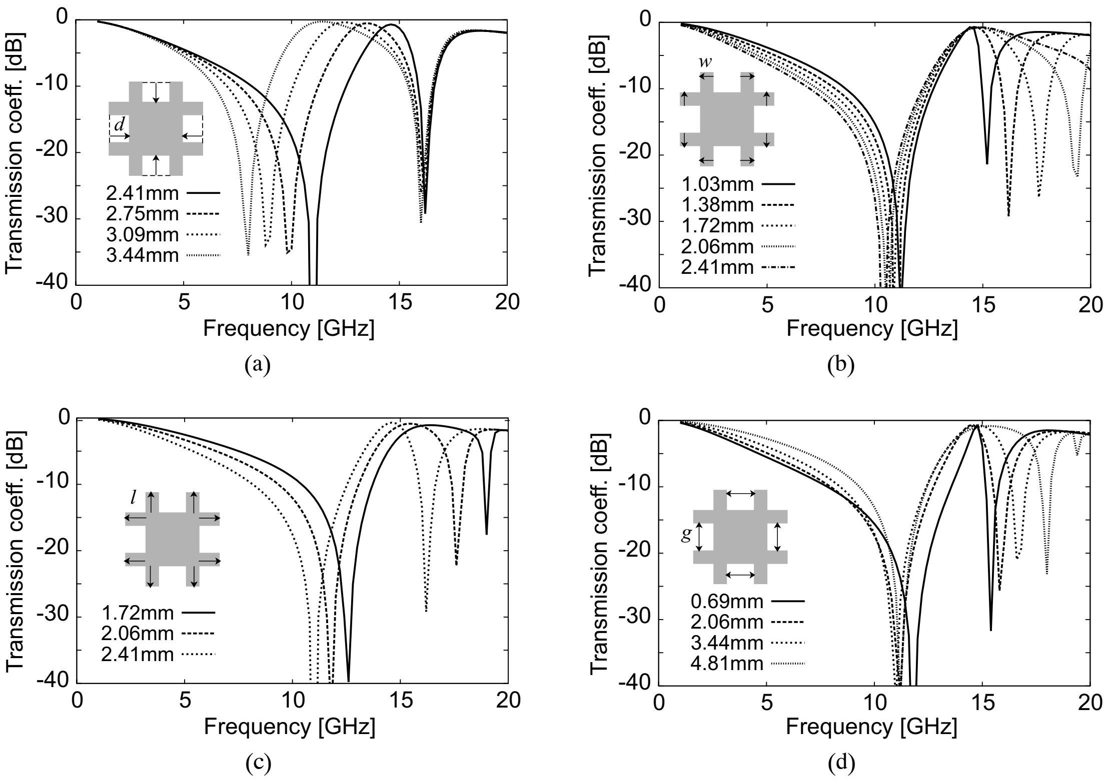
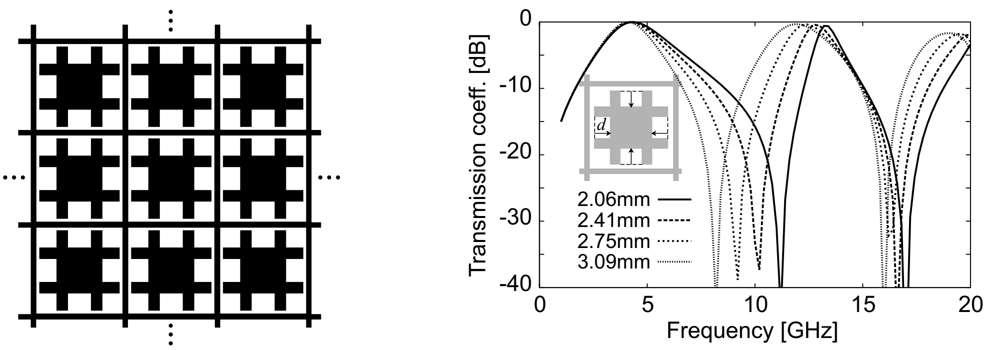


Fig. 2. Transmissino characteristics of eight-legged resonant element for various parameters of (a) the inner length d (l: fixed), (b) the leg width w (g: fixed), (c) the leg length $l(= d)$ and (d) the gap g. Geometrical parameters: $w = 1.38$, $l = 2.41$, $d = 2.41$, $g = 2.75$, $s = 0.34$, Periodic spacing: $p_x = p_y = 11.0$ (unit: mm).

The eight-legged element has the problem that the second reflection band is narrow, of which the fractional bandwidth is about 0.05 and that of the first resonant frequency is about 0.25–0.40. It refers to the -10dB levels. To obtain the broader reflection bandwidth, the combination of a resonant grid and the proposed elements is utilized here [7]. The FSS is called hereafter the gridded eight-legged element. The structure and its frequency characteristics are shown in Fig. 3. The fractional bandwidth at the second reflection band is improved in the range 0.13–0.22, of which the values are sufficient to construct reflection band. In addition, a new full transmission point f_t appears at lower frequency. The transmission at f_t is generated by the resonance of the aperture between the eight-legged element and the grid. These multiple resonant frequencies can be useful for design of a single-layer multiband FSS.



(a) (b)

Fig. 3. Gridded eight-legged elements. (a) The structure and (b) the transmission responses for normal plane-wave incidence. Geometrical parameters: $w = 1.38$, $l = 2.41$, $g = 2.75$, $s = 0.34$, Grid conductor width: 0.69, Periodic spacing: $p_x = p_y = 11.0$ (unit: mm).

3. Experimental Verification

To prove the validity of the eight-legged element, the FSSs are fabricated by etching technique in our laboratory, and the measurements of the frequency characteristics are performed. Fig. 4 gives the photographs of the fabricated eight-legged elements and gridded ones. The periodic spacing is the same as the previous section. Each FSS consists of 442 elements supported by a dielectric substrate of 1.6 mm thick with $\varepsilon_r = 4.29$. Fig. 5 shows the comparison of the transmission and the reflection characteristics for TE and TM oblique incidences at $\theta = 20^\circ$ between the measured and the calculated results of the FSS with eight-legged elements. Fig. 6 also shows those of the gridded ones. In the numerical analysis, the dielectric loss (loss tangent 0.02) is taken into account. In both figures, the measured results agree very well with the calculated results. Although the sharp dips at 9 GHz except for Fig. 5(b) are caused by singular resonances [8], the transmission and reflection responses including the singular behaviors are in good agreements between the measured and the calculated results. It can be confirmed numerically and experimentally that the resonant frequencies f_{r1} and f_{r2} are not so sensitive to both the angle of incidence and the incident polarization. Also, the cross-polarized components are much less than -40dB. Therefore, the effectiveness of the proposed resonant element can be validated.

4. Conclusions

The eight-legged resonant element has been proposed for realizing multiband operation of spatial filters. The patch element has two resonant frequencies, which can be easily controlled by adjusting the shape of the element. In addition, introducing the resonant grid has improved the reflection bandwidth at higher band. The proposed FSS is superior to our GA-designed FSSs in the easy fabrication and the flexibility of the band separation. Finally, from the good agreement between the measured and the calculated results, it can be concluded that the eight-legged element is useful for the design of a multiband FSS.

Acknowledgement

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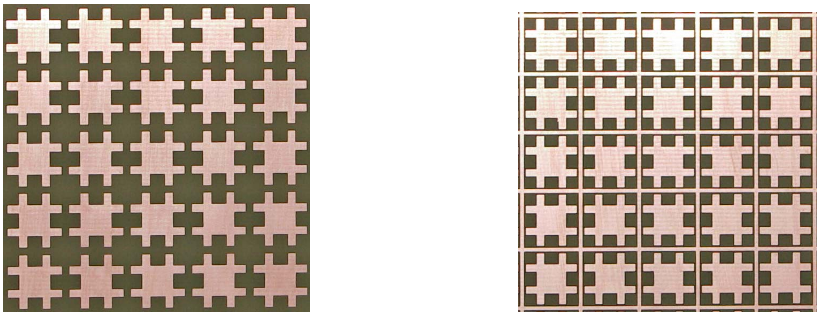
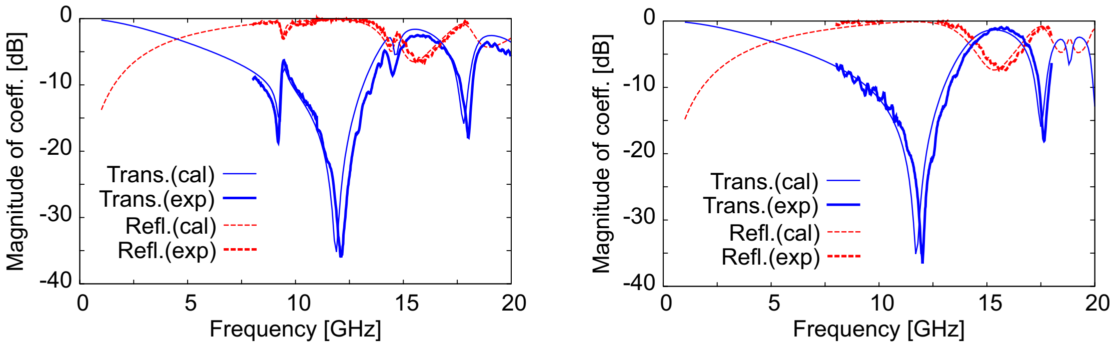


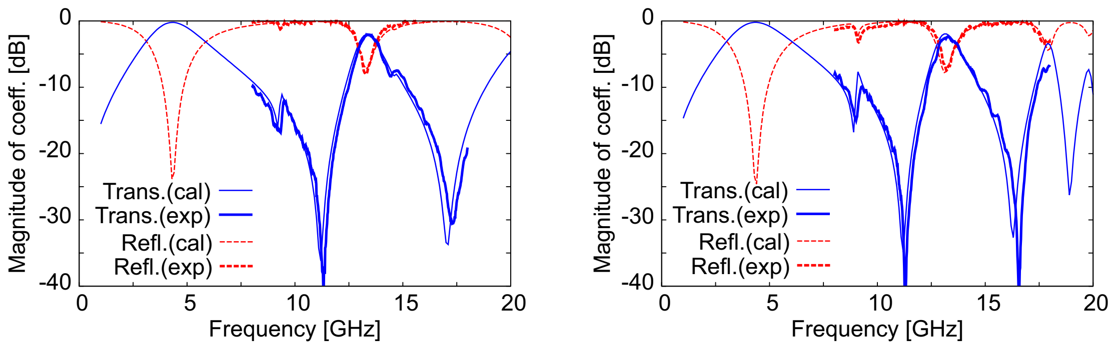
(a) (b)

Fig. 4. Near-view photograph of the fabricated FSSs. (a) Eight-legged elements and (b) gridded ones.



(a) (b)

Fig. 5. Comparison of the frequency characteristics between the calculated and the measured results of the FSS with eight-legged element.



(a) (b)

Fig. 6. Comparison of the frequency characteristics between the calculated and the measured results of the gridded eight-legged elements.

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