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DUAL-BAND FREQUENCY SELECTIVE SURFACE WITH MINIATURIZED ELEMENT IN LOW FREQUENCIES

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Abstract—In this paper, we propose a dual-band frequency selective surface (FSS) in low frequencies with miniaturized element. A dual-concentric square element with two different slot sizes is constructed to realize dual-band passband responses. Each passband is realized by a square slot structure. Besides, we reduce the slot sizes to make the element miniature and compact. Based on this technique, a dual-band FSS with miniaturized element in low frequencies is designed. Both the simulation and experiment results show that such a FSS owes its advantages to miniature element, stable performance with various incident angles and different polarizations, which is suitable for dual-band shipboard communication.

1. INTRODUCTION

Frequency selective surfaces (FSSs) are usually composed of periodically arranged metallic patches or slots that function as bandstop or bandpass filters, respectively. For many years, FSSs have been attractive for their various applications in spatial microwave and optical filters. They have been used as polarizers, filters, subreflectors, band-pass hybrid radomes for radar cross section (RCS) controlling [1–6]. For decades, many novel methods have been proposed to obtain

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FSSs with excellent performances. Effects of dielectric loading on FSS were studied by Luebbers and Munk [7]. Complementary FSSs were investigated in [8, 9]. Isotropic FSS were designed by using three-dimensional structures [10]. Miniaturized FSSs whose periodic sizes were much smaller than the operating wavelength were designed and investigated in [11–15]. Coupled-resonator spatial filter (CRSF) FSS was firstly proposed in [16] and further studied in [17, 18], in which two patches are coupled through an aperture to form a higher-order bandpass filter. A convoluted FSS with very small unit cell dimensions was proposed in [19, 20]. Substrate integrated waveguide (SIW) technology was introduced in [21, 22] to design high performance FSSs with high quality factor of open resonance structures.

In some applications, multiband FSSs are needed for the design of dual-reflector antennas. The use of such FSSs has made it possible to share the main reflector among different frequency bands. In addition, multiband FSSs also have been proven as a way to increase the capabilities of satellite communications. In such applications, FSSs with multiple passbands are required. Early studies mainly focused on multi-concentric elements to design multiband FSSs [23, 24]. Two FSSs cascaded on complementary surface layers were studied in [9]. Fractal elements were proposed to design multiband FSSs in [25]. A second-order dual X-/Ka-Band FSS was presented and experimentally verified in [26]. A triband second-order FSS was studied in [27]. Dualband FSS using substrate-integrated waveguide technology was proposed in [28]. To our knowledge, typical radar installations for shipboard are often below 3 GHz and so are most communication systems. In such applications for dual-band shipboard communication, a dual-band FSS in low frequencies is required. Low-frequency miniaturized dual-band FSSs with close band spacing by loading lumped elements were presented in [29, 30]. However, these FSSs in [29, 30] are costly and not easy to be fabricated. In view of these considerations, we propose a dual-band FSS in low frequencies with miniaturized element by constructing a dual-concentric square element with two different slot sizes. Each passband is realized by a square slot structure. Both the simulation and experiment results show that such a FSS owes its advantages to miniature element, stable performance with various incident angles and different polarizations and is easy to be fabricated by the print circuit board (PCB) technology without post processes.

2. DESIGN AND ANALYSIS

Figure 1 shows the front view of the FSS structure. It is a single-layer structure with no metallic structure on the back of the substrate. The metallic structure etched with dual-concentric square slots. Dimensions of the structure are $p = 24.4\,\text{mm}$, $a = 21.6\,\text{mm}$, $w = 0.2\,\text{mm}$. The FSS uses a F4B-2 substrate with relative permittivity of $\varepsilon_r = 2.65$, loss tangent of 0.001 and thickness of $h = 10\,\text{mm}$.

We use the CST Microwave Studio to calculate this FSS's transmission and reflection characteristics. The four sides of the

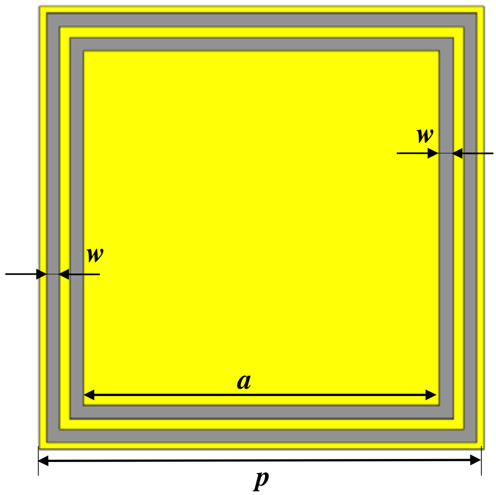


Figure 1. Geometrical configuration of the unit cell. The FSS is a single-layer structure with no metallic structure on the back of the substrate.

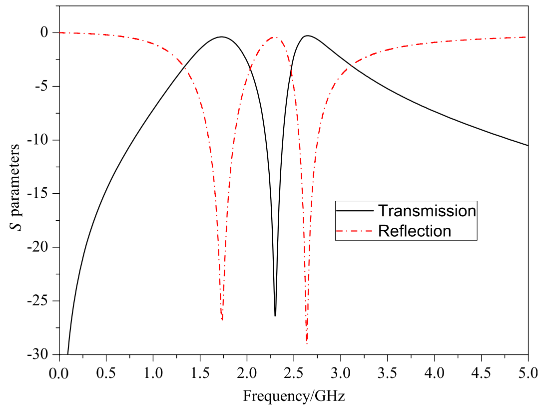


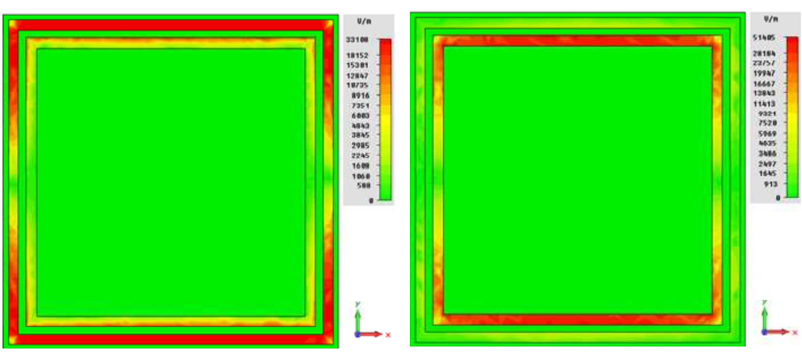
Figure 2. Simulated frequency response of the structure for normal incidence.

unit cell are set to be unit cell conditions. The single unit cell is excited by an incident plane wave with different incident angles and polarizations. Fig. 2 shows the S parameters of the FSS structure for normal incidence. We see that two resonances pole transmission response occur at about 1.73 GHz and 2.64 GHz, respectively. -1 dB bandwidths of the two passbands are 0.31 GHz (1.56–1.87 GHz) and 0.26 GHz (2.55–2.81 GHz), respectively. Periodic size is about $\lambda/7$ of the operating wavelength for the low frequency passband. In order to clarify the physical mechanism of the two passbands, we give the electric field distribution diagrams at 1.73 GHz and 2.64 GHz, which can be seen in Fig. 3. From Fig. 3 we can observe that two electric field resonances occur in the slots at 1.73 GHz and 2.64 GHz, respectively. Outside the two slots, electric field values are very weak. Consequently, the two passbands arise from enhanced transmission assisted by two slot resonances.

3. FSS WITH STABLE PERFORMANCES

As special filters, FSSs are not only functions of frequency, but also functions of incident angle and polarizations of electromagnetic waves. Accordingly, FSS should keep stable performance for both incidence angles and different polarizations within its operating frequencies.

Figure 4 gives the transmission responses under different incident incidence angles for (a) TE polarization and (b) TM polarization. It can be seen from Fig. 4 that the two passbands are rather stable for various incident angles within 45 degrees and different polarizations.



(a) (b)

Figure 3. Electric field distribution diagrams at two different frequencies. (a) 1.73 GHz. (b) 2.64 GHz.

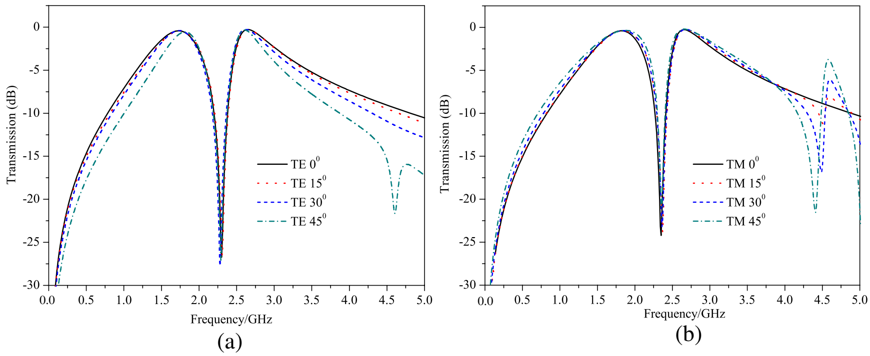


Figure 4. Transmission responses under different incidence angles and polarizations. (a) TE polarization. (b) TM polarization.

For TE polarization, bandwidths of the passband become a litter narrower as the incidence angles increase. However, resonance of the transmission is rather stable even when the incident angle comes to 45 degrees. For TM polarization, bandwidths of the passband become a litter wider as the incident angles increase. And grating lobes appear at about 4.7 GHz when the incidence angles increase to 30 degrees. But the transmission of the grating lobes is still less than −4.0 dB. Consequently, the dual-band FSS keeps good performances for various incidence angles within 45 degrees and different polarizations.

4. EXPERIMENT

The proposed FSS is fabricated by printed circuit board (PCB) technology. Prototype of the FSS structure is shown Fig. 5(a). Substrate of the fabricated FSS is F4B-2, whose relative permittivity is 2.65, loss tangent 0.001, and thickness 10 mm. The overall size of the structure is 244 mm × 244 mm with the array of 10 × 10 unit cells. Free space measurement method is carried out to implement the experiment. Measured and simulated transmission coefficients with a plane wave normal incidence are presented in Fig. 5(b). We can observe from Fig. 5(b) that measured results have the same trend as the simulated ones, but there are some differences. The ripples arise in the measured results, which is mainly attributed to three factors. Firstly, in the simulation, the FSS is an infinite structure, while in the experiment the sample is a finite structure, so edge diffraction will lead to the ripples of the measured results [20]. Secondly, the unit cells of sample are connected because of fabrication precision of the structure. Thirdly, the losses of the measuring system can also cause

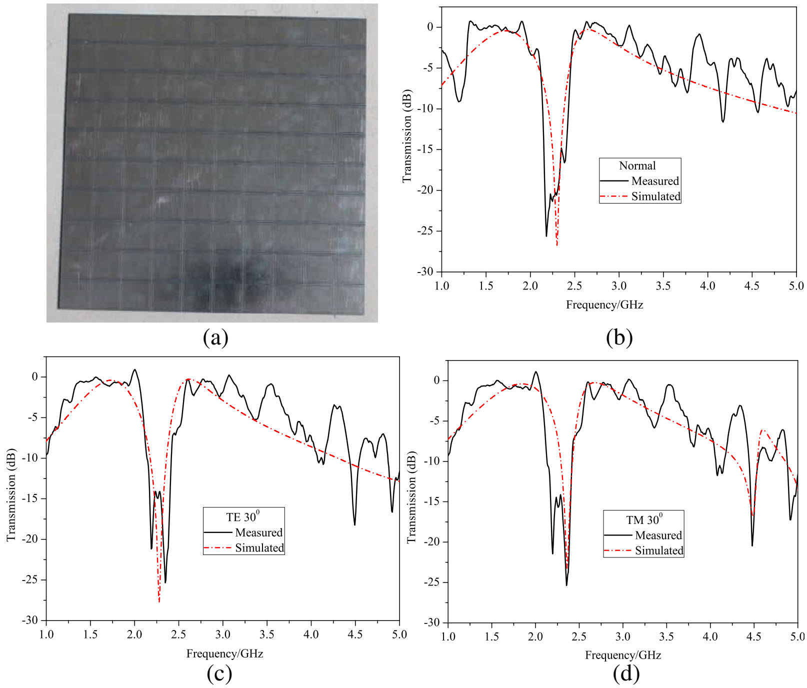


Figure 5. Experiment. (a) Prototype of the fabricated structure. (b) Simulated and measured results comparison with plane wave normal incidence. (c) Measured transmission curves with 30 degrees incident angle with TE polarization. (d) Measured transmission curves with 30 degrees incident angle with TM polarization.

the discrepancies. Limited by the size of the sample, the incident angles in the measurement are limited below 30 degrees. Figs. 5(c) and (d) show the experimental results versus simulated ones with 30 degree incidence angles for TE and TM polarizations, respectively. From these measured results, it can be seen that experimental results agree well with the simulated ones.

5. CONCLUSION

In this paper, we propose a dual-band FSS in low frequencies with miniaturized element. The design procedure, analysis, simulation and measurement results of the FSS are presented and discussed. Both the simulated and experimental results show that such a FSS has advantages of dual-band passband in low frequencies, quite stable performance, miniaturized element (about $\lambda/7$), and its thickness is less than $\lambda/173$ for low frequency passband. By virtue of these advantages, the proposed FSS provides practical applications for dual-band shipboard communications.

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