A Low-Profile Bandpass Frequency Selective Surface with Highly Selective Response

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Abstract- **A novel low-profile bandpass frequency selective surface (FSS) is presented in this paper, which is composed of three metal layers separated by two thin dielectric substrates. The structure provides a frequency response with two transmission poles and three transmission zeros for both transverse electric (TE) and transverse magnetic (TM) polarizations. A coupling topology and an equivalent circuit model are established to further discuss the operation principle of the FSS. And the FSS is modeled and simulated in the commercial software CST MWS to validate the frequency response characteristic. Besides, simulation results indicate that the designed FSS is insensitive to the incident angles and polarizations of the incoming electromagnetic wave.**

I. INTRODUCTION

Frequency selective surfaces (FSSs) have been widely researched as spatial electromagnetic (EM) filters for several decades [1][2]. For practical application, FSSs usually operate as sub-reflectors, polarizers, hybrid radomes, sensors in microwave and some other modules in many microwave communication systems. Similar to planar microwave filter, FSSs can be designed to obtain bandpass, bandstop, highpass, or lowpass characteristic. However, the frequency responses of FSSs are not only functions of frequency, but also functions of incident angle and polarization of electromagnetic wave. In recent years, many methods have been proposed to design bandpass FSSs. Antenna-filter-antenna modules were first presented and applied to construct bandpass FSSs [3]. A novel low-profile FSS was designed by using non-resonant subwavelength constituting unit cells in [4]. And the three-dimensional (3-D) structure was utilized to design bandpass FSSs in [5], which introduces multiple transmission zeros to improve the selectivity of the filter response. More recently, annular rings resonators with aperture coupling were applied to construct a bandpass filter with wide out-of-band rejection [6]. However, it is not easy to design a bandpass FSS which simultaneously possesses the merits of low-profile structure, high selective frequency response, wide out-of-band rejection and easy manufacturing process.

This paper proposes a novel low-profile bandpass FSS with two transmission poles and three transmission zeros which endows the FSS with significant frequency selectivity response and wide out-of-band rejection. The proposed FSS is based on multilayers physical structure, which is easy to fabricate. In what follows, the structure model, operating principle, simulation results and analysis of the proposed FSS are presented and discussed.

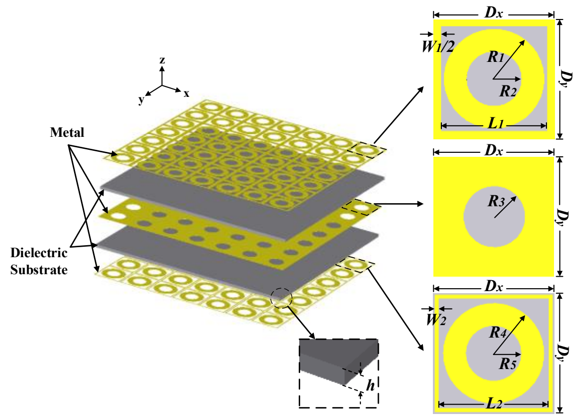

Fig. 1 Three-dimensional topology of the proposed FSS and its constituting unit cells

II. STRUCTURE MODEL AND OPERATING PRINCIPLE

A. Geometry of the FSS

The perspective view of the proposed FSS and the 3-D topology of the unit cells that constitute the whole structure are showed in Fig. 1. The FSS is mainly composed of three metal layers separated from one another by the two thin dielectric substrates. The top layer is composed of wire grid and annular ring which is positioned at the center of the wire grid. The middle metal layer is etched with circular apertures, which induce the coupling between the top layer and bottom layer. The bottom layer has the same annular ring locating at the top layer, while the wire grid is replaced by a square loop. For the whole topology, the unit cell is arranged in the *x*- and *y*-directions with periodicity of $D_x = D_y$. The thickness and dielectric constant of the dielectric substrate used to separate the metal layers are h and ε_r . And the overall thickness of the whole structure is nearly twice of the dielectric substrate, which makes it possible to realize low-profile characteristic. W_1 and W_2 denotes the width of the wire grid and square loop respectively. And the length of the wire grid and square loop is denoted by L_1 and L_2. The outer and inner radius of the annular ring on the top layer is R_1 and R_2. While the ones on the bottom layer are denoted by by R_4 and R_5. On the middle metal layer,

TABLE I

PHYSICAL PARAMETERS OF THE PROPOSED FSS

Parameter	$D_x = D_y$	$R_1 = R_4$	$R_2 = R_5$	R_3	W_1
Value	15.0 mm	6.2 mm	3.4 mm	3.8 mm	2.0 mm
Parameter	W_2	L_1	L_2	h	ε_r
Value	0.5 mm	13 mm	13.5 mm	1.52 mm	3

R_3 refers to the radius of the etched circular aperture. And The detailed geometrical parameters of the designed FSS are listed in Table I.

B. Principle Operation of the FSS

Fig. 2(a) shows the coupling topology of the designed FSS. The circular aperture etched on the middle metal layer introduces the electrical and magnetic coupling between the top and bottom layers [7]. Due to the framework of the FSS, the couplings of the wire grid and square loop are negligible compared with the coupling between the rings positioned at the center of the unit cell. So only the electrical and magnetic coupling paths, denoted by M_C (M_{C1}, M_{C2} and M_{C3}) and M_L (M_{L1}, M_{L2} and M_{L3}), between annular rings and circular aperture are depicted in Fig. 2(a).

Based on the coupling topology of the structure, an equivalent circuit model is established in Fig. 2(b) to better understand the operating principles of the structure. And the circuit model is valid for normal incidence. The annular rings on the top and bottom layer are modeled with series LC resonators (L_2, C_2, L_4 and C_4), whereas the circular aperture on the middle metal layer is represented by a parallel branch (L_3 and C_3). And the wire grid on the top metal layer possess equivalent inductive impedance to a normal incoming wave, which is represented by a parallel inductance (L_1). While the square loop on the bottom metal layer is represented by a series LC circuit (L_5 and C_5). Due to the weak coupling between annular rings and circular aperture compared with that exits between annular rings, it can be ignored to simplify the equivalent circuit model. And the electrical and magnetic coupling paths between the two annular rings are modeled with C_m and L_m respectively. Two semi-infinite transmission lines with characteristic impedance of $Z_0 = 377\ \Omega$ are utilized to represent the free space in both sides of the structure. The two dielectric substrates used to separate the metal layers are modeled with two short transmission lines with wave impedance of $Z_S = Z_0 / \sqrt{\varepsilon_r}$, and length of d_s, which is equal to the thickness of the substrates.

Based on the equivalent circuit model, the designed FSS possesses two transmission poles and two transmission zeros, which enables the FSS to possess a bandpass and high selectivity frequency response. The two transmission poles are determined by the two coupled series LC branches (L_2, C_2, L_4 and C_4). And one transmission zero is due to the series LC circuit (L_5 and C_5), while the other transmission zero is achieved by the electrical and magnetic coupling [7]. And the parallel inductance L_1 is only used to adjust the matching between port1 and port 2.

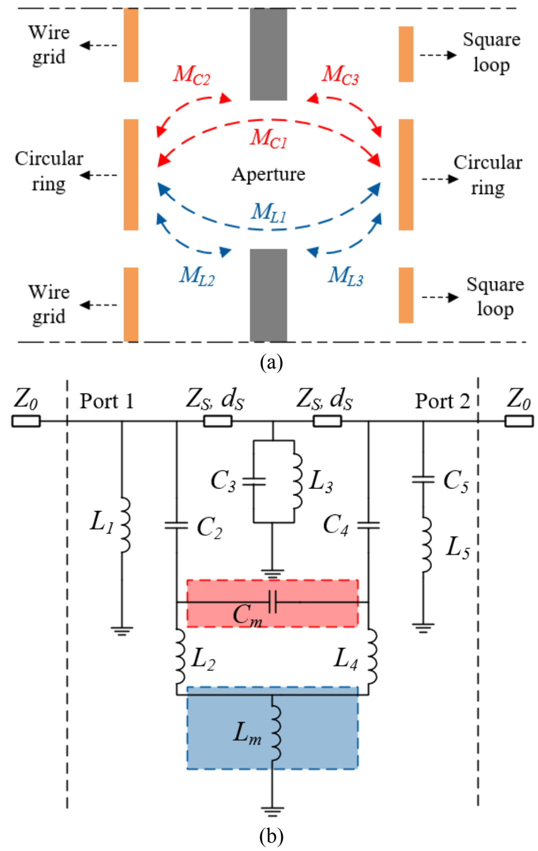

Fig. 2 (a) Coupling topology of the proposed FSS (b) Equivalent circuit model of the proposed FSS

III. SIMULATION AND ANALYSIS

Fig. 3 shows the full-wave simulation results of the designed FSS by CST MWS and the calculation results of the equivalent circuit model by the software ADS, where the circuit response fits well with the full-wave simulation results. The same as the mechanism analysis in section II, the passband is determined by the two ring resonators on the top and bottom layers. And the circular aperture is utilized to control the coupling strength between the two circular rings. The transmission zero in lower stopband is caused by the square loop on the bottom layer. Due to the mixed electrical and magnetic coupling, the first transmission zero at the upper sideband is caused. While the second transmission zero at the upper sideband is induced by the harmonic effects [8]. As observed in Fig. 3, the designed FSS possesses two transmission poles, located at 5.82 GHz and 6.09 GHz respectively. It has insertion losses of 0.25 dB at the center frequency of 5.96 GHz. Besides, it has a fractional 3-dB bandwith of 13.3%. In the lower stopband, a transmission zero is located at 2.95 GHz with an attenuation level over 50 dB, which is useful to enhance the selectivity at lower sideband. While in the upper stopband, two transmission zeros are located at 7.72 GHz and 11.50 GHz respectively, both of which have attenuation levels over 70 dB. The two transmission zeros lead to well frequency selectivity and wideband suppression simultaneously.

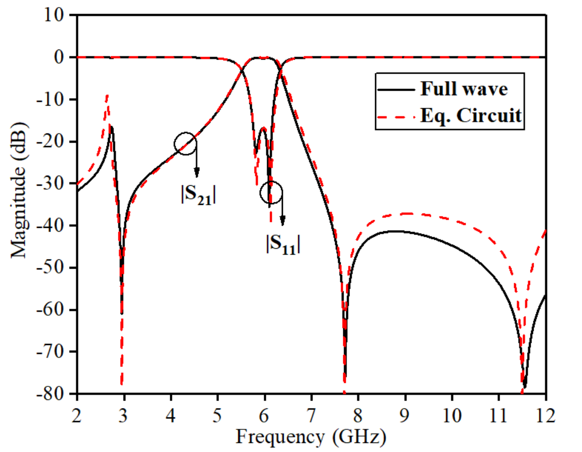

Fig. 3 Scattering parameters calculated from the equivalent circuit model and the full-wave simulation results.

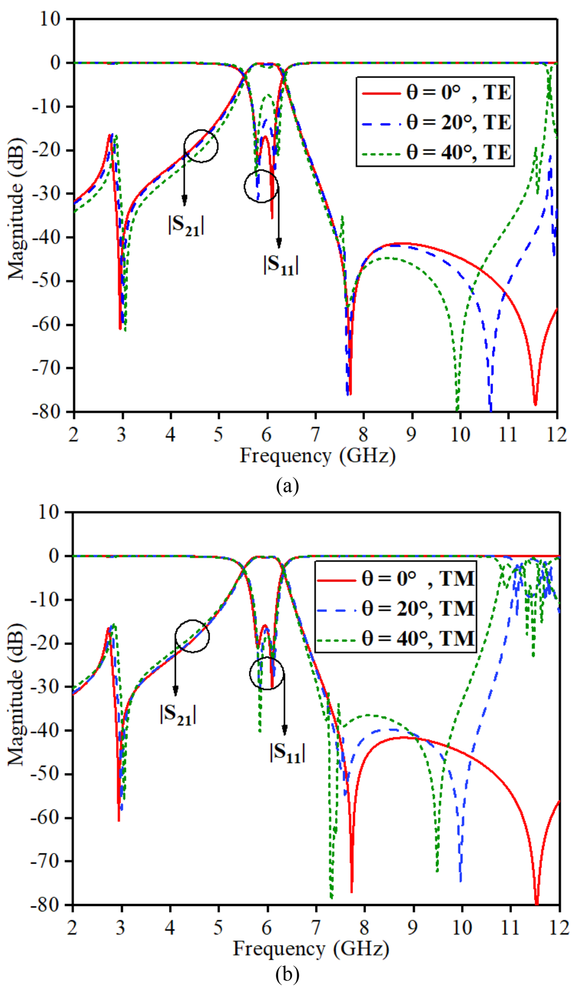

Fig. 4 Simulation results of the proposed FSS under oblique incident angles. (a)TE polarization. (b) TM polarization

The symmetrical and low-profile structure enable the designed FSS to be insensitive to the incident angles and polarizations of the incoming electromagnetic wave. And the simulation results of the FSS under different polarizations and incident angles are depicted in Fig. 4. For TE and TM polarizations the passband and the lower stopband keep stable as the incident angle increases. The first transmission zero shifts slightly in different incident angle for both TE and TM polarizations. And the frequency shifts of the second transmission zero is mainly caused by the side lobe effects. However, due to the high level of the suppression at upper sideband, the frequency shifts have little effect to the frequency selectivity of the FSS.

IV. Conclusion

In this paper, a novel low-profile bandpass FSS with highly selective response is presented. The frequency selective surface is designed by stacking three metal layers and two thin dielectric substrate layers, used to separate the metal layers, together. A coupling topology and an equivalent circuit model are built to analyze the operating principle of the FSS further. And the designed FSS is modeled and simulated by CST MWS. The simulation results verify the validity of the equivalent circuit model and indicate that the proposed FSS has a stable frequency response under the incoming electromagnetic wave with different incident angles and polarizations.

Acknowledgment

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