Low-Cost All-Metal Bandpass Frequency Selective Surface

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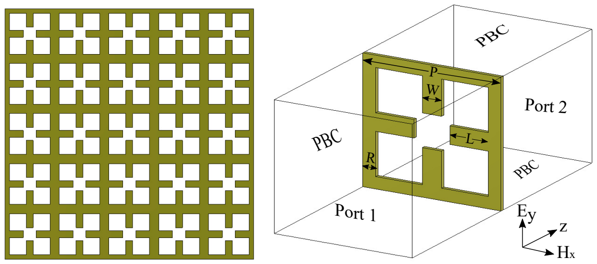
***Abstract*—In this paper, a new type of low-cost free-standing all-metal frequency selective surface (AM-FSS) is studied and presented. The AM-FSS is developed using an extremely thin sheet of metal having a total thickness of $\lambda_0/80$, where λ_0 is the free-space wavelength at the operating frequency. The fundamental element of the AM-FSS is a square ring of area $0.45\lambda_0 \times 0.45\lambda_0$ and having fork-type stubs extending from four sides towards the center of the ring. The transmission and reflection characteristics of the AM-FSS are predicted using a commercial electromagnetic simulator. Higher-order bandpass FSSs are realized using two and three layers of the proposed AM-FSSs. The independent polarization characteristic of the AM-FSS is demonstrated by predicting the performance of the three-layered AM-FSS for two orthogonal TE and TM polarizations. The proposed AM-FSS does not use any commercial laminates, making it extremely attractive for low-cost and high-power microwave applications.**

***Index Terms*—All-metal, Bandpass filter, Dielectric-free, Frequency Selective Surface, High-power, Low-cost FSS.**

I. INTRODUCTION

Because of their ability to block or pass certain frequencies, Frequency Selective Surfaces (FSS) are of great interest in the radio-frequency (RF) and microwave research community for a range of commercial, aerospace, and medical applications [1]. FSSs are engineered using arbitrary geometrical patterns of scatterers that are periodically arranged in a two-dimensional (2D) or three-dimensional (3D) lattice. Recently, FSSs have been used to develop filters [2], [3], radio-frequency (RF) absorbers [4], partially reflecting surfaces [5], sheets for reflectors [6], phase correcting surfaces [7], [8], electromagnetic (EM) shielding application [9], and artificial magnetic conductors [10]. There are various bandpass type FSS designs reported in the literature that aim to achieve minimal insertion loss and flat-top response in the passband. A second-order bandpass filter with three cascading layers with miniaturized elements is reported in [2] with stable in-band frequency response. Multiband bandpass frequency selective surfaces have been proposed in [11] for the wireless communication system. Besides these, fully dielectric [12] and fully metallic [13] frequency selective surfaces have also been studied for bandpass characteristics.

Almost all of the reported designs use commercially available dielectric materials. These are costly and sometimes have great limitations when it comes to high power microwave and millimetre-wave applications. Moreover, dielectric laminates are highly lossy at high frequencies [13] as well. In [13], the frequency selective surface is made of a fully metallic three-dimensional complex periodic structure that increases manufacturing cost and complexity. Therefore, this work demonstrates the development of extremely low-cost frequency selective surface using cost-effective designs and manufacturing techniques to circumvent these challenges. In this regard, we explore the design of fully metallic frequency selective surface (AM-FSS) made out of free-standing thin sheets of metal with wideband bandpass frequency response. This paper deals with the preliminary investigation and results, whereas extended results and analysis on the oblique incident angles have been presented in [14].



(a) (b)

Fig. 1: Topology of the proposed AM-FSS: (a) Front view of a finite size AM-FSS, and (b) Unit cell structure.

The paper is ordered as follows. The design principle of AM-FSS and its constituent scattering unit element are discussed in Section II. Bandpass frequency response and its performance are studied in Section III. Section IV concludes the paper.

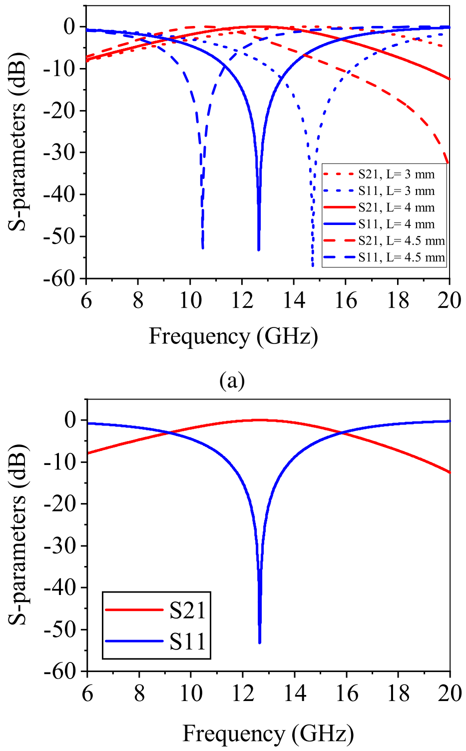
II. DESIGN OF ALL-METAL FSS

The topology of the proposed AM-FSS and its constituting scattering element is shown in Fig. 1. The FSS is made from an extremely thin sheet of metal having a thickness of $\lambda_0/80$, where λ_0 is the free-space wavelength at the operating frequency. The unit cell of the FSS is depicted in Fig. 1(b). It has square geometry and a lateral size of $0.45\lambda_0$. The unit cell comprises a square metal ring with fork-type stubs extended towards the center of the ring. Typically, a square ring can provide high-pass frequency response, whereas extended fork-type stubs can be treated as a shunt resonator. Arranging such a resonating unit element in a 2D periodic pattern forms a first-order bandpass FSS.

The unit cell was simulated with CST Microwave Studio to understand the electromagnetic (EM) behaviour of the proposed FSS. An infinitely extended two-dimensional FSS was modeled using periodic boundary conditions along the unit cell's lateral dimensions and was analyzed with full-wave simulations. The FSS is analyzed for transmission and reflection characteristics using input and output port and for the wave propagation along the +z-axis as labeled in Fig. 1(b). A parametric analysis was carried out for the unit cell to obtain the optimized physical dimensions of the FSS. The parametric analysis yield an optimal cell size of 10.8 mm (or P = 10.8 mm), the fork-type stubs length (L) and width (W) is 4 mm and 1.5 mm, respectively, and outer ring width (R) is 1 mm.

III. PERFORMANCE OF BANDPASS AM-FSS

The magnitude of transmission and reflection coefficient of the FSS in a frequency band between 6 GHz and 20 GHz are given in Fig. 2. The result of the parametric study is plotted in Fig. 2(a). It indicates that if the unit cell size is fixed, then the stubs' length can control the resonant frequency independently. At optimal values of the unit cell, the ultra-thin ($\lambda_0/80$) free-standing AM-FSS produces transmission pole at its resonant frequency demonstrated in Fig. 2(b).

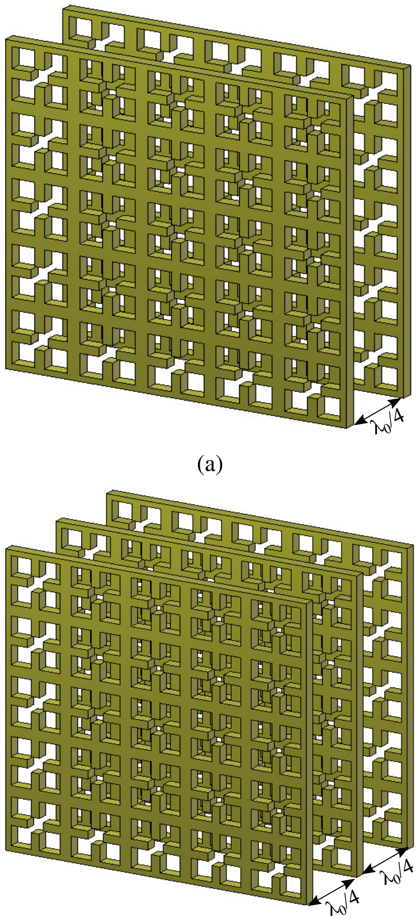


(a)

(b)

Fig. 2: Transmission characteristics of proposed single layer AM-FSS at (a) Variable length and (b) Optimal length of fork-type stubs.

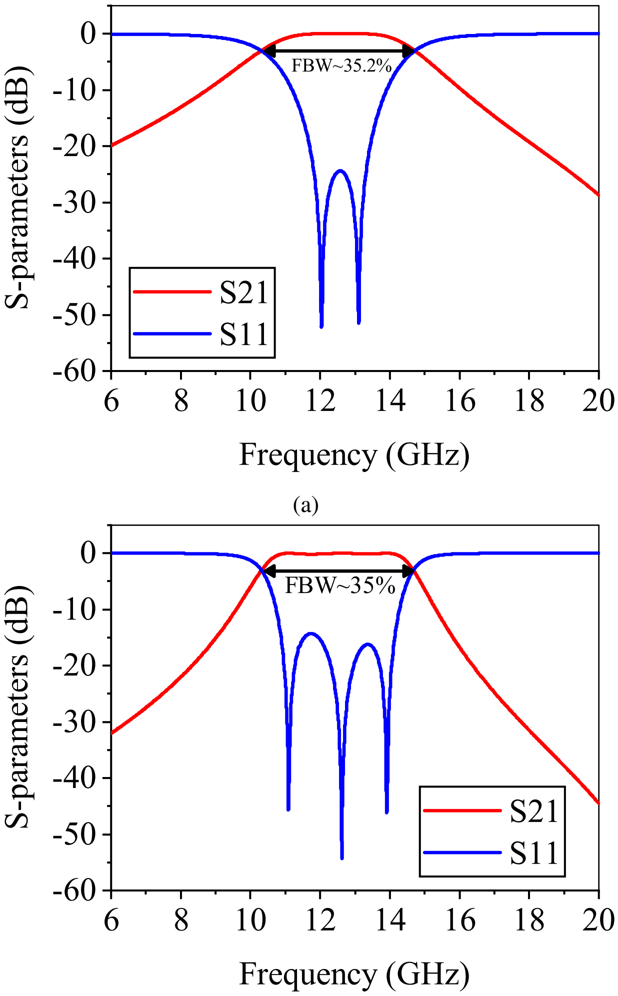
The roll-off factor for the single-layer bandpass AM-FSS is not optimal. Multiple layers of the AM-FSS can be cascaded to address this issue and, at the same time, to realize a higher-order bandpass response with a sharp roll-off. Therefore, two- and three-layered FSS were also investigated by simply stacking multiple identical copies having a $\lambda_0/4$ spacing between two consecutive layers, as shown in Fig. 3. The resonance performance of the two- and three-layered AM-FSS is plotted in Fig. 4. It is worth emphasizing here that the multi-layered FSSs used optimal physical dimensions obtained through a parametric study. From Fig. 4(a) and 4(b), it is noted that the higher-order passband is realized as the layer increases and vice versa. At the same time, a sharp roll-off factor is also achieved as expected. In the case of two- and three-layered AM-FFS, the achievable fractional -3 dB bandwidths are approximately 35.2% (Fig. 4(a)) and 35% (Fig. 4(b)) around its centre frequency of 12.5 GHz, respectively. Furthermore, the proposed AM-FSS is symmetric at 90° rotational aspects, and hence, the bandpass response at normal incidence for both TE and TM modes should be the same as depicted in Fig. 5 in the case of three-layered AM-FSS.



(a)

(b)

Fig. 3: Three-dimensional view of finite size of (a) Two-layered and (b) Three-layered AM-FSS.



(a)

(b)

Fig. 4: Transmission and reflection characteristics of (a) Two-layered AM-FSS and (b) Three-layered AM-FSS.

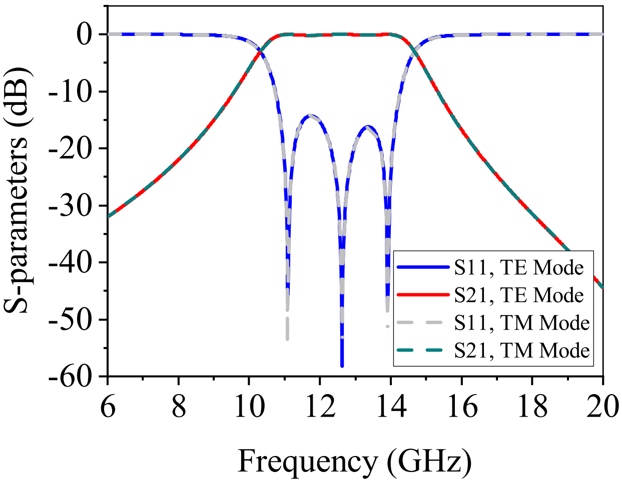


Fig. 5: Transmission and Reflection characteristics of proposed three-layered AM-FSS at TE and TM modes.

IV. CONCLUSION

A simple design concept of bandpass all-metal frequency selective surface (AM-FSS) is demonstrated, and its performance is verified through full-wave numerical simulations. The bandpass response can be controlled easily by changing the length and width of fork-type stubs attached to the inside walls of identical square-shaped metal rings. Higher-order bandpass frequency response can easily be realized by cascading multiple layers of identical thin AM-FSS sheets with keeping $\lambda_0/4$ spacing between two consecutive layers. The 3 dB transmission bandwidth is more than 35% in the case of second-order and third-order bandpass AM-FSSs. The use of only metallic sheets in the proposed design eliminates the dielectric materials completely and dramatically reduces the cost associated with the procurement of expensive dielectric laminates.

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