Low-Profile Second-Order Terahertz Bandpass Frequency Selective Surface with Sharp Transitions

M. Hussein[1], J. Zhou[1], Y. Huang[1], J. Jin[2], C. Balocco[2], [3]R. A. Habeeb
[1]Department of Electrical Engineering and Electronics, University of Liverpool, Liverpool, UK
M.N.Hussein@liverpool.ac.uk, zhouj@liverpool.ac.uk, Yi.Huang@liverpool.ac.uk
[2]School of Engineering and Computing Sciences, Durham University, Durham, UK
[3]School of Engineering, University of Basra, Iraq

***Abstract*- This paper proposes a new approach to implement Frequency Selective Surfaces (FSSs) with sharp transition edges and almost flat bandpass responses. The design is suitable for submillimetre wave and terahertz applications. The proposed structure exhibits a low insertion loss in the desired band. The structure is realized by combining bandstop and bandpass FSS structures on the same plane. By cascading more than one layers of surfaces, separated by dielectric slabs, the response with the desired flat passband characteristics can be achieved. The structure is polarization independent and exhibits low insertion loss at the passband around 170 GHz.**

***Index Terms:* Second order frequency selective surface, spatial filter, THz, Complimentary structures.**

I. INTRODUCTION

Nowadays, bandpass frequency selective surfaces (FSSs) with an order (N ≥ 2) have gained a significant amount of attention. Many approaches with different types of structures have been adopted to obtain bandpass responses. A frequency response with an almost flat top and a fast roll-off can be obtained by using two or more cascaded surfaces [1]. An FSS filter is inherently much more complicated than a classical connectorized one, although, theoretically, they are similar. A classical filter has a pair of ports, input and output. A signal is fed to the input port while the response is recorded at the output. On the other hand, a spatial filter has an incident field arriving with varied incident angles as well as polarizations. Furthermore, an FSS can achieve a flat passband response with fast roll-off by cascading non-resonant or resonant surfaces separated by dielectric slabs. Such performance can be obtained when the thickness of the dielectric slab is around a quarter wavelength [2]. At microwave frequencies, different higher-order FSS structures have been proposed [3-6].

However, at higher frequency, the loss is usually high due to the thick dielectric material. In this study, a new approach is proposed to design a low-loss bandpass FSS with almost flat passband and sharp transition edges. The spatial filter exhibits very low insertion loss and simultaneously with sharp selectivity to provide high isolation between adjacent frequency channels.

Also, satellite systems tend to operate in the Circular Polarizations (CP) mode, which can provide flexibility to effects such as Faraday rotation [7]. It can also make the alignment in polarization between the transmitter and receiver easier. Polarization independent FSSs has attracted a lot of interests. Several FSS geometries with such characteristics have been proposed at millimeter- and sub-millimeter waves including crossed dipoles [8], Jerusalem crosses [9], rings [10], two layers of semi-circle surfaces [11], double square loop arrays and gridded double square loop arrays [12].

In this paper, the FSS is designed based on combining a bandstop and a bandpass structures on the same layer to achieve fast roll-off. Two surfaces are cascaded and separated by a dielectric slab, to achieve almost flat bandpass response.

It is demonstrated that using the proposed technique, second-order FSSs with an overall thickness of less than λ/7 can be designed. The proposed method focuses on designing a second order bandpass FSS with desired features, such as: low insertion loss, flat passband and sharp transition edges.

II. CIRCUIT DESIGN

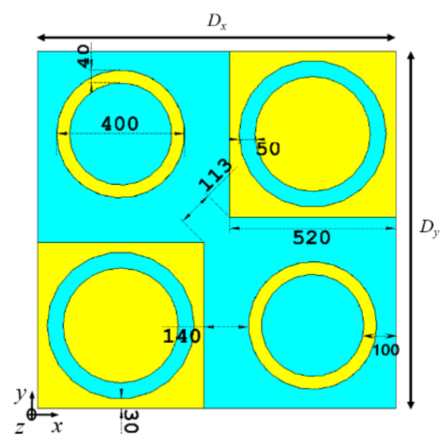

Fig. 1. Geometric parameters of the proposed surface, unit: µm.

In this paper, a bandpass FSS is realized by combining a bandstop and a bandpass structures. The FSS is needed to separate signals at 166 GHz and 183 GHz for satellite applications. Circular ring and circular slot are used here. The two structures can co-exist on the same layer without significantly affecting each other. The proposed single-layer FSS is shown in Fig. 1. The element of the proposed FSS consists of two circular rings and their complementary structures on the same plane. D_x and D_y are the dimensions of the array element toward the x and y axes, respectively. D_x and D_y are 560 µm. The two rings and two slots are arranged to be rotationally symmetrical around the *xy*-plane shown in Fig. 1. By this arrangement, the performance is insensitive to the polarization of incident waves.

The proposed structure can be designed in three steps. The first step is to achieve the appropriate bandpass structure based on the desired frequency response. A circular slot is used as the bandpass structure. By cascading two such structures in two layers, the desired frequency response with a flat top can be achieved.

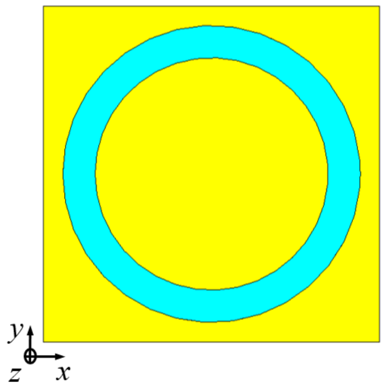

Fig. 2. Top view of the passband FSS element (metal is shown in yellow and the slot is shown in cyan).

The second step is to design an appropriate structure with suitable bandstop characteristics, such as the frequency response, the array element size and the shape. The circular ring structure shown in **Error! Reference source not found.** is used as the secondary structure in this design.

The final step is to combine the two structures, the circular slot and the ring, as shown in **Error! Reference source not found.**. It is worth mentioning here that the frequency response of the combined structure will be different from two individual circuit combined. This is mainly because of the coupling between the two structures. For that reason, tuning is needed to achieve the desired response.

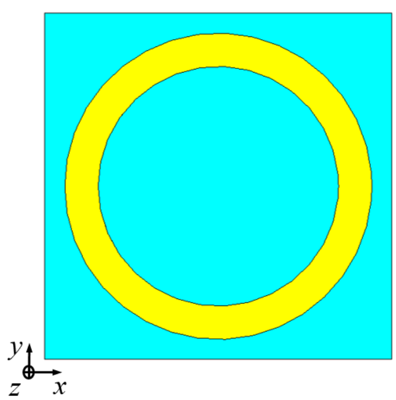

Fig. 3. Top view of the stopband FSS element.

To verify the response of the combined structures, simulation was carried out on both the bandpass and stopband structures. It was done with CST Microwave Studio, using unit cell boundary conditions to provide periodicity along the x and y axes. The structure is excited by an electromagnetic wave with the propagation vector (**K**) towards the z-axis direction, magnetic field vector (**H**) towards the x–axis direction and electric field vector (**E**) towards the y-axis direction. The bandpass response was achieved by cascading two layers of circular slots, which were separated by a Polyethylene Naphthalene (PEN) substrate with a thickness of 250 μm. The filter has a fraction bandwidth of 40% (150 GHz - 225 GHZ), as can be observed from the simulated results of the transmission and reflection coefficients shown in Fig. 4.

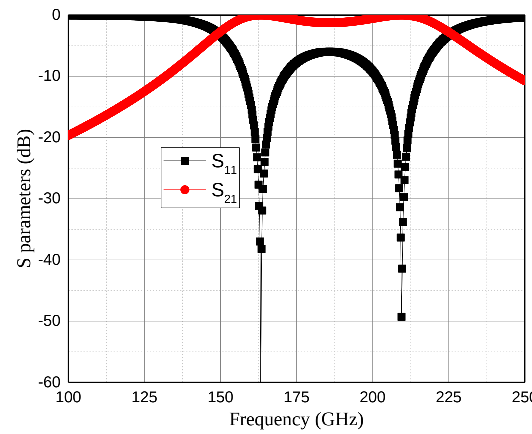

Fig. 1. Simulated transmission and reflection coefficients of the slot structure (bandpass).

The simulated results of the cascaded rings, which are separated by the same PEN substrate, is shown in Fig. 5. The structure exhibits performance with a stopband from 150 GHz to 266 GHz.

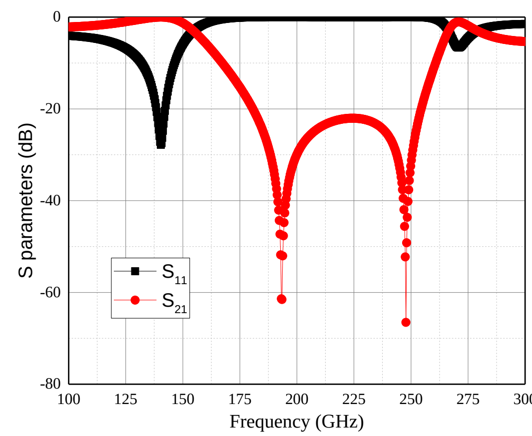

Fig. 5. Simulated transmission and reflection coefficients of the ring structure (bandstop).

Fig. 6 shows the proposed two-layer combined structure with 3×3 array elements. Each element consists of two rings and two circular slots on two layers. It should be noted here that the dimensions of the circular slots and the rings are slightly different. The transmission characteristics of the FSS is predicted and obtained by simulation. The simulated response is shown in Fig. 7. It can be seen that the response has a flat passband from 162 to 177 GHz, with very high selectivity and low insertion loss. The insertion loss is less than 0.2 dB, the first rejection band is at around 152 GHz with an attenuation of 17 dB. The second rejection band is at around 183.5 GHz as specified with a high attenuation of better than 40 dB. The structure exhibits the same response for TE and TM polarizations at the normal incident angle.

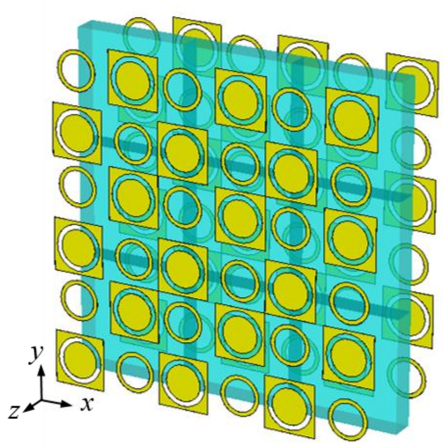

Fig. 6. Schematic view of the two-layer FSS with 3×3 array elements.

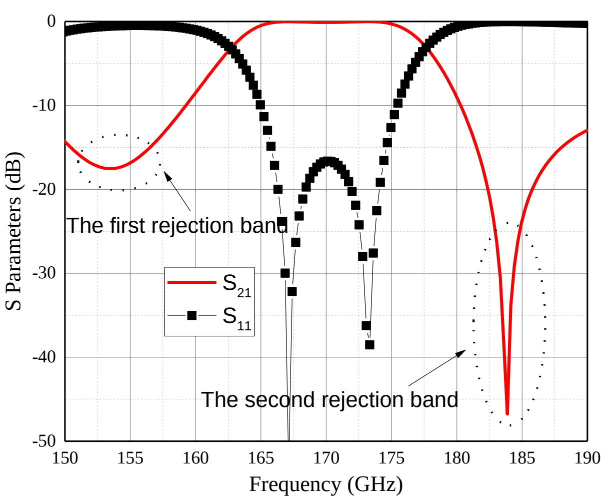

Fig. 7. Simulated transmission response of the two-layer FSS structure for TE and TM polarizations.

Standard photolithography and lift-off processes were used to pattern the single-layer FSS on a PEN. For the metallic layer, a bilayer of approximately 25 nm thick Ti and 100 nm of Au was deposited by e-beam evaporation. The array element dimensions are 1120 µm ×1120 µm. A prototype of the size of 3 cm × 3 cm has been fabricated. A two-layer FSS is also being fabricated. The fabricated devices will be tested in the near future.

III. Discussion

In this paper, a new approach to design high order bandpass FSSs for submillimeter wave applications has been proposed. The proposed approach is built by using a simple configuration of two different structures. It is shown that the transmission coefficient is independent from polarization angles. The proposed FSS exhibits excellent characteristics such as low insertion loss and sharp roll-off, and a flat passband.

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