Narrow Band, Sharp Roll-Off Rejection Frequency Selective Surface Based on Substrate Integrated Waveguide

Mehran Shamaei Samani, Reza Sarraf Shirazi, and Gholamreza Moradi

Department of Electrical Engineering
Amirkabir University of Technology, Tehran, Iran
Mehranshamaey@aut.ac.ir, Sarraf@aut.ac.ir, Ghmoradi@aut.ac.ir

***Abstract* —** In this paper, a novel frequency selective surface which has a narrower passband and sharper roll-off rejection than the other single layer designs, is presented. Also, it has better independency from angle and polarization of incident plane wave. In this design a ring loop is placed on a cylindrical cavity of substrate integrated waveguide (SIW). Because of the most compatibility between loop and the electric fields of cylindrical cavity, minimum insertion loss and narrow passband are achieved.

***Index Terms* —** Cylindrical cavity, frequency selective surface (FSS), ring loop, substrate integrated waveguide (SIW).

I. INTRODUCTION

The frequency selective surfaces are recognized as spatial filters which pass or stop some frequency bands [1-3]. This filtering can be used in RCS controlling, radomes, sub-reflectors, anti-interfering walls, and so on.

In designing FSS's, like in other filters, obtaining the appropriate frequency characteristics, such as low insertion loss in passband, sharp roll-off and high rejection in out of bands, is one of the greatest challenges. More important than this, is making the frequency characteristics independent from the angle and polarization of incident plane wave [4]. There are so many attempts to improve these two factors such as dielectric loading [5], different periodic elements [4], close coupled FSS [6], and super dense stacked patches [7]. All above methods improve some characteristics of FSS but some of them by increasing the cost. As all improving methods work in the microstrip layout, no increment in Q-factor achieved and need for increasing Q-factor is sensible [8]. In recent years, with introducing SIW technology [9-10] and implementation of FSS on the cavity of SIW, brilliant results are obtained such as sharp roll-off rejection, stability of response about angle and polarization of incidence [11-13].

All recent FSS's are implemented on square SIW cavity and with resonators compatible with square cavity like square loop, cross slot. But we know for the same size, cylindrical cavity has more Q-factor than square cavity [14], so cylindrical SIW cavity can be used to achieve better characteristics than conventional FSS implemented with square SIW cavities (SIWC). In this paper, a FSS structure with circular loop placed on cylindrical SIW cavity is presented, which has a narrower passband and sharper roll-off rejection than available FSS-SIWs

II. DESIGN

One of the important facts in stability of FSS's response is geometrical symmetry [15]. It seems that using a more symmetrical resonator such as circular loop instead of square loop or cross slot, improves this independency. Also keep in mind that circular cavity, for the same dimension, has more Q-factor than square cavity. So it is obvious that a FSS structure which is implemented with circular loop placed on cylindrical SIW cavity has better frequency characteristics and incident independency than conventional SIW FSSs. According to above descriptions, one cell of FSS structure is shown in Figs. 1 and 2, and the geometrical parameters are listed in Table 1.

Via diameter and via spacing come from these inequalities:

$$0.05 < p/\lambda < .025,$$

$$1 < p/d < 2,$$

which p is via diameter and d is via spacing. Other parameters and how they are determined will be described in the next section in which two formulas for the resonance of structure will be mentioned.

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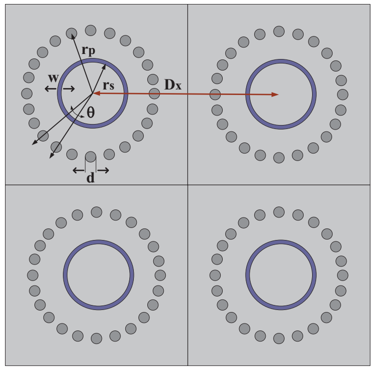

Fig. 1. Geometry of FSS with cylindrical cavity.

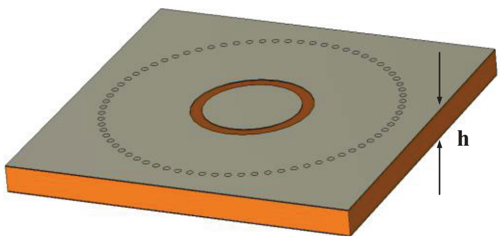

Fig. 2. One cell of SIWC-FSS simulated in CST software.

III. FORMULATION

In SIW-FSS structures, because of SIW cavity resonant mode, there is one more resonating mode than conventional FSS structures. Cavity resonant mode in our design is TE_{010} (for which there is no variation in the z axis because of thin substrate height [14]). The resonant frequency of this structure is calculated:

$$f_{cav} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\left(\frac{A \cdot p'_{01}}{r_{eff}}\right), \tag{1}$$

$$r_{eff} = r_p - B \cdot \frac{d}{2}, \tag{2}$$

p'_{01} is the first root of the derivative of Bessel function of kind 1 with $n=0$ and that is equal to 3.832. A and B are empirical constants derived from numerical methods and for X-band frequency is 0.927 and 0.73. Also, the resonance frequency of circular loop is:

$$f_{slot} = \frac{c}{2\pi C(r_s + \frac{w}{2})\sqrt{\varepsilon_{eff}}}, \tag{3}$$

C is another empirical constant and here is 0.926.

Suppose that a FSS in 12 GHz with 350 MHz bandwidths (f_1 to f_2) should be designed. f_{cav} and f_{slot} in equations (1) and (3) are selected equal to f_1 and f_2. By solving these equations, r_s and $(r_p+w/2)$ are obtained. The spacing between cells should be less than $\lambda/2$. These are the rough parameters and after some optimization the final parameters can be achieved.

IV. SIMULATION RESULTS

For analysis and simulation of FSS structures, according to type of the design, there are some methods such as FDTD [16], FDFD, MoM [17], spectral domain approach, variational method [18], point matching method [19], mutual impedance method [5]-[20], modal matching method [21-22], multimode equivalent network method [23] and equivalent circuit method [24].

In this paper as our novelty is in the design, no numerical methods have been used directly. So powerful full-wave simulator, CST, which is applying finite integral equation, was utilized and following results were obtained.

Figure 3 shows the transmission and reflection of SIW-FSS for normal incident. It is obvious that there is a sharp roll-off in 12.18 GHz because of SIW cavity.

Figures 4 and 5 show transmission, and Figs. 6 and 7 show reflection of SIW-FSS for some different angle of incident and two polarizations. It is clear that for all incident angles until 30° and two polarizations, there is a stable frequency response for this SIW-FSS.

A comparison between the results obtained from this SIW cylindrical cavity FSS and one which is presented in [8], shows the narrowness of this design.

The configuration of FSS rectangular SIW cavity is illustrated in Fig. 8. Transmission and reflection response of these two designs shows in Figs. 9 and 10.

This narrow band property is about the essence of circular loop in comparison with the square loop. The other fact is the compatibility between resonant mode of circular loop and cylindrical cavity.

Field contours of TE_{01} for cylindrical SIW is shown in Fig. 11. If the circular loop cuts the field contours, a compatible mode matching happens and electromagnetic wave suck in the cavity, for the other side of cavity, this procedure happens inversely.

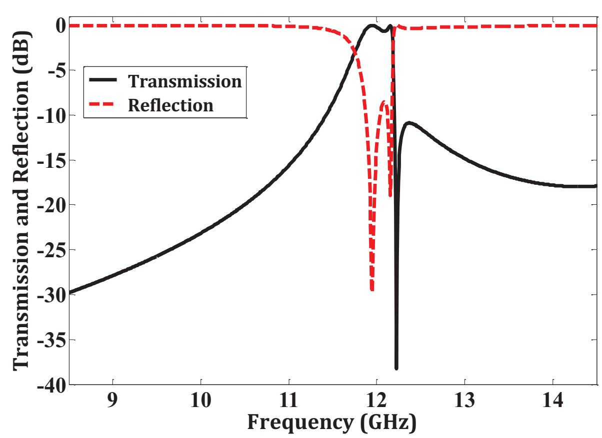

Fig. 3. Frequency response of SIWC-FSS (reflection and transmission).

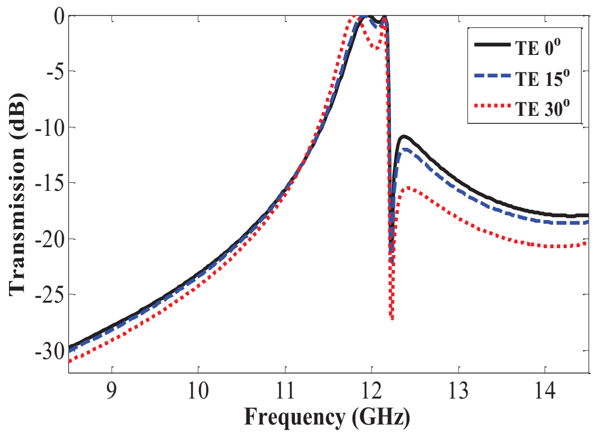

Fig. 4. Transmission response versus angle of incidence for TE polarization.

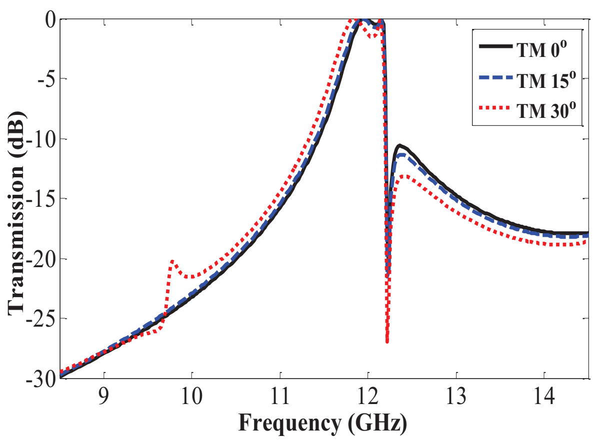

Fig. 5. Transmission response versus angle of incidence for TM polarization.

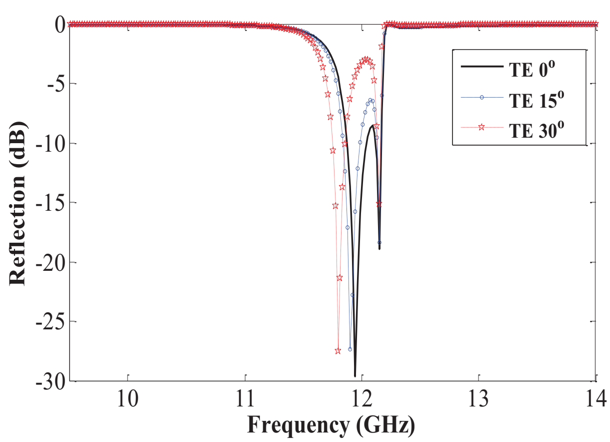

Fig. 6. Reflection response versus angle of incidence for TE polarization.

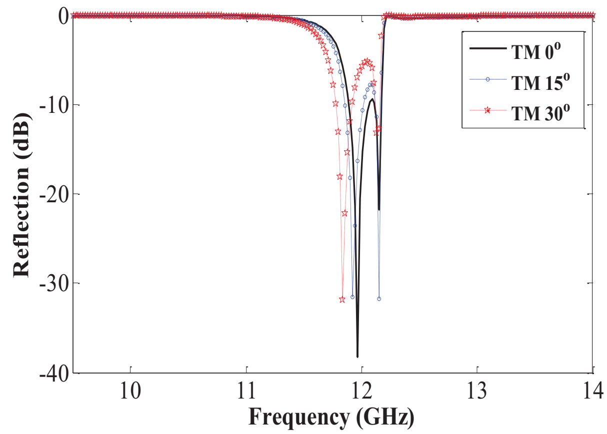

Fig. 7. Reflection response versus angle of incidence for TM polarization.

Table 2: Geometrical parameters for SIW square cavity FSS in simulation

Parameter	Value	Parameter	Value
D_x	14 (mm)	D_y	14 (mm)
L_1	8 (mm)	L_2	8 (mm)
W_1	1 (mm)	W_2	1 (mm)
d_1	3 (mm)	d_W	3 (mm)
d	1 (mm)	d_p	3 (mm)
h	1 (mm)	ε_r	2.65

The resonance which appears in 16 GHz in proposed design is related to circular patch existing in the centre of the shape. In narrow-band application, most of the time, sharp roll-off rejection is more important than beyond out of band behavior.

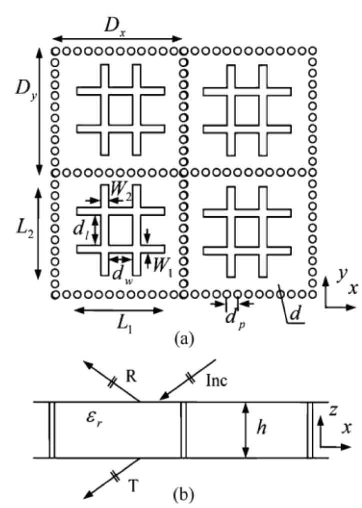

Fig. 8. Configuration of SIW square cavity FSS which is compared with proposed SIWC-FSS.

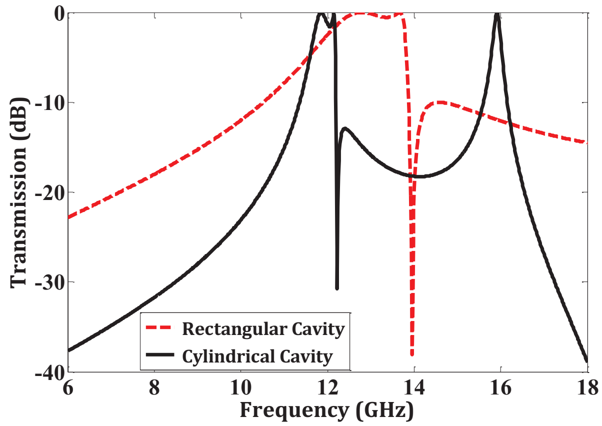

Fig. 9. Comparison between transmission response of SIW square cavity FSS and proposed SIWC-FSS.

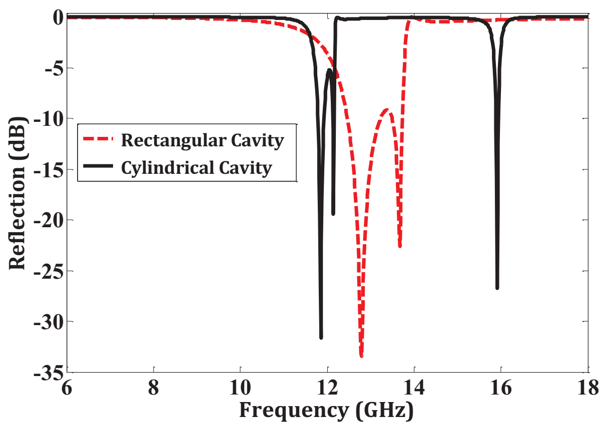

Fig. 10. Comparison between reflection response of SIW square cavity FSS and proposed SIWC-FSS.

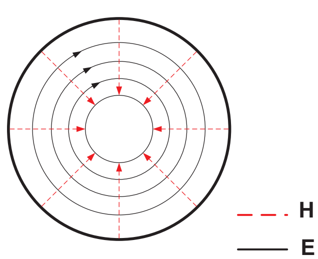

Fig. 11. Electromagnetic fields of TE_{01} for cylindrical SIW and conventional waveguide.

V. CONCLUSION

A FSS design with narrow passband and sharp roll-off rejection in a single layer format was presented. These features are related to use of SIW cylindrical cavity and circular loop mounted on it. As shown in the previous sections, the most compatibility between resonant modes of cylindrical cavity and circular loop, cause to these features. Also, because of extremely symmetrical shape, the maximum independency from angle and polarization of incident plane wave obtained.

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Mehran Shamaei was born in 1984 and received the B.S. and M.S. degrees from the Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran, in 2008 and 2010, respectively; all in Electrical Engineering. He is currently working towards the Ph.D. degree at same university. His research interests include frequency selective surfaces and reflect array antennas.

Reza Sarraf Shirazi was born in Yazd, Iran in 1958. He received the Ph.D. degrees in Electrical Engineering from Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran in 2006. His main research interests are numerical Electromagnetics and radio wave propagation. He is currently an Assistant Professor with the Electrical Engineering Department, Amirkabir University of Technology. He has published several papers in the refereed journals and international conferences.

Gholamrreza Moradi was born in Shahriar, Iran in 1966. He received the Ph.D. degree in Electrical engineering from Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran in 2002. His main research interests are numerical Electromagnetics, antennas, active microwave and mm-wave circuits and systems. He is currently an Associate Professor with the Electrical Engineering Department, Amirkabir University of Technology. He has published several papers in the refereed journals and international conferences.