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REGULAR ARTICLE

Design of a Unique Band-Pass Frequency Selective Surface for RADAR Application

Anindya Ghosh[1], Rakhi Neogi[1], Tapas Tewary[1], Sunandan Bhunia[2,*]

[1] *Department of ECE, Academy of Technology, West Bengal, India*
[2] *Department of ECE, Central Institute of Technology Kokrajhar, Assam, India*

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This study introduces the design and full-wave simulation of a band-pass frequency selective surface (BPFSS) optimized for indoor Internet of Things (IoT) networks and radar-based sensing applications. To achieve improved frequency selectivity and higher operational efficiency, the proposed FSS employs a concentric polygonal split-ring resonator encircled by circular patch elements. The unit cell comprises a 24-sided polygonal split-ring resonator surrounded by six circular disks arranged in a regular hexagonal layout. Implemented as a single-layer design without backside metallization, the structure follows standard practices for spatial filtering applications. This configuration enables the single-layer FSS to operate within the 6.75-8 GHz band, delivering strong spatial filtering performance at the resonant frequency of 7.5 GHz. Proposed unique BPFSS unit cell is designed by using a 0.508 mm thick Rogers RO5880 substrate having relative dielectric constant of 2.2 and loss tangent of 0.009 at 10 GHz. The final structure has compact dimensions of 10.8 mm × 10.8 mm × 0.508 mm. Simulations were performed using ANSYS HFSS software, employing unit cell boundary conditions and Floquet ports to emulate infinite periodic behaviour. This work is also supported by approximate calculation of resonant frequency of circular ring resonator. The results confirm the structure's suitability for band-pass filtering applications with good angular and polarization stability.

Keywords: Frequency Selective Surface (FSS), Band pass filter, Split ring resonator (SRR), RADAR.

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1. INTRODUCTION

Frequency Selective Surfaces (FSS) have emerged as a pivotal research area in applied electromagnetic due to their ability to control the propagation of electromagnetic (EM) waves. An FSS is essentially a two-dimensional periodic arrangement of conductive elements (patches) or apertures on a dielectric substrate. Based on the design arrangement, these structures serve as spatial filters that selectively transmit or reflect particular frequency bands, acting as either band-pass or band-stop filters. [1-3]. The versatility and tunability of FSS have enabled their application in a diverse array of technologies, including but not limited to: frequency-scanned and electronically steerable antennas, microwave absorbers for stealth and RCS (Radar Cross Section) reduction, electromagnetic shielding, random, and smart surfaces for energy harvesting and wireless communication enhancement [4-6]. In particular, their use in RADAR systems for both military and civilian applications has grown rapidly, as they enable the control of signal propagation characteristics without requiring bulky, active components. The resonance characteristics of an FSS structure are primarily influenced by the geometry of the unit cell, its electrical size, the dielectric substrate parameters, and the inter-element spacing. Traditional FSS geometries have included dipoles, circular and square loops, and slotted apertures [7]. With advances in computational design tools and simulation techniques, researchers have introduced more complex geometries such as double square loops [8], complementary spiral and Hilbert curve-based fractals [9], and multilayered or stacked FSS designs [10]. These complex configurations have enabled improved control over parameters such as bandwidth, angular stability, frequency tunability, and polarization insensitivity. FSS structures can be broadly classified into two categories based on their functionality: patch-type FSS, which primarily reflects incident EM waves at the resonance frequency, and slot-type (or aperture-type), FSS, which allows transmission at the resonance frequency [11]. D. H. Hwang et al. [12] proposed Band-Pass and Band-Stop FSSs with Harmonic Suppression. S. Kundu in [13] presented a miniaturized Swastika shape mono layer FSS with band stop and band pass characteristic. José R. Montejo-Garai et al. in [14] developed and tested an improved synthesis technique for elliptic band-stop FSS responses. A systematic process based on the Generalized Chebyshev Function and the extracted pole technique was exercised to generate an equiripple rejection response. In [15] S. Das et al. described a revolutionary miniaturized unit-cell FSS based bandstop filter (BSF). This design has a 10-dB rejection bandwidth of 3.13 to 4.75 GHz. The structure exhibits

* Correspondence e-mail: bhuniasunandan@gmail.com

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polarization-independent properties and has a consistent frequency response for normal and oblique angles. T. Tamoor et al. [16] proposed a single layer FSS with band stop characteristics. It provides effective shielding from 8.7 GHz to 14.8 GHz. The suggested structure provides angular stability to variations in the incident *E*-field up to 75 degrees. The angular stability, size compactness, and wideband operation make it an excellent option for electromagnetic (EM) shielding applications. H.M. Ucar et al. in [17] presented a tunable FSS based on split ring resonators (SRRs). The band-stop FSS response is dynamically tailored to different frequency bands based on switching status. Furthermore, loadings placed at the corners of outer ring elements, producing a fan-like shape, with extra switches are proven to provide considerable fine-tuning capacity. N. Liu et al. [18] presented miniaturized FSS made up of a wire grid and a tortuous pattern of cross-dipole elements to achieve a first-order band-pass response. The suggested FSS's resonant frequency and angular stability may be changed by adjusting the tortuous factor. In [19] authors give a pedagogical overview of IRS-aided wireless communications to solve the concerns, as well as expound on its reflection and channel models, hardware design and practical limits, and several attractive wireless network applications. S. Dhegaya et al. in [20] proposed a single-layer FSS consisting of two transmission poles and a stop band filter, providing effective isolation between C and X bands. The overall performance is governed by several design variables, including unit cell shape, element size, periodicity, and substrate dielectric properties such as relative permittivity ()(ε_r) and loss tangent. Additionally, environmental factors like the angle of incidence (AOI) and polarization of the incoming wave also influence performance, particularly in real-world RADAR scenarios where oblique wave incidence is common [12-16]. To accurately predict and optimize FSS behaviour, several numerical techniques have been developed. Among them, the Finite Element Method (FEM), the Method of Moments (MoM), and the Finite-Difference Time-Domain (FDTD) method are most widely used. Analytical methods such as Equivalent Circuit (EC) modelling have also proven useful for initial approximations and insight. In this study, FEM-based solver in Ansys HFSS (Version 24) is employed due to its superior handling of complex geometries such as concentric split-ring resonators with polygonal patterns. FEM provides accurate full-wave electromagnetic analysis by solving Maxwell's equations over a discretized mesh, capturing both near-field and far-field effects. Additionally, it incorporates realistic material parameters like dielectric loss and surface roughness—key for high-frequency applications.

The proposed unique FSS in this paper is designed to operate within the 6.75 GHz to 8 GHz range, which is suitable for indoor IoT and short-range RADAR applications. The proposed BPFSS exhibits angular stability up to 65 degree under Transverse Electric (TE) polarizations. This frequency range falls under the extended C-band and is particularly useful in environments require secure and interference-resistant signal transmission. The proposed BPFSS operating in the 6.75 GHz to 8 GHz range has been successfully designed and simulated using ANSYS HFSS v2024 R2.

2. PROPOSED FSS CONFIGURATION

Fig.1 illustrates the top view of the designed unit cell. The unit cell is designed and simulated using ANSYS HFSS v24, which employs the Finite Element Method (FEM) for accurate full-wave electromagnetic analysis. The proposed unit cell consists of a concentric split-ring resonator designed from a 24 sided regular polygonal structure, surrounded symmetrically by six circular disk resonators. Six resonators are arranged in a regular hexagonal pattern coinciding with the centre of the regular polygonal split ring. The structure is modelled as a single-layer surface with no metallization on the backside of the substrate, following a common approach for spatial filtering applications. Periodic boundary conditions were applied along the X and Y directions, and Floquet ports were used to emulate an infinite array response under normal and oblique wave incidence. Using standard formula (1-4) [1-2], the reference band-pass FSS dimensions have been determined for the resonance frequency of 7.5 GHz.

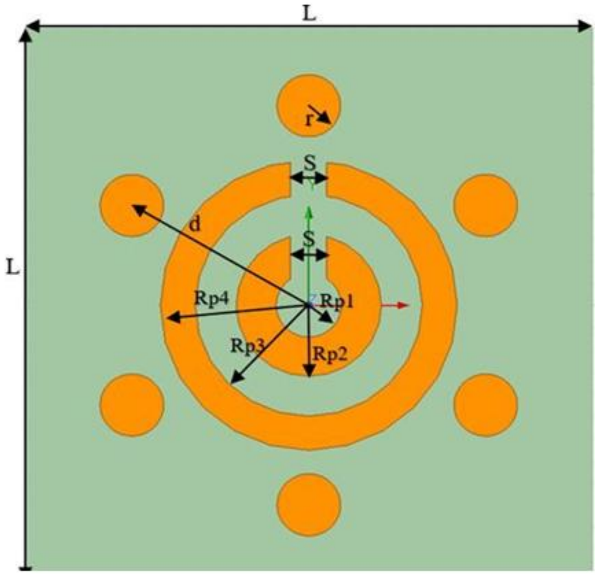

Fig. 1 – Proposed FSS structure (Top View)

All the dimensions of the FSS parameters are tabulated in Table 1.

Resonant frequency of circular ring resonator (f_r) can be approximated using:

$$f_r = \frac{c}{2*\pi*r_{eff}*\sqrt{\varepsilon_{eff}}} \quad (1)$$

Where

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} * [1 + 12 * \frac{h}{W}]^{-\frac{1}{2}} \quad (2)$$

Where,

$c = 3 \times 10^8$ m/s (speed of light)

r_{eff} = Effectiveradiusofthering

ε_{eff} = Effective permittivity of the substrate

ε_r = relative permittivity of the substrate

h = thickness of substrate

W = width of outer ring

The split in the ring affects the resonance and is typically related to the guided wavelength (λ_g) using:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \quad (3)$$

$$L_{split} = \frac{\lambda_g}{\mathrm{N}} \quad (4)$$

λ_g = Guided wavelength (the wavelength of the signal as it propagates through a dielectric medium or guided structure)
λ_0 = Free-space wavelength
N = The number of sides of the polygon
L_{split} = The length of the split

Table 1. Design Parameters with optimal measurements

Parameter	Description	Value (mm)
L	Unit Cell Size	10.8
h_2	Substrate Thickness	0.508
h_1	Copper Thickness	0.017
S	Split Length	0.8
r	Radius of Circular Resonators	0.8
d	Distance from the centre of the resonator to the centre of the Regular polygon	4.3
R_{p1}	Inner Ring Inner Radius	0.72
R_{p2}	Inner Ring Outer Radius	1.6
R_{p3}	Outer Ring Inner Radius	2.25
R_{p4}	Outer Ring Outer Radius	3.27

3. RESULTS AND DISCUSSIONS

All of the simulation results are performed using ANSYS HFSS simulation software. Floquet Port excitation and master/slave periodic boundary conditions have been utilized to simulate the infinite periodic structure. The unit cell is excited with a plane wave under periodic conditions to analyze its frequency response within the range of 6.75 GHz to 8 GHz.

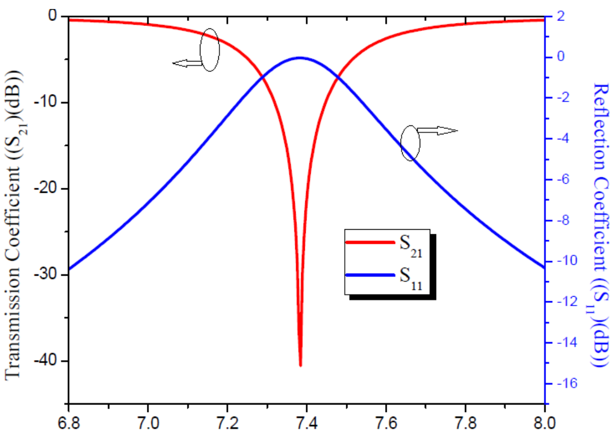

Fig. 2 – Reflection and transmission coefficients (S_{11} and S_{21}) under TE polarization

Fig. 2 shows the frequency response of reflection and transmission coefficient for the proposed FSS under TE polarization. Furthermore, there is a minor variation in the FSS response at various incident angles, although it is still within an acceptable range.

The transmission coefficient (S_{21}) for various incident angles (Theta (θ) = 00°, 15°, 25°, 35°,45°,55°,65°,75° and 85°) is shown in Fig. 3, while the corresponding reflection coefficient (S_{11}) is presented in Fig. 4.

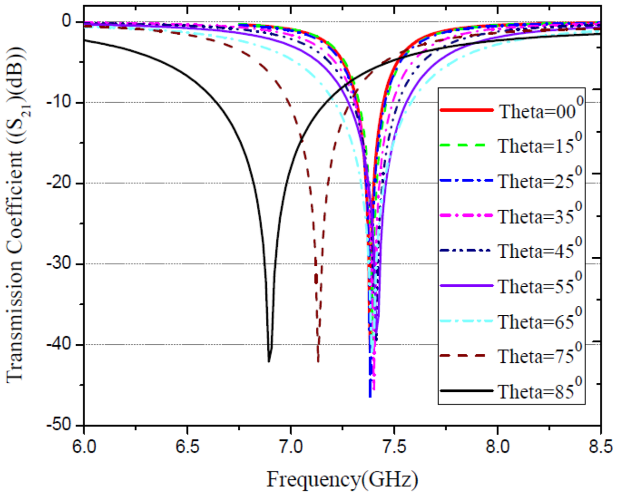

Fig. 3 – Transmission coefficient (S_{21}) of the proposed FSS with different incident angles

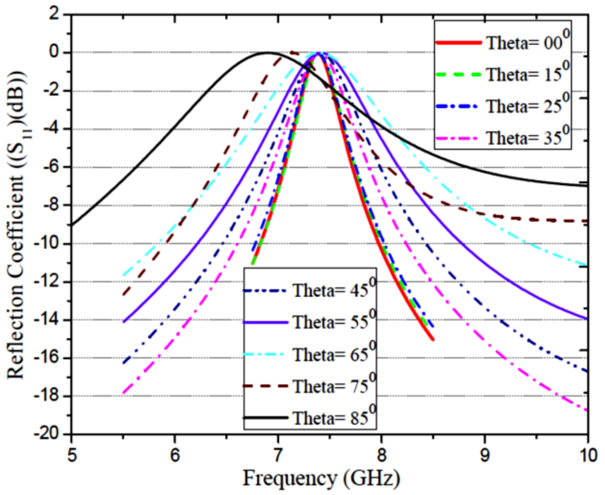

Fig. 4 – Reflection coefficient (S_{11}) of the proposed FSS with different incident angles

From the observations, it is evident that the structure exhibits a band-pass behaviour centered around 7.4 GHz with a sharp and deep notch in the transmission response. The transmission loss exceeds − 40 dB at resonance, indicating strong frequency selectivity. The shift in frequency response due to oblique incidence is minimal and remains well within acceptable limits, confirming the angular stability of the structure up to 65°. At higher incidence angles, the shift in resonance frequency is attributed to the effective reduction in capacitive coupling and an increase in the equivalent inductance of the resonant elements. However, this shift remains moderate for angles below 65°, demonstrating robust angular performance.

It is also observed that the structure does not exhibit any unwanted transmission harmonics up to 8 GHz, making it suitable for operation in the upper mid-band spectrum of FR1(C) and FR3 applications.

Table 2 – Angular stability performance for the proposed BPFSS

Incidence Angle (Theta (θ))	Resonant Frequency (GHz)		Deviation from Normal incidence (NI) (%)
	For Transmission Coefficient (S_{21})	For Reflection Coefficient (S_{11})	
00° (NI)	7.38	7.38	0
15°	7.39	7.39	0.14
25°	7.38	7.38	0
35°	7.40	7.40	0.27
45°	7.41	7.41	0.41
55°	7.41	7.41	0.41
65°	7.39	7.39	0.14
75°	7.13	7.13	3.39
85°	6.90	6.90	6.50

Angular stability in Frequency Selective Surfaces (FSS) is crucial for maintaining filtering (stop/pass band), bandwidth, preventing frequency shift and loss in wireless applications. Without it, an FSS intended for one angle performs poorly at others, rendering it unsuitable for dynamic settings. The proposed BPFSS is simulated to check angular stability by altering the angles of incidence between 0° and 85° while maintaining the steady resonant frequency. Table 2 tabulates angular stability performance for the proposed BPFSS. It can be observed that, the design achieves excellent angular stability, with the maximum resonant-frequency shift limited to just 0.03 GHz with respect to normal incidence angle of 0 degree, as the incident angle varies from 0° to 65°. Maximum allowable frequency deviation is considered as 0.5 % which is well less than the standard deviation (1 %).

4. CONCLUSION

A band-pass Frequency Selective Surface (FSS) operating in the 6.75 GHz to 8 GHz range has been successfully designed and simulated using ANSYS HFSS v2024 R2. The proposed FSS demonstrates high frequency selectivity with a deep transmission null at ~ 7.4 GHz, wide operational bandwidth of 1.25 GHz, and excellent performance under oblique incidence angles up to 65°, under TE polarizations considering only 0.5 % allowable frequency shift. Up to 65 this confirms its angular stability – key requirements for practical applications like 6G wireless reflectors and smart surfaces, Radar-absorbing structures (RAS) for aerospace and defence, Substrate-integrated waveguide (SIW) filters and EMI shielding in communication towers and data centers.

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Розробка унікальної смугово-частотної селективної поверхні для радіолокаційного застосування

Anindya Ghosh[1], Rakhi Neogi[1], Tapas Tewary[1], Sunandan Bhunia[2]

[1] *Department of ECE, Academy of Technology, West Bengal, India*
[2] *Department of ECE, Central Institute of Technology Kokrajhar, Assam, India*

У цьому дослідженні представлено проектування та повнохвильове моделювання смугово-частотно-селективної поверхні (BPFSS), оптимізованої для мереж Інтернету речей (IoT) у приміщеннях та радіолокаційних сенсорних застосувань. Для досягнення покращеної частотної селективності та вищої експлуатаційної ефективності запропонована FSS використовує концентричний полігональний розщеплений кільцевий резонатор, оточений круговими патч-елементами. Елементарна комірка складається з 24-гранного полігонального розщепленого кільцевого резонатора, оточеного шістьма круговими дисками, розташованими у формі правильного шестикутника. Реалізована як одношарова конструкція без металізації задньої сторони, структура відповідає стандартним практикам для застосувань просторової фільтрації. Така конфігурація дозволяє одношаровій FSS працювати в діапазоні 6,75-8 ГГц, забезпечуючи високу продуктивність просторової фільтрації на резонансній частоті 7,5 ГГц. Запропонована унікальна елементарна комірка BPFSS розроблена з використанням підкладки Rogers RO5880 товщиною 0,508 мм з відносною діелектричною проникністю 2,2 та тангенсом кута втрат 0,009 на частоті 10 ГГц. Кінцева структура має компактні розміри 10,8 мм × 10,8 мм × 0,508 мм. Моделювання було виконано за допомогою програмного забезпечення ANSYS HFSS з використанням граничних умов елементарної комірки та портів Флоке для емуляції нескінченно періодичної поведінки. Ця робота також підтверджується наближеним розрахунком резонансної частоти кругового кільцевого резонатора. Результати підтверджують придатність структури для застосувань смугової фільтрації з хорошою кутовою та поляризаційною стабільністю.

Ключові слова: Частотно-селективна поверхня (FSS), Смуговий фільтр, Розщеплений кільцевий резонатор (SRR), Радіолокаційна станція (RADAR).