2.4/5.8 GHz WLAN Filtering in Secure Electromagnetic Applications: A Single Layer Frequency Selective Surface

Maryam Majidzadeh

Department of Electrical and Computer Engineering, Urmia Girls Faculty, West Azarbaijan Branch, Technical and Vocational University (TVU), Urmia, Iran

ABSTRACT
This paper aims to propose a novel frequency selective surface (FSS) sketch for 2.45 and 5 GHz WLAN protection applications. The proposed FSS unit cell is printed on 10 × 10 mm² FR4 substrate with thickness of 1.6 mm. Simple conductive elements are printed on top and bottom sides of the single substrate layer. Wise inclusion of elements and precise tuning of their dimensions yields in rejection of two frequency bands in 2.45 and 5 GHz WLAN frequency bands. The presented structure exhibit stable response against different angles of TE and TM polarized waves. Suitable performance of the designed FSS makes it a suitable choice for use in secure electromagnetic buildings, and communication filtering applications.

1. Introduction
Todays, information protection has become a very important issue in communications. This feature becomes more critical in hospitals, prisons, and buildings with secure information. So far, many researches have been conducted on information protection era [1–3]. As the most practical method, it has been shown that embedding conductive sheets although could effectively reject the signals, but face some problems and challenges which call the need for some more reliable solution. One important problem is that the conductive wall rejects all possible impinging signals with different frequencies. This issue becomes a problem in special applications where specific frequency ranges should be stopped while the other should be passed. Having a more meticulous look at the matter and a brief literature review reveals that in most of the communication filtering applications, such a situation is present, that is, needing to pass and reject special frequency bands. As a
solution, frequency selective surfaces (FSSs) are promising candidates to be used in such cases. FSS is defined as an array of single elements which are arranged in a special order and exhibit filtering characteristics [4]. As an advantage, precise design of FSS could provide the opportunity to have pass or reject bands in desired frequency ranges. Owing to their marvelous merits, FSSs have gathered widespread applications such as antenna radomes [5], polarization convertor [6], absorbers and radar cross-section reduction [7], secure electromagnetic buildings and electromagnetic shielding [8–14], in which by adoption of FSS, special frequency ranges could be smartly prevented from running away of the building and provide a secure working environment. Literature review confirms that great effort has been devoted to design FSSs in recent years and interesting results are obtained. However, there are still some issues which could be enhanced. Some of them include:

- Designing small sized FSS unit cells to be in line with techno-economic goals.
- Tuning the operating frequency bands to most applicable frequency ranges such as WiMAX, WLAN, and X band.
- Utilizing simple and single layer structures to reach cost-effective fabrication.

Being biased by the above discussion, this paper intends to present a novel scheme of a single layer and simple FSS structure with 2.4/5.8 GHz WLAN rejection. The presented configuration is composed of a single layer FR4 substrate with simple conductive elements on both sides. Wise tuning of the conductive elements positions and dimensions yields in rejection of 2.4/5.8 GHz WLAN frequency bands. Moreover, stable frequency response against different angles of TE and TM polarized waves is obtained for the FSS in this work. The proposed structure is suitable for WLAN information shielding applications in smart buildings.

The remainder of this paper is organized as follows: Section 2 discusses the FSS unit cell design steps, simulation model, and S parameters. To analyze the FSS performance in varying environmental condition, FSS performance is studied in different angles and polarizations. Section 4 surveys the measurement results obtained for the experimental prototype. Section 5 compares the operational and structural characteristics of the designed FSS and some similar structure. Eventually Section 6 concludes the paper.

2. Unit Cell Design, Analysis, and Performance

Figure 1 shows the FSS unit cell configuration. As seen, FR4 material with thickness of 1.6 mm, dielectric constant of 4.4, and loss tangent of 0.02 is adopted as substrate. As it is seen, on top side of the substrate, a mirrored C-shaped element with folded edges is adopted. On back side, another mirrored C-shaped conductive element is embedded. Detailed values of unit cell parameters are reported in Table 1. Each conductive element, excites a resonance at a special frequency. Hence, including two conductive elements on two sides of the substrate yields in excitation of two resonance frequencies which results in dual band operation. As the resonance frequencies are in touch with the conductive elements positions and dimensions wise inclusion of suitable elements on top and bottom sides of the substrate would effectively yield in tuning the pass and rejected bands at desired frequency ranges. Moreover, features of substrate such as material, loss tangent, dielectric constant, and the other important parameters highly influence the obtained operating bands. Consequently, obtaining an appropriate frequency response requires a combination of suitable substrate with effective and well-tuned conductive elements.

FSS structures are two port networks including an input and an output port. Signals with wide frequency range are illuminated on the FSS. Based on the filtering characteristics and frequency response, some frequencies are laid in pass band and the others are in stop band area. Signal with frequencies in pass band, find the chance to pass the FSS and reach the output port. On the other side, receiver antenna receives the signals arriving to the output port. By studying the received signal, detailed analysis of the FSS performance could be conducted. Figure 2 shows the FSS unit cell as a two port network with corresponding $S_{11}$, $S_{12}$, $S_{21}$, and $S_{22}$ parameters. As $S_{21}$ indicates the rejected signal by FSS, this parameter is the important one in FSS performance analysis.

The proposed design is simulated using Ansoft High Frequency Structure Simulator. Simulation model of the FSS is shown in Figure 3. Master–slave boundary condition with floquet port excitation is adopted. As shown, right and top faces are defined as two master faces while left and bottom are the corresponding slave ones. Also, floquet ports are defined at the front and back of the FSS unit cell.

Figure 4 depicts simulated S parameters of the proposed FSS unit cell. It is clearly seen that two resonances are excited within 2.4 and 5.8 GHz WLAN frequency ranges. As well, to have a deeper insight on FSS design process and shedding light on the role of each conductive element on its final performance, a detailed analysis is carried out. It is shown that the resonance at 2.5 GHz is excited by the top side conductive element while 5.7 GHz is contributed by the backside mirrored C-shaped element. To investigate the FSS performance in a more meticulous way, surface current distribution analysis is conducted as in Figure 5. With respect to the obtained results, it could be obviously inferred that at 2.5 GHz, the
main current is concentrated on the top side conductive element, while at 5.7 GHz, current is mainly distributed on the backside mirrored C-shaped element. Accordingly, each of the elements is responsible for one of the excited resonances. It is worth mentioning that the results obtained from the surface current distribution confirm the previous discussions.

### 3. Angular and Polarization Stability Analysis

In real-world applications, different waves with varying polarizations and angles of incidence could impinge on FSS. A well-designed FSS is the one which exhibits stable frequency response against different operating conditions. This section intends to conduct angular and polarization sensitivity analysis to assess the FSS performance in changing conditions. Figures 6 and 7 depict $S_{21}$ parameter for TE and TM polarizations extended for $0^\circ$–$50^\circ$ angles. The incidence angle changes by a step of $10^\circ$. It can be seen that in both kind of polarizations, relatively stable response is obtained. That is, the proposed FSS demonstrates similar results at the investigated conditions. This notice confirms the FSS outperformance and its reliable solution.

The other affecting factor in FSS performance is substrate characteristics. The most important feature of substrate is the dielectric permittivity which could influence the FSS filtering characteristics. Herein, FSS performance is studied for three sample values of 2.2, 4.4, and 6.2 for which corresponding $S_{21}$ curves are plotted in Figure 8. It is seen that by increasing the dielectric constant values from 2.2 to 6.2, the resonance frequency shifts toward lower frequencies. This observation originates from the fact that resonance frequency is in inverse proportion to square root of the dielectric constant.

### 4. Measurement Results and Discussion

To investigate the FSS operation in real-world applications, an experimental prototype is fabricated and put under measurement analysis. Figure 9 shows top and bottom view of the fabricated prototype. Figures 10 and 11 depict the simulated and measured $S_{21}$ curves for TE and TM polarizations. A close agreement is reflected between the simulated and measured results in terms of resonance frequencies and rejected bands which confirms the FSS
outperformance. However, there are small discrepancies between the obtained results which could be originated due to different issues. Some of the most important issues include fabrication tolerance in terms of substrate material characteristics. Loss tangent and dielectric constant, measurement setup tolerances, and errors such as an improper calibration and operator errors during the measurement process could also be named. Considering all these issues, it can be seen that the proposed design demonstrates a satisfactory response and is not highly sensitive to the aforementioned factors. Accordingly, the measurement and simulated results are in good agreement with each other and the existing differences could be suitably neglected.

5. Comparison with Similar Designs

This section establishes a complete comparison of the proposed FSs with some of the previously designed structures proposed in [10–14]. Comparison points include unit cell size, number of substrate layers, number of operating bands, and compatibility with famous and applicable frequency bands. Studying the provided data in Table 2

![Figure 2. S parameters presentation for the proposed FSS unit cell.](image)

![Figure 3. Simulation model of the proposed FSS unit cell in HFSS.](image)
FSS geometry in [14] is the same size as the unit cell in this work with one wideband frequency range. As mentioned earlier, the proposed FSS unit cell smartly shields 2.4 and 5.8 GHz WLAN which could be utilized in modern and smart buildings for information security applications.

reveals that the proposed unit cell structures in [10–12] occupy larger size with respect to the unit cell in this work. This is while; they exhibit only one operating frequency band. The unit cell in [13] is smaller than the presented configuration and provides X band operation. Also, the

FSS geometry in [14] is the same size as the unit cell in this work with one wideband frequency range. As mentioned earlier, the proposed FSS unit cell smartly shields 2.4 and 5.8 GHz WLAN which could be utilized in modern and smart buildings for information security applications.
A novel sketch of a FSS with two stop bands at 2.4 and 5.8 GHz was proposed. Two conductive elements with the shape of mirrored C-shaped element with modified edges, and a simple mirrored C-shaped element is adopted on top and bottom sides of the FR4 substrate. By wise tuning of the elements dimensions and position, 2.4/5.8 GHz WLAN frequency bands are smartly shielded. Stable frequency response against different wave polarizations and angles of incidence are obtained. Also, suitable agreement between the simulated and measured results confirms the FSS outperformance. Comparison of the proposed FSS with some previous designs reveal that the presented FSS unit cell has smaller size and better performance with respect to similar previous FSS structures.

### 6. Conclusion

A novel sketch of a FSS with two stop bands at 2.4 and 5.8 GHz was proposed. Two conductive elements with the shape of mirrored C-shaped element with modified edges, and a simple mirrored C-shaped element is adopted on top and bottom sides of the FR4 substrate. By wise tuning of the elements dimensions and position, 2.4/5.8 GHz WLAN frequency bands are smartly shielded. Stable frequency response against different wave polarizations and angles of incidence are obtained. Also, suitable agreement between the simulated and measured results confirms the FSS outperformance. Comparison of the proposed FSS with some previous designs reveal that the presented FSS unit cell has smaller size and better performance with respect to similar previous FSS structures.

### Disclosure Statement

No potential conflict of interest was reported by the author.

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