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Design and Analysis of High Angular Stability Wideband Bandstop FSS for 6G D Band Applications

Harsh Choudhary*(1), D Venkata Siva Prasad(2) ,and Shrivishal Tripathi(2)
(1) Central University of Rajasthan, Rajasthan, India
(2) IIIT Naya Raipur, Chattisgarh, India

Abstract

This work aims to present a new design for Frequency Selective Surfaces (FSS), especially for high-bandwidth 6G applications using the sub-THz spectrum while keeping the existing angular stability above both TE and TM waves of more than 70° at a certain frequency of 141.36 GHz. The proposed FSS is realized with copper elements on a quartz substrate, whereby the notch frequency is highly attenuated at -50 dB. It has a large bandwidth in the stopband of 54.1 GHz with upper and lower stopband frequency of 171.3 and 117.2 GHz respectively, which corresponds to a relative bandwidth of 38.27% with respect to a -10 dB reference. In addition, it is found that its bandwidth for a -20 dB band is very large, around 20 GHz, and its performance is good. CST simulations proved the design is effective. Therefore, with its strong angular stability and high-attenuation characteristics, this FSS could be a potential solution to mitigate interferences and ensure signal quality of high-frequency large-capacity 6G communication systems. It will catalyze a smooth convergence with other millimeter-wave (mm-wave) communication frameworks.

1. Introduction

Growing demand for data and the inability of 5G to provide ultra-high data rates and minimal latencies are the factors in the literature that mention women's increase in the necessity for 6G, with the main research for the 6G spectrum being more than 100 GHz to give the real-time experience, and the data rate is to be higher than 1 Tb/s. Compact high integration, followed by the straightforwardly structured device ability, is therefore imperative that will enable the realization of 6G. Amongst these, the FSSs present a potential solution having the characteristic in manipulating electromagnetic waves' propagation.

Only very few design realizations for such FSSs designed for the frequency band of 100 to 200 GHz have been reported to the best of author's knowledge [4-8]. Certainly, none of these designs can be considered to be of general or universal applicability; invariably the application-specific benefits are gained at the price of correspondingly high levels of complexity. For example, the FSS designed in [5] will have good polarization stability for sure, due to its hexagonal cavity structure, but have more complexity. The FSS in [6] has a flat passband, but the structure has eight layers and thus, leads to non-easily manufacturable. FSS in [7], provided with a quad-band frequency response, but evidenced practicality limited by a considerable thickness. The simple FSS in [4,8] is characterized by weaker obtained performance parameters.

It is an effective way to solve the above problems and provides a new single-layer, simple, compact, and easy-to-fabricate ability for possible implantation in 6G communication systems. In this work, we operate to design an FSS structure with a metallic array on a quartz substrate that manages to sustain a sub-THz range resonance frequency with a significantly large stopband bandwidth. Therefore a simple, single-layer structure results in a very low cost of materials and easy fabrication, making it an extremely promising candidate for 6G communication systems.

2. Design, Analysis & Discussion

This FSS uses a single-layer metallic structure, and it is based on the very well-understood circular loop for simplicity and ease of fabrication. Eight inner stubs extend inwards from the loop, further enhancing performance to achieve a higher working frequency within a compact footprint. This approach, detailed in [9], increases the electrical length of the FSS without introducing significant fabrication complexities. It is built with a metallic array on a 0.5 mm thick substrate, as illustrated in Figure 1. The length and width of the stub are important parameters to adjust and change the position of the resonance frequency so that the specific filtering response pursued is reached.

2.1 Physical Characteristics of the FSS

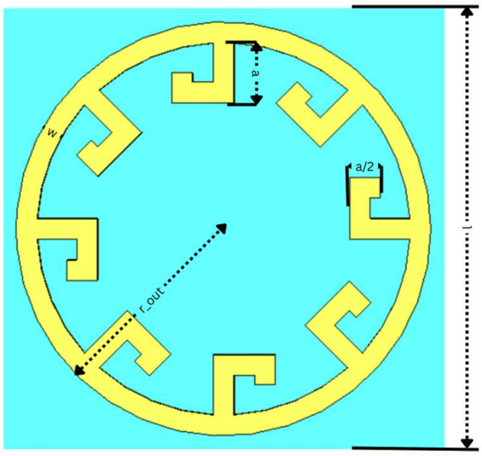

Figure 1. Geometry of the proposed FSS design.

This FSS incorporates a circular ring with a specific width and outer diameter for enhanced electromagnetic performance in D-band. The FSS design is mounted on a quartz substrate (Dielectric) with relative permittivity of 3.75 and loss tangent of 0.0004. These reference values make a sound impact on the electromagnetic behavior of the FSS at many frequencies. The substrate is designed on a square configuration measuring 0.516 mm x 0.516 mm with a thickness of 0.5 mm. In this configuration, there is a circular metallic ring made of copper, which is deposited on top of the substrate. Configuration of this idea over others presents several advantages, some of which are unique. Very importantly, the patch has a small rectangular extension on one side, referred to as a stub (hook like structure). The proposed FSS will be with the following dimensions: r_out = 0.24 mm, w = 0.024 mm, a = 0.07 mm, and the width of copper = 0.035 mm. These parameters are required to get the desired characteristic of frequency response of FSS.

2.2 Simulation Results

Frequency response of the proposed FSS is shown in Figure 2. The figure shows a notch frequency at 121.36 GHz frequency with deep attenuation of -50 dB. This design shows a wide bandwidth of 54 GHz with upper and lower stopband frequency of 171.3 and 117.2 GHz respectively. This notch behavior can be considered to be effective in reducing interference and high signal quality.

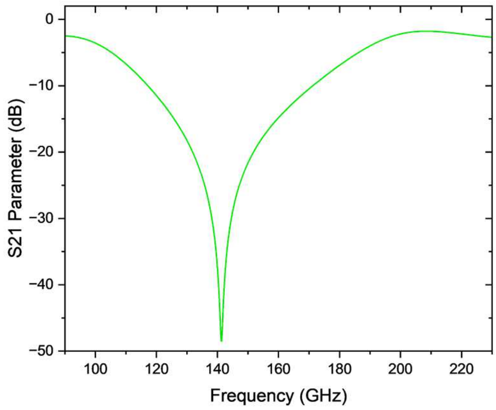

Figure 2. Transmission Response of the proposed FSS

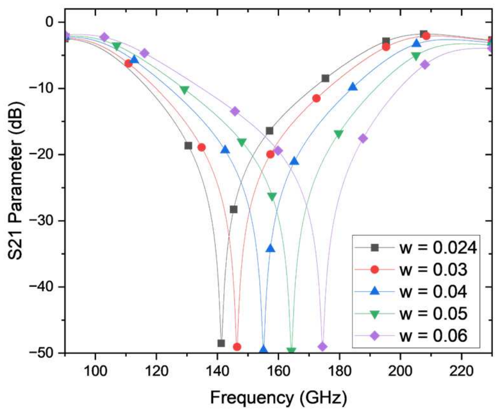

Figure 3. Transmission characteristics with variation in width of circular ring(w).

2.3 Variation of Response with Physical Parameters

The vital evaluation characteristic is the sensitivity and robustness of the design against physical parameters, such as width (w), and outer radius (r_out). The variations in the S21 parameter is analyzed; the variation of the S21 parameter while the width, w, of the circular ring is varied is shown in Figure 3. Results have clearly shown a sound impact of this width on the resonant frequencies of the proposed FSS, which shows the forward shifting of the notch frequency. In the same manner, by means of Figure 4, the change in S21 (dB) with the change in the outer radius of the ring (r_out) is shown. The result of this analysis suggests that it presents the most optimal resonant frequencies upon the rise in the value of the outer radius, and hence results in a downward shift in the notch frequency.

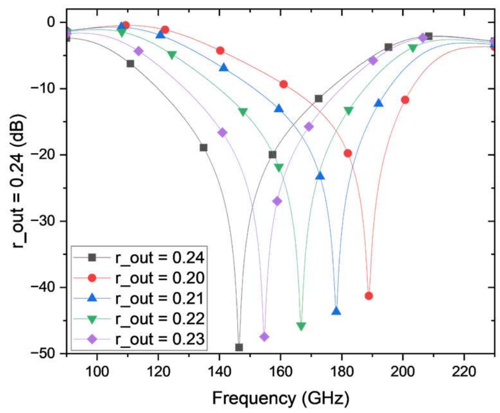

Figure 4. Transmission characteristics with variation in outer radius(r_out).

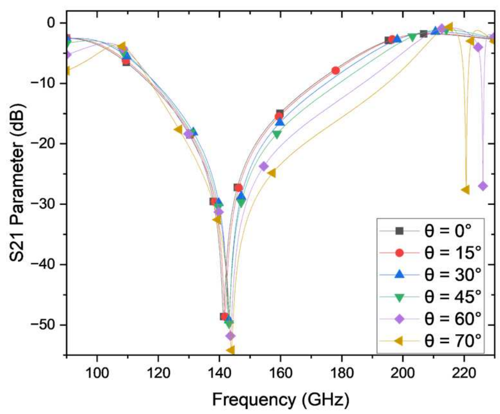

Figure 5. Transmission response under different incident angles for TE polarization.

2.4 Transmission Response under Different Incident Angles

The functional needs often require electromagnetic waves to be incident from many directions. Hence, FSS designs must exhibit low angular sensitivity. Transmission characteristics of the FSS for TE and TM wave polarizations have been plotted in Figures 5 and 6 at oblique angles of incidence. The great aspect about the obtained results is the truly stable response in frequency for wide angle values in this case, up to 70° with a small variation in the notch frequency. This notch frequency has a small relative error of ±1.8% (TE modes) and ±1.7% (TM modes)[10]. This excellent angle-insensible characteristic will just show a very low degree of angling influence and gives the possibility of even realization in real-world applications in irregular environments.

2.5 Distribution of Surface Current Density

The distribution of the surface current density of the FSS at its resonant frequency is presented in Figure 7. It is observed that the circulation is mainly at the edges of the

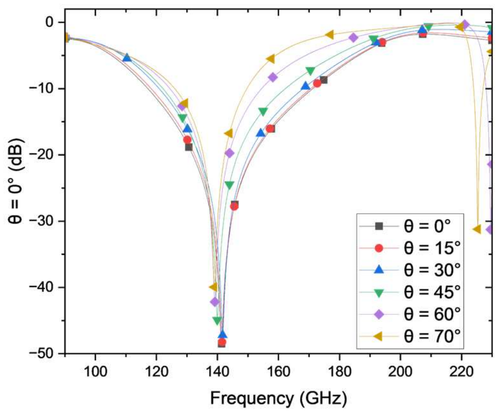

Figure 6. Transmission response under different incident angles for TM polarization.

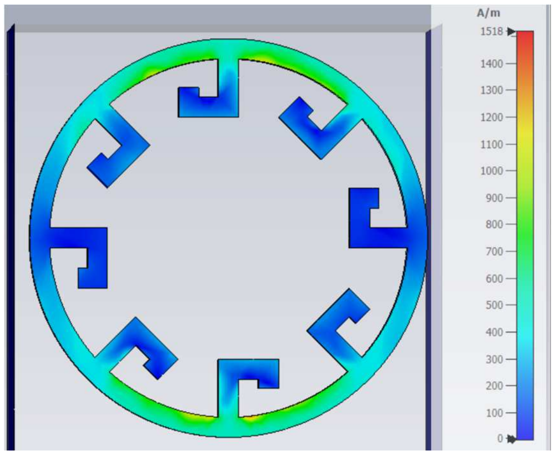

Figure 7. Distribution of surface current density at resonant frequency

circular ring and the stubs. Brighter areas represent the high current density areas. In fact, it comes out to be such a distribution that effectively drives the current in the FSS structure, which is a very strong requirement for obtaining desired resonance, which in turn leads to effective electromagnetic responses.

Table 1 Electromagnetic Parameters Variation with Number of Stubs

No. of Stubs	E-Field (V/m)	H-Field (A/m)	Surface Current (A/m)	Notch Frequen-cy
4	516227	1196.32	1404.06	147.12
6	352536	1161.28	1425.04	142.64
8	306211	1139.02	1517.98	141.36
10	309771	1261.24	1760.61	140.24

Table 2 Comparison of the proposed FSS with the reported FSSs

FSS	Type	Band -width	Max. Angle of Incidence	Trans mitta nce
[6]	Bandpass	10	15	0.28
[7]	Bandpass	10	-	1
[8]	Bandstop	20	-	40
[4]	Bandstop	37	60	39
This work	Bandstop	54.1	70	49

2.6 Development and Analysis of proposed FSS

FSS with varying stub numbers (4, 6, 8, and 10) changes electromagnetic properties, mainly the electric field, magnetic field, surface current, and resonant frequency, as shown in Table 1.

FSS with the eight stubs is considered the best choice because of its low interference, low electric field and low magnetic field, high surface current, and notch frequency suitable for 6g communication.

3. Comparison with the proposed FSSs

A comparison of the proposed FSS with reported FSSs are shown in Table 2. Sound improvements are demonstrated by the proposed FSS such as good angular stability, up to 70° for both TE and TM waves, and bandwidth of 54 GHz, hence suitable for real-world applications.

4. Conclusion

This paper proposed a new simple design for FSS - compact, and efficient in its filtering behavior for future 6G communication systems. This single-layer structure has been designed with strategically augmented stubs to obtain the resonance at 141.36 GHz and stopband of 54 GHz with upper and lower stopband frequency of 171.3 and 117.2 GHz respectively. The design shows very good radiation characteristics for the proposed spectrum, while its angle-insensitivity up to 70° makes it quite suitable for practical deployments. Further optimization is completed by variation analysis of the parameters. It is an attractive candidate for communication systems that require low-cost, miniaturized filtering solutions with high performance for 6G communication systems.

5. References

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