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Design and Performance Analysis of Band Pass Filter Using Frequency Selective Surface for 5G Communication

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Abstract

In recent years, frequency selective surfaces (FSSs) have been extensively investigated in terms of their design and practical applications at microwave and optical frequencies. This study proposes a new design of a FSS layer, which is directly placed over the surface of an antenna to enhance its characteristics such as directivity, frequency selectivity, radiation efficiency, and gain. In the proposed design, two different substrates are used to analyze the improved performance of the FSS layer. For this purpose, FR-4 Epoxy and Duroid 5880 are used for cost effectiveness and to achieve the optimized performance of the antenna. The simulated and measured results are in good agreement, indicating the enhanced performance of antenna for WLAN and WiMAX applications. Finally, it is concluded that the proposed FSS layer ensures the best possible results of the filtering response as the first null gives divergence of more than 10 dB with its peak value layer.

Keywords: frequency selective surface, bandpass filter, resonance, WiMAX, WLAN

1. Introduction

Frequency selective surfaces (FSSs) are periodic surfaces that are used as filters and are composed of two or three dimensional lattices. The FSS can provide a wideband structure to certain frequency ranges and act as band pass filters or band stop filters [1-4]. The characteristics and performance of the FSS as filters have been validated in previous studies. For example, Zhu et al. [4] proposed an antenna with the FSS, which enhanced 40% antenna performance by affecting the bandwidth and improving the gain up to 5.6 dBi. The FSS is a potential way to work efficiently even in the presence of interference [5].

The complementary FSS and fractal FSS were analyzed and designed based on the resonance phenomena [6-7]. Wu et al. [8] presented wideband gridded square frequency selective services for electromagnetic (EM) waves. A stop band (4 GHz – 7 GHz) was achieved using two cascaded layers of the FSS [9]. A wide frequency tunable FSS in a range of 3.5 GHz – 5.8 GHz for EM shielding applications were discussed [10-13]. Braz and Campos [14] investigated the use of the FSS with multifractal geometry with a very simple structure.

The research community has turned their focus toward the FSS considering their effective performance in applications, such as polarizers, beam splitters, antennas, RADAR cross section reduction, absorbers in military, and satellite communication [15-20]. The dealings among the unit cells help end into the frequency assortment distinctiveness. Hence, a

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huge amount of unit cells is required for in-questing the actual frequency selective property [10, 19, 21-22]. In this method, besides using a resounding configuration as the primary unit of the frequency discerning area, distinctive entity cells with few definitions are utilized. The subject entity cells behave as lumped capacitive and inductive elements and are finely arrayed, so they are joined to make up the electric and magnetic fields of an incident ray, respectively.

This study reports a novel design of a bandpass filter by using the FSS for WLAN and WiMAX at the frequency of 5 GHz. The proposed FSS layer is designed and simulated in the commercially available software – high frequency structure simulator (HFSS). To support the simulated results, a couple of measurement setups, which will be described later, are considered using a network analyzer, signal generator, spectrum analyzer, and anechoic chamber (facility at the National University of Sciences and Technology, Pakistan).

2. Design Geometry

Two different substrates were used to analyze the performance of the FSS during design process. Service material FR-4 Epoxy is utilized at first to see the results. The relative permittivity of the substrate is 4.4 and the height is 1.6 mm. The second substrate utilized is Duroid 5880 in lieu of the primitive FR-4. The relative permittivity of Duroid 5880 is 2.2 and the height is same as the one in the first case, i.e., 1.6 mm. The design geometries of the FSS using both substrates are depicted in Fig. 1 and Fig. 2, whereas the dimensions (length × width × depth) of the designed geometries are given in Table 1.

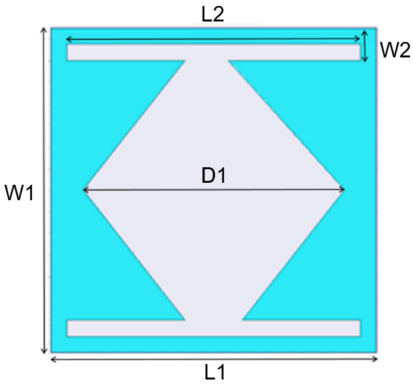


Fig. 1 Design geometry of the FSS at 5 GHz using FR-4

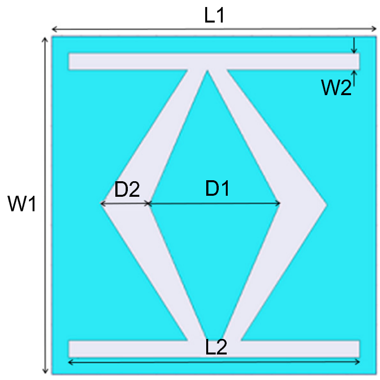


Fig. 2 Design geometry of the FSS using Duroid 5880/Rogers RT

Table 1 Design parameters of the FSS's unit cell

Using FR-4 as a substrate			
Parameters	Dimension (mm)	Parameters	Dimension (mm)
W1	15	L2	13
W2	75	D1	12
L1	15	-	-
Using Duroid 5880 as a substrate			
W1	85	L2	15.3
W2	17	D1	6.8
L1	17	D2	2.6

A periodic surface is molded when identical elements are stacked in an infinite array of one or two dimensions [23]. An incident plane wave and the attached generators applied to individual elements are two primary methods to excite a periodic array. The incoming plane wave (E_i) is partially transmitted (E_t) in the forward direction and partially reflected (E_r) specularly in the former type. In resonance, the reflected wave (E_r) equals the incident wave (E_i), whereas the transmitted signal (E_t) is zero. Γ is the specular reflection coefficient and can be expressed as in Eq. (1).

$$\Gamma = \frac{E_r}{E_i} \tag{1}$$

Likewise, the transmission coefficient (T) can be expressed as in Eq. (2)

$$T = \frac{E_t}{E_i} \tag{2}$$

Columbic energy, associated with the electrostatic forces of a system of particles, could be developed with the help of a capacitor, which can be fashioned by involving 02 different conductors at singular DC levels [24]. If an electric (E) field is established between two conductors, it means there is a formation of a capacitor. From the electrodynamics concept, the inductive consequence can be achieved by exciting charges in a conductor. Likewise, the inductor can be formed subject to the conductive wire in the magnetic field that is changeable w.r.t time [25]. Therefore, filters can be modified as per application requirements by changing the dimensions of a patch in the design geometry.

3. Results and Discussion

3.1. Simulated results

The FSS is employed on the surface of the antenna to attain the filter response. The filter response changes as the distance between the antenna and FSS are changed. To get the optimized distance between the patch and FSS, a parametric analysis for various distances (0-50 mm) is conducted using HFSS.

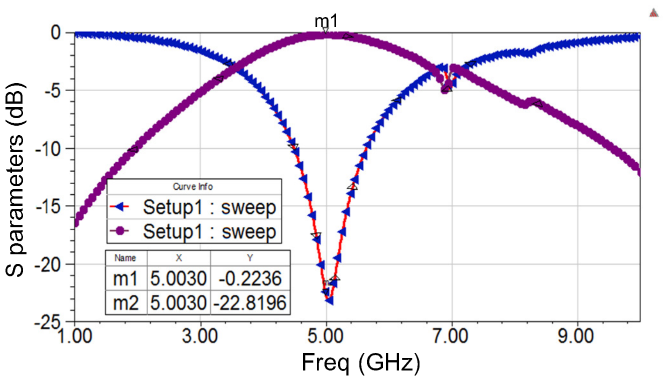


Fig. 3 S(2,1) and return loss at 5 GHz with FR-4

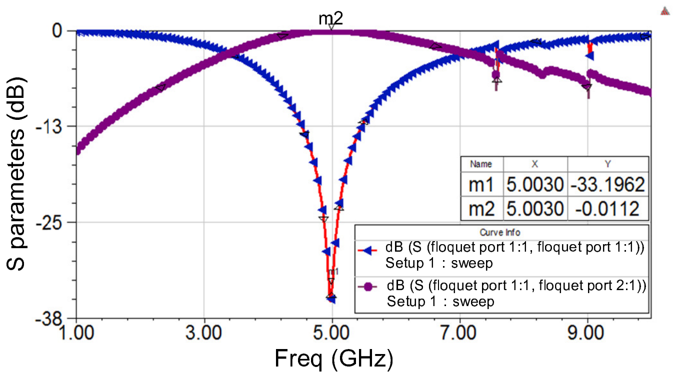


Fig. 4 S(2,1) and return loss at 5 GHz with Duroid 5880/Rogers RT

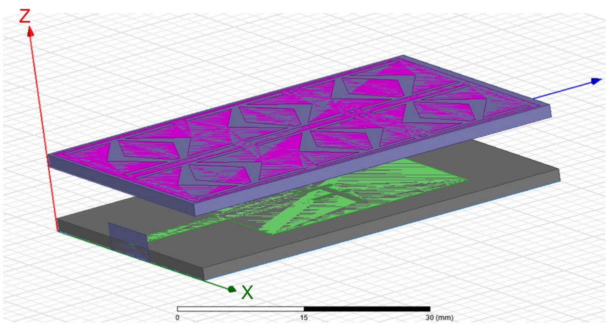


Fig. 5 Antenna and FSS setup in HFSS

FSS patches create inductance (*L*) and resistance (*R*), while FSS gaps create capacitance (*C*). This simple electrostatic principle applies to different FSS elements, e.g., *L* of two parallel wires and *C* created by a parallel plate capacitor. Therefore, these capacitive and inductive elements are combined to form a filter response. Changing the FSS dimensional parameters alters the *L* and *C* values. When an FSS unit cell is illuminated by an EM wave, it becomes an analogous resonance circuit. The resonance frequency can be calculated by Eq. (3), where *L* and *C* are the equivalent inductance and capacitance of an FSS unit cell.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{3}$$

The simulated response of the bandpass filter using the material FR-4 Epoxy is shown in Fig. 3 and Fig. 4, which demonstrate the S(2,1) parameters and return loss of the bandpass filter using Duroid 5880 at 5 GHz. The optimum distance range between the antenna and the FSS is 5-10 mm as depicted in Fig. 5, and the simulated results of return loss after employing the FSS is shown in Fig. 6.

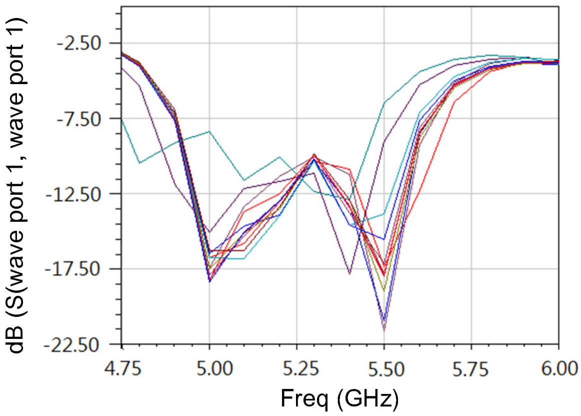


Fig. 6 Return loss after employing the FSS at a distance of 1 mm ~ 50 mm

3.2. Measured results

To achieve precise outcomes, an intermittent arrangement of base cells is shown in Fig. 7, the antenna as shown in Fig. 8 is considered, and the FSS is machined manually. The port S(2,1) is examined after measuring results from the vector network analyzer (VNA). Firstly, the port S(2,1) is monitored without the FSS with antennas on both ports of VNA, the port S(1,1) is gauged whereas the FSS is placed with the antenna. The simulated results before and after employing the FSS are depicted in Fig. 9.

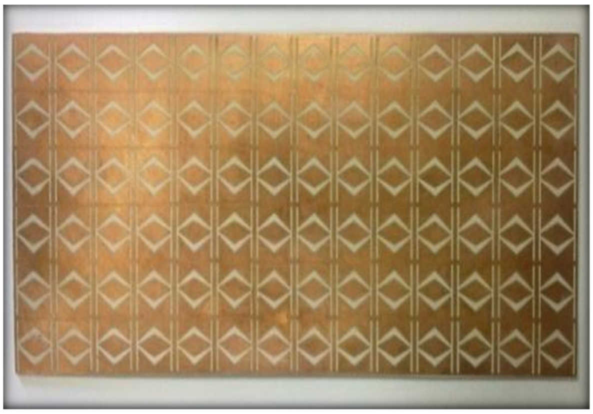


Fig. 7 An intermittent arrangement of base cells at 5 GHz

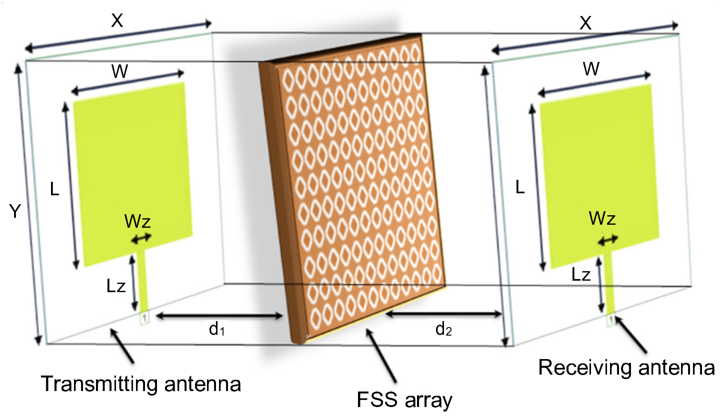


Fig. 8 Placement of the FSS between the antennas for measurement of S(2,1)

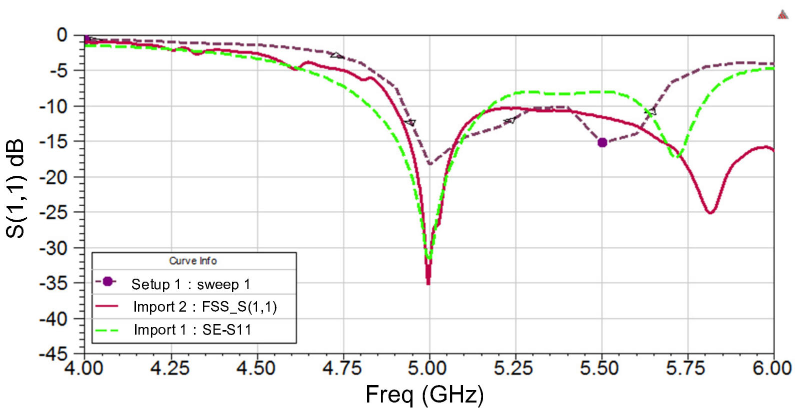


Fig. 9 Comparison of simulated results for S(1,1) with and without the FSS at 5 GHz

It is observed that bandwidth (BW) becomes narrower with improved selectivity. As the BW is tapered, the selectivity boosts. The first curve is for antenna without the FSS, the second curve is with FSS placed between the antennas with the substrate is of material FR-4, and the third curve has superior traits. The bandpass behavior of the FSS is depicted in Fig. 10.

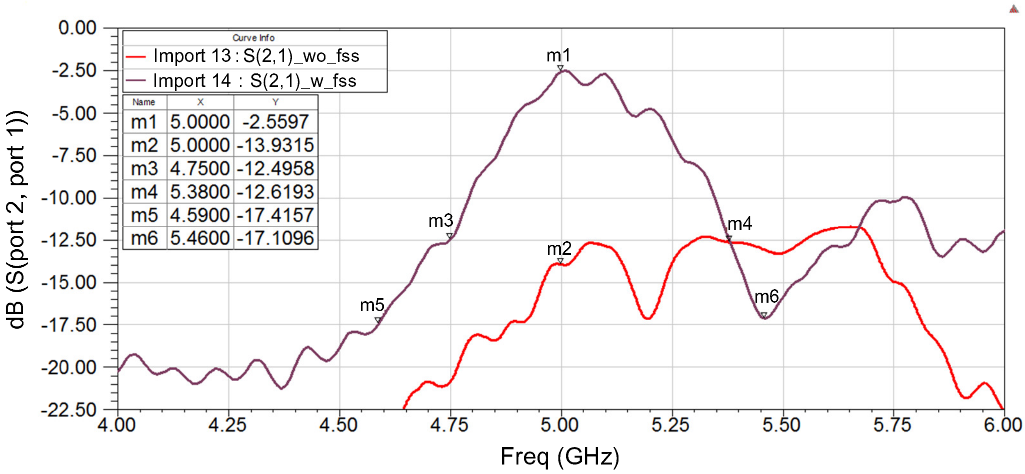
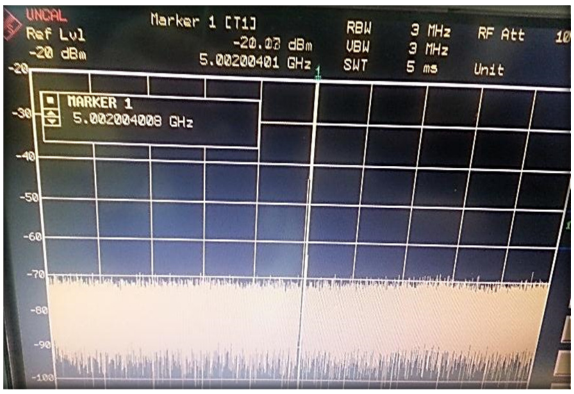
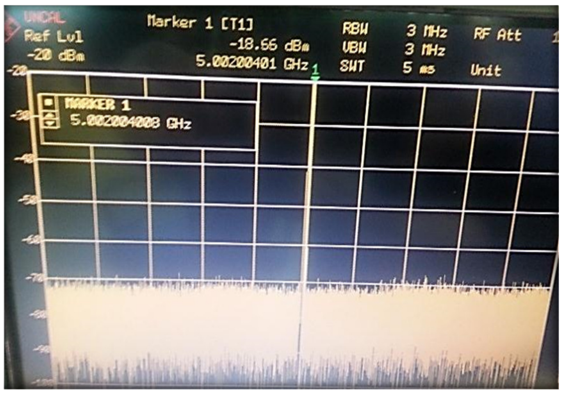


Fig. 10 Bandpass response measurement of S(2,1) with the FSS at 5 GHz

The antenna radiation efficiency is good with a return loss of -32 dB, accentuating a fine efficient bandpass filter response in the presence of the FSS. A boost in the receiving capability of the antenna is observed since the peak value rapidly raised from -13 dB to -2.5 dB. To further investigate the performance of the FSS and the antenna elements, another test is performed with the help of a signal generator tuned at 5 GHz. A comparison of the received power is given in Figs. 11(a) and (b), where two identical antennas are used at the transmitter and receiver. At a distance of 1 meter, the FSS was able to bring the receiver power from -18 dBm to -12 dBm, significantly improving the antenna receiving efficiency.



(a) Power received in the absence of the FSS



(b) Received power after employing FSS antennas

Fig. 11 Power analysis of FSS antennas

4. Chamber Results

To analyze the radiation patterns, the antennas are tested in an anechoic chamber. This process consists of two setups. The 1st antenna is tested without the FSS, and then the radiation pattern is investigated in the presence of the FSS. The complete setup of the fabricated antenna is shown Fig. 12.

The FSS structure serves as an effective reflector, diverting the majority of the wasted energy from the undesirable direction to the desired direction without impairing the performance of the meta-material antenna return loss [24]. The most important objective of the FSS on the superstrate layer is to provide protection for the microstrip antenna with less insertion loss and the enhanced radiated signal. Furthermore, the usage of FSS decreases the complexity of the transceiver by removing the band pass filters.

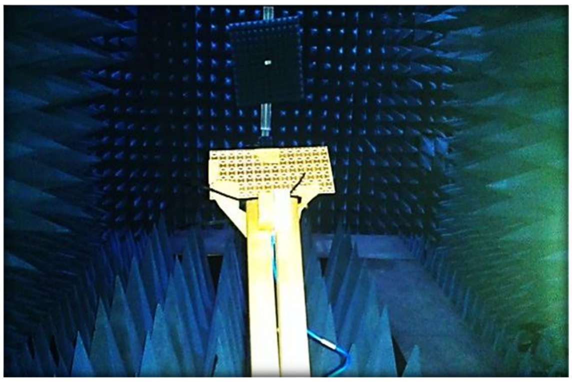
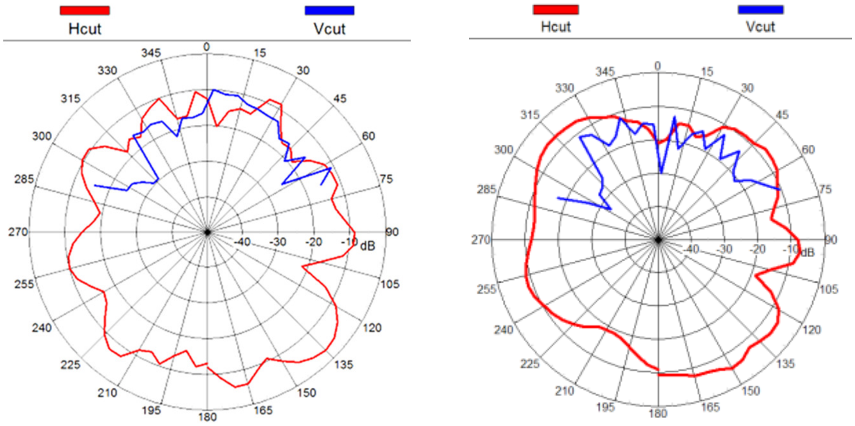


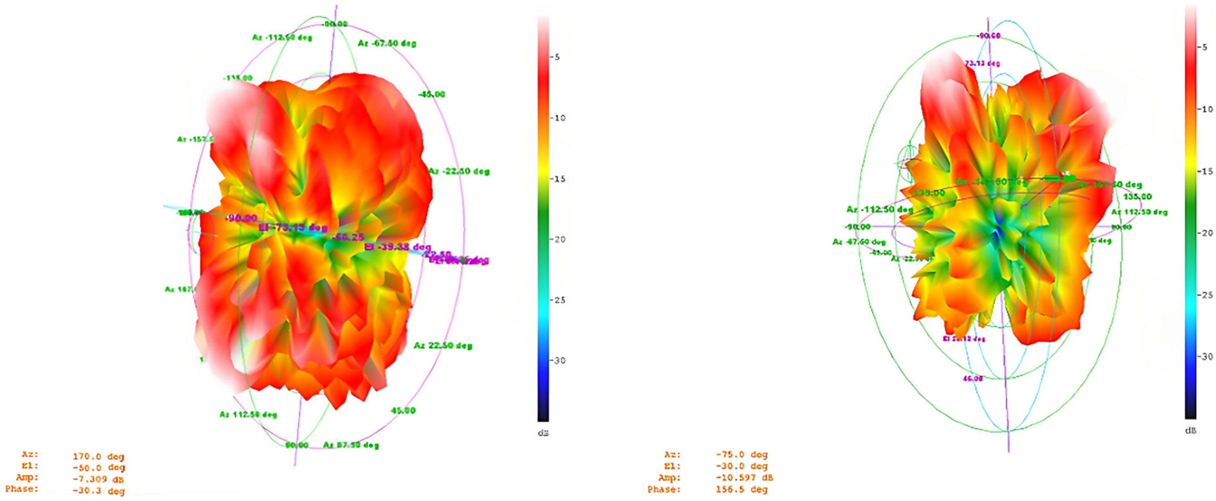
Fig. 12 Antenna and FSS setup in anechoic chamber for radiation analysis

Two 2D emission patterns are depicted in Fig. 13 and 3D patterns are shown in Fig. 14. There is an increase in the directivity, and it's in the XY plane. The improved gain can be noticed in Fig. 10, where S(2,1) is better with forming a filter containing sharp edges. Also, the improved gain has reduced the bandwidth up to 300 MHz.



(a) Without FSS (b) With FSS

Fig. 13 Two dimensional radiation patterns at 5G



(a) Without FSS (b) With FSS

Fig. 14 Three dimensional directivity of the antenna at 5 GHz

5. Future Trends of FSS

The future of the FSS can be projected based on existing patterns, as there is massive innovative research going on. Sharp band edges, broader bandwidth, stability (which contains the variation of incident angle), and EM wave polarization are the required characteristics of an FSS. Some important applications of the FSS are summarized in Table 2.

Table 2 Summary of practical application of the FSS

Sr. No.	Applications	Sr. No.	Applications
1	Double curved FSS service	6	Smart absorbers FSS
2	Tunable and software defined FSSs	7	FSS for high power radar communication
3	Metamaterial FSS for satellite communication	8	FSS for wireless power transfer applications
4	Wearable sensing FSS	9	Dynamically reconfigurable FSSs
5	Chipless passive structure strength monitoring FSS	10	FSS for isolating unwanted and harmful radiation

6. Conclusions

A frequency selective surface is designed on Duroid 5880/Rogers RT for wireless and microwave communications that can be used as a band pass filter. The FSS is placed on the surface of an antenna and complicated with an SMA connector of 50 Ω (input impedance) to get the required results from the network analyzer and anechoic chamber. The simulated and measured results have a good resemblance. Filtering response is in its best possible results as the first null is giving divergence of more than 10 dB with its peak value. Impedance bandwidth is fulfilling the requirements for the 5G communication applications such as WiMAX 5.2 GHz and WLAN (5.15 GHz ~ 5.35 GHz) frequency bands (for wireless communications).

Conflicts of Interest

The authors declare no conflict of interest.

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