Design and Analysis of Frequency Selective Surface (FSS) Using Complementary Techniques on Glass

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***Abstract*—This paper presents the design of square Frequency Selective Surface (FSS) based on a complementary technique for energy saving glass (ESG) application. In this paper, there are four designs of FSS that have been presented which are a square patch (Design A), square patch rectangular slot (Design B), complementary square patch with a rectangular slot (Design C) and complementary square patch with rectangular slot and square loop (Design D). All design used glass as a substrate and aluminum as the conductive patches. The unit cells of each design are simulated using CST Microwave Studio software. The simulation process is based on the characteristics of reflection coefficient (S11) and transmission coefficient (S21) of the FSS. The simulation result shows that Design B exhibit pass band at 5.2 GHz. While, Design D produce dual pass band at 1.7 GHz and 5.2 GHz. Therefore, this design can be used to improve the transmission of the wireless communication signal.**

***Index Terms*—Frequency Selective Surface (FSS), Square Patch FSS, Square Patch FSS With A Rectangular Slot, Complementary Techniques, Reflection Coefficient (S11), Transmission Coefficient (S21).**

I. INTRODUCTION

The uses of Energy Saving Glass (ESG) is increasingly widespread implement in the nowadays modern building to development their thermal properties. A metal coating such as silver material or aluminum material is implementing on the glass due to their low-emissivity properties. The features of microwave propagation using metallized windows glass are presented in several papers that only applied frequency below 6GHz. It shows that not many researchers applied higher frequency to implement a metal coating on the Energy Saving Glass (ESG) [1].

In [1], the paper implements microwave frequency from 1 to 20GHz on the modern energy-saving glass. It observed the shielding effectiveness (SE) of modern energy saving glass. It found that attenuation of microwave radiation passing through modern energy saving glass can maximize until 60dB during the process. Nearly some of the energy saving glass was studied and presented at a high value of shielding effectiveness at GSM and Wi-Fi frequency bands. Before fixing new window or energy saving glass, it can be valuable to think through from this report [1], [2]. Several classifications of energy saving glass were studied experimentally by attenuation maximum to 40dB at three fitted frequencies [3].

A tri bandpass frequency selective surface (FSS) is applied on energy saving glass (ESG) some frequency such as 0.9GHz, 1.8GHz, 2.1GHz and 5G technology. The incident angles increasing from 0˚ to 45˚ for both TE and TM polarizations achieve a stable frequency response [4],[5],[6].

A double glazed soft-coated energy saving glass (ESG) is studied for parametric analysis of a band-pass FSS. A hexagon FSS shape is etched with soft coated to attenuate the transmission of microwave signals. Through the sputtering method, the soft coated is placed on the surface of the energy saving glass (ESG) [7],[8],[9].

Frequency Selective Surface (FSS) is a planar periodic structure of identical patches or apertures of conducting elements repeating periodically in either a one- or two-dimensional array on a dielectric substrate [10]. FSS are two-dimensional periodic arrays that can function as a spatial filter in free space which consists of two types of elements. The two types of elements are patches elements and aperture element (slot). The different design elements of FSS can produce different results such as patch element that can produce band-stop characteristics while the aperture element can produce the band-pass signal [11],[12]. Frequency selective surface (FSS) can be done with sharp band edge. By combining two bandstop FSS, a bandpass FSS can be produced [13],[14],[15].

In this paper, a square patch FSS is presented. A square patch FSS is designed in two ways. First is the basic design on the glass and second is a basic design using the complementary technique on the glass. The process of the design will be explained is Section II. Through the FSS design, the design can achieve a single band and dual band.

II. FSS DESIGN

The proposed FSS is shown in Figure 1, Figure 2, Figure 3 and Figure 4 are designed and simulated using CST Microwave Studio. This structure has been designed on glass material substrate with a thickness of 2mm, dielectric constants of 4.89 and loss tangent of 0.0054. Meanwhile the structure of FSS layer is made of aluminum material with a thickness of 0.089. The dielectric constant of aluminum is 3.56 and loss tangent of 0.07. Figure 1 shows Design A, a square patch on the glass. Figure 2 shows Design B, a square patch with a rectangular slot on the glass. Figure 3 shows Design C is a complementary square patch FSS with a rectangular slot at the center. Figure 4 shows Design D, a square patch FSS with a rectangular slot at the center and square loop using complementary techniques. The first step is to design glass with a thickness of 2mm. The second step is to design a square patch FSS using the aluminum material. After designing is done, all designs are simulated using CST MWS

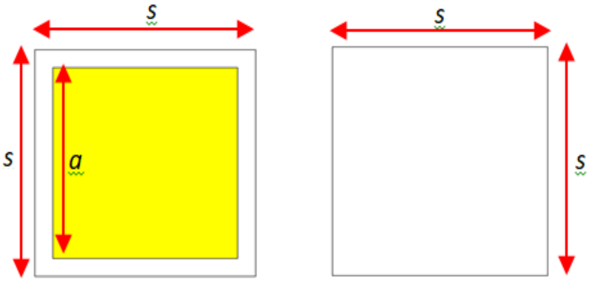

Figure 1: Design A (square patch on the glass)

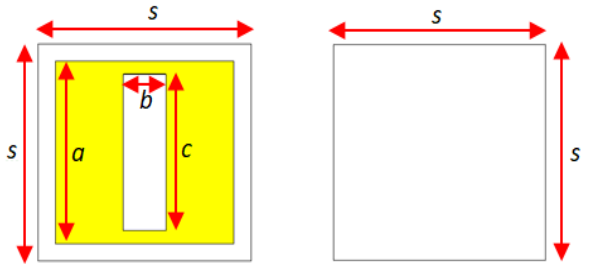

Figure 2: Design B (square patch with rectangular slot)

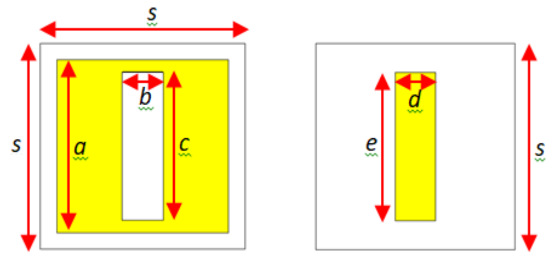

Figure 3: Design C (square patch with a rectangular slot on the glass using complementary techniques)

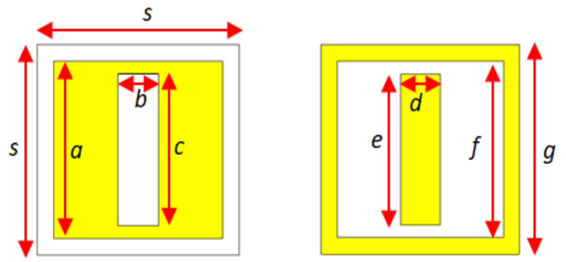

Figure 4: Design D (square patch with rectangular slot and rectangular with a square loop using complementary techniques)

Figure 5 shows that when the parameter *s* is increased, the reflection coefficient shows that no frequency is resonated. Figure 6 shows the transmission coefficient of parameter *s*. When the parameter *s* is increased, the transmission shows not many changes in frequency response.

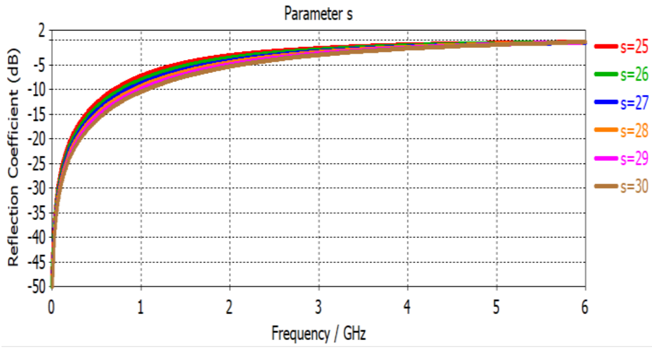

Figure 5: Reflection coefficient analysis of parameter s

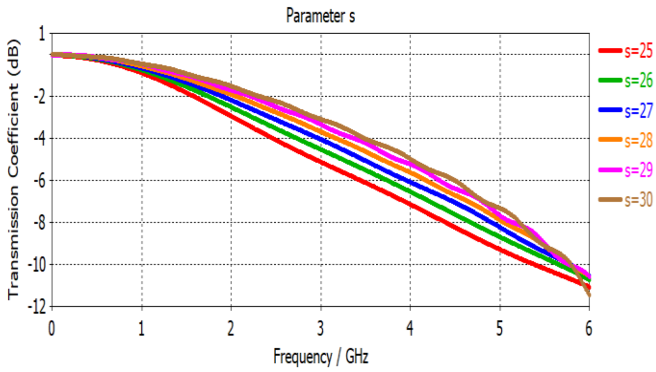

Figure 6: Transmission coefficient analysis of parameter s

Figure 7 shows the reflection coefficient analysis of parameter *a*. When the parameter *a* is increased, the frequency approaches frequency to 0dB. Figure 8 shows the transmission coefficient analysis of parameter *a*. The transmission coefficient is same like transmission coefficient analysis of parameter *s* in figure 6.

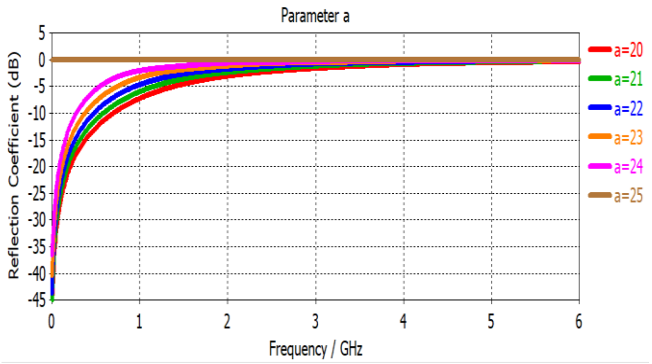

Figure 7: Reflection coefficient analysis of parameter a

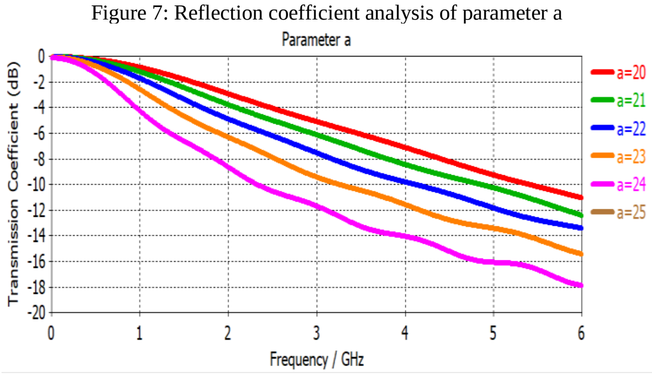

Figure 8: Transmission coefficient analysis of parameter a

Figure 9 shows that when the parameter *b* is increased, the frequency is shifting to the right and approaches frequency from 5GHz to 5.5GHz. The reflection coefficient is still in the same range at -21dB or -22dB. In Figure 10, the transmission coefficient at range frequency 5GHz shows that all signal approaches 0dB. Therefore, less loss is occurring in all transmission signals for parameter *b*.

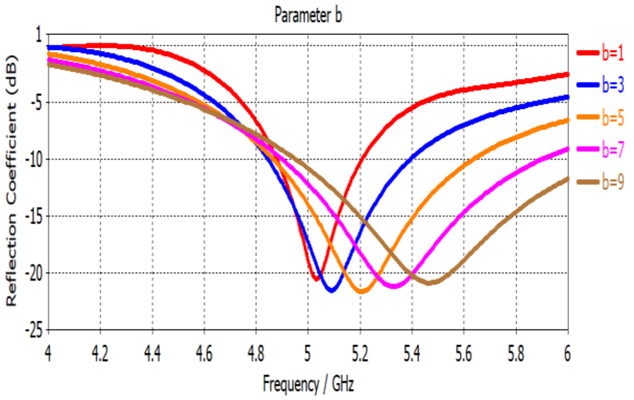

Figure 9: Reflection coefficient analysis of parameter *b*

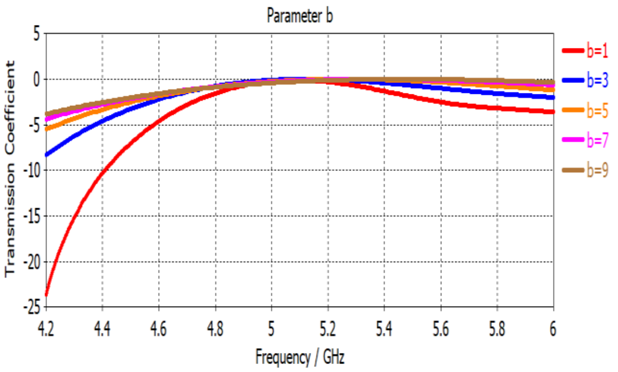

Figure 10: Transmission coefficient analysis of parameter b

Figure 11 shows that when the parameter *c* is increased, the frequency is shifting to the left and approaches frequency from 6.3GHz to 4.8GHz. The reflection coefficient also changes from -18dB to -24dB. In Figure 12, the transmission coefficient at range frequency 5GHz to 6.5GHz show that all signal approaches 0dB. Therefore less loss is occurring in all transmission signals for parameter *c*.

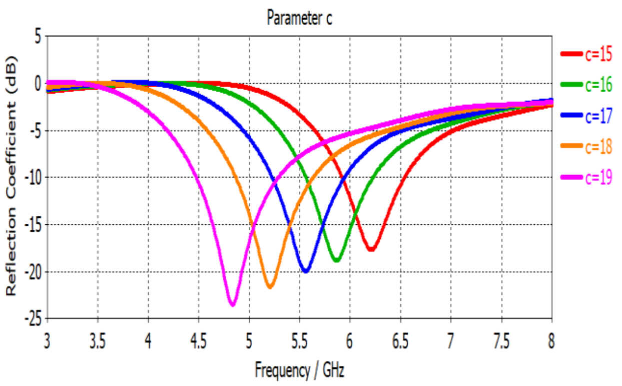

Figure 11: Reflection coefficient analysis of parameter c

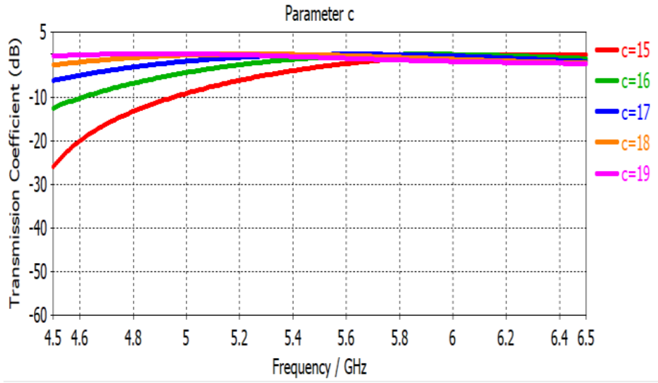

Figure 12: Transmission coefficient analysis of parameter *c*

Figure 13 shows that when the parameter *c* is increased, the frequency is shifting to the left and approaches frequency from 6.3GHz to 4.8GHz. The reflection coefficient also changes from -18dB to -24dB. In Figure 14, the transmission coefficient at range frequency 5GHz to 6.5GHz show that all signal approaches 0dB. Therefore, less loss is occurring in all transmission signals for parameter *c*.

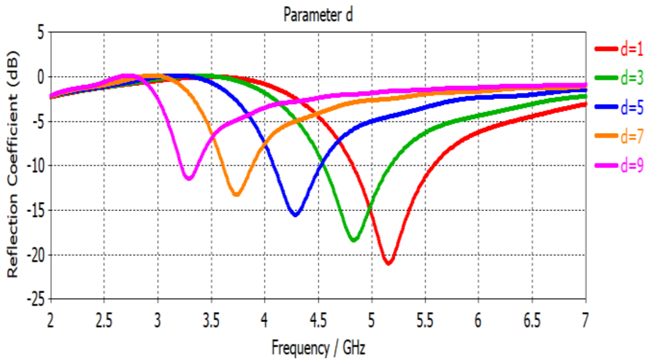

Figure 13: Reflection coefficient analysis of parameter d

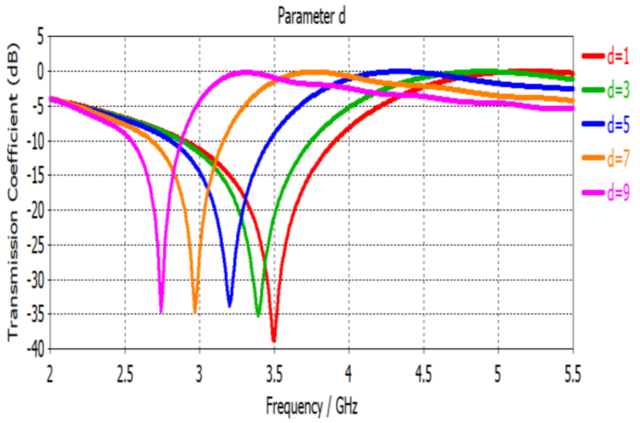

Figure 14: Transmission coefficient analysis of parameter d

Parameter *e*, *f* and *g*, when Parameter *e*, *f* and *g* is increased, the reflection coefficient and transmission coefficient show not many changes in frequency response. But when parameter *f* and parameter *g* is added, the dual band is produced.

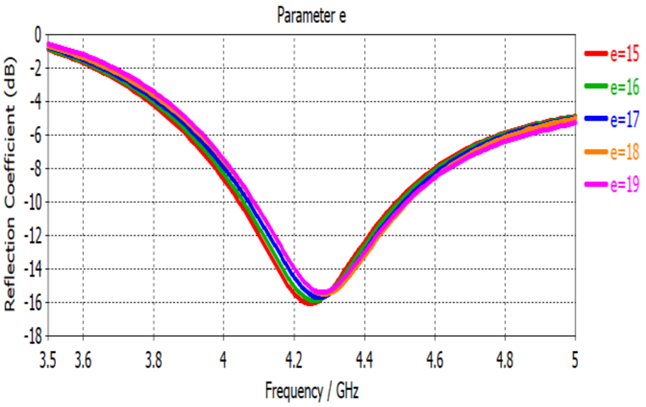

Figure 15: Reflection coefficient analysis of parameter e

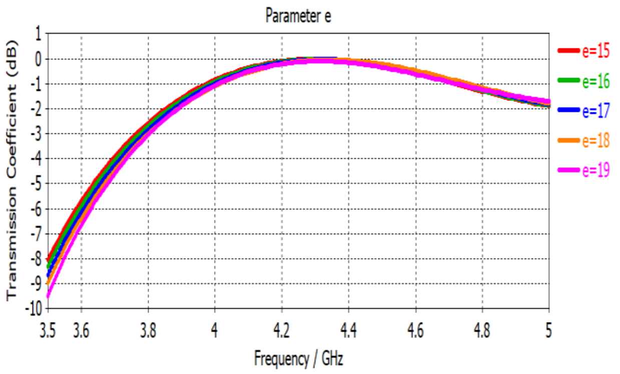

Figure 16: Transmission coefficient analysis of parameter e

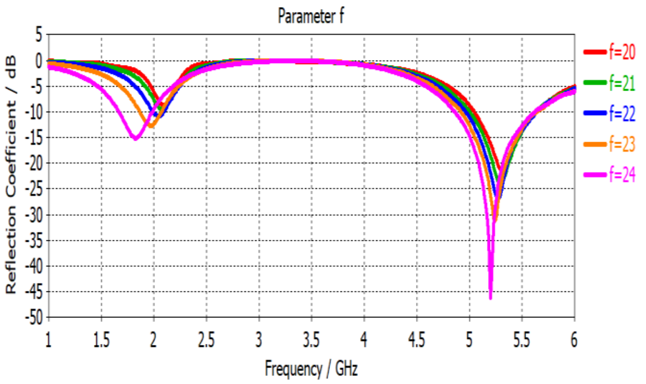

Figure 17: Reflection coefficient analysis of parameter f

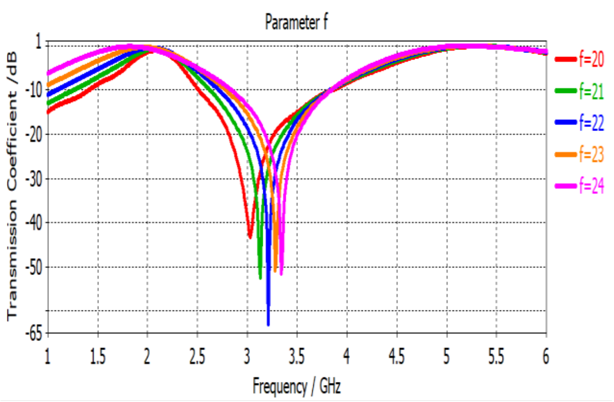

Figure 18: Transmission coefficient analysis of parameter f

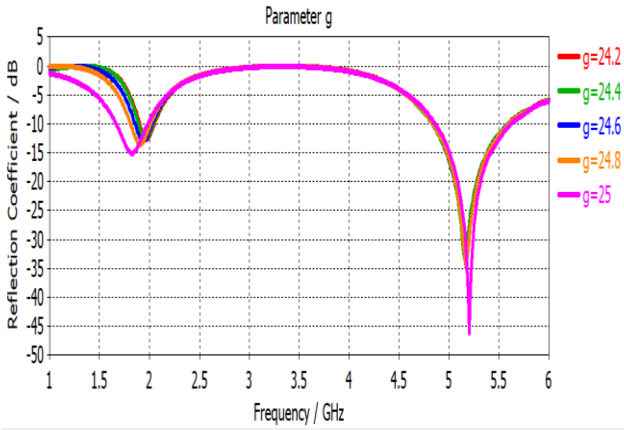

Figure 19: Reflection coefficient analysis of parameter g

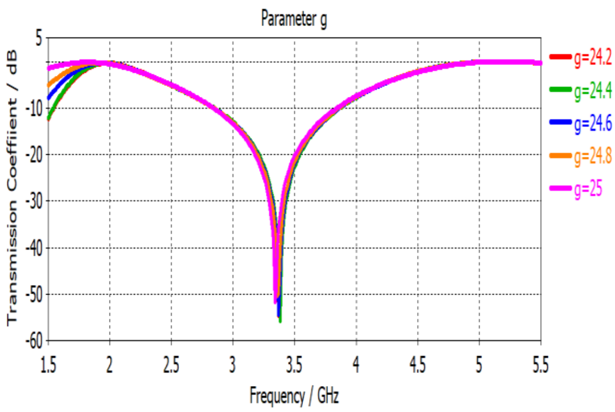

Figure 20: Transmission coefficient analysis of parameter g

The design parameters that have been observed for each design are the length and width of the square, the length and width of the square loop, the length and width of rectangular and lastly length and width of the rectangular slot. To observe the effects of each design parameter, the parametric studies were carried out using CST MWS. From the observations, some parameters affect the performance of the FSS. After that, to get the best performance of the FSS, the optimization was carried out using CST MWS. Other details of the design parameters are shows in Table 1.

Table 1
Parameters of Design

Parameter	Dimension (mm)	Description
a	21	Length and width of the patch
b	5	The width of the rectangular slot
c	18	Length of the rectangular slot
d	5	Width of the rectangular
e	18	Length of the rectangular
f	22	Length of the inner square
g	25	Length of the outer square
s	25	Length of the substrate
ta	0.089	Thickness of the FSS
tg	2	Thickness of the substrate

III. Results and Discussion

The FSS is designed and simulated using CST Microwave Studio for a single band and dual band frequency. Design A shows a no band frequency, Design B and Design C shows a single band frequency. Design D shows dual band frequency. The range of the frequency is set from 0GHz to 6.5GHz.

A. Simulation results

Figure 20 shows the reflections coefficient (S11) for Design A, Design B, Design C and Design D. For Design A there is no frequency resonates. Meanwhile, Design B and Design C resonate at the single band, 5.2GHz and 4.3GHz. Design D resonates at dual band frequencies which are at 1.8GHz and 5.2GHz. Figure 22 shows the transmission coefficient (S21) for Design A, Design B, Design C and Design D. From figure 22, it shows that all transmission coefficients for all design are resonating at -0dB.

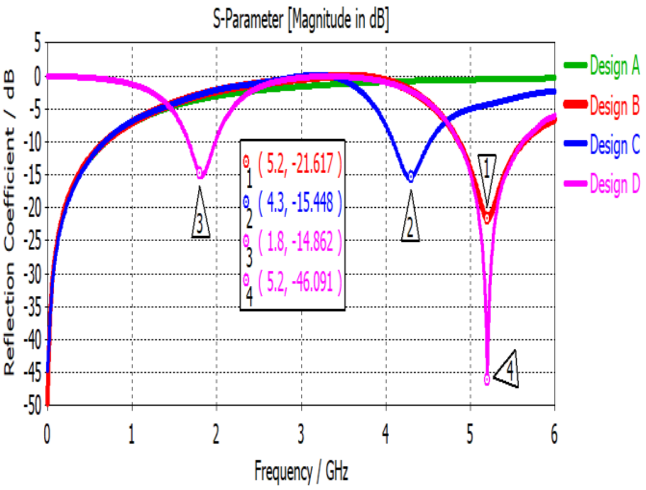

Figure 21: Reflection coefficient (S11) for Design A, Design B, Design C and Design D

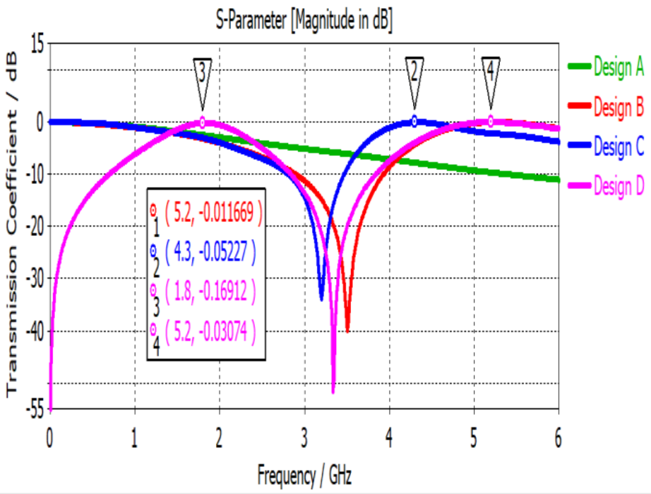

Figure 22: Transmission coefficient (S21) for Design A, Design B, Design C and Design D

The impedance characteristic of dielectric substrate and bandwidth for Design A, Design B, Design C and Design D are shown in Table 2. The ranges of the resistance are between 351.15 Ω to 454.2 2 Ω. This impedance characteristic is very useful which can be used to design the equivalent circuit of the FSS. From the analysis, bandwidth for Design B was much broader than other design which is 0.82. Other details of bandwidth are shows in Table 2.

Table 2
Impedance Characteristic of Dielectric Substrate and Bandwidth of Design A, Design B, Design C and Design D

Design	Frequency (GHz)	Impedance ZL (Ω)	Bandwidth
A	-	-	-
B	5.2	ZL = 351.15-j54.93	d = 0.82 4.85GHz to 5.67GHz
C	4.3	ZL = 454.2-j118.70	d = 0.4464 4.08GHz to 4.53GHz
D	1.8	ZL = 368.4-j136.75	d = 0.34 1.66GHz to 2GHz
	5.2	ZL = 374.55-j3.02	d = 0.80 4.85GHz to 5.65GHz

IV. Conclusion

This paper presented four designs for microwave transmission application of single band frequency and dual band frequency. The four designs namely as Design A, Design B, Design C and Design D. Design A is a square patch FSS. Design B is a square patch with the rectangular slot. Design C is a complementary square patch FSS with the rectangular slot. Design D is a square patch FSS with rectangular slot and square loop using the complementary technique. Through the simulation, firstly a clear glass is analyzed. Then, follow by Design A, Design B, Design C and Design D. From the observation of the simulation, Design A no frequency resonate. Design B and Design C resonate at the single band. Design D resonates with the dual band. Lastly, through the simulation and analysis, it can be concluded that the complementary techniques have a great effect on the resonant frequency. Combining two bandstop FSS structure can produce a single passband FSS. The passband and bandstop of the FSS can be controlled by choosing appropriate dimensions of parameters to obtain desired characteristics. As the complementary techniques are implemented in this paper, the single band and dual band application can be achieved. In the future, the measurement process can be done to compare and validate the simulation results.

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