# Design and Impedance Modeling for Rectangular Slot Frequency Selective Surface (FSS) on Glass

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*Abstract*—**This paper presents a square patch with rectangular slot frequency selective surface (FSS) on energy saving glass (ESG). In this paper, there are two designs that have been presented, namely Design A which is a square patch with rectangular slot; and Design B which is a square patch with rectangular slot using complementary techniques. The unit cell of Design A and Design B are simulated using CST Microwave Studio software at 1.8 GHz and 5.2 GHz. The simulation process is based on the characteristics of the reflection coefficient (S11) and transmission coefficient (S21) of the FSS. Design A resonates at a frequency of 1.8 GHz. Design B resonates at two frequencies, 1.8 GHz and 5.2 GHz.**

*Index Terms*—**Square Patch with Rectangular Slot; Frequency Selective Surfaces (FSS); Reflection Coefficient (S11); Transmission Coefficient (S21); Complementary Techniques.**

## I. INTRODUCTION

The design and manufacture of windows or walls are now implementing Energy Saving Glass (ESG) for current day buildings due to their low-emissivity properties. The researchers idealized low-emissivity or ESG due to the metallic oxide coating on the front view and back view of the glass which are capable of reflecting most of the incident infrared power. The metallic oxide coating such as silver oxide is used in this paper. This coating provides good thermal isolation to the building by blocking infrared radiation from the outside while being almost transparent to visible light [1-4].

Metamaterials have properties that may not be found in nature. The word 'metamaterials' is a combination of 'meta' and 'material'. Meta is a Greek word which means something beyond, altered, changed or something advanced as presented in [5]. In another meaning, metamaterials can have their electromagnetic properties altered to something beyond what can be found in nature. They gain their properties not from their composition but from their design structures. It consists of a periodic structure and subwavelength characteristics where the particles are smaller than light wavelength with which it interacts. Other structures that exhibit the subwavelength characteristics are Frequency Selective Surface (FSS) or also known as Artificial Magnetic Conductor (AMC) or High Impedance Surface (HIS) [5-6].

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 [7].

 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 [8].

FSS is a planar periodic structure of an identical array of patch or aperture type elements arranged in a one or two-dimensional plane. FSS is designed on a dielectric substrate. Bayatpur [5] mentioned that FSS acts like a spatial filter when it is exposed to electromagnetic radiation. FSS periodic arrays have inherent inductive and capacitive properties, combined to obtain the desired frequency response.

FSS has filtering characteristics, which are band-pass and band-stop behaviours; where some of the frequency bands are transmitted, while some are reflected. The technology of Frequency Selective Surface (FSS) has a long history of development. Over the past few decades, numerous applications for FSS have been found in both commercial and military sectors to provide multiple frequency band operation. Extensive analytical research has been performed to predict the reflection coefficient and transmission coefficient properties of FSSs [9-10].

## II. FSS DESIGN

The proposed FSS shown in Figure 1 and Figure 2 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 5.4 and loss tangent of 0.1204. Meanwhile, the structure of FSS layer is made from a silver material with a thickness of 0.035mm. Design A is a square patch with rectangular slot in the middle. Figure 2 shows Design B, a square patch with rectangular slot using complementary techniques.
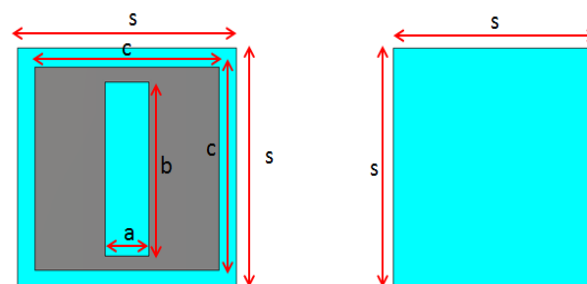


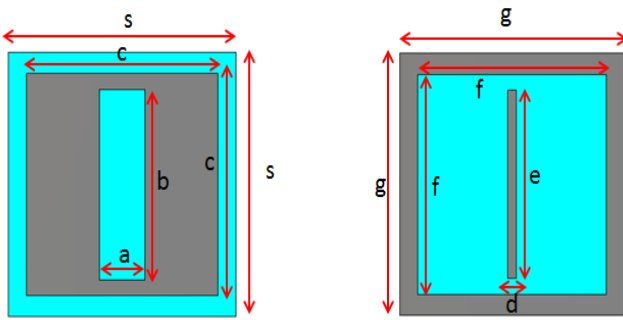Figure 1: Design A (square patch with rectangular slot)

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

Figure 3 shows that when the parameter *s* is increased, the reflection coefficient at 1.8 GHz approaches -12dB. When parameter *s* is decreased, the reflection coefficient at 1.8 GHz approaches -33dB. For Design A and Design B, the length of parameter *s* is 25mm with a glass thickness of 2mm. Then, the square patch is added to the glass using a silver material with the silver thickness of 0.035mm. After that, the rectangular slot is added.
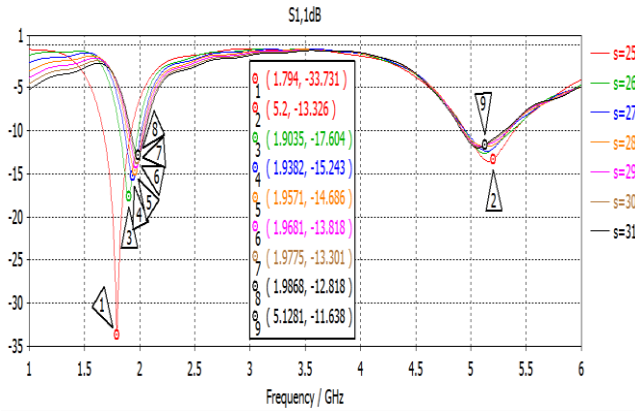


Figure 3: Reflection coefficient analysis of parameter *s*

Design B uses a complementary technique. Figure 4 shows the FSS design step by step. The back view of Design B is added with a rectangular patch and square loop. This proposed that FSS is suitable for a microwave single band-pass filter and dual band-pass filter.

The design parameters that have been identified for each design are the length of the rectangular, the width of the rectangular, and length of the square loop The parametric studies were carried out using CST MWS to investigate the effects of each design parameter. It seems that the performance of the FSS was influenced by several parameters. Then, optimization was done to obtain the best performance of the FSS for a single band and dual band frequency. Other details of the design parameters are shown in Table 1 and Table 2.

Table 1
Parameters of Design A

| Parameter | Dimension(mm) | Description |
|---|---|---|
| *a* | 5 | Width of the rectangular |
| *b* | 18 | Length of the rectangular |
| *c* | 21 | Length of square patch |
| *s* | 25 | Length of glass |
| *ts* | 0.035 | Thickness of silver |
| *tg* | 2 | Thickness of glass |
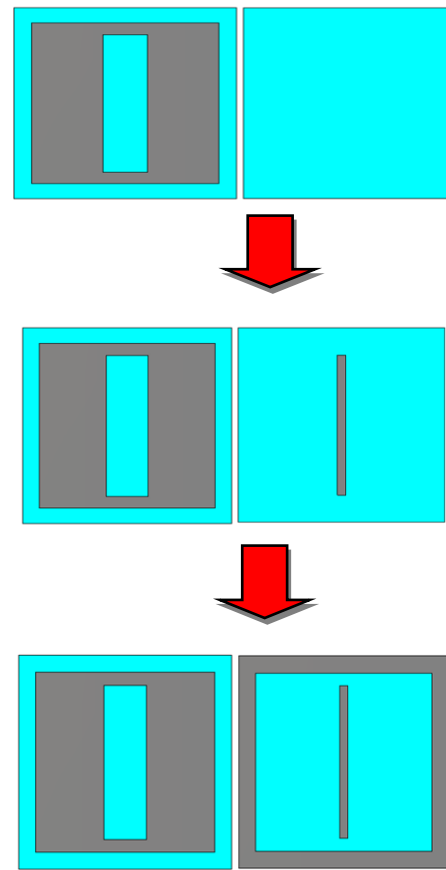


Figure 4: Step by step design of FSS

Table 2
Parameters of Design B

| Parameter | Dimension(mm) | Description |
|---|---|---|
| *a* | 5 | Width of the rectangular |
| *b* | 18 | Length of the rectangular |
| *c* | 21 | Length of square patch |
| *d* | 1 | Width of the rectangular |
| *e* | 18 | Length of the rectangular |
| *f* | 21 | Inner loop of square |
| *g* | 25 | Outer loop of square |
| *s* | 25 | Length of glass |
| *ts* | 0.035 | Thickness of silver |
| *tg* | 2 | Thickness of glass |

III. RESULTS AND DISCUSSION

The FSS is designed and simulated using CST Microwave Studio for a single band and dual band frequency. Design A presented a single band frequency. Meanwhile, Design B presented a dual-band frequency.

A. *Simulation Results*

Figure 5 shows the reflection coefficient (S11) for Design A and Design B. For Design A the frequency resonates at one frequency, 5.2GHz. For Design B, the frequency resonates at two frequencies, 1.8GHz and 5.2GHz. The maximum reflection coefficient at frequency 5.2GHz was found in Design B, which is −13.32dB. The minimum reflection coefficient at frequency 5.2GHz was found in Design A, which is -11.44dB. The reflection coefficient at frequency 1.8GHz was found in Design B, which is -33.72dB. Based on the observation for Design B in Figure 5, the highest reflection coefficient between two frequencies is at 1.8GHz which is -33.72dB.
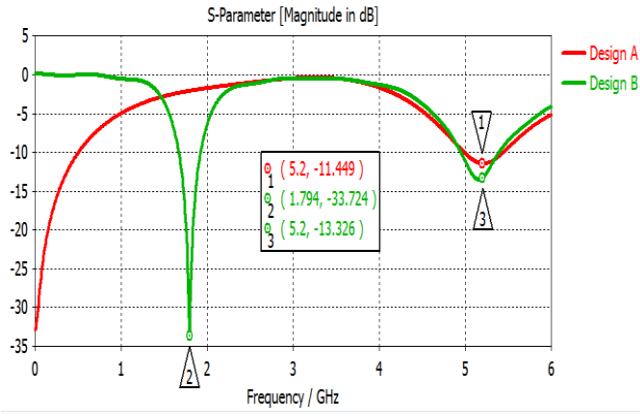
Figure 5: Reflection coefficients (S11)

Figure 6 shows the transmission coefficient (S21) for Design A and Design B. For Design A, the frequency resonates at one frequency, 5.2GHz. For Design B, the frequency resonates at two frequencies, 1.8GHz and 5.2GHz. The transmission coefficient at frequency 5.2 GHz in Design A is −1.87dB. The maximum transmission coefficient in Design B is at 5.2GHz, which is -2.57dB. At frequency 1.8GHz, the minimum transmission coefficient in Design B is -3.32dB. The maximum transmission coefficient at frequency 5.2 GHz was found in Design A, which is -1.87dB. Based on the observation for Design B in Figure 6, the lowest transmission coefficient between two frequencies is at 1.8 GHz which is -3.32dB.
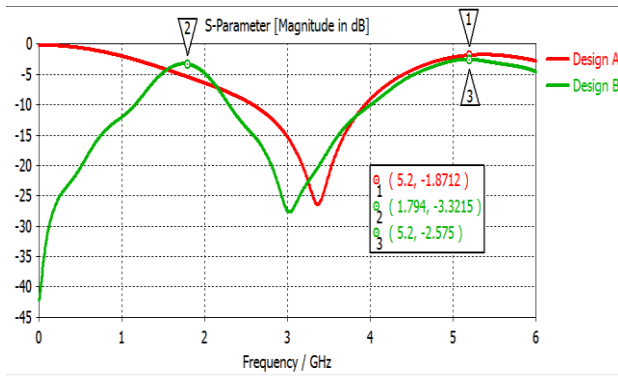


Figure 6: Transmission coefficients (S21)

*B. Impedance Characteristics*

Using the well-known circuit theory, the FSS can be equivalently modeled as a resonant circuit consisting of parallel-connected two series L-C resonator. The reflection coefficient can be represented as Γ which is the ratio of the amplitude of the reflected wave to the amplitude of the incident wave. The impedance at the load $Z_L$ can be calculated using (1). $Z_0$ is the impedance of free space (376.7 Ω). The waveguide ports in the design represent the $Z_0$ [11].

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (1)$$

Table 3
Impedance Characteristics of Dielectric Substrate
for Design A and Design B

| Design | Frequency (GHz) | Impedance ZL (Ω) |
|---|---|---|
| *Design A* | 5.2 | ZL = 219.12-j 25.28 |
| *Design B* | 1.8 | ZL = 377.81+j 18.25 |
| | 5.2 | ZL = 243.70-j 29.72 |

The impedance characteristics of the dielectric substrate for Design A and Design B are shown in Table 3. The ranges of the resistance are between 219.12Ω to 377.81Ω. The reactance for Design B at a frequency 1.8GHz is inductive. Meanwhile, the reactance for Design A and Design B at a frequency of 5.2 GHz is capacitive. This impedance characteristic is very useful and can be used to design the equivalent circuit of the FSS.

Table 4
Impedance Modelling Resistance for Design A

| Parameter | Impedance Modeling | | |
|---|---|---|---|
| | Resistance, ohm (Ω) | Length/Width (mm) | |
| *a* | R = 0.4803$a^6$ -11.78$a^5$ | 1 < a < 2 | (1) |
| | R = 113.9$a^4$ | 2 < a < 3 | (2) |
| | R = -549.5$a^3$ | 3 < a < 4 | (3) |
| | R = 1375$a^2$ | 4 < a < 5 | (4) |
| | R = -1644a | 5 < a < 6 | (5) |
| | R = 806 | 6 < a < 7 | (6) |
| *b* | R = 4.542$b^4$ | 16 < b < 17 | (7) |
| | R = -322.6$b^3$ | 17 < b < 18 | (8) |
| | R = 8551$b^2$ -1.003$e^5$b +4.387$e^5$ | 18 < b < 20 | (9) |
| *c* | R = -4.165$c^6$ + 540.7$c^5$ - 2.92$e^4c^4$ | 19 < c < 21 | (10) |
| | R = 8.394$e^5c^3$ -1.355$e^7c^2$ | 21 < c < 23 | (11) |
| | R = 1.165$e^8$c | 23 < c < 24 | (12) |
| | R = -4.168$e^8$ | 24 < c < 25 | (13) |
| *s* | R = -0.256$s^6$ + 41.38$s^5$ -2783$s^4$ | 24 < s < 26 | (14) |
| | R = 9.973$e^4s^3$ | 26 < s < 27 | (15) |
| | R = -2.007$e^6s^2$ | 27 < s < 28 | (16) |
| | R = 2.152$e^7$s | 28 < s < 29 | (17) |
| | R = -9.605$e^7$ | 29 < s < 30 | (18) |

Table 5
Impedance Modelling Reactance for Design A

| Parameter | Impedance Modeling | | |
|---|---|---|---|
| | Reactance, ohm (Ω) | Length/Width (mm) | |
| *a* | X = 0.3486$a^6$ -8.576$a^5$ | 1 < a < 2 | (1) |
| | X = 83.38$a^4$ | 2 < a < 3 | (2) |
| | X = -405.9$a^3$ | 3 < a < 4 | (3) |
| | X = 1028$a^2$ | 4 < a < 5 | (4) |
| | X = -1242a | 5 < a < 6 | (5) |
| | X = 546.3 | 6 < a < 7 | (6) |
| *b* | X = -0.1511$b^4$ | 16 < b < 17 | (7) |
| | X = 18.56$b^3$ | 17 < b < 18 | (8) |
| | X = -702.7$b^2$ + 1.071$e^4$b - 5.746$e^4$ | 18 < b < 20 | (9) |
| *c* | X = 0.3537$c^6$ -46.28$c^5$ + 2519$c^4$ | 19 < c < 21 | (10) |
| | X = - 7.302e4$c^3$ + 1.189$e^6c^2$ | 21 < c < 23 | (11) |
| | X = -1.031$e^7$c | 23 < c < 24 | (12) |
| | X = 3.72$e^7$ | 24 < c < 25 | (13) |
| *s* | X = -0.3901$s^6$ + 63.26$s^5$ - 4270$s^4$ | 24 < s < 26 | (14) |
| | X = 1.535$e^5s^3$ | 26 < s < 27 | (15) |
| | X = -3.101$e^6s^2$ | 27 < s < 28 | (16) |
| | X = 3.337$e^7$s | 28 < s < 29 | (17) |
| | X= -1.495$e^8$ | 29 < s < 30 | (18) |

Table 4 shows the impedance modeling for the resistance of Design A at a frequency 5.2GHz. Meanwhile, Table 5 shows the impedance modeling for reactance of Design A at frequency 5.2GHz. The impedance is modelled using polynomial type in Matlab for resistance, R, and reactance, X, of the impedance. The impedances were divided into certain ranges of length Sof physical dimension of FSS so that an accurate impedance modelling can be produced based on the physical parameters. The parameters for Design A are *a, b, c,* and *s*. The resistance and reactance modelling of Design A are represented by (1) to (18). The highest degree of the resistance and reactance of all designs is a 6th degree polynomial. The

lowest degree of the resistance and reactance of all designs is a 4th degree polynomial.

Table 6
Impedance Modelling Resistance for Design B at 1.8 GHz

| Parameter | Impedance Modeling | | |
|---|---|---|---|
| | Resistance, ohm (Ω) | Length/Width (mm) | |
| $a$ | $R = -0.04251a^6 + 1.001a^5 - 9.405a^4 + 44.5a^3 -108.6a^2 + 104.7a$ | $1 < a < 6$ | (1) |
| | $R = 501$ | $6 < a < 7$ | (2) |
| $b$ | $R= 0.025b^6 -2.448b^5 + 99.42b^4 -2144b^3 + 2.592e4b^2$ | $14 < b < 18$ | (3) |
| | $R = -1.664e5b + 4.441e5$ | $18 < b < 20$ | (4) |
| $c$ | $R = -0.2996c^6 + 39.4c^5 -2155c^4$ | $19 < c < 21$ | (5) |
| | $R = 6.275e4c^3 -1.026e6c^2$ | $21 < c < 23$ | (6) |
| | $R = 8.921e6c -3.224e7$ | $23 < c < 25$ | (7) |
| $d$ | $R = 0.05947d^6 -1.337d^5 + 11.78d^4 -51.74d^3 + 118.1d^2$ | $1 < d < 5$ | (8) |
| | $R = -132.1d$ | $5 < d < 6$ | (9) |
| | $R = 433$ | $6 < d < 7$ | (10) |
| $e$ | $R = -0.02936e^6 + 2.662e^5$ | $12 < e < 13$ | (11) |
| | $R = -100.2e^4$ | $13 < e < 14$ | (12) |
| | $R = 2004e^3$ | $14 < e < 15$ | (13) |
| | $R = -2.246e4e^2$ | $15 < e < 16$ | (14) |
| | $R = 1.337e5e$ | $16 < e < 17$ | (15) |
| | $R = -3.298e5$ | $17 < e < 18$ | (16) |
| $f$ | $R = -0.7122f^5 + 76.36f^4 -3270f^3 + 6.989e4f^2 -7.459e5f + 3.18e6$ | $19 < f < 24$ | (17) |
| $g$ | $R = -1.758e6g^6 + 2.615e8g^5$ | $24.5 < g < 24.6$ | (18) |
| | $R = -1.621e10g^4$ | $24.6 < g < 24.7$ | (19) |
| | $R = 5.36e11g^3$ | $24.7 < g < 24.8$ | (20) |
| | $R = -9.968e12g^2$ | $24.8 <g < 24.9$ | (21) |
| | $R = 9.886e13g -4.085e14$ | $24.9 < g < 25.1$ | (22) |
| $s$ | $R = -0.1952s^6 + 32.99s^5$ | $25 < s < 26$ | (23) |
| | $R = -2324s^4$ | $26 < s < 27$ | (24) |
| | $R = 8.737e4s^3 -1.849e6s^2$ | $27 < s < 29$ | (25) |
| | $R = 2.088e7s -9.837e7$ | $29 < s < 31$ | (26) |

Table 7
Impedance Modelling Reactance for Design B at 1.8 GHz

| Parameter | Impedance Modeling | | |
|---|---|---|---|
| | Reactance, ohm (Ω) | Length/Width (mm) | |
| $a$ | $X= 0.001161a^6 -0.09251a^5 + 1.395a^4 -8.59a^3 + 23.96a^2 - 6.265a$ | $1 < a < 6$ | (1) |
| | $X = -110.4$ | $6 < a < 7$ | (2) |
| $b$ | $X = 0.1405b^6 -14.12b^5 + 589.8b^4 -1.31e4b^3 + 1.632e5b^2$ | $14 < b < 18$ | (3) |
| | $X = -1.082e6b +2.978e6$ | $18 < b < 20$ | (4) |
| $c$ | $X= 0.143c^6 -18.98c^5 + 1051c^4$ | $19 < c < 21$ | (5) |
| | $X = -3.11e4c^3 + 5.18e5c^2$ | $21 < c < 23$ | (6) |
| | $X = -4.608e6c +1.709e7$ | $23 < c < 25$ | (7) |
| $d$ | $X = -0.05749d^6 + 1.293d^5 - 11.42d^4 + 50.36d^3 -115.5d^2$ | $1 < d < 5$ | (8) |
| | $X = 130.1d$ | $5 < d < 6$ | (9) |
| | $X = -36.59$ | $6 < d < 7$ | (10) |
| $e$ | $X = 0.04088e^6 -3.692e^5$ | $12 < e < 13$ | (11) |
| | $X = 138.4e^4$ | $13 < e < 14$ | (12) |
| | $X = -2756e^3$ | $14 < e < 15$ | (13) |
| | $X = 3.076e4e^2$ | $15 < e < 16$ | (14) |
| | $X = -1.823e5e$ | $16 < e < 17$ | (15) |
| | $X = 4.486e5$ | $17 < e < 18$ | (16) |
| $f$ | $X = 0.7226f^5 -77.67f^4 + 3334f^3 -7.145e4f^2 + 7.643e5f -3.264e6$ | $19 < f < 24$ | (17) |
| $g$ | $X = -1.879e5g^6 + 2.799e7g^5$ | $24.5 < g < 24.6$ | (18) |
| | $X = -1.737e9g^4$ | $24.6 < g < 24.7$ | (19) |
| | $X = 5.748e10g^3$ | $24.7 < g < 24.8$ | (20) |
| | $X = -1.07e12g^2$ | $24.8 <g < 24.9$ | (21) |
| | $X = 1.062e13g -4.395e13$ | $24.9 < g < 25.1$ | (22) |
| $s$ | $X = 0.1056s^6 -19.2s^5$ | $25 < s < 26$ | (23) |
| | $X = 1449s^4$ | $26 < s < 27$ | (24) |
| | $X = -5.813e4s^3 + 1.306e6s^2$ | $27 < s < 29$ | (25) |
| | $X = -1.56e7s +7.737e7$ | $29 < s < 31$ | (26) |

Table 6 shows the impedance modeling for the resistance of Design B at a frequency of 1.8GHz. Meanwhile, Table 7 shows the impedance modeling for the reactance of Design B at a frequency 1.8GHz. The impedance is modeled using polynomial type in Matlab for resistance, R, and reactance, X, of the impedance. The impedances were divided into certain ranges of length of the physical dimension of FSS. The parameters for Design B are *a, b, c, d, e, f,* and *s*. The resistance and reactance modeling of Design B are represented by (1) to (26). The highest degree of the resistance and reactance of all designs is a 6th degree polynomial. The lowest degree of the resistance and reactance of all designs is a 5th degree polynomial.

Table 8
Impedance Modelling Resistance for Design B at 5.2 GHz

| Parameter | Impedance Modeling | | |
|---|---|---|---|
| | Resistance, ohm (Ω) | Length/Width (mm) | |
| $a$ | $R = -0.0707a^6 + 1.651a^5 - 15.03a^4 + 67.25a^3$ | $1 < a < 4$ | (1) |
| | $R = -159.3a^2 + 233.1a$ | $4 < a < 6$ | (2) |
| | $R = 10.25$ | $6 < a < 7$ | (3) |
| $b$ | $R= 0.05688b^6 -5.13b^5 + 189.3b^4 -3650b^3 + 3.863e4b^2$ | $14 < b < 18$ | (4) |
| | $R = -2.114e5b + 4.63e5$ | $18 < b < 20$ | (5) |
| $c$ | $R = 0.1826c^6 -24.52c^5$ | $19 < c < 20$ | (6) |
| | $R = 1369c^4$ | $20 < c < 21$ | (7) |
| | $R = -4.065e4c^3$ | $21 < c < 22$ | (8) |
| | $R = 6.773e5c^2 -6.005e6c$ | $22 < c < 24$ | (9) |
| | $R = 2.213e7$ | $24 < c < 25$ | (10) |
| $d$ | $R = 0.03319d^6 -0.7883d^5$ | $1 < d < 2$ | (11) |
| | $R = 6.73d^4 -22.47d^3 + 11.63d^2$ | $2 < d < 5$ | (12) |
| | $R = 17.72d + 232.9$ | $5 < d < 7$ | (13) |
| $e$ | $R = 0.009063e^6 -0.8175e^5$ | $12 < e < 13$ | (14) |
| | $R = 30.6e^4$ | $13 < e < 14$ | (15) |
| | $R = -608.4e^3$ | $14 < e < 15$ | (16) |
| | $R = 6775e^2$ | $15 < e < 16$ | (17) |
| | $R = -4.007e4e$ | $16 < e < 17$ | (18) |
| | $R = 9.86e4$ | $17 < e < 18$ | (19) |
| $f$ | $R = 0.005197f^5 -0.4285f^4$ | $19 < f < 20$ | (20) |
| | $R = 13.52f^3$ | $20 < f < 21$ | (21) |
| | $R = -201.2f^2 + 1376f$ | $21 < f < 23$ | (22) |
| | $R = -3028$ | $23 < f < 24$ | (23) |
| $g$ | $R = 3.526e4g^6 -5.235e6g^5$ | $24.5 < g < 24.6$ | (24) |
| | $R = 3.239e8g^4$ | $24.6 < g < 24.7$ | (25) |
| | $R = -1.069e10g^3$ | $24.7 < g < 24.8$ | (26) |
| | $R = 1.983e11g^2$ | $24.8 <g < 24.9$ | (27) |
| | $R = -1.963e12g + 8.095e12$ | $24.9 < g < 25.1$ | (28) |
| $s$ | $R = 0.06037s^6 -10.27s^5$ | $25 < s < 26$ | (29) |
| | $R = 727.6s^4$ | $26 < s < 27$ | (30) |
| | $R = -2.746e4s^3 + 5.822e5s^2 - 6.578e6s +3.093e7$ | $27 < s < 31$ | (31) |

Table 8 shows the impedance modeling for the resistance of Design B at a frequency of 5.2GHz. Meanwhile, Table 9 presents the reactance of the FSS for various parameters of Design B at a frequency of 5.2GHz. The impedance is modeled using polynomial type in Matlab for resistance, R, and reactance, X, of the impedance. The impedances were divided into certain ranges of length of the physical dimension of FSS so that an accurate impedance modeling was produced based on the physical parameters. The parameters for Design B are *a, b, c, d, e, f,* and *s*. The resistance and reactance modeling of Design B at a frequency of 5.2GHz are represented by (1) to (31). The highest degree of the resistance and reactance of all designs is a 6th degree polynomial. The lowest degree of the resistance and reactance of all designs is a 5th degree polynomial.

Table 9
Impedance Modelling Reactance for Design B at 5.2 GHz

| Parameter | Impedance Modeling | | |
|---|---|---|---|
| | Reactance, ohm ($\Omega$) | Length/Width (mm) | |
| $a$ | X= $-0.06674a^6 + 1.664a^5 - 16.26a^4 + 77.35a^3$ | $1 < a < 4$ | (1) |
| | X = $-178.7a^2 + 200.5a$ | $4 < a < 6$ | (2) |
| | X = $-183.6$ | $6 < a < 7$ | (3) |
| $b$ | X = $-0.3163b^6 + 32.07b^5 - 1349b^4 + 3.013e4b^3 -3.77e^5b^2$ | $14 < b < 18$ | (4) |
| | X = $2.506e^6b -6.912e^6$ | $18 < b < 20$ | (5) |
| $c$ | X = $0.04879c^6 -6.681c^5$ | $19 < c < 20$ | (6) |
| | X = $379.9c^4$ | $20 < c < 21$ | (7) |
| | X = $-1.149e^4c^3$ | $21 < c < 22$ | (8) |
| | X = $1.947e^5c^2 -1.755e^6c$ | $22 < c < 24$ | (9) |
| | X = $6.572e^6$ | $24 < c < 25$ | (10) |
| $d$ | X = $-0.04129d^6 + 1.189d^5$ | $1 < d < 2$ | (11) |
| | X = $-13.6d^4 + 76.46d^3 -205.7d^2$ | $2 < d < 5$ | (12) |
| | X = $199.1d -87.05$ | $5 < d < 7$ | (13) |
| $e$ | X = $-0.05571e^6 + 5.03e^5$ | $12 < e < 13$ | (14) |
| | X = $-188.5e^4$ | $13 < e < 14$ | (15) |
| | X = $3753e^3$ | $14 < e < 15$ | (16) |
| | X = $-4.187e^4e^2$ | $15 < e < 16$ | (17) |
| | X = $2.482e^5e$ | $16 < e < 17$ | (18) |
| | X= $-6.105e^5$ | $17 < e < 18$ | (19) |
| $f$ | X = $-0.06587f^5 + 6.579f^4$ | $19 < f < 20$ | (20) |
| | X = $-261.4f^3$ | $20 < f < 21$ | (21) |
| | X = $5165f^2 -5.076e^4f$ | $21 < f < 23$ | (22) |
| | X = $1.987e^5$ | $23 < f < 24$ | (23) |
| $g$ | X = $6.723e^4g^6 -9.996e^6g^5$ | $24.5 < g < 24.6$ | (24) |
| | X = $6.192e^8g^4$ | $24.6 < g < 24.7$ | (25) |
| | X = $-2.046e^{10}g^3$ | $24.7 < g < 24.8$ | (26) |
| | X = $3.802e^{11}g^2$ | $24.8 < g < 24.9$ | (27) |
| | X = $-3.768e^{12}g +1.556e^{13}$ | $24.9 < g < 25.1$ | (28) |
| $s$ | X = $-0.03424s^6 + 5.72s^5$ | $25 < s < 26$ | (29) |
| | X = $-397.6s^4$ | $26 < s < 27$ | (30) |
| | X = $1.471e^4s^3 -3.058e^5s^2 + 3.383e^6s -1.557e^7$ | $27 < s < 31$ | (31) |

## IV. CONCLUSION

This paper presented the design of a square patch with rectangular slot FSS for microwave transmission application of single band and dual band frequencies. Design A is for single band application while Design B for dual band application. Design B uses complementary techniques. Design A resonates at one frequency of 1.8GHz. Design B resonates at two frequencies, 1.8GHz and 5.2GHz. The impedance is modeled using polynomial type in Matlab for resistance and reactance of the impedance. The impedances were divided into certain ranges of length of the physical dimension of FSS so that an accurate impedance modeling was produced based on the physical parameters. The impedance was modeled for frequency in the range of 1.8GHz and 5.2GHz. Through the simulation and analysis, it can be concluded that the complementary techniques have a great effect on the resonant frequency. As the complementary techniques are implemented in this paper, the multi-band application can be achieved. The measurement process can be done in the future in order to compare and validate the simulation results.

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