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INVESTIGATION ON THE IMPEDANCE MODELING OF COMBINATION CIRCLE FOR FREQUENCY SELECTIVE SURFACE (FSS)

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ABSTRACT

This paper presents the investigation of a unit cell for combination of circle frequency selective surface (FSS). Two types of configuration for the simulation has been investigated and analyzed. The investigation has been done on the radius of circle FSS (*a*) and the spacing between the first and another circle (*b*) in order to analyze its effects towards the resistance and reactance of the circuit. The impedance mathematical modeling of the design FSS in terms of, resistance and reactance have been formulated from parameters *a*, *b*, *c* and *d*. This model can be used to design the FSS at the ISM band application. The bandwidth of the first configuration is 158.27 MHz which covered the frequency range from 2.3261 GHz until 2.4843 GHz. Meanwhile, the bandwidth for the second configuration is 297.17 MHz which covered the frequency range from 2.1515 GHz until 2.4486 GHz.

Keywords: impedance modeling, frequency selective surface (FSS), reflection.

INTRODUCTION

In 1958, metamaterial had been proposed by V.G Vesalago. These metamaterials consist of characteristics of sub-wavelength particles smaller than light wavelength and have properties that may not be available in nature. Normally these multilateral gains are due to their properties from design structure instead of their composition. Therefore, antennae, filters, FSS and etc. are some of the potential applications of the matematerial in the design of radio frequency components (Shridhar and Yogeshwar, 2011), (Sun *et al*., 2008), (Abd Aziz *et al*., 2013) and (Aziz *et al*, 2013).

Functioning as a spatial filter in free space, FSS is a two-dimensional periodic array which consists of two types, i.e. patches element and apertures element (slot). The design element of FSS has their own function to produce different results such as the patch element that can produce the band pass signal. The examples of FSS application in electromagnetic fields are such as radomes, electromagnetic shielding, RFID, WLAN security and etc. (Aziz *et al*., 2013), (Sohail, Esselle and Kiani, 2012) and (Xuesong and Aixin, 2009).

FSS can also be modeled as an energy storing capacitive or inductive component by using Equivalent Circuit Method where it can be determined by the shape of its element. Equivalent Circuit Model allows performing a very simple model that is able to describe every kind of shape after a full-wave computer simulation. Impedance is one of the important parameters in modeling the FSS by using the EC method (Dubrovka *et al*., 2006), (Sung, Sowerby and Williamson, 2005) and (Kent, Bora and Mesut, 2010). Two effects of the impedance caused by these are referred to as resistance and reactance. The resistance is formed by the real part while reactance is formed of the imaginary part of complex impedance. In this paper, the mathematical impedance modeling of a combination circle FSS is proposed by using polynomial method.

DESIGN OF FSS

Figure-1 shows the unit cell of the proposed design FSS. The design of FSS has been built up by using copper material with a thickness 0.035mm etched on the FR4 board with thickness of 1.6mm, loss tangent of 0.019 and dielectric constant of 4.4. This FSS is designed and simulated by using CST Microwave Studio.

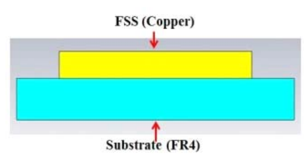
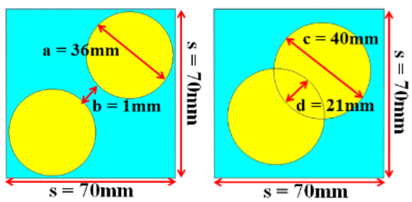


Figure-1. Structure of FSS.

In this paper, there are two types of configuration that will be investigated. The physical parameters that have been analyzed are the radius of the circle (***a***) and the space between circles (*b*) for configuration I. While for configuration II, the radius of the circle (*c*) and the space overlapping within circles (*d*) have also been investigated and analyzed. Lastly, the impedances of each configuration has been modeled by using Polynomial Method in Matlab software.

The first configuration is referring to two circles without combining the circle as shown in Figure-2. The parameters that have been set for this design are the radius of the circle FSS (*a*), the spacing of the circle (*b*) and length of substrate (***s***).

The second configuration is a design of combination circle FSS with the same width as shown in Figure-2. The parameters that have been set up in this configuration are the radius of the circle FSS (***c***), the space overlapping between the first circle and another circle (***d***) and the length of substrate (***s***).



a. Configuration I b. Configuration II

Figure-2. Configuration I and configuration II.

In configuration I, a parametric study has been done to analyze the effect of the parameter (*a*) and parameter (*b*) from the range of 30mm to 42mm and from 0.5mm to 3.5mm respectively. Figure-3 shows the effect of increasing the parameter (*a*) that shifted the center frequency to the left for the frequency 2.5GHz and 3.8GHz. While for parameter (*b*), the result will shift to the right side as shown in Figure-4. However, there is no significant effect upon varying the parameters (*a*) and (*b*) for the frequency of 3.5GHz. The reflection result for parameter (*a*) will show an increase upon increasing of parameter (*a*) for the frequency of 2.5GHz and 3.8GHz but vice versa for parameter (*b*). Besides that, the result of bandwidth has also increased for parameter (*a*) when increasing the radius from 30mm to 42mm, contrary to parameter (*b*) which decreased.

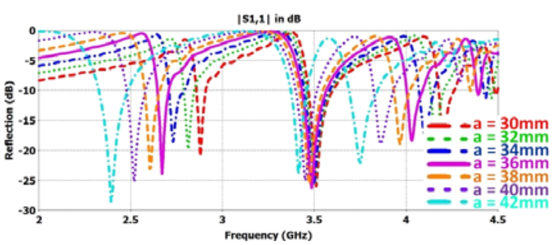


Figure-3. Parametric study of reflection (Parameter ***a***).

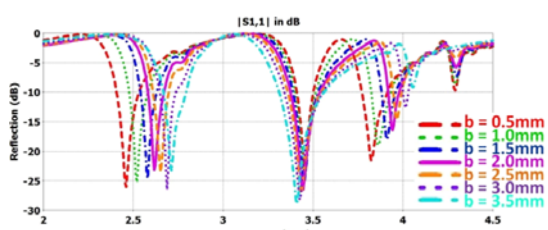
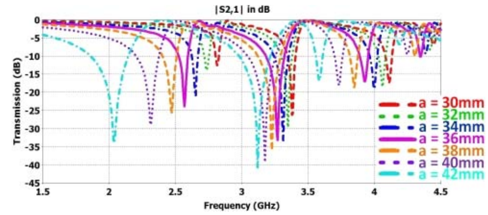
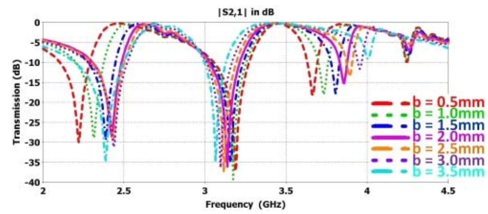


Figure-4. Parametric study of reflection (Parameter ***b***).

Then, the transmission result of parameter (*a*) and (*b*) can be observed as shown in Figure-5. In Figure-5, the maximum transmission occurred at -0.227dB for the radius of 42mm and -0.233dB for the radius of 36mm at frequency 2.4GHz and 3.5GHz respectively. The efficiency of parameter (*b*) is about 95% compared with parameter (*a*).



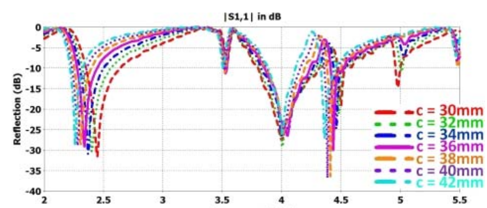
a. Parameter ***a***



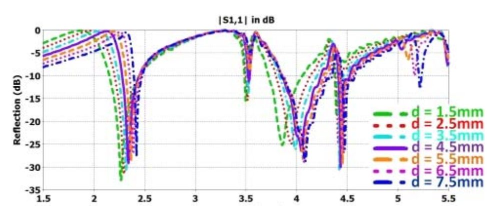
b. Parameter ***b***

Figure-5. Parametric study of transmission.

The parametric study has been done on configuration II to investigate the effect of each designed parameters. The parameters (*c*) and (*d*) have been varied from 30mm to 42mm and 1.5mm to 7.5mm respectively. The increase of the parameter (*c*) and (d) will shift the center frequency to the left and right side. However, there are no significant effects on frequency and reflection when the design parameter values are changed for the frequency 3.5GHz and 4GHz as shown in Figure-6. Besides that, the bandwidth of parameter (*c*) and parameter (*d*) also has no significant effect for the frequency 2.4GHz, 3.5GHz and 4GHz.



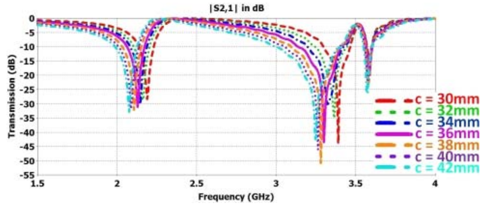
a. Parameter ***c***



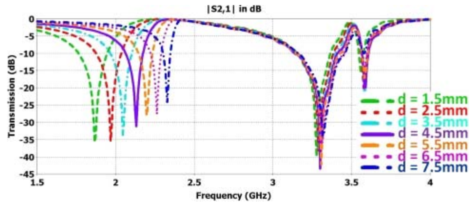
b. Parameter ***d***

Figure-6. Parametric study of reflection.

Figure-7 shows the transmission result for the parameter (c) and (d). The efficiency achieved is about 92-95% at the frequency 2.4GHz and 4.0GHz for both parameters. At frequency 3.5GHz the efficiency is around 80-85%. At this application, the signal will transmit around 80-85% compared with another application which is around 92-95%.



a. Parameter ***c***



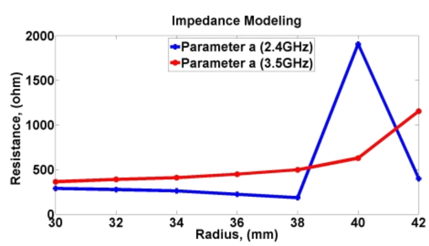
b. Parameter ***d***

Figure-7. Parametric study of transmission.

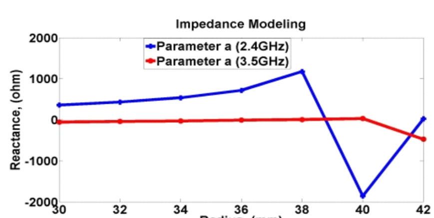
RESULT AND DISCUSSIONS

Configuration I

In this part, the effect of radius of the circle (*a*) has been investigated as shown in Figure-8 (a) and Figure (b). In Figure-8 (*a*), the effect of varying the radius is directly proportional to the resistance for the frequency 3.5GHz. While the increasing of radius from 30mm to 38mm at the frequency 2.4GHz, the result shows the decreasing of resistance value from 287ohm to 183ohm. The maximum and minimum values of resistance and reactance occurred at 1906ohm and 1858ohm at 40mm and 38mm respectively. The resistance and reactance for parameter (*a*) can be modeled to the FSS and is written as equation (1) to (4). The highest degree of impedance is the 4^{th} degree polynomial type as shown in equation (1) to (3).



a. Resistance



b. Reactance

Figure-8. Impedance modeling for parameter *a*.

$$R = \begin{cases} -1.901e^{-5}a^4 + 0.008251a^3 - 0.2206a^2 + 7.406a - 498.7 & 30 > \lambda < 38 \\ 0.4671a - 414.7 & 40 > \lambda < 42 \end{cases} \quad (1)$$

$$R = \begin{cases} 0.888a - 427.8 & 30 > \lambda < 32 \\ -0.01736a^2 + 1.869a - 448 & 34 > \lambda < 38 \\ 0.4671a - 414.7 & 40 > \lambda < 42 \end{cases} \quad (2)$$

$$X = \begin{cases} -1.849e^{-5}a^4 + 0.002695a^3 - 0.1484a^2 + 3.345a - 29 & 30 > \lambda < 38 \\ -0.1918a - 8.071 & 40 > \lambda < 42 \end{cases} \quad (3)$$

$$X = \begin{cases} 0.0135a - 0.4171 & 30 > \lambda < 32 \\ 0.003825a^2 - 0.2255a + 3.459 & 34 > \lambda < 38 \\ -0.1918a + 8.071 & 40 > \lambda < 42 \end{cases} \quad (4)$$

The impedance modeling for parameter (*b*) is described in Figure-9 (a) and Figure-9 (b). At the frequency of 2.4GHz, the values of resistance and reactance fluctuate from length of 0.5mm to 3.5mm. The maximum values of resistance and reactance can be obtained at 1906ohm and 3095ohm, at radius 1mm and 1.5mm respectively. At the frequency of 3.5GHz, there is no significant effect of resistance and reactance when varying the length for spacing circle FSS. The resistance and reactance for parameter (*b*) can be modeled to the FSS and is written as equation (5) to (8). The cubic polynomial has been used for the length of 2.5mm, while for the length at 1.5mm; the quadratic polynomial has been used.

$$R = \begin{cases} 2723a - 817.8 & 0.5 < \lambda > 1.0 \\ -712.4a - 1618 & 1.5 < \lambda > 2.0 \\ 408.1a^2 - 2272a + 3299 & 2.5 < \lambda > 3.5 \end{cases} \quad (5)$$

$$R = \begin{cases} 74.27a^2 - 276.7a + 852.2 & 0.5 < \lambda > 1.0 \\ 260a^3 - 1932a^2 + 4633a - 3526 & 1.5 < \lambda > 3.5 \end{cases} \quad (6)$$

$$X = \begin{cases} -3090a + 1232 & 0.5 < \lambda > 1.0 \\ -2205a + 6402 & 1.5 < \lambda > 2.0 \\ 1822a^2 - 9948a + 1.34e^4 & 2.5 < \lambda > 3.5 \end{cases} \quad (7)$$

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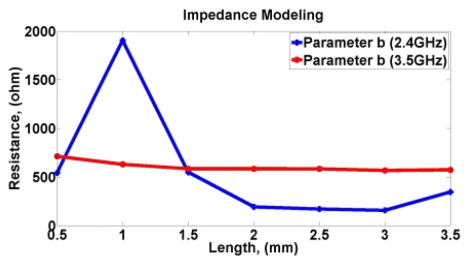
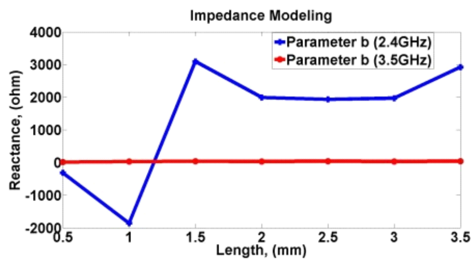
$$X = \begin{cases} -27.01c^2 - 78.11c - 20.43 & 0.5 < \lambda > 1.0 \\ 1088c^3 - 7920c^2 + 1.908e^4c - 1.303e^4 & 0.5 < \lambda > 1.0 \end{cases} \quad (8)$$



a. Resistance

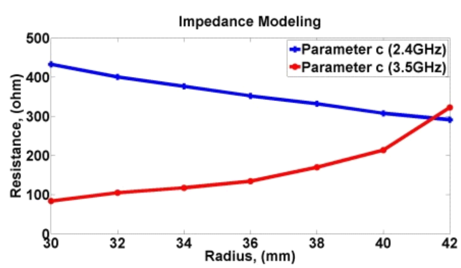


b. Reactance

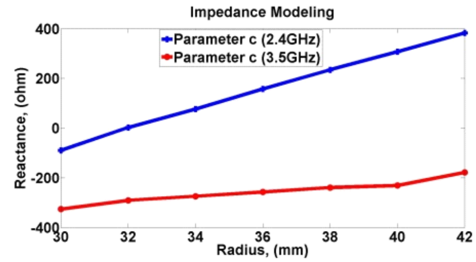
Figure-9. Impedance modeling for parameter *b*.

Configuration II

Figure-10 (a) and Figure-10 (b) show the graph impedance modeling for the parameter (*c*). It can be observed that the resistance is inversely proportional to the radius for the frequency at 2.4GHz, but for the reactance, are directly proportional. Meanwhile, both resistance and reactance at the frequency of 3.5GHz is directly proportional to the radius of the circle FSS. The modeling equation of this parameter (*c*) is written as (9) to (12). The highest degree for this model is the 6th degree polynomial in equation 9 and 11.



a. Resistance



b. Reactance

Figure-10. Impedance modeling for parameter ***c*** (Resistance).

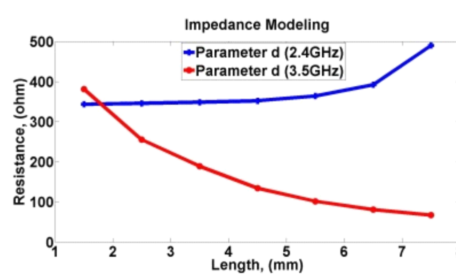
Figure-11 (a) shows the graph of resistance versus length (parameter d) while graph of reactance versus length is depicted in Figure-11 (b). In this parameter, the length varying from 1.5mm to 7.5m is inversely proportional to the resistance and reactance at frequency 3.5GHz. But for the frequency 2.4GHz, the length varyiation is directly proportional to the resistance. The maximum value of resistance occurred at 498ohm while at 176ohm for the reactance. The modeling equation of this parameter is written as (13) to (16). When the length is more than 3.5mm, the 4th degree polynomial is used as in equation 14 and 16. While in equation 13 and 15 the quadratic polynomial is used at length 1.5mm.

$$R = 0.0012799c^6 - 0.2758c^5 + 24.63c^4 - 1173c^3 + 3.133e^4c^2 - 4.453e^5c + 2.632e^6 \quad (9)$$

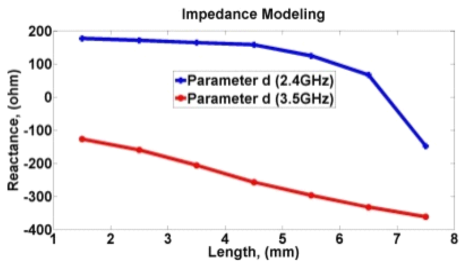
$$R = \begin{cases} 10.51c - 231.5 & 30 < \lambda > 32 \\ 0.3812c^2 - 49.4 + 1442 & 34 < \lambda > 38 \\ 54.54c - 1968 & 40 < \lambda > 42 \end{cases} \quad (10)$$

$$X = -0.001172c^6 + 0.2589c^5 - 23.73c^4 + 1159c^3 - 3.172e^4c^2 + 4.317e^5c - 2.793e^6 \quad (11)$$

$$X = \begin{cases} 17.69c - 557.1 & 30 < \lambda > 32 \\ -0.5482c^2 + 79.06c - 1978 & 34 < \lambda > 38 \\ 26.02c - 1272 & 40 < \lambda > 42 \end{cases} \quad (12)$$



a. Resistance



b. Reactance

Figure-11. Impedance modeling for parameter *d*.

$$R = \begin{cases} 0.1354d^3 + 1.946a + 340, & 1.5 < \lambda > 3 \\ 3.322d + 333.7 & 4.5 < \lambda > 5 \\ 97.86d - 244.1 & 6.5 < \lambda > 7 \end{cases} \quad (13)$$

$$R = \begin{cases} -126d + 370.2 & 1.5 < \lambda > 2 \\ 0.2459d^4 - 6.688d^3 + 70.46d^2 - 362.3d + 841.5 & 3.5 < \lambda > 7 \end{cases} \quad (14)$$

$$X = \begin{cases} -0.4632d^3 - 3.876d - 183.5 & 1.5 < \lambda > 3 \\ -6.339d + 193.7 & 4.5 < \lambda > 5 \\ -215.1d + 1464 & 6.5 < \lambda > 7 \end{cases} \quad (15)$$

$$X = \begin{cases} -32.9d - 77.67 & 1.5 < \lambda > 2 \\ 0.362d^4 - 8.402d^3 + 74.72d^2 - 337.5d + 365.4 & 3.5 < \lambda > 7 \end{cases} \quad (16)$$

CONCLUSIONS

In this paper, the mathematical impedance modeling for a unit cell of the combination circle Frequency Selective Surface (FSS) structure is presented. The unit cell of the combination circle FSS is designed and simulated based on industrial, scientific and medical bands (ISM) standard by using the CST Microwave Studio software. The configuration of FSS is simulated for two configurations; space between the circles and the space overlapping within the circle FSS. The real and imaginary component of the design has been modeled by using Polynomial method in Matlab software based on physical parameters of the design structure of the FSS.

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