Australian Journal of Basic and Applied Sciences, 8(4) Special 2014, Pages: 150-157

AENSI Journals
Australian Journal of Basic and Applied Sciences
ISSN:1991-8178

Journal home page: www.ajbasweb.com

Investigation of a Double Slot FSS for Dual Band Applications on Hybrid Material

[1]M. Md. Shukor, [1]M.Z.A. Abd. Aziz, [1]H. Nornikman, [1]B.H. Ahmad, [1]M.K. Suaidi, [1]M.F. Johar, [1]M.A. Othman, [1]S.N. Salleh, [1]F.A. Azmin, [2]M.F. Abd. Malek.

[1]*Center for Telecommunication Research and Innovation, UniversitiTeknikal Malaysia Melaka Melaka, MALAYSIA.*
[2]*School Of Computer and Communication Engineering Universiti Malaysia Perlis, Perlis, MALAYSIA.*

ARTICLE INFO
Article history:
Received 20 November 2013
Received in revised form 24 January 2014
Accepted 29 January 2014
Available online 5 April 2014

Key words:
Frequency Selective Surface (FSS); hybrid; ISM; reflection; transmission

ABSTRACT
The design FSS structure consists of square FSS structures placed on the FR4 and glass. The circular and square slot is added on the FSS to design and simulate by using the CST Microwave Studio software for 2.4 GHz and 5.2GHz based on industrial, scientific and medical bands (ISM) standard. The reflection (S11) and transmission (S21) of the design FSS structure is analyzed based on the six types of configuration that have been set up. The hybrid material (FR4 and glass) affects the transmission and reflection of the FSS. The highest efficiency for 2.4 GHz and 5.2 GHz are 73% and 89% respectively by using configuration 2. The frequency response of the FSS is shifted to the lower part when the hybrid materials are used. So, the size of the FSS can be reduced by using hybrid materials to achieve the frequency response needed.

© 2014 AENSI Publisher All rights reserved.

To Cite This Article: M. Md. Shukor, M.Z.A. Abd. Aziz, H. Nornikman, B.H. Ahmad, M.K. Suaidi, M.F. Johar, M.A. Othman, S.N. Salleh, F.A. Azmin, M.F. Abd. Malek., Investigation of a Double Slot FSS for Dual Band Applications on Hybrid Material. ***Aust. J. Basic & Appl. Sci.**, 8(4): 150-157, 2014*

INTRODUCTION

Metamaterials have properties that may not be found in nature. It gains its properties not from their composition but from their designed structures. It consists of periodic structure and subwavelength characteristic which particle smaller than the light wavelength with which it interacts. Others are structured that exhibit the subwavelength characteristics are Frequency Selective Surface (FSS) or also known as Artificial Magnetic Conductor (AMC) or High Impedance Surface (HIS) (Bayatpur. F, 2009). FSS is a planar periodic structure of the identical array of patch or aperture type elements arranged in one or 2D plane. FSS have inherent inductive and capacitive properties that useful in designing to get a desired frequency response. Its filtering characteristic is depending on the array element type (Munk B. A. *et al*., 2000).

The frequency behavior of the FSS is entirely determined by the geometry of the surface in one period (unit cell), the size of the FSS, the way the surface is exposed to the electromagnetic wave (incidence angle of the incoming wave), substrate parameters, inter-element spacing and materials used. They are various methods to analyze the periodic structures of the FSS such as the mutual impedance method, the method of moments (MoM) (Langley R. J., 1982) the finite element method (FEM) (Kominami M., 1994), the finite-difference time-domain (FDTD) method and Equivalent Circuit (EC) method (Bardi. I, *et al*., 2002).

By using Equivalent Circuit method, FSS can be modeled as an energy-storing inductive or capacitive component which is determined by the shape of its elements. At any specific frequency, impedance may be represented by either a series or a parallel combination of an ideal resistive element and an ideal reactive element which is either capacitive or inductive as in Fig. 1. Such a representation is called an equivalent circuit. The values of these elements or parameters depend on which representation is used, series or parallel, except when the impedance is purely resistive or purely reactive. Impedance is a comprehensive expression of any and all forms of opposition to electron flow, including both resistance and reactance. It is present in all circuits, and in all components. When alternating current goes through an impedance, a voltage drop is produced that is somewhere between 0° and 90° out of phase with the current. Impedance is one of the important parameters in modeling the FSS by using the EC method (Pozar D.M, *et al*, 2005).

To achieve a certain spectral response for the FSS, many parameters can be adjusted such as the dimensions of periodicity, element shape, dielectric thickness and constant, and number of periodic screens. The frequency behavior of the FSS is entirely determined by the geometry of the surface in one period (unit cell), the size of the FSS, the way the surface is exposed to the electromagnetic wave (incidence angle of the incoming wave),

Corresponding Author: Mohamad Zoinol Abidin Abd. Aziz, Centre for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, UniversitiTeknikal Malaysia Melaka (UTeM), Hang Tuah Jaya 76100 Durian Tunggal, Melaka, Malaysia.
E-mail: mohamadzoinol@utem.edu.my

substrate parameters, inter-element spacing and materials used (Sakran F, 2008). Previous work has been done on the FSS structure for single materials such as glass, Rogers, biased ferrite substrate andso on (Y. Liu, *et al*., 2010). This paper proposed the investigation of the double slot FSS on two materials (hybrid) to observe the performance of the FSS for dual band applications.

2. FSS Design:

The unit cell geometry of the proposed design double slot FSS structure which consists of circular and square slot that etched on the dielectric substrate as shown in Fig. 1. Besides that, Fig. 1 also has shown the unit cell of the double slot FSS structure. The double slot FSS is made up of copper with thickness 0.035 mm. In this paper the FSS is etched on the FR4 board (210m×210mm) for 7×7 elements. The two materials of dielectric substrate have been used in this paper which is FR4 board and glass. The dielectric constant of FR4 is 4.4 and a tangent loss of 0.019 with a thickness of 1.6 mm while the glass dielectric constant is 6.9 and conductivity is 5×10^{-4} S/m with thickness of 5 mm. The double slot FSS is designed and simulated in this paper by using CST Microwave Studio. The double slot FSS is chosen in this paper because of the design gave the lowest transmission losses at -0.5 dB at 2.4 GHz and 0.44 dB at 5.2 GHz compared to others designed. The design chosen is based on the targeted frequency response. The square slot produces 2.4 GHz frequency response while 5.2 GHz is produced by circular slot.

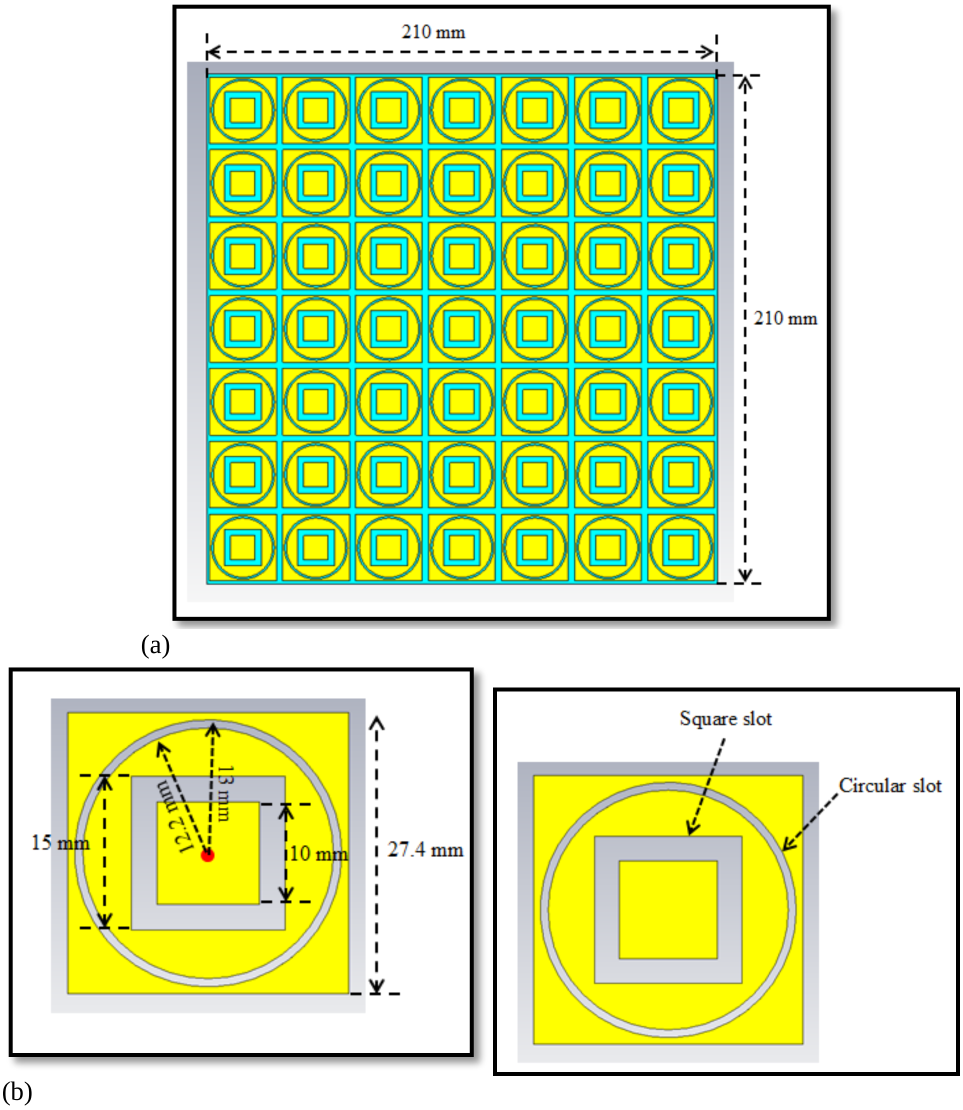

Fig. 1: Geometryof the design FSS structure (a) double slot FSS (7×7) (b) unit cell double slot FSS

The unit cell geometry of the proposed design double slot FSS structure is designed and simulated by using CST Microwave Studio at 2.4 GHz and 5.2 GHz. The simulation setup of the design double slot FSS structure is as in (M. Z. A. Abd Aziz *et al*., 2013).

3. FSS Hybrid Materials:

There are six types of configurations that will be investigated in this paper based on two materials (FR4 and glass) as shown in Fig. 2. The dielectric constant of FR4 is 4.4 and a tangent loss of 0.019 with a thickness of 1.6 mm while the glass dielectric constant is 6.9 and conductivity is 5×10^{-4} S/m with thickness of 5 mm. The double slot FSS is etched on the FR4 board. Then the glass is placed at the back of the FR4 board and on the double slots FSS.

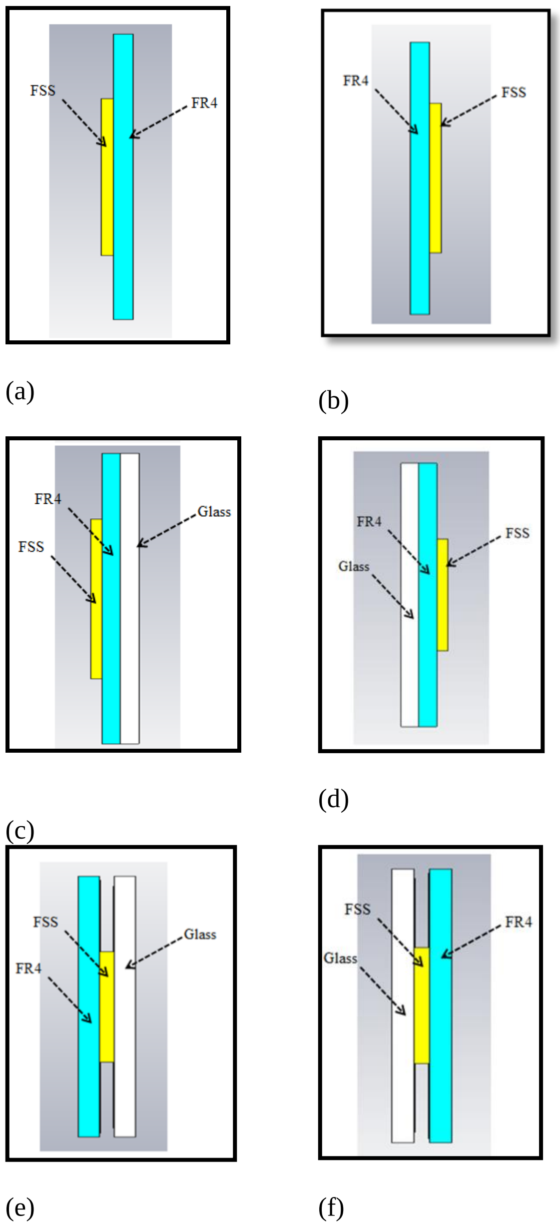

Fig. 2: Design FSS structures from side view (a) configuration 1 (b) configuration 2 (c) configuration 3 (d) configuration 4 (e) configuration 5 (f) configuration 6

By using the well-known circuit theory, the FSS can be equivalently modeled as a resonant circuit consisting of parallel-connected two series L-C resonators. Reflection coefficient can be represented as Γ (capital gamma) 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 by using Eq. (1). $Z_0$is the impedance of free space (376.7 Ω) (M. Z. A. Abd Aziz *et al*., 2013). The waveguide ports in the design represent the Z_0.Fig. 1 is the graph of efficiency versus the rotor and slip frequency. When $\Delta\omega$ is fixed, the motor efficiency increases with the increasing of the rotor angular frequency. However, when ω_r is fixed, the motor efficiency is increases at first, and starting to show the decreasing trend with the maximum changing process. The value is the maximum efficiency with the increasing of the rotor angular frequency.

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

Then the complex impedance can be written as in Eq. (2) where the real part of the impedance (Re) is resistance, R and the imaginary part of the impedance (Im) is reactance, X.

$$Z = R + jX \qquad (2)$$

The reactance,X is the total of the inductive reactance, X_L and capacitive reactance, X_C and the equation of the reactance can be written as in Eq. (3).

$$X = X_L - X_C \qquad (3)$$

A. Measurement Setup:

Fig. 3 shows the measurement setup for the design double slot FSS structure (7×7). This measurement setup is for all six types of configurations. Two horn antennas are used as the receiver and the transmitter. Both antennas are connected to the Network Analyzer. Antenna at the transmitter is connected to port 1 and antenna at the receiver is connected to port 2 of Network Analyzer. The distance of the design double slot FSS structure from both antennas is 130 mm. The double slot FSS structure is placed between both horn antennas. The reflection and transmission results are measured to observe the performance of the FSS. The prototype of the design double slot FSS structure (7×7) is shown in Fig. 4.

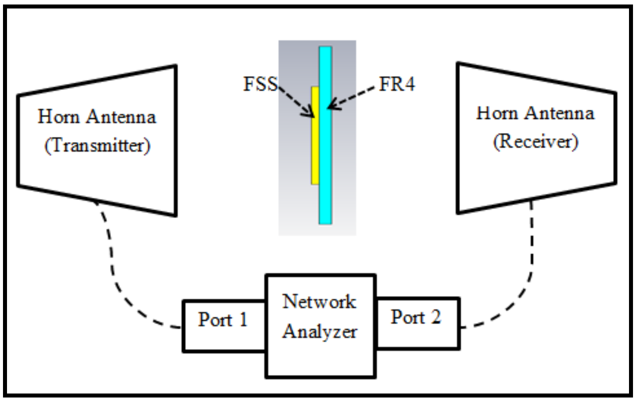

Fig. 3: Measurementsetup showing the design double slot FSS structure positioned between two horn antenna

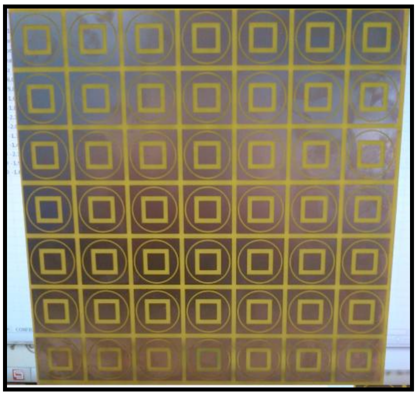

Fig. 4: Double slot FSS prototype

RESULT AND DISCUSSION

A. Impedance Characteristic:

The characteristic impedance of the double slot FSS at 2.4 GHz and 5.2 GHz are shown in Table 1. The ranges of the resistance are between 18 Ω to 2913 Ω. The resistance of the characteristic impedance except for the configuration 4 can be decreased by using hybrid material (FR4+glass and glass+FR4) configurations. Due to this investigation, the resistance of the characteristic impedance can be reduced about 51 to 424 Ω by using hybrid material configuration 3, 5 and 6. This impedance characteristic is very useful which can be used to design the equivalent circuit of the FSS.

Table 1: Impedance Characteristics Of FSS AT 2.4GHz And 5.2GHz

Configuration	Impedance , *Z* (Ω)	
	2.4 GHz	5.2 GHz
1	550 – j57	294.2 – j72.53
2	478 – j98	18.73 – j20.81
3	318 + j1098	85.62 + j81.93
4	2913 – j24675	37.73 + j93.43
5	126 + j3516	45.91 – j35.81
6	499 + j1197	107.35 + j31.23

B. Simulation Result:

All configurations are simulated with the same size of the design double slot FSS structure. Fig. 5 and 6 are shown the simulation results for the reflection and transmission of the double slot FSS for all configurations. The results are shown in Table 2 and 3 to investigate the effect of each configuration at 2.4 GHz and 5.2 GHz frequency response. The hybrid materials (FR4 and glass) effects return loss and also the transmission losses.

At 2.4 GHz, the return loss and the transmission loss have large changes about 14 dB and 36 dB. While at 5.2 GHz, the changes for the return loss and transmission loss are 16 dB and 5 dB. The highest return loss for 2.4 GHz is -15.54 dB by using configuration 2. The efficiency is 73%. Then the highest efficiency for frequency response of 5.2 GHz is 89% with return loss of -17.65 dB by using configuration 2. Besides that, the frequency for both 2.4 GHz and 5.2 GHz are shifted to the lower part when using hybrid materials. This is shown that the hybrid material can shift the frequency and led to the compact structure.

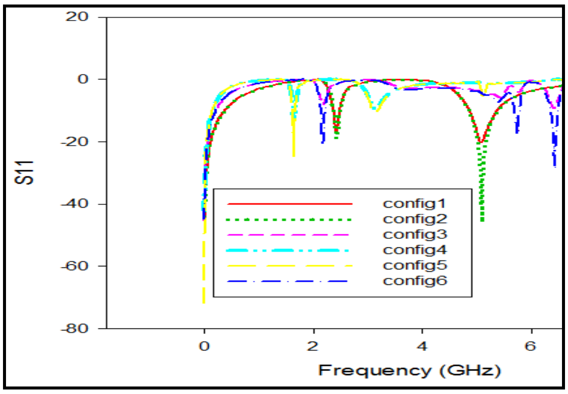

Fig. 5: Simulated reflection (S11) results of the design FSS structure for each configuration

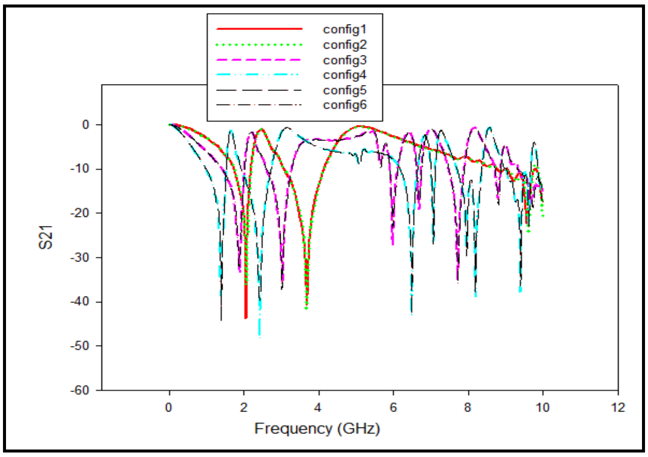

Fig. 6: Simulated transmission (S21) results of the design FSS structure for each configuration

Table 2: Simulated S11 And S21 Results Between All Configurations At 2.4 GHz

Configuration	S11(dB)	S21(dB)
1	-14.33	-1.43
2	-15.54	-1.37
3	-1.47	-6.37
4	-0.03	-33.30
5	-0.09	-37.23
6	-1.84	-6.15

Table 3: Simulated S11 And S21 Results Between All Configurations At 5.2 GHz

Configuration	S11(dB)	S21(dB)
1	-15.94	-0.53
2	-17.65	-0.52
3	-4.67	-1.87
4	-1.56	-5.62
5	-2.12	-5.51
6	-5.04	-2.15

C. Measurement Result:

Fig. 7 and 8 are shown the measurement results for the reflection and transmission of the double slot FSS structure for all configurations. Table 4 and 5 are the S11 and S21 results of all configurations at 2.4 GHz and 5.2 GHz. The measurement results are tally with the simulation results but the different is due to the transmission losses. The transmission losses different is about 6.84%. The transmission losses for the measurement results are higher due to the measurement environment such as air, temperature, humidity and so on. The return loss decreases about 3 dB at 2.4 GHz and 9 dB at 5.2 GHz. The transmission losses are increased about 12 dB at 2.4 GHz and 14 dB at 5.2 GHz. At 2.4 GHz and 5.2 GHz frequency response, the highest return loss is -18.85 dB by using configuration 2 and -26.60 dB by using configuration 1 respectively.

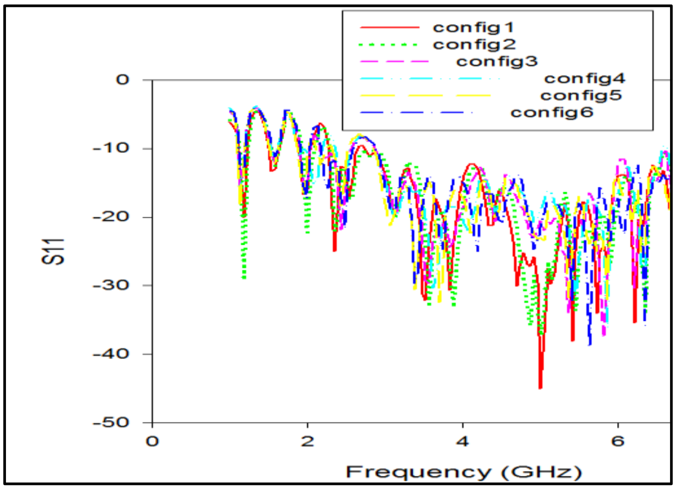

Fig. 7: Measured reflection (S11) results of the design FSS structure for each configuration

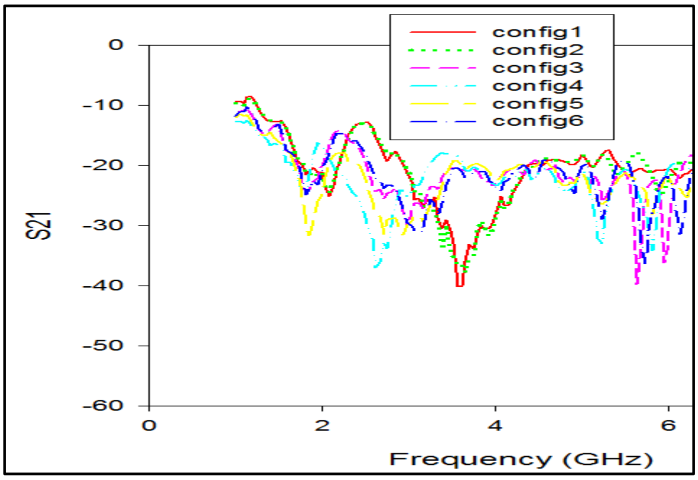

Fig. 8: Measured transmission (S21) results of the design FSS structure for each configuration

Table 4: Measured S11 And S21 Results Between All Configurations At 2.4 GHz

Configuration	S11(dB)	S21(dB)
1	-16.20	-13.04
2	-18.85	-13.02
3	-16.17	-16.58
4	-13.09	-25.27
5	-15.17	-19.58
6	-13.58	-16.00

Table 5: Measured S11 And S21 Results Between All Configurations At 5.2 GHz

Configuration	S11(dB)	S21(dB)
1	-26.60	-18.82
2	-24.55	-18.77
3	-20.24	-23.75
4	-18.48	-32.40
5	-18.82	-26.17
6	-17.86	-26.99

Conclusion:

The design double slot FSS structure (7×7) is designed and simulated in this paper at 2.4 GHz and 5.2 GHz. The two materials of dielectric substrate which are FR4 board and glass have been used to produce hybrid materials. There are six types of hybrid configurations have been studied in this paper. The results show that the resistance can be reduced by using hybrid certain type of hybrid materials. There are also effects of the return loss and transmission signal by using hybrid which led to the compact structure. So, future work is needed to reduce the size of the FSS so that the cost of the project can be reduced. This design can be used for material scanning based on the material properties.

ACKNOWLEDGMENT

The authors would like to thank UTeM and NSG (Malaysia) Sdn. Bhd. for their support in obtaining the information and material in the development of our work and we also want to thank anonymous referees whose comments led to an improved presentation of our work. Lastly we also thank the Ministry of Higher Education for MTUN/2012/UTeM-FKEKK/5 M00013 research grant.

REFERENCES

Abidin, M.Z.A., M. Md. Shukor, M.K. Suaidi, 2013. “Phase shift of the transmission coefficients for frequency selective surface”. In the proceeding of 6th International Conference on Information Technology (ICIT’13).

Abidin, M.Z.A., M. Md. Shukor, M.K. Suaidi, B.H. Ahmad, M.F. Johar, F.A. Azmin, S.N. Salleh, M.F. Malek, 2013. “Impedance modeling for a unit cell of the square loop frequency selective surface at 2.4 GHz”.In the proceedings of the Internation Conference on IEEE RFID Technical and Application (IEEE RFID 2013).

Bardi, I., R. Remski, D. Perry and Z. Cendes, 2002.“Plane wave scattering from frequency-selective surfaces by the finite-element method”. Journal of IEEE Transactions on Magnetics, 38(2): 641-644.

Bayatpur, F., 2009. “Metamaterial-inspired Frequency selective surfaces”, thesis, The University of Michigan.

Dubrovka, R.J., C. Vazquez, Parini and D. Moore, 2006.“ Equivalent circuit method for analysis and synthesis of frequency selective surfaces”. Journal of Microwave Antennas Propagation, 153(3): 213-220.

Kent, E.F., B. Döken and M. Kartal, 2010. “A new equivalent circuit based FSS design method by using genetic algorithm”, pp: 1-4.

Kominami, M., H. Wakabavashi, S. Sawa and H. Nakashima, 1994. “Scattering from a periodic array of arbitrary shaped elements on a semi-infinite substrate”. Journal of Electronics and Communications in Japan (Part I: Communications), 77(1): 85-94.

Langley, R.J. and E.A. Parker and T.K. Chang, 1994. “Frequency selective surfave on biased ferrite substrates”. 30(75): 3-4.

Langley, R.J. and E.A. Parker, 1982.“Equivalent circuit model for arrays of square loops”. Journal of Electronic Letters, 18(7): 294-296.

Lee, C.K and R.J. Langley, 1985. “Equivalent-circuit models for frequency-selective surfaces at oblique angles and incidence”. Journal IEEE, 132(6): 395-399.

Liu, H.T., H.F. Cheng, Z.Y. Chu *et al.*, 2007. “Absorbing properties of frequency selective surface absorbers with cross-shaped resistive patches”. Journal of Material Design, 28: 2166-2171.

Liu, Y., Q. Ye, B. Xiao and H. Yang, 2010. “A novel application of frequency selective surface in dual-band WLAN antenna”. In the proceedings of Isape, pp: 512-514.

Mias, C., C. Tsakanos and C. Oswald, 2001. “an investigation into the feasibility of designing frequency selective windows employing periodic structures”, Ref. AY3922, Tech. Rep., Final Report for the Radio-Communications Agency, Nottingham Trent University, Ref. AY3922.

Munk, B.A., 2000.“Freuency selective surfaces-theory and design”. John Wiley and Sons, Inc., New York.

Pozar, D.M., 2005.“Microwave Engineering”.3rd edition. United States: John Wiley and Sons, Inc.

Sakran, F. and Y. Neve-Oz, 2008.“Absorbing frequency-selective surface for the mm-wave range”. Journal of IEEE Transactions on Antennas and Propagation, 56(8): 2649-2655.

Sung, G.H., K.W. Sowerby and A.G. Williamson, 2005.“Equivalent circuit modeling of a frequency selective plasterboard wall”. In the proceedings of IEEE Antennas and Propagation Society International Symposium, pp: 400-403.

Ullah, I., D. Habibi and G. Kiani, 2011. “Design of RF/Microwave efficient building using frequency selective surface”. In the proceedings of the 2011 IEEE 22nd International Symposium on Personal, Indoor and Mobile Radi Communication, pp: 2070-2074.

Wang, D., W. Che, S. Member, Y. Chang, K. Chin, Y.L. Chow and L. Member, 2013. “A low-profile frequency selective surface with controllable triband characteristics”, 12: 468-471.

Wu, T.K., 1995. “Frequency selective surfaces and grid array”. John Wiley and Sons, Inc., New York.

Young, M. the Technical Writer’s Handbook Mill Valley. CA: University.