View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Research Online

UNIVERSITY
OF WOLLONGONG
AUSTRALIA

University of Wollongong
Research Online

University of Wollongong in Dubai - Papers

University of Wollongong in Dubai

2018

Number of iteration analysis for complex fss shape using GA for efficient ESG

Nornikman Hassan
Universiti Teknikal Malaysia Melaka

Zahriladha Zakaria
Universiti Teknikal Malaysia Melaka

Badrul Ahmad
Universiti Teknikal Malaysia Melaka

Naim Pee
Universiti Teknikal Malaysia Melaka

Siti Salleh
Universiti Teknikal Malaysia Melaka

See next page for additional authors

Publication Details

Hassan, N., Zakaria, Z., Ahmad, B. H., Pee, N. C., Salleh, S. N., Aziz, M. Z. A. A., Abdul Malek, M. F. & Ismail, M. K. 2018, 'Number of iteration analysis for complex fss shape using GA for efficient ESG', Bulletin of Electrical Engineering and Informatics, vol. 7, no. 4, pp. 505-513.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Authors
Nornikman Hassan, Zahriladha Zakaria, Badrul Ahmad, Naim Pee, Siti Salleh, Mohamad Zoinol Abi Aziz, Mohd Fareq Abdul Malek, and Mohd K. Ismail

This journal article is available at Research Online: https://ro.uow.edu.au/dubaipapers/1036

Bulletin of Electrical Engineering and Informatics
Vol. 7, No. 4, December 2018, pp. 505~513
ISSN: 2302-9285, DOI: 10.11591/eei.v7i4.1354

Number of Iteration Analysis for Complex FSS Shape Using GA for Efficient ESG

Nornikman Hassan[1], Zahriladha Zakaria[2], Badrul Hisham Ahmad[3], Naim Che Pee[4], Siti Nadzirah Salleh[5], Mohamad Zoinol Abidin Abd Aziz[6], Mohd Fareq Abdul Malek[7], Mohd Khairy Ismail[8]
[1,2,3,5,6,8]Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka, Malaysia
[4]Faculty of Information and Communication Technology (FTMK), Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka, Malaysia
[7]Faculty of Engineering and Information Sciences, University of Wollongong in Dubai (UOWD), United Arab Emirates (UAE)

Article Info

Article history:

Received Aug 25, 2018
Revised Oct 26, 2018
Accepted Nov 05, 2018

Keywords:

Energy Saving Glass (ESG)
Finite difference time domain
Frequency Selective Surface (FSS)
Genetic algorithm

ABSTRACT

ESG stand for Energy-Saving Glass is a special shielded glass with a metallic oxide layer to abuse undesirable of infrared and ultraviolet radiation into construction assemblies like our home. Firstly, different number of the iteration is the main thing to study a performance of the frequency selective surface shape using genetic algorithm (GA) for efficient energy saving glass (ESG). Three different values for the number of iterations were taken that is 1500, 2000 1nd 5000. Before that, the response of this complex FSS shape on incident electromagnetic wave with different symmetry shape are investigating. Three of them are no symmetrical shape, ¼ symmetrical shape, and 1/8 symmetrical shape. The 1500 number simulation considered about 89.000 per second, compared with 2000 iteration and 5000 iterations had consumed 105.09 per second and 196.00 per second, respectively. For 1/8 symmetry complex FSS shape, it demonstrations the improved performance of transmission loss at 1.2 GHz with - 40 dB. A 2 dB of transmission loss is achieved at WLAN application of 2.45 GHz with 0°, 30°, and 45° incidence angle shows.

Copyright © 2018 Institute of Advanced Engineering and Science.
All rights reserved.

Corresponding Author:

Nornikman Hassan
Center for Telecommunication Research and Innovation (CeTRI),
Faculty of Electronics and Computer Engineering (FKEKK),
Department of Electrical and Computer Engineering,
Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka, Malaysia.
Email: nornikman@utem.edu.my

1. INTRODUCTION

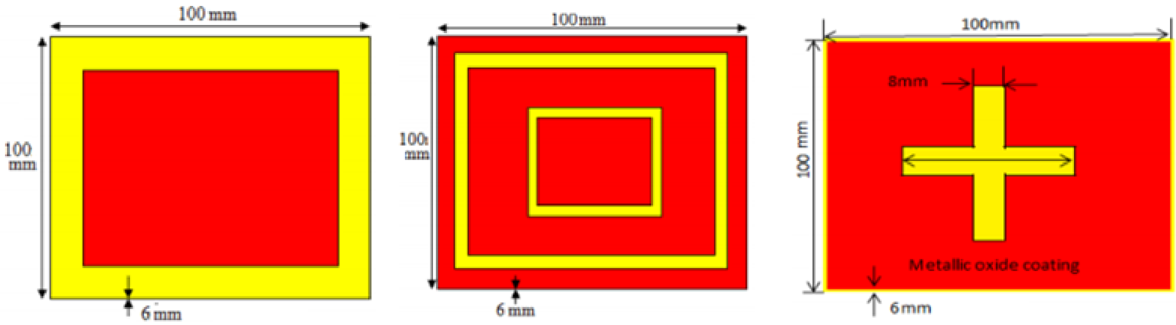
Energy-saving glass (ESG) using transparent metallic oxide covering on one sideways of the glass is the best choices to get the most out to obstructive of ultraviolet or infrared radiation from the outdoors into the home or buildings [1]. In Malaysia, this ESG is very important to investigate because its weather and high temperature condition. There are several examples on ESG had been designed previously.

For example, in Habib [2-3] paper, he had been designed indoor environment glazed soft-covered ESG using a band-pass FSS that achieved improvement of 20 dB in the range between 0.1 GHz to 2.3 GHz while achieve 10 dB and 25 dB attenuation at 2.45 GHz and 5.25 GHz, respectively. In another work of Ma [4], the performance of its triband ESG-FSS design shown the result of –3dB bandwidth in between 833 MHz –1009 MHz, 1842 MHz –2200 MHz and 3420 MHz -4 300 MHz, respectively.

Also, another example can be found in Sohail [5] work that apply bandpass FSS for soft-coated glass ESG application. He stated that, the results, performance shows the coverage between 0.5 GHz to 2.0

GHz. This range basically covered two important applications of GSM signal at 1.8 GHz and WLAN signal at 2.45 GHz with FSS aperture of 9%. Ragulis [6] in his paper had been investigating ESG performance in between of 1 GHz to 20 GHz with the maximum best signal passing through the window as high as 60 dB.

Basic shape coatings are presented as the explanation to overwhelm the signal sufferers of RF signal with ESG. In addition, the basic shape is meant because the same dimension size and the equalization in the all angle values. The existing methods and investigates on the numerous projects of basic shapes. For example, there several shaped used like double square loop, triangular, dipole, and others and this shape have function to improve the transmission signal (S21) of beneficial signal. Other than that, it also effect to decrease signal attenuation. Figure 1 shows the designs of basic shape that are usually chosen as ESG structure. Other by that, the combination or complex had been done by some researchers such as cross dipole [7], Swastika [8], Jerusalem [9], double square loop [10], and others [11-14].



(a) (b) (c)

Figure 1. Basic shape for structure of ESG, (a)rectangular, (b rectangular with ring, (c)cross

Before this, the modelling investigation of a transmission signal in RF/microwave signal was typically practical done by experimental technique of measurement work. Extra numerical calculations for analytical process are obligatory where further time is occupied to research the essential equation. Thus, the numerical modelling is desired to improve the construction work in defining the performance result, such as a transmission signal for dissimilar structures or shapes. Besides that, it is actual differential to physically achieve the calculations and to progress a model via measurement work. Figure 2 shows the flow chart of the project.

In this work, firstly, the theories, literature review and the concepts of ESG, FDTD, GA, FSS and others must be researched. Then, the Finite-difference time-domain (FDTD) program was written in the FORTRAN software model the ESG. The simulation has taken place to evaluate the performance of the corrected code until there no error was found in the coding. Several the iterations are the main thing to study a performance of the frequency selective surface shape using genetic algorithm (GA) for efficient energy saving glass (ESG). In this work, three values for the number of iterations were taken that is 1500, 2000 1nd 5000. Before that, the response of this complex FSS shape on incident electromagnetic wave with different symmetry shape are investigating. Three of them are no symmetrical shape, ¼ symmetrical shape, and 1/8 symmetrical shape. In this work, several parameters were considered, that is the patches of FSS, the rate of bit chromosome, and transmission coefficient. This part examined the kind of symmetrical castoff for FSS complicated shape.

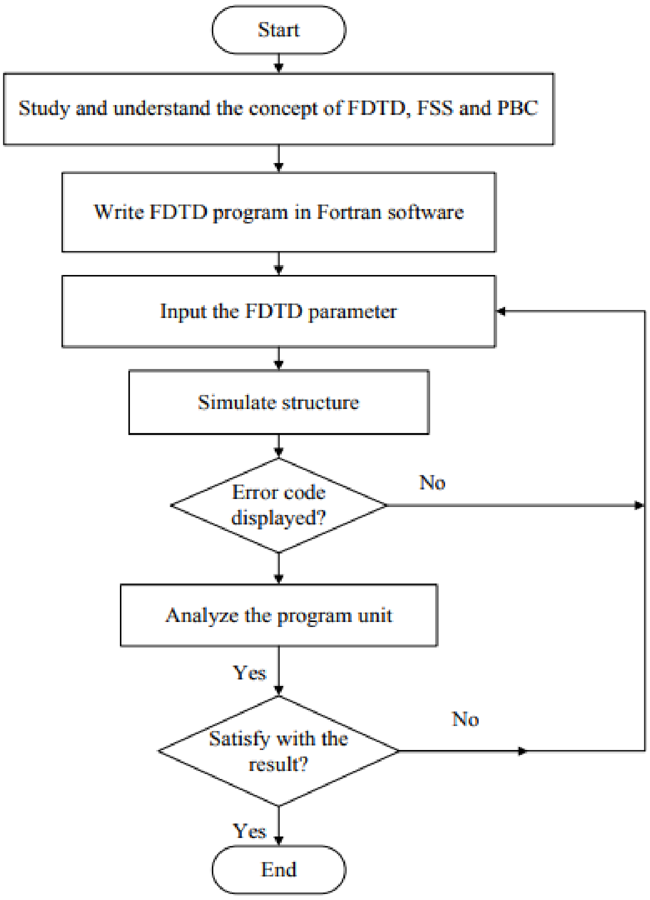


Figure 2. Flow chart of the project

2. GENETIC ALGORITHM (GA)

There are two different types that used in in technique of synthesis namely analysis tool and optimizer tool. There are two different parts that can be devide, firstly called global optimization and the second part is the local optimization.

Genetic algorithm (GA) that announced in the 1970s by John Holland from University of Michigan, United States included in the global optimization method [15]. GA is the best-known technique and extensively used by investigator to generate the unique pattern of FSS. GA enhancers are stochastic pursuit procedures, intense, exhibited on the standards and view of regular determination and advancement. This streamlining agent is a powerful heuristic of the GA with the best settling unpredictable, combinations and related issues [16].

Compare with other optimization technique, the attractive reason to choose the GA is its performance improvements of computational systems [17-18]. This GA has likewise given the best execution on the blended mode on the nonstop and discrete combinatorial issues with less defenceless to getting 'stuck' at nearby optima than slope look strategies [19].

In Bossard [20] work, he had designed the low-loss negative index metamaterials (NIM) of cascaded FSS using the GA optimizer to realize a concurrently negative permeability and permittivity value at the wavelength around 3 µm. After done, its shows the low absorption and mismatch losses index of refraction of –1.

In other work, Luo [21] had been introduced a freestanding FSS structure to dipole element design using real-coded GA technique or RGA with the association of electromagnetic solver of Method of Moments (MOM). Shim [22] also had been using the GA simulator to create the numerous shaped of FSS. It shows that the successfully better performance on the acceptable running time, and the value outcome is provided by manufactured FSS.

Figure 3 shows the doubly-periodic multilayer screens of FSS with unique pattern cells that generate by GA simulator using the method of moments (MoM) on Manara [23] design. The dimension of dx=3.837 cm while dy=3.35 cm. This structure creates a dual-band, consist of L-band at 1.0 GHz to 2.0 GHz while another S-band frequency range between 3.0 GHz and 4.0 GHz at an incident angle of 450. In another project example, Jun [24] in his paper stated in his FSS design using GA. Figure 4 shows the 32 x 32 unique pattern of FSS. This optimize FSS creates a centre frequency of 6.0 GHz. It mentions that also the Q value of this FSS rises as the incident angle of electromagnetic wave growth.

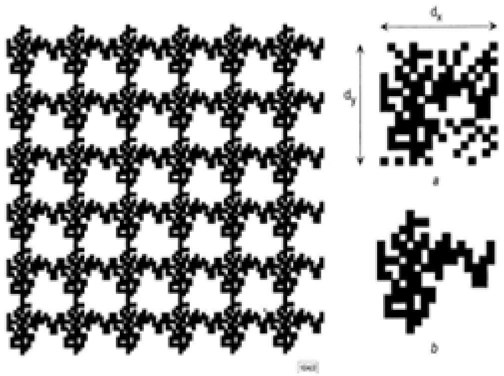


Figure 3. Multilayer screens of FSS with unique pattern cell by Manara [23]

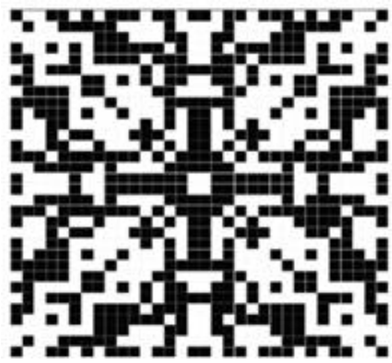


Figure 4. Unique element of FSS by Jun

Before the application a GA, signify the solution to the problem as a chromosome must be done. After that, this GA generates a population of solutions and used genetic operators like crossover and mutation to develop the solutions in the right direction to discover the finest performance [25]. This GA capability to produces the chromosome that composed of numerous variable genes. Moreover, GAs comprise procedures termed encoding, selection, initial population set, crossover, fitness evaluation, mutation and reproduction [26]. Figure 5 displays the block diagram of chromosome with the genes that created from the optimization of GA

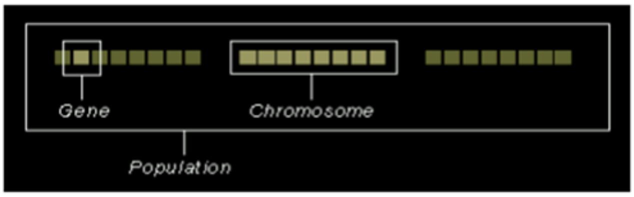


Figure 5. Block diagram of chromosome with the genes that created from the optimization of GA

Then, optimization tool input had been controlled in several works such as the amount of Yee cells, the symmetry type, chromosome number, the type of complex, the metal chromosome types, and the type of cell used in the design. The coding has been representing in the Matlab code:

```
Cell=42          % length of unit cell input
sym=8            % symmetrical type that is 4-quart, 8-octal or 0-no symmetry
numchro=1        % the amount of chromosome
random=1         % can choose: 1-random, or 0=no random
allone=0         % can choose: 1-for all chromosomes is metal, 0-no chromosome is metal
HalfCell=Cell/2;
```

After that, to plan the complex (random) shape, the type of symmetry is considered using calculation created in the input that selected by the user for the number of bits chromosome. Below shows the

Matlab code that is applied by the user for the calculation process. In this case, the 1/8 symmetry had been used.

```
if sym==4
 Nbits=HalfCell*HalfCell      %if quarter part symmetrical chromosome
elseif sym==8
 Nbits=(HalfCell*HalfCell-HalfCell)/2+HalfCell; %if eight-part symmetrical chromosome
elseif sym==0
 Nbits=Cell*Cell;                  %if not symmetrical chromosome
End
```

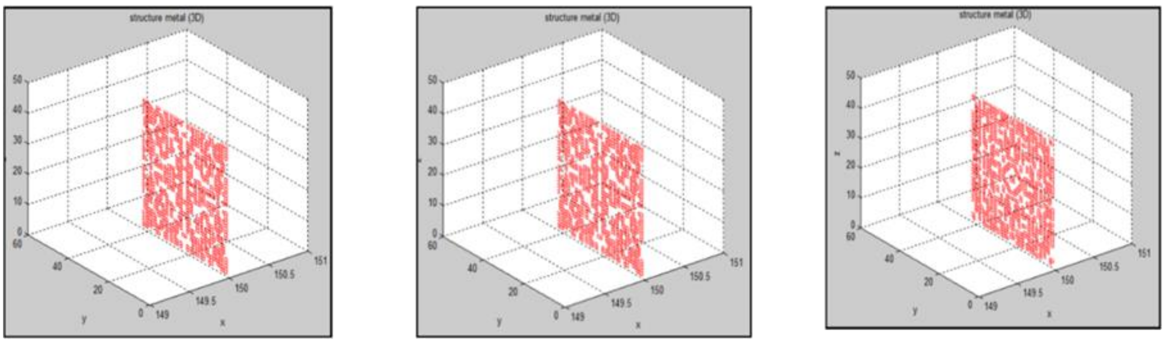
3. FREQUENCY SELECTIVE SURFACE DESIGN

Frequency Selective Surface (FSS) in random shapes that intensively research since the early 1960s. Before that in the year of 1919, Marconi patented has periodic structures that used FSS in his parabolic dish antenna application. This frequency selective surface is a planar occasional construction of the indistinguishable exhibit of a fix or gap compose components organised in one- (1D) or two-dimensional (2D) planes. FSS is working in FSS examination initiates with a mode coordinating method to be starting utilized as a part of the waveguide where the mode coordinating system mains to the comparable circuit.

Currently, there are several random terrestrial and electromagnetic shielding applications had been done. For example, in the paper of Azemi, [27-28] stated the research on effective incident angle independence at the modification square cross section cylinder unit elements of 3D Frequency Selective Surfaces.The showing model proficiencies are confined by the ineptitude of DSP modes concurrently to any geometric model of FSS. Besides, with the start of PC numerical, strategies need to set up for exact FSS examination as the procedure of minutes (with the fundamental elements of the entire or sub-area) limited change system and limited component method [29]. As a result, FSS is the best choice resolutions to increase the transmission signal to permit through the ESG. By referring the periodic structure in single or double occupancy in the FSS by [30].

In this effort, the complex shape stated with three different of types of symmetrical which1/8 symmetry, 1/4 symmetry with comparable elements of no symmetry. If compare all this three symmetrical, there are no differences in design and has the approximately performance results, but with variance in the number of bits chromosome and time simulation progress. The purpose of this work is to show out the time simulation cut down as the result of bits chromosome decrease. The permittivity was fixed at 1.07, with 10 mm of dielectric thickness while it is using 1/8 symmetry shape of FSS, but in various patterns and plans.

The FSS patch created a design with shape is shown in Figure 6. This three dimensional, no symmetrical shape, ¼ symmetrical shape and 1/8 symmetrical shape of FSS patch had been made constructed on the bit chromosome. Different symmetrical shape effect the time to simulate the design, example 162.056 second, 98.056 seconds and 81.509 seconds in one loop of iteration for no symmetrical shape, ¼ symmetrical shape, and 1/8 symmetrical shape, respectively. The Yee cells size of FSS patch is 21 mm length, L and 21 mm width, W with a value of 42 Yee cells with 0.5 mm length x 0.5 mm width in axes y and z. Figure 7 shows 1/8 symmetrical shape FSS in two dimensions with 231 of number bits.



(a) (b) (c)

Figure 6. FSS in three dimensional, (a)no symmetrical shape, (b)¼ symmetrical shape, (c)1/8 symmetrical shape

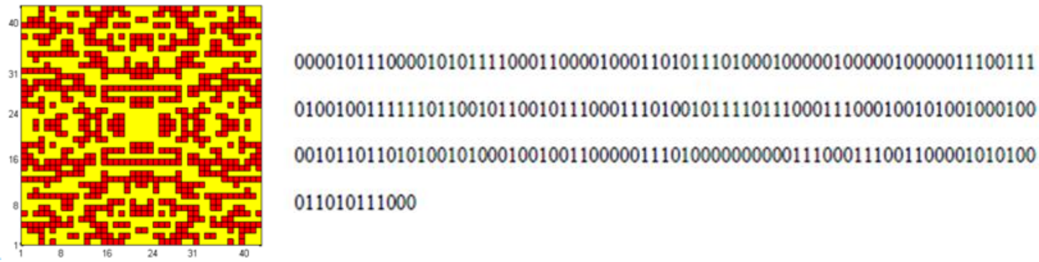


Figure 7. FSS in three dimensional with its number bits

4. RESULTS AND DISCUSSION

After the reproduction was done, the reaction of this shape on the occurrence electromagnetic wave that exactly hit the substrate at the centre part is shown in Figure 8. It demonstrates that at 1.2 GHz individually, for no symmetry FSS shape had been moved to - 43 dB as the TE reduced. At 0°, 30°, and 45° incidence angles that reached from 0 GHz till 6 GHz, the simulation displayed by 0 dB, 0 dB, and 3 dB attenuation, respectively. At 2.45 GHz and 5.25 GHz it created –5 dB and -8 dB transmission loss of attenuated signal. For FSS shape with 1/4 symmetry, the lower bandstop shows at 1.2 GHz and the upper bandstop at 4.3 GHz. It shows the attenuation results at 2.45 GHz with 0°, 30°, and 45° incidence angles shows the 1 dB, 1 dB, and 2 dB, respectively. For 5.25 GHz, all three incidences angles show transmission loss of 8 dB. From the results, it shows the optimistic performance as they point to the probability of preserving WLAN detention at the transmission in the wanted band.

For 1/8 symmetry complex FSS shape, it demonstrations the improved performance of transmission loss at 1.2 GHz with - 40 dB. At 2.45 GHz of WLAN frequency at 0°, 30°, and 45° incidence angle shows the transmission loss of 2 dB. At 5.25 GHz had been shows 8 dB of 0°, 30°, and 45° incidence angles. The diagram also displays that the lower frequency moved to - 40 dB as the signals passed via to WLAN bands.

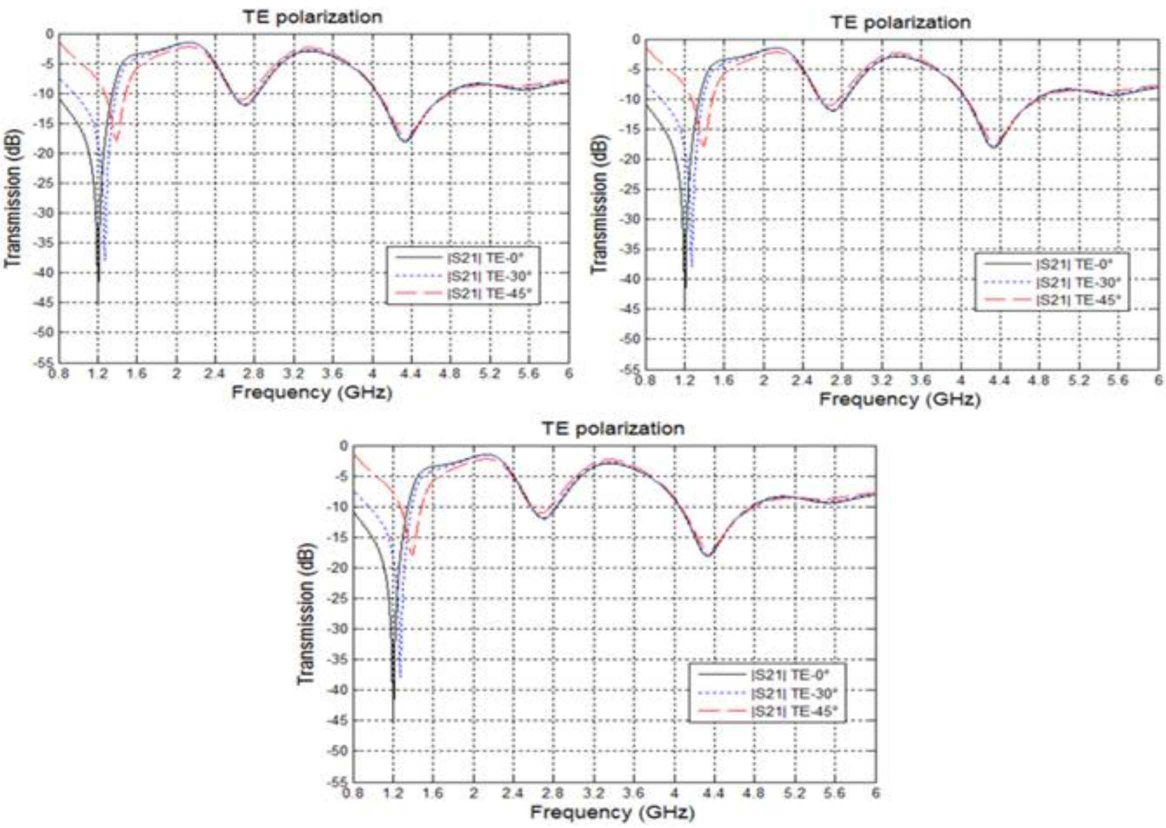


Figure 8. Diagram of transmission coefficient of complex FSS shape, (a)no symmetrical shape, (b)¼ symmetrical shape, (c)1/8 symmetrical shape

From the graph in Figure 9, three values for the number of iterations were considered. Figure 9 demonstrations results performance attained in FORTRAN in evaluation to the results among the three values of number iteration. It shows that, if the number of iterations achieved at 1500 number of iterations, the graph had been inaccurate in the result. It presented unsure results since the graph plotted not same when compared to 2000 and 5000 number of iterations.

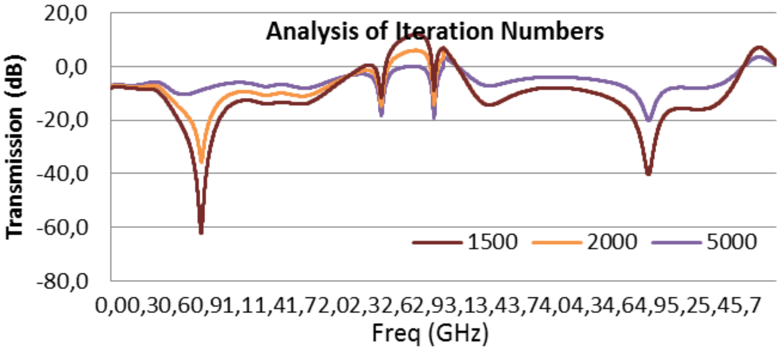


Figure 9. Graph for number of iteration analysis

Conversely, the graph enhanced by the number of iterations of 2000. It additionally demonstrated relatively comparable example to that of 1500 result at 3.1 GHz to 6.0 GHz of frequency Hence, 2000 emphasis had been satisfactory for the Fortran recreation, yet so as to accomplish a more precise outcome, 5000 cycles had been applied. 5000 iterations displayed almost no reflected signal. In terms of time taken for simulation work, the 1500 number simulation considered about 89.000 per second, compared with 2000 iteration and 5000 iterations had consumed 105.09 per second and 196.00 per second, respectively. So, in this case, it can be reflected that the 5000 iteration shows more accurate and delivered efficient result compared to 1500 iterations and 2000 iteration.

The outcome of the transmission coefficient results not only caused by the shape of FSS structure. The other factor is the number of iterations and another parameter. The quantity of cycle in the FORTRAN programming program had been different to the fitting amount of emphasis required for the simulation.

5. CONCLUSION

This paper finished to designing a complex frequency selective surface (FSS) shape using genetic algorithm (GA) for efficient energy saving glass (ESG). This complex FSS test system device and transmission coefficient (S21) were trial made on the parameters and the materials of the FSS. It likewise demonstrates the test system simulator in view of the info content record embedded by the input and the output from the information and the yield in the summons window; either with comparative information or to fizzle the instrument. The test system charges window introduced that the instrument can be approve with different apparatuses to affirm that the device can be attractive for reenacting transmission coefficient in a few applications. The difference between no symmetry, 1/4 symmetry, and 1/8 symmetry are thought about considering time iteration in this investigation. It demonstrates that the 1/8 symmetry expend less time in iteration due to a smaller number of bits chromosome. The quantity of emphasis for the mimicked FSS complex shape impact to make the aftereffect of the transmission coefficient (S21). From the quantity of iteration performance, it distinguished that when the quantity of cycle for reenactment improved.Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

ACKNOWLEDGEMENTS

The writers would like to thank Faculty of Electronics and Computer Engineering (FKEKK), and Center for Research and Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM) for supportive in attaining the information and material in the development for our work. The appreciation also goes to the Ministry of Higher Education (MOHE) and the Government of Malaysia which funding this project under the research grant JURNAL/2018/FKEKK/Q00001 and PJP/2017/FKEKK/HI10/S01532. Finally, we also thank the nameless referees whose comments led to an enriched presentation of our project.

REFERENCES

[1] G. I. Kiani, K. L. Ford, L. G. Olsson, K. P. Esselle, and C. J. Panagamuwa. Switchable Frequency Selective Surface for Reconfigurable Electromagnetic Architecture of Buildings. IEEE Transactions on Antennas and Propagation. 2010; 58(2): 581-

[2] S. Habib, M. F. U Butt, and G. I. Kiani. Parametric analysis of a band-pass FSS for double glazed soft-coated energy saving glass. 2015 International Symposium on Antennas and Propagation (ISAP). 2015; 1-4.

[3] S. Habib, G. I. Kiani and M. F. U. Butt. Interference mitigation and WLAN efficiency in modern buildings using energy saving techniques and FSS, 2016 IEEE International Symposium on Antennas and Propagation (APSURSI). 2016; 965-966.

[4] Ma, F. and Li, L. Design of a Tri-bandpass FSS on dual-layer energy saving glass for improving RF transmission in green buildings. 2015 IEEE International Conference on Communication Problem-Solving (ICCP). 2015; 405-407

[5] S. I. Sohail, K. P. Esselle and G. Kiani. Design of a bandpass FSS on dual layer energy saving glass for improved RF communication in modern buildings. Proceedings of the 2012 IEEE International Symposium on Antennas and Propagation. 2012; 1-2.

[6] P. Ragulis, P. Ängskog, R. Simniškis, B. Vallhagen, M. Bäckström, and Ž. Kancleris, Shielding Effectiveness of Modern Energy-Saving Glasses and Windows. IEEE Transactions on Antennas and Propagation. 2017; 65(8): 4250-4258

[7] G. I. Kiani, L. G. Olsson, A. Karlsson, K. P. Esselle and M. Nilsson. Cross-Dipole Bandpass Frequency Selective Surface for Energy-Saving Glass Used in Buildings, IEEE Transactions on Antennas and Propagation. 2011; 59(2): 520-525

[8] B. Sangeetha, G. Gulati, R. U. Nair and S. Narayan, Design of airborne radome using Swastika-shaped metamaterial-element based FSS, 2016 IEEE Annual India Conference (INDICON), 2016; 1-5.

[9] H. V. H. Silva Filho, C. P. N. Silva, M. R. T. de Oliveira, E. M. F. de Oliveira, M. T. de Melo, T. R. de Sous, Gomes Neto, Multiband FSS with Fractal Characteristic Based on Jerusalem Cross Geometry, Journal of Microwaves, Optoelectronics and Electromagnetic Applications, 2017; 16(4); 932-941

[10] G. I. Kiani, A. R. Weily, and K. P. Esselle. Frequency Selective Surface Absorber using Resistive Cross-Dipoles, 2006 IEEE Antennas and Propagation Society International Symposium. 2006; 4199 – 4202

[11] G. I. Kiani, A. Karlsson, L. Olsson, and K. P. Esselle, Glass Characterization for Designing Frequency Selective Surfaces to Improve Transmission through Energy Saving Glass Windows, 2007 Asia-Pacific Microwave Conference. 2007; 1-4

[12] G. I. Kiani, O. L. Karlsson, and K. Esselle. Transmission analysis of energy saving glass windows for the purpose of providing FSS solutions at microwave frequencies. 2008 IEEE Antennas and Propagation Society International Symposium (AP-S 2008). 2008; 1-4

[13] Y. Pang, Y. Li, J. Zhang, Z. Xu and S. Qu, Design of Frequency Selective Surface Based on Spoof Surface Plasmon Polariton Modes, IEEE Antennas and Wireless Propagation Letters, 2018; 17(6): 1123-1126

[14] M. A. Belen, A. H. Gülseren and F. Güneş, Narrow dual band frequency selective surface design for X-band application, 2018 26th Signal Processing and Communications Applications Conference (SIU). 2018; 1-4.

[15] T. Weise, Global Optimization Algorithm. Theory and Application, 2nd edition. 2009; 21-55

[16] J. M. Johnson, and S. R. Yahya, Genetic Algorithms in Engineering Electromagnetics. IEEE Antennas and Propogation Magazine. 1997; 39(4)

[17] F. M. Johar, S. N. Salleh, F. A. Azmin, B. H. Ahmad, and M. Md. Shukor. A Review of Method in FDTD for the Analysis of Oblique Incident Plane Wave on Periodic Structures. International Journal of Engineering & Technology (IJET). 2013; 5(5): 3900 – 3906

[18] F. M. Johar, S. N. Salleh, F. A. Azmin, M. Md. Shukor, B. H. Ahmad, M. K., Suaidi, and A. S. Shibghatullah. Comparison of CST and Customize Program in Theoretical for Scattering Transmission Parameter for Energy Saving Glass (ESG) Application, International Conference on Internet Services Technology and Information Engineering 2014 (ISTIE). 2014; 20: 2064-2068

[19] A. Smyk, and M. Tudruj, Parallel FDTD Computations Optimized by Genetic Algorithms. 2011 Sixth International Symposium on Parallel Computing in Electrical Engineering. 2011; 99-104

[20] J. A. Bossard, S. Yun, D. H. Werner, and T. S Mayer. Low loss multilayer frequency selective surface negative index metamaterials for the mid-infrared, 2008 IEEE Antennas and Propagation Society International Symposium, 2008; 1-4.

[21] X. F. Luo, A. Qing, and C. K. Lee. The design of frequency selective surfaces (FSS) using real-coded genetic algorithm (RGA), Proceedings of the 2003 Joint Fourth International Conference on Information, Communications and Signal Processing and the Fourth Pacific Rim Conference on Multimedia. 2013; 1: 391-395

[22] S. Hyungwon, L. Jihong, F. Y. Lee, B. H. Jun. Optimal design of frequency selective surface by genetic algorithm, International Journal of Precision Engineering and Manufacturing. 2010; 11(5):725-732.

[23] G. Manara, A. Monorchio, and R. Mittra. Frequency selective surface design based on genetic algorithm, Electronics Letters. 1999; 35(17): 1400-1401

[24] L. Jun, W. Jian-Bo, S. Guan-Cheng. Frequency selective surface structure optimized by genetic algorithm, Chinese Physics B. 2009; 18(4): 01598

[25] R. Sivaraj, T. Ravichandran, A review of selection methods in genetic algorithm, International Journal of Engineering Science and Technology. 2011; 3(5): 3792 – 3797
[26] J. M. Johnson and V. Rahmat-Samii. Genetic algorithms in engineering electromagnetics, IEEE Antennas and Propagation Magazine. 1997; 39(4): 7-21
[27] S. N. Azemi, K. Ghorbani, and W. S. T. Rowe. 3D Frequency Selective Surfaces. School of Electrical and Computer Engineering, RMIT University. 2012; 29: 191–203
[28] S. N. Azemi, Ghorbani K.; and Rowe, W. S. T. Angularly Stable Frequency Selective Surface with Miniaturized Unit Cell, IEEE Microwave and Wireless Components Letters. 2015; 25(7): 454-456
[29] D. Singh, A. Kumar, S. Meena, and V. Agarwala. Analysis of Frequency Selective Surface for Radar Absorbing Materials, Progress in Electromagnetics Research B. 2012; 38: 297-314
[30] S. Habib, M. F. U. Butt, and G. I. Kiani. Parametric analysis of a band-pass FSS for double glazed soft-coated energy saving glass. 2015 International Symposium on Antennas and Propagation (ISAP); 2015: 1-4. R. Arulmozhiyal and K. Baskaran, "Implementation of a Fuzzy PI Controller for Speed Control of Induction Motors Using FPGA," *Journal of Power Electronics*, vol. 10, pp. 65-71, 2010.