Study of Frequency Selective Surfaces on Radar Cross Section Reduction

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Abstract

With recent technology in radar cross section reduction (RCSR), a periodic array of frequency selective surfaces (FSSs) which exploits a non-metallic ground plane and slot embedded in the patch elements have been presented. In this study, the single layer FSSs with different incidence angles and substrate thicknesses have been investigated and simulated at the X-band frequency range using CST computer model. Based on the FSSs design, the minimum reflection response is shown to be -74.68 dB while the minimum RCS is -5577 dBm^2 occurred at the incidence angle which is equal to 75 degree. Moreover, the maximum value of RCS at -4417 dBm^2 has been observed when the incident wave and observer is located at the 0 degree which is offers maximum RCS reduction. Analysis of the CST computer model has been integrated with MATLAB 7 to show the reliability of the two computer model in order to study the feasibility of reflection response in reducing RCS. RCS calculations have been carried out using MATLAB 7 computer model in order to investigate the performance of minimum reflection response which offers reduction in RCS. From the simulated results, it can be concluded that, 75 degree's incidence angles offered the best performance on RCS reduction due to the angles of incidence, minimum reflection response and lower surface current distribution.

Keywords: Angle of incidence , Frequency Selective Surfaces, radar cross section, reflection response

1. INTRODUCTION

The use of the radar cross section reduction, RCSR [1] is one of the techniques that can reduce radar cross section, RCS. The most common technique that had been used is shaping of the periodic structure [2]. Although the shaping of the periodic structure can be used to reduce the RCS by minimizing the area presented of the radar but it also has significant disadvantages. In this study, frequency selective surfaces, FSS are proposed in order to minimize the radar cross section which can offer a significant improvement in the radar cross section technology. The structure of the frequency selective surface consists of the periodic array of dipole slots with the non-metallic ground plane [3]. By applying FSS technique, the transmission and reflection properties of FSS array can be achieved and the possibility of reducing radar cross section has been investigated. The main objectives of this study are to minimize the radar cross section by applying frequency selective surface technique and to observe the relationship between the angle of incidence and the transmission/reflection coefficient due to radar cross section reduction.

While varying the incidence angles, there have the change in frequency and reflection/transmission plot. As the incidence angles increased, the resonance frequency has been increased and transmitted signal is getting higher. Based on the value of reflection/transmission properties, the radar cross section has been calculated using equation 1.1 [4]:

$$\sigma_{target}(\theta) = \frac{P_{rt}(\theta)}{P_{rs}(\theta)} \times \sigma_{flat\ plate} \quad (1.1)$$

where

$$\sigma_{flat\ plate} = \frac{4\pi A^2}{\lambda^2} \quad (1.2)$$

P_{rt} = Received power
P_{rs} = Return signal Strength
A = Area of the flat plate, m^2
ó = Radar cross section, dBm^2

2. FSS DESIGN SPECIFICATIONS

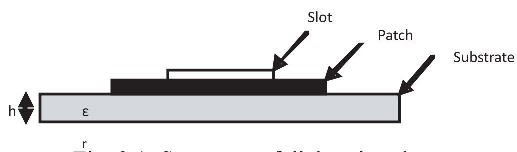
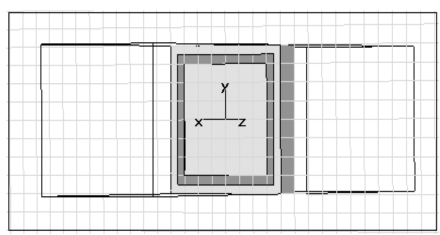
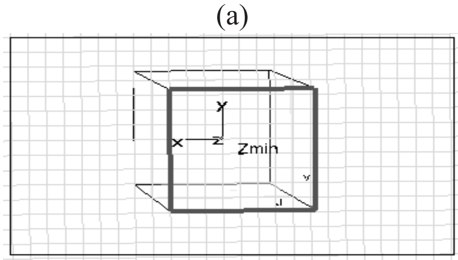


Fig. 2.1: Structure of dielectric substrate.

Parameters	Value
Dielectric Constant, ε_r	2.2
Dissipation Factor, tan δ	0.0009
Substrate Thickness, h	1.6 mm



(a)



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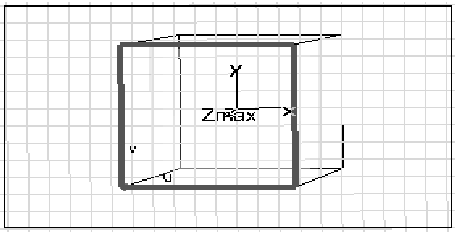
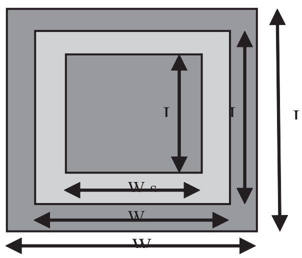


(c)



(d)

Fig. 2.2 Geometry structure of the frequency selective surface using (a) CST Microwave Studio (c) Zmin port excitation (c) Zmax port excitation (d) theoretical design.

A single layer FSS array as shown in Fig. 2.2 (a) has been simulated in the CST Computer Software at the X-Band frequency range. The FSS array has been designed using Rogers RT5880 as the substrate materials which dielectric constant is 2.2 and the dissipation factor is 0.0009. With the dimensions of the substrate elements is 4 mm length and 4 mm width, patch element is 3.5 mm length and 3.5 mm width and the slot element is 3 mm length and 3 mm width, the FSS array has been simulated in order to obtain the minimum reflection.

Table 2.2 : Design Specifications of Frequency Selective Surfaces.

Substrate	L	W
	4mm	4mm
Patch	Lp	Wp
	3.5mm	3.5mm
Slot	Ls	Ws
	3mm	3mm

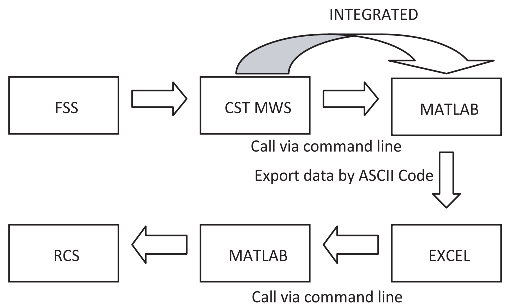
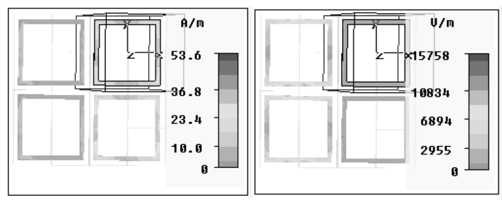


Fig. 2.3 Flow of the FSS array study on the RCS Reduction.



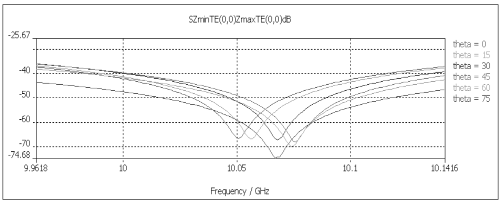
(a) (b)

Fig. 2.4: (a) Surface current distribution (b) E-field intensity on the patch elements at theta = 75 degree

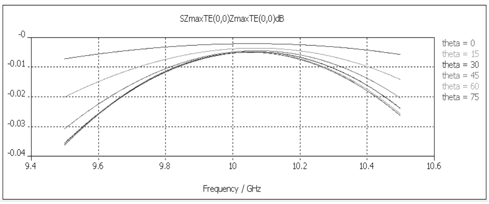
Fig. 2.2 (b) and (c) shows the Zmin and Zmax port excitation during the simulation on the reflection/transmission response. Minimum reflection was excited from port Zmin to port Zmax while maximum transmission was excited from port Zmax to port Zmax. The FSS array design has been integrated to reduce the radar cross section as shown in fig. 2.3.

3. RESULTS & ANALYSIS

3.1 Effect of Varying Angles of Incidence to the Transmission and Reflection Response.



(a)



(b)

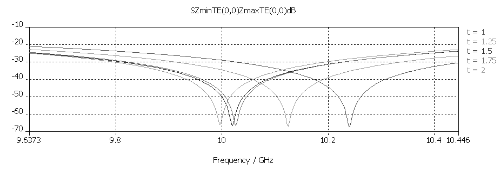
Fig. 3.1: Simulated Result of the (a) Reflection and (b) Transmission Response by varying Angles of Incidence.

In this study, simulated results have been carried out using the CST computer software which gives better performance on simulating the FSS array. Fig. 3.1 (a) and (b) shows the performance of the reflection/transmission and resonance frequency as the incidence angles have been varied from 0 to 75 degrees. The change in resonant frequency occurred because of the resonance frequency is not strongly dependent on the angles of incidence [5].

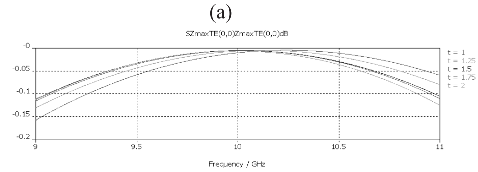
Table 3.1: Simulated Value of the Resonant Frequency and S_{11} and S_{21} curve by varying the Incidence Angles.

Theta, θ (degree)	Frequency, GHz	S_{11} curve, dB	S_{21} curve, dB
0	10.0500	-66.46	-0.004856
15	10.0566	-66.63	-0.004837
30	10.0679	-67.04	-0.004717
45	10.0760	-67.87	-0.004329
60	10.0746	-69.73	-0.003442
75	10.0680	-74.68	-0.001965

A. Effect of Variable Thickness Substrate to the performance of Transmission and Reflection Response.



(a)



(b)

Fig. 3.2 Reflection and Transmission Response of the FSS array for Different Substrate Thicknesses.

Both of Fig. 3.2 (a) and (b) are the simulation results that had been carried out from the CST computer model using different thickness of the substrate material [7]. Substrate thicknesses are indeed an important consideration in designing the FSS array.

Table 3.2: Simulated Value of the Resonant Frequency, S_{11} and S_{21} curve using Different Substrate Thicknesses

Thickness, mm	Frequency, GHz	S_{11} curve, dB	S_{21} curve, dB
1	10.24	-66.74	-0.003953
1.25	10.13	-66.68	-0.004280
1.5	10.02	-65.58	-0.004651
1.75	10.01	-66.09	-0.005127
2	9.998	-65.23	-0.005688

B. Integration Workflow from MATLAB to CST Computer Model.

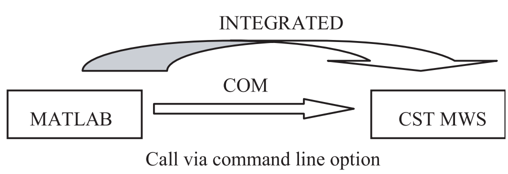


Fig. 3.3: Integration Workflow between MATLAB and CST Computer Model.

Fig. 3.3 shows the workflow how the interface between MATLAB and CST computer model has been done using command line option in the MATLAB. The command line writing in the M-File Editor has been called the CST computer model and the interfaces between both of the computer model have been successes. By using the Computer Object Model (COM), it enables the interaction between MATLAB and CST computer software. The main command that had been used to call the CST computer model is *actxserver* and this command act to create the COM server and returns the COM object. The object that is return by the *actxserver* is the CST computer model. In the CST computer model, the transmission/reflection plots have been displayed.

C. Integration Workflow from CST Computer Software to MATLAB.

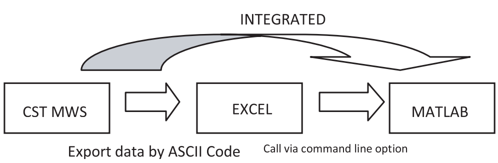
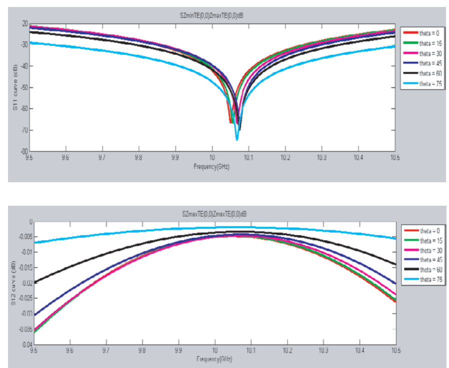


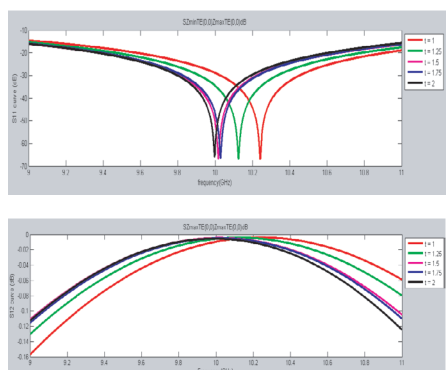
Fig. 3.4: Flow of the integration between CST MWS and MATLAB.

Fig. 3.4 above shows the integration workflow in order to get the transmission and reflection response in the MATLAB. From the CST MWS, the transmission and reflection response were exported using the ASCII code to the EXCEL computer software. From EXCEL computer software, by using the *load* command written in the MATLAB's M-File Editor, the data in the EXCEL computer software have been call and the transmission and reflection plot have been displayed in the MATLAB computer software. Fig. 3.5 (a) show the transmission and reflection response when the incidence angle had been varied while Fig. 3.5 (b) showed the transmission and reflection plot for different substrate thickness. It shows that the reflection and transmission plots observed in the MATLAB computer software were quite similar with the CST computer software.

From fig. 3.6 (a) and (b), the results show that the value of the resonant frequency and reflection response at the 75 degree's incidence angles is quite similar between each other. From the CST MWS, the resonance frequency is equal to 10.068 GHz while from the MATLAB 7 the resonance frequency is equal to 10.07.



(a)

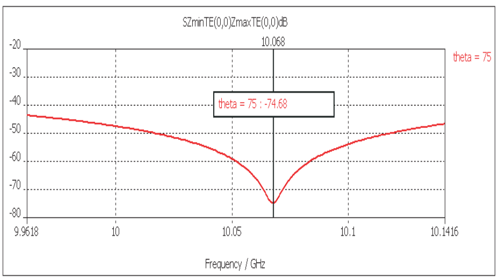


(b)

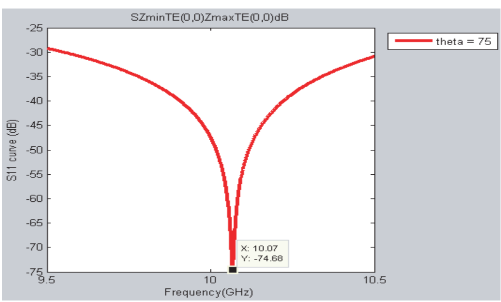
Fig. 3.5 (a) Reflection and Transmission plot by varying the Incidence Angles (b) Transmission and Reflection plot for Different Substrate Thicknesses generated from MATLAB 7.

D. Comparison on Reflection Response using CST MWS and MATLAB.

For the reflection plot, the value that has been carried out from CST MWS is equal to -74.68 dB while from MATLAB 7 is equal to -74.68 dB. From the results above, it shows that, CST MWS can be integrating between MATLAB in order to get the transmission/reflection response of the FSSs design.



(a)



(b)

Fig. 3.6: Reflection Response for theta = 75 degree using (a) CST MWS and (b) MATLAB 7.

E. Radar Cross Section Reduction.

i) Effect of Different Incidence Angles on the Radar Cross Section.

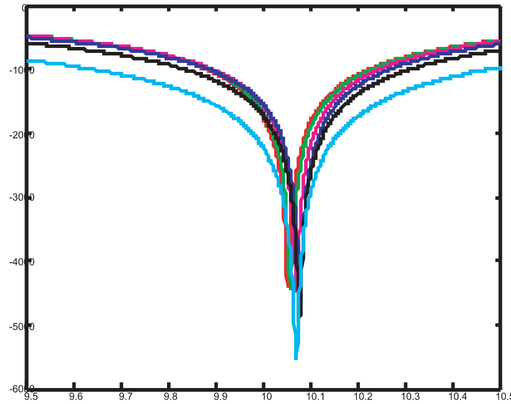


Fig. 3.7: Plot of radar cross section based on different angles of incidence.

Radar cross section is dependent on the direction where the energy is illuminates. And it has been proved based on the simulated results that, the RCS value is maximized when the angle of incidence is equal to zero degree.

Table 3.3: Calculated value of RCS using MATLAB computer software.

Theta, θ (degree)	Frequency, GHz	RCS, dBm^2
0	10.05	-4417
15	10.06	-4429
30	10.07	-4447
45	10.08	-4607
60	10.07	-4854
75	10.07	-5577

Based on the results that have been shown in Fig. 3.7 and Table 3.3, maximum RCS occurs when the incident signal and observer is located at the normal incidence (theta = 0 degree) [9]. While for the oblique angles of incidence, the RCS have been reduced until the lowest RCS which is equal to 75 degree. At the 75 degree's incidence angles, the value of RCS is equal to -5577 dBm^2 which is the minimum value of RCS from the minimum value of reflection response. Therefore, in order to reduce the RCS, the incident signal must be transmitted at the oblique angles of incidence which were equal to 15^o, 30^o,45^o, 60^o and 75^o. The best performance in reducing RCS occurred at 75 degree's incidence angles.

F. Effect of Different Substrate Thicknesses on the Radar Cross Section.

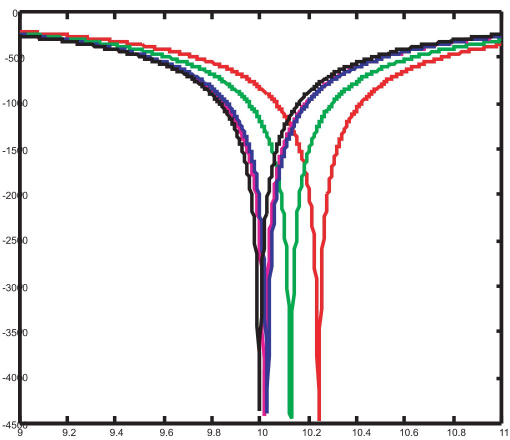


Fig. 3.8: Plot of radar cross section based on different substrate thicknesses.

Fig. 3.8 and Table 3.4 show the simulated results based on the MATLAB's calculation. From the results above, it can be concluded that, the value of RCS is not really dependent on the substrate thickness.

Table 3.4: Calculated value of RCS by using MATLAB computer model.

Thickness, mm	Frequency, GHz	RCS, dBm^2
1	10.24	-4424
1.25	10.13	-4446
1.5	10.02	-4424
1.75	10.01	-4388
2	9.996	-4351

The RCS's value is not stable due the change of the substrate thickness. Due to the theoretical study, the RCS is dependent on the shape, material composition, size of the body and frequency of the incident electromagnetic wave [10].

4. CONCLUSION

In this study, design of frequency selective surfaces, FSS with analysis the different angles of incidence and thickness have been demonstrated using CST computer model in order to reduce the RCS. The interfaces between MATLAB and CST computer model have been developed to see the reliability of the two computer models. Based on the transmission and reflection responses for different incidence angles and substrate thicknesses, the minimized values of RCS have been presented. There are limitations due to computer model while doing the integration between CST 2009 and MATLAB 7.

ACKNOLEDGEMENT

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