NUMERICAL ESTIMATION OF PERFORMANCES OF FREQUENCY SELECTIVE SURFACE-IMPACTED SANDWICH RADOME

Dae-Sung Son[1], *Jung-Ryul Lee[1]

[1] Division of Aerospace Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea
*Corresponding author e-mail: leejrr@kaist.ac.kr

Keywords: Frequency Selective Surface, Sandwich structure, Radome, Transmission loss, Equivalent Circuit Model

ABSTRACT

In this paper, electromagnetic performance of radome applied sandwich structure inserted frequency selective surface was estimated. It was designed that transmission efficiency of radome structure was over 80% at 9.5~10.5GHz band width considering FSS pattern and size and sandwich structure. Also, Equivalent impedance of FSS-impacted sandwich structure was calculated using equivalent circuit model. it was used to estimate electromagnetic performance of the whole radome model. In that results, it was satisfied that Main lobe decrease was under 0.969dB, Side lobes increase was under 2dB and boresight error was under 2mrad.

1 INTRODUCTION

In general, Radom materials is used to transmit electromagnetic wave such as glass fiber reinforced plastic or ceramics like dielectric materials[1]. But if these materials are used in radome of combat aircraft, radar cross section of aircraft is increased because external electromagnetic wave is transmitted and radar antenna and aircraft parts is exposed by external wave. Thus, fighters applies to RAM(Radar Absorbing Material) or RAS(Radar Absorbing Structures) for absorption of electromagnetic waves and RCS reduction. However, in the case of a stealth radome, the antenna frequency must be transmitted in order to use the antenna. For this electromagnetic performance, FSS(Frequency Selective Surface) is applied to selectively transmit only a specific frequency band, and RCS is reduced by not passing another frequency except antenna frequency [2-8].

In order to analyze FSS, numerical analysis technique such as FDTD(Finite-Difference Time-Domain method) or FEM(Finite element method) technique is mainly used and has the advantage of less restriction of the shape. But If the analytical model is large, a lot of analysis costs are required. To improve efficiency, equivalent circuit model is used by applying the capacitance or inductance caused by the pattern of the FSS. The equivalent circuit model has the advantage of being able to understand and analyse electromagnetic characteristics more easily and quickly[9].

In this paper, it was designed that transmission efficiency of radome structure was over 80% at 9.5~10.5GHz band width. In the case of radome, the sandwich structure was applied because of the mechanical stiffness required to withstand the operating environment. In order to satisfy the electromagnetic demand performance, the FSS impacted the sandwich structure was used. FSS pattern design is most important because electromagnetic performance is mainly determined by FSS. Therefore, the electromagnetic performance of various FSS patterns was evaluated to satisfy the required performance. When FSS is inserted in sandwich structure, radome was design simultaneously considering the sandwich structure and the pattern of the FSS because electromagnetic characteristics are changed by permittivity of structure materials. It is impossible to evaluate the electromagnetic performance by applying the FSS-impacted sandwich structure to the whole radome shape. Therefore, the electromagnetic characteristics of the radome were evaluated by calculating the equivalent impedance using the equivalent circuit model. After the equivalent circuit model of the FSS was constructed, the main lobe decrease, side lobes increase, and boresight error of the entire radome were evaluated by calculating the equivalent impedance of the FSS-impacted sandwich unit cell.

2 UNIT CELL MODEL OF FSS-IMPACTED SANDWICH STRUCTURES

In case of FSS, Various electromagnetic characteristics appear depending on the shape of the FSS. For design of FSS, four arbitrary shapes are selected and Each pattern was designed so that the transmission frequency was 10 GHz. The electromagnetic analysis was carried out using the commercial S/W(HFSS). The results of the analysis are shown in Fig. 1. In the result, the transmission performance of the square loop was poor due to the widest transmission frequency bandwidth. And The cross loop pattern satisfied the transmission efficiency 80% (0.969dB) at 9.5 ~ 10.5GHz part. Therefore, a unit cell was designed using a cross loop among four patterns.

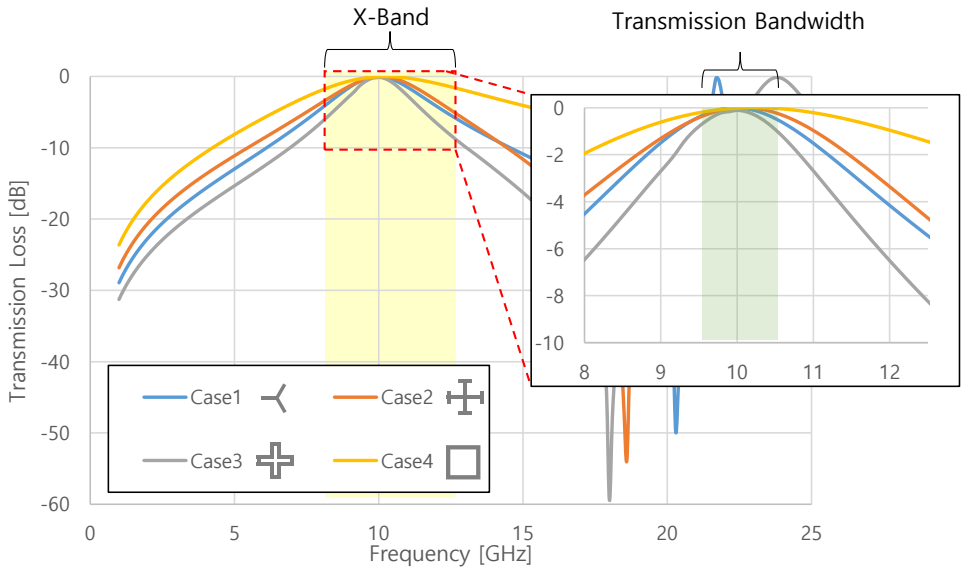


Figure 1. Transmission loss of various FSS

When the FSS was applied inside the sandwich, the unit cell model as shown in Fig. 2 was used for the electromagnetic analysis. As a result, when the FSS is inserted into the sandwich, the transmission frequency is shifted as shown in Fig. 3. When the electromagnetic wave passes through the FSS, the characteristics of electromagnetic waves are different depending on whether the electromagnetic wave passes through the free space or the core. Therefore, the dimension correction of the FSS was performed to satisfy the required transmission frequency. As a result, the electromagnetic performance of FSS-impacted sandwich unit cell is shown in Fig. 4, and the required electromagnetic performance of 80% transmission efficiency was satisfied in 9.5 ~ 10.5GHz band in X band.

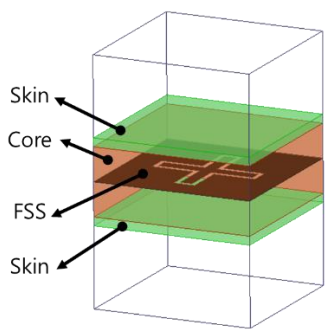


Figure 2. Unit cell model

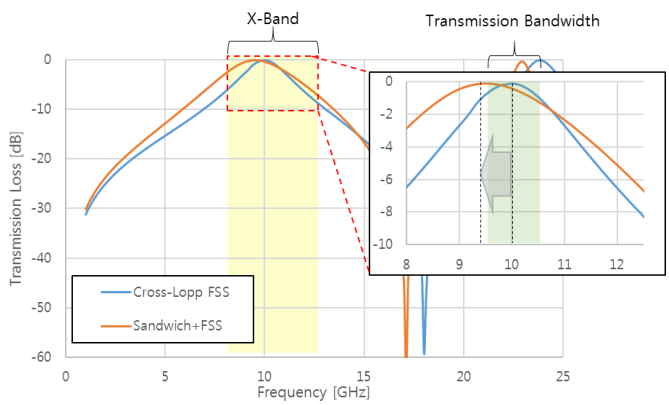


Figure 3. Analysis results of FSS and FSS-impacted sandwich

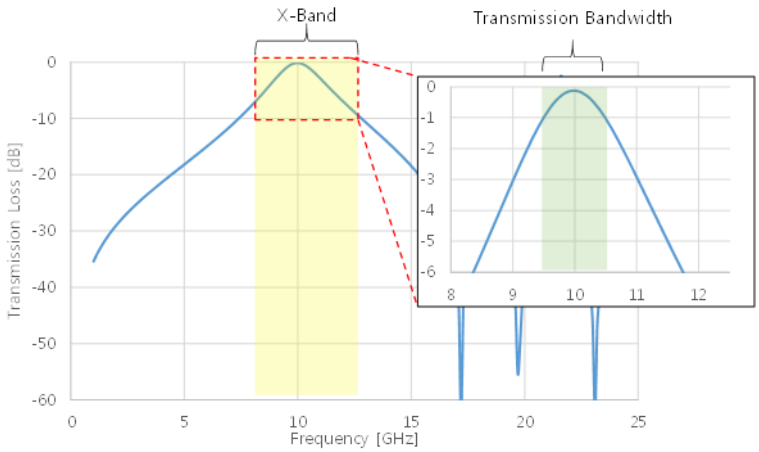


Figure 4. Transmission loss of various FSS

3 EQUIVALENT CIRCUIT MODEL OF FSS-IMPACTED SANDWICH UNIT CELL

The cross-loop pattern can be expressed by the equivalent circuit model as shown in Fig. 5. When the cross-loop pattern is inserted into the sandwich, it can be expressed by the equivalent circuit model as shown in Fig. 6. At this time, the reflection loss of the equivalent circuit model can be calculated by Equation (1-6). And the equivalent impedance of the unit cell can be expressed as shown in Eq. (7). The equivalent impedance of the designed unit cell is shown in Fig. 7. The result of using the equivalent circuit model and the electromagnetic analysis result are shown in Fig. 8 and confirmed to have the same electromagnetic characteristics.

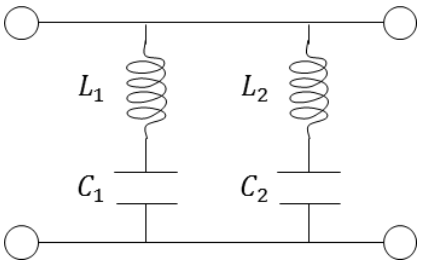


Figure 5. Equivalent circuit model of FSS

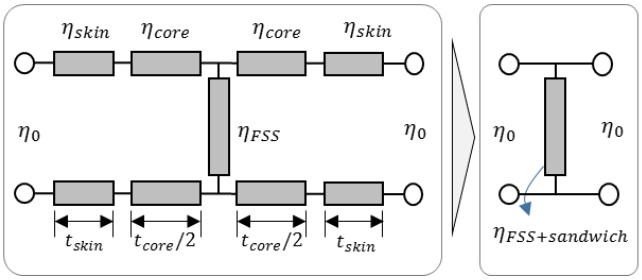


Figure 6. Equivalent circuit model of FSS-impacted sandwich

$$\eta_a = \eta_1 \frac{\eta_0 \cos \beta_1 t_1 + j\eta_1 \sin \beta_1 t_1}{\eta_1 \cos \beta_1 t_1 + j\eta_0 \sin \beta_1 t_1} \tag{1}$$

$$\eta_b = \eta_2 \frac{\eta_a \cos\left(\frac{\beta_2 t_2}{2}\right) + j\eta_2 \sin\left(\frac{\beta_2 t_2}{2}\right)}{\eta_2 \cos\left(\frac{\beta_2 t_2}{2}\right) + j\eta_a \sin\left(\frac{\beta_2 t_2}{2}\right)} \tag{2}$$

$$\eta_c = \frac{\eta_{FSS}\eta_b}{\eta_b + \eta_{FSS}} \tag{3}$$

$$\eta_d = \eta_2 \frac{\eta_c \cos\left(\frac{\beta_2 t_2}{2}\right) + j\eta_2 \sin\left(\frac{\beta_2 t_2}{2}\right)}{\eta_2 \cos\left(\frac{\beta_2 t_2}{2}\right) + j\eta_c \sin\left(\frac{\beta_2 t_2}{2}\right)} \tag{4}$$

$$\eta_e = \eta_1 \frac{\eta_d \cos\beta_1 t_1 + j\eta_1 \sin\beta_1 t_1}{\eta_1 \cos\beta_1 t_1 + j\eta_d \sin\beta_1 t_1} \tag{5}$$

$$\Gamma = \frac{\eta_e - \eta_0}{\eta_e + \eta_0} \tag{6}$$

$$\eta_{FSS+sandwich} = \frac{\eta_e \eta_0}{\eta_0 - \eta_e} \tag{7}$$

(where, $\beta = \frac{\omega}{c_0}\sqrt{\mu_r \varepsilon_r}$, $\eta = \sqrt{\frac{\mu}{\varepsilon}}$)

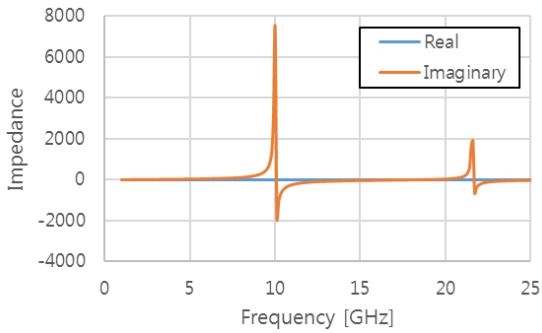


Figure 7. Equivalent impedance

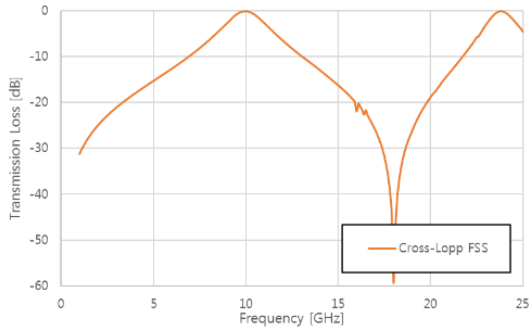


Figure 8. Results of equivalent circuit model

4 PERFORMANCES ESTIMATION OF RADOME

The calculated equivalent impedance of unit cell was applied to the radome to evaluate the electromagnetic performance. The difference between the antenna gain at the transmission frequency with and without radome shall be less than the reference value (Main 0.969dB, Side 2dB). To evaluate the electromagnetic performance of the radome, an arbitrary dipole antenna array was used as shown in Fig. 9. Using this antenna array, electromagnetic analysis was performed with and without a radome. The results are shown in Fig. 10. The results were that Main lobe decrease was under 0.969dB, Side lobes increase was under 2dB and boresight error was under 2mrad.

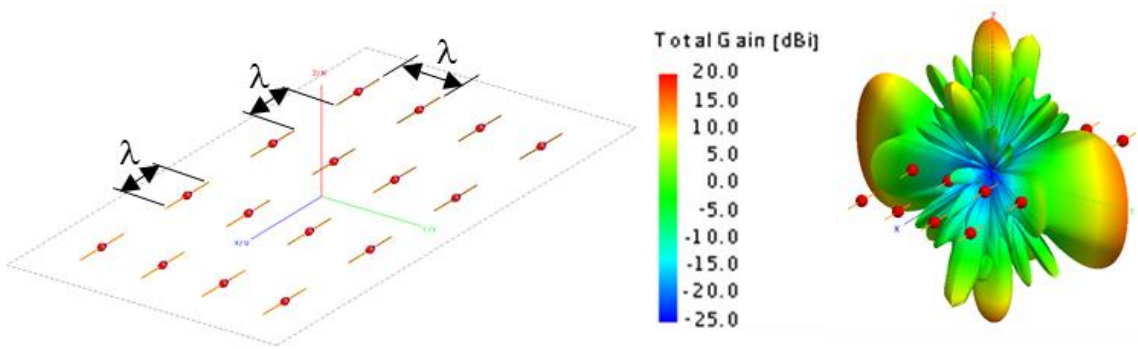
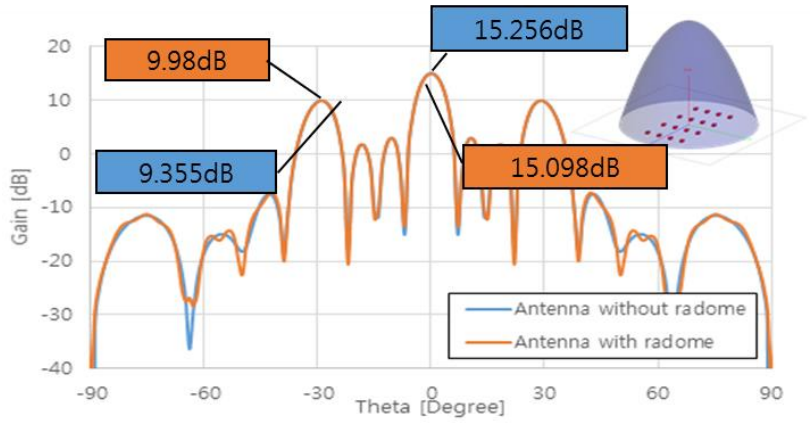
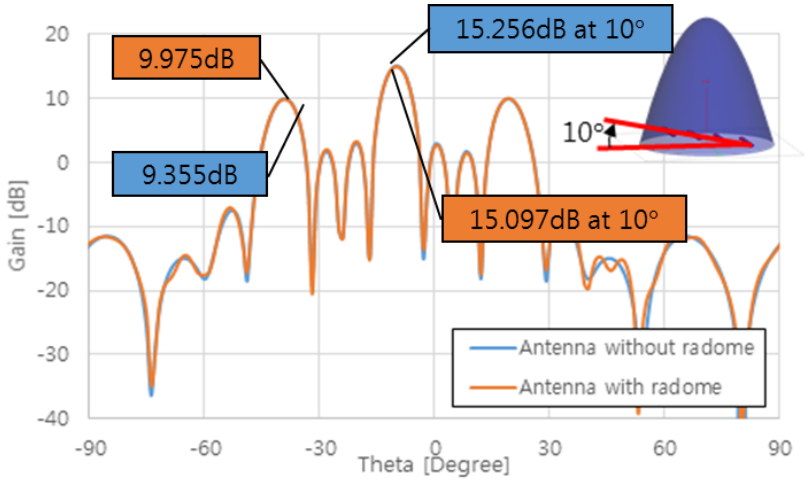


Figure 9. Dipole antenna array and analysis results



(a)



(b)

Figure 10. Analysis results of radome at transmission frequency (a) antenna angle=0° (b) antenna angle=15°

5 CONCLUSION

In this study, we designed a radome that can transmit only antenna frequency band using the FSS-impacted sandwich structure and evaluated its performance. To satisfy the required electromagnetic performance, the unit cell was designed considering the change of FSS characteristics inserted in the sandwich. The electromagnetic performance of the radome was also evaluated by calculating the equivalent impedance. Through this study, it was confirmed that it is an important design technique to calculate the equivalent impedance using the equivalent circuit model of the FSS-impacted sandwich structure to perform the electromagnetic performance evaluation of the radome.

ACKNOWLEDGEMENTS

This research was supported by Korean Evaluation Institute of Industrial Technology and the Ministry of Trade, Industry and Energy in 2016('10074278'), and Leading Foreign Research Institute Recruitment Program (2011-0030065) through the National Research Foundation of Korea funded by the Ministry of Science, ICT and Future Planning.

REFERENCES

[1] DJ Kozakoff, *Analysis of Radome-Enclosed Antennas second edition*, Artech House, 2010.

[2] Mei Li and ShaoQiu Xiao, An Ultrathin and Broadband Radar Absorber Using Resistive FSS, *IEEE Antennas Wireless Propag. Lett.*, **11,** 2012, pp. 748-751

[3] Volakis, J. L., A. Alexanian, and J. M. Lin, Broadband RCS reduction of rectangular patch by using distributed loading, *Electron. Lett.*, **28(25)**, 1992, pp. 2322-2323

[4] Li, Y., H. Zhang, Y. Fu, and N. Yuan, RCS reduction of ridged waveguide slot antenna array using EBG radar absorbing material, *IEEE Antennas Wireless Propag. Lett.*, **7**, 2008, pp. 473-476

[5] Wang, F. W., S. X. Gong, S. Zhang, X. Mu, and T. Hong, RCS reduction of array antennas with radar absorbing structures, *Journal of Electromagnetic Waves and Applications*, **25(17)**, 2011, pp. 2487-2496

[6] BA Munk, *FREQUENCY SELECTIVE SURFACES:Theory and Design*, Hoboken: John Wiley & Sons, 2000.

[7] Vinoy KJ, Jha RM, *Radar absorbing materials from theory to design and characterization*, Boston: Kluwer Academic Publishers, 1996.

[8] KY Park, SE Lee, CG Kim, JH Han, Fabrication and electromagnetic characteristics of electromagnetic wave absorbing sandwich structures, *Composites Science and Technology*, 66, 2006, pp. 576–584

[8] F Costa, A Monorchio, G Manara, An Overview of Equivalent Circuit Modeling Techniques of Frequency Selective Surfaces and Metasurfaces, *ACES JOURNAL*, **29(12)**, 2014, pp. 960–976