International Journal of Advanced Culture Technology Vol.10 No.4 555-560 (2022)
DOI https://doi.org/10.17703/IJACT.2022.10.4.555

IJACT 22-12-65

Implementation of Low Loss Radome with Hexa mesh for Ku-Band

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Abstract

In this study, the insertion loss and phase delay according to the multi-layer structure radome parameters were analyzed using the boundary value solution approach, and the multi-layer structure and hexa mesh structures with low-loss electrical characteristics for the Ku-band transmission/reception frequency of 10.7 ~ 14.5 GHz were designed and manufactured. A hexa mesh was applied to minimize radio wave transmission and scattering, which lowered the transmittance refractive index according to the radio incident angle and minimized dielectric loss through high-density foam. Similar to the simulation result, the transmission loss obtained the gain in a specific receiving frequency band, and in the transmission frequency band, an excellent low loss characteristic was obtained with an insertion loss of 0.8dB or less. The results of this study can be used in radio transmission radomes of low-weight, low-cost end-system protection devices.

Keywords: *Hexa Mesh, Low Loss, Material, Multilayer, Radome*

1. INTRODUCTION

The radome research to protect the antenna system and to minimize the signal loss for the transmission/ reception signal has been studied along with the development of the radar system since the Second World War. Radome is a compound word of radar and dome, and is a dielectric cover manufactured to protect the internal communication system from various environmental factors.

It is classified in detail according to the frequency band, structure and use of the radome [1]. In order to design a radome, various factors such as frequency band, insert loss, side lobe level, and phase delay are considered [2]. Since the characteristics change depending on the material and thickness of the radome, the structural shape must be determined by considering the electrical characteristics. In general, there are two methods to analyze a flat multi-layer radome: Boundary value solution and Recursive method.

In this paper, the insertion loss and phase delay according to the multi-layered radome parameters were analyzed using the Boundary value solution approach, and a complex and multi-layered radome with multi-layered and hexa mesh structures was designed [3], [4]. Here, it is designed considering the structure (patch stack) of the Ku band satellite transmission and reception antenna. The first design was optimized with the thickness of each layer as a parameter, and the second was optimized with both skins fixed and the physical properties and thickness of one inner layer and the hexa mesh structure as parameters. That is, the optimized parameters are analyzed and results are derived by Boundary value solution.

Manuscript received: November 26, 2022 / revised: December 4, 2022 / accepted: December 9, 2022
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Therefore, through the results of this paper, a radome with a loss of less than 0 ~ 0.8dB in the entire Ku band by each parameter (thickness, material dielectric constant, shape) having a multi-layer structure and hexa mesh was developed.

2. MULTILAYER RADOME DESIGN

The ideal conditions of the radome should be the thickness of the physical properties constituting the radome and the physical property structure that can be matched when electromagnetic waves are incident in a flat state. A material with dielectric constant is called a loss tangent as shown in Equation (1), which can be expressed as having reflection at the surface boundary condition, and appears as the incidence and reflection of electromagnetic waves as shown in Figure 1.

$$Z_D = \frac{377\Omega}{\sqrt{\varepsilon_r}} \tag{1}$$

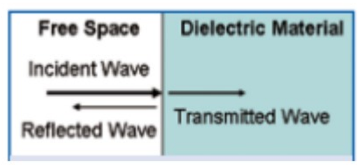

Figure 1. Reflection transmission through a dielectric material

Table 1. Design Specificaition

Terms	Parameter	Design Goals & Spec.
dB	Rx. Frequency Range Insert Loss	-0.8dB
dB	Tx. Frequency Range Insert Loss	-0.8dB
-	Multi-layer structure (3 layer)	PVC , Form, ABS
mm	F Stack 1 (PVC)	Er of 3.2 , t : 0.1mm
mm	F Stack 2 (High Density Form)	Er of 1.05 , t : 10mm
mm	F Stack 3 (ABS)	Er of 3.5 , t : 5.0mm

Table 1 shows the radome structure and design specifications, and Figure 2 is a configuration diagram of a multi-layer structure according to incident refraction. It is assumed that each layer is a multi-layer structure stacked in the incident direction θ and the thickness is the same.

The propagation path of the electromagnetic wave, which determines the permittivity and damping rate of the multilayer structure material, can be obtained using Snell's law. At this time, the phase velocity (V) propagating along the material plane is equal to Equation (2).

$$\begin{aligned} V_1 &= \frac{\omega \sin\phi}{\beta_{11}\sin^2\phi + \beta_{33}\cos^2\phi} \\ V_2 &= 0 \\ V_3 &= \frac{\omega \cos\phi}{\beta_{11}\sin^2\phi + \beta_{33}\cos^2\phi} \end{aligned} \tag{2}$$

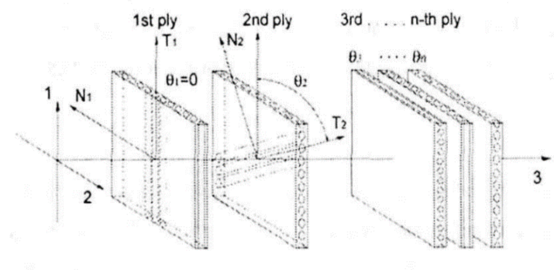

Figure 2. Schematic drawing material made up of several unidirectional plies stacked

If Snell's law is expressed by the phase velocity and incident angle between the m-th layer and the m+1-th layer, Equation (3) is obtained.

$$\frac{|V_m|}{\sin\phi_m} = \frac{|V_{m+1}|}{\sin\phi_{m+1}} \tag{3}$$

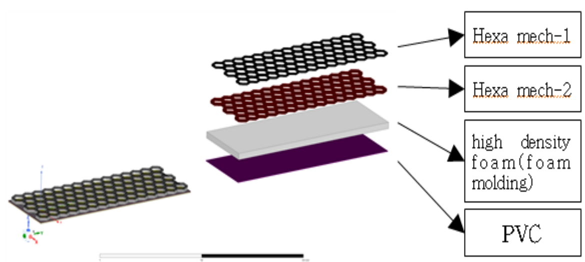

Figure 3. Multi-layer radome with hexa mesh

Figure 3 is a radome structure with a multi-layered structure, which has a combined structure that is easy to arrange with a stack structure of satellite transmission and reception antenna top & bottom patches. In addition, the hexa mesh of the material is a structure that minimizes scattering when electromagnetic waves are incident and maintains the plane wave characteristics for the transmission of electromagnetic waves. The optimized multi-layered radome considering insert loss was simulated as shown in Figure 4 using an EM simulator.

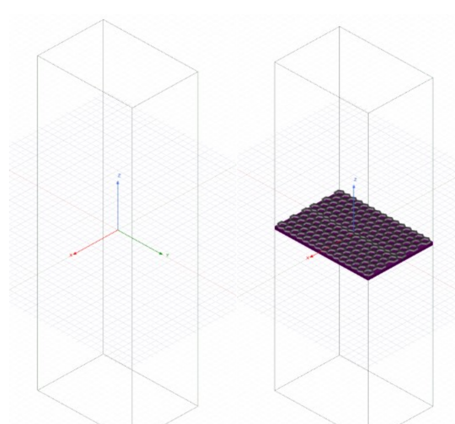

Figure 4. 3D modeling of Plane wave transmission for Multi-layer with hexa mesh (Left) Free space, (Right) Multi layer

The insertion loss results for material penetration are shown in Figure 5. The solid line is the insertion loss for material transmission (S21), and the dotted line is the insertion loss for free space transmission.

What is noteworthy is that in the low frequency band corresponding to the reception frequency region of the Ku Band, the gain increased by 0.5dB from -2.4dB to -1.9dB. This showed the same result in the actual production. The plane wave characteristics without distortion and without square wave characteristics after penetration of the material means low loss, which is shown in Figure 6 as E-field.

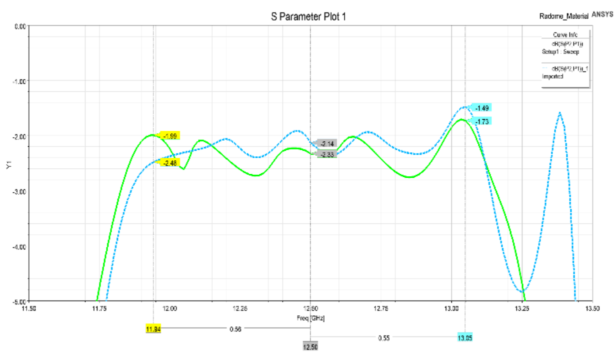

Figure 5. Compare Insert loss simulation result of Multi-layer material & non material

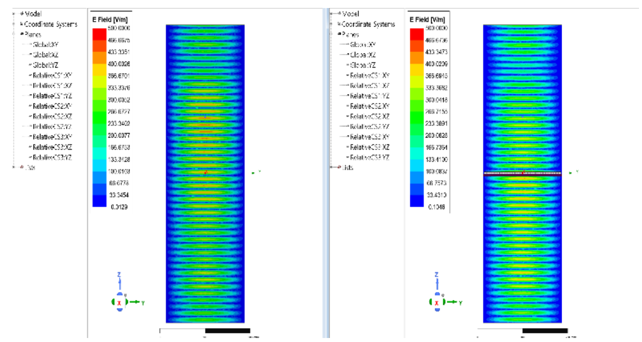

Figure 6. Compare electric field simulation result of free space & Multi-layer material

3. FABRICATION AND MEASUREMENT OF PHYSICAL PROPERTIES

The physical properties and shapes of this design are shown in Table 2. The radome structure with a 3-layer multi-layer structure was designed and manufactured in consideration of complex matters such as weight, electrical characteristics, unit price, and resistance to external impact.

Table 2. Specification & fabrication of Radome Structure

Item	Specification
Product. Name	Radome Material
Model. Name	Cube-Radome-3Layer
Freq. Range	Rx : 10.70 ~ 12.75GHz Tx : 13.75 ~ 14.50GHz
Material & Structure	3layer 1st : ABS(hexa mesh) 2nd : High density foam form 3rd : PVC
Size	390 × 305 × 12 [mm]
Weight	600g
Picture	 (Top) (Bottom)

In order to measure the material of the manufactured radome, it was measured in an anti-reflection chamber by requesting a test from the National IT Promotion Agency (Nipa). Two Ku Band transmission and reception antennas, SGA (Standard Gain Antenna), were fixed on both sides, and the corresponding sample was placed in the center as shown in Figure 6. In order to have the distance that the Ku Band propagation becomes a plane wave in the far-field region, the distance was set to 1.5m.

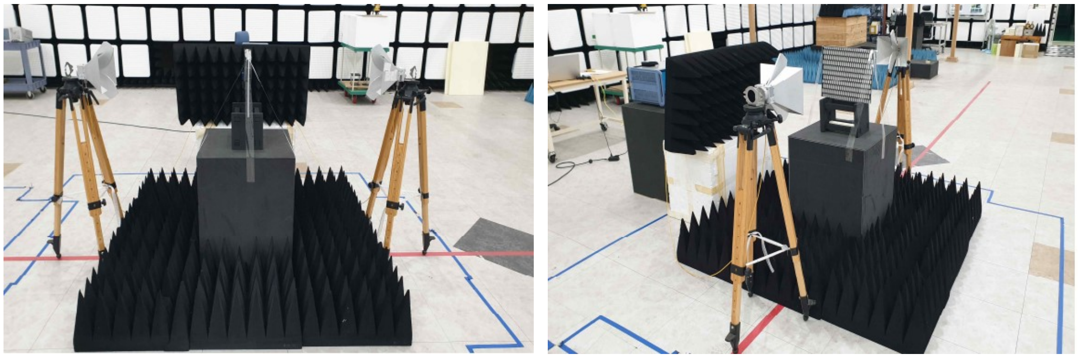

Figure 7. Test environment of multi layer radome

Table 3. Data table of insert loss (S21)

Item	Freq. [GHz]	Test Result (dB)		
		1. Path Loss (Free Space)	2. Path Loss (Radome)	3. Insert Loss (No.1-No.2)
Insert Loss (S21)	10.7GHz	31.34	31.07	+0.27
	11.7GHz	31.01	31.24	-0.23
	12.7GHz	31.26	31.67	-0.41
	13.7GHz	33.67	34.11	-0.44
	14.0GHz	34.17	34.72	-0.51
	14.5GHz	34.42	35.21	-0.79

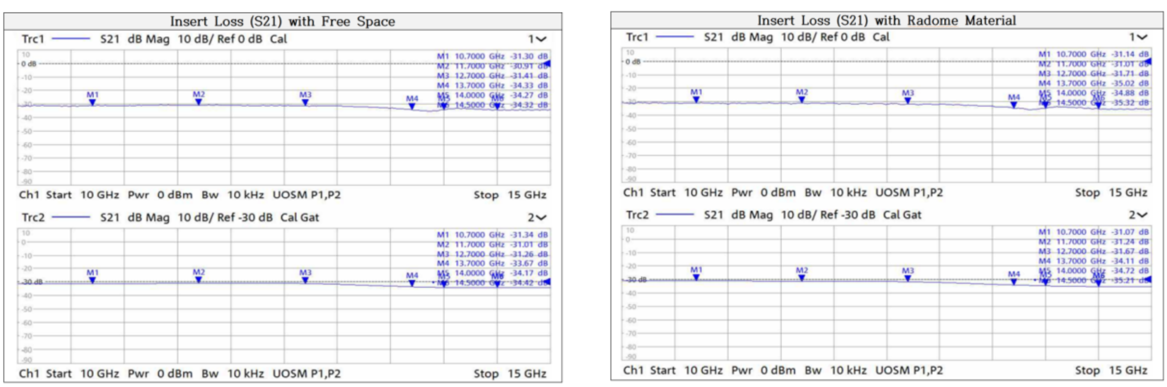

Figure 8. Compare of Free space & Radome Material Graph of insert loss (S21)

3. CONCLUSION

In this paper, a multi-layered radome of material with low-loss electrical characteristics for the Ku-band transmission/reception frequency of 10.7 ~ 14.5 GHz was designed and fabricated. Electromagnetic waves incident on the surface of the material are transmitted and reflected (scattered) according to Snell's law, and transmission loss occurs due to dielectric loss during transmission. A hexa mesh was applied to minimize radio wave transmission and scattering, which lowered the transmittance refractive index according to the radio incident angle and minimized dielectric loss through high-density foam. Similar to the simulation result, the transmission loss obtained the gain in a specific receiving frequency band, and in the transmission frequency band, an excellent low loss characteristic was obtained with an insertion loss of 0.8dB or less. The results of this study can be used in radio transmission radomes of low-weight, low-cost end-system protection devices.

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