



Introduction

This document elaborates on the impact of antenna radomes on the performance of mmWave sensors and provides key principles for radome design. Through this document, readers will gain an understanding of how the material and external design of radomes affect the performance of mmWave sensors, along with practical data references and design recommendations.

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1 Impact of Radome on mmWave Sensor Performance

MmWave radar, with advantages such as compact form factor, light weight, and high spatial resolution, has been widely used in fields such as automotive, smart homes, and security monitoring. In practical applications, to protect mmWave antennas and electronic devices from external environmental influences, radar antenna radomes are typically installed for sensors. However, although radomes have minimal attenuation of electromagnetic signals, they still have a series of effects on mmWave signals.

When radar waves propagate at the boundary of the radome, reflection and loss occur, resulting in a reduction in the total power of radar radiation or reception. Meanwhile, reflected waves may also enter the receiving channel, affecting the isolation between the transmission and reception channels. Additionally, reflection may deteriorate the standing wave of the antenna, thereby affecting antenna gain. Moreover, radar waves propagate in the medium will also incur losses, with higher frequencies resulting in greater losses. Furthermore, electromagnetic waves undergo refraction when passing through the medium, affecting the radiation pattern of the antenna, thus causing changes in the coverage area of the sensor. Figure 1-1 illustrates the propagation loss of electromagnetic waves in the medium.

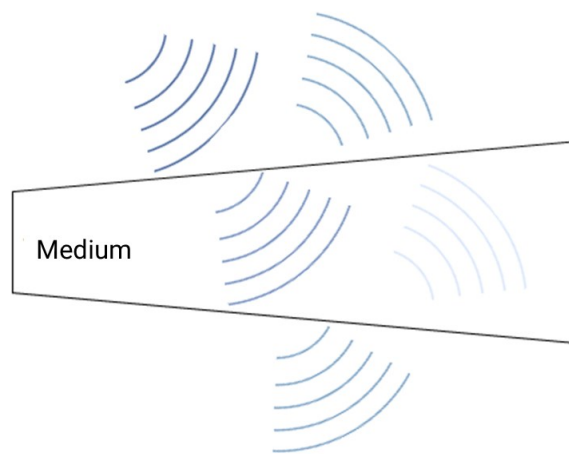


Figure 1-1 Electromagnetic wave attenuation through a radome medium

2 Principles of Antenna Radome Design

The material and structural appearance of antenna radomes are crucial to the impact on radar signals. Therefore, when designing antenna radomes, the following principles should be followed:

Firstly, the structural shape of the radome should ensure a smooth and even surface within the field of view (FOV), with uniform thickness to avoid irregularities. If there is a surface coating, it should be ensured that it does not contain any metallic or conductive materials to prevent interference with electromagnetic signals. At the same time, the radome surface should be parallel to the antenna plane to ensure the stability of signal transmission.

Furthermore, the distance H from the antenna to the inner surface of the radome is also a critical parameter in the design. It is defined as:

$$H = \frac{m}{2} \times \frac{c_0}{f}$$

Where m is a positive integer, c_0 is the speed of light in vacuum, and f is the center frequency of operation. The ideal distance should be an integer multiple of half-wavelength in air. If space permits, it is recommended to choose either 1 or 1.5 times the wavelength in air as the distance H . For example, for a mmWave with a center frequency of 24.125 GHz, the half-wavelength in air is approximately 6.2 mm, thus the recommended radome thickness can be either 12.4 mm or 18.6 mm. If space is limited, 6.2 mm can be chosen as the distance H , but the error should be controlled within ± 1.2 mm.

Finally, the thickness D of the radome is also a factor to consider in the design. It is defined as:

$$D = \frac{m}{2} \times \frac{c_0}{f\sqrt{\epsilon_r}}$$

Where ϵ_r is the relative dielectric constant of the radome material. The ideal thickness should be an integer multiple of half-wavelength in the medium, with the error controlled within $\pm 20\%$. When it is not possible to meet the requirement of half-wavelength thickness in the medium, it is recommended to use materials with a low dielectric constant and ensure that the thickness is less than or equal to $1/8$ wavelength in the medium. This is done to maintain consistent impedance before and after the radome, reducing reflection and penetration losses of electromagnetic waves. Moreover, when the customer finds it difficult to accept a half-wavelength thickness shell, using a shell with a thickness less than or equal to $1/8$ wavelength can minimize the penetration path of electromagnetic waves, further reducing penetration losses.

3 Recommended Radome Materials

The material of the antenna radome is crucial for the performance of mmWave radar as it directly determines the electromagnetic wave's losses and propagation characteristics. When selecting the material for the antenna radome, its electrical properties must be thoroughly considered to ensure the stable transmission of signals. Table 3-1 lists common mmWave antenna radome materials and their characteristics for readers' reference. In the actual design process, it is recommended to engage in extensive communication with suppliers to obtain accurate material parameters.

Table 3-1 Electric Characteristics of Common Radome Material (Based on 24.125 GHz)

Medium	Typical Value of ϵ_r	Half-wavelength (mm)	1/8 wavelength (mm)	1/10 wavelength (mm)
Air	1.00	6.20	1.55	1.24
ABS1	1.50	5.06	1.27	1.01
ABS2	2.50	3.92	0.98	0.78
PC	3.00	3.58	0.89	0.72
PMMA1	2.00	4.38	1.10	0.88
PMMA2	5.00	2.77	0.69	0.55
PVC (hard)	4.00	3.10	0.78	0.62
PVC (soft)	8.00	2.19	0.55	0.44
HDPE	2.40	4.00	1.00	0.80
LDPE	2.30	4.09	1.02	0.82
Silex	5	2.77	0.69	0.55

For non-uniform materials or composite materials, complex reflection and refraction phenomena may occur during the propagation of electromagnetic waves, thus affecting radar performance. Therefore, in the design process, it is advisable to experimentally adjust to determine the optimal material combination and thickness.

When selecting the material for the outer shell of the antenna radome, smooth and uniform materials are preferred. Matte materials, due to their surface roughness, are prone to increase electromagnetic wave reflection, leading to increased signal loss and affecting the antenna pattern. Therefore, it is recommended to avoid using matte materials as much as possible in the design process.

4 Design and Adjustment Tips

In the shell area near the radar sensor, structures such as cavities and screws that may interfere with signal transmission should be avoided. At the same time, ensure that there are no obstructions inside the FOV cavity of the radar radiation to ensure unimpeded signal transmission. The inner and outer surfaces of the antenna cover shell should be smooth and flat, with uniform thickness, to reduce electromagnetic wave reflection and loss. The shape of the shell can be planar or spherical, but uneven designs should be avoided. Additionally,

there should be no metallic or conductive material coating on the shell surface to prevent interference with electromagnetic signals.

During the debugging process, if saturation occurs in the radar module, the following methods can be tried for adjustment: First, adjust the spacing between the radar module and the antenna cover appropriately to ensure that the radar performance is not affected without saturation. The adjusted spacing should preferably be integer multiples of the radar center frequency wavelength in air. If it is not possible to ensure the requirement of integer multiples of half-wavelength due to conditions, it is recommended to use relevant debugging tools to ensure the stability of radar performance when adjusting the spacing. Additionally, different materials can be tried for processing the antenna cover or reducing the gain of the TX or RX link to solve saturation issues.

5 Comparison of Two Antenna Radome Designs

According to the different requirements of terminal devices, radar antenna covers can be designed in various shapes, such as planar, spherical, and geodesic. These different shapes of antenna radomes will have a certain impact on the radiation pattern and maximum measurement distance of the radar sensor. For example, antenna covers with large curved surfaces, as shown in Figure 5-1, will result in inconsistent distances from the antenna to the antenna cover at various angles, severely affecting the antenna radiation pattern. This impact can be quantitatively analyzed through comparative experiments, as shown in Figure 5-2, to choose the appropriate antenna cover shape in practical design.

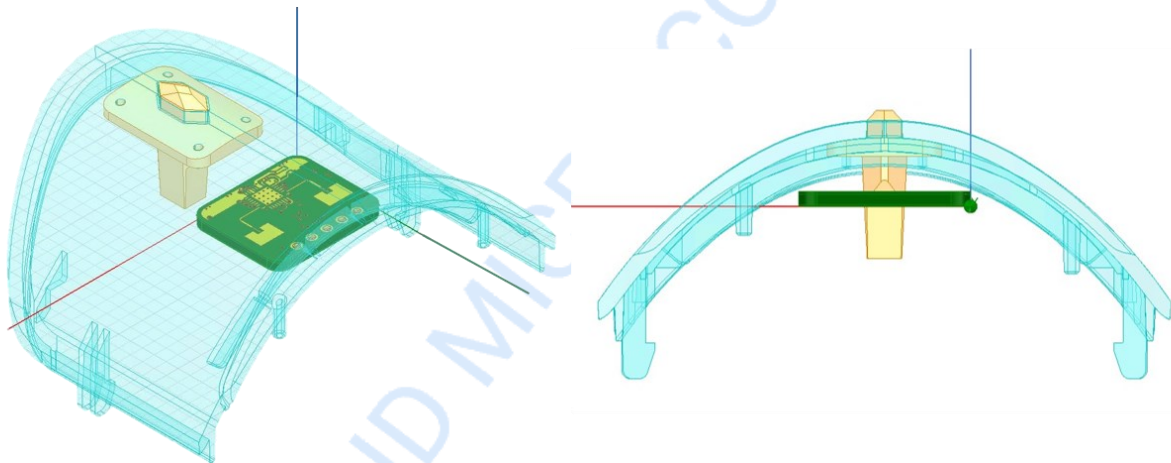


Figure 5-1 Schematic diagram of a curved surface antenna radome

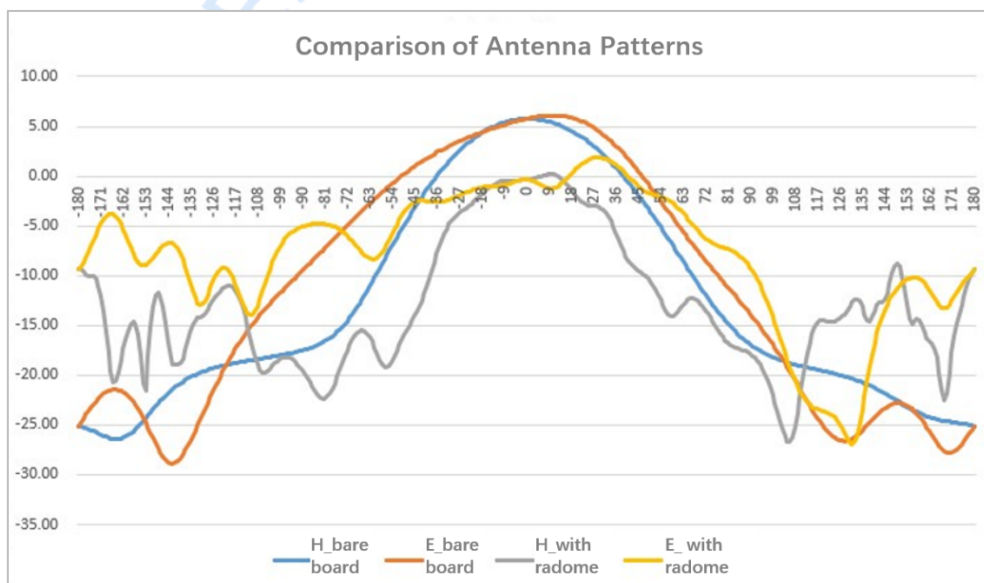


Figure 5-2 Influence of curved antenna radome on radar signals

Moreover, when there are multiple layers of media within the FOV range of the antenna cover and obstructions around, as shown in Figure 5-3, it will cause severe deterioration of the antenna radiation pattern (refer to Figure 5-4). In this case, signals will undergo multiple reflections and refractions during propagation, resulting in weakened signal strength and deteriorated directionality received by the antenna. Therefore, when designing the antenna cover, it is necessary to avoid introducing multiple layers of media or obstructions within the FOV range to ensure the stable and reliable performance of the radar sensor.

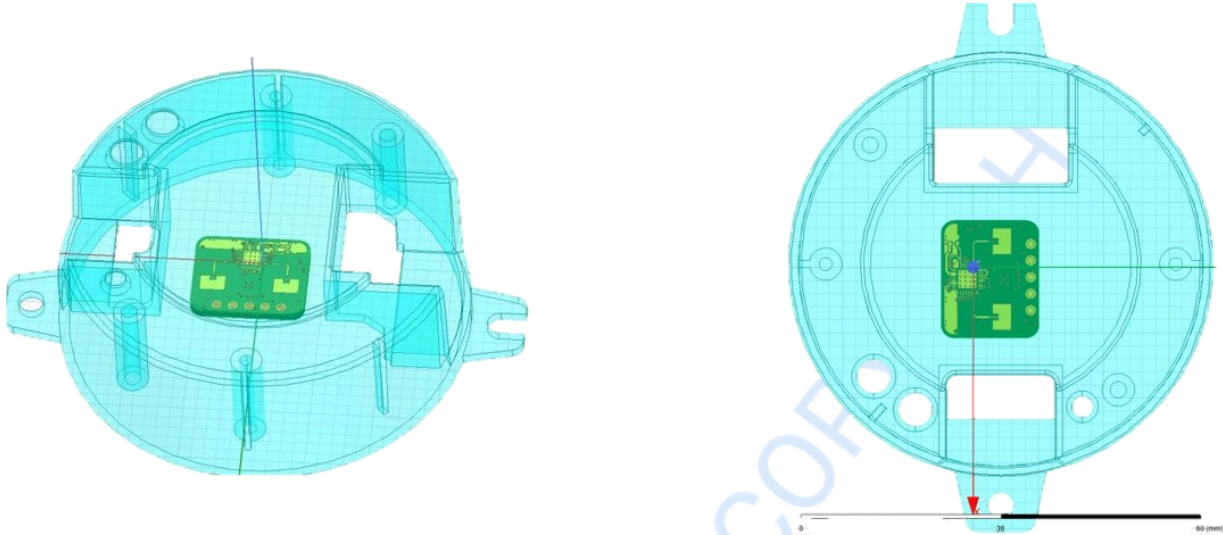


Figure 5-3 Schematic diagram of an antenna radome with obstructions around

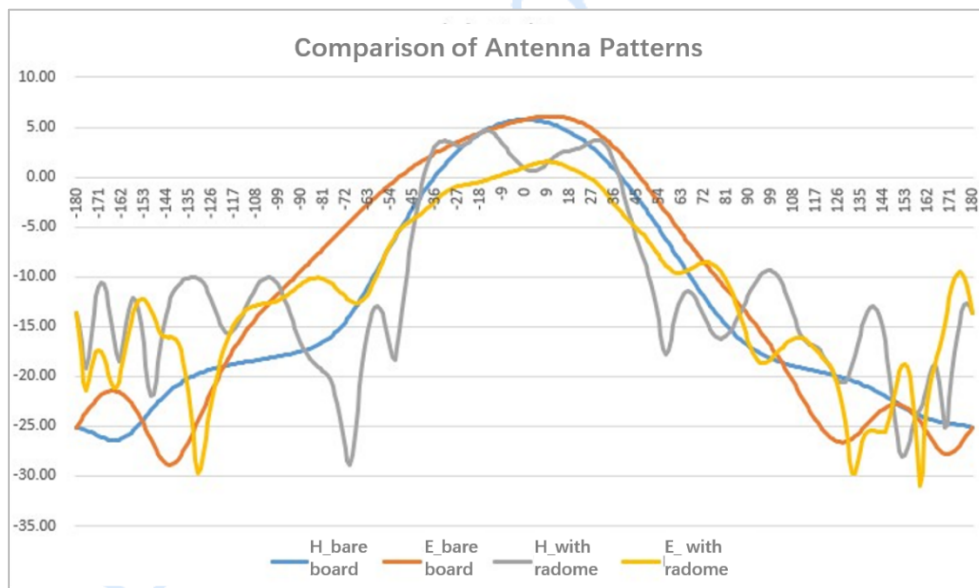


Figure 5-4 Influence of an antenna radome with obstructions around on radar signals

6 Revision History

Revision	Date	Content
1.0	2023/8/29	Initial Released.
1.1	2024/3/15	Optimized the document text.

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