UNICO I+D Project
6G-INTEGRATION-4

E18-6G-INTEGRATION-4

5G POD material selection study for airborne operations

Abstract

This deliverable provides an in-depth analysis of the use of polymeric materials in electromagnetic shielding and radome applications. It explores the advantages of polymer-based materials over traditional options, focusing on their electromagnetic properties, durability, and cost-effectiveness. Key concepts related to electromagnetic shielding effectiveness, dielectric constant measurements, and the selection of appropriate materials are discussed. Additionally, the document examines radome design considerations, including sizing, positioning, and material thickness optimization. Practical applications in various industries, from telecommunications to aerospace, are highlighted, along with an overview of 5G and 6G frequency bands and their impact on radome performance. Validation testing methodologies are also presented to ensure compliance with performance and safety standards.

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL
SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES
Plan de Recuperación, Transformación y Resiliencia

Document properties

Document number	E14-6G-INTEGRATION-4
Document title	Preliminary 5G comms POD design
Document responsible	Eduardo Cano Corral (Edair Technologies)
Document editor	Pedro Baquero Jaen (Edair Technologies)
Editorial team	Alfonso Torrelo Vaca (Edair Technologies)
Target dissemination level	Public
Status of the document	Edition
Version	1.0

Production properties

Reviewers	Eduardo Arca Ramirez (Edair Technologies) Eduardo Cano Corral (Edair Technologies) Daniel Segovia Vargas

Disclaimer

This document has been produced in the context of the 6G-INTEGRATION-4 Project. The research leading to these results has received funding from the Spanish Ministry of Economic Affairs and Digital Transformation and the European Union-Next Generation EU through the UNICO 5G I+D programme.

Contents

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES
Plan de Recuperación, Transformación y Resiliencia
UNICO I+D

List of Figures

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES
Plan de Recuperación, Transformación y Resiliencia
UNICO I+D

List of Tables

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES
Plan de Recuperación, Transformación y Resiliencia
UNICO I+D

List of Acronyms

APU – Auxiliary Power Unit

AC – Alternating Current

ANN – Artificial Neural Network

DC – Direct Current

EMS – Energy Management System

ESS – Energy Storage Systems

FLC – Fuzzy Logic Control

HESS – Hybrid Energy Storage Systems

MEA – More Electrical Aircraft

PEM – Proton Exchange Membrane

PEMFC – Proton Exchange Membrane Fuel Cell

RAT – Ram Air Turbine

RES – Renewable Energy Sources

SOC – State of Charge

MF – Membership Functions

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES
Plan de Recuperación, Transformación y Resiliencia
UNICO I+D

Executive Summary

This deliverable focuses on the selection and evaluation of polymeric materials for radome applications in the telecommunications sector, particularly for 5G and 6G networks. Radomes serve as protective enclosures for antennas, shielding them from environmental factors while maintaining electromagnetic transparency. The primary challenge in radome material selection lies in achieving a balance between mechanical strength, durability, and minimal electromagnetic interference. Key insights include Material Properties, Electromagnetic Shielding, 5G and 6G Compatibility, Material Thickness and Positioning and Validation Testing.

The study concludes that polymeric materials, particularly those with low dielectric constants and high durability, provide viable solutions for radome construction. With proper material selection, design considerations, and testing, these materials can support the growing demands of 5G and 6G communication systems.

1 Introduction

Polymeric materials have revolutionized multiple industries by offering lightweight, cost-effective, and versatile solutions. Their utilization spans from structural components in transportation to electromagnetic shielding in telecommunications. As wireless communication technologies advance, particularly with the advent of 5G and the anticipated 6G networks, the need for materials that balance mechanical strength and electromagnetic transparency becomes critical.

Radomes, serving as protective covers for antennas, are essential in ensuring consistent signal performance while protecting sensitive components from environmental elements. The choice of material for radome construction directly impacts signal attenuation, structural integrity, and service longevity. Polymeric materials, particularly reinforced plastics, polyurethane foams, and composite materials, have emerged as leading candidates due to their adaptable properties and customization potential.

This document provides a comprehensive analysis of polymeric materials for radome applications. It includes discussions on electromagnetic shielding mechanisms, material selection criteria, dielectric properties, and structural considerations. Furthermore, the importance of material testing and validation to ensure compliance with performance standards is explored. The insights presented herein aim to aid in the development of robust radome solutions for modern and future telecommunications systems.

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES
Plan de Recuperación, Transformación y Resiliencia
UNICO I+D

2 Material Study and Selection

Polymeric materials are increasingly used in sectors where materials with high performance and advanced properties are required, such as the construction and transportation sectors. This is due to the great advantages of polymeric materials, which has led to their introduction in many applications, replacing other families of materials. Among others, they have the following differentiating characteristics:

- Good performance: inherently corrosion-resistant material with high durability, as well as great lightness and with a high strength/weight ratio.

- Design freedom: Allows complex shapes and a variety of manufacturing processes.

- Allows high production volumes at low cost.

Another sector where polymeric materials have great potential is telecommunications, where there is a need for materials that serve as a barrier to electromagnetic radiation. Advances in synthesis, functionalization and doping techniques have made it possible to take advantage of the benefits of these materials while at the same time offering the capacity to shield electromagnetic waves, serving as shielding materials.

3 Electromagnetic shielding

Electromagnetic shielding (EMI-Shielding) is the ability to block or minimize electromagnetic fields through barriers made of conductive or magnetic material, in a specific space. Shielding can reduce unwanted effects regarding electromagnetic interference such as coupling of radio waves, electromagnetic fields and electrostatic fields. The characteristics of a shielding will depend on several factors such as the material used, the geometry of the space, the frequency of the electromagnetic field and the presence of openings.

The shielding material is one that produces a loss of electromagnetic waves, acting as a barrier, i.e. causing a large part of the electromagnetic waves that hit the material not to pass through it. First, the wave is partially reflected by the surface and, subsequently, part of the transmitted (non-reflected) waves are attenuated when they pass through the material. Thus, two electromagnetic loss effects are distinguished, reflection and absorption. Therefore, the Shielding Effectiveness of a shielding material is equal to the sum of both effects, and quantifies the electromagnetic field that is prevented from passing through it.

3.1.1 Applications of shielding materials

Shielding materials have a wide range of applications as electromagnetic shielding materials. They are used, among others, in sanitary instrumentation (magnetic resonance devices), in computer data storage rooms or cabinets, in electronic components or sensors sensitive to electromagnetic noise, in the protection of transformers or power supplies, or in the insulation of electric vehicle batteries. In the case of wanting to isolate an emission source, or in the case of wanting to immunize a specific space/equipment, the most common solution is to install shielding panels or coatings. In this way, the walls, ceiling and floor of the space where the equipment is located can be covered. On the other hand,

in the case of smaller elements, the best option is to cover the equipment/component with an outer casing.

3.1.2 Dielectric constant

The dielectric constant is a physical quantity that quantifies the capacity of a material to accumulate electric charge; therefore, the lower the dielectric constant, the lower the accumulation and the lower the electromagnetic shielding.

The main requirement for a material to be considered a radome is that being preferably opaque to visible light, it should be transparent to electromagnetic waves. Therefore, radomes are very low-loss dielectric materials. In fact, an ideal material for radome functionality would have a dielectric constant of 1, equivalent to air for practical purposes. Materials with dielectric constants closer to 1 are usually the best for radome design.

Material	ε_r
Vacuum	1 (by definition)
Air	1,00058986 + 0,0000005
Paper	1,4
PTFE/Teflon	2,1
Polyethylene/XLPE	2,25
Polypropylene	2,2-2,36
Hidrocyanic acid	158,0-2,3
Polystyrene	2,4-2,7
Carbon disulfide	2,6
BoPET	3,1
Polyimide	3,4
Silicone Rubber	2,9-4
Silicon dioxide	3,9
Concrete	4,5
Mica	3-6
Pyrex (Glass)	4,7 (3,7-10)
Neoprene	6,7
Natural rubber	7
Electroactive polymers	2-12
Silicon nitride	7-8
Diamond	5,5-10
Melamine resin	7,2-8,4
Salt	3-15
Sapphire	8,9-11,1
Silicon	11,68
GaAs	12,4
Graphite	10-15
Ammonia	26-17
Methanol	30
Ethylene glycol	37
Furfural	42
Glycerol	42,5
Hydrazine	52
Hydrogen peroxide	60-128
Water	80
Hydrofloric acid	83,6
Formamide	84
Sulfuric acid	84-100
Titanium dioxide	86-173
Strontium titanate	310
Barium Strontium titanate	500
Barium titanate	1200-10000
Lead Zirconate Titanate	500-6000
Conjugated polymers	1,8-6 up to 100000
Calcium copper titanate	>250000

Table 3.1: Dielectric constant of materials

:

4 Radome applications

The main application of radomes is the protection of antennas. The use of these materials helps to reduce the wind load on the antenna itself and the structure, and avoids the accumulation of ice, as well as other adverse environmental effects. There are mainly 2 types of radome type protection. One of these types are the side covers, which come in different configurations (spherical, conical or flat), and are placed on the antenna structure adjacent to the area/s to be protected, protecting them laterally. The other type are the external covers, which are not part of the antenna structure, but form a structure of their own that completely surrounds the antenna and therefore houses it inside. There are cases of external radomes in which the structure of the object itself is the one that additionally fulfills this function, such as the fuselage of aircraft. External radomes are the most common.

Figure 4.1: Radome Structure overview

4.1 Role of Polymeric Materials in the Evolution of Shielding and Radomes

Thanks to their great versatility, diverse performance, light weight and low cost, polymeric materials offer a highly competitive alternative for a wide range of radome solutions, where each specific application can find its optimal solution.

In addition, the developments carried out in this field are allowing important technological advances to be made. In fact, shielding materials based on thermoplastic polymers, thermosetting polymers and continuous fiber composites are being developed to reduce weight compared to solutions based on metallic components and to achieve high electromagnetic shielding effectiveness. These materials have particular potential in applications related to sustainable mobility. But radome materials based on continuous fiber composites are also being developed that allow the integration of antennas of different types. This opens the door to the development of new products, such as urban or home furniture, adapted to the current challenge of the IoT (Internet of Things) and smart cities.

Radomes are structures that protect antennas from inclement weather and other environmental factors, without interfering with radio frequency signals. The materials used to manufacture radomes must be transparent to electromagnetic waves, have good mechanical strength and be durable.

Some of the most common materials used in the manufacture of radomes are:

- **Glass fiber reinforced plastics (GRP):** These are composite materials with high mechanical strength and low dielectric permittivity, making them ideal for high frequency applications.

- **Polyurethane foams**: These are lightweight and inexpensive materials but have lower mechanical strength than GRP. They are used in low frequency applications and less demanding environments.

- **Ceramics:** These materials are very resistant to weathering and high temperatures but are heavier and more expensive than plastics. They are used in special applications where high strength and durability are required.

- **Composite materials:** Combinations of different materials are used to obtain specific properties. For example, carbon fibers can be combined with epoxy resins to obtain lightweight, high-strength radomes.

Choosing the right material for a radome depends on several factors, such as antenna operating frequency, environmental conditions, mechanical requirements and cost. It is important to keep in mind that the radome material can affect the performance of the antenna, so testing and adjustments are necessary to ensure optimal performance.

In addition to the above materials, there are other materials used in the manufacture of radomes, such as polycarbonate, acrylic and PVC. Each of these materials has its own advantages and disadvantages, and the choice of the appropriate material will depend on the specific needs of the application.

4.2 5G Frequency Bands

5G technology uses a wider frequency range than previous generations of wireless technology, allowing it to offer faster data speeds and lower latency.

Generally speaking, 5G operates in three main frequency ranges:

• Low band (600 MHz - 900 MHz): This band offers good indoor coverage and penetration, but data speeds are slower compared to higher bands. It is primarily used for rural and suburban areas.

• Mid band (1 GHz - 6 GHz): This band offers a balance between coverage and data speeds. It is the most widely used band for 5G deployment in urban areas.

• High band (24 GHz - 47 GHz): This band, also known as millimeter waves, offers extremely fast data speeds, but has limited coverage and is more susceptible to blockage. It is primarily used in dense urban areas and for applications requiring very high bandwidth. It's important to note that not all countries and operators use the same frequency bands for 5G. For example, in Spain, the frequency bands used for 5G are 700 MHz, 3.5 GHz, and 26 GHz.

Choosing the appropriate frequency band for a 5G deployment depends on several factors, such as population density, topography, and user needs. Generally, a combination of different bands is used to provide optimal coverage and performance.

In addition to the frequency ranges mentioned above, other bands are also being explored for future 5G development, such as terahertz (THz) frequencies. These frequencies could enable even faster data speeds and new applications, but are still in research and development.

In short, 5G uses a wide and diverse range of frequencies to offer a variety of services and applications. Choosing the appropriate frequency band depends on the specific needs of each deployment.

In our case, the chosen frequency band is 3.5 GHz, well into the range of the selected antenna.

4.3 Selected Antenna and Baseband

Ericsson AIR 3227 is a 32TR TDD AAS for LTE and NR, operating as standalone or as mixed mode. The AIR unit has beamforming and MU-MIMO technology, capable of fully utilising radio resources in both azimuth and elevation.

The main benefits compared to previous macro solutions are improvements in:

- Enhanced coverage - High gain adaptive beamforming
- Enhanced capacity - High-order spatial multiplexing and multi-user MIMO
- Advanced RAN features - Vertical and horizontal beamforming
- Improved network performance - Low inter-cell interference

Description	Value
Maximum nominal output power[1] [2]	200 W (License key is required for total output power over 20 W.)
Minimum configurable output power	10 W
Number of carriers	LTE: Up to four for B42 AS NR: Up to two Mixed mode: Up to four for B42 AS (only support 1 carrier for NR and 3 carriers for LTE)
Frequency[3]	B42 AS for NR and LTE 3400–3600 MHz
	B43 for NR 3600–3800 MHz
	B78T for NR 3410–3610 MHz

Table 4.1: Ericsson AIR 3227 Antenna Technical Data

Ericsson baseband 6648 is a self-contained 19-inch unit with an easily removable fan tray unit. Each unit can be installed standalone in any 19-inch rack or enclosure or in an RBS.

Baseband 6648 facilitates a scalable, modular system with one or more indoor 19-inch baseband units and a number of external radios.

The Baseband has the following functions:

- Timing function
- Loadable software
- Downlink (DL) baseband processing
- Uplink (UL) baseband processing
- IP traffic management
- Radio interface
- Backhaul handling
- External synchronization

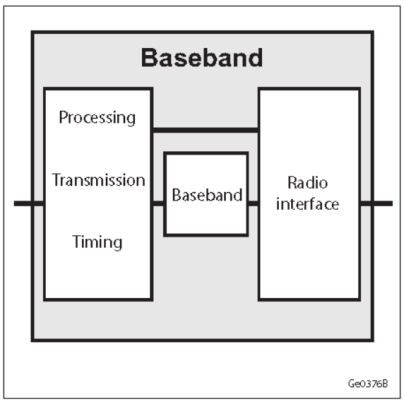

Figure 4.2: Baseband block diagram

4.4 6G Frequency Bands

6G technology is still under development, but it is expected to use a wider frequency band than previous generations of wireless technology. The exact frequency range for 6G has not yet been determined, but it is expected to include higher frequencies than those used by 5G, possibly in the terahertz (THz) range.

The greater bandwidth capacity of terahertz frequencies is expected to enable even faster data speeds and lower latency than 5G networks. This could enable new applications such as more immersive virtual and augmented reality, advanced telemedicine, and autonomous vehicles.

However, the use of higher frequencies also presents challenges. Terahertz signals are more susceptible to attenuation and obstruction than lower frequency signals, meaning that 6G networks may require a denser infrastructure with more base stations to provide reliable coverage.

4.5 Sizing and positioning of the radome

When designing a radome, it is crucial to use the correct material. If electromagnetic waves strike objects or people, the properties of the material influence their propagation. To determine which materials are suitable for a radome, it is important to consider the effect produced when radar waves reach them.

Table 3 provides an overview evaluating various materials for microwave absorption and reflection, as well as their penetration capacity.

Material	Absorption	Reflection	Penetration capacity
Metal	None	Straight incidence: complete; diagonal incidence angle: partial refraction and reflection possible	Virtually impossible, only millimetric fractions penetrate the surface (skin effect)
Wood (depending on humidity)	Medium to high	Low	Low
Water	Very high	Depending on the angle of incidence: Partial or complete reflection is possible	None due to absorption
Foam (polystirene, Roofmate,...)	Low	None	Very good
Plastic	Low to High (depending on material and thickness)	Low to High (depending on material, thickness and distance)	Low to High (depending on material, thickness and distance)

Table 4.2: Influence of various materials on radio waves

The thickness of a radome depends on several factors, including the antenna frequency, the radome material, environmental conditions, and mechanical requirements. There is no single formula for determining the optimal thickness, but there are some general considerations:

- Frequency: As the frequency increases, the signal wavelength decreases. In general, a thinner radome is required for higher frequencies to minimize signal attenuation.
- Material: Each material has its own dielectric and mechanical properties, which influence the required thickness. Materials with low dielectric permittivity and high mechanical strength may allow for thinner radomes.
- Environmental Conditions: Radomes exposed to extreme weather conditions, such as high winds, heavy rain, or snow, may require a greater thickness to ensure strength and durability.
- Mechanical Requirements: The radome must be strong enough to withstand mechanical loads, such as the weight of the antenna, wind pressure, and impact from objects.

In practice, radome thickness is determined through theoretical calculations, simulations, and experimental testing.

It is important to note that radome thickness can affect antenna performance, especially at higher frequencies. A radome that is too thick can attenuate the signal and reduce antenna efficiency. Therefore, choosing the appropriate thickness is critical to ensure optimal performance.

Radio waves must be able to penetrate the radome. Metals block the sensor due to their highly reflective properties; they are unsuitable for placement in front of an antenna. Wood panels (usually with a certain degree of residual moisture) are also unsuitable due to their limited ability to be penetrated by electromagnetic waves.

Foams such as polystyrene are well-suited for use as a covering material. They can even be applied directly to the antenna in a very rough structure. However, due to their low stability and sensitivity to chemicals, foams often do not make the cut when it comes to material selection.

Therefore, plastics are the most common alternative for producing a protective cover or housing. However, when planning a radome, the designer must take the properties of the plastic into account. The thicker and closer the material is to the antenna, the fewer electromagnetic waves penetrate it.

In the case of black plastics, measurement losses can occur, as they often contain carbon. Accumulating water that doesn't drain can also impair front-end data acquisition. Post-treatment of the plastic radome, such as painting, also negatively affects data collection by the radar antenna.

When constructing a radome, not only the selected material but also the precise mounting and shape of the radome are very important. To avoid restricting its functionality, the following aspects must be considered:

The distance between the bottom of the radome and the antenna

The thickness of the radome material

The shape of the radome (as homogeneous as possible)

These factors determine whether the constructed radome reflects or absorbs most radar waves.

4.5.1 The correct distance

The uniformity of the individual distances from the radome to the antenna is of great importance. Even small deviations, for example, a small notch at the bottom of the protective cover, can alter the propagation of electromagnetic waves. For this reason, tilted radomes also have an adverse impact, as they can be detrimental to proper reflection. The same applies to rounded ends, lugs, reinforcements, or slots in the material.

To determine the correct and uniform distance, the following applies:

Wave propagation is only slightly disturbed if they strike a radome at exactly half a wavelength (or a multiple thereof).

This means that the antenna surface (center of the wave) should be placed parallel to the cover, at a distance of λ/2 (or a multiple thereof).

With a center frequency of 3.5 GHz (with a half-wavelength of about 43 millimeters (mm), the optimal distance is approximately 42.83 mm.

4.5.2 The Correct Material Thickness

The same principle applies here as for determining the appropriate distance: to minimize disruption to wave propagation, the waves should strike the radome at half a wavelength. Similarly, the thickness of the radome material must also be appropriately selected for the half-wavelength.

However, the way in which the wave is altered by the substance of the radome (as it penetrates the material) must also be taken into account. This adaptation corresponds to the conductivity of the material used (dielectric function ε). It shortens the wavelength by the factor √(εr).

For example, in the case of plastics, this dielectric constant is between three and four, which, however, varies greatly in practice. To obtain an approximate figure, a calculation can be performed with the average value of 1.5. The thickness of the material can then be calculated using the formula $\lambda/2\sqrt{(\varepsilon r)}$. This would be equivalent to 28.5 mm with these initial values.

5 Radome Validation Testing

Validation testing of a radome is crucial to ensure that it meets performance and safety requirements. These tests cover a wide range of tests, designed to evaluate the electromagnetic, mechanical and environmental properties of the radome. Some of the most common validation tests are described below:

1. **Electromagnetic Testing:**
    a. Transmission Loss Measurement: This test measures the amount of electromagnetic signal that is attenuated as it passes through the radome. The objective is to ensure that the radome does not significantly degrade the performance of the antenna.
    b. Radiation Pattern Measurement: This test evaluates how the radome affects the radiation pattern of the antenna. The gain, beamwidth and sidelobes of the antenna with and without the radome are measured to determine any distortion or alteration in the radiation pattern.
    c. Transmission phase measurements and radome homogeneity analysis: This type of test is performed to ensure the homogeneity of the radome and its material.
2. **Mechanical Tests:**
    a. Structural Strength Tests: These tests evaluate the radome's ability to withstand static loads, such as antenna weight and wind pressure. Gradual loads are applied to the radome to determine its failure point and ensure that it meets structural strength requirements.
    b. Vibration Tests: These tests evaluate the radome's ability to withstand vibrations, which may be caused by wind, vehicle movement or antenna operation. The radome and antenna are subjected to controlled vibrations to determine their response and ensure that no damage or failure occurs.
    c. Impact Tests: These tests evaluate the radome's ability to withstand impacts, such as those caused by hail, debris or birds. High velocity projectiles are launched against the radome to assess its resistance and determine if damage occurs.
3. Environmental Tests:
    a. Temperature and Humidity Tests: These tests evaluate the radome's ability to withstand extreme temperature and humidity conditions. The radome is subjected to controlled temperature and humidity cycles to determine its response and ensure that no deformation, cracking or failure occurs.
    b. UV Radiation Tests: These tests evaluate the radome's ability to resist degradation caused by ultraviolet radiation from the sun. The radome is exposed to intense UV radiation for an extended period of time to determine its resistance to discoloration, cracking and loss of mechanical properties.
    c. Rain and Salt Fog Tests: These tests evaluate the radome's ability to resist corrosion caused by exposure to rain and salt spray. The radome is exposed to controlled rain

and salt spray environments to evaluate its corrosion resistance and ensure that no damage occurs.

d. Lightning Strike Damage: Lightning presents a serious, immediate and dynamic threat to an aircraft radome. The regulatory rule states that for nonmetallic materials the lightning current shall be conducted in some manner not to endanger the aircraft.

One common type of damage caused by lightning strikes to the radome is a puncture. Unless a quick repair, a lightning puncture will promote moisture absorption and/or water ingestion into radome walls, which will greatly deteriorate its electrical performance characteristics. Such a puncture can also cause secondary damage to RF subsystems as well as the plane superstructure itself, potentially endangering the aircraft.

Additional Considerations:

- The choice of specific validation tests will depend on the application requirements, radome specifications and applicable norms and standards.
- It is important that validation tests are performed in accredited laboratories and by qualified personnel to ensure the accuracy and reliability of the results.
- Validation test results should be carefully documented and analyzed to determine if the radome meets performance and safety requirements.

6 References

Buchanan, T. (2022). *PLASTIC MATERIALS FOR HIGH.* Curbell Plastics.

Chethan, K., Habeeb Ur Rahman, M., & Peake, G. (2021). *mmWave Radar Radome Design Guide.* Texas Instruments.

Gopal, V., & Feroz, D. (n.d.). Materials Used in 5G Communication. *Scitech Patent Art*.

Manufacturing, 4. (n.d.). *4a Manufacturing*. Retrieved from https://www.radome.at/usecases/5a6g/

Wang, Y., Zhao, W., Tan, L., Li, Y., Qin, L., & Li, S. (2023). Review of Polymer-Based Composites for Electromagnetic Shielding Application. *Molecules (Basel, Switzerland)*, 28(15), 5628.