Radome R&D White Paper

Prepared by

Competition Composites Inc. (CCI)

168 Wescar Lane
Carp, Ontario
Canada K0A 1L0

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Introduction

Radomes, are used to enclose antennas. The main function of a radome is to provide protection for the enclosed equipment (antenna and other electronics). This improves system availability since the antenna is not affected by winds, rain or ice. It also provides a stable environment for service personnel from harsh weather conditions. The benefits are reduced structural requirements, reduced fabrication, installation and maintenance costs.

Uses vary from large terrestrial installations, tower mounted conical shrouds vehicle mounted and aviation installations. Typical applications include antennas for radar, telemetry, tracking, communications, surveillance, and radio astronomy.

Potential customers may include the satellite, broadcast, communications, radar, weather and cable industries, defense and government agencies worldwide. This report will concentrate mostly on Land based terrestrial radomes.

The Radome Market

The radome market is relatively large with a wide range of both customers and manufacturers. Most applications are very application specific and customer focused solutions. Standard offerings for land based geodesic radomes range from 10 ft – 200 ft in diameter. Standard warranty offerings generally include; 2 year water intrusion, 5 year surface degradation and 20 year on overall structure.

Some recent installations have been found as replacements for aging infrastructure.
Existing market data research can be found (purchased) from Lucintel.com

Product Applications

- Military and Civil Radar
- Weather Radar
- Microwave
- Surveillance
- Telecommunications
- Satellite Communications
- Broadcast Equipment
- Coastal Surveillance
- Military and Civil Flight Simulation

Existing Manufacturers

Manufacturers vary greatly from small job shops making custom one off to low production radomes and some are large, well established turnkey solutions providers from engineering to worldwide installations. ***Please see page 7 for a list of qualified manufacturers.***

Types / Classes / Styles

Radomes for use on flight vehicles, surface vehicles and fixed ground installations are classified into various categories according to MIL-R-7705B. Categories are determined by the specific radome use and wall construction. Customer satisfaction is met by the following:

Types Definitions

- Type I: low frequency radomes at or below 2 GHz.
- Type II: Directional guidance radomes having specified directional accuracy requirements. Boresight error (BSE), boresight error slope (BSES), antenna pattern distortion and antenna sidelobe degradation.
- Type III : narrowband radomes with an operational bandwidth less than 10%.
- Type IV: multiple frequency band radomes used at two or more narrow frequency bands.
- Type V: broadband radomes generally providing an operational bandwidth between 0.100GHz and 0.667GHz.
- Type VI: very broadband radomes that provide and operational bandwidth greater than 0.667GHz.

Style Definitions

Radome styles are defined according to the dielectric wall construction. There are 5 basic styles.

- **Style A:** Half wave wall solid (monolithic).
- **Style B:** Thin wall monolithic with a wall thickness equal to or less than 0.1λ wavelengths at the highest operating frequency.
- **Style C:** A-Sandwich multilayered wall. Consisting of three layers: two high density skins and a low density core. The dielectric constant of the skins is greater than the dielectric constant of the core material. 0.25λ wavelengths.
- **Style D:** Multi layered wall having 5 or more dielectric layers. Odd number of high density layers and an even number of low density core layers. As the number of layers is increased, the broadband frequency performance is improved.
- **Style E:** Other radome wall constructions not fitting into the above style definitions. Including the B-Sandwich consisting of two low density skins and a high density core. Dielectric constant of the skins is less than the dielectric constant of the core.

Design Considerations for Terrestrial Based Radomes

The majority of radomes are designed individually to satisfy a unique set of specific requirements. These requirements include; cost, operating frequency, broadband performance, signal noise, signal distortions such as insertion loss, boresight error and scattering. There are multiple techniques used to improve the performance of the radome.

Cost considerations

The cost of a radome is primarily dependent on the size of the structure and increases with the radome surface area. The material and labor costs in a radome will increase dramatically with the diameter. This is due to the fact that doubling the diameter of a sphere will increase the surface area by a factor of four. Thin wall dielectric space frame radomes are approximately 35 percent less expensive than a comparable 3-layer sandwich core radome.

Mechanical Considerations

Most sandwich radomes are designed to operate with wind loads of up to 150mph and snow and ice loading of up to 50 lb-ft^2. Structural supports are generally used for thin laminate radomes while the flange structure of sandwich radomes provides the basis for support.

- Wall Design: radome styles, # of layers, thickness, permittivity of materials, panel sizes and shape (flat is better), dome geometry, truncation, flange design.
- Ancillary inclusions; doors, hatches, hoists, lightning protection, lighting, hydrophobic coatings and accessory buildings.

Construction and Materials

Materials used in the construction of radomes include fiberglass, quartz, graphite and Kevlar. Resins include polyester, vinyl ester, cyanate ester and epoxies. Construction techniques include hand lamination, infusion and prepreg fibers. Laminate consistency is also a component in radome performance and as such some manufacturers only produce radomes using prepreg materials. Core materials such as honeycomb and foams (thermo formable cores) are used. For high toleranced specifications a clean room is required. No carbon can enter the laminate as this can significantly reduce system performance. ***See Table 1 and 2 on page 4.***

DiElectric Properties of Reinforcements

Table 1: Radome materials and their electrical properties. (x-band data).

Reinforcement:	Relative Permittivity:	Loss Tangent:
E-Glass	6.06	.004
S-Glass	5.2	.007
D-Glass	4	.005
Spectra	2.25	.0004
Kevlar	4.1	.02
Quartz	3.8	.0001
Reinforcement:	Relative Permittivity:	Loss Tangent:
Polyester	2.95	.007
Epoxy	3.6	.04

Table 2: Combined materials and their electrical properties.

Reinforcement:	Resin	Relative Permittivity:	Loss Tangent:
E-Glass	Epoxy	4.4	.016
	Polyester	4.7	.015
D-Glass	Polycyanate	3.45	.009
Spectra	Epoxy	2.8	.004
Kevlar	Polyester	3.5	.05
Quartz	Epoxy	3.12	.011
	Polyester	3.6	.012

Operating Frequency Considerations (Focus on Sandwich Radomes)

A-Sandwich radomes can be tuned if the foam core thickness is varied for a particular RF frequency to achieve a desired insertion loss. Insertion loss reduces the available signal, decreasing effective radiated power and G/T (the ability of the antenna to receive a weak signal).

In order to maintain minimum transmission loss the core thickness would vary from 1in at 3 GHz to 1/4in at 8GHz. The insertion loss of sandwich material is a function of the thickness of the core. By varying the thickness, optimal performance is achieved for the particular frequency of interest. This is known as quarter wave matching.

- Insertion loss – Total energy loss due to reflection and absorption loss.
- Reflection loss – Energy loss because it is reflected by the radome.
- Absorption loss – Energy loss because it is absorbed and converted to heat.

Detailed formula and calculations can be found in: Analysis of Radome Enclosed Antennas ** Dennis J. Kozakoff.*

Radome Geometry Considerations

Three common varying configurations of radome geometries in use classified by the number of different panels used to construct them. 3-Panel, 5-Panel and Quasi-random radomes.

The geometry chosen can cause a scattering error at certain frequencies. If the radome were constructed of identical panels the error would be repeated. To minimize this scattering the radome can be designed in a random panel design configuration or the quasi-random panel. Quasi-random geometry radomes may have triangular, hexagonal or pentagonal panel shapes. A geodesic radome using triangular panels is an alternate implementation of the quasi-random radome geometry.

Framework shadowing is more complicated and depends on the radome geometry. Radome geometry is a term used to describe how the truncated sphere is separated into panel shapes. The mathematical process is known as tessellating the sphere. The orange peel style is practical for domes under 6.7m in diameter, while the Quasi-random is well suited for larger radomes. Not shown is the 5 panel “igloo” design.

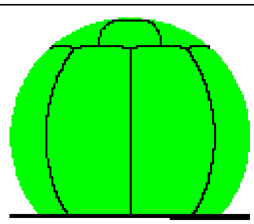	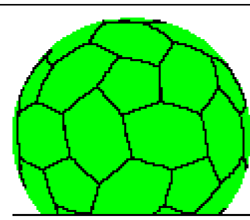
Fig. 1 Orange Peel	Fig 2 Quasi-Random

“Considering the radome geometry of Figures 1 and 2, the framework shadow on the reflector surface is a complicated geometry problem dependent on the radome diameter, panel size, the antenna diameter and antenna scan angle. To keep scattering loss low, normal practice is to use large radome panels. Therefore as the radome diameter gets smaller, the radome is manufactured from fewer panels.”

www.radome.net

“the quasi-randome geometry is fundamental to achieving enhanced RF performance.”

www.radome.net

a.manz@gematronik.com

Radome Flanges and Joints

The electromagnetic performance of a sandwich radome is made up of loss or scattering attributable to 1) the panel window area and 2) the panel flanges.

Loss and shift of phase due to the second factor (i.e., the panel flanges) can be nine times that of the panel window area. As a result, the flanges must be tuned or impedance-matched to the window area.

There are 2 flange framework forms common to the radome industry. The first type is called a perpendicular joint. The second type is called a parallel lap joint. Figures 3 and 4 picture flange framework forms.

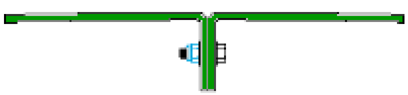

Fig. 3

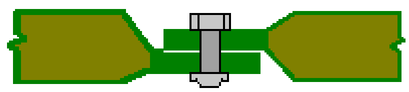

Fig. 4

The hardware for the perpendicular joint is internal to the radome. In contrast from Figure 4, the parallel lap joint hardware punctures the radome surface and is both external and internal to the radome. Parallel lap joint hardware protrusions collect dirt and fungus and allows corrosion to attack metals exposed to the outside environment. From a framework shadow point of view, the perpendicular joint has a very narrow cross section. This contrasts significantly with the large lap joint cross section shadowing the dish reflector. Due to its smaller width, the perpendicular joint has a scattering width 8 times smaller than its parallel lap joint counterpart.

Hydrophobic Coatings

Nothing degrades radome performance more than a thin sheet of water. Water has a very high dielectric constant and loss tangent at microwave frequencies. Non-hydrophobic surfaces cause water to stick to the radome, creating a thin film which serves as a shield to RF transmission, resulting in significant signal attenuation. Well-designed radomes feature a hydrophobic surface that causes water to bead up and run off. Even in high rain conditions, a radome with a hydrophobic surface has little additional attenuation. A surface is hydrophobic if the contact angle is greater than 90 degrees.

Photo above shows both a non-coated surface and a coated hydrophobic surface.

®HUZHENG/CS-101

For Additional Information see Following Titles and Website Links

Manufacturers of Radomes

- Competition Composites Inc.: www.fastcomposites.ca
- ESSCO: www2.L-3com.com
- AFC: www.radome.net
- Military Systems & Technology: www.militarysystems-tech.com
- Alan Dick Radar & Cellular Technology: www.alandickrc.com
- Tods Aerospace Limited: www.tods.co.uk
- L-3 Communications: www2.l-3com.com/the importance of hydrophobic coating.html

Appendix of Documents:

- Scattering Effect of Seams on Sandwich Radome Performance by Reuven Shavit
    - Scat-effect-in-sand-radomes.pdf

- NeverWet_White_Paper___General.pdf

- Electromagnetic Modelling of Dielectric Geodesic Radomes using the Finite Difference-Time Domain
    - Method by Stavros Papadopoulos: STAVROS_Papadopoulos_Thesis.pdf

- Radome Influence on Weather Radar Systems Principles and Calibration Issues
  by Alexander Manz, radcal-11-manz-radome.pdf

- Radomes and antennas Electronically Transparent Materials - Low Dielectric Composites
    - TCAC_radomesantennasguide.pdf

- Standard Molded Radomes ,
    - Standard-Molded-Radomes.pdf

- RFbeam Microwave GmbH,
    - AN-03-radome.pdf

- Analysis and Design of Radome in Millimeter Wave Band
    - Hongfu Meng and Wenbin Dou
    - InTech-Analysis_and_design_of_radome_in_millimeter_wave_band.pdf

- EEC (Enterprise Electronics Corporation)
    - Stealthradome.pdf

Other References

A Fundamental and Technical Review of Radomes
http://www.mpdigest.com/issue/articles/2008/may/mfg/default.asp

AFC Radome.Net-
www.Radome.net/tl.html#design

Micris ltd
www.micris.co.uk/radomes

Tods
www.tods.co.uk/radome/radomes.html

Legacy Radomes
www.legacyradomes.com

Comtek
www.comtek.com

Essco
www2.l-3.com/essco/radomes

MFG Galileo
www.moldedfiberglass.com

Saint-Gobain
www.radome.com

CSS
www.canspace.com

AlanDickInc
www.militarysystems-tech.com / www.alandickrc.com

Advanced Composites Engineering
www.Advancedcompositesengineering.com

Dielectric Constant, Strength, & Loss Tangent
www.rfcafe.com/references/electrical/dielectric-constants-strengths.htm

Geodesica (geodesic dome modeling software)

Hydrophobic coatings information:
http://cytonix.com/coatingdata.html

www2.l-3com.com/the importance of hydrophobic coating.html

http://www.cytonix.com/honeywell.html

Competition Composites Inc. Contact Information

Dave Bradly
President, Competition Composites Inc.
168 Wescar Lane, Carp, Ontario, Canada K0A 1L0
T: +1-613-599-6951
E: dave@fastcomposites.ca

