Waves and Devices Chapter of IEEE Phoenix

Radomes

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Contents

Introduction to Radomes

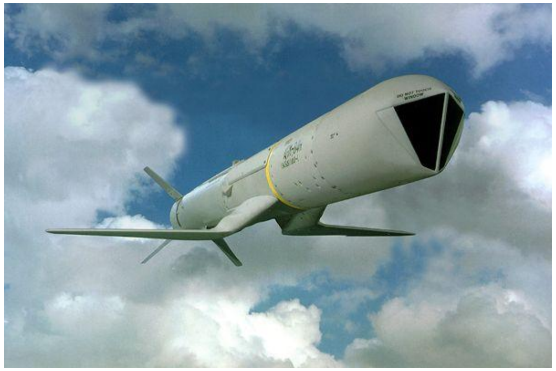
- A radome (from RADAR + Dome, coined circa 1944) is a dome or other structure protecting antenna equipment and made from an electromagnetically transparent material.

- Radomes may be designed to protect terrestrial antennas, spacecraft antennas, aircraft antennas, or even underwater applications.

- Radomes come in variety of shapes and sizes, and protect a wide variety of antenna types including weather radar, communications and navigation systems, and various sensors.

- Common radome types we see in Boeing:
    - Nose cone radomes
    - Leading/Trailing edge wing/tail radomes
    - Wing/tail tip radomes
    - Fuselage radomes

Aircraft Radomes



Boeing Photos

Terrestrial Radomes

Eurocontrol Photo

NASA Photo

NOAA Photo

Army Photo

USAF Photo

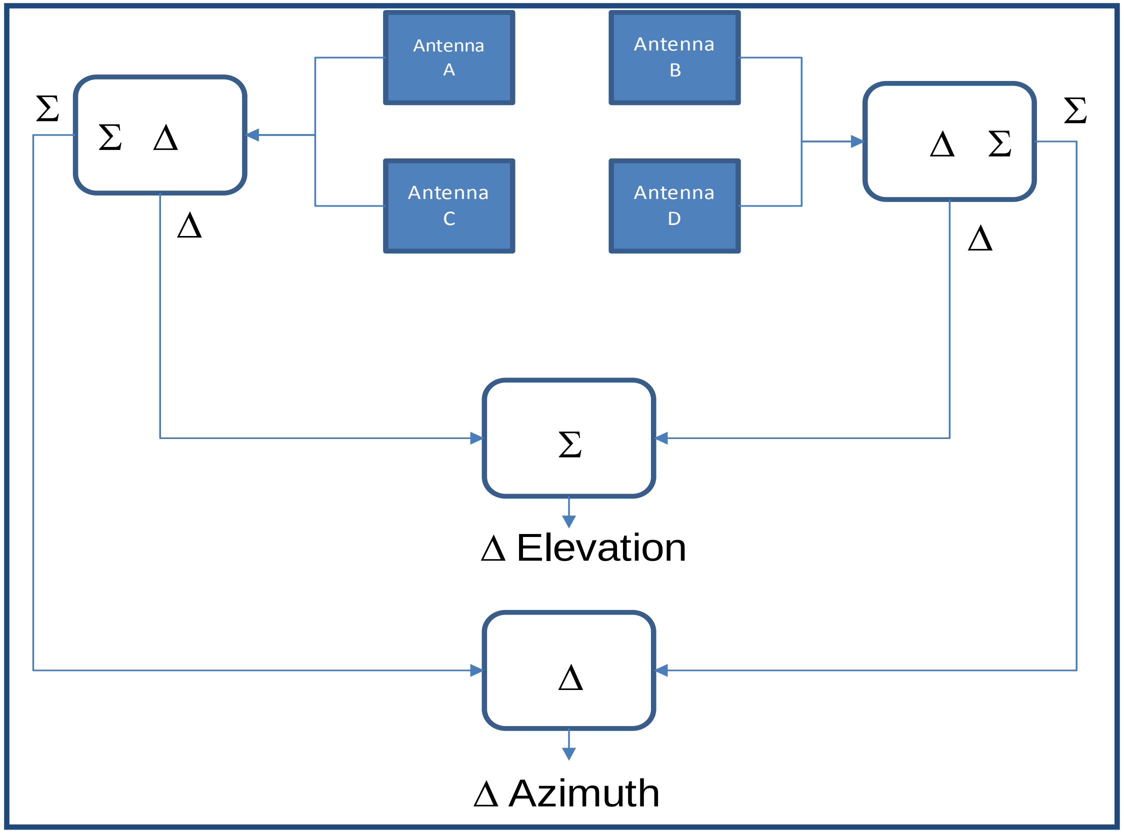
General Radome Effects to System Performance

Radomes affect systems by changing the antenna pattern. They can:

1. Introduce angle of arrival errors
2. Refract or reflect radiated signals
3. Depolarize radiated signals
4. Attenuate radiated signals
5. Change input impedance or resonant frequency of nearby antennas

Measurement of Angle of Arrival

- RADAR systems are sensitive to angle of arrival errors.
- The target's azimuth and elevation angles are determined through summation and difference of signal amplitudes received by the individual antennas.
- Some systems compensate for radome wall in software and predict errors across the flight envelope.



Amplitude Comparison Monopulse RADAR
Angle of Arrival Algorithm for a 4-Antenna Array

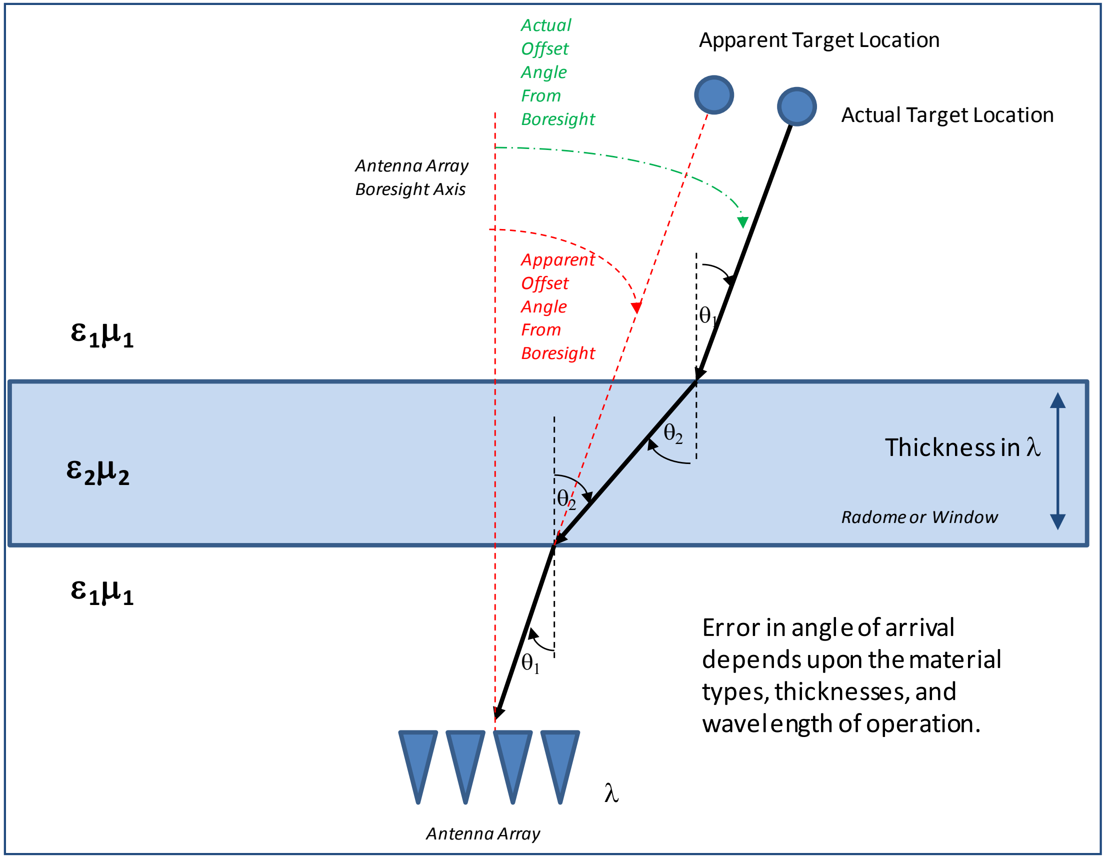
Real versus Apparent Angle of Arrival

- Radomes may introduce errors in the measurement of angle of arrival due to refraction of the incoming signal through the radome wall layers.

– This effect is called Boresight Error (BSE).

- No boresight error occurs for signals normal to the medium.

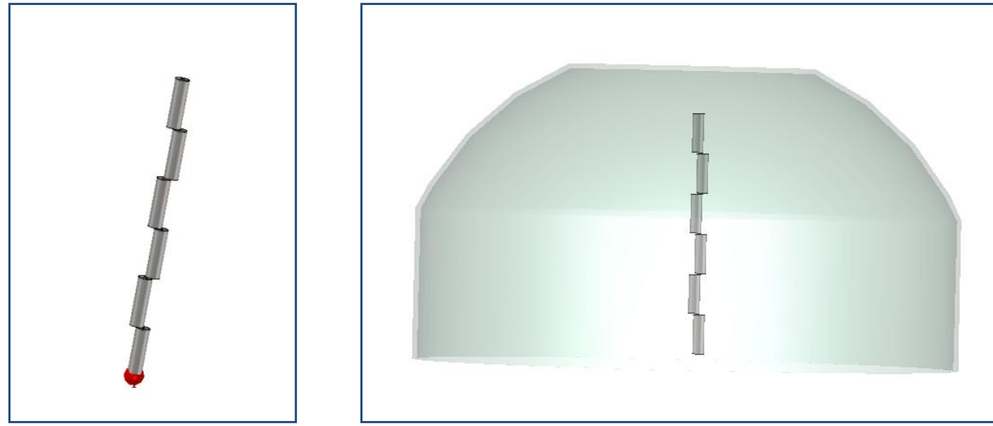
- Boresight error occurs for signals off-normal to the medium.



Boresight Error

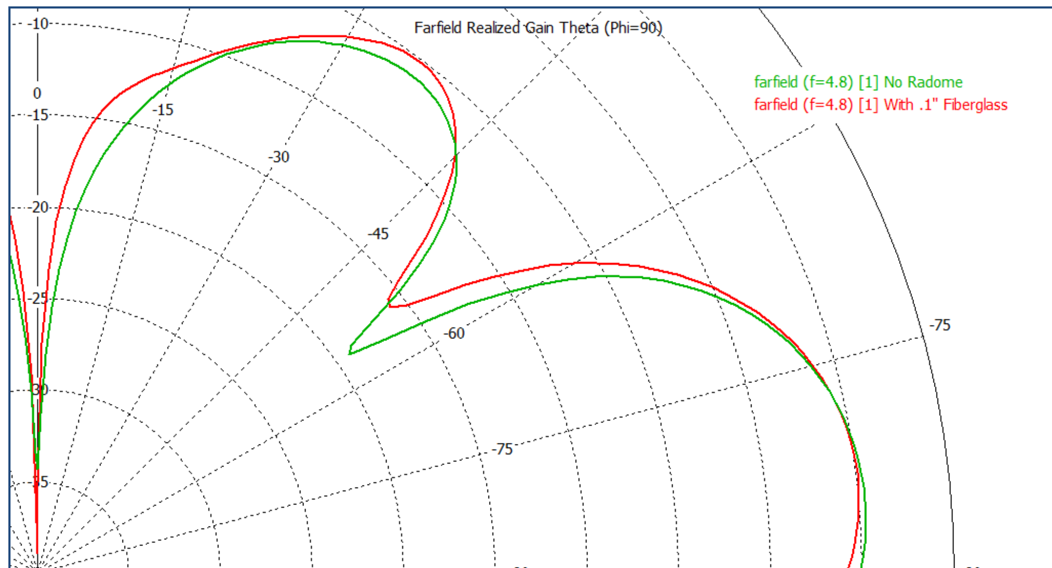
Far Field Distortion

- Shown at right is the elevation radiation pattern of a 4.8 GHz coaxial collinear antenna, with and without a .1” thick fiberglass (lossless) radome
  – *Note the wavelength is about 3” and the radome is 5” from the antenna*
  – *Note primary lobe angles of incidence to radome wall are approximately 0 to 40 degrees.*



Coaxial Collinear Antenna with and without Radome

- At each angle, the change in gain is a combination of :
  – power loss
  – depolarization
  – reflections
  – refractions



Realized Gain Comparison

- Minimizing the transmission loss over all angles minimizes these losses

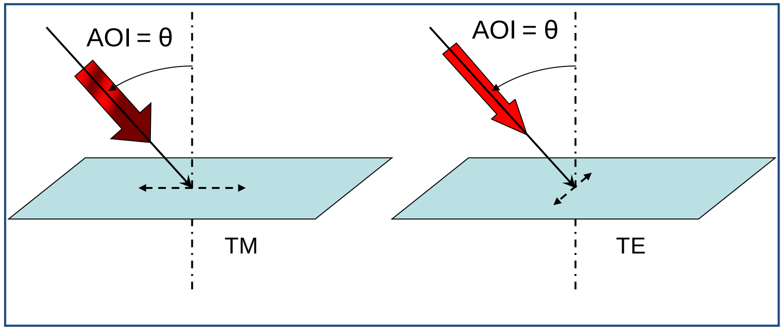
Depolarization: TE-TM Mode Balance

•Angles of reflection and diffraction are polarization dependent

•TE (transverse electric) and TM (transverse magnetic) components of the incoming TEM electromagnetic plane wave are considered separately.

•The figure depicts definitions of AOI and TE and TM components of the electromagnetic wave required to account for polarization effects.

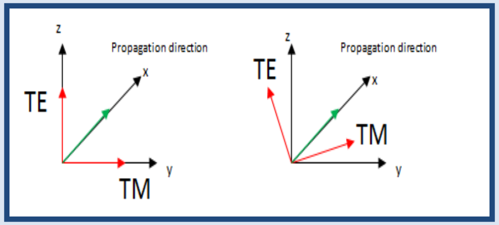
•Axial Ratio is a measure of TE-TM balance usually taught in context with circularly or elliptically polarized waves

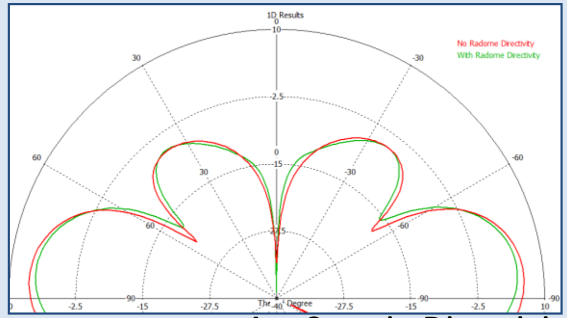


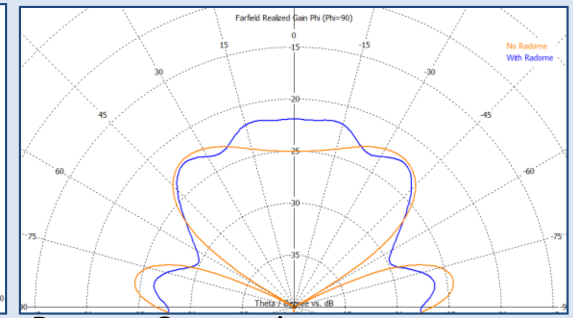
TE and TM polarizations are relative to the radome normal vector, and are independent of vehicle coordinates.

Far Field Distortion Contributors

TEM Wave Rotation Effects

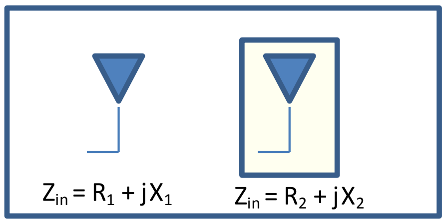


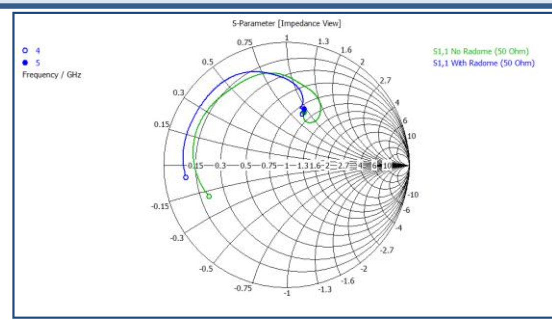


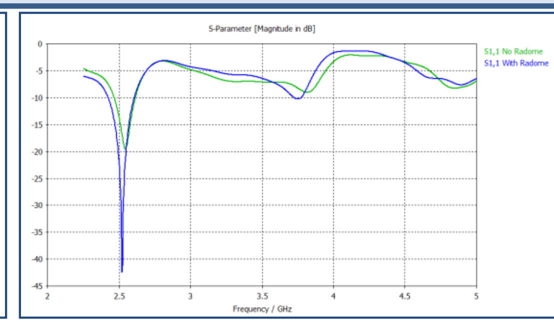


Are Seen in Directivity Pattern Comparisons

VSWR/Input Impedance Effects







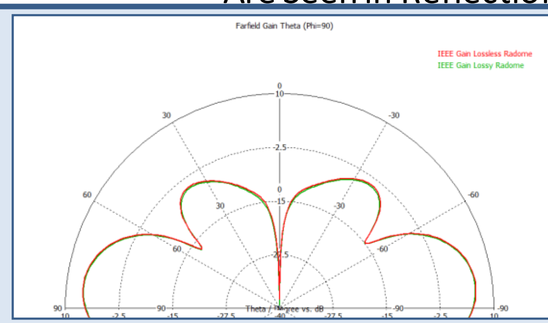
Are Seen in Reflection Coefficient Comparisons

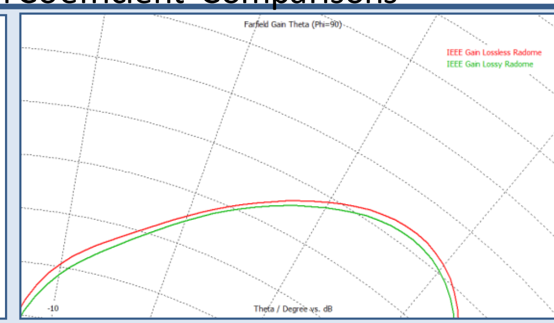
Dielectic Heating Effects

$\varepsilon = \varepsilon' + j\varepsilon''$

$\sigma' = \omega\varepsilon''$

Power Factor $= E^2 \times \sigma'$





Are Seen in IEEE Gain Pattern Comparisons

IEEE

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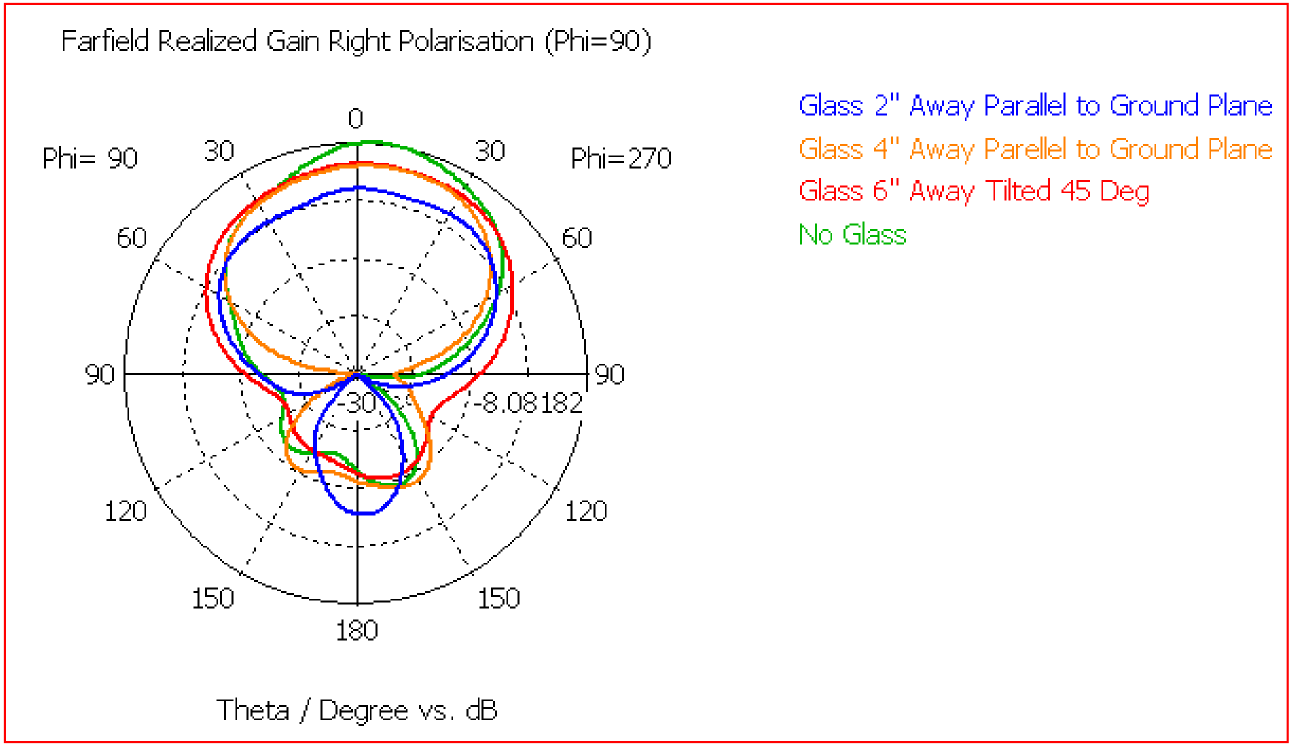
Radome Electrical Design Considerations

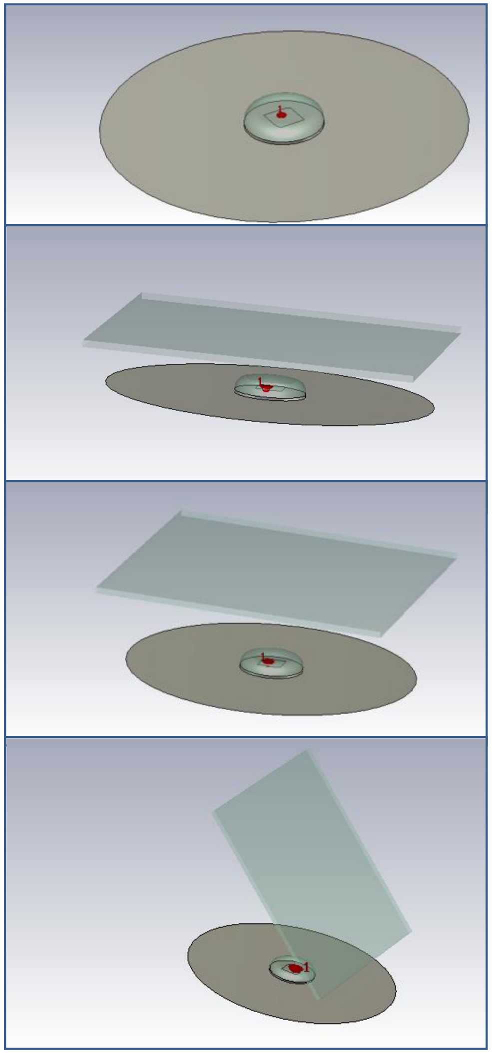
- Radome impact on nearby antenna performance depends upon:

  1. Material composition and thickness of the radome wall
  2. Wavelength and polarization of the antenna's electromagnetic radiation
  3. Distance from the antenna to the radome wall
  4. Geometry of the antenna
  5. Geometry of the radome wall

Pattern Distortion:
Elevation Pattern of a GPS Antenna Under Glass

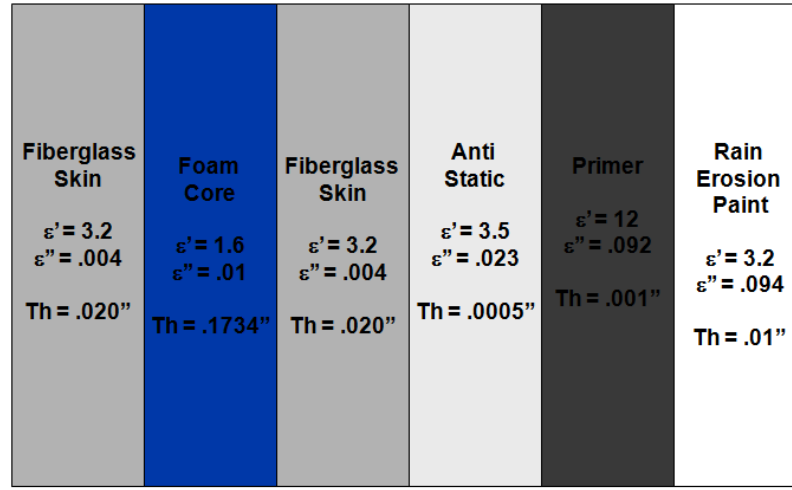
It's not just antennas under radomes that experience pattern distortion.   Here is a GPS antenna under glass, with glass at different heights and attitudes relative to the antenna:



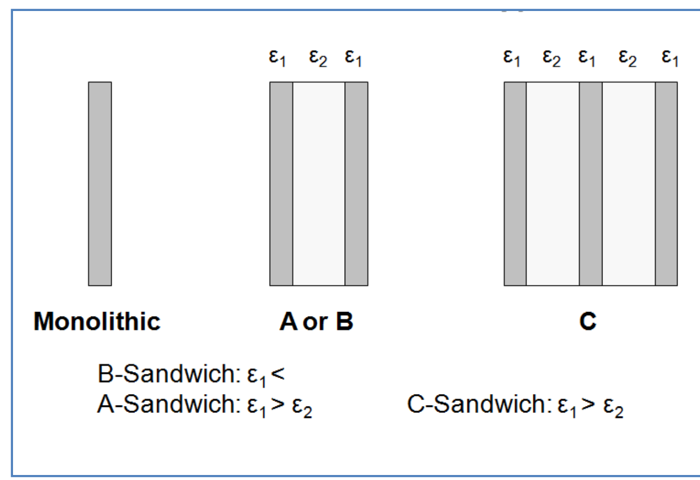


Radome Wall Construction

- 3 Radome Wall Types:
  - Monolithic – One or more plies of skin material, for structurally less demanding applications. A single layer wall which is constructed of a fiberglass or variant that is $\lambda/10$ thick or less, is practically transparent to an impinging electromagnetic wave.
  - A or B sandwich – Lightweight core material with face sheets for added strength without weight. Bandpass characteristics are tuned with inner core thickness, as outer face sheet thickness is set by structural properties.
  - C sandwich – Alternating layers of core and face sheets for broadband low loss performance and more complex bandpass tuning.
- Designing a radome involves determining the thickness and permittivity of each wall layer.



Typical Radome Wall



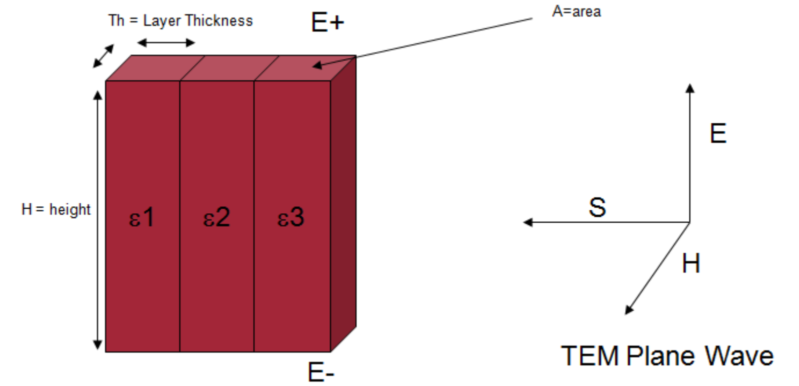
Radome Wall Sandwich Types

Effective Medium Approximation

- Using the capacitor definition, the effective permittivity of a stack can be calculated.

- <u>Rule of Thumb:</u>

  If the wavelength is greater than 10 x the total thickness of the radome wall, this can greatly simplify and speed full wave analysis without loss of gain accuracy.



Capacitor Definition:	$C = \varepsilon A/H$
From Diagram:	$C_n = \varepsilon A/H = \varepsilon_n \times W \times Th_n/H$
For Parallel Capacitors:	$C_{eff} = \sum C_n$
	$\varepsilon_{eff} \times Th_{total} = \sum \varepsilon_n \times Th_n$

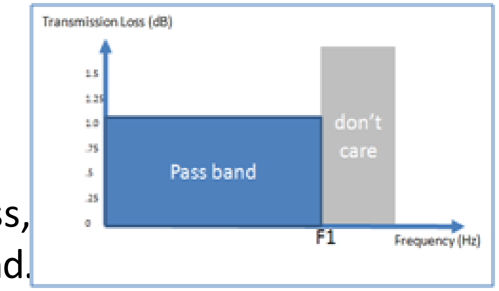
Steps in Radome Wall Design

1. Determine frequency and bandwidth of operation and required transmission losses.

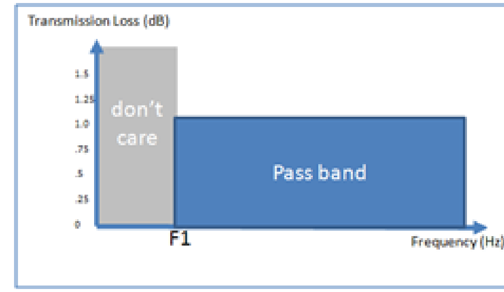
   A. Response may be low pass, high pass, band pass, multi-band, or broadband.

   B. Most radome design is for inband performance; that is, within the operational band of the antenna under the radome. Out of band performance is also sometimes considered for interference or other reasons.

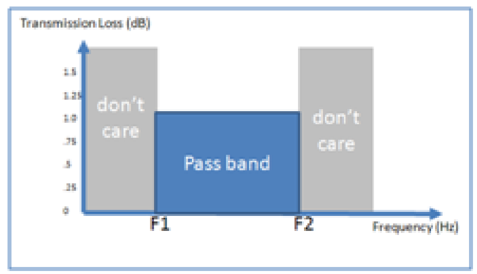
   C. Typical commercial requirement is .5 to 1 dB of inband transmission loss.



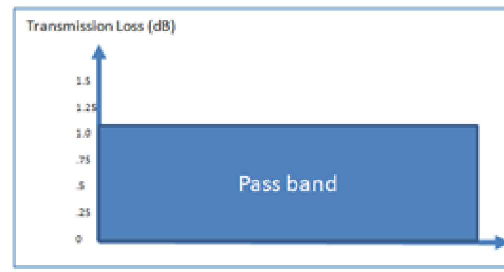
Low Pass Response



High Pass Response



Band Pass Response



Broad Band Response

Steps in Radome Wall Design

2. Select materials and determine desired radome shape

   A. Define mechanical characteristics including weight, load handling, and shape.

   B. Select materials from the list of qualified materials most commonly used.

   C. Ensure the shape is feasible from manufacturing standpoint and define tooling or manufacturing approach.

- Key considerations for materials selection are
  - Strength, hardness, and flexibility
  - Material density of the material
  - Water absorption of the material (*hydrophobic* or *hydrophilic*)
  - Particle impact resistance (rain erosion)
  - Temperature range
  - Electrical properties (dielectric constant and loss tangent)

- Materials used in radomes include:
  - Honeycomb Core
  - Rohacell® Foam
  - Filament wound composites (Glass fiber, carbon fiber, and aramid fibers)
  - Resins (epoxy, polyester, vinylester, polyurethane, phenolics, furans, polyimides. Epoxy generally preferred for aerospace.)
  - Syntactic Foams
  - Nylon variants, e.g. Nylon 11, 12, under various trade names.
  - Astroquartz®
  - Fiberglass

Steps in Radome Wall Design

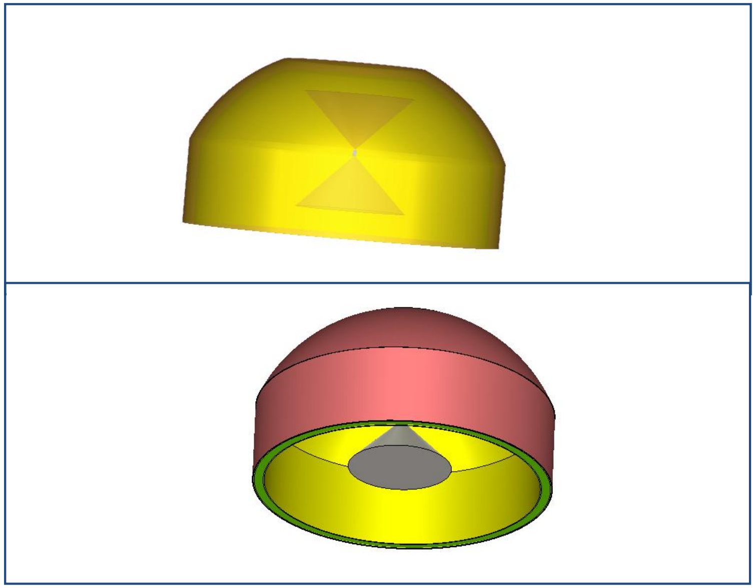
3. Optimize the stack for required transmission loss and TE/TM mode balance versus angle of incidence and frequency.
   A. 1D stack codes allow sweeps of core thickness (or dielectric constant) versus AOI and frequency.
   B. 1D stack code analysis is appropriate <u>only</u> if radome is in the antenna far-field If not, we <u>must</u> use a 3D full wave analysis and not a 1D approach.

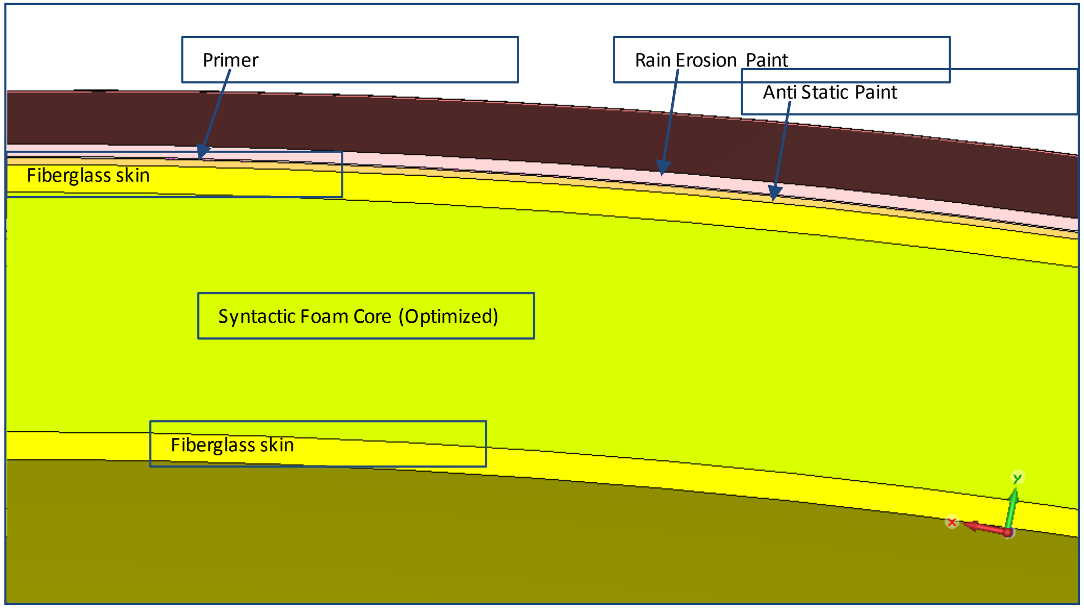
Fiberglass Skin	Foam Core	Fiberglass Skin	Anti Static	Primer	Rain Erosion Paint
ε' = 3.2	ε' = 1.6	ε' = 3.2	ε' = 3.5	ε' = 12	ε' = 3.2
ε" = .004	ε" = .01	ε" = .004	ε" = .023	ε" = .092	ε" = .094
Th = .020" (FIXED)	Th = X (Variable)	Th = .020" (FIXED)	Th = .0005" (FIXED)	Th = .001" (FIXED)	Th = .01" (FIXED)

An Example of an A-Sandwich with Top Coats

4. Add lightning strike provisions such as diverter strips to the design.

Example 1:
.5 dB A-Sandwich at Ku Band



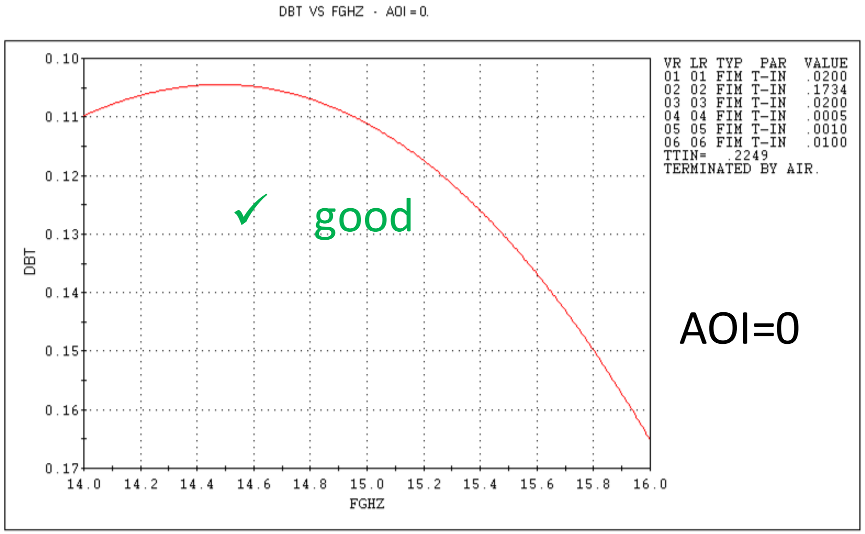


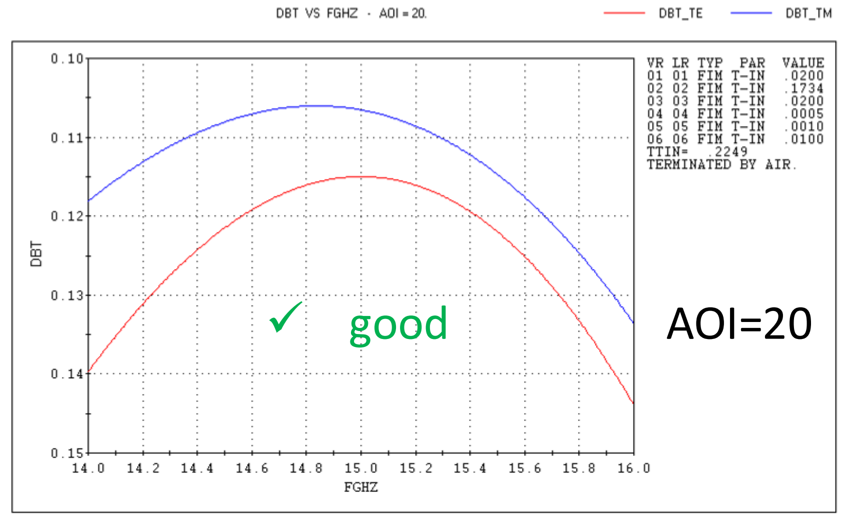
Since we are using a bi-cone in this example, we optimize for AOI=50 degrees and obtain a thickness of .1734"

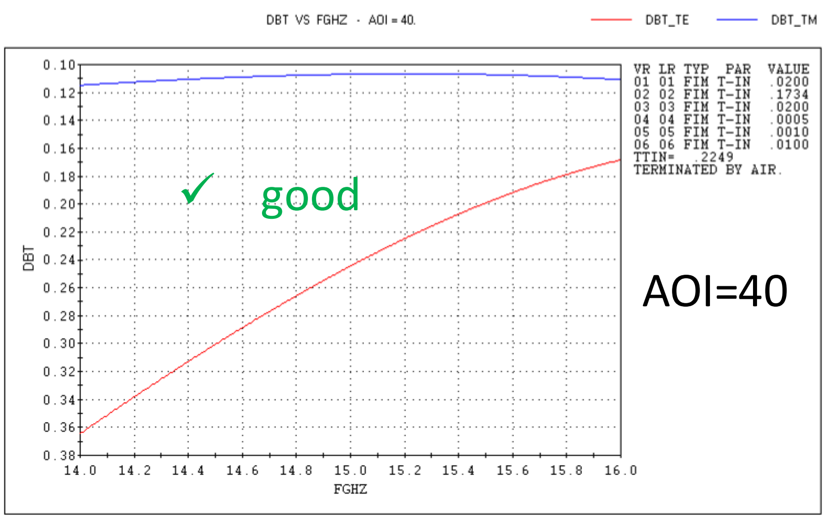
CURRENT STACK CONFIGURATION. -- STACK IS TERMINATED BY AIR.

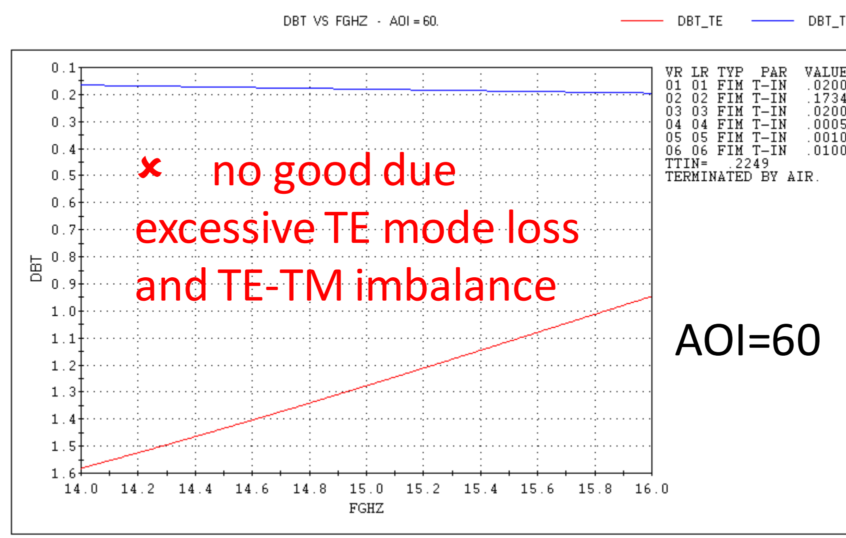
VAR #	LAYER #	TYPE	PAR	VALUE	LO-LIM	HI-LIM	STEP	% RANGE	T-IN	LBS/SQFT	STATUS
1	1	FIM	T-IN	0.0200	0.0200	0.0200	0.0000		0.0200	0.0667	FIXED
2	2	FIM	T-IN	0.1734	0.0500	0.5000	0.0100	27.4306	0.1734	0.2891	FREE
3	3	FIM	T-IN	0.0200	0.0200	0.0200	0.0000		0.0200	0.0667	FIXED
4	4	FIM	T-IN	0.0005	0.0005	0.0005	0.0000		0.0005	0.0008	FIXED
5	5	FIM	T-IN	0.0010	0.0010	0.0010	0.0000		0.0010	0.0017	FIXED
6	6	FIM	T-IN	0.0100	0.0100	0.0100	0.0000		0.0100	0.0167	FIXED

Example 1:
TE-TM Balance for Different AOI's

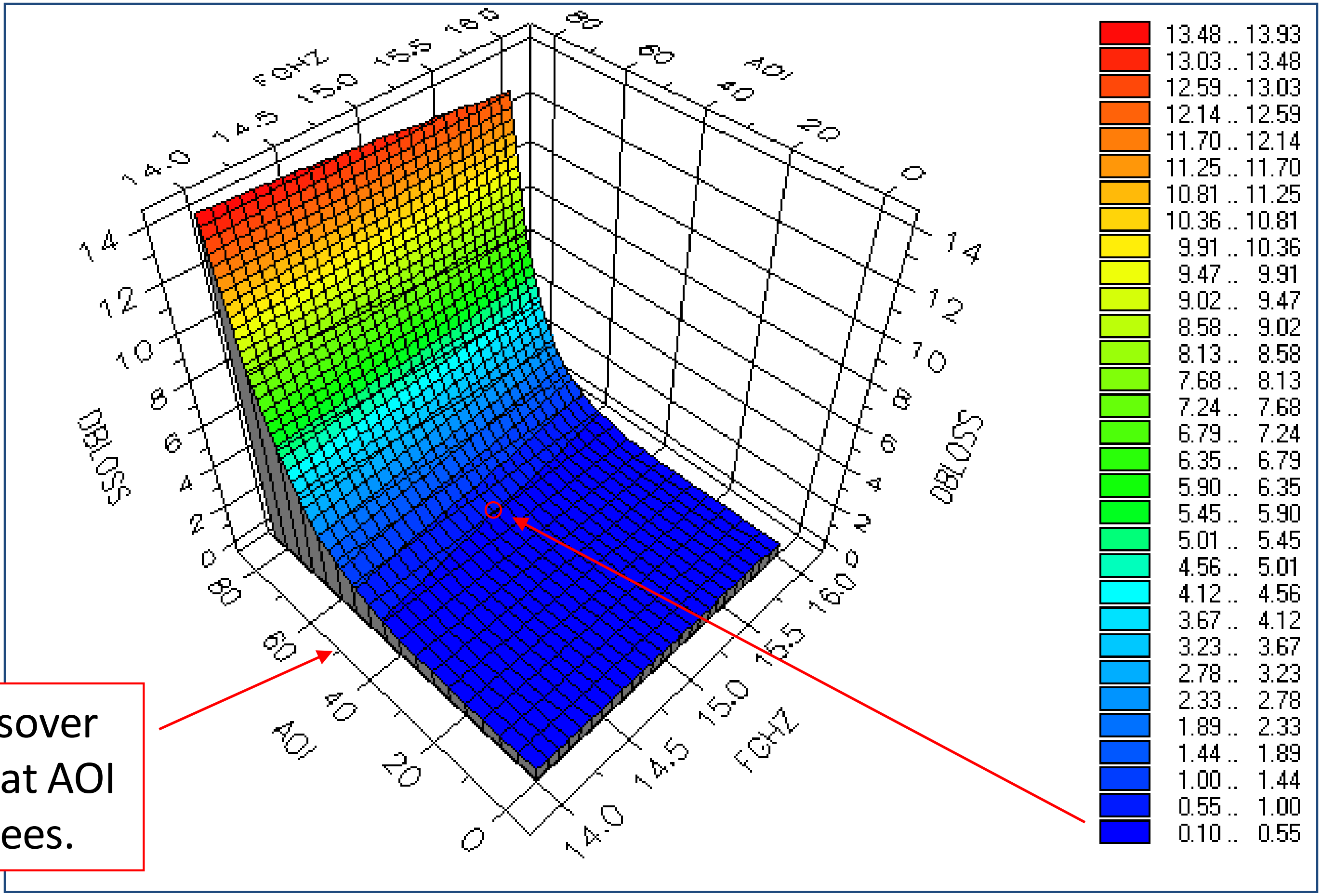








Example 1 Result:
AOI vs Transmission Loss vs Frequency

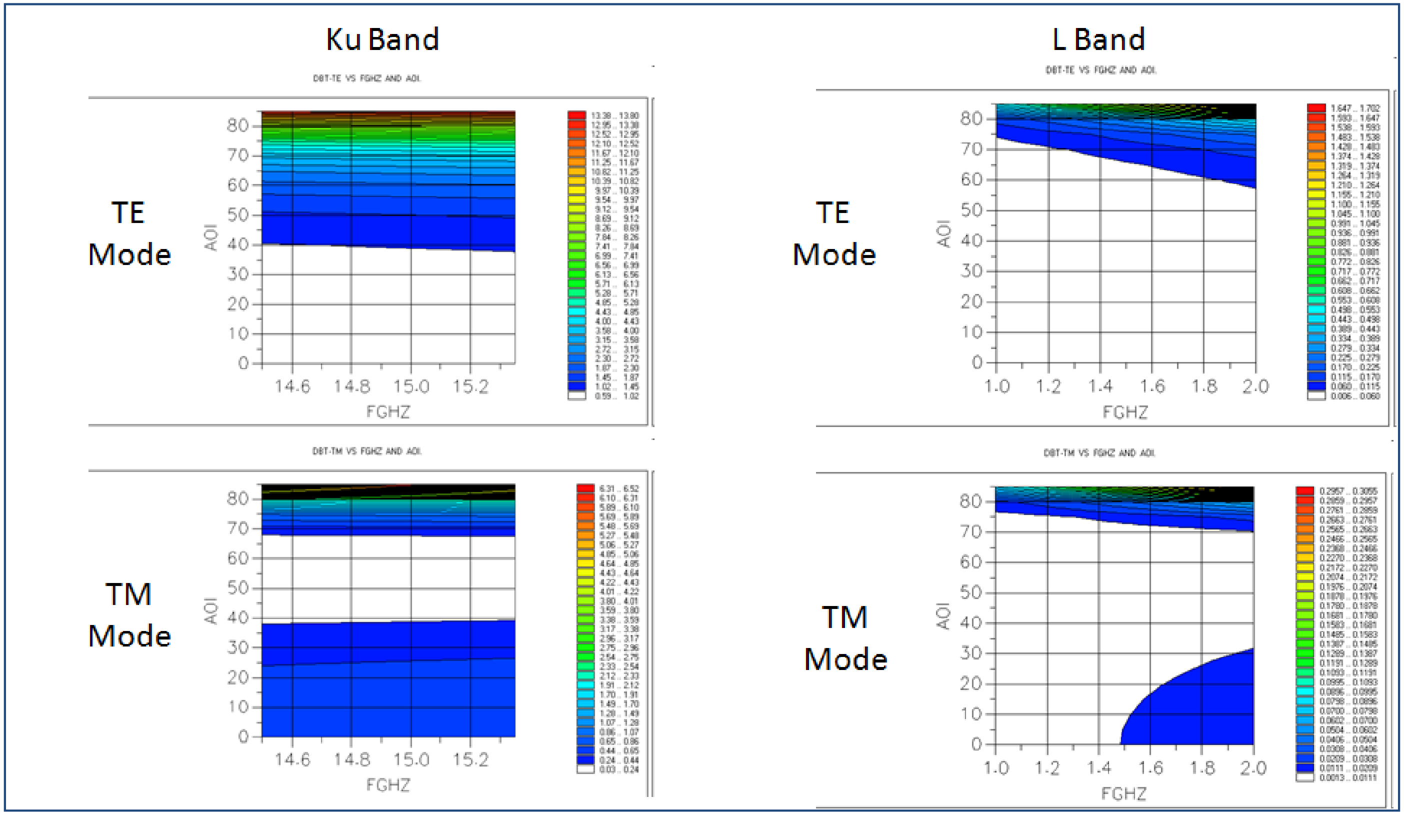


.5 dB Crossover at 15 GHz at AOI of 50 degrees.

This A-Sandwich has good TE/TM balance and .5 dB transmission loss out to ≈ 50 degrees AOI

Example 2:
L and Ku Band Analysis of 5 Gallon Bucket

- 5 Gallon Bucket used as a monolithic wall radome
- Dielectric of around 2.5 with loss tangent about .01
- .075" Thick Wall

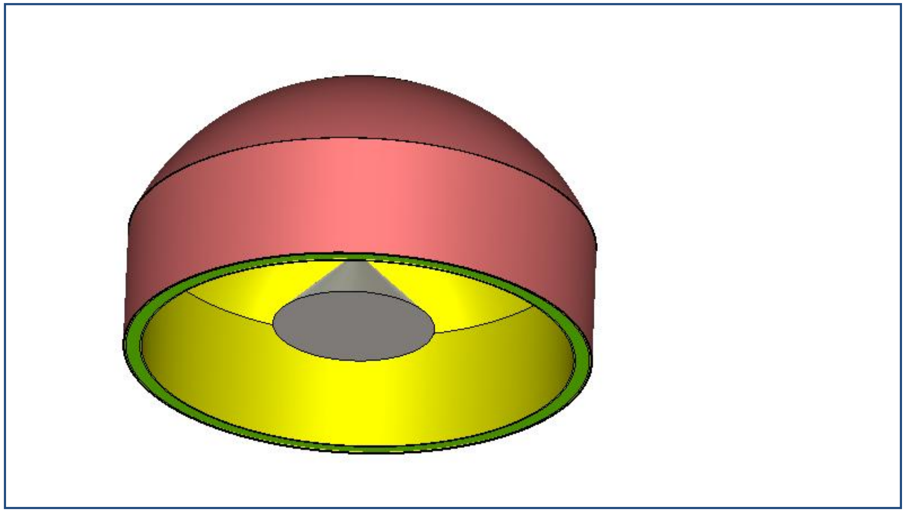


<u>Result:</u>

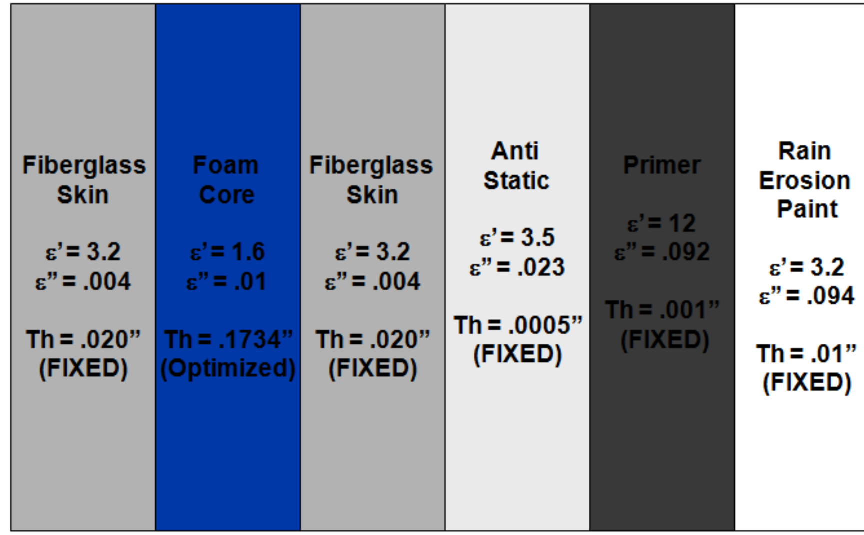
Ku Band: 1 dB balanced loss up to 40 degrees AOI

L Band: <1 dB loss up to almost 90 degrees AOI

Example 3:
Effective Medium Approximation



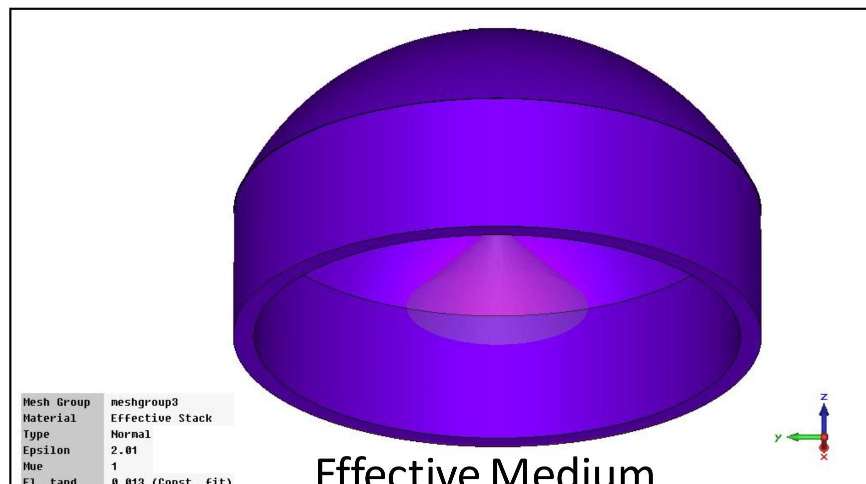
A-Sandwich



Equivalent Effective Approximation of Stack

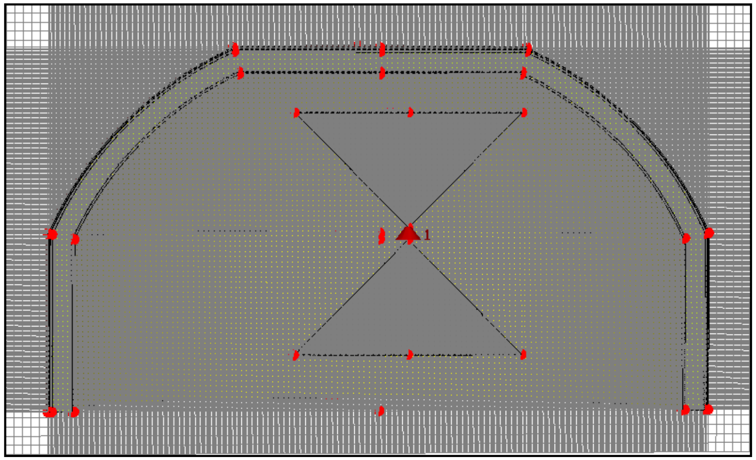
$$\varepsilon_{eff}' = \varepsilon_0 (3.2*.02 + 1.6*.1734 + 3.2*.02+3.5*.0005+12*.001+3.2*.01)/\ .2249 = 2.01\varepsilon_0$$

$$\varepsilon_{eff}'' = \varepsilon_0 (.004*.02 + .01*.1734 + .004*.02+.023*.0005+.092*.001+.094*.01)/\ .2249 = 0.013\varepsilon_0$$



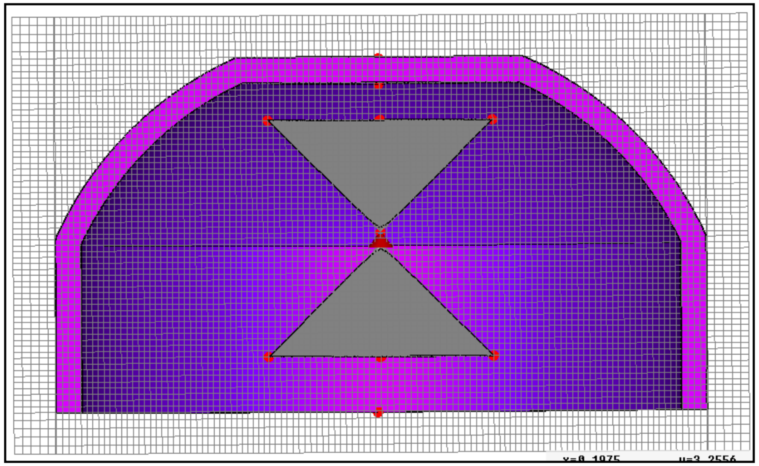
Effective Medium

Example 3:
Effective Medium vs A-Sandwich



Full A-Stack = 112M Mesh Cells

Runtime = 2 hours, 16 minutes, 48 seconds*



Effective medium = 1.06M Mesh Cells

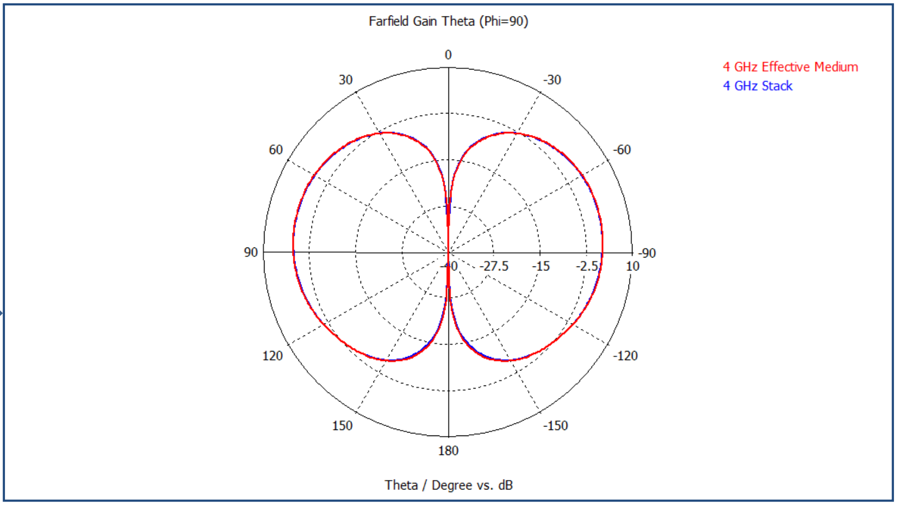
Runtime = 6 minutes 49 seconds*

** Hardware Platform: CST Microwave Studio t-Solver running on Dell T5500 Dual Hex Core With 72 GB RAM, no GPU acceleration, Windows 7*

Example 3:
Effective Medium vs A-Sandwich

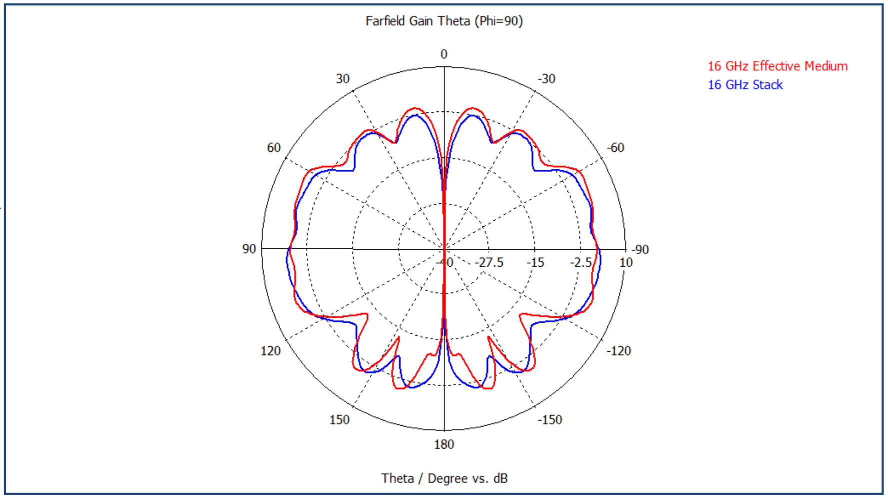
<u>λ at 4 Ghz = 2.955” -> λ/10 = .2955”</u>

Since λ/10 > total thickness (.2249”) , the effective medium approximation is accurate.



<u>λ at 16 GHz = .73875” -> λ/10=.073875”</u>

Since λ/10 < total thickness (.2249”) , the effective medium approximation is not accurate.



References

References for further reading:

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- I. Rudge et. al. The Handbook of Antenna Design, Vol. 2, Peter Peregrinus Ltd., 1983. (Radomes chapter by R.H.J. Cary)
- D. Hess, Radome Testing Lecture notes, Microwave Antenna Measurements Course Notes, UCLA Extension / MI Technologies, 15 May 2008.
- C. Balanis, Antenna Theory 3rd Ed., John Wiley & Sons, 2005.

Software codes used in this presentation:

- CST Microwave Studio 2014: www.cst.com
- VBROP from MUEPS: http://www.mueps.com/vbrop.pdf

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