SIMULATION OF ANTENNA MEASUREMENT RANGES USING ADVANCED COMPUTATIONAL TECHNIQUES

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Outline

- Simulation of Antenna Measurements
- Introduction to Computational Electromagnetics (CEM)
- CEM Solver Technologies
  - Full wave Solutions (MoM, MLFMM, FEM, FDTD)
  - Asymptotic Solutions (PO, RL-GO, UTD)
  - Hybrid Solutions
- Anechoic Chamber Modeling and Design
- Compact Range Modeling
- Conclusions

SIMULATION OF ANTENNA MEASUREMENTS

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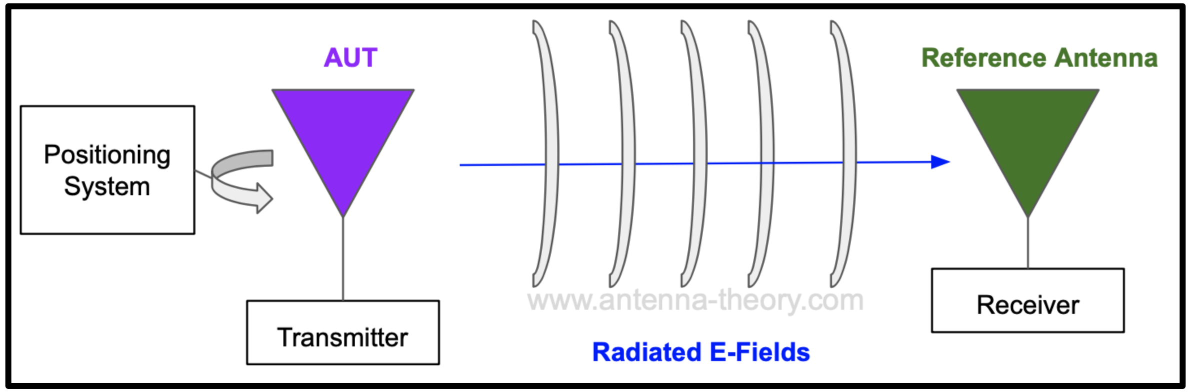
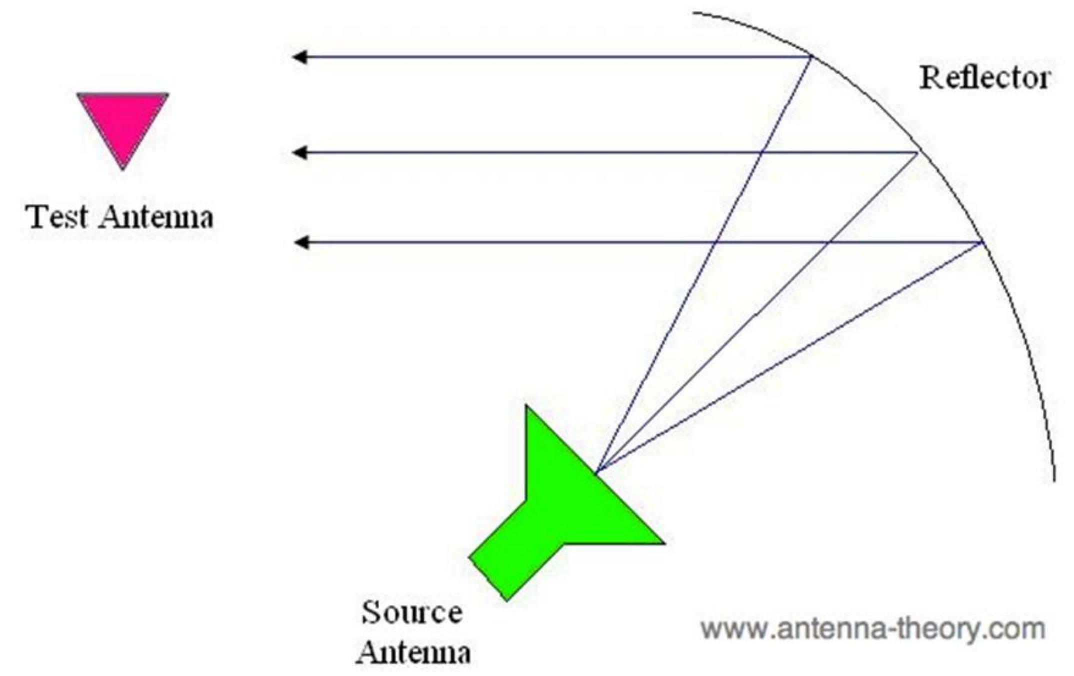
Antenna Measurements

Far field Measurements



Compact Range Measurements



Source: http://www.antenna-theory.com/measurements/antenna.php

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Benefits of Simulating Antenna Measurement Ranges

- **Enhance Measurements with Simulations**
- **Characterize Quiet Zone Behavior**
  - **Anechoic Chambers and Compact Ranges**
- **Obtain Critical Insight for Design Cycles**
  - **Antennas, Measurement Techniques, Chamber Designs**
- **Facilitate Decisions Based on Quantifiable Errors**
  - **Identify and Quantify Quiet Zone Disturbances**
  - **Predict Antenna Measurement Performance**
    - **Non-Ideal Environments**
  - **Predict Performance Levels and Costs**
    - **Constructing, Purchasing and Refurbishing Equipment**

Computational Electromagnetics (CEM)

- **Maxwell's equations describe electromagnetic field phenomena**
- **Computational electromagnetics: numerical solution of Maxwell's equations**

Computer modeling

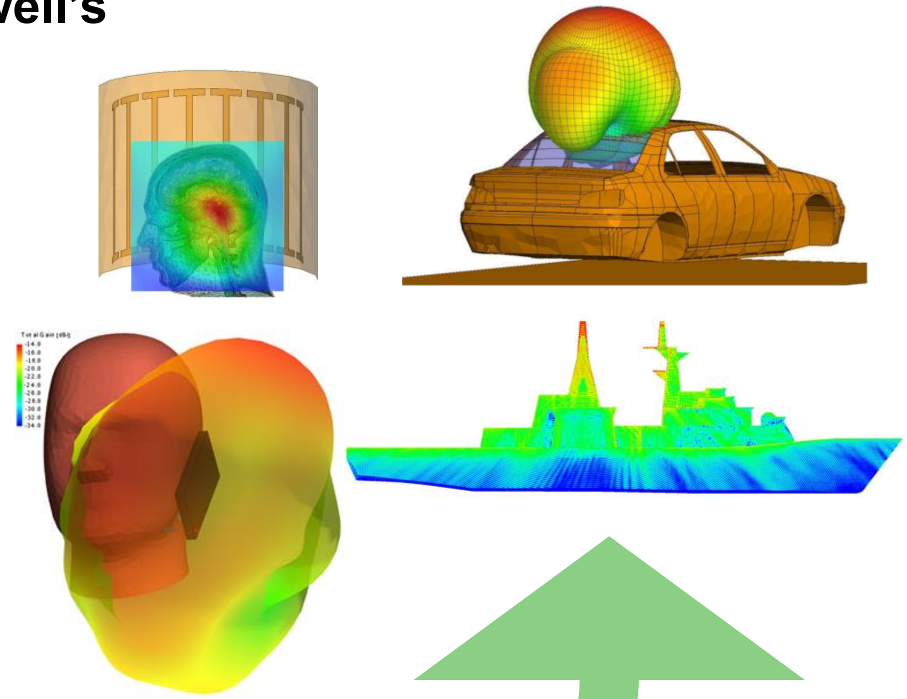
$$\vec{\nabla} \times \vec{H} = \vec{J}_v + \varepsilon \frac{d\vec{E}}{dt}$$

$$\vec{\nabla} \times \vec{E} = -\vec{M}_v - \mu \frac{d\vec{H}}{dt}$$

$$\vec{\nabla} \bullet \vec{H} = \frac{1}{\mu} \sigma_m$$

$$\vec{\nabla} \bullet \vec{E} = \frac{1}{\varepsilon} \sigma_e$$

CEM tool



Numerical analysis

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CEM Solver Technologies

A basic knowledge of CEM Solver Technologies is required to understand the advantages and disadvantages of each and how these affect their applicability to solve different classes of EM problems.

- **Full Wave Solutions**
  - Method of Moments (MoM)
  - Multilevel Fast Multipole Method (MLFMM)
  - Finite Element Method (FEM)
  - Finite Difference Time Domain (FDTD)

Full wave solutions solve Maxwell Equations accurately and provide reliable results provided a good CAD model and mesh is available.

- **Asymptotic Solutions**
  - Physical Optics (PO)
  - Large Element Physical Optics (LE-PO)
  - Ray Lunching Geometrical Optics (RL-GO) (also known as Shooting and Bouncing Ray – SBR method)
  - Uniform Theory of Diffraction (UTD)

Asymptotic solutions also solve Maxwell Equations, but with appropriate assumptions and approximations. They also can provide reasonably accurate results, provided the approximations and assumptions are properly considered during the simulation process.

CEM Solver Technologies

- **Hybrid Solutions**
  - FEM/MoM/MLFMM
  - MoM/PO
  - MLFMM/PO
  - MoM/LE-PO
  - MLFMM/LE-PO
  - MoM/RL-GO
  - MoM/UTD

While full wave solutions are accurate, they are computationally expensive when applied to electrically large structures.

While asymptotic solutions may provide an alternative, they may not be suitable for modeling complex antenna geometries.

Hybrid solutions that combine, both full wave and asymptotic solutions can facilitate simulation of electrically large antenna problems with less computational resources, but at the same time providing required accuracy.

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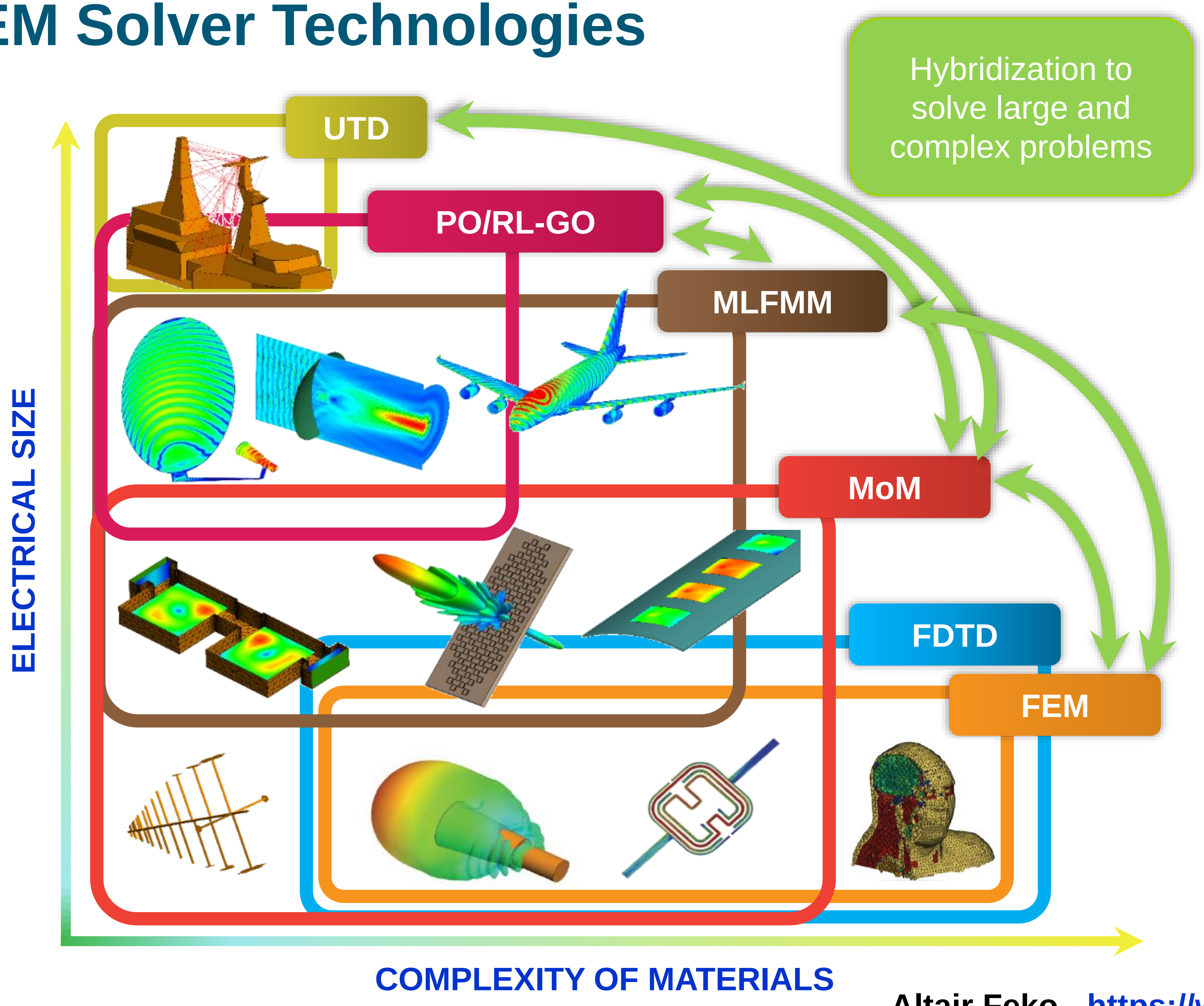
CEM Solver Technologies



Asymptotic Methods
(high-frequency approximation)

Full-wave Methods

(physically rigorous solution)

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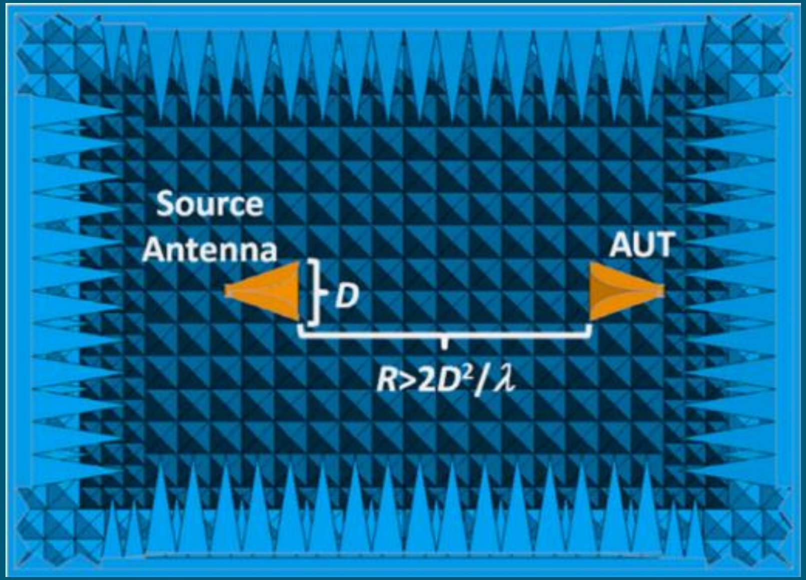
FAR FIELD MEASUREMENTS



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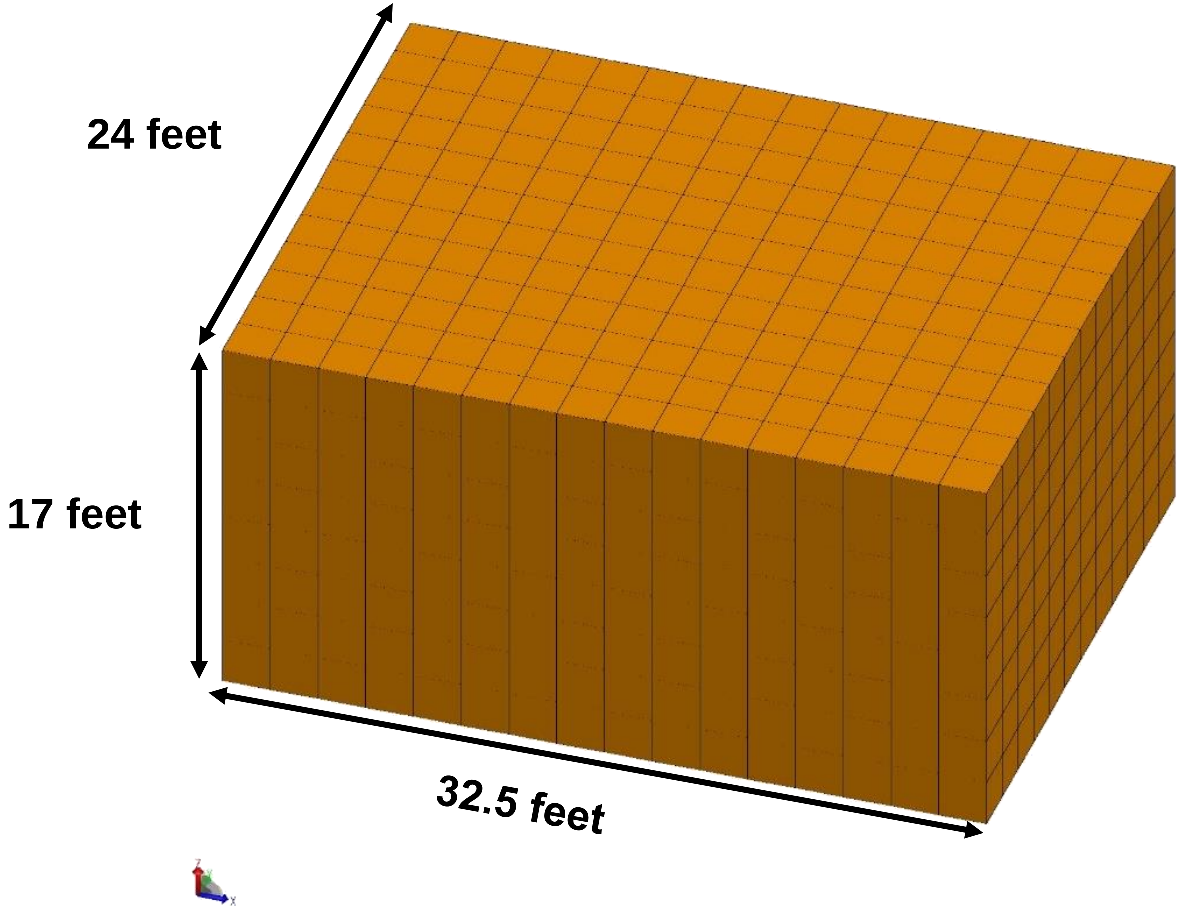
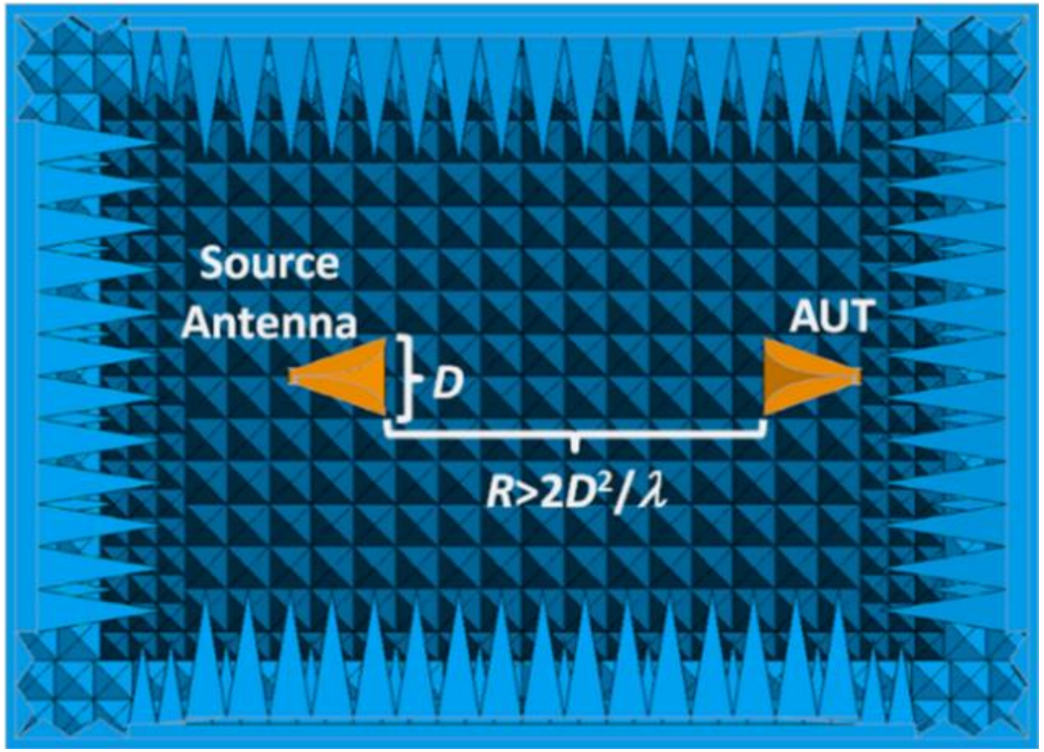
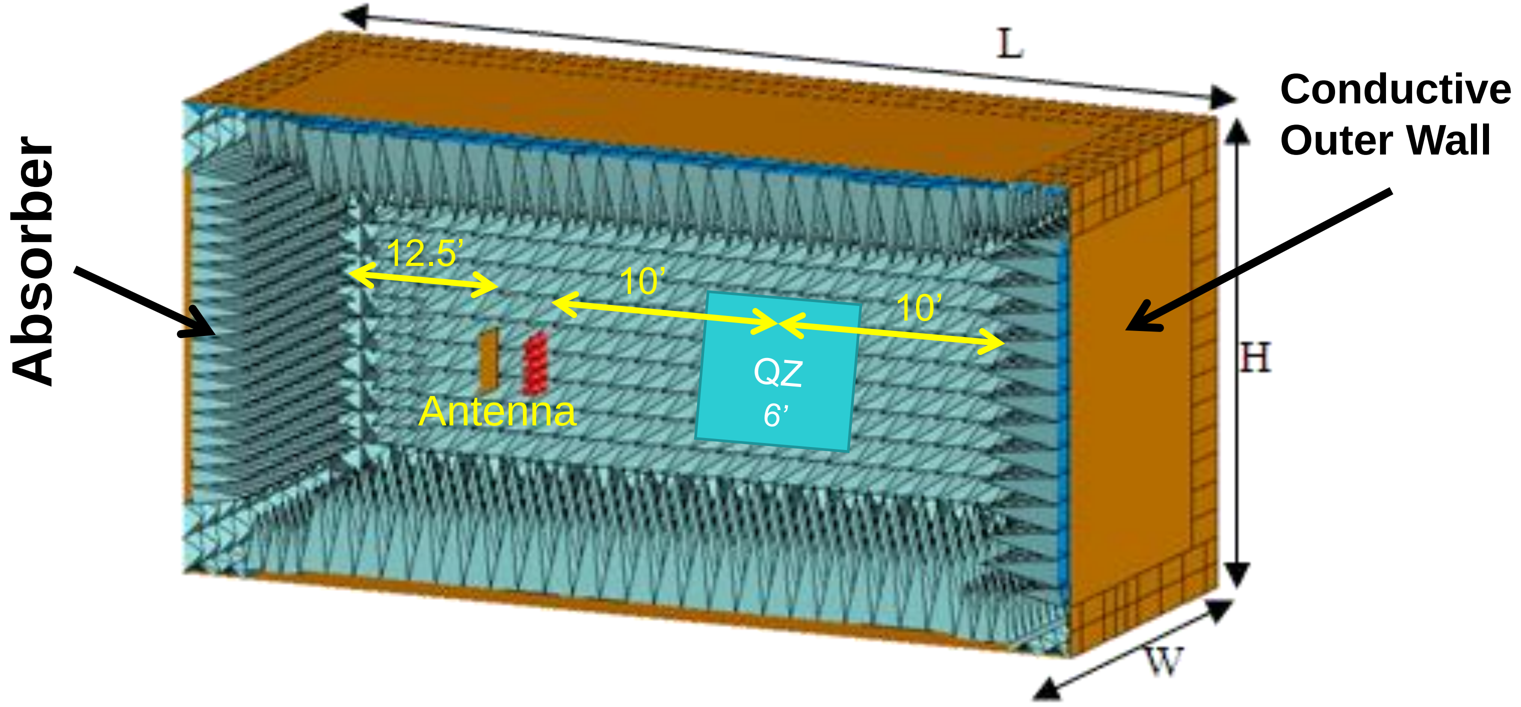
Anechoic Chamber Modeling

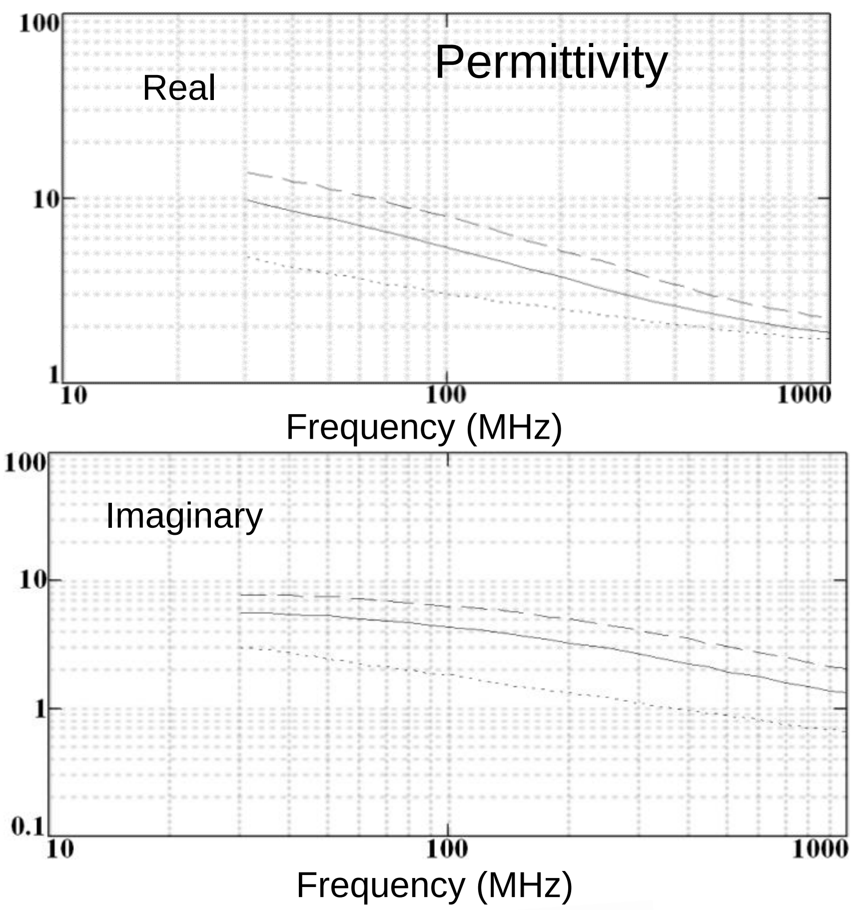
Rectangular Chamber





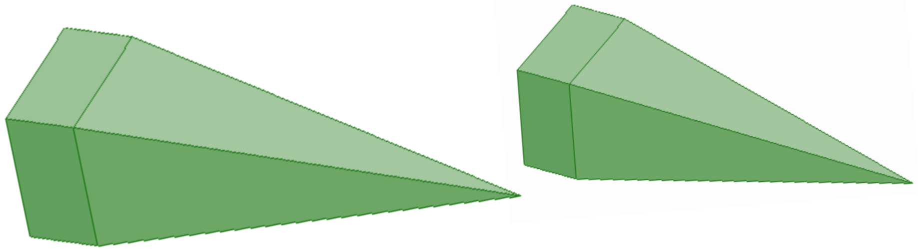
Anechoic Chamber Modeling





Absorber Pyramids:

1) **Transmit Wall: Base (8” x 8” x 4”); Height (24”)**
2) **Center Patch: Base (12” x 12” x 6”); Height (36”)**



Performance Analysis

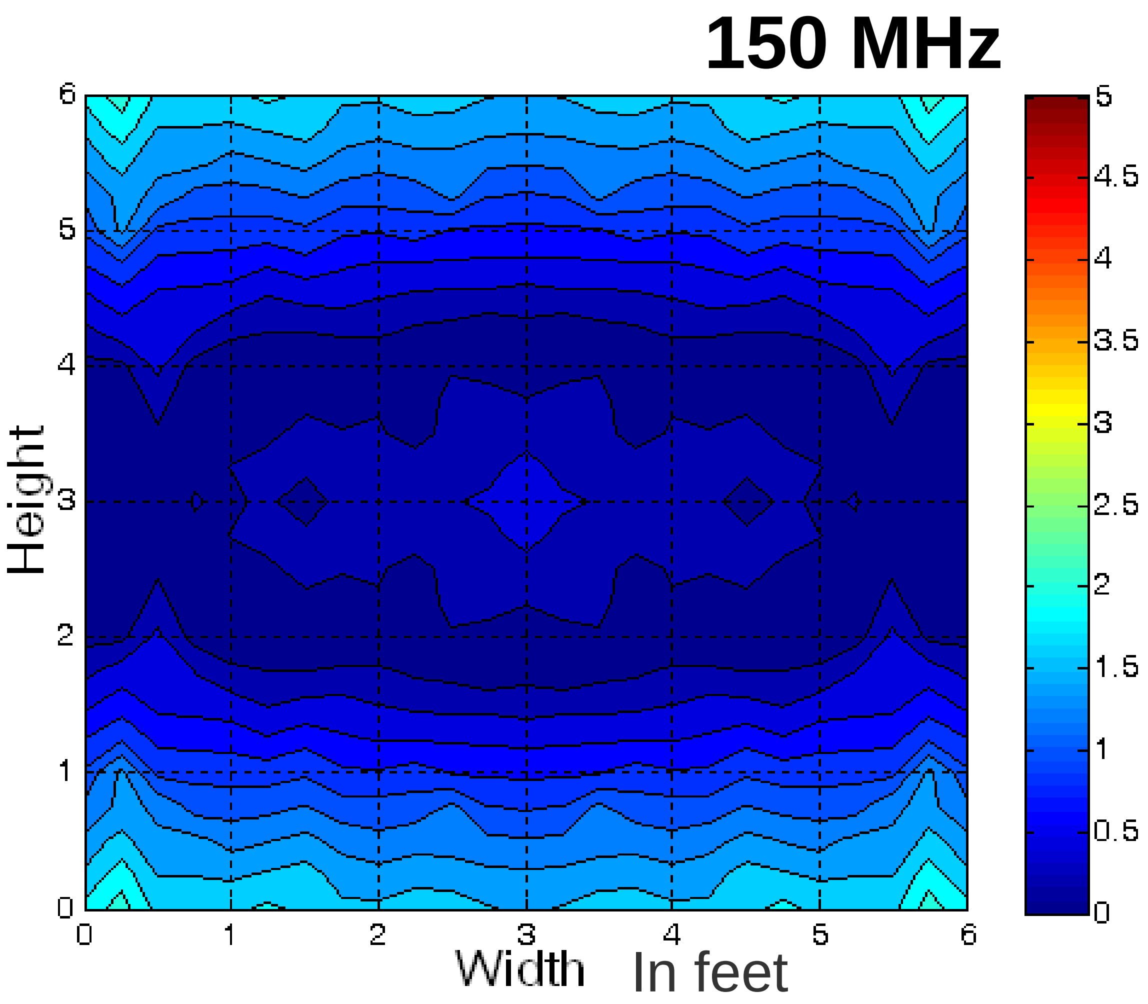
- **Chamber Error**

$$\varepsilon = \left| 20\log\sqrt{\frac{\sum|Chamber\ Field\ Components|^2}{\sum|Clear\ Site\ Field\ Components|^2}} \right|$$

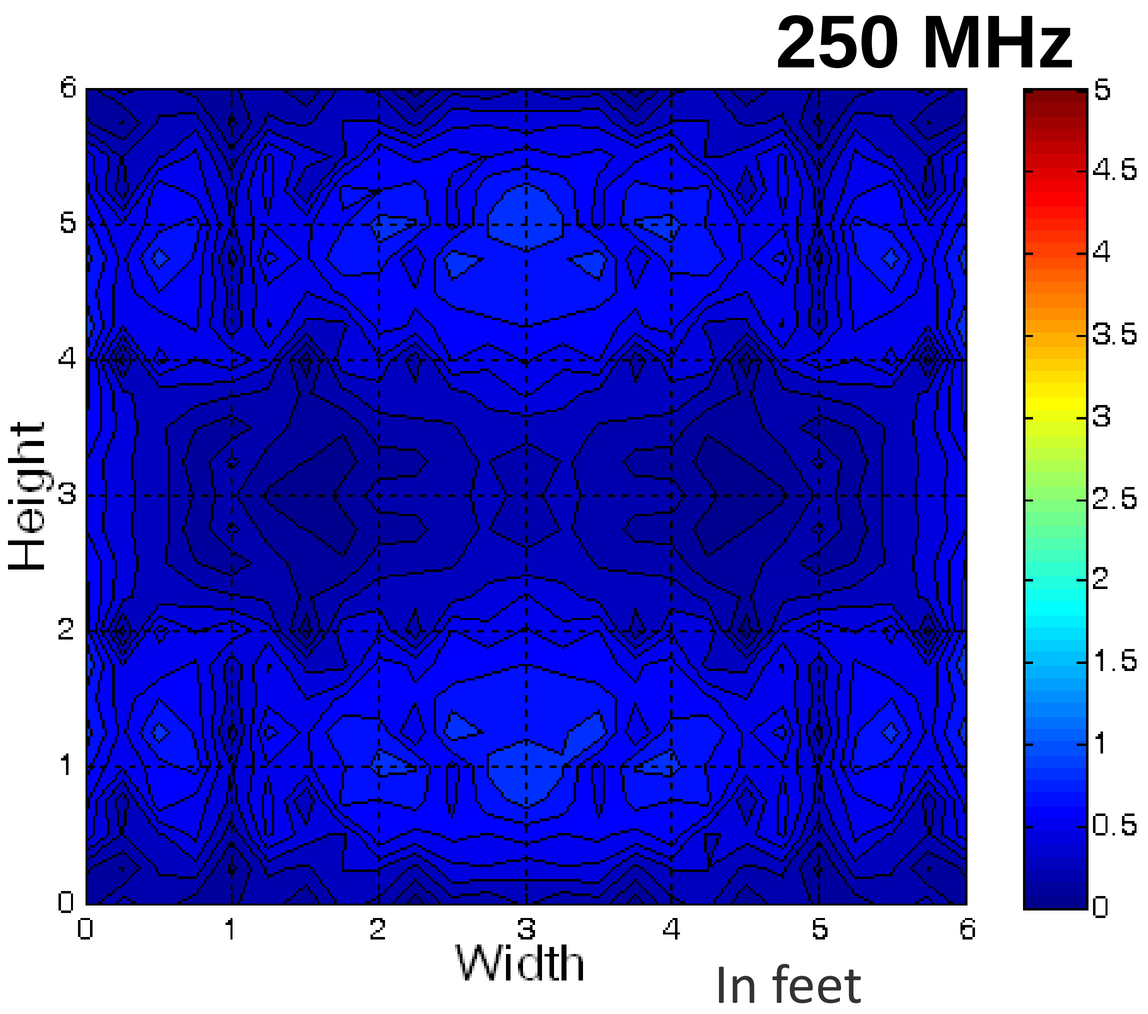
- **Axial Ratio**

$$AR = \left| 20\log\sqrt{\frac{\sum|H\ Pol\ Field\ Components|^2}{\sum|V\ Pol\ Field\ Components|^2}} \right|$$

Chamber Error



Maximum Chamber Error:
2.1 dB



Maximum Chamber Error:
0.9 dB

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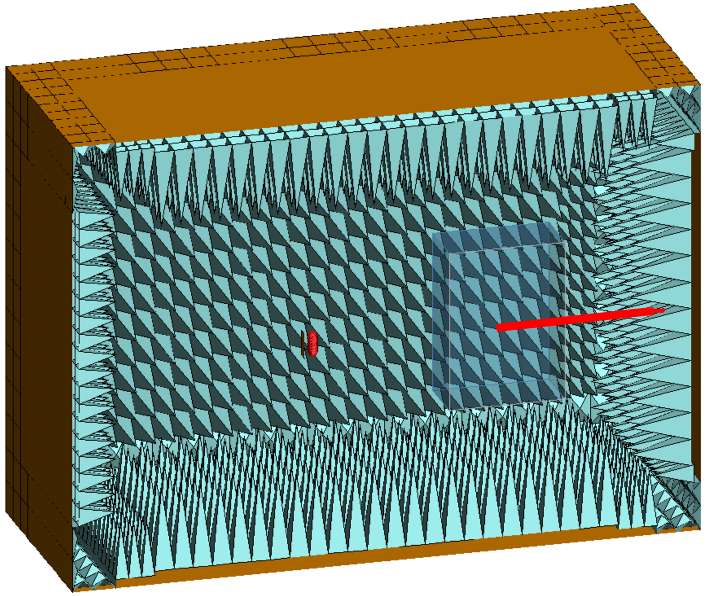
Axial Ratio

Low- & Medium-Gain Source Antenna @ 150 & 250 MHz



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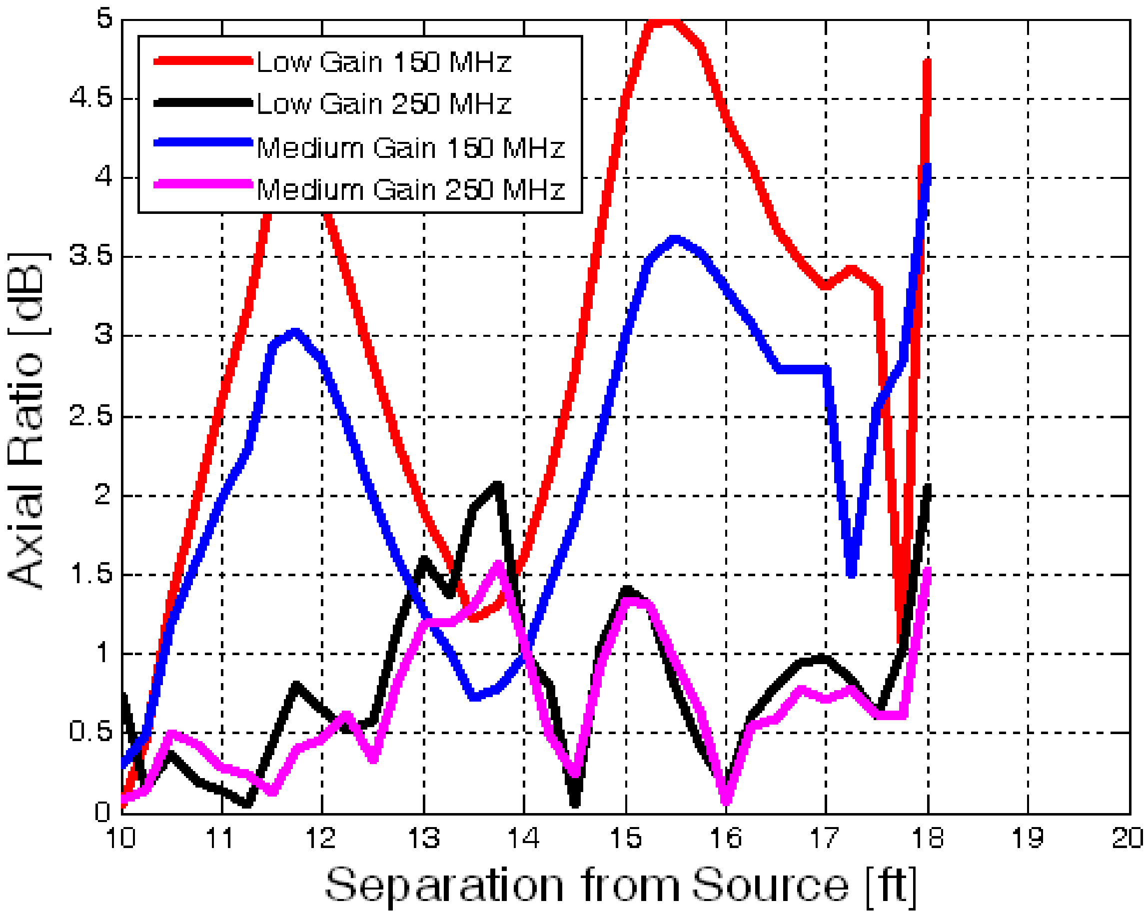

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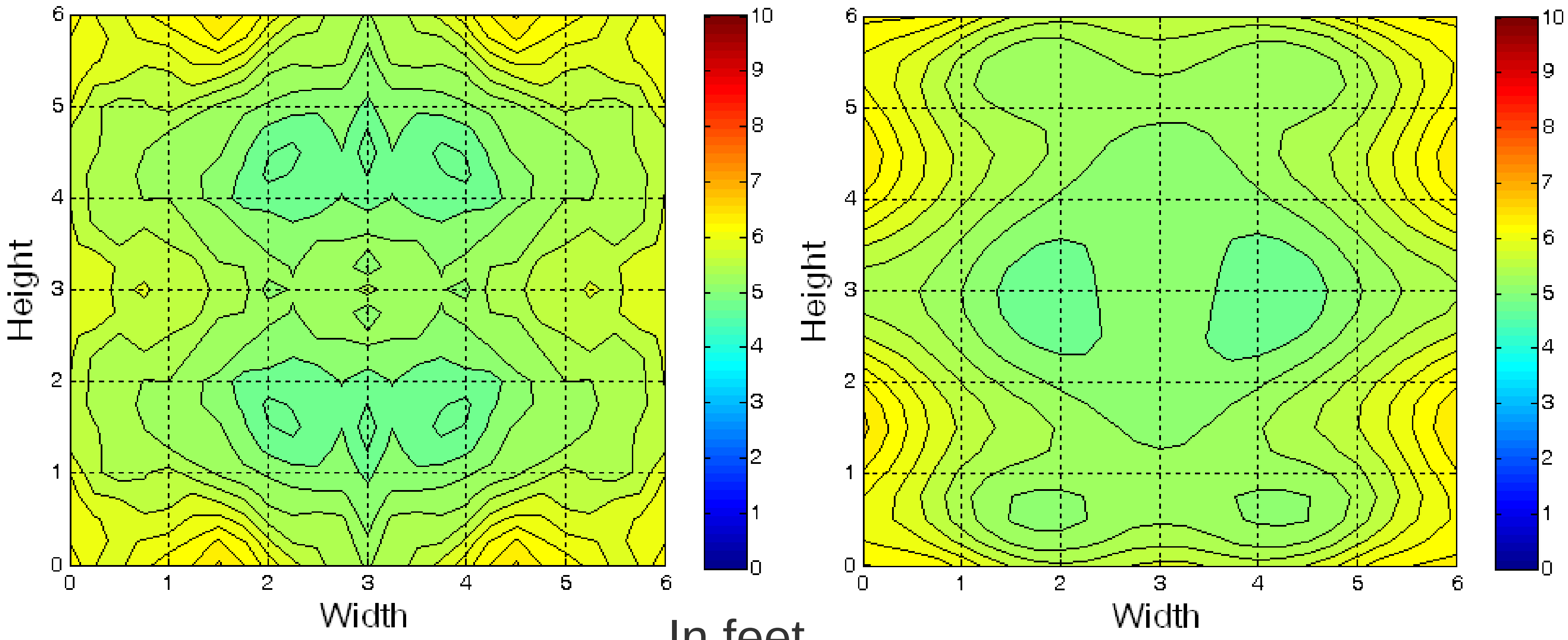
FEM and Physical Optics @ 500MHz
Quiet Zone Performance with H-Pol – Low Gain Antenna

FEM **Near Fields (dB)** **PO**



In feet

Finite Element Method
Unknowns: 10.9 Million
Solution: 8.4mins
Near Field: < 1 sec
Memory: 45GB
Cores: 8

Physical Optics
Unknowns: 2.5 Million
Solution: 35secs
Near Field: 7.7mins
Memory: 900MBs
Cores: 8

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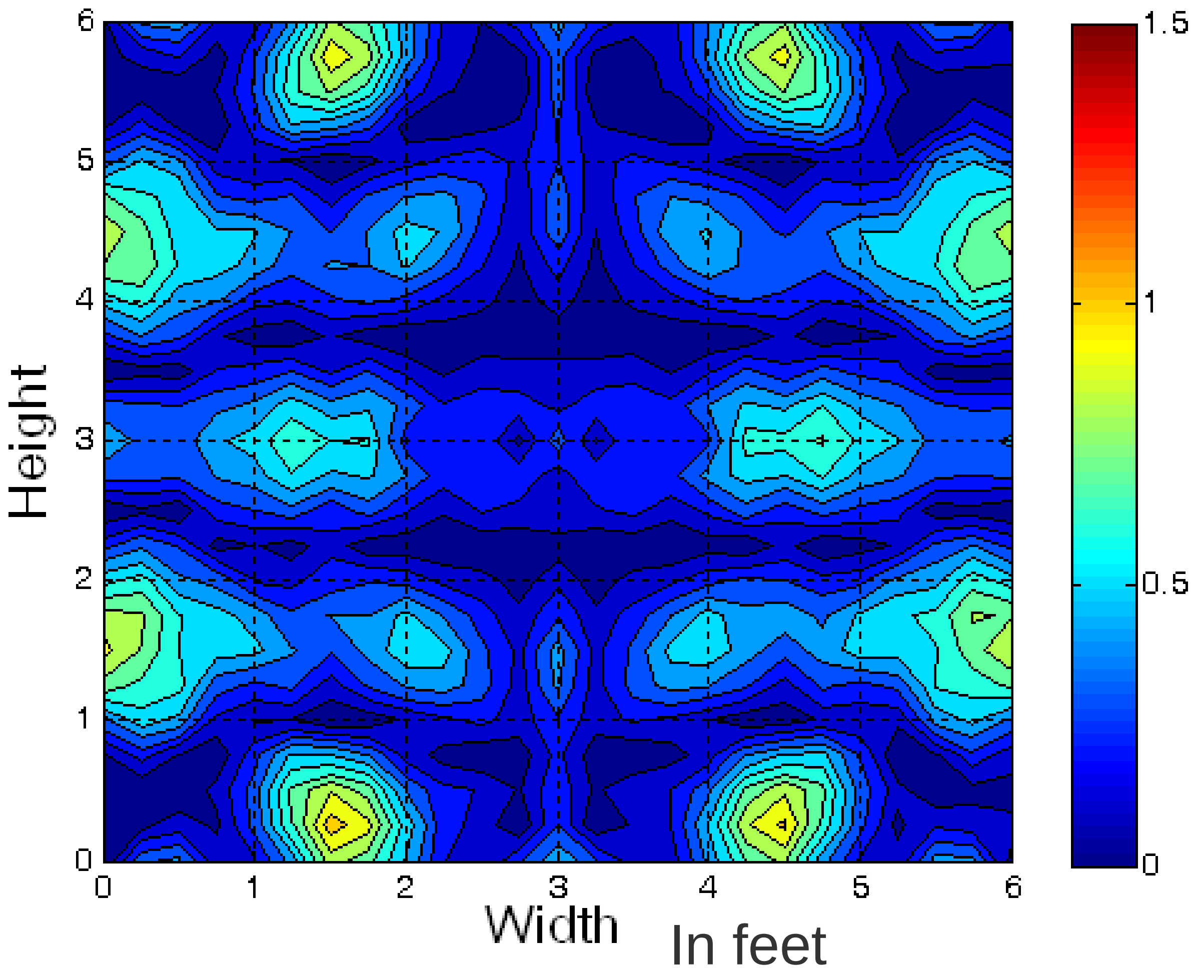
Physical Optics @ 500MHz
H-Pol – Low Gain Antenna

Difference Between PO & FEM in dB

**Maximum Error:
1.0 dB**



In feet

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Updated Computational Resources

Intel(R) Core(TM) i7-10700 CPU @ 2.90GHz
Memory: 64GBs
Microsoft Windows 10 Operating System.

Altair Feko 2021

Method	Frequency	#Cores	Solution Time	Near Field Comp. Time	Memory	# of Unknowns
FEM	150MHz	8	22 secs	0.17secs	1.7GB	569,450
FEM	250MHz	8	1.2 min	0.174secs	5.6GB	1.7mil
FEM	500MHz	8	8.4 min	0.5secs	44.8GB	10.9mil
FEM	650MHz	4	1.64 hours	0.5secs	54.8GB	22mil
PO	500MHz	8	35 secs	7.7mins	900MB	2.5mil
PO	650MHz	8	56 secs	10.3mins	1.32GB	3.8mil
PO	1GHz	8	2mins	21.5mins	2.93GB	8.9mil
PO	2GHz	8	12mins	1.3 hours	11GB	34.9mil
PO	5GHz	8	43mins	3.2 hours	25GB	78.3mil

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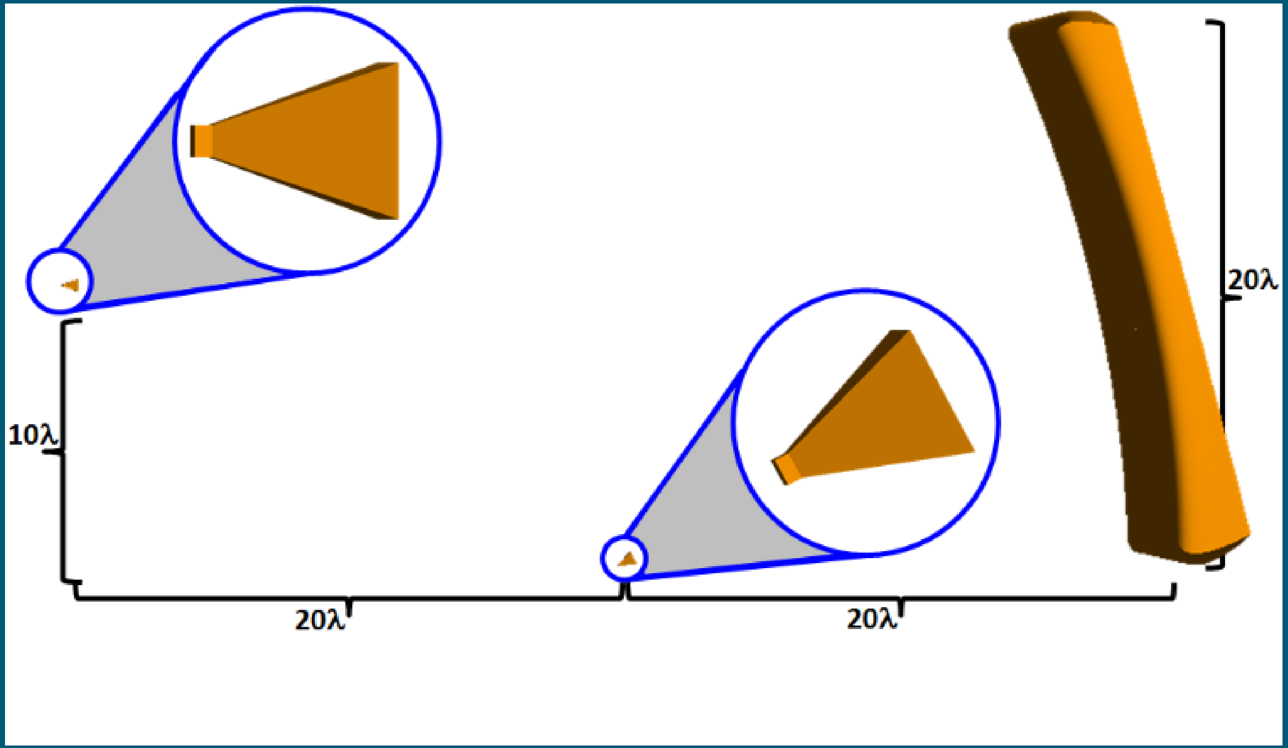
COMPACT ANTENNA TEST RANGE (CATR)



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Reflector Design Challenges

Optimize Electric Fields in the Quiet Zone

Minimize
- Edge and Corner Diffracted Fields

Minimize
- Stray Signals in the Quiet Zone

Minimize
- Amplitude and Phase Ripple

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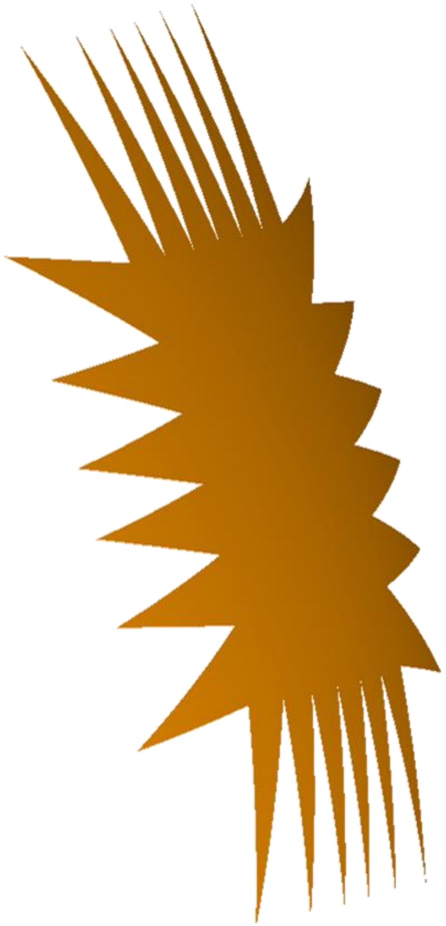
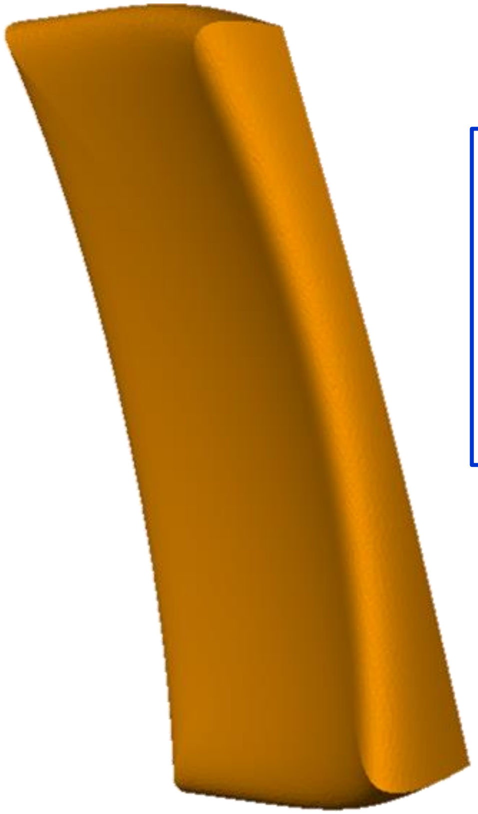
Compact Range Reflector Modeling

Knife Edge

Serrated Edge



Blended Rolled Edge



Teh-Hong Lee and Walter Burnside, Performance Trade-off Between Serrated Edge and Blended Rolled Edge Compact Range Reflectors, IEEE Transactions on Antennas and Propagation (Volume: 44 , Issue: 1 , pp: 87-96 Jan 1996)

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Simulation of CATR

Feed - Dual-ridge horn antenna with a boresight gain of 6.618 dBi at 1GHz

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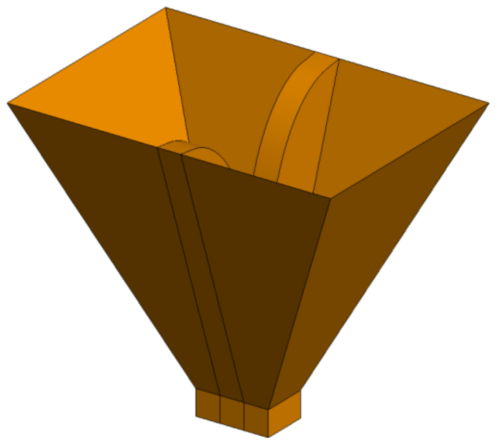

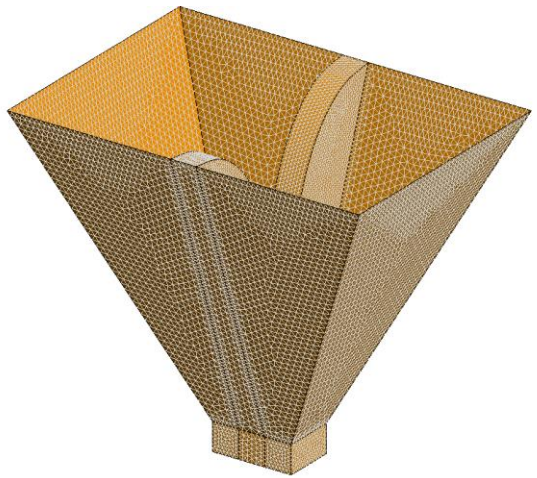

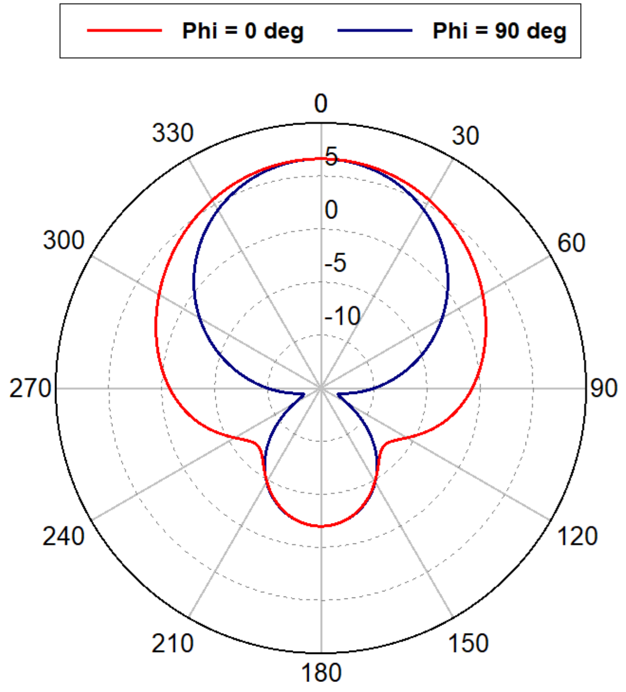

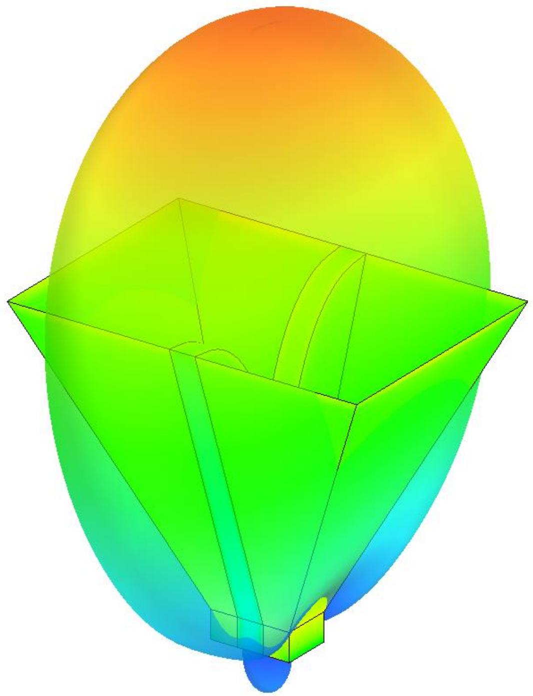

MoM
Time: 14 mins
Memory: 2.2 GBs

Triangles: 31, 452

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Quiet Zone Characterization at 1GHz

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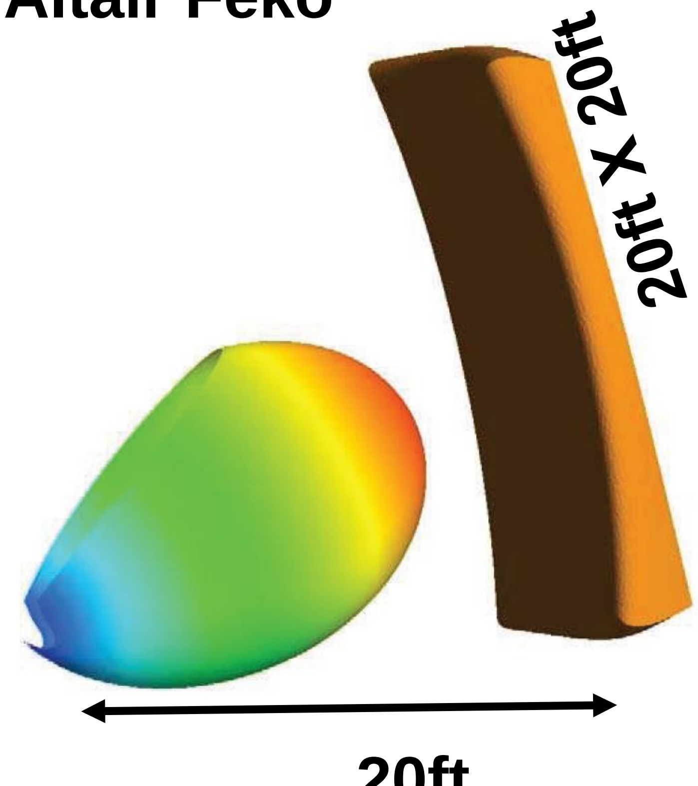
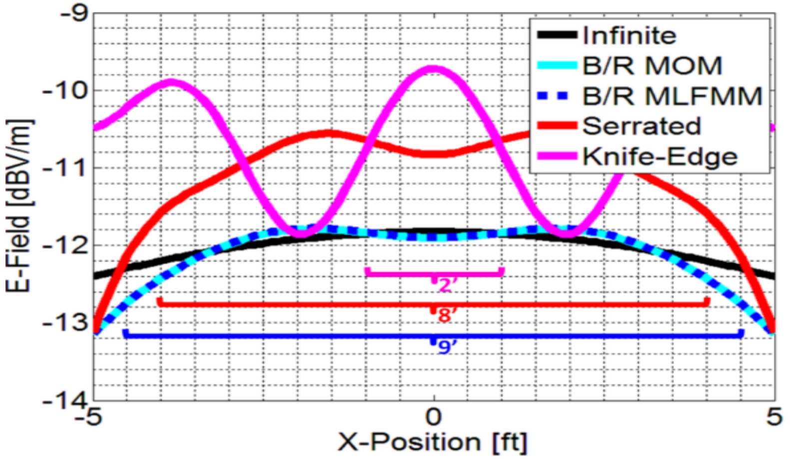
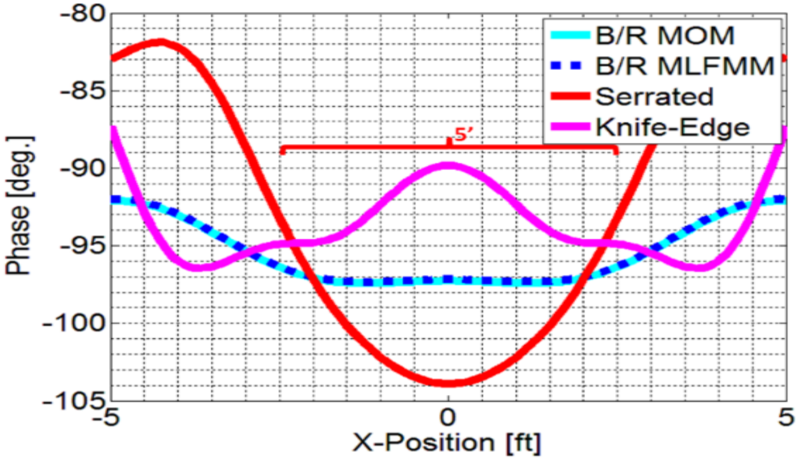


***Partially imported radiation pattern to minimize quiet zone disturbances*

Altair Feko Simulations





Principal Plane (40ft from the reflector)

- **Horizontal Cut**
- **Infinite**
  - **Ideal Behavior**
- **QZ Dimensions**
  - **B/R: 9 feet**
    - **Amplitude Limited**
  - **Serrated: 5 feet**
    - **Phase Limited**
  - **Knife: 2 feet**
    - **Amplitude Limited**

Derek Campbell, Martin Vogel, C.J. Reddy and Teh-Hong Lee, "Simulating Antenna Measurements with Parabolic Reflectors," AMTA 2014 Proceedings, Tucson AZ, pp. 481-485.

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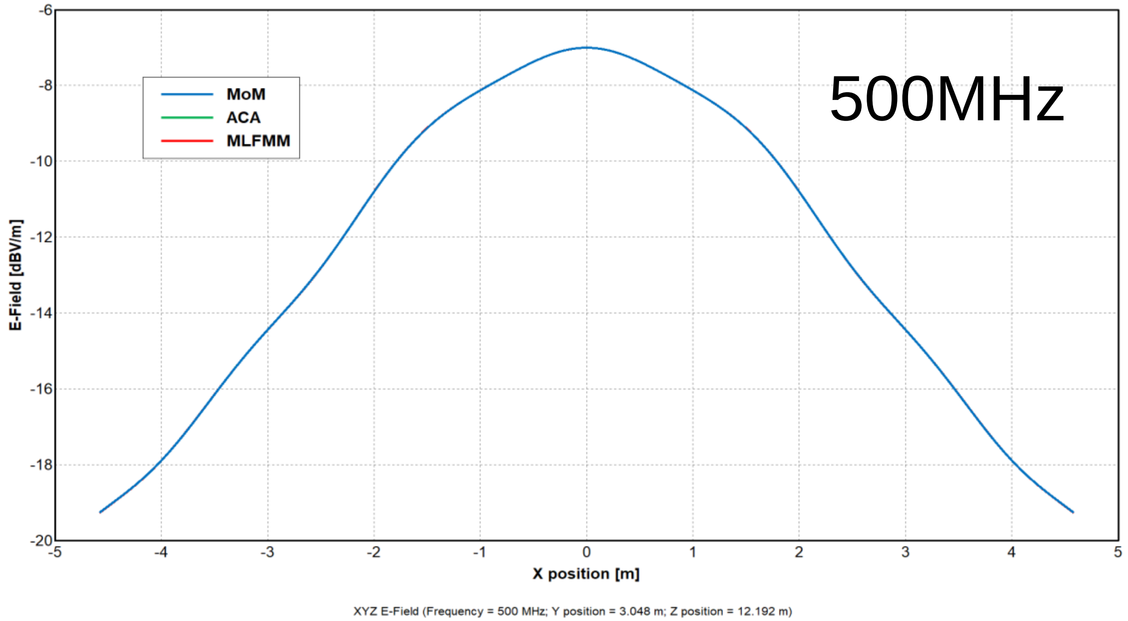
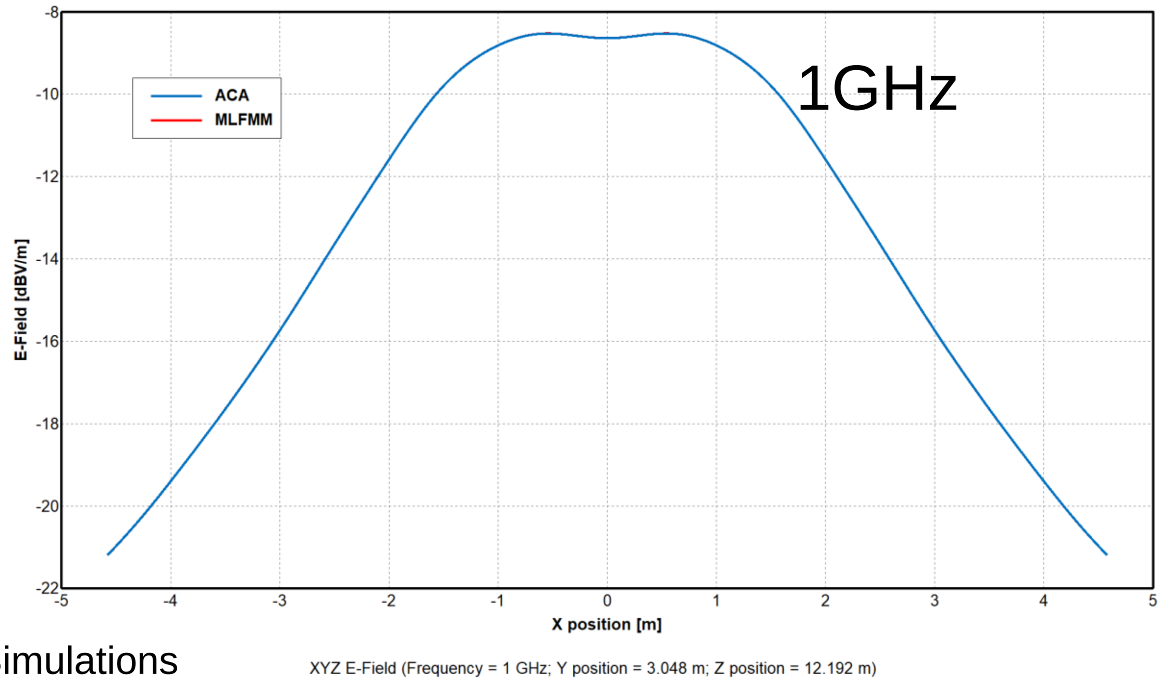
Blended Rolled Edge Analysis at 500MHz and 1GHz



500MHz (44,554 triangles)

Method	Memory	CPU Time
MoM	4.45GB	24mins
ACA	2.9GB	20mins
MLFMM	1.9GB	41secs



1GHz (176,046 triangles)

Method	Memory	CPU Time
MoM	159GB	Not Solved
ACA	17GB	2.4 hours
MLFMM	5.8GB	2.5 mins

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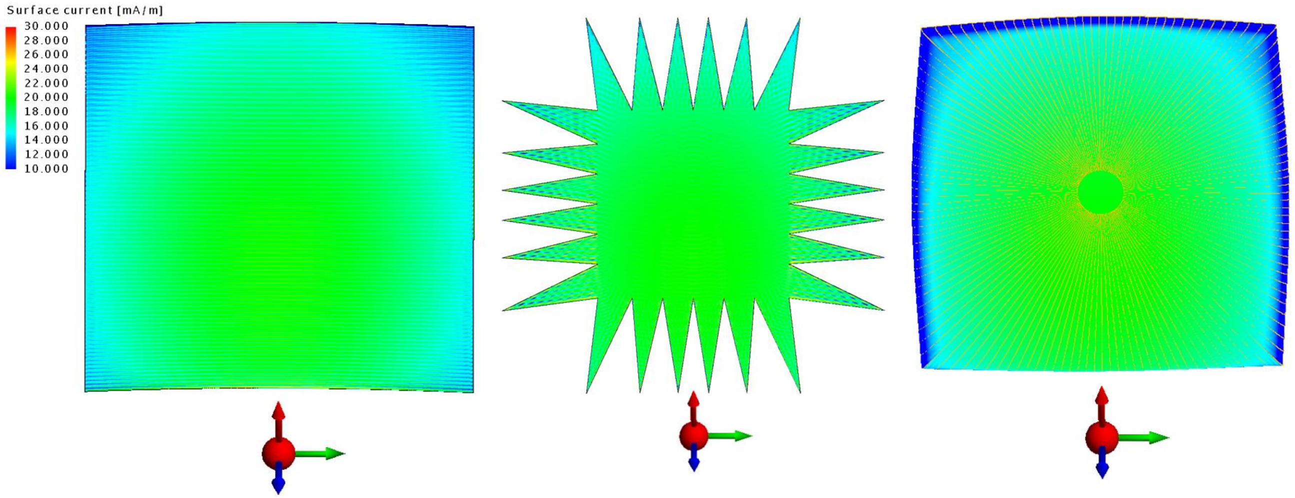
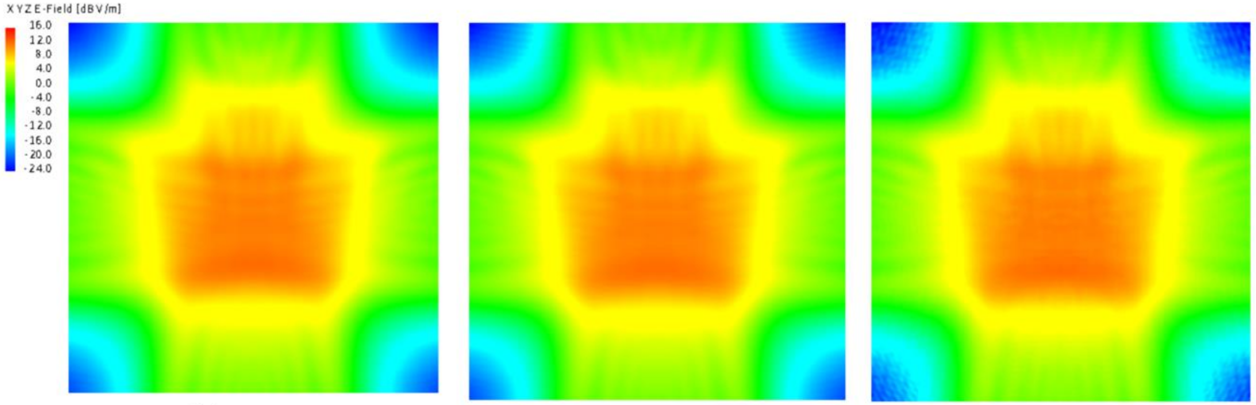
Analysis at 5GHz

Current distribution on the reflector geometries at 5GHz (MLFMM).



Near field pattern at 40ft from the **Blended Rolled-Edge Reflector**



(a) MLFMM (b) PO (c) RL-GO

MLFMM

Reflector Type	Number of Triangle (Millions)	Memory (GB)	CPU Time (Hours)
Knife Edge	3.6	43.6	3
Serrated Edge	1.8	26.2	1.12
Blended Rolled-Edge	**4.5**	**54.7**	**3.5**

Method	Memory	CPU Time
PO	3GB	12mins
RL-GO	917MB	6.3mins

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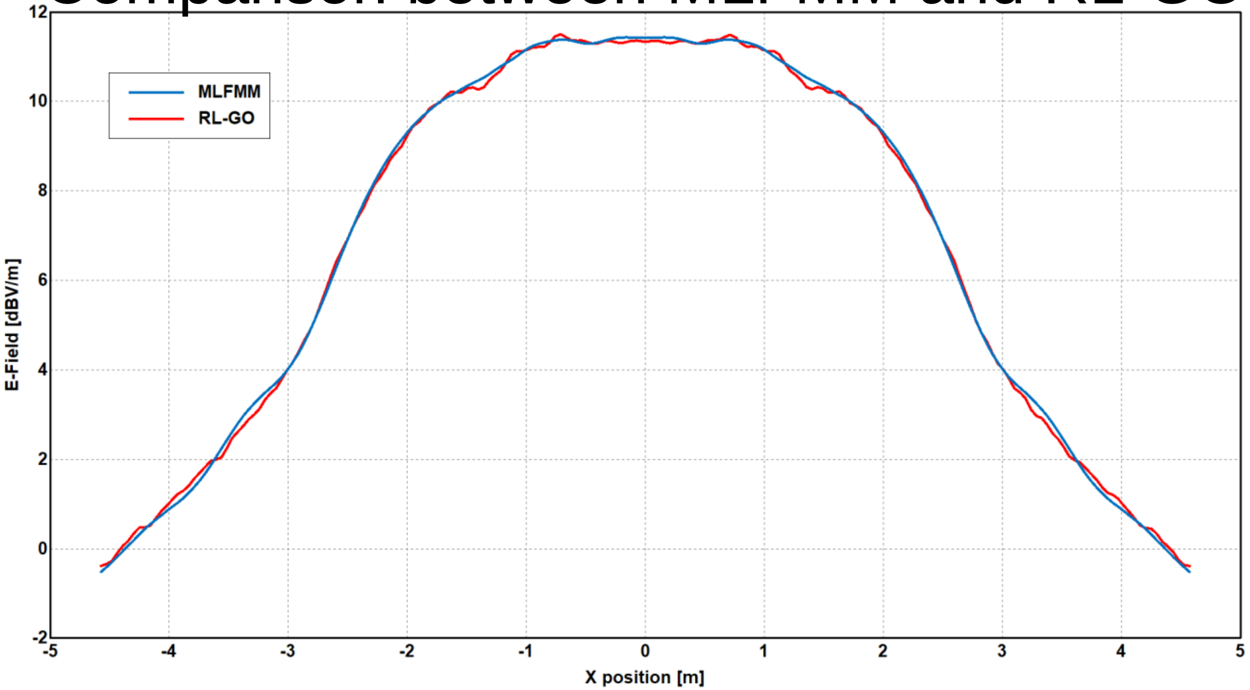
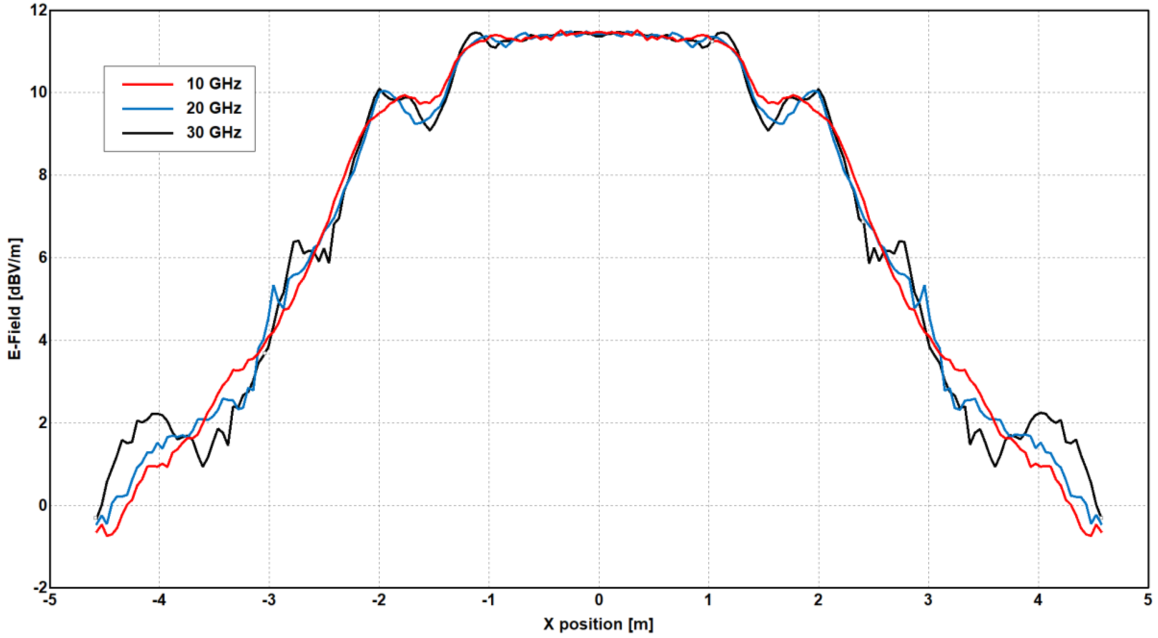
Blended Rolled Edge Analysis 5GHz to 30GHz

5GHz
Comparison between MLFMM and RL-GO



XYZ E-Field (Frequency = 5 GHz; Y position = 3.048 m; Z position = 12.192 m)

5-30GHz
RL-GO



XYZ E-Field (Y position = 3.048 m; Z position = 12.192 m)

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Computational Scalability 500MHz to 30GHz

Altair Feko Simulations - 3.70GHz quad core 64-bit Intel processor; Memory of 64GBs Microsoft Windows 10 Operating System

Frequency (GHz)	Triangles	Method	Memory	CPU Time (4 cores)
0.5	44,554	MoM	4.45 GB	24mins
		ACA	2.9 GB	20mins
		MLFMM	1.9 GB	41secs
1.0	176,046	MoM	159 GB	Not Solved
		ACA	17.2 GB	2.4 hours
		MLFMM	5.5 GB	2.5mins
5.0	4,451,532	MLFMM	54.7 GB	3.5hours
	1,975,654	PO	3 GB	12mins
	5,378	RL-GO	274 MB	6.3mins
10	5,378	RL-GO	2.45 GB	19mins
20	5,378	RL-GO	8.5 GB	1.2hours
30	5,378	RL-GO	18 GB	5 hours

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- **Characterize Quiet Zone Behavior**
  - ➢ **Anechoic Chambers and Compact Ranges**
- **Obtain Critical Insight for Design Cycles**
  - ➢ **Antennas, Measurement Techniques, Chamber Designs**
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    - ➢ **Non-Ideal Environments**
  - ➢ **Predict Performance Levels and Costs**
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References

1. Derek Campbell, Gopinath Gampala, C.J. Reddy, M. Winebrand and John Aubin, "Modeling and Analysis of Anechoic Chamber Using CEM Tools," ACES Journal, pp.755-762, September 2013.
2. Derek Campbell, Gopinath Gampala, C.J. Reddy and John Aubin, "Simulating Antenna Measurements in an Anechoic Chamber," AMTA 2013 Symposium Proceedings, November 2013.
3. Derek Campbell, Gopinath Gampala, Martin Vogel and C.J. Reddy, "Simulating Antenna Measurements in an Anechoic Chamber," Microwave Journal, July 2014.
4. Derek Campbell, Martin Vogel, C.J. Reddy and Teh-Hong Lee, "Simulating Antenna Measurements with Parabolic Reflectors," AMTA 2014 Symposium Proceedings, November 2014.
5. Derek Campbell and C.J. Reddy, "Simulation of Antenna Measurements Using Advanced Computational Techniques," AMTA 2016 Symposium Proceedings, November 2016.
6. Derek Campbell and C.J. Reddy, "Advanced Computational Methods for Compact Range Analysis," 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting (Virtual), July 2020.

QUESTIONS

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