Optimizing EMC and RF Test Chamber Design and Performance

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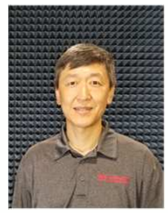

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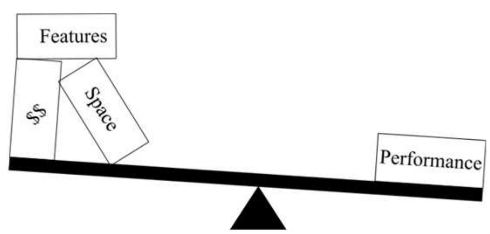
You can benefit from this talk, if …

- You are involved in procuring a new EMC Chamber or need to refurbish an existing one.
- You are a user of a chamber that has marginal performance. You struggle to meet the site requirements.
- You have a product needing EMC compliance test. You want to understand how a chamber impacts the measurement uncertainties.
- You wonder if my chamber is optimized. What can I do to make it better?
- You are curious about chamber technology and modeling techniques.



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Some Optimization Scenarios

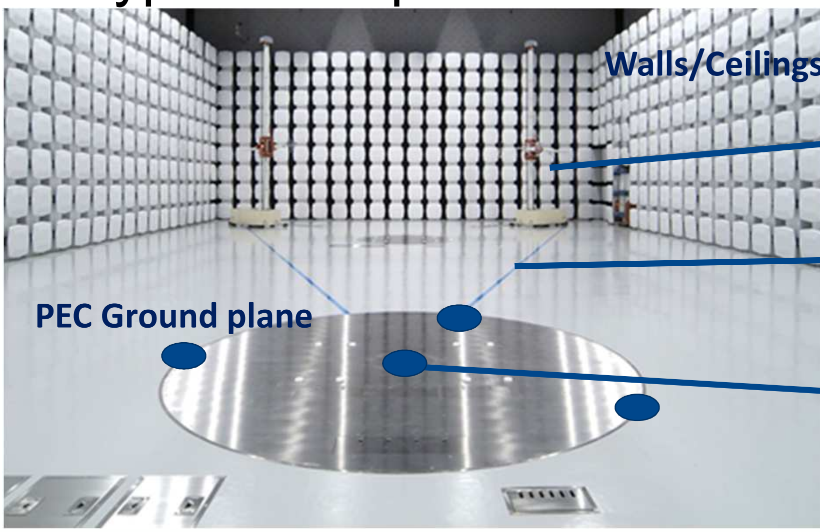
- Need to tightly fit into an available building space
- Have budget constraints – need to tradeoff between QZ size, partial absorber linings, and performance
- Need to place access doors in a certain "non-ideal" area
- Need to optimize antenna locations
- Need to use shorter absorber in certain areas to maximize test area
- Need to place dual test ranges to increase test throughput

Before committing to a large investment, you want to make sure a chamber design is sound well **in advance, not afterwards.**

Background

- For < 1 GHz, the figure of merit for a EMC semi-anechoic chamber is Normalized Site Attenuation deviation (ΔNSA). It is essentially the height scanned antenna response difference between that in the chamber and on an ideal site. ΔNSA must be < ±4 dB to meet the standard requirements.
- For > 1 GHz, the chamber is converted to a full-anechoic room. The figure of merit is Site VSWR (SVSWR).
- Chamber performance prediction is essential to optimize the chamber design, including the chamber size, shape, absorber selection, layout etc…
- Accurate modeling is the key component
  - Raytracing (Geometric Optics) – inaccurate, especially at low frequency (<100 MHz)
  - Full-wave – slow and computationally expensive
  - Hybrid method – We will illustrate how a hybrid approach is ideal

A typical setup in a EMC Chamber



Walls/Ceilings are lined with absorbers

Antenna scanned 1-4m in height

Distance is typically 3 or 10 m

*NSA is measured with several fixed antenna heights, polarizations and positions in the QZ

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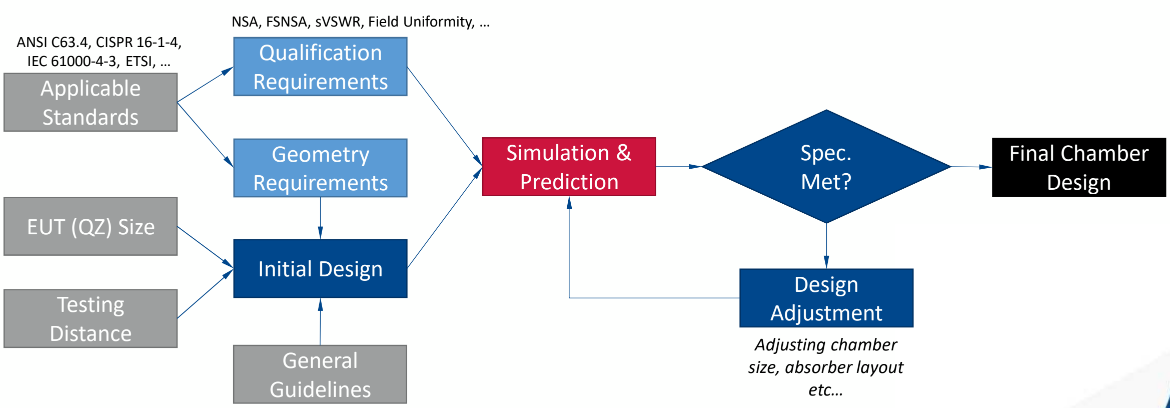
Chamber Design Process

- **Chamber testing requirements** specified in standards:



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General Design Guidelines

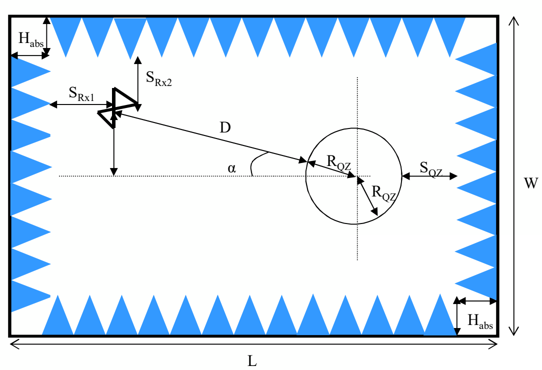
- Some general "rules of thumb" should be observed when sizing an EMC Chamber once the QZ size and the test distance are known.
  - Slant measurement axis is preferred so that reflections from the side walls do not arrive in phase to the test area
  - Separation between antenna and absorber tips should be larger than **1 meter** to avoid excessive coupling from absorbers to the antenna
  - Remember to allow extra space for antenna mast, especially "boresight" towers where the backside of the boom can tilt up.

Length and Width of Chamber

- NSA testing

$$L=(D+R_{QZ})\cdot\cos(\alpha)+R_{QZ}+S_{Rx1}+S_{QZ}+2\cdot H_{abs}$$
$$W=(D+R_{QZ})\cdot\sin(\alpha)+R_{QZ}+S_{Rx1}+S_{QZ}+2\cdot H_{abs}$$
$$\text{where } S_{Rx1}=2m, S_{Rx2}=1m, S_{QZ}=1m$$

- S_{Rx1} **can be a minimum of 1.5m**

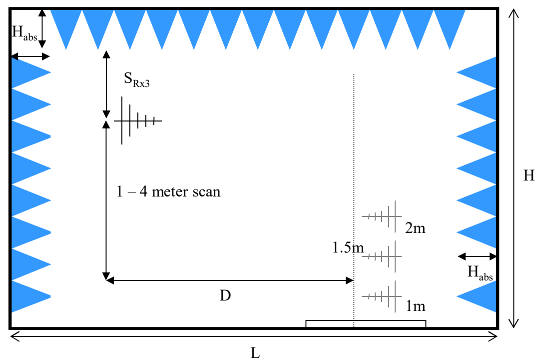


These rules of thumb are sometimes violated to various degrees, but these provide a good starting point

Height of Chamber

- NSA testing

$$H = 4m + S_{Rx3} + H_{abs}$$
where $S_{Rx3} = 1m$

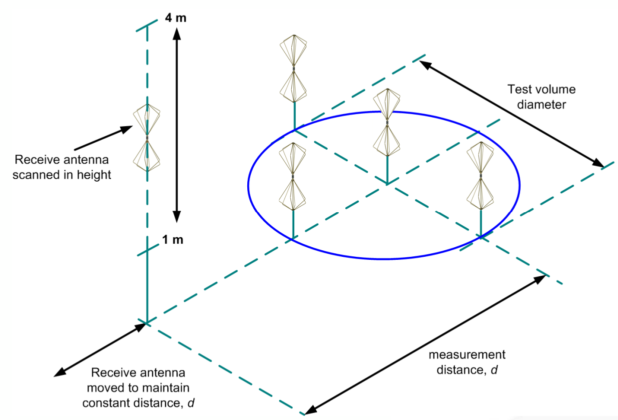


NSA

According to standard CISPR 16-1-4 and ANSI C63.4, the measured NSA for a semi-anechoic chamber needs to be within ±4 dB of the theoretical NSA.

$$NSA = \frac{|V_I|}{\max |V_R| \cdot AF_T \cdot AF_R}$$

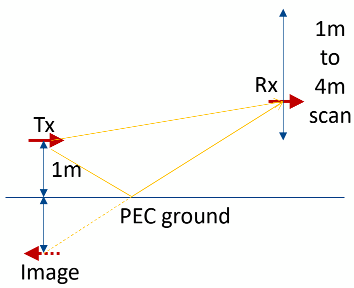
V_I : the input voltage fed into Tx
V_R : the received voltage of Rx
AF_T : the antenna facto of Tx
AF_R : the antenna facto of Rx

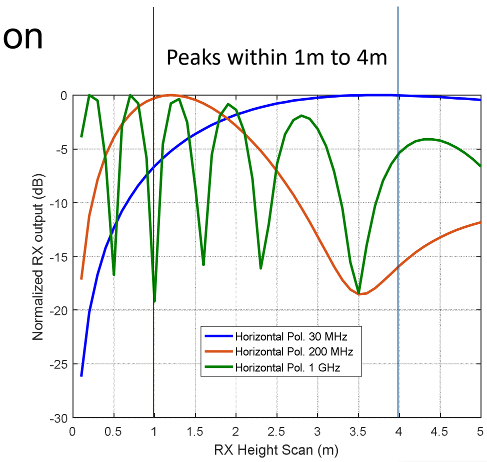


NSA: Why 4m Height Scan?

- Catching the peak of the summation of the direct wave and the ground reflecting wave

Two dipoles separated by 3 m over ground





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Simulation: the Challenge

- Even though <100 MHz is the most critical frequency range in determining a chamber design (size and absorber selection), Geometry Optics (GO) raytracing is the most lacking in accuracy in this range.
- We adopt an improved algorithm for simulating EMC chambers:
  - We treat the first antenna/absorber interface in a more rigorous manner – using Discrete Complex Image Method (DCIM)
  - Higher order reflections are subsequently treated as optical rays
  - The hybrid approach is shown to be much more accurate, and it retains the efficiency of the GO method.

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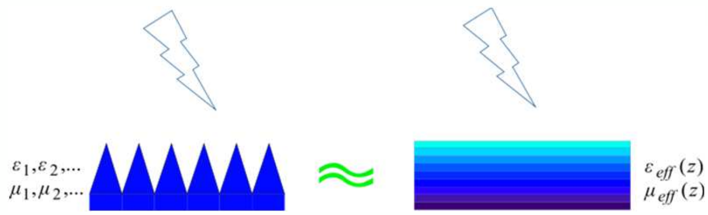
1st step: Absorber Homogenization

- At low frequency, when the incident wave encounters a periodic composite (period p), and when $p << \lambda$, the shape of individual absorber is unimportant. The periodic absorber array can be represented by layered dielectric medium through homogenization.

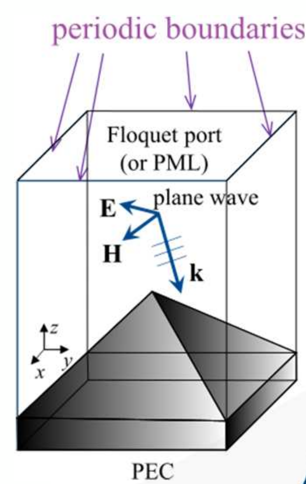


Unit Cell Simulation (full wave simulation)

- Simulation setup (e.g., using HFSS)
  - Excite with a plane wave with contains all x, y, z components
  - Floquet port (or PML) @ top, PEC @ bottom

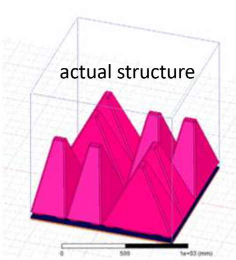
$$\mu^{eff}_{x,y,z}(z) \approx \frac{\int_{V_z} \mu(x',y',z') H^0_{x,y,z}(x',y',z')dv'}{\int_{V_z} H^0_{x,y,z}(x',y',z')dv'}$$

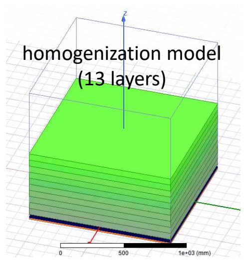
$$\varepsilon^{eff}_{x,y,z}(z) \approx \frac{\int_{V_z} \varepsilon(x',y',z') E^0_{x,y,z}(x',y',z')dv'}{\int_{V_z} E^0_{x,y,z}(x',y',z')dv'}$$

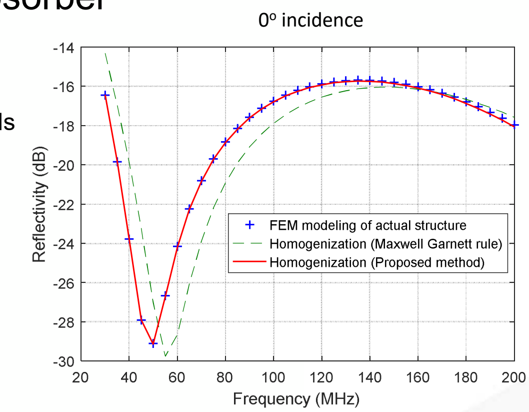


Validation of Homogenization

- An actual hybrid 60cm EMC absorber
  - Hollow pyramids
  - Alternating arrangement of pyramids
  - Hybrid lossy dielectric and magnetic materials



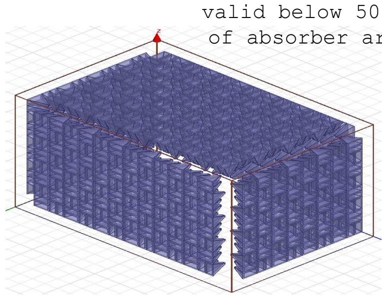


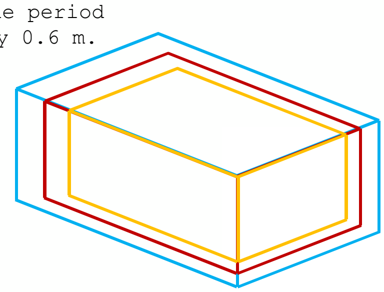


Simplified Chamber Model

- Homogenization of absorber arrays leads to a simplified chamber model with layered structures.

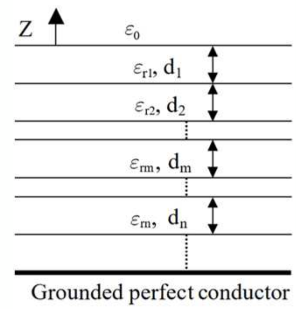
valid below 500 MHz, since the period of absorber arrays is usually 0.6 m.





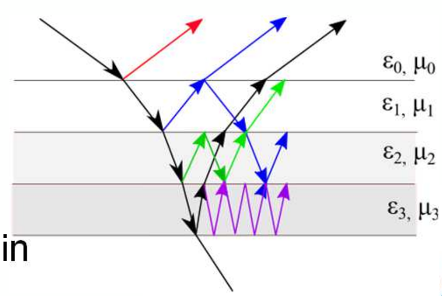
2nd Step: Discrete Complex Image Method (DCIM)

- For antennas over layered media
  - Green's functions for multilayered media are converted into spatial-domain Green's function.
  - DCIM allows for an efficient evaluation of the spatial domain Green's function
  - In DCIM, field above the media can be closely represented by waves emanate from a series of **images at complex depth below the interface**.
  - One disadvantage is that since the image locations are non-physical, further ray bounce is not possible. However, as distance becomes large, raytracing becomes much more accurate



3rd Step: high order reflections

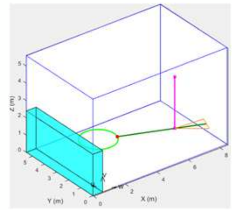
- Hybrid: For higher order reflections, GO is used to account for wall-to-wall interactions
- Efficiency: The DCIM approach is **computationally efficient**. Speed is similar to GO. A full EMC chamber simulation which includes 20 test configurations takes 1 minute on a PC.
- Flexibility: Visibility Tree scheme is used in the GO. This allows the flexibility of simulating an **arbitrary shaped chamber**, not limited to rectangular boxes.

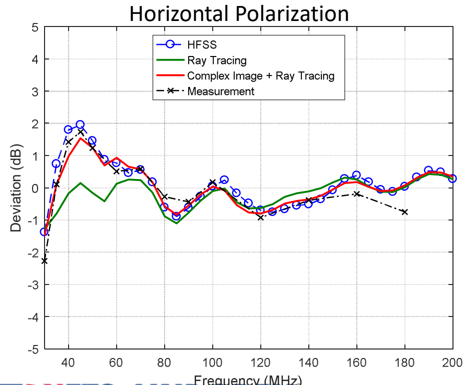


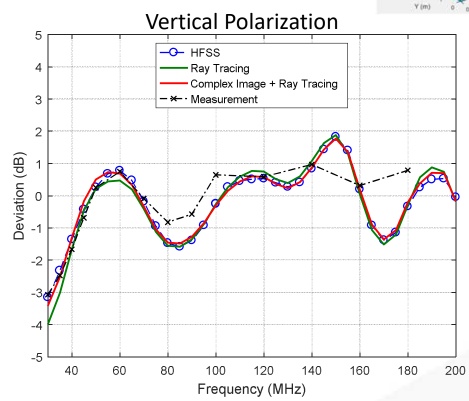
Validation of Chamber Simulation

- Front position

NSA simulation of a 3m chamber with 60cm hybrid absorbers partial lining



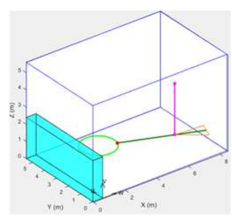


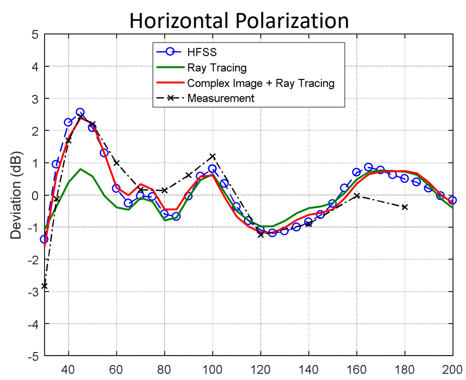


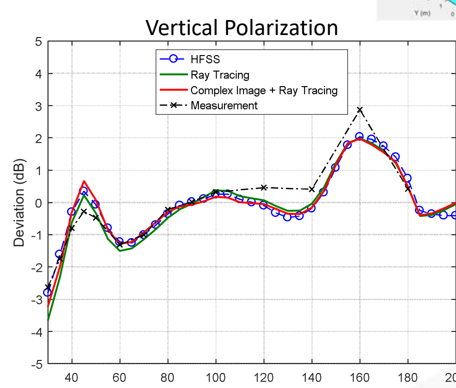
Validation of Chamber Simulation

- Left position

NSA simulation of a 3m chamber with 60cm hybrid absorbers partial lining







Building A Chamber Simulation Toolkit

- Musts:
  - Must be accurate including at low frequencies.
  - Can simulate an EMC chamber in minutes, therefore allowing optimization and studies on what-if scenarios.
  - Can simulate various chamber tests including NSA, FSNSA, SVSWR and Field Uniformity.
- Nice to haves:
  - Visualization of ray paths to provide guidance on cost-effective designs, and assist with chamber troubleshooting.

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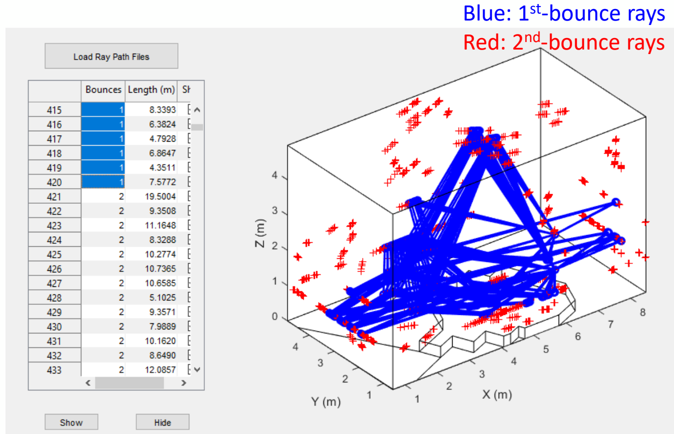
Cost-Effective Designs

- Identifying critical areas
  - 1st bounces
  - 2nd bounces
- Partial Lining
  - Ferrite tiles everywhere
  - Pyramidal absorbers on 1st bounce areas only
- Mixed coverage
  - Larger absorbers on 1st bounce areas

Blue: 1st-bounce rays
Red: 2nd-bounce rays



	Bounces	Length (m)	Sh
415	1	8.3393	
416	1	6.3824	
417	1	4.7928	
418	1	6.8647	
419	1	4.3511	
420	1	7.5772	
421	2	19.5004	
422	2	9.3508	
423	2	11.1648	
424	2	8.3288	
425	2	10.2774	
426	2	10.7365	
427	2	10.6585	
428	2	5.1025	
429	2	9.3571	
430	2	7.9889	
431	2	10.1620	
432	2	8.6490	
433	2	12.0857	

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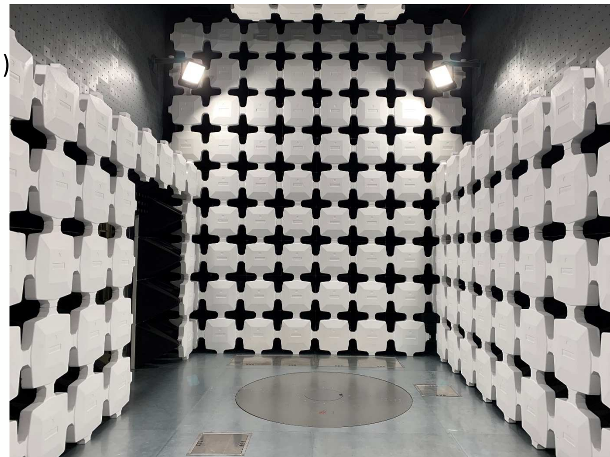
22

Case Study I: A Compact 3m Chamber

Type: 3m Semi Anechoic Chamber
Dimensions: 8.64m(L) x 5.12m(W) x 5.83m(H)
Date of manufacture: February – 2020

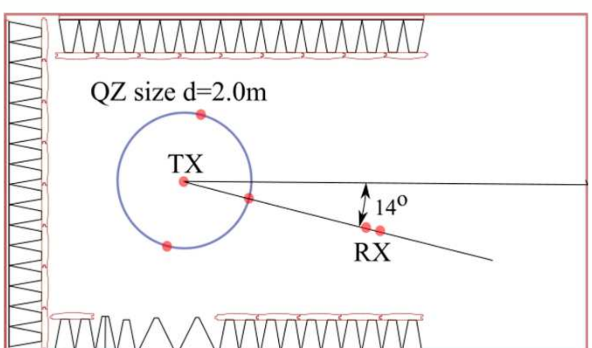


Absorbers:

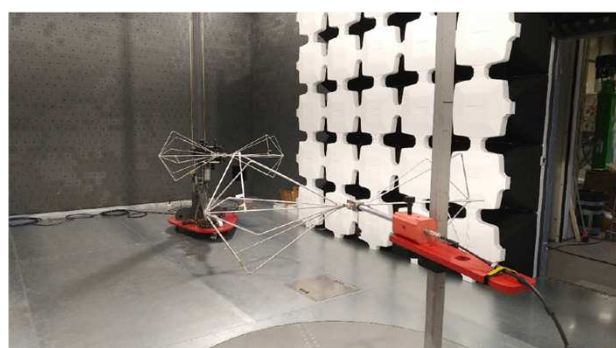
Walls and ceilings: ferrite tiles and DSH-600H
End wall (antenna mast side): ferrite tiles

Chamber Layout & NSA Test Setup

This chamber uses partial lining on some surfaces – combined with 60 cm tall hybrid absorbers in some areas and ferrite tiles only in other areas.



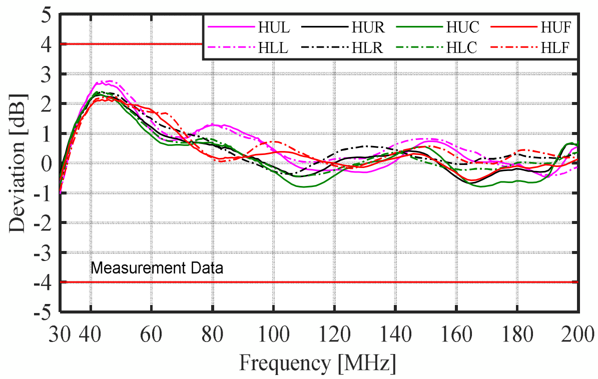
Top view of the chamber, test volume and measurement axis



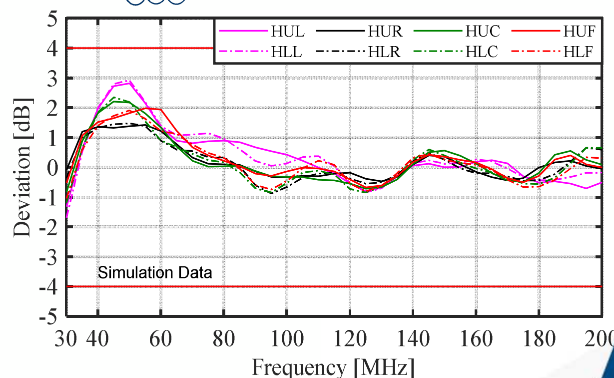
Simulation vs. Measurement

Site attenuation deviations

KEY: HUL
- Polarization: **H**oriz. or **V**ert.
- TX antenna height: **U**pper or **L**ower
- TX antenna location: **L**eft/**R**ight/**F**ront/**C**enter



Horizontal measured data



Horizontal simulated data

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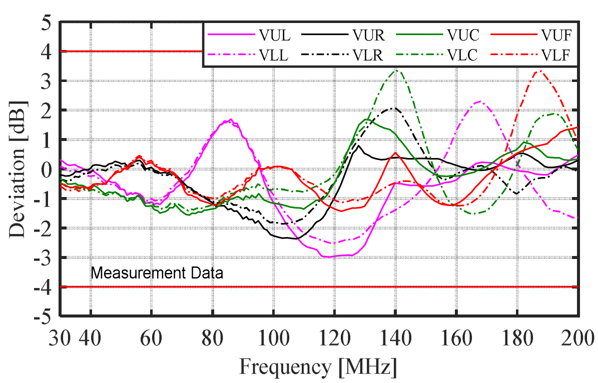
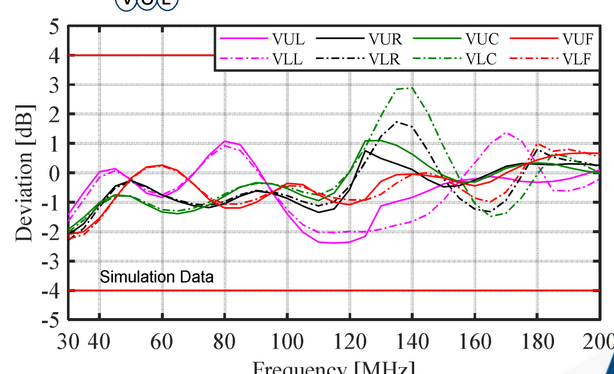
Simulation vs. Measurement

Site attenuation deviations

KEY: VUL
- Polarization: **H**oriz. or **V**ert.
- TX antenna height: **U**pper or **L**ower
- TX antenna location: **L**eft/**R**ight/**F**ront/**C**enter



Vertical measured data



Vertical simulated data

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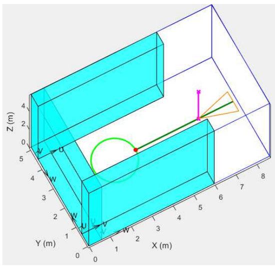
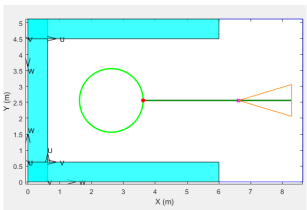
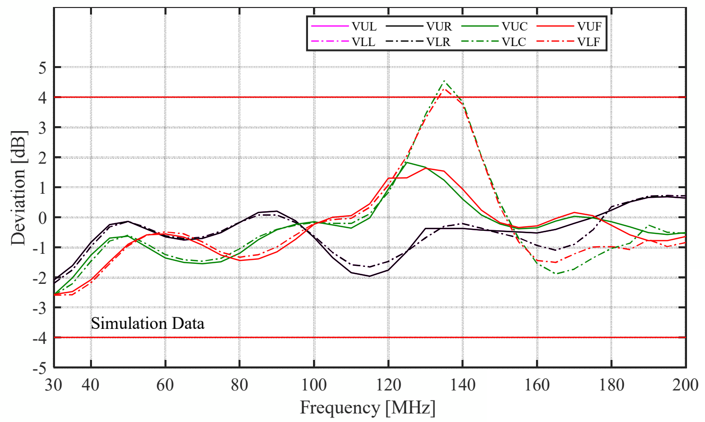
26

Non-optimized Design #1 – placing antennas on the centerline





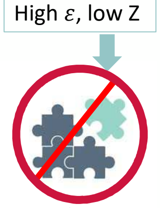


KEY:
Polarization: **H**oriz. or **V**ert.
TX antenna height: **U**pper or **L**ower
TX antenna location: Left/Right/Front/Center
VUL

Non-optimized Design #2: microwave absorbers + Ferrite tiles = trouble

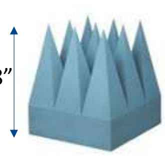
$$Z = \sqrt{\frac{\mu}{\varepsilon}}$$

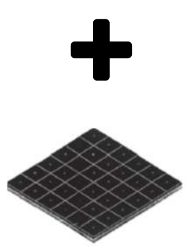
High ε, low Z

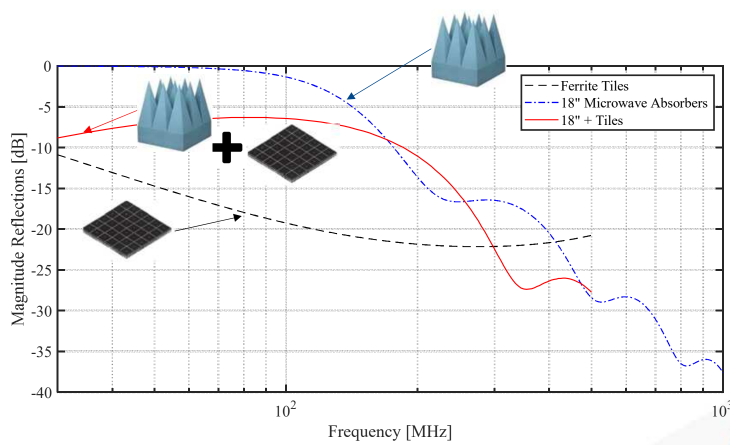


High μ, high Z

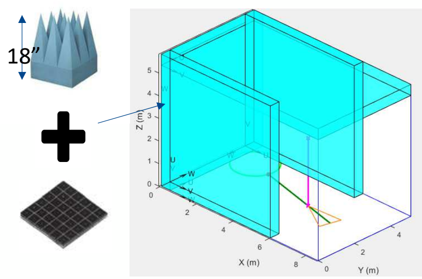
18”

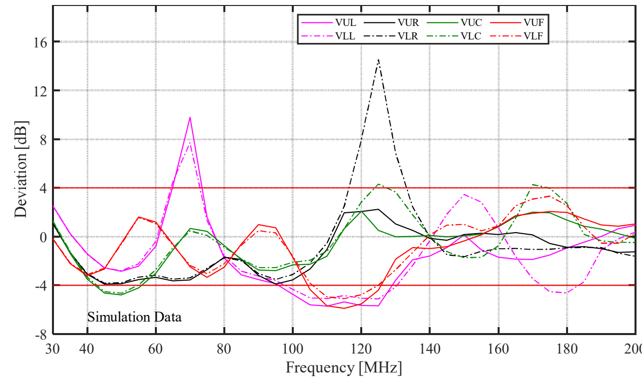






Non-optimized Design #2 – continued





KEY: VUL
Polarization: **H**oriz. or **V**ert.
TX antenna height: **U**pper or **L**ower
TX antenna location: **L**eft/**R**ight/**F**ront/**C**enter

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Case Study II: 10 m "Dual-Range" Chamber

Type: 10m Semi Anechoic
Dimensions: 20.9m x 11.2m x 7.9m
Initial install date: 1992

Date of installation of the new absorbers: January 2020

Absorbers:

Partial lining: Ferrite tiles and DSH1250

Picture of the chamber

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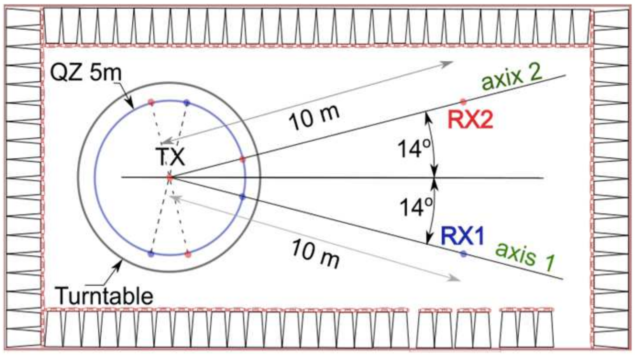
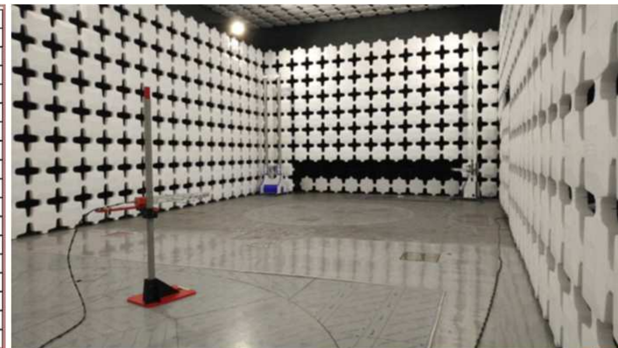
Chamber Layout & NSA Test Setup

dual-range chamber": 2 antennas/masts can operate at the same time to save testing time.



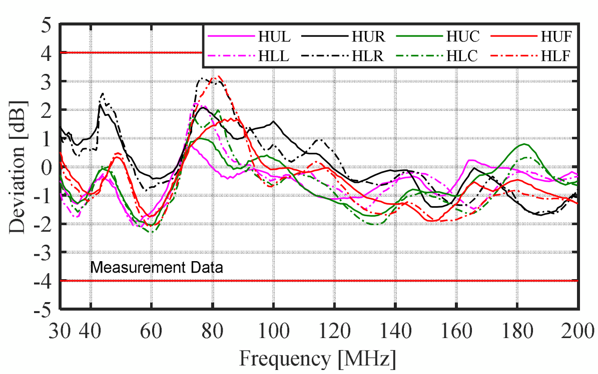


Top view of the chamber, test volume and measurement axis

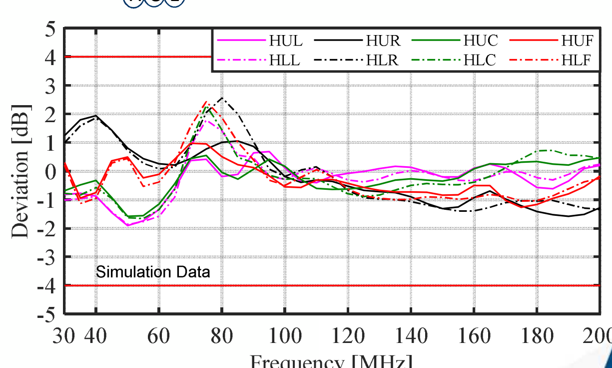
Simulation vs. Measurement

Site attenuation deviations

KEY: (H)(U)(L)
Polarization: **H**oriz. or **V**ert.
TX antenna height: **U**pper or **L**ower
TX antenna location: **L**eft/**R**ight/**F**ront/**C**enter



Horizontal measured data

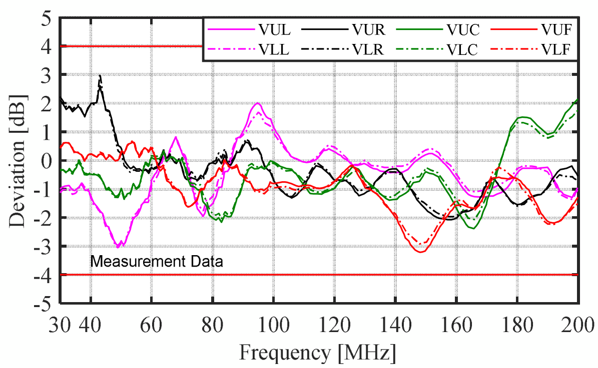


Horizontal simulated data

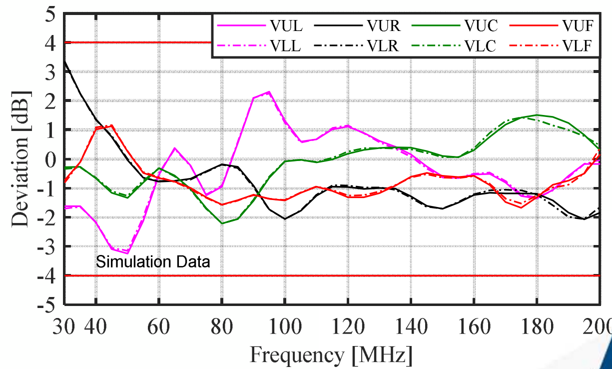
Simulation vs. Measurement

Site attenuation deviations

KEY: VUL — Polarization: **H**oriz. or **V**ert.; TX antenna height: **U**pper or **L**ower; TX antenna location: **L**eft/**R**ight/**F**ront/**C**enter



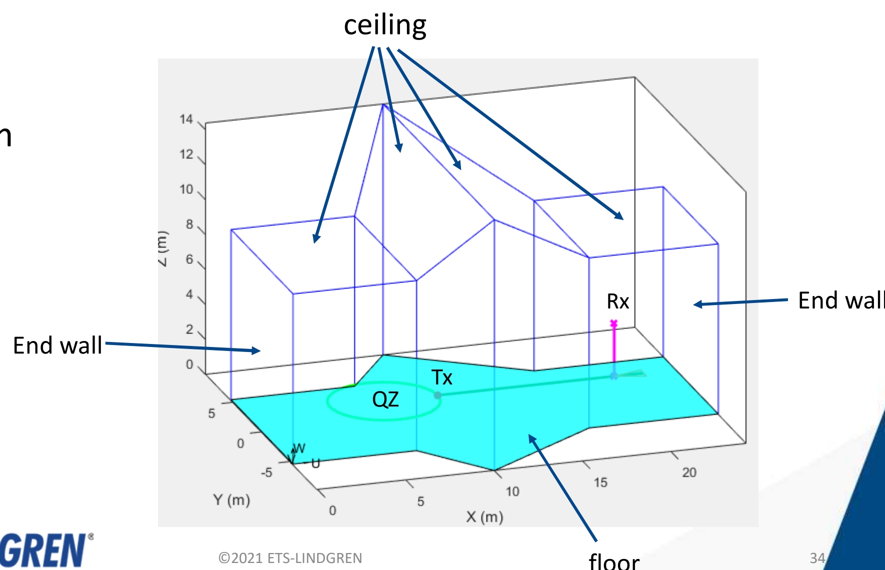
Vertical measured data



Vertical simulated data

Case Study III: Irregular shaped chamber

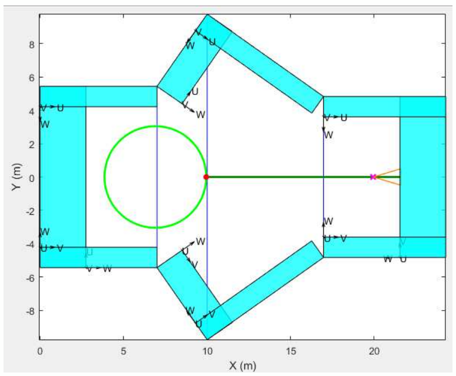
QZ diameter: 6m
Test distance: 10m



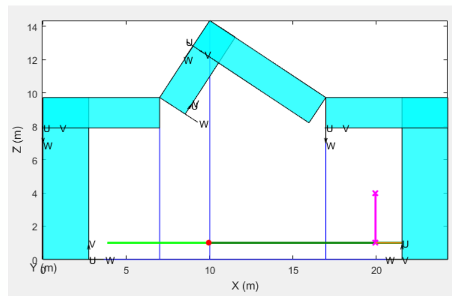
Pyramidal Absorbers (Existing Design)

Pyramidal absorbers in **4ft (1.2m)**, **6ft (1.8m)**, **9ft (2.7m)** lengths.

No Ferrite Tiles



Top View



Side View

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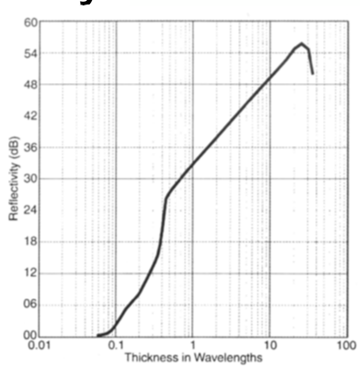
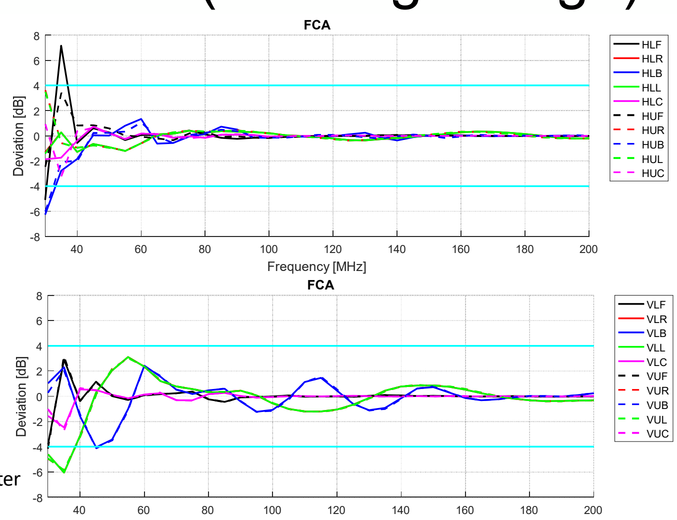
Pyramidal Absorbers (Existing Design)



Normal incidence reflectivity performance of pyramidal absorbers.



KEY:

HUL	Polarization:	**H**oriz. or **V**ert.
	TX antenna height:	**U**pper or **L**ower
	TX antenna location:	**L**eft/**R**ight/**F**ront/**C**enter

Ref: L. Hamming," **Electromagnetic Anechoic Chambers: A Fundamental Design and Specification Guide"**

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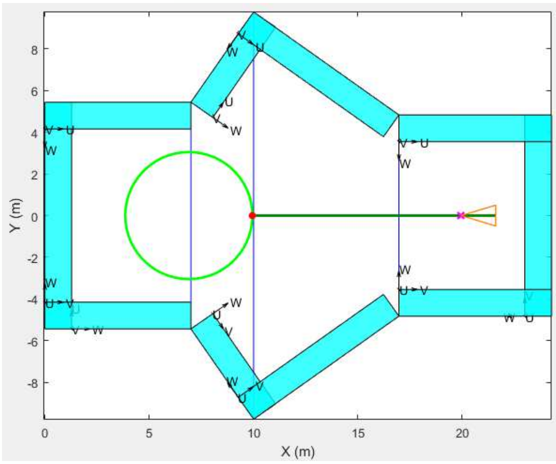
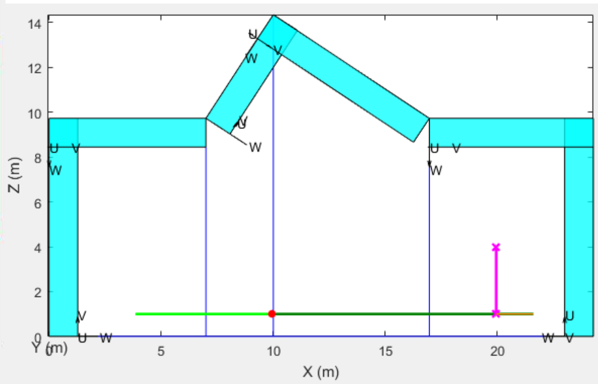
Replace with 1.25 m tall Foam/Ferrite absorbers

DSH-1250H (4' with tiles) everywhere



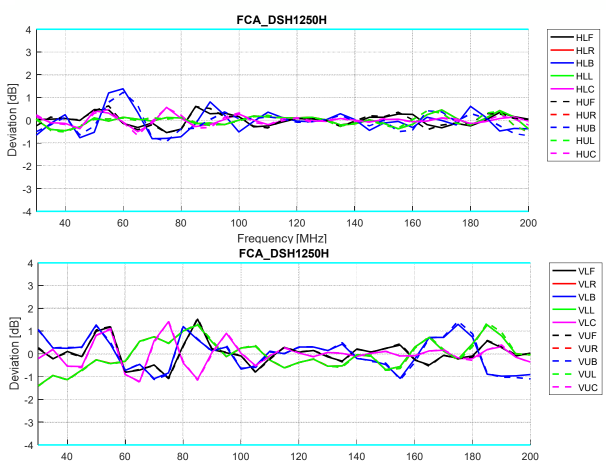
Top View



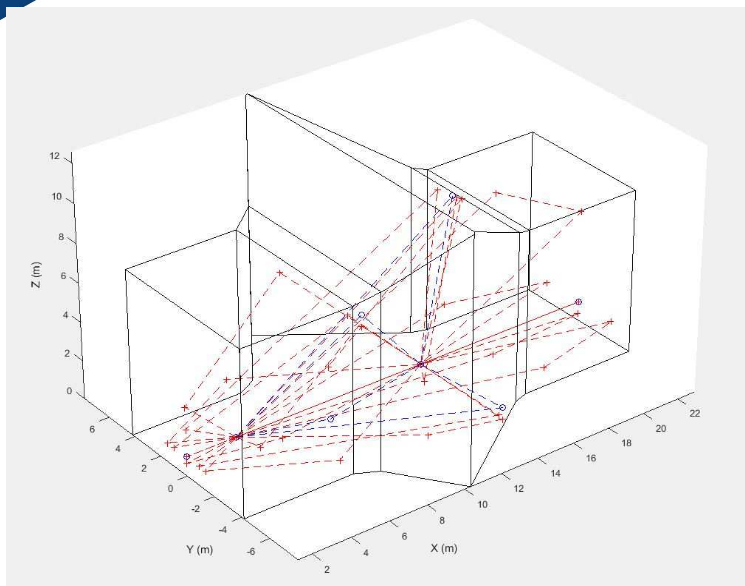
Side View

Hybrid Absorbers DSH-1250H

Site attenuation deviations



KEY:
Polarization: **H**oriz. or **V**ert.
TX antenna height: **U**pper or **L**ower
TX antenna location: **L**eft/**R**ight/**F**ront/**C**enter
HUL



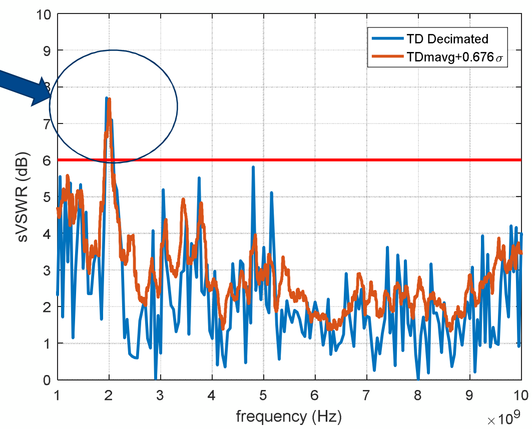
Optical rays (1st –blue and 2nd order - orange) provides insights into the chamber performance

Case Study IV: Assisting High Frequency Chamber Design

- Debugging a chamber which has failed SVSWR
- We will demonstrate how the simulation tool in combination with time domain analysis can pinpoint failure sources

TD SVSWR before correction

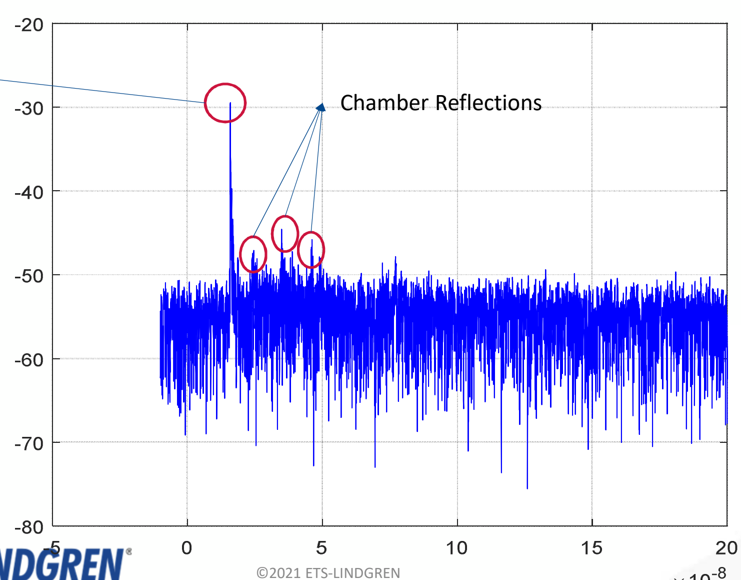
Don't exact know why failed?



Time Domain response

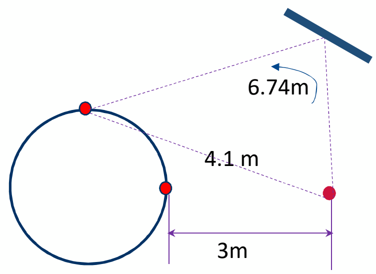
Main response

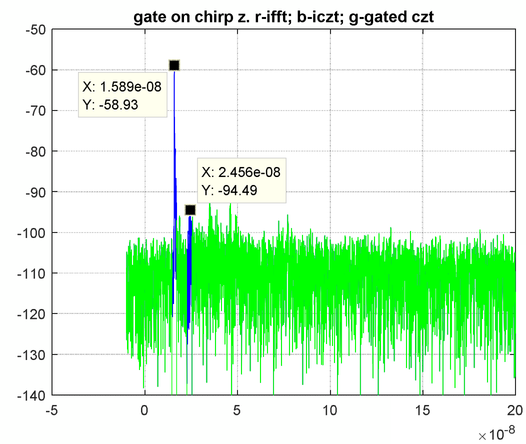
We can mathematically remove any one or more reflections and see their effects on SVSWR



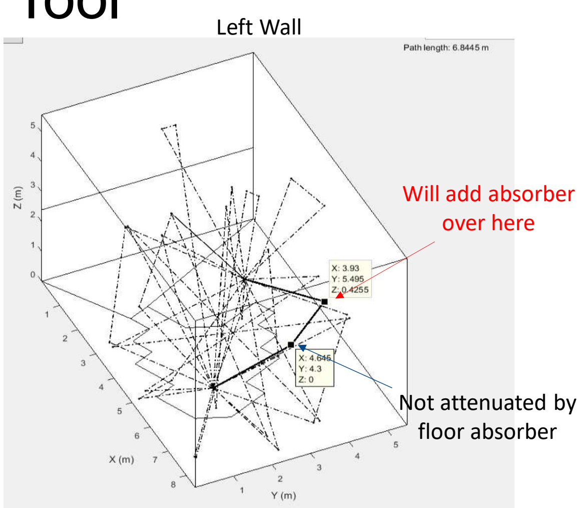
Getting the right reflection distance

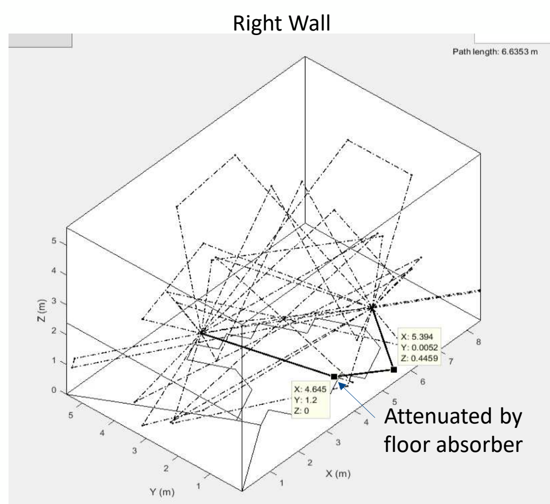
Difference = 24.56ns – 15.89ns
= 8.67 ns
~ 8.67 ft
= 2.643 m
Total reflection path length,
T = 4.1 + 2.643 = **6.743** m





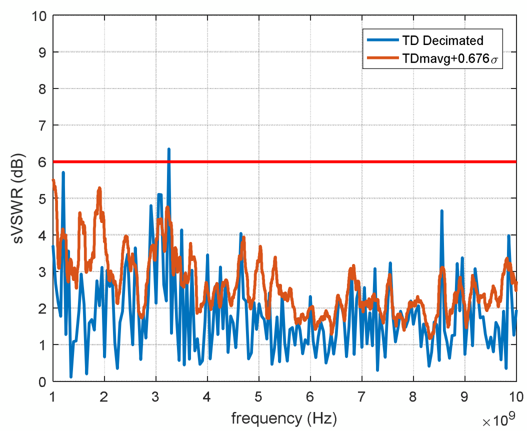
Finding the right reflection in Ray Path Tool





Final Measured Result

After adding a piece of absorber on left wall



For more info, go to Youtube and search "TD SVSWR" for an indepth discussion and demo (~45 min)

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Conclusion

- We have provided an overview of EMC chamber design process and how accurate EMC chamber simulations can aid a challenging design.
- In real-world designs, one rarely encounters a "standard" chamber, some customization is inevitable. "Winging it" is simply too risky for a large investment. A trustworthy simulation tool is a must.
- Through several case studies, we documented the features and accuracies of a hybrid full wave/GO approach. We demonstrated how simulation in combination with measurement can aid in debugging a non-compliant chamber.

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Hope you gained some insights into EMC chamber design!

Thank You

For questions, please contact:
zhong.chen@ets-lindgren.com

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