Advances in the Design of Chambers for Modern Vehicles

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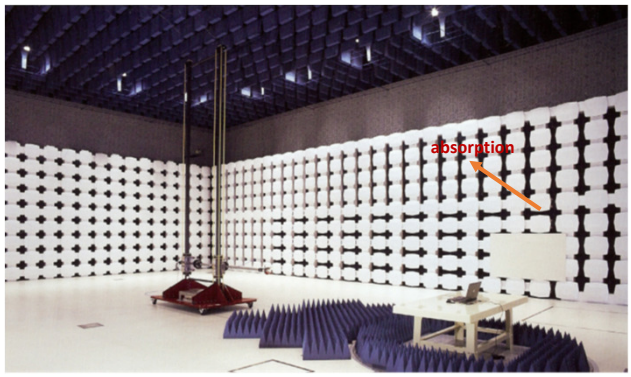
Introduction

- This presentation aims to provide understanding on anechoic chambers, absorbers, design tradeoffs, and chamber test methods.
- Three aspects are of particular interest for vehicle applications:
  - Chamber designs for EMC applications specified in MIL-STD-461
  - Chamber designs for convergent EMC/ antenna or radar measurements
  - High power measurements in an anechoic chamber (absorber material power handling)

Anechoic Chamber

A shielded room (an all-metal room) lined with anechoic material (absorbers), mimics an infinite open space with no obstructions anywhere.

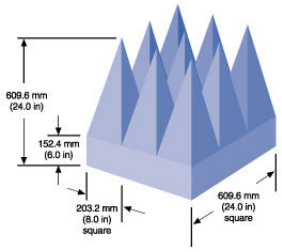
Environmental interferences



Environmental interferences

Absorber Type 1

- Pyramidal absorber



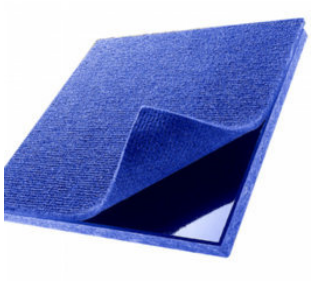
Electric Losses

Preferred technology for High frequencies

It can be used for low frequencies if size (length) is increased .

Absorber Type 2

- Ferrite Tile



Magnetic Losses

Preferred technology for Low frequencies (up to 1GHz)

It cannot be used for high frequencies.

Absorber Type 3

- Hybrid Absorber

Electric and Magnetic Losses

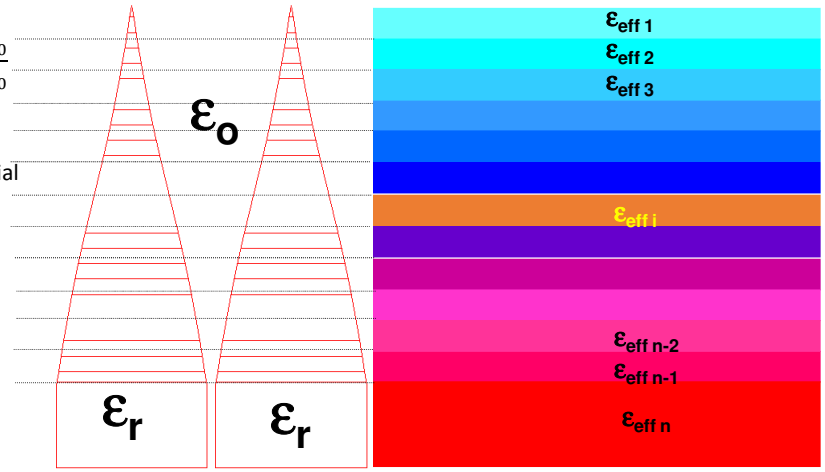
Preferred technology for EMC applications. Foam has to have special formula for good matching with ferrite tile at the bottom.

At High frequencies its performance is not as good as MW pyramid of equal size. Flat top causes undesired reflections at MW range.

Understanding the absorbers (effective property)

$$\varepsilon_{eff} = \varepsilon_0 \frac{(1+g)\varepsilon_1 + (1-g)\varepsilon_0}{(1-g)\varepsilon_1 + (1+g)\varepsilon_0}$$

g is the fractional area occupied by the absorber material



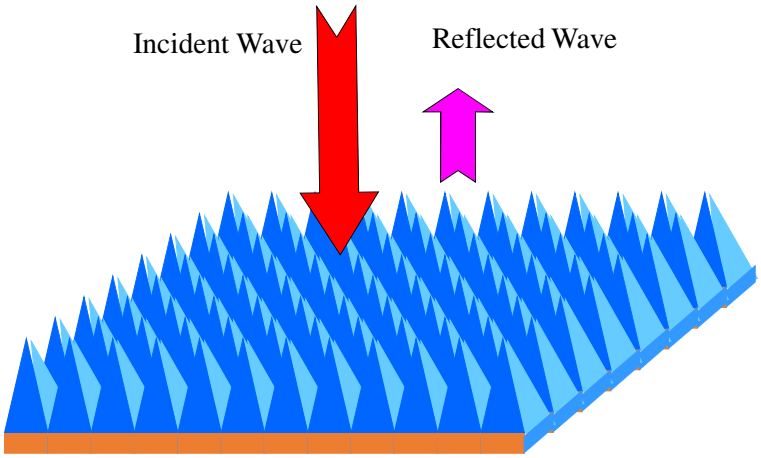
Typical Absorber Performance Given by Manufacturers

Maximum Reflections at Normal Incidence

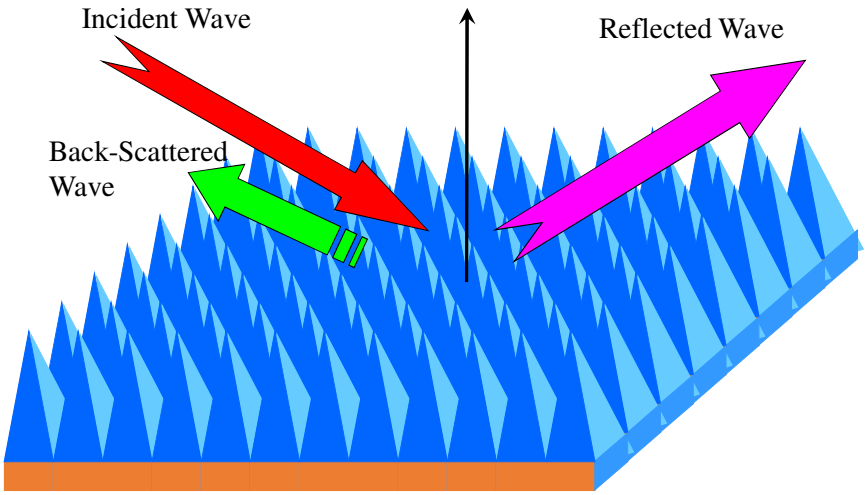
Model Number	80 MHz	120 MHz	200 MHz	300 MHz	500 MHz	L Band 1-2 GHz	S Band 2-4 GHz	C Band 4-8 GHz	X Band 8-12 GHz	Ku Band 12-18 GHz	K Band 18-40 GHz
EHP-3PCL								-30 dB	-40 dB	-45 dB	-45 dB
EHP-5PCL							-30 dB	-40 dB	-45 dB	-50 dB	-50 dB
EHP-8PCL						-30 dB	-40 dB	-45 dB	-50 dB	-50 dB	-50 dB
EHP-12PCL						-35 dB	-40 dB	-45 dB	-50 dB	-50 dB	-50 dB
EHP-18PCL					-30 dB	-40 dB	-45 dB	-50 dB	-50 dB	-50 dB	-50 dB
EHP-24PCL			-20 dB	-30 dB	-35 dB	-40 dB	-50 dB	-50 dB	-50 dB	-50 dB	-50 dB
EHP-36PCL	-11 dB	-13dB	-25 dB	-30 dB	-40 dB	-45 dB	-50 dB	-50 dB	-50 dB	-50 dB	-50 dB
EHP-48PCL	-15 dB	-20 dB	-30 dB	-35 dB	-40 dB	-45 dB	-50 dB	-50 dB	-50 dB	-50 dB	-50 dB
EHP-72PCL	-20 dB	-30 dB	-40 dB	-40 dB	-45 dB	-50 dB	-50 dB	-50 dB	-50 dB	-50 dB	-50 dB

Understanding RF Absorbers

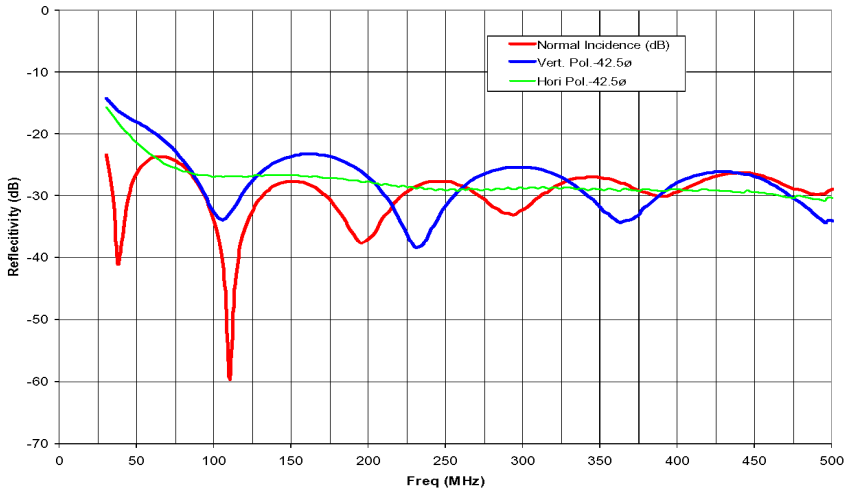
Perform the best at normal incidence!



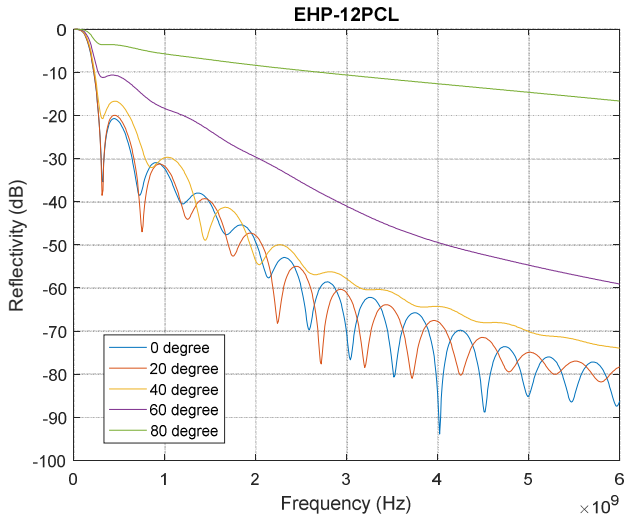
Performance degrade at oblique incidence!



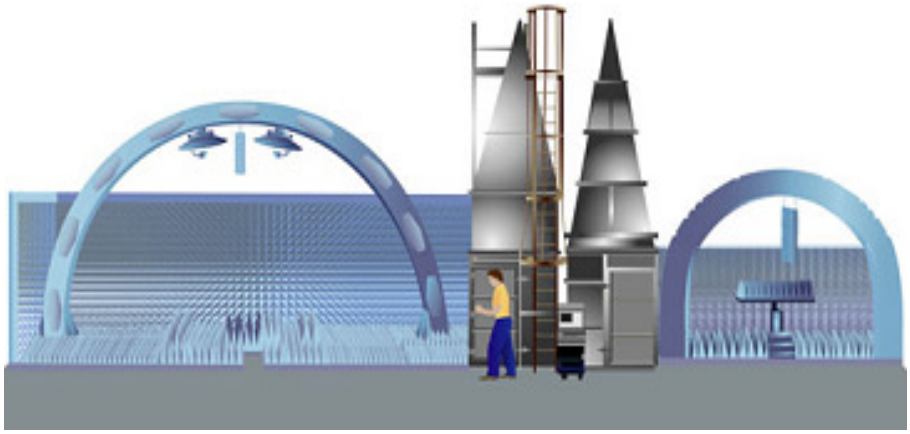
Typical Lower-Frequency RF Absorber Performance
(1.25m height hybrid ferrite tile and foam absorber)



Absorber Reflectivity vs. Incidence Angle



Absorber Reflectivity Measurement Devices from DC to 40 GHz



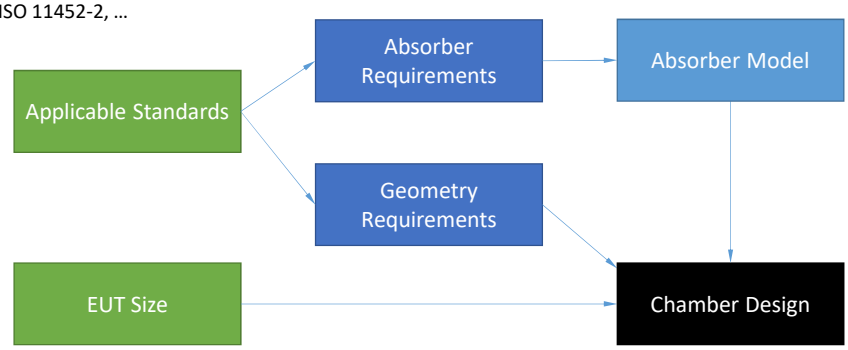
EMC Chambers & Standards

Application	Standards
Commercial	Radiated Emission (RE): ANSI C63.4 / CISPR 16-1-4 Radiated Immunity (RI): IEC 61000-4-3
Military / Aerospace	MIL-STD-461 / RTCA DO-160
Automotive	CISPR 25 / ISO 11452-2
Telecom	Radiated Spurious Emissions: ETSI

Chamber Design Procedure (MIL)

- **Absorber requirements** specified in standards:

MIL-STD-461, RTCA DO-160, CISPR 25, ISO 11452-2, …



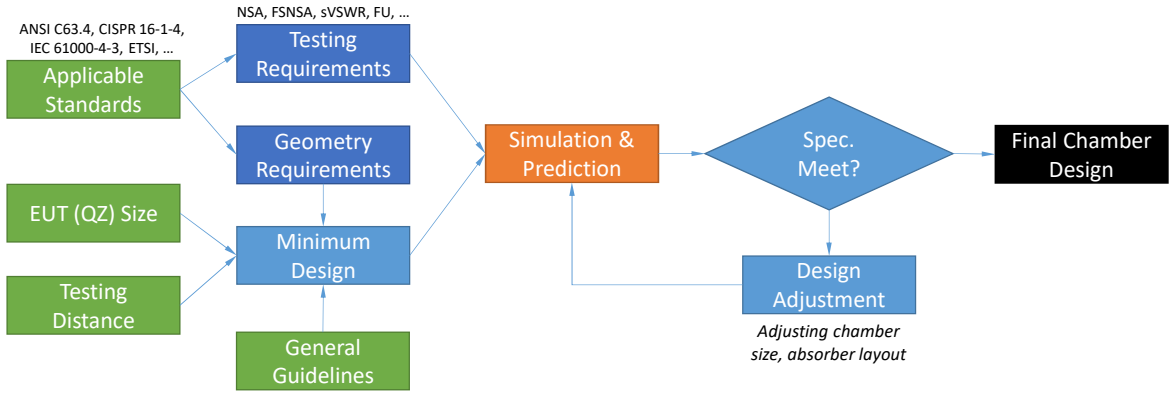
Chamber Tests and Requirements

- For commercial applications:

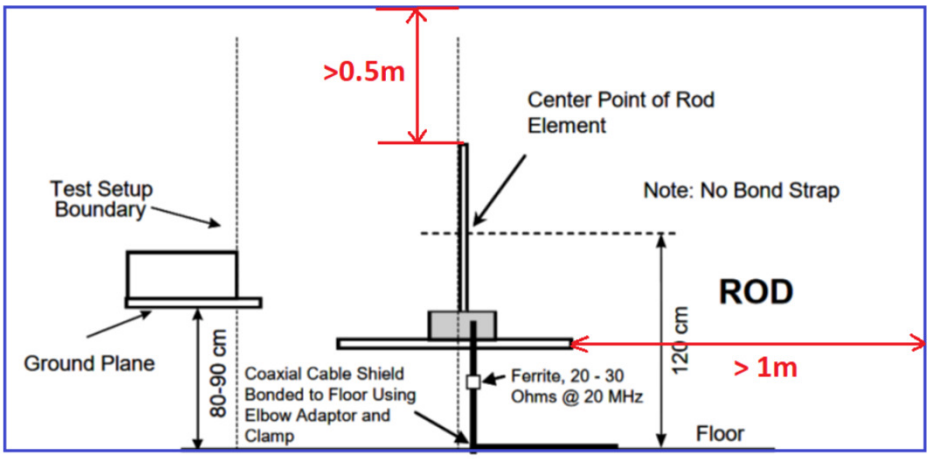
Chamber Type	Radiated Emission 30 MHz – 1 GHz	Radiated Emission 1 GHz – 18 GHz	Radiated Immunity 80 MHz – 18 GHz
SAC	±4 dB **NSA** deviation per ANSI C63.4 / CISPR 16-1-4	6 dB **sVSWR** per CISPR 16-1-4	6 dB **FU** per IEC 61000-4-3
FAC	±4 dB **FSNSA** deviation per CISPR 16-1-4	6 dB **sVSWR** per CISPR 16-1-4	6 dB **FU** per IEC 61000-4-3

Chamber Design Procedure (Commercial)

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

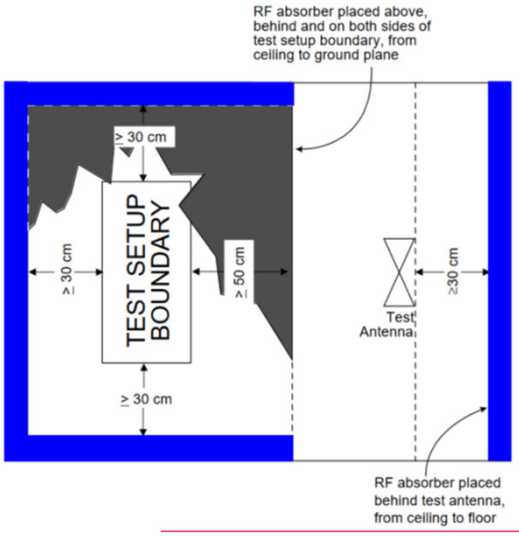


Size of MIL-STD Chambers



- no part of any antenna is closer than 1 meter from the walls and 0.5 meter from the ceiling of the shielded enclosure.

Absorber Layout MIL STD

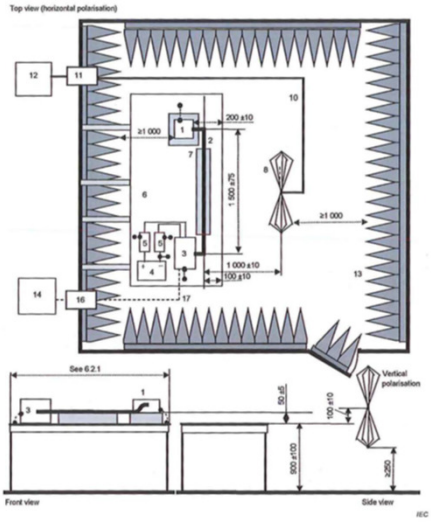


- The chamber shall be large enough to accommodate the EUT and antenna so they satisfy minimum distance to absorber constraints.
- Metal ground plane
- "RF absorbers shall be placed above, behind, and on both sides of the EUT, and behind the radiating and receiving antenna"

TABLE I. Absorption at normal incidence.

Frequency	Minimum absorption
80 MHz - 250 MHz	6 dB
above 250 MHz	10 dB

CISPR 25 is Similar to MIL-STD 461



Performance of the absorption material shall be greater than or equal to 6 dB in the 70 MHz to 2 500 MHz frequency range.

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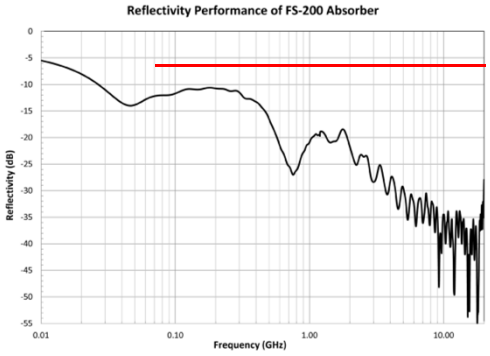
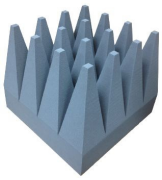


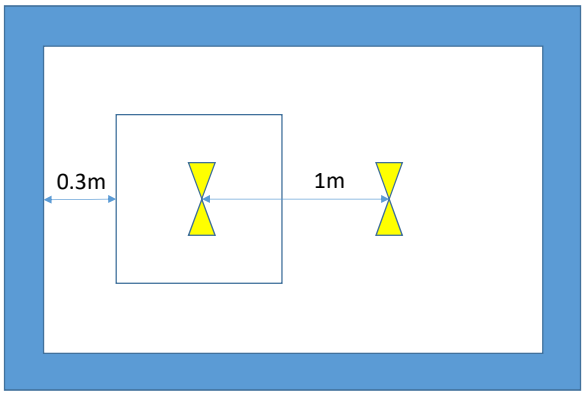
Ref: CISPR 25 (2016)

MIL-STD 461 Chambers



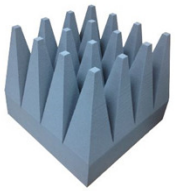
- The only RF requirement is absorber normal incident angle reflectivity better than 6 dB from 80 MHz to 250 MHz, and better than 10 dB > 250 MHz.
- Commercial foam only absorbers can meet this requirement (e.g., EMC-20PCL, EMC-24PCL). Ferrite/Foam Hybrid absorbers can perform much better.
- Unlike commercial EMC tests (NSA and sVSWR), there are no specific chamber level test criteria.
- **Almost impossible to have a failing MIL standard chamber! But it doesn't mean all chambers perform equivalently.**

An Example of Diff. Absorber Treatment on MIL-STD 461 Measurements



Height of antennas: 1.55m

Absorber #1: EMC-20PCL

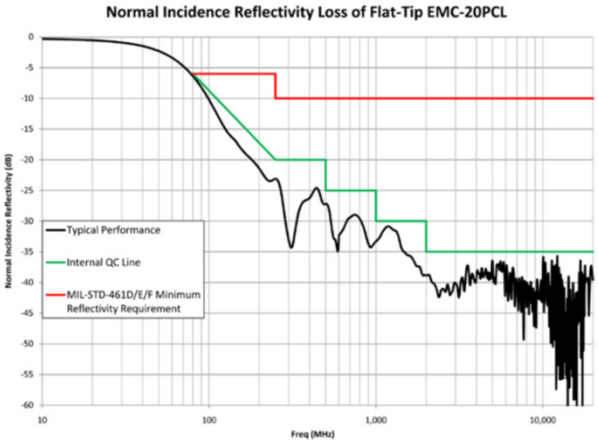


Electrical Specifications

MODEL	FREQUENCY	POWER HANDLING (CW)
EMC-20PCL	80 MHz - 40 GHz	600.0 V/m 775.0 W/m² 0.5 W/sq. in

Physical Specifications

MODEL	DIMENSIONS (L X W X H)	WEIGHT
EMC-20PCL	610 mm x 610 mm x 508 mm 24" x 24" x 20"	4.6 kg 10.1 lb

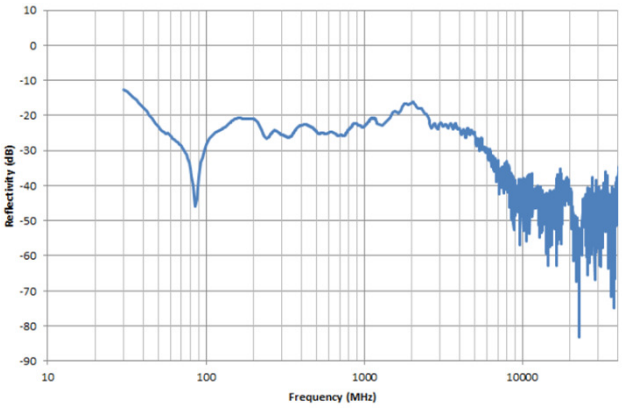


Typical chamber size: **5.5m × 5.5m × 3.1m**

Absorber #2: DSH-600H

Technical Specifications

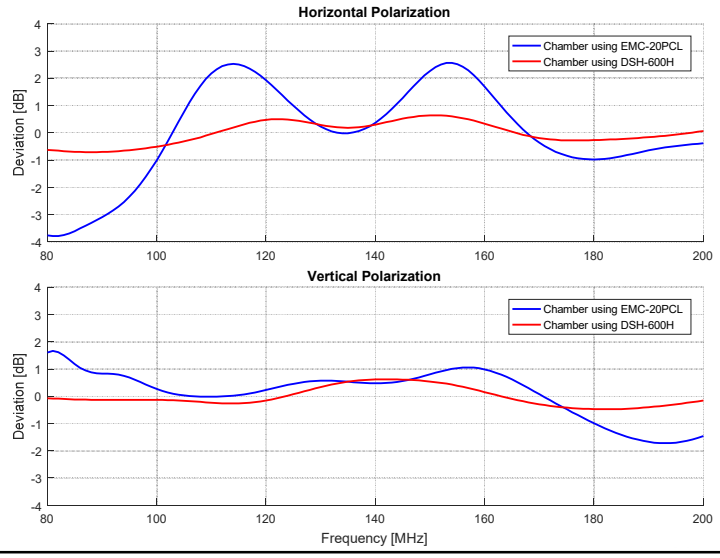
Electrical	
Frequency	30 MHz to >40 GHz
Power Handling	200 V/m
	106 W/m²
	0.068 W/in²
Physical	
Height[1]	60.0 cm
	23.6 in
Width	60.0 cm
	23.6 in
Depth	60.0 cm
	23.6 in
Weight[2]	2.7 kg
	6.0 lbs



Typical chamber size: **5.7m × 5.7m × 3.2m**

Comparing chambers using different absorbers

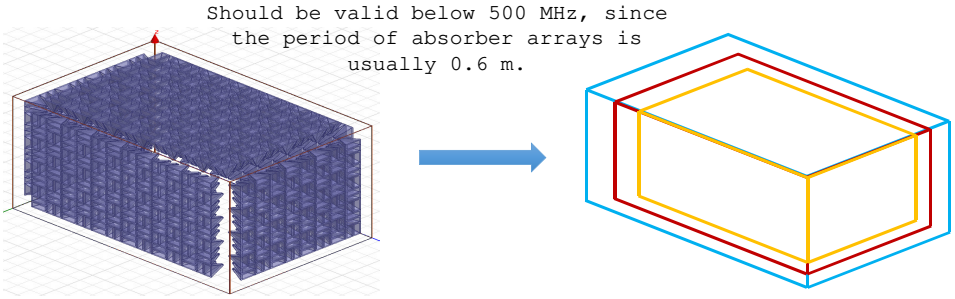
Range loss deviation from an ideal site



Better Chamber Design through Simulation

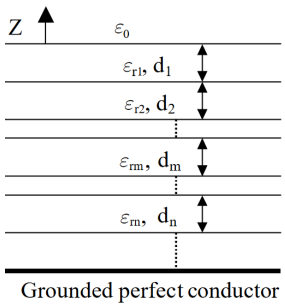
- Homogenization of absorber arrays leads to a simplified chamber model with layered structures.

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



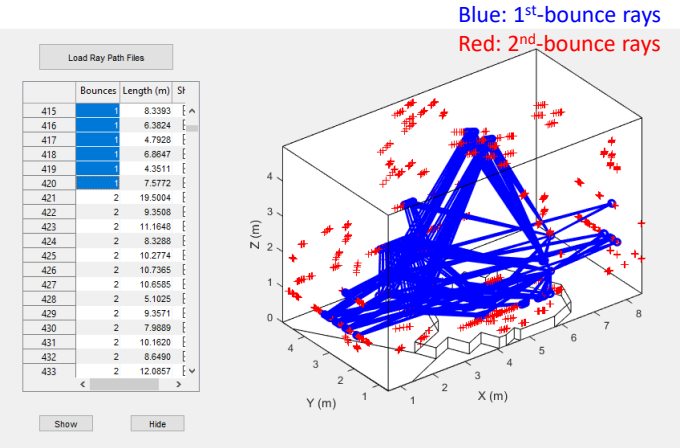
Discrete Complex Image Method

- Discrete Complex Image Method - an semi-analytical solution for a multi-layered media for rapid evaluation of spatial-domain Green's functions.
- Complex images are series of images at complex depths fit to the analytical expressions (to approximate the spectral kernel by a sum of complex exponentials).
- They are strictly mathematical constructs, with no physical meanings of a normal image.



Raytracing to visually aid 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



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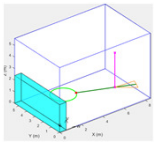
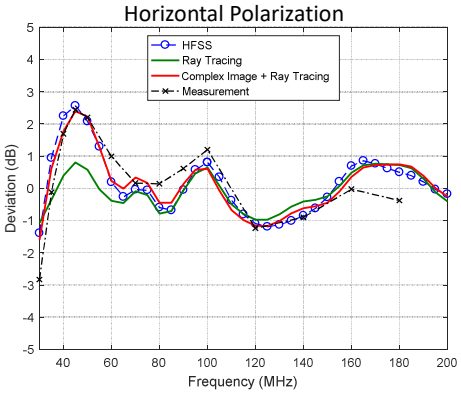
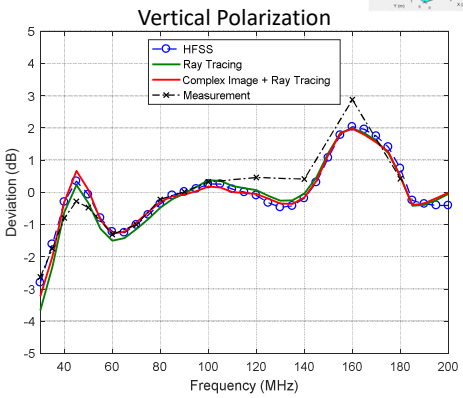
Simulation Validation: An example

- Left position

NSA simulation of a 3m chamber with 24in hybrid absorbers partial lining







Design for a Limited Space

- It is very often that the user's available space does not fit into any standard design.
- Based on the available space, suggest maximum quite zone size and testing distance.
- Run simulation to optimize the absorber treatment, and determine the performance.

Upgrade an Existing Chamber

- Many chambers need upgrade
  - Absorber degradation over time
  - The low frequency performance of old style pyramidal absorbers is marginal by today's standards
  - Adding new testing capabilities
- Simulation tool can provide a quick and trustworthy solution.

Refurbishing Example

- 20-years old 1.8m twisted pyramidal absorbers in a 10m chamber
- Absorbers perform not as good as current hybrid absorbers.
- All the works had to be completed within 5-6 weeks.

Refurbishing Example (cont.)

- Simulation showed that replacing with hybrid absorbers DuraSorb™ DSH-600 can meet the performance requirements.
- Independent measurements verified the excellent correlation to the simulation data.

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Some Upgrading Guidelines

- Replacing old long foam absorbers with state-of-the-art hybrid absorbers may
  - Better chamber performance at low frequencies
  - Can increase the test volume by ~1 meter
- Upgrading hybrid absorbers on an existing ferrite lined chamber to add testing capability above 1GHz
- Single-purpose to Multi-purpose
- Understand what the refurbished chamber will be used for.
- Always ask for simulation data!

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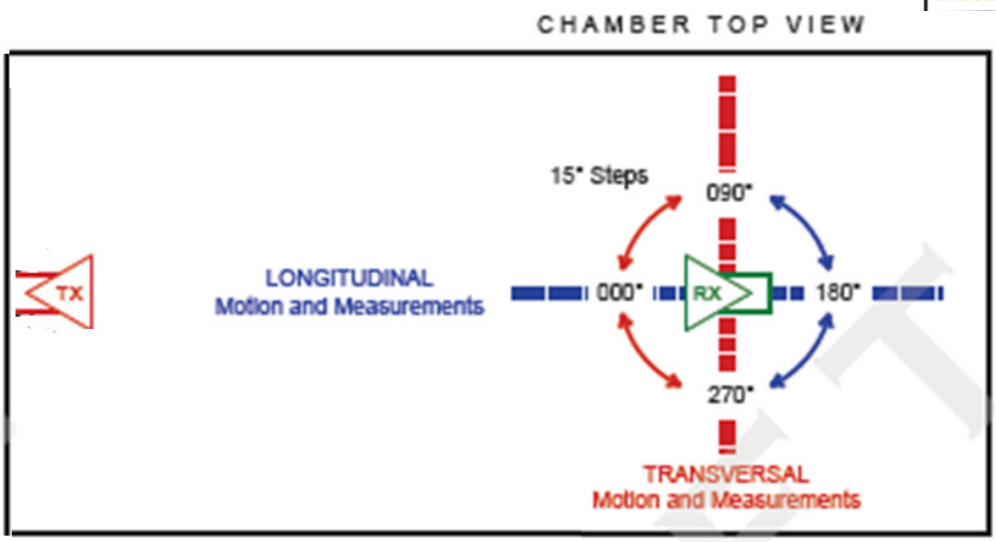
Antenna/Radar Measurement Chambers

Antenna Chambers: Different Design and Test Considerations

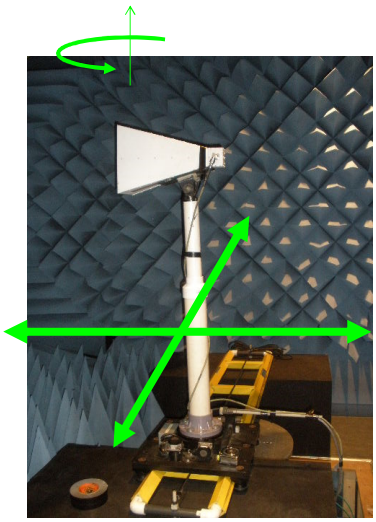
- For antenna measurement or radar cross section (RCS) chambers, the test requirements are different from typical EMC chambers
- Full anechoic chamber is required
- The industry standard is based on Free-Space VSWR method
- **ANSI/IEEE Std 149-1979** (Revision of IEEE Std 149-1965)
- University of Michigan Report 5391-1-F February 1963 (free space VSWR test)

Free Space VSWR



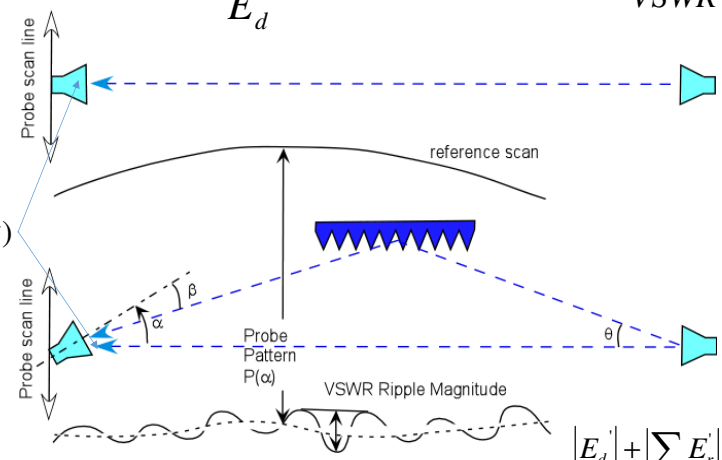
Transverse/ Longitudinal Scan

The probe antenna is scanned across the QZ
For each scan the antenna points at a different direction



$$R = \frac{\sum E_r^{'}}{E_d} \Rightarrow |R| = P(\alpha)\frac{VSWR-1}{VSWR+1}$$

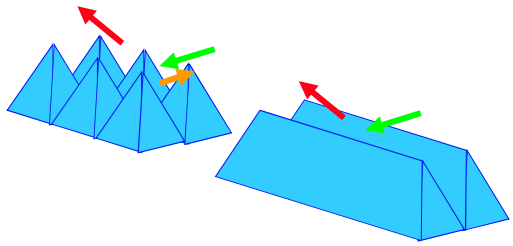
$$E_d^{'} = E_d \times P(\alpha)$$



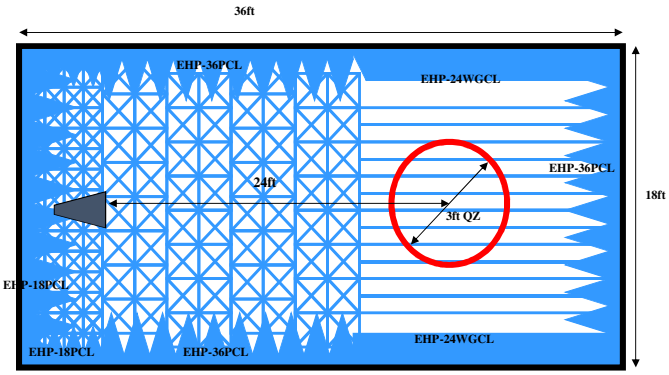
$$VSWR = \frac{|E_d^{'}| + |\sum E_r^{'}|}{|E_d^{'}| - |\sum E_r^{'}|}$$

Antenna Chamber: The Absorber Treatment

- Traditionally in RCS chambers the backscatter of the side walls (and ceiling/floor pair) is to be reduced using Wedge. By using wedge around the QZ section of the chamber we can improve the quality of the measurements at high frequencies



Wedge it is usually used to treat around the QZ



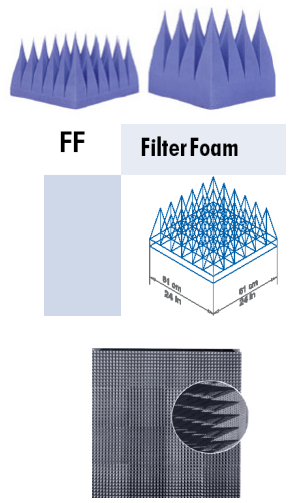
Let's not burn down the chamber in the process!

Anechoic Chamber – High Power Application Considerations

- Absorbers convert electromagnetic wave energies into heat. Invariably, absorber temperature is elevated from the ambient when RF energy is applied.
- In recent years, there has been an increasing need to perform EMC measurements at high power levels.
- Not much published information or test methodology is available for absorber power handling capabilities.

Cost Structure of Different Absorbers

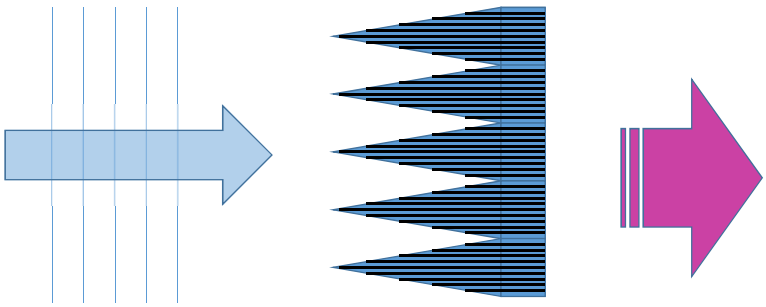
- Conventional absorbers without forced air are most cost effective
- Filter Foam absorbers with some capabilities of forcing the ventilated air with about 3-5x cost
- Honeycomb high power absorbers allows easy forced air to ventilate the heat with about 12x cost



Summary of RF/Microwave Absorber Power Handling Capability

- Most polyurethane based RF absorber can safely handle up to 0.5W/in² (775W/m²).
- Some larger cell airvent foam absorber may handle up to 0.75W/in² (1165W/m²)EM power density without forced air ventilation.
- Phenolic rasin honeycomb absorber may handle up to 2.0W/in² (3.1kW/m²) without forced air ventilation
- For higher power density, some kind of forced air ventilation will be needed to take out the energy from the absorber body to sustain the measurement

Honeycomb Absorbers: Conversion and Transport of RF Energy

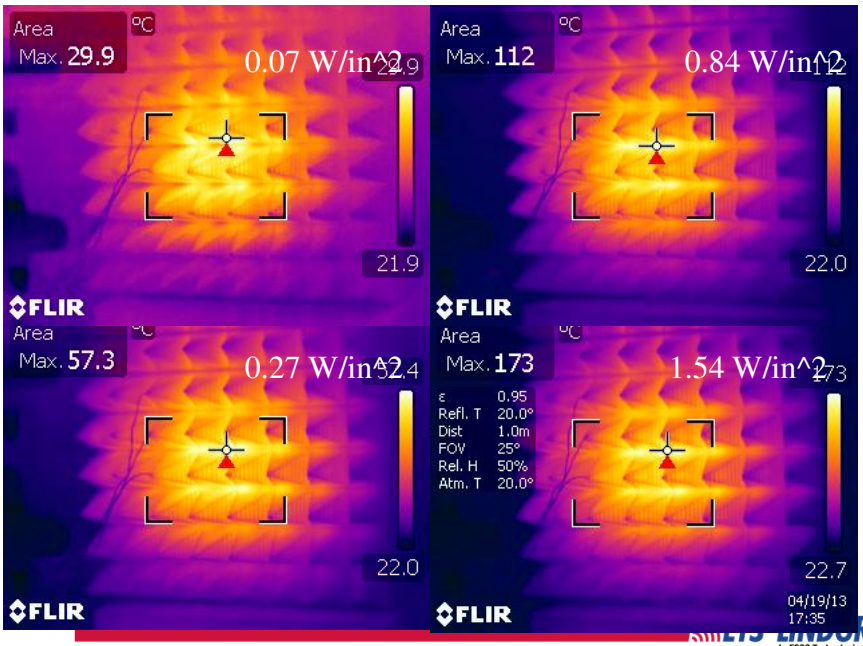


Incident Electromagnetic Wave Energy

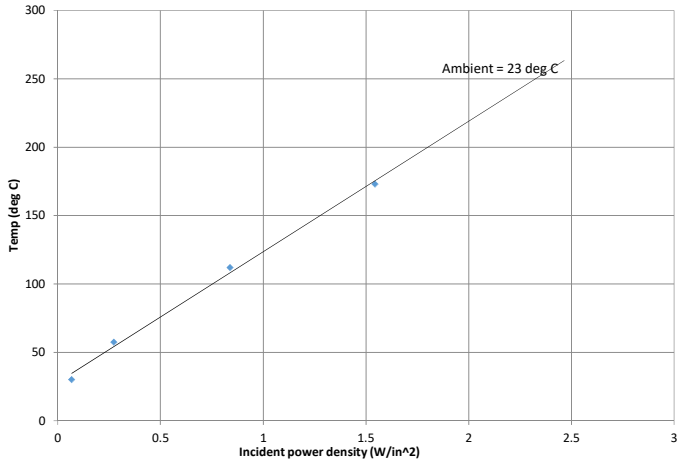
RF Absorber Converts EM energy into heat

Heat is transferred to air predominantly by convection

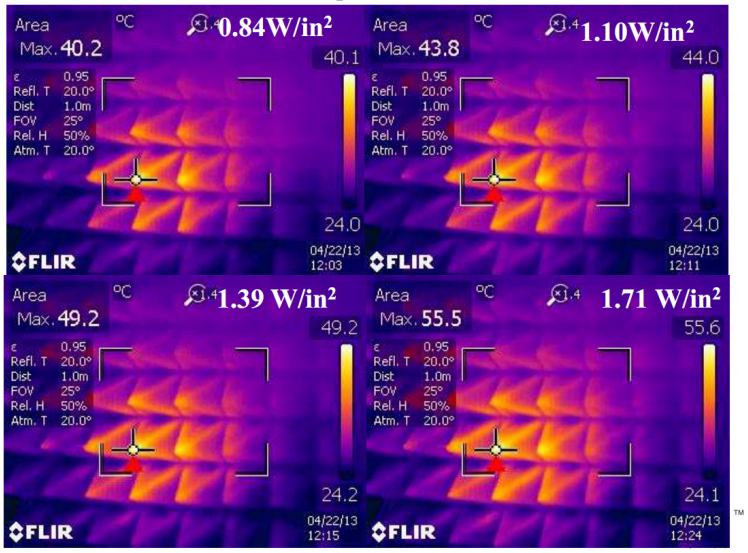
Natural Convection



HP12 (12" pyramids) , f=12.4 GHz, Natural Convection



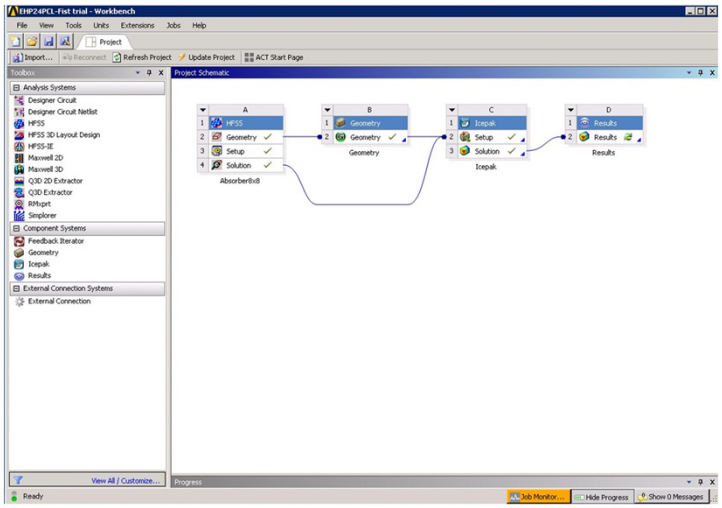
Fan Speed 3



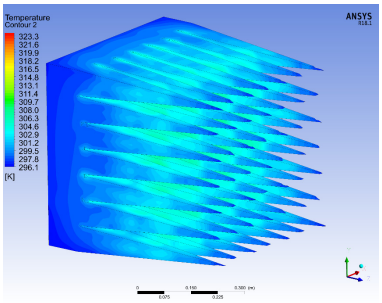
Determine Absorber Power through multi-physics simulation

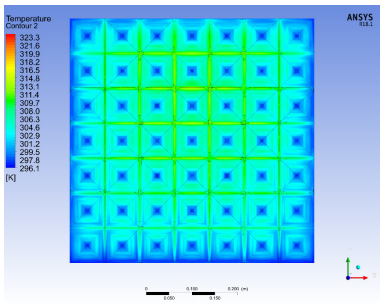
- Absorber power handling can depend on frequency, absorber type, material heat conductivity, surface area etc…
- Numerical modeling allows multi-physics simulation of full wave EM modeling + Thermal modeling, which gives more complete and specific analyses

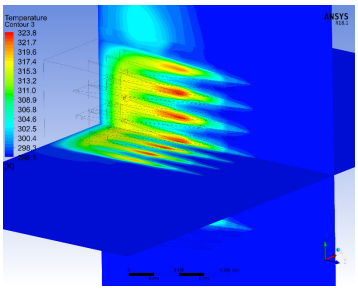
Example: ANSYS HFSS + ICEPAK



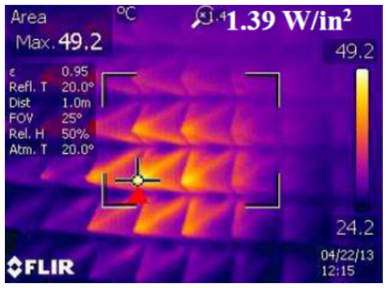
EHP24PCL
Power = 100 W



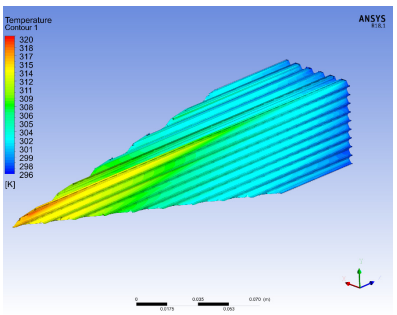




HP 12 Q=1.39 W/in^2 Velocity = 330 ft/min



(a) Experimental



(b) Numerical

Absorber Power Handling

- Polyurethane substrate (ETS-Lindgren) can withstand ~115°C with no short or long term adverse effects.
- Because of the fire retardant, the absorbers do not smoke or burn at 200°C, but it can lose physical properties permanently (charring/stiff).
- Internal temperature typically is approximately 20° higher than surface temperature

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Power Handling Summary

- Power handling analysis is a combined EM/thermal multi-physics effort.
- Power handling is a function of absorber
  - shape/size
  - Material
  - ambient condition: airflow/ temperature
  - Frequency !
- If you perform high power EMC test, make sure to understand the thermal effect.
- Simulation/Testing!

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Summary

- We provided discussions on anechoic chambers, absorbers, design tradeoffs, and chamber test methods for today's modern military vehicles .
- Three aspects are of particular interest for vehicle applications:
  - Chamber designs for EMC applications specified in MIL-STD-461
  - Chamber designs for antenna or radar measurements
  - High power measurements in an anechoic chamber (absorber material power handling)