Insights into EMC Chamber Design: How to achieve an optimized chamber for accurate EMC Measurements

Zubiao Xiong, PhD
zubiao.xiong@ets-lindgren.com
November 16, 2017
EMC Compliance Testing

Emission (*Disturbance*)

Anechoic chambers serve for radiated tests.

Immunity (*susceptibility*)
Anechoic Chamber

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

• Semi-Anechoic Chamber (SAC)
  • Absorbers on walls and ceiling
  • Reflective metal floor

• Fully Anechoic Chamber (FAC)
  • All surfaces are covered with absorbers

• Partially Lined
  • Only critical areas are covered with absorbers
EMC Absorber Family 1

• Pyramidal absorber

**Electric Losses**

Preferred technology for High frequencies

It can be used for low frequencies if size (length) is increased.
EMC Absorber Family 2

• Ferrite Tile

Magnetic Losses

Preferred technology for Low frequencies (up to 1GHz)

It cannot be used for high frequencies.
EMC Absorber Family 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.
EMC Standards

- Anechoic chamber related:

<table>
<thead>
<tr>
<th>Application</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>Radiated Emission (RE): ANSI C63.4 / CISPR 16-1-4</td>
</tr>
<tr>
<td></td>
<td>Radiated Immunity (RI): IEC 61000-4-3</td>
</tr>
<tr>
<td>Military / Aerospace</td>
<td>MIL-STD-461 / RTCA DO-160</td>
</tr>
<tr>
<td>Automotive</td>
<td>CISPR 25 / ISO 11452-2</td>
</tr>
<tr>
<td>Telecom</td>
<td>Radiated Spurious Emissions: ETSI</td>
</tr>
</tbody>
</table>
## Chamber Tests and Requirements

- For commercial applications:

<table>
<thead>
<tr>
<th>Chamber Type</th>
<th>Radiated Emission 30 MHz – 1 GHz</th>
<th>Radiated Emission 1 GHz – 18 GHz</th>
<th>Radiated Immunity 80 MHz – 18 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAC</td>
<td>±4 dB <strong>NSA</strong> deviation per ANSI C63.4 / CISPR 16-1-4</td>
<td>6 dB <strong>sVSWR</strong> per CISPR 16-1-4</td>
<td>6 dB <strong>FU</strong> per IEC 61000-4-3</td>
</tr>
<tr>
<td>FAC</td>
<td>±4 dB <strong>FSNSA</strong> deviation per CISPR 16-1-4</td>
<td>6 dB <strong>sVSWR</strong> per CISPR 16-1-4</td>
<td>6 dB <strong>FU</strong> per IEC 61000-4-3</td>
</tr>
</tbody>
</table>

Full compliance vs Pre-compliance
Normalized Site Attenuation (NSA)


Standards call for NSA being within +/-4 dB of the theoretical NSA.
Free-Space Normalized Site Attenuation (FSNSA)

Ref: CISPR 16-1-4 (2010)
Standards call for NSA being within +/-4 dB of the theoretical NSA.
Site Voltage Standing Wave Ratio (sVSWR)

Ref: CISPR 16-1-4 (2010)
Standards call for sVSWR ≤ 6dB.
Field Uniformity (FU)

This plane includes the uniform area.

Ref: IEC 61000-4-3 (2010)
Standards call for 75% E-field values (12 of the 16 points) within a spread of 6dB.
MIL-STD-461

CISPR 25

Performance of the absorption material shall be greater than or equal to 6 dB in the 70 MHz to 2500 MHz frequency range.

Ref: CISPR 25 (2016)

ETS-Lindgren
FS-200
<table>
<thead>
<tr>
<th></th>
<th>Classical Chamber Conditions</th>
<th>NEW Chamber Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>version</td>
<td>By v.1.7.1 (2006/10)</td>
<td>As of v.1.8.1 (2012/06)</td>
</tr>
<tr>
<td>shielding</td>
<td>(shielding)</td>
<td>Enough Shielding (80~140dB) (Described in TR 102-273-1-1)</td>
</tr>
<tr>
<td>anechoic performance</td>
<td>(absorber)</td>
<td>NSA ≤ ±4.0 dB per ETSI TR 102 273-2~3 (2001/12)</td>
</tr>
</tbody>
</table>
Chamber Design Procedure 1

- **Absorber requirements** specified in standards:

  - MIL-STD-461, RTCA DO-160, CISPR 25, ISO 11452-2, ...
Chamber Design Procedure 2

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

  - ANSI C63.4, CISPR 16-1-4, IEC 61000-4-3, ETSI, ...
  - NSA, FSNSA, sVSWR, FU, ...

|----------------------|----------------------|-----------------------|----------------|--------------------|------------------------|------------|-------------------|----------------------|

- Adjusting chamber size, absorber layout
General Design Guidelines

• Some rules can be applied 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
  • Extra space is needed for antenna mask
Minimum Length and Width of Chamber

• NSA testing

\[
L = (D + R_{QZ}) \cdot \cos(\alpha) + R_{QZ} + S_{Rx1} + S_{QZ} + 2 \cdot H_{abs}
\]

\[
W = (D + R_{QZ}) \cdot \sin(\alpha) + R_{QZ} + S_{Rx1} + S_{QZ} + 2 \cdot H_{abs}
\]

where \( S_{Rx1} = 2m, S_{Rx2} = 1m, S_{QZ} = 1m \)

• \( S_{Rx1} \) can be a minimum of 1.5m
Minimum Height of Chamber

• NSA testing

\[ H = 4m + S_{Rx3} + H_{abs} \]

where \( S_{Rx3} = 1m \)
NSA: Why 4m Height?

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

Two dipoles separated by 3 m over ground

Peaks within 1m to 4m
Design Example

• FACT 3-2.0 Standard Plus

D = 3m, R_QZ = 1m
α = 18°

DSH-600H absorber
0.62m tall

Minimum Design

L = 8.55m
W = 5.48m
H = 5.62m

Simulation to verify its performance
Simulation Methodology

• Running simulations multiple times may be needed to achieve optimized design. Therefore, simulation speed is critical.
• Full-wave solvers (FEM, FDTD, etc.) are usually not applicable due to long simulation times.
• Ray Tracing is the “standard” method used in the industry.
• However, Ray Tracing is not accurate below 80 MHz (Ray representation not accurate in the near field when the antenna is too close to absorbers in wavelengths).
• Low frequency simulation (< 80 MHz) is the difficult point.
Homogenization Modeling of Absorber

- When an incident wave encounters a periodic composite (period $p$), it does not “see” the fine structure if $p \ll \lambda$.
- Instead, the incident wave behaves as though it encountered an effective flat solid medium.

Assuming the structure period is smaller than the free space wavelength.

$\varepsilon_1, \varepsilon_2, \ldots \approx \varepsilon_{\text{eff}}(z)$

$\mu_1, \mu_2, \ldots \approx \mu_{\text{eff}}(z)$

Unit Cell Simulation

• Simulation setup
  - two orthogonally-polarized plane waves incident in normal direction (0°)
  - two orthogonally-polarized plane waves incident in 90°
  - Floquet port (or PML) @ top, PEC @ bottom

\[
\mu_{x,y,z}^{\text{eff}}(z) \approx \frac{\int_{V_z} \mu(x',y',z') H_{x,y,z}^0 (x',y',z') dv'}{\int_{V_z} H_{x,y,z}^0 (x',y',z') dv'}
\]
\[
\varepsilon_{x,y,z}^{\text{eff}}(z) \approx \frac{\int_{V_z} \varepsilon(x',y',z') E_{x,y,z}^0 (x',y',z') dv'}{\int_{V_z} E_{x,y,z}^0 (x',y',z') dv'}
\]

Periodic boundary conditions on four sides
Validation of Homogenization

- A real hybrid EMC absorber
  - Hollow pyramids
  - Alternating arrangement of pyramids
  - Hybrid lossy dielectric and magnetic materials

![Actual structure and homogenization model](image)
Simplified Chamber Model

- 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.
Validation of Chamber Simulation

- Back position

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

![Diagram showing horizontal and vertical polarization simulations](image)
Validation of Chamber Simulation (cont.)

- Center position

NSA simulation of a 3m chamber with 24in hybrid absorbers partial lining
Validation of Chamber Simulation (cont.)

- Front position

NSA simulation of a 3m chamber with 24in hybrid absorbers partial lining
Validation of Chamber Simulation (cont.)

• Left position

NSA simulation of a 3m chamber with 24in hybrid absorbers partial lining
Validation of Chamber Simulation (cont.)

- Right position

NSA simulation of a 3m chamber with 24in hybrid absorbers partial lining
Summary of Our In-house Chamber Simulation Tool

• Excellent accuracy even at very low frequencies.
• It can simulate an EMC chamber in a couple of minutes, therefore allowing us to optimize the chamber design efficiently.
• It can simulate various chamber tests including NSA, FSNSA, sVSWR and FU.
• Its ray path tool provides guidance on cost-effective designs.
• It allows us to provide a customized design for a limited space.
• It can assist with chamber troubleshooting.
Cost-Effective Designs

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

Blue: 1\textsuperscript{st}-bounce rays
Red: 2\textsuperscript{nd}-bounce rays
Design for a Limited Space

• It is very often that the customer’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

• Lots of chambers from 90’s will need upgrade sooner or later
  • Absorber degradation over time
  • The low frequency performance of old style pyramidal absorbers is marginal by today’s standards
  • Adding new testing capabilities

• Our 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 below 80MHz.
- 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.
Some Upgrading Guidelines

• Replacing old long foam absorbers with state-of-the-art hybrid absorbers may
  • get better chamber performance at low frequencies
  • possibly increase the QZ 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!
Chamber Debugging: TD + Simulation Tool – A powerful combination
TDsVSWR before correction

Don’t exact know why failed?
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

Left Wall

Right Wall

Will add absorber over here

Not attenuated by floor absorber

Attenuated by floor absorber
Final Measured Result

After adding a piece of absorber on left wall
Thank you!

Questions?