Modeling & Analysis of Anechoic Chambers

A white paper demonstrating how FEKO models were used during the design stages of an anechoic chamber that operates in UHF ranges.

Introduction

Anechoic chamber design is often a trade-off between optimum quiet zone performance and minimum system cost. These trade-offs are in turn influenced by the operational frequency range that the chamber is being designed for and the available space and shape of the chamber.

Typical design methods that are used include empirical formulae and ray tracing methods. Unfortunately mathematical methods in the ray tracing family suffer from numerical inaccuracy, especially in scenarios where the room's characteristic dimensions are only a couple of wavelengths in size (i.e. typical VHF/UHF frequency bands).

The following information is based on the work of Campbell et. al. [1] and demonstrates how full wave EM simulation of a chamber at VHF/UHF frequencies is a useful tool that may be used to predict performance of a new chamber design.

Factors that may be investigated using the methods described by Campbell et. al. include:

- Absorber design, incl. various material parameters, shape of the absorbing cones and layout of the absorbers in the chamber
- Separation and beam width of antennas in the chamber
- Geometry and materials used in construction of positioning equipment

Numerical Models

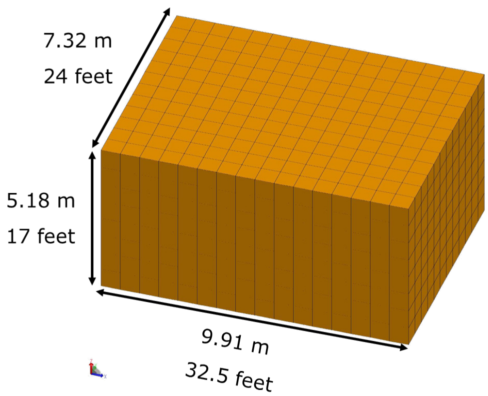
Constructing appropriate numerical models for the modelling of an anechoic chamber leverages FEKO's hybrid FEM/MoM formulation. The chamber itself is electrically large, while the absorbers are great in numbers and geometrically complex dieletric structures. For this combination of simulation requirements the FEM is well suited to modelling field propagation inside the chamber for the VHF/UHF frequencies of interest.

The FEKO models that are described further in this section model the entire internal chamber (space, absorbers and antennas) inside a FEM region which is decoupled from the MoM region. This invokes a particularly useful feature of FEKO's FEM implementation in that a PEC metallic boundary condition is applied to the FEM region and no MoM external problem is solved. The full solution is thus FEM-based, which forms sparse matrices during the solution phase and is therefore a memory efficient solution method for this problem.

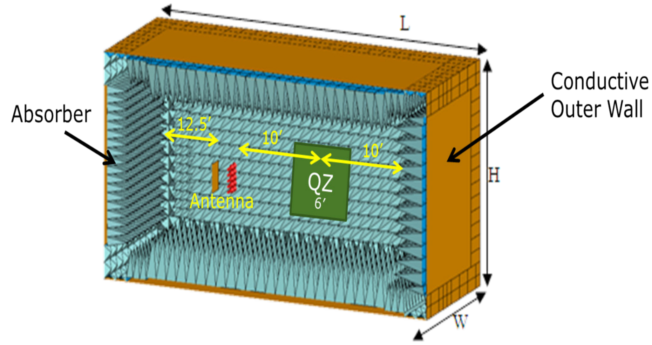
The following paragraphs describe the detail of the different model elements.

Chamber

The chamber itself is essentially a PEC bounding box for the FEM problem to be solved here. In the decoupled FEM-MoM problem, the surface area of the box is of no concern from a computational requirements perspective as the MoM problem will not be solved. The internal volume is of concern as this has to be meshed using FEM tetrahedra and although this forms a sparse matrix during the solution phase, storage is still required for the mesh geometry and related preconditioners. The total internal volume of the chamber thus plays a significant role in determining the total memory requirements of the solution.



Outside dimensions



Internal dimensions

W x H x L = 7.32 m x 5.18 m x 9.91 m

At 500MHz, this equates to dimensions in wavelength:

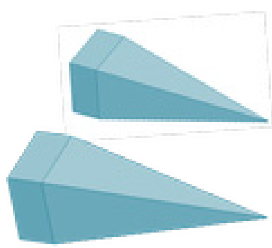
W x H x L = 12.22 λ x 8.64 λ x 16.54 λ

Total volume = 1746 λ_2

Anechoic chamber dimensions

Absorbers

Typical rectangular base cones are used to form the absorbing boundaries inside the chamber. Two sizes of cone are used in different areas, which have the following dimensions. Once a single cone has been created using CADFEKO primitives, this cone can be copied to the required extents very simply using the "Copy Special... and Translate" geometry duplication feature.

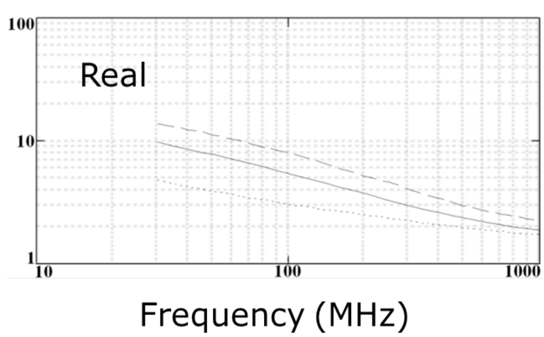


Transmit Wall: Base (8" x 8" x 4"); Height (24")

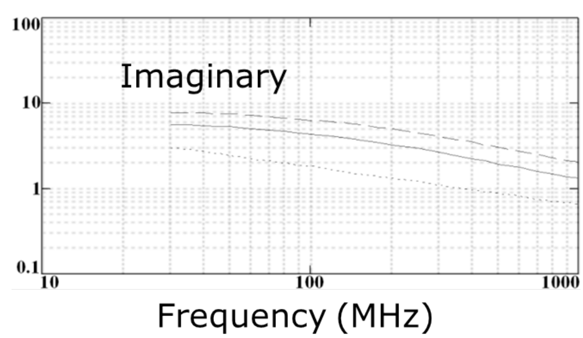
Center Patch: Base (12" x 12" x 6"); Height (36")

Absorber dimensions

The absorbers are made from material with dieletric properties that vary with frequency. The following graphs demonstrate the permittivity of the absorber material and specific frequencies of interest to VHF/UHF simulations. The relevant frequency parameters can easily be setup as a custom material in CADFEKO.



Real



Imaginary

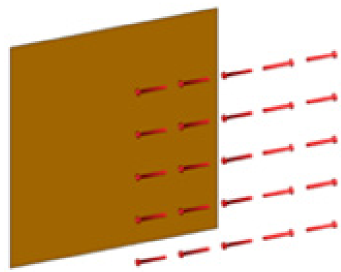
Permittivity

Frequency	ε'_r	ε''_r	$\tan\delta$
150 MHz	4.76	4.47	0.9388
250 MHz	3.50	3.00	0.8571
500 MHz	2.40	1.95	0.8125
1000 MHz	1.95	1.40	0.7179

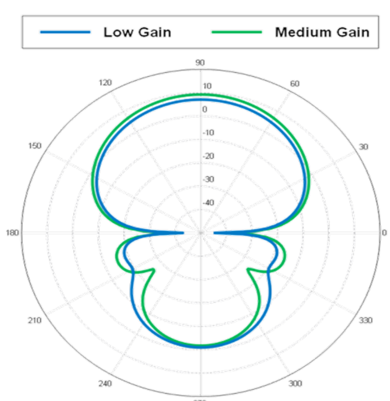
Antenna

The antennas inside the FEM region of this problem space is modeled as a combination of current sources. These current sources combine appropriately to form both a low and medium gain antenna with performance detailed in the following table and images.

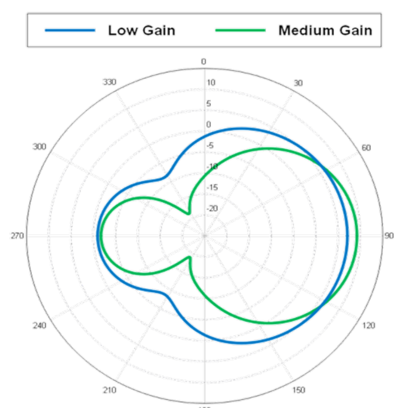
Gain	E-Plane 3dB BW	H-Plane 3dB BW
Low	68°	111°
Medium	65°	67°



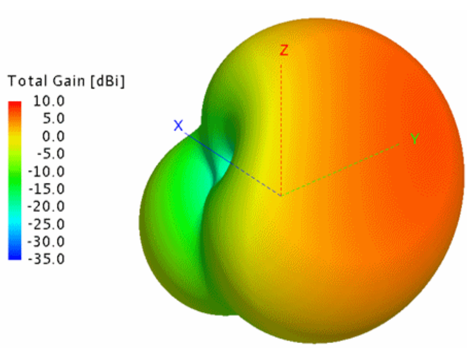
FEM line sources antenna model



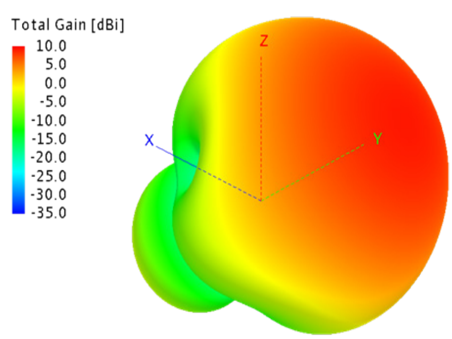
E-Plane Performance



H-Plane Performance



Low Gain Antenna Performance



Medium Gain Antenna Performance

Performance Analysis

Metrics

The fundamental purpose of an anechoic chamber is to approximate an infinite measurement space in a confined environment. As such, the performance metrics of an anechoic chamber measure how closely the chamber reproduces an infinite measurement space. This is done with two metrics:

- Chamber error that represents the ratio between any particular field component in the chamber and the corresponding component in free space.
- Axial ratio that demonstrates the differences in magnitude between horisontal and vertical polarization of any particular field component.

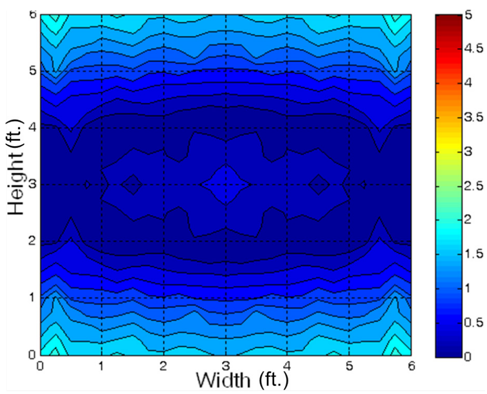
These metrics are formulated mathematically as follows:

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

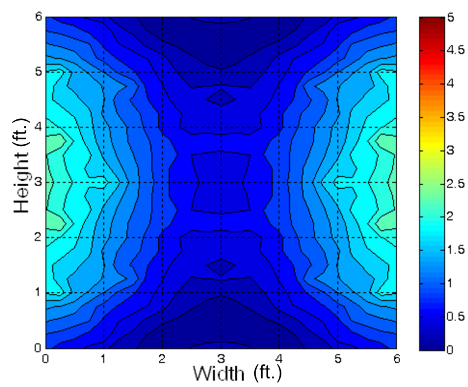
Chamber error was computed for the chamber in question at the following frequencies:

- 150 MHz
- 250 MHz
- 500 MHz

150 MHz Chamber Error

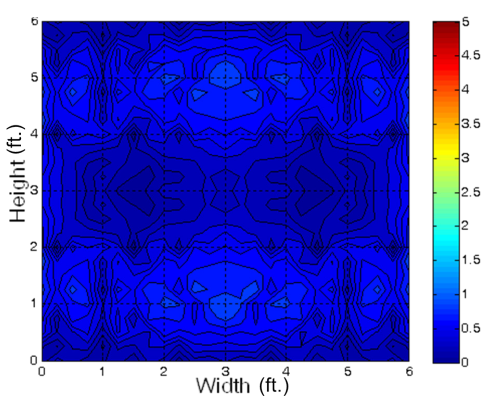


H-Pol - Low gain antenna
Maximum error = 2.1 dB

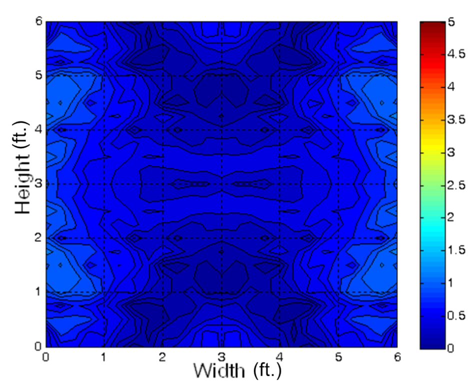


V-Pol - Medium gain antenna
Maximum error = 2.4 dB

250 MHz Chamber Error

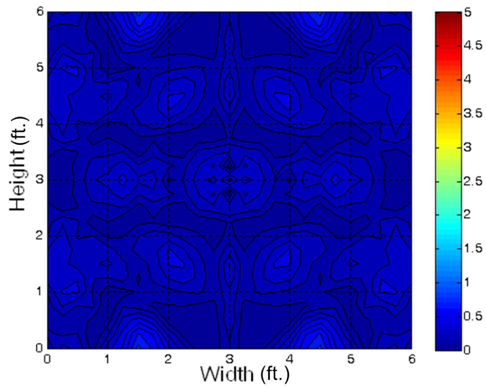


H-Pol - Low gain antenna
Maximum error = 0.9 dB



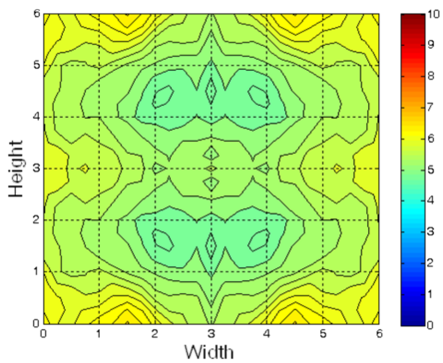
V-Pol - Medium gain antenna
Maximum error = 1.1 dB

250 MHz Chamber Error

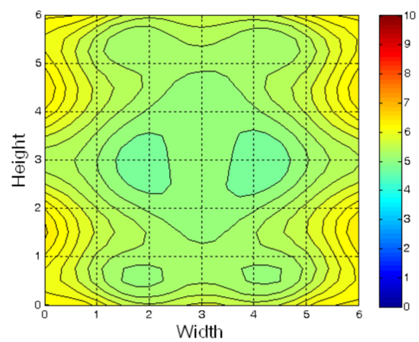


H-Pol - Low gain antenna
Maximum error = 0.8 dB

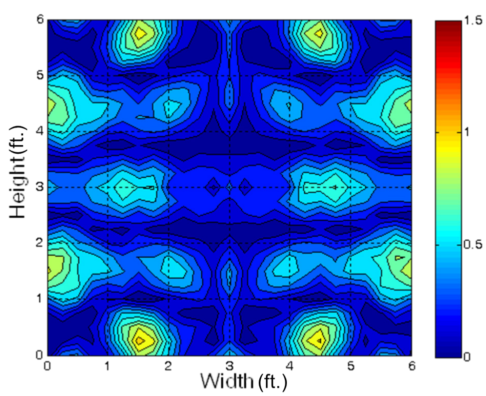
At 500 MHz the computational requirements for the simulation was already significant in terms of available resources and physical optics (PO) was investigated as a high frequency asymptotic method for modelling of the same problem. The following comparisons demonstrate that in the current scenario PO produced accurate results for the chamber error metric, differing by less than 1dB from the FEM result across the entire area of interest.



FEM (Full wave solution)
H-Pol - Low gain antenna

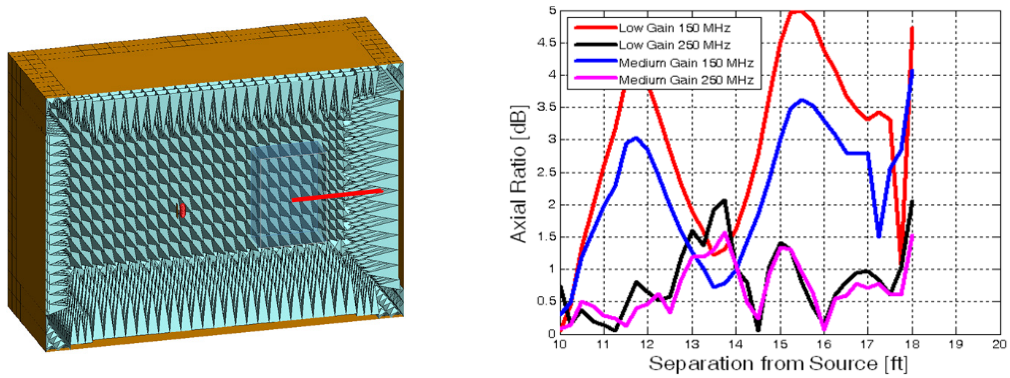


PO (High frequency asymptotic solution)
H-Pol - Low gain antenna



Difference between FEM and PO (maximum difference = 1.0 dB)

Axial Ratio



Axial ratios for low and medium gain antennas at 150 MHz and 250 MHz

Conclusion

This white paper has demonstrated that FEKO's hybrid FEM/MoM formulation is well suited to the modelling of anechoic chambers at VHF/UHF frequency ranges, where traditional design and qualification processes are difficult and time consuming. The chamber in question has been characterized and chamber performance has been evaluated for medium and lower gain antennas. In this case the medium gain antenna has superior quite zone and axial ratio performance.

References

[1] D. Campbell (1), G. Gampala (1), C.J. Reddy (1), M. Winebrand (2), J. Aubin(2), „Modeling and Analysis of Anechoic Chamber using CEM Tools," Proceedings of AMTA 2012 Conference, October 2012, (1) EM Software & Systems (USA) Inc., USA, (2) ORBIT/FR Inc., USA