Chaotic reverberation chamber by using curved diffractors

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Short Term Scientific Mission from 11/01/2015 to 11/15/2015 at School of Mathematical Sciences, University of Nottingham, UK.

ACCREDIT – IC1407

Outline

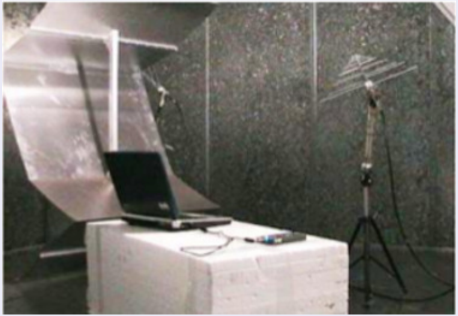
- ⋆ Motivation
- ⋆ Analysis
- ⋆ Simulation results
- ⋆ Conclusions
- ⋆ Future activities

Motivation

- ⋆ This STSM was related to the possibility of giving a first contribution to the COST Action through the background in applied electromagnetics of Ancona's group, while learning new theoretical and experimental methods. In particular, in collaboration with Dr. Gabriele Gradoni to use the Wave Chaos Methods to study the field behavior in a chaotic environment.
- ⋆ The goal: characterize the operation of electronic circuits inside a chaotic cavities, as well as to create a severe electromagnetic (EM) stress on the circuitry.

Method

Reverberation chamber



How improve the performances of traditional reverberation chamber

- ⋆ They do not perform well at intermediate/low frequencies

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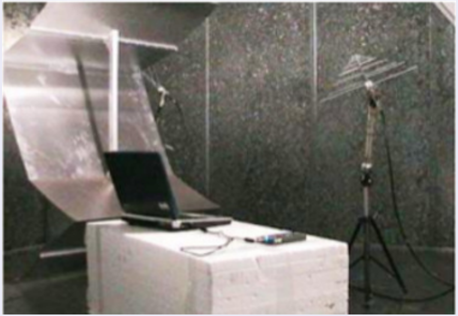

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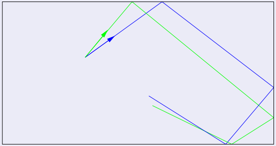
Idea

Question

- ⋆ How to create a compact environment able to provide broadband interferences from low to high frequency regimes?

Answer

- ⋆ Wave chaotic reverberation chamber placing inside curved diffractors



◇ L. Arnaut, *"Operation of electromagnetic reverberation chambers with wave diffractors at relatively low frequencies"*, IEEE Trans. on EMC 2001, pp. 637-653, Vol. 43, No. 4, Nov

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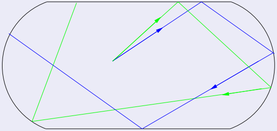

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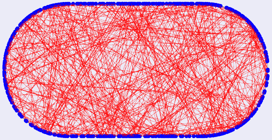

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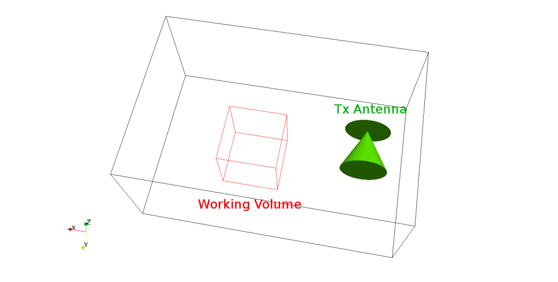
Analysis

Simulated reverberation chamber



- Dimensions: $6 \times 4 \times 2.5$ m^3
- $f_0 \simeq 45$ MHz
- Discone antenna
- Curved diffractors

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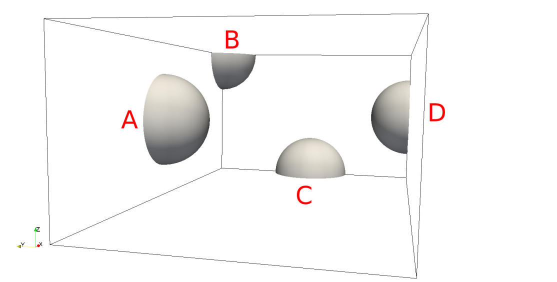

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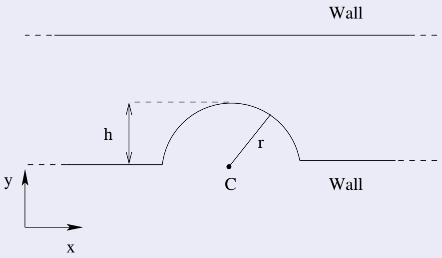
Different kind of diffractors

Hemisphere



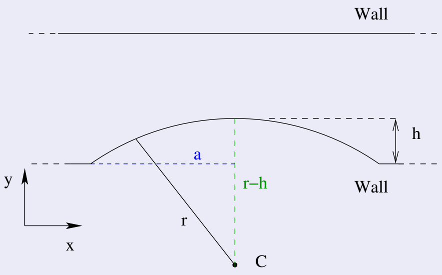
- r: radius
- C: center
- h: penetration
- $h/r = 1$

Volume and surface corrections:

- $V = \frac{4}{3}\pi r^3$
- $S = 4\pi r^2$

Different kind of diffractors

Spherical Cap



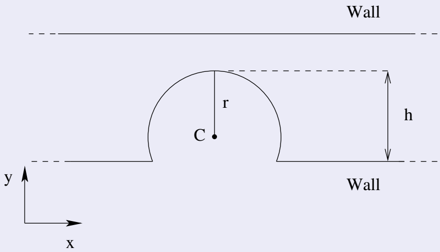
- r: radius
- C: center
- h: penetration
- $h/r < 1$

Volume and surface corrections:

- $a = \sqrt{2hr - h^2}$
- $V = \frac{\pi}{3} h^2 (3r - h)$
- $S = \pi \left(a^2 + h^2\right)$

Different kind of diffractors

Spherical mushroom



- r: radius
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- h: penetration
- $h/r > 1$

Volume and surface corrections:

- $V = \frac{4}{3}\pi r^2 - \frac{\pi}{3}(2r - h)^2 (3r - (2r - h))$
- $S = 4\pi r^2 - 2\pi r (2r - h)$

Analysis

The ability of an RC to operate well is given by several performance indicators

Performance indicators

- Uncorrelated stirrer positions
- **Uncorrelated frequencies**
- Uncorrelated points
- Field uniformity
- . . .

Uncorrelated frequencies

A first evaluation of ΔN_f

$$\Delta N_f = N_f^{ws} - N_f^{s} \approx \frac{\Delta f}{B_c} = \frac{\Delta f}{f}\Delta Q$$

where $\Delta Q = Q^{ws} - Q^{s}$

- ⋆ Wall losses are dominant

$$Q_{ws} = \frac{3V^{ws}}{2\mu_r \delta S^{ws}} \; , \; Q_s = \frac{3V^{s}}{2\mu_r \delta S^{s}} \; , \delta = \frac{2}{\sqrt{\omega\mu\sigma}}$$

- ⋆ The total volume and surface including diffractors are:

$$V^s = V^{ws} - \alpha\frac{4}{3}\pi r^3$$
$$S^s = S^{ws} + \beta\pi r^2$$

- ⋆ α and β depend on the number and position of diffractors

Evaluation of Uncorrelated frequencies

At each frequency step, the electric field values are computed in each point of a volumetric spatial grid.

Multivariate approach

Matrix of the fields:

$$\underline{\underline{e}} = \begin{bmatrix} e_1^{(1)} & \dots & e_1^{(N_f)} \\ e_2^{(1)} & \dots & e_2^{(N_f)} \\ \vdots & \ddots & \vdots \\ e_{N_p}^{(1)} & \dots & e_{N_p}^{(N_f)} \end{bmatrix}$$

- ⋆ The columns are the field values at each frequency step
- ⋆ The rows are the field values in each spatial point

Multivariate Approach

Correlation matrix build up

ρ_{jk} is the Pearson correlation coefficient between the frequency points field arrays j and k for all the probed points

$$\underline{\underline{R}} = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1N_f} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2N_f} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{N_f1} & \rho_{N_f2} & \cdots & \rho_{N_fN_f} \end{bmatrix} \qquad \rho_{jk} = \frac{\mathrm{Cov}\left(\underline{e}^{(j)}, \underline{e}^{(k)}\right)}{\sqrt{\mathrm{Var}\left(\underline{e}^{(j)}\right)\mathrm{Var}\left(\underline{e}^{(k)}\right)}}$$

- ⋆ Counting of uncorrelated frequency points using a threshold $[IEC\ 61000\ 4-21]$

$$N_u = \frac{N_f^2}{\#\left[\underline{\underline{R}} > r\right]}, \quad r = \frac{1}{e}\left[1 - \frac{7.22}{\left(N_f^2\right)^{0.64}}\right]$$

- ⋆ where r is the threshold value

FDTD Simulation

Pros and Cons

- ⋆ “Embarrassingly parallel” structure: each geometry realization can run on a different job
- ⋆ FDTD code is easily parallelizable with OpenMP or MPI
- ⋆ High Q-factor implies very long time for simulations
- ⋆ High performance computing needed to perform full wave simulation of a cavity at a different boundary conditions

Parameters

- ⋆ Investigated band: 0.2–1.0 GHz
- ⋆ Time step: 50 ps and cell size: 30 mm ($\lambda/10$ at 1.0 GHz)
- ⋆ FDTD grid: $201 \times 134 \times 84$
- ⋆ Simulated geometries: 16 where the radius were varied
- ⋆ We analyzed 512 frequencies, equispaced by 31.25 kHz

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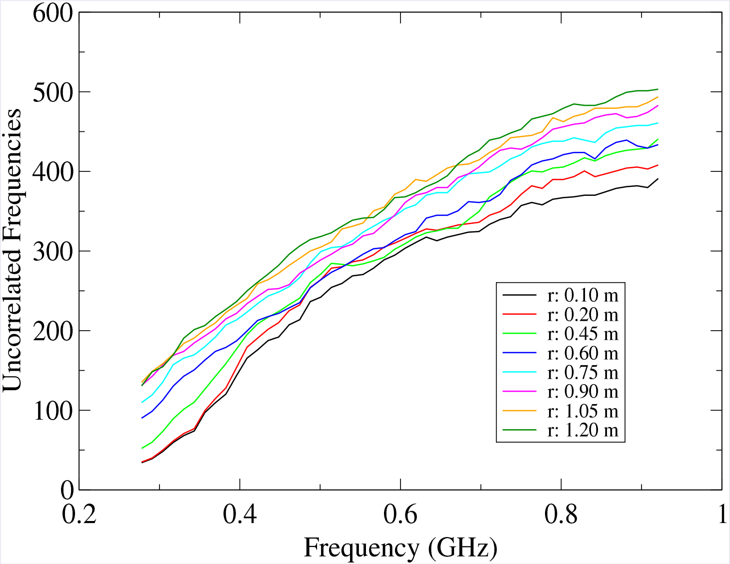
FDTD Simulation

Computing resource: CINECA IBM BlueGene/Q (FERMI)

- ⋆ Architecture: 10 BG/Q Frames
- ⋆ Processor Type: IBM PowerA2, 1.6 GHz
- ⋆ Computing Nodes: 10 240
- ⋆ Computing Cores: 163 840
- ⋆ RAM: 1 GByte / core
- ⋆ Internal Network: Network interface with 11 links -> 5D Torus
- ⋆ Disk Space: 2.6 PByte of scratch space
- ⋆ Ranked at position 37 in the Top 500 list of November 2015
- ⋆ We acknowledge PRACE for awarding us access to resource FERMI based in Italy at CINECA

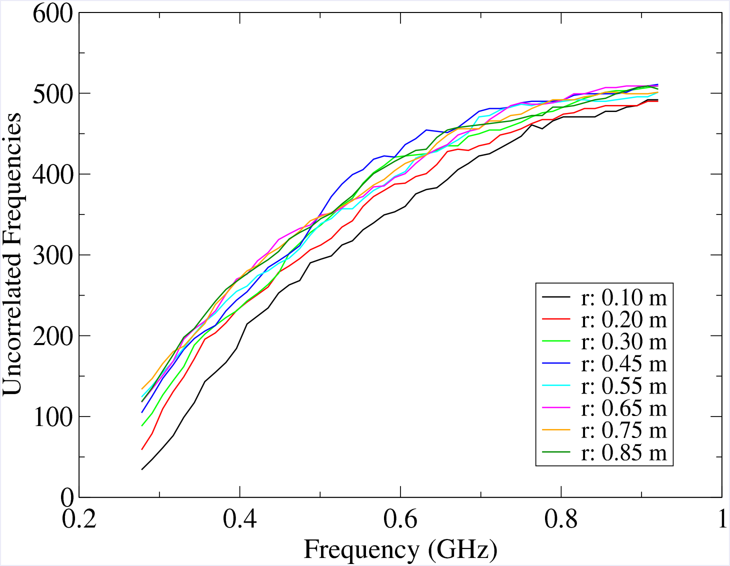
Results

One hemisphere on the corner: increasing the radius



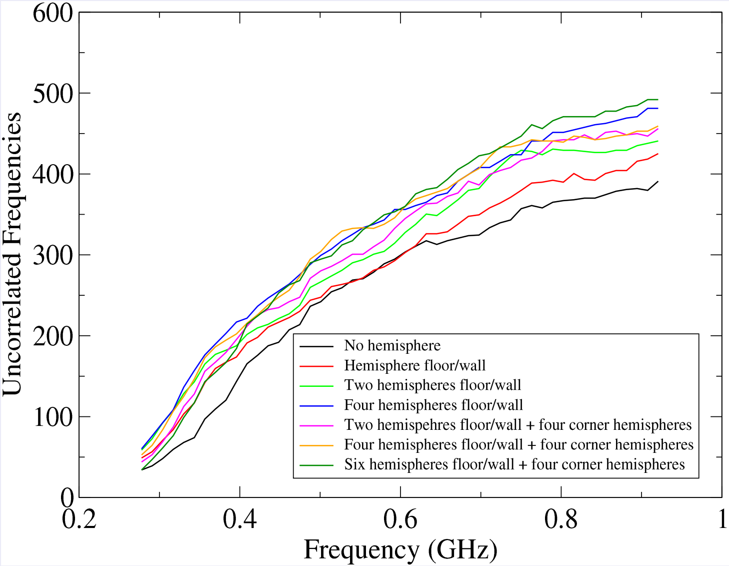
Results

Twenty hemispheres: increasing the radius



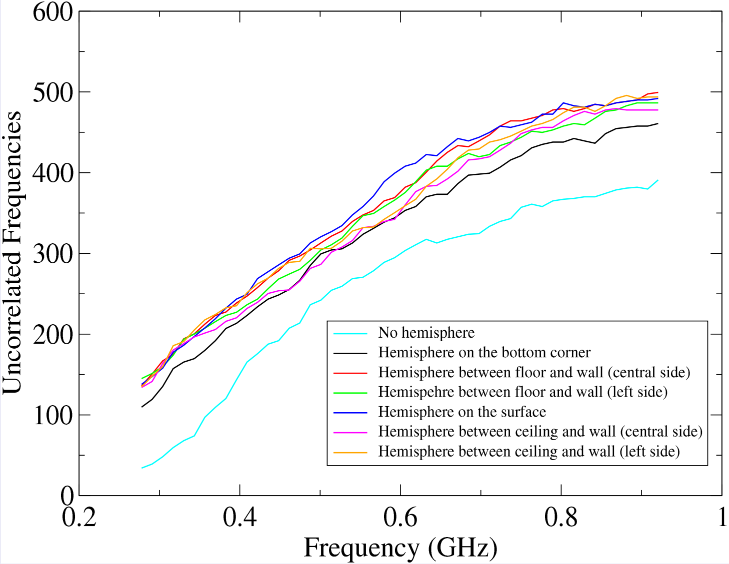
Results

Increasing the number of hemispheres (fixed radius)



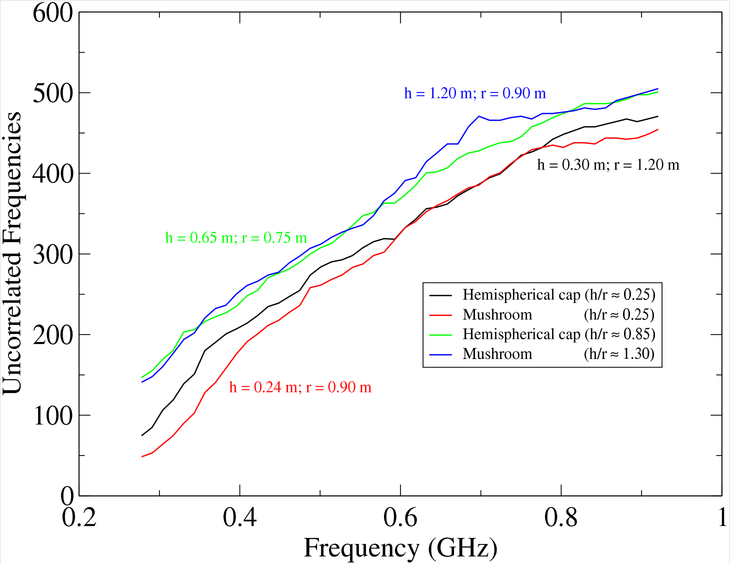
Results

Different hemispheres positioning (fixed radius)



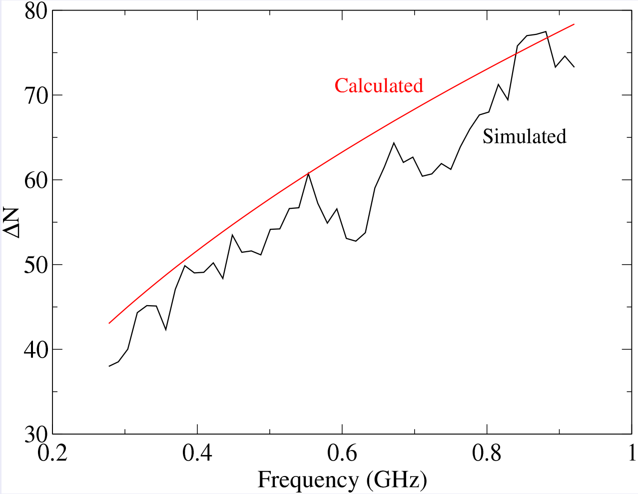
Results

Different kinds of diffractors on a corner



Results

ΔN empty chamber/single hemisphere on the corner



- ⋆ Surface corrections on Weyl's law may explain discrepancies

Conclusions

To improve the chamber's performances

- ⋆ Increase the radius
- ⋆ Increase the number of diffractors
- ⋆ Placement of diffractors is relevant
- ⋆ Choose the optimal diffractor

- ⋆ Trade off: performances/usable volume

- ⋆ In preparation: IEEE Transactions on Electromagnetic Compatibility paper
- ⋆ Follow up activity planned during this meeting

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Future activities

- ⋆ Simulate same geometry using mushroom shape diffractors
- ⋆ Evaluate field uniformity according to the standard limit
- ⋆ Compare ΔN theoretical and simulated for other configurations
- ⋆ Study the modal density by the Weyl's law considering the geometric surfaced corrections
- ⋆ Simulations and a comparison when a mechanical stirrer is added into the chamber
- ⋆ Simulations of single PCBs into the reverberation chamber
- ⋆ Try to replicate the chaotic behavior inside real RC

THANK YOU FOR YOUR KIND ATTENTION!