Fine Analysis of the Behavior of a Reverberation Chamber in the Frequency Domain with a Model Based upon Image Theory

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Outline

Introduction

Goal

Looking for a simple numerical model of an RC for transients simulation[1]...

- We choose to use image theory
- Very simple optical approach (no spatial discretization, no direct use of Maxwell's equations)
- Source stirring[2] instead of mechanical stirring
- The parameters of the model are:
  - the dimensions of the cavity
  - the position and the orientation of the emitter
  - the losses (through a loss coefficient)

[1] Amador et al. "Studying the Pulse Regime in a Reverberation Chamber with a Model Based on Image Theory", IEEE EMC 2010, Fort Lauderdale

[2] Huangand et al.,"A novel reverberating chamber: the source-stirred chamber," TEMC,1992

Image theory and currents

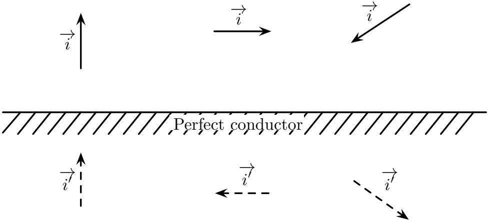


Figure: Image theory gives construction rules for currents in front of infinite perfect conductor planes, it gives a boundary condition description

Image theory and reverberation chambers

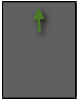


Image theory and reverberation chambers

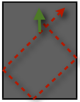
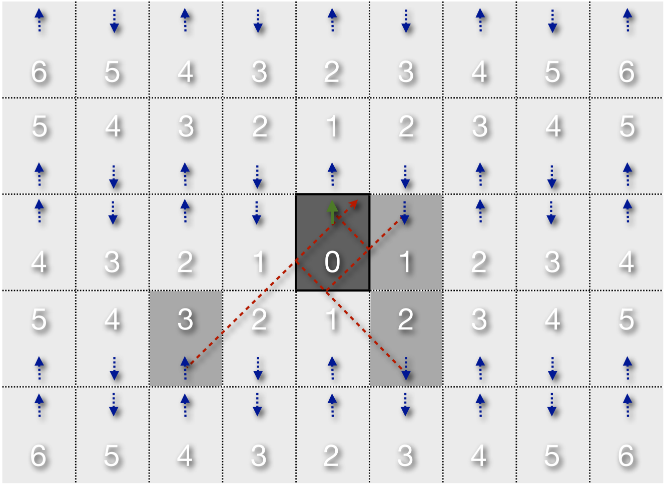
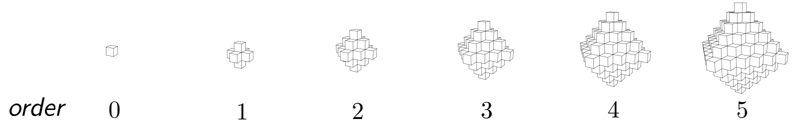


Image theory and reverberation chambers



In a 2D cavity, the multiple reflections generate an infinite number of image currents around the real cavity

3D cavities and memory usage



In 3D, the total number of cavities after n reflections (n$^{\text{th}}$ order) is given by

$$M_n = 1 + 2n + \frac{2n(n+1)(2n+1)}{3}. \quad (1)$$

Table: Order, Time-windows, M_n and memory usage for the RC at the IETR $(8.7 \times 3.7 \times 2.9\text{m})$

Order n	L_T	Number of currents M_n	Memory usage
100	1 μs	8.8×10^6	700 MB
300	3 μs	240×10^6	19 GB
600	6 μs	1.9×10^9	152 GB
3000	30 μs	240×10^9	19 TB

Loss simulation

- Losses are simulated through a loss coefficient R. It takes into account the losses through the walls as well as the losses from lossy objects in the cavity
- The magnitude of the current image in a n$^{\text{th}}$ order cavity is

$$I_n = I_0 R^n, \text{ with } 0 \leq R \leq 1. \quad (2)$$

In this numerical model, the loss coefficient simulates losses as if they were an absorbing paint spread on the cavity walls

Loss coefficient estimation[1]

If we consider an exponential model, the power received follows

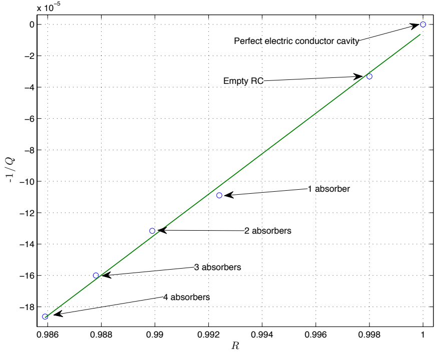
$$|P_m(t)| = P_{m_0} e^{-t/\tau}, \quad (3)$$

if D is a typical dimension of the chamber,

$$\tau \sim \frac{-D}{2c \ln R} \text{ and } R \sim 1 - \frac{D}{2c\tau}. \quad (4)$$

If we consider $Q = 2\pi f_0 \tau$, we have

$$\boxed{R \sim 1 - \frac{\pi D}{\lambda_0 Q}} \quad (5)$$



$$R = 1 - \frac{1}{AQ}$$

[1] Amador et al. "Reverberation Chamber Modeling Based on Image Theory : Investigation in the Pulse Regime", (in press). TEMC.

E-field calculation

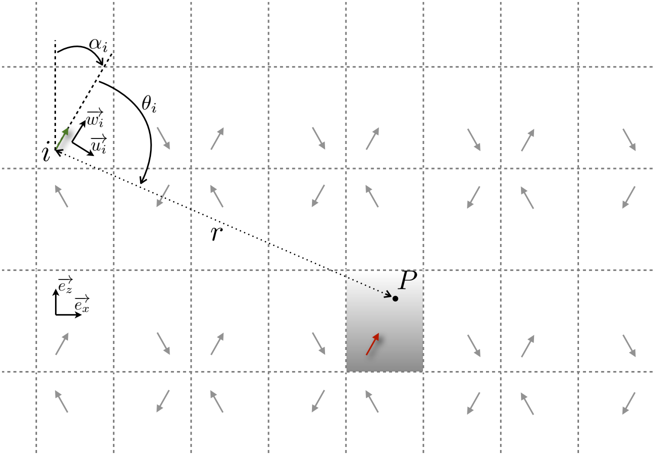


Figure: Let a current image i be placed in a n$^{\text{th}}$ order cavity with tilt α_i and azimuth β_i

E-field and Channel impulse response

At the reception point P in the reverberation chamber:

E-field created by the current i

$$\vec{E}_i(t) = -\omega\mu \frac{dhI_0 R^n f(t - r/c)}{4\pi r} \sin\theta_i \begin{cases} \cos\theta_i \cos\phi_i \cdot \vec{u_i} \\ \cos\theta_i \sin\phi_i \cdot \vec{v_i} \\ -\sin\theta_i \cdot \vec{w_i} \end{cases} \quad (6)$$

with: $\vec{u_i} = \mathcal{R}_{\alpha_i,\beta_i}\vec{e_x}$, $\vec{v_i} = \mathcal{R}_{\alpha_i,\beta_i}\vec{e_y}$, $\vec{w_i} = \mathcal{R}_{\alpha_i,\beta_i}\vec{e_z}$.

CIR

The channel impulse response is given by:

$$s_{x,y,z}(t) = \sum_{i=0}^{M} \left(\mathcal{R}^{-1}_{\alpha_i,\beta_i} \vec{E_i}(t) \right) \cdot \overrightarrow{e_{x,y,z}} \quad (7)$$

Preliminary results

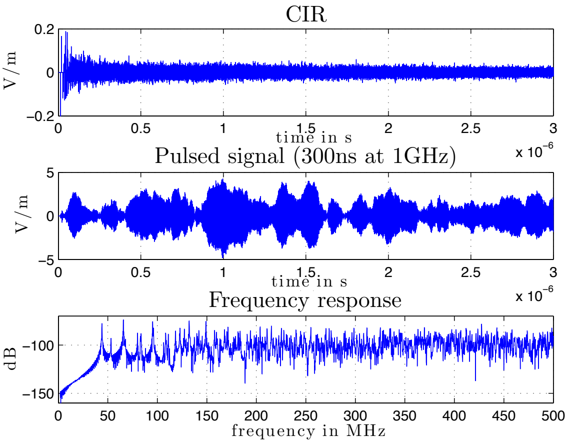
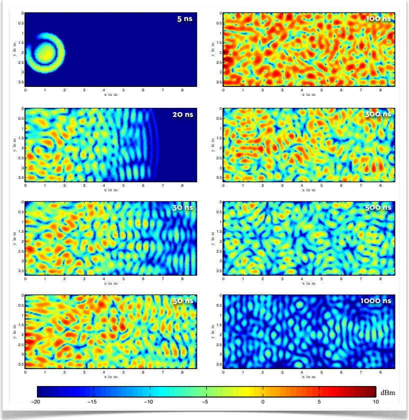


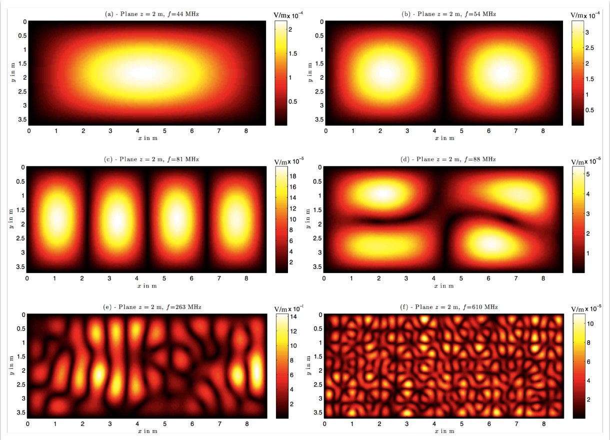
Figure: Channel impulse response, pulse signal response and frequency response

Preliminary results



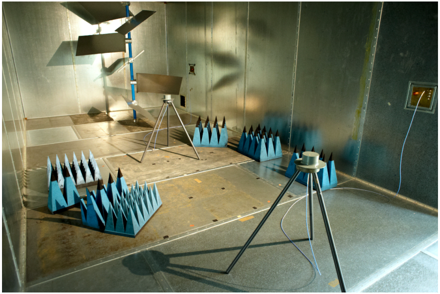
Propagation of a 100ns long pulse at 500 MHz in an horizontal plane, power in dBm (→YouTube)

Preliminary results

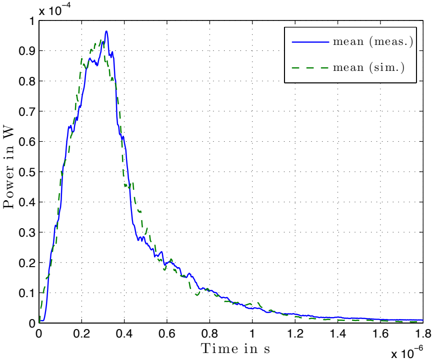


E_z component in an horizontal plane (linear values) (→YouTube)

Losses validation



Experimental configuration



Mean power vs. time in a loaded cavity ($R = 0.975$) *with a 300ns pulse at 1GHz, 50 positions*

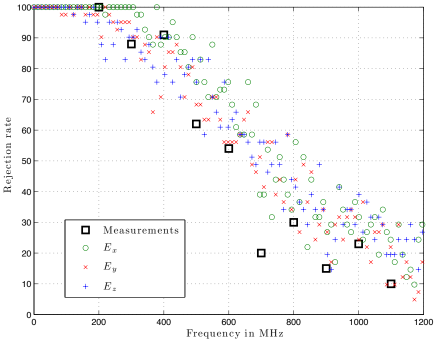
Statistical behavior of the rectangular components

Weibull/Rayleigh distributions have been observed in the past[1], can we reproduce the stochastic properties of the E-field with such a simple model ?

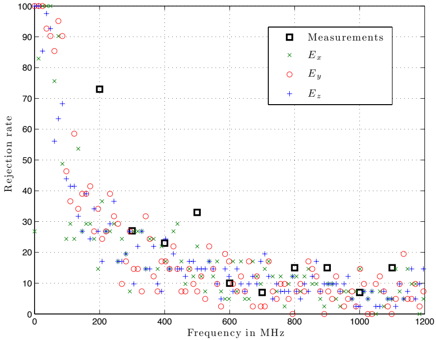
- We use the Anderson Darling goodness of fit statistical test
- Rayleigh distributions (for high frequencies) and Weibull (for low frequencies) distributions are tested
- Simulation results are compared with measurements

[1] Lemoine et al. “Investigation of Reverberation Chamber Measurements Through High-Power Goodness-of-Fit Tests”, TEMC 2007

Statistical behavior of the rectangular components: Rayleigh & Weibull distributions



(a) - Rayleigh



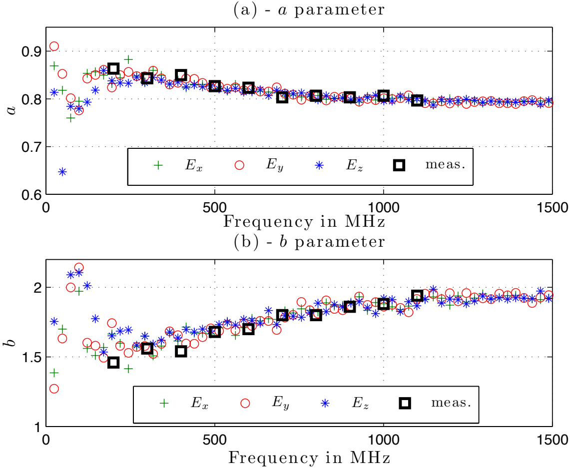
(b) - Weibull

Rejection rate with the Anderson Darling goodness of fit test for the Rayleigh (a) and Weibull (b) distributions with N=150, measurements and simulations

Simulated Weibull parameters vs. experimental parameters

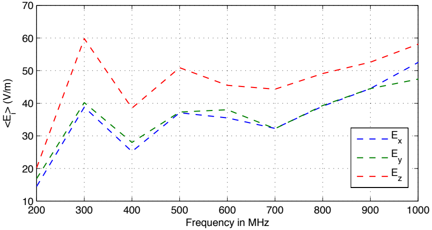
Weibull distribution uses 2 parameters, a scale parameter a and a shape parameter b:

$$f(x; a, b) = a x^{b-1} e^{-a x^b / b} \text{ with } x \geq 0 \qquad (8)$$

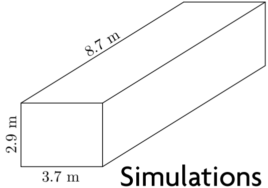


Effect of the chamber dimensions on the rectangular components of the E-field

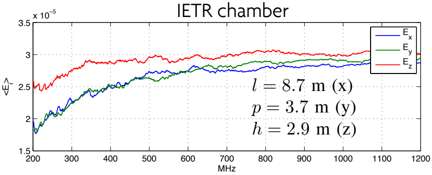
Measurements

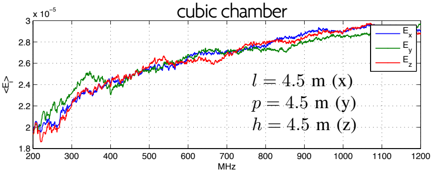


Measurements show that the vertical component E_z of the field in our RC are greater than the two other components. Simulations with our numerical model exhibits this deviation.



Simulations

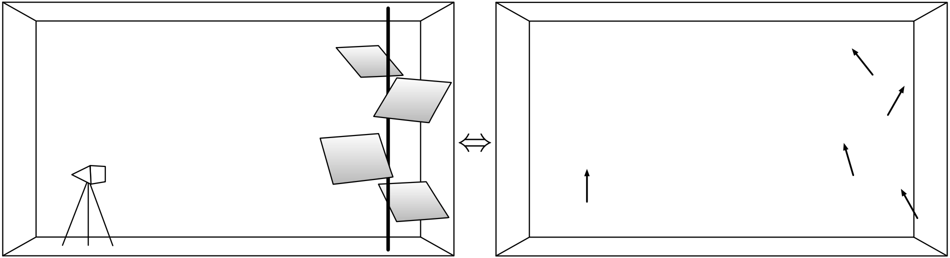




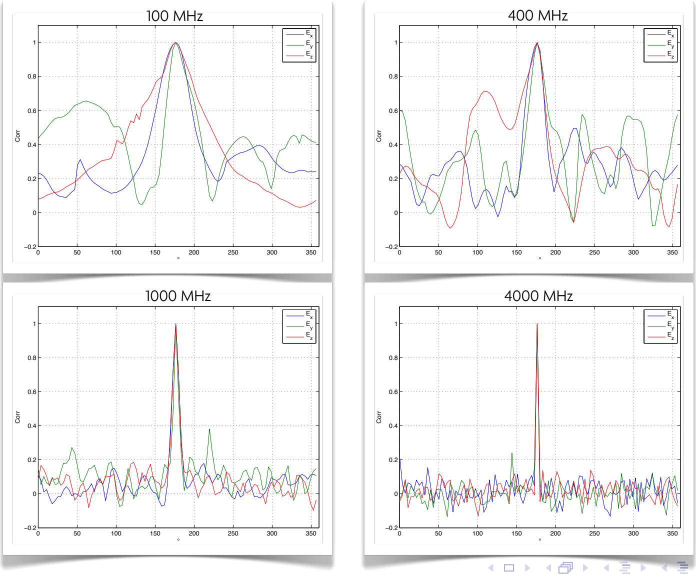
Mechanical stirrer simulation (work in progress)

A precise and rigorous stirrer simulation requires a fine discretization of the environment. In our model, the simulation of a mechanical stirrer is still possible.

→*Each surface of the stirrer can be simulated by a current*



E-field decorrelation with our stirrer



Summary

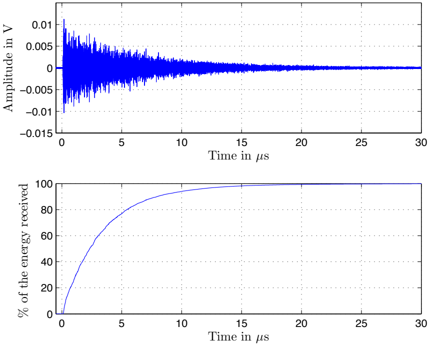
- A straightforward model of a reverberation chamber that carries the physics of rectangular cavities
- Ability to study the time domain as well as the frequency domain
- The unbalance of the rectangular components of the E-field observed in our chamber is caused by the shape of the cavity
- The stochastic properties of the E-field (Weibull & Rayleigh) in frequency domain are reproduced with accuracy

Perspectives

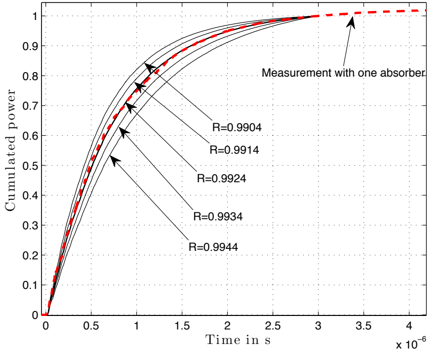
- Immunity testing simulations: simulation of induced currents on thin wires
- Comparison of immunity testings in an RC and in an anechoic chamber with this model

Thank You.

Determination of the loss coefficient R

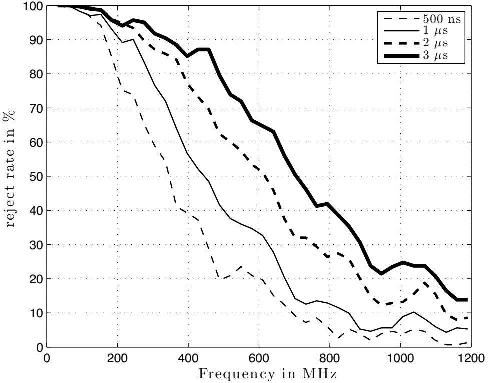


Channel impulse response and cumulated power in an RC



Finding the correct R value

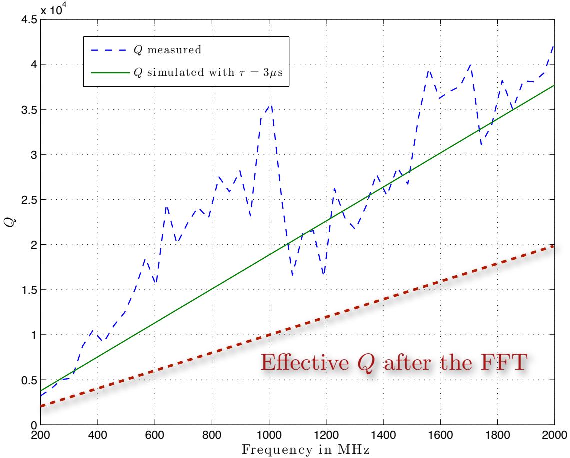
From time-domain to frequency-domain



The length of the time-window simulated affects the low frequencies, if the time window is too short, the resonances at lower frequencies are dampened as if the Q factor were artificially reduced.

Q measured and Q simulated

With $Q = 2\pi f \tau$, we can compare the Q factor simulated with the Q factor measured:



Effective Q in frequency domain

If, $Q_r = 2\pi f_0 \tau$ and $Q_{L_T} = 2\pi f_0 L_T$:

$$\frac{1}{Q_{\text{eff}}} = \frac{1}{Q_r} + \frac{1}{Q_{L_T}} \quad (9)$$

$$Q_{\text{eff}} = \frac{Q_r Q_{L_T}}{Q_r + Q_{L_T}} \quad (10)$$

$$Q_{\text{eff}} = 2\pi f_0 \frac{L_T}{L_T + \tau} \quad (11)$$