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Time Reversal for Reverberation Chamber Performance Evaluation

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Abstract

The time reversal (TR) is applied to verify the capability of a scatterer to improve the field chaos inside a resonant environment. In particular, the capability to focus the field in the observation point is analysed. The method is used in the design stage of a reverberation chamber to check numerically the goodness of the stirrer under design. It might be useful to experimentally check stirrer performance if applied to the measured chamber time response.

1 Introduction

Reverberation chambers (RCs) are electromagnetic compatibility (EMC) test facilities [1], also employed in shielding effectiveness measurements [2, 3], material characterization [4, 5] antenna characterization [6] and the testing of wireless devices and systems [7, 8, 9]. An RC is considered suitable for testing if it provides a sufficient degree of field statistical uniformity and isotropy [10, 11], accomplished by a proper modal stirring action. The using of rotating metallic paddles is most common method to stir the field inside a large cavity. The stirring efficiency of rotating paddles depends on their dimension [12] positioning and number [13]. Another way to mechanically stir the cavity is to move the chamber walls, by using the intrinsic vibration of flexible walls [14, 15], or using the vibration of one rigid wall of the chamber [16, 17]. Some source stirring techniques were developed to avoid moving elements inside the cavity: the frequency stirring [18, 19] and antenna positioning stirring [20, 21, 22]. The introduction of chaotic behavior for the field has been demonstrated to improve RC performance [23]. The generation of chaotic fields within the cavity can be accomplished by deforming the cavity shape inspired by the quantum chaos theory, for example by realizing a confined geometry similar to chaotic billiards [24, 25]. This was early explored in [26, 27], and successively in [23], [28] by analyzing the introduction of spherical diffractors. Also the addition of a tilted wall is able to enhance chaoticity inside the RC [29]. Common stirring techniques are well described in [30], and a lot of performance indicators, typically adopted for validation, are described in [31]. Among them, the lowest usable frequency (LUF), the number of uncorrelated field states [32] and the field uniformity are widely adopted. An alternative way to check the performance of a stirring mechanism might be based on the application of the time reversal (TR) technique [33, 34]. It was widely used inside resonant enclosure to achieve a focusing action both in time and spatial domain [35, 36, 37] It was demonstrated that the presence of reflecting walls and chaoticity is able to improve the focusing of the TR signal in biological media too [38, 39]. In this framework, the idea is to apply the TR to the RC response to check the chaos in terms of capability to focus the time response respect to the launched initial pulse. The RC field is computed by means of an ad-hoc full wave FDTD code. It is parallelized for use on supercomputers, thus providing the electromagnetic field inside the RC in all the volume and for each state of the chamber, thus allowing the application of spatial uncorrelation matrices to verify its chaos [40]. The TR is applied to the camber transmission response, computed between two point in the working volume, when different metallic scatterers are located in the chamber. It is shown that the better the TR focusing the better is the scattering properties of the object and consequently its ability to enhance chamber chaos.

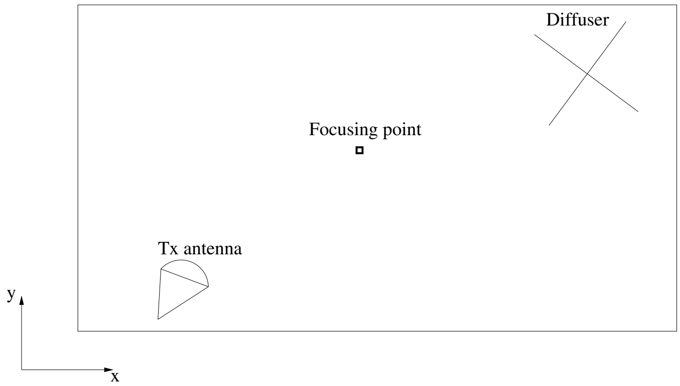

Figure 1. Horizontal section of the simulated chamber.

2 RC Simulations

An in-house FDTD parallel code has been used in order to simulate the whole RC, and subsequently to perform a statistical analysis. The simulated RC, Figure 1, has dimensions $6 \times 4 \times 2.5$ m^3. The chamber is excited by a transmitting antenna fed by the following gaussian pulse modulated signal

$$s(t) = \cos(2\pi f_0 (t - t_0))\, e^{-\frac{(t-t_0)^2}{t_g}} \qquad (1)$$

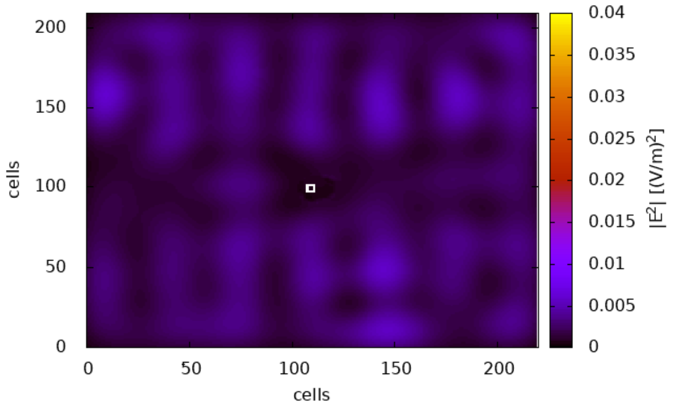

Figure 2. Electric field amplitude plot inside the chamber.

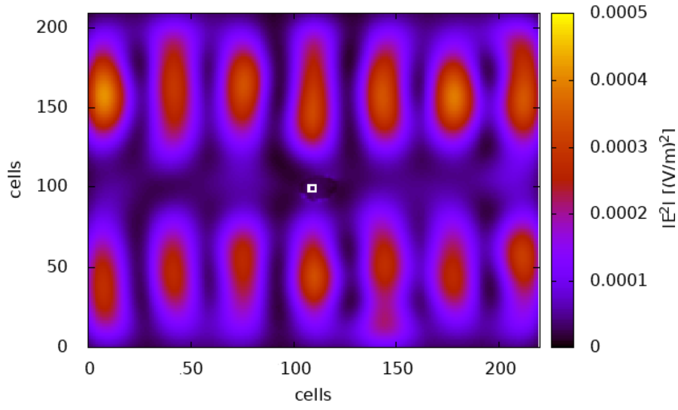

Figure 3. Electric field amplitude plot inside the chamber with the reversed signal.

where

$$t_g = \frac{12}{[\pi (f_{max} - f_{min})]^2} \quad (2)$$

and

$$t_0 = 3\sqrt{t_g} \quad (3)$$

with $f_{min} = 0.3839$ GHz, $f_{max} = 0.4839$ GHz and $f_0 = 0.4339$ GHz, with medium ratio 384.6. Given the impulse response $h(t)$ of the RC, the received signal at the cell the signal is to be focused:

$$u(t) = s(t) \otimes h(t) \quad (4)$$

where $\otimes$ denotes the time convolution. Applying the well known ordinary TR procedure, we apply the TR mirrored signal $u(-t)$ to the Tx achieving the reconstructed response:

$$s_r(t) = u(-t) \otimes h(t) \quad (5)$$

The response reconstructed in such a way in the original sampling point is then analysed to check the focusing capability determined by the adopted stirrer geometry.

3 Results

The proposed method is preliminary applied to check the improvement determined by the insertion of a scatterer made of planar paddles. Figure 2 shows the electric field distribution within the empty RC whereas Figure 3 reports field distribution when the antenna was fed by the reversed signal. In this scenario there is no focusing on the chosen point. Then, the chamber field has been computed adding a scatterer. Figure 4 shows the electric field amplitude when the diffuser was added in the RC, Figure 5 shows the electric field amplitude of the same scenario when the input signal is reversed.

It is evident the capability of the scatterer to destroy the modal regularity of the field inside the chamber.

The scatterer is able to better focus and enhance the field in the observation point.

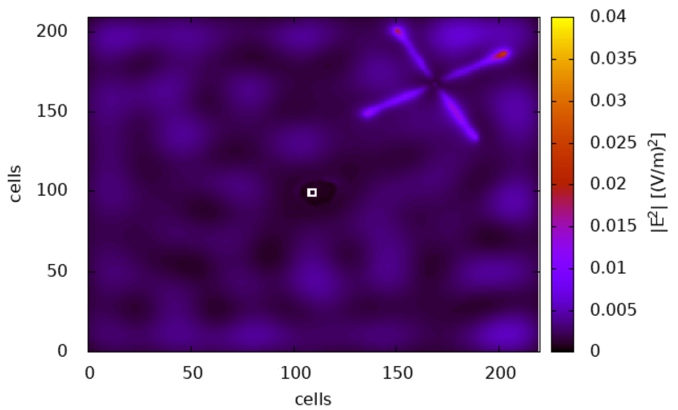

Figure 4. Electric field amplitude plot inside the chamber when a diffuser is added.

4 Conclusions

The TR technique has been applied to provide a way to check the performance of a scatterer inside an RC. In particular, it has been highlighted that the field produced by the TR pulse is more focused in the observation point due to the scatterer presence, if compared to the empty chamber. This might be ascribed to the chaoticity enhancement of the chamber field and the consequent higher modal density able to improve the time and spatial focusing of the reconstructed pulse. Future work will be devoted in applying the technique to other kind of scatterers, also including spherical diffractors, and to provide a suitable metric to univocally interpret the obtained time response. The method can be applied during the design stage of the RC accomplished by numerical simulations of the whole chamber geometry. Furthermore, it can be applied to experimentally check existing RC considering the measured time response between techniques for determining the radiation and total efficiency of antennas," IEEE Trans. Antennas Propag., vol. 60, no. 4, pp. 1758–1770, Apr. 2012.

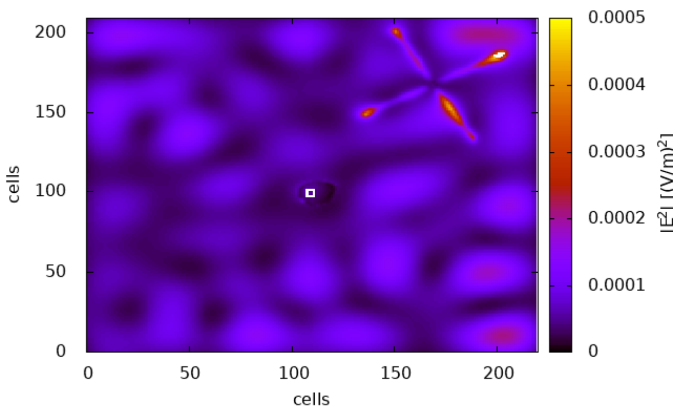

Figure 5. Electric field amplitude plot inside the chamber when a diffuser is added with the reversed signal.

two (or more) spatial points.

5 Acknowledgements

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References

[1] Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods, 2nd ed., International Standards - IEC 61000-4-21, Geneva, Switzerland, Apr. 2011.

[2] C. L. Holloway, D. A. Hill, J. Ladbury, G. Koepke, and R. Garzia, "Shielding effectiveness measurements of materials using nested reverberation chambers," IEEE Trans. Electromagn. Compat., vol. 45, no. 2, pp. 350–356, May 2003.

[3] D. Fedeli, G. Gradoni, V. Mariani Primiani, and F. Moglie, "Accurate analysis of reverberation field penetration into an equipment-level enclosure," IEEE Trans. Electromagn. Compat., vol. 51, no. 2, pp. 170–180, May 2009.

[4] U. Carlberg, P.-S. Kildal, A. Wolfgang, O. Sotoudeh, and C. Orlenius, "Calculated and measured absorption cross sections of lossy objects in reverberation chamber," IEEE Trans. Electromagn. Compat., vol. 46, no. 2, pp. 146–154, May 2004.

[5] E. Amador, M. Andries, C. Lemoine, and P. Besnier, "Absorbing material characterization in a reverberation chamber," pp. 117–122, 2011.

[6] C. L. Holloway, H. A. Shah, R. J. Pirkl, W. F. Young, D. A. Hill, and J. Ladbury, "Reverberation chamber techniques for determining the radiation and total efficiency of antennas," IEEE Trans. Antennas Propag., vol. 60, no. 4, pp. 1758–1770, Apr. 2012.

[7] D. Micheli, M. Barazzetta, F. Moglie, and V. Mariani Primiani, "Power boosting and compensation during OTA testing of a real 4G LTE base station in reverberation chamber," IEEE Trans. Electromagn. Compat., vol. 57, no. 4, pp. 623–634, Aug. 2015.

[8] M. Barazzetta, D. Micheli, L. Bastianelli, R. Diamanti, M. Totta, P. Obino, R. Lattanzi, F. Moglie, and V. Mariani Primiani, "A comparison between different reception diversity schemes of a 4G-LTE base station in reverberation chamber: a deployment in a live cellular network," IEEE Trans. Electromagn. Compat., vol. 59, no. 6, pp. 2029–2037, Dec. 2017.

[9] D. Micheli, M. Barazzetta, R. Diamanti, P. Obino, L. Remo, L. Bastianelli, V. Mariani Primiani, and F. Moglie, "Over-the-air tests of highspeed moving LTE users in a reverberation chamber," IEEE Trans. Veh. Technol., vol. 67, no. 5, pp. 4340–4349, May 2018.

[10] J. G. Kostas and B. Boverie, "Statistical model for a mode-stirred chamber," IEEE Trans. Electromagn. Compat., vol. 33, pp. 366–370, Nov. 1991.

[11] D. A. Hill, "Electromagnetic theory of reverberation chambers," National Institute of Standards and Technology, Tech. Rep. NIST TN - 1506, Dec. 1998.

[12] J. Clegg, A. C. Marvin, J. F. Dawson, and S. J. Porter, "Optimization of stirrer designs in a reverberation chamber," IEEE Trans. Electromagn. Compat., vol. 47, no. 4, pp. 824–832, Nov. 2005.

[13] F. Moglie and V. Mariani Primiani, "Analysis of the independent positions of reverberation chamber stirrers as a function of their operating conditions," IEEE Trans. Electromagn. Compat., vol. 53, no. 2, pp. 288–295, May 2011.

[14] F. Leferink, J. C. Boudenot, and W. Van Etten, "Experimental results obtained in the vibrating intrinsic reverberation chamber," in IEEE Int. Symp. Electromagn. Compat. (EMC), Washington, D.C., USA, Aug. 2000, pp. 639–644.

[15] N. K. Kouveliotis, P. T. Trakadas, and C. N. Capsalis, "Fdtd modeling of a vibrating intrinsic reverberation chamber," Progress Elecromagn. Research, vol. 39, pp. 47–59, 2003.

[16] H. Zhao and Z. Shen, "Modal-expansion analysis of a monopole in vibrating reverberation chamber," Progress Elecromagn. Research, vol. 85, pp. 303–322, 2008.

[17] N. K. Kouveliotis, P. T. Trakadas, and C. N. Capsalis, "Theoretical investigation of the field conditions in a vibrating reverberation chamber with an unstirred

component," IEEE Trans. Electromagn. Compat., vol. 45, no. 1, pp. 77–80, 2003.

[18] D. A. Hill, "Electronic mode stirring for reverberating chambers," IEEE Trans. Electromagn. Compat., vol. 36, no. 4, pp. 294–299, Nov. 1994.

[19] T. A. Loughry, "Frequency stirring: an alternative approach to mechanical mode-stirring for the conduct of electromagnetic susceptibility testing," PHilips Lab. Tech. Report PL-TR-91-1036, 1991.

[20] Y. Huang and D. J. Edwards, "A novel reverberating chamber: the source stirred chamber," in 1992 IEEE Eighth Int. Symp. Electromagn. Compat. (EMC), Edinburgh, UK, 1992, pp. 120–124.

[21] C. Tsigross, M. Piette, and G. Vandenbosch, "Static source-mode tuning using a costellation of lpda antennas in a reverberation chamber," in 2010 Int. Symp. Electromagn. Compat. (EMC Europe), Wroclaw, Poland, Sep. 2010, pp. 445–450.

[22] E. Voges and T. Eisenburger, "Electrical mode stirring in reverberating chambers by reactively loaded antennas," IEEE Trans. Electromagn. Compat., vol. 49, no. 4, pp. 756–761, Nov. 2007.

[23] L. Bastianelli, F. Moglie, V. Mariani Primiani, and G. Gradoni, "Reverberation chambers deformed by spherical diffractors," in Proc. Int. Symp. Electromagn. Compat. (EMC EUROPE), 2017, pp. 1–5.

[24] U. Dorr, H.-J. Stockmann, M. Barth, and U. Kuhl, "Scarred and chaotic ÂÍ field distributions in a three-dimensional sinai-microwave resonator," Phys. Rev. Lett., vol. 80, pp. 1030–1033, Feb. 1998.

[25] H. Stockmann, "Quantum Chaos: An Introduction". Cambridge University Press, 2006.

[26] J.-B. Gros, O. Legrand, F. Mortessagne, E. Richalot, and K. Selemani, "Universal behaviour of a wave chaos based electromagnetic reverberation chamber," Wave Motion, vol. 51, no. 4, pp. 664–672, 2014.

[27] H. Stockmann, "Chaos in microwave resonators", 2013, vol. 66.

[28] L. Bastianelli, F. Moglie, G. Gradoni, and V. Mariani Primiani, "Full wave computation of the electromagnetic field in chaotic reverberation chambers," in 2019 Int. Conf. on Electromagn. in Adv. Applic. (ICEAA), 2019, pp. 1104–1106.

[29] L. Bastianelli, F. Moglie, V. Mariani Primiani, and G. Gradoni, "Hpc simulations of a reverberation chamber with nonparallel walls," in Proc. Int. Symp. Electromagn. Compat. (EMC EUROPE), 2019, pp. 912–916.

[30] R. Serra, A. C. Marvin, F. Moglie, V. Mariani Primiani, A. Cozza, L. R. Arnaut, Y. Huang, M. O. Hatfield, M. Klingler, and F. Leferink, "Reverberation chambers a la carte: An overview of the different modestirring techniques," IEEE Electromagn. Compat., vol. 6, no. 1, pp. 63– 78, 2017.

[31] R. Serra, "Reverberation chambers through the magnifying glass: an overview and classification of performance indicators," IEEE Electromagn. Compat., vol. 6, no. 2, pp. 76–88, 2017.

[32] G. Gradoni, V. Mariani Primiani, and F. Moglie, "Reverberation chamber as a multivariate process: FDTD evaluation of correlation matrix and independent positions," Progress Electrom. Research, vol. 133, pp. 217–234, 2013.

[33] J. de Rosny, G. Lerosey, and M. Fink, "Theory of electromagnetic time reversal mirrors," IEEE Transactions on Antennas and Propagation,vol. 58, no. 10, pp. 3139–3149, Oct. 2010

[34] G. Lugrin, N. M. Mora, F. Rachidi, M. Rubinstein, and G. Diendorfer, "On the location of lightning discharges using time reversal of electromagnetic fields," IEEE Transactions on Electromagnetic Compatibility,vol. 56, no. 1, pp. 149–158, Feb. 2014

[35] H. Vallon, A. Cozza, F. Monsef, and A. Chauchat, "Time-reversed excitation of reverberation chambers: Improving efficiency and reliability in the generation of radiated stress," IEEE Transactions on ElectromagneticCompatibility, vol. 58, no. 2, pp. 364–370, Apr. 2016.

[36] A. Cozza and F. Monsef, "Steering focusing waves in a reverberation chamber with generalized time reversal," IEEE Transactions on Antennas and Propagation, vol. 65, no. 3, pp. 1349–1356, Mar. 2017.]

[37] B. Xiao, T. M. Antonsen, E. Ott, and S. M. Anlage, "Focusing waves at arbitrary locations in a ray-chaotic enclosure using time-reversed synthetic sonas," Phys. Rev. E, vol. 93, p. 052205, May 2016.

[38] A. T. Frisco, L. Bastianelli, F. Moglie, and V. M. Primiani (2019, July). Time reversal in reverberation chambers: Application to lossy media. In 2019 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity (EMC+ SIPI) (pp. 664–669). IEEE.

[39] E. Colella, L. Bastianelli, F. Moglie, and V. M. Primiani, "Time Reversal in Reverberating Environments for Electromagnetic Focusing in Biological Bodies" to be submitted in URSI AT-AP-RASC, Gran Canaria.

[40] G. Gradoni, F. Moglie, and V. Mariani Primiani, "Correlation matrix methods to assess the stirring performance of electromagnetic reverberation chambers," Wave Motion, vol. 87, pp. 213–226, 2019, innovations in Wave Modelling II