REVERBERATION CHAMBER LOW FREQUENCY FIELD UNIFORMITY IMPROVEMENT WITH CONDUCTING PYRAMIDAL STRUCTURES

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Abstract: Reverberation chambers are commonly used in industry for measuring electromagnetic interference because they are cost-effective. We attempt to stir modes more evenly inside reverberation chambers by introducing passive field uniformity enhancement (PFUE) structures. These structures augment the existing rotating stirrers. Measured results for a 2.445 x 2.475 x 3.72 m reverberation chamber are presented. The results show that the inclusion of passive structures improves the field uniformity in the low 300 - 400 MHz band. The standard deviation of the electric field distribution in this band is improved by up to 0.93 dB. The PFUE structures also reduced the dynamic range, in the worst case, by 2 dB at high frequencies.

Keywords: Field uniformity, lowest usable frequency, reverberation chamber, standard deviation.

1. INTRODUCTION

The proliferation of electronic systems leads to an increasingly contaminated electromagnetic (EM) environment. Electromagnetic compatibility (EMC) standards regulate radiation by these systems. Electronic equipment which radiates unwanted EM waves is reciprocally susceptible to electromagnetic interference (EMI) from other sources [1].

A widely-used facility to test EMI is a reverberation chamber (RC). RCs have gained much popularity in industry as a complement to well-established radiated interference sites and systems such as anechoic chambers (ACs), Gigahertz transverse electromagnetic cells (GTEM) and open area test sites (OATS). RCs are cost-effective and they function independently of weather conditions. EMI and EMS (susceptibility) measurements can therefore be conducted at any time; a high reproducibility rate of measurements is also obtainable [2].

An RC, also called a mode-stirred chamber, is an electrically large shielded cavity [3], [4]. It is usually equipped with one or several mechanical rotating stirrers which provide a statistically-isotropic field with a Rayleigh amplitude distribution when excited by an internal EM source [5], [6]. Dawson *et al.* [7] have described the optimisation of the stirrer shapes. In this paper, we investigate passive field uniformity enhancement (PFUE) structures in conjunction with the stirrers. The objective of using combined active stirring and PFUE structures is to obtain a better field uniformity at lower frequencies, which reduces the lowest usable frequency (LUF) for a particular RC.

An RC test setup consists of a receive antenna, stirrers, computer, spectrum analyser or EMI receiver, and the device-under-test (DUT) as shown in Figure 1. The transmit antenna is only used during chamber calibration. In an ideal RC, the fields are uniformly distributed, which implies that a high number of modes are excited within the cavity. The chamber's volume and stirrers play an important role in how many modes can be supported. The field strength distribution is considered adequately uniform if the distribution meets the 0 - 3 dB standard deviation limit stipulated by the IEC 61000-4-21 standard [8] for frequencies above 400 MHz (below 400 MHz the standard deviation limit increases). The size of an RC is usually determined by the working volume and the LUF that the end-user requires.

Two chambers are considered in this paper: a screened room at the Cape Peninsula University of Technology (CPUT), and a reverberation chamber at the University of Stellenbosch (US). The CPUT chamber is to be converted to an RC with the addition of rotating stirrers and PFUE structures. The US RC is slightly bigger than the CPUT chamber, and is being used for EMC measurements. PFUE structures were added to the chamber to determine the effect of these structures on the chamber's performance, especially at lower frequencies.

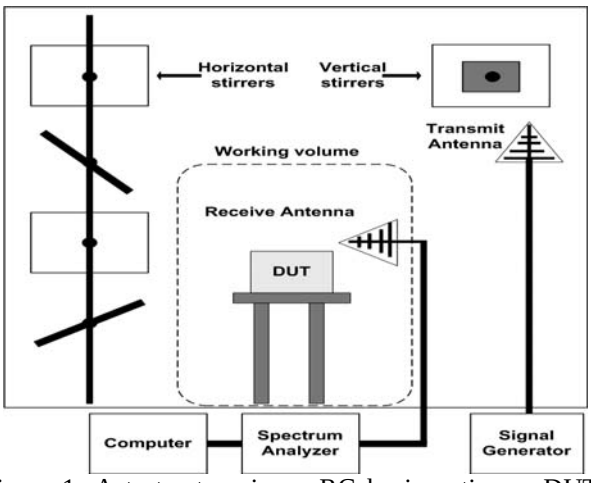

Figure 1: A test set-up in an RC having stirrers, DUT, antennas and a defined working volume (adapted from [3]).

2. FIELD UNIFORMITY ENHANCEMENT TECHNIQUES

2.1 Mode Stirrers

The use of rotating, conductive plates to 'stir' the electromagnetic modes inside an RC distributes the internal fields more evenly. There are also less commonly used alternative methods of mode stirring inside RCs, for example, frequency stirring, source stirring, or the use of a vibrating intrinsic RC [4], [9]. To obtain optimum field uniformity, the stirrers should have a complex shape and be electrically large, but a compromise between stirrer size and the usable working volume is necessary. Having more than one stirrer inside an RC is also beneficial. In a conventional RC, two techniques of stirring exist, namely that of mode-stirring and mode-tuned. In the mode-stirred technique, the stirrer rotates continuously and measurements are taken over a full revolution at a single frequency. In the mode-tuned technique, the stirrer is rotated in fixed steps and measurements are taken after every incremental rotation at a single frequency.

2.2 Field Uniformity

The field uniformity of an RC can be quantified by the standard deviation of the field strength distribution as sampled throughout the working volume inside the RC. The standard deviation σ of the field strength distribution along one axis, or combining the three axes measurements, is calculated, respectively, using the following formulae [10]:

$$\sigma_{\xi} = \sqrt{\frac{\sum_{i=1}^{8}\left(\vec{E}_{\xi,i} - \left\langle \vec{E}_{\xi} \right\rangle\right)^2}{8-1}} \tag{1}$$

$$\sigma_{xyz} = \sqrt{\frac{\sum_{\xi=\{x,y,z\}}\sum_{i=1}^{8}\left(\vec{E}_{\xi,i} - \left\langle \vec{E}_{xyz} \right\rangle\right)^2}{24-1}} \tag{2}$$

where $\left\langle \vec{E}_{\xi} \right\rangle$ and $\left\langle \vec{E}_{xyz} \right\rangle$ are the arithmetic means of the normalised maximum E-field measurements. The number 8 originates from field uniformity measurement methods and is the number of arbitrary locations used inside the RC at which the fields are measured. The standard deviation calculated in (2) is expressed in dB as [10]:

$$\sigma(dB) = 20\log_{10}\left(\frac{\sigma_{xyz} + \left\langle \vec{E}_{xyz} \right\rangle}{\left\langle \vec{E}_{xyz} \right\rangle}\right) \tag{3}$$

The IEC 61000-4-21 standard requires that standard deviation falls within the range of 0 - 3 dB above 400 MHz.

2.3 Lowest Usable Frequency (LUF)

The LUF is directly related to the RC size, hence, a larger chamber leads to a lower LUF. The LUF corresponds to the lowest frequency where the chamber conforms to the IEC 61000-4-21 standard. One definition states that the LUF is 3 to 6 times the lowest resonant frequency of the chamber [11].

3. PASSIVE MODE-STIRRER STRUCTURES

The objective of incorporating passive mode stirrer structures in a conventional RC is to improve field uniformity for a lower LUF. This is especially relevant to small chambers, such as the chamber at CPUT which has dimensions 1.863 × 2.443 × 2.473 m (*x y z* respectively). PFUE structures that were investigated through simulation and practical measurement are line, groove and cone structures, as depicted in Figures 2, 3 and 4, respectively. These structures were placed at different positions throughout the chamber and also in different combinations, to determine the optimum placement, whilst considering the practicalities of the actual chamber. The maximum protrusion of the PFUE structures is related to the LUF that is required. In the current investigation, these protrusions were one wavelength at the LUF, which is required to be 1 GHz for the planned CPUT RC.

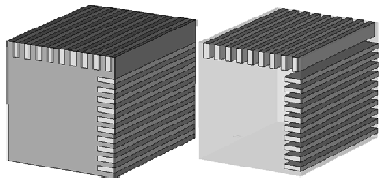

Figure 2: Cavity fitted with line structures on the ceiling and on the side walls.

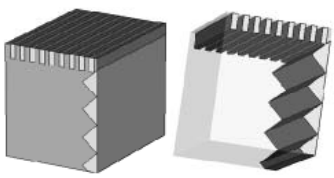

Figure 3: Cavity fitted with line structures on the ceiling and groove structures on the side walls.

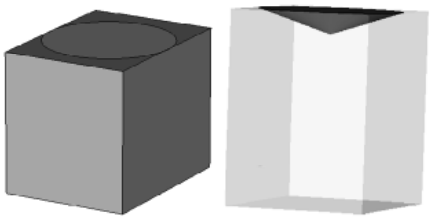

Figure 4: Cavity fitted with a cone structure on the ceiling.

4. SIMULATION SET-UP

Electromagnetic characterisation of the CPUT chamber was done through CST simulations [12]. Matched Yagi-Uda antennas were used as excitation sources. They were designed for each of the specified frequencies to ensure that the radiated power was the same over the frequency band. Simulations with the Yagi-Uda antenna took, on average, one to three days to complete. The antennas were orientated in both the horizontal and vertical to mimic real-life measurement procedures. The simulated frequencies were chosen to be harmonically independent. The simulated frequency range was 1 - 2 GHz for the CPUT RC.

During the simulation the Perfect Electric Conductor (PEC) was chosen as the background material in all directions. The empty cavity was constructed of vacuum material and the antenna, PFUE structures and stirrers were made of aluminium. The antenna excitation was an S-parameter discrete edge port with an impedance of 50 Ω. The Fast Perfect Boundary Approximation (FPBA), which is a hexahedral meshing option, was chosen as it reduces the number of mesh cells normally used by a factor of three when compared to the PBA option. A high performance PC with the following specification was used: Intel (R) Xeon CPU E5620@2.40GHz (2 processors) with a 1.5 TB hard drive and 48 GB DDR3 memory.

5. SIMULATION RESULTS

Simulations were based on the CPUT chamber. A working volume of 1 m^3 was chosen, defined within 0.5 to 1.5 m in the three axes, relative to the one corner. The standard deviation of the electric field strength distribution inside the CPUT chamber was simulated for each of the three PFUE structures. The vertical and horizontal stirrers were rotated simultaneously in steps of 30° angles. This leads to 12 simulations for the cavity fitted with stirrers only as well as 12 simulations for the cavity fitted with stirrers and passive structures.

The simulation results are presented in Figure 5. It is clear that the groove structures, placed on the ceiling of the chamber, exhibit the lowest standard deviation of the four scenarios over the frequency band. The improvement in standard deviation is marginal, showing a reduction of about 0.4 dB across the band when compared to the empty cavity where no mode stirring takes place. Hence, these passive structures alone do not ensure compliance with the IEC 61000-4-21 standard. However, this does raise the plausible question that, since they improve field uniformity, will the use of passive structures in addition to active stirring with rotating stirrer plates further improve the field uniformity? If this is true, a lower LUF for the same RC may be realised. This hypothesis was tested through measurement of the US RC.

6. MEASUREMENT RESULTS

The structure with the best performance in the CPUT RC, namely the groove structure, was adapted to the US RC since, being bigger, is operating at a lower frequency range than the envisaged CPUT RC. The groove structures protrusions were redesigned to be 0.47 m, which is one wavelength at 646 MHz as this is the lowest frequency at which this chamber had been experimentally characterised by Wiid [3]. Before the actual grooves were designed, it was decided to replace the groove structures with pyramid structures. The notion was that the pyramid structures could scatter the fields even more inside the RC since they have groove-like protrusions for both horizontal and vertical positions.

The 8 pyramid structures were manufactured from galvanised steel since aluminium would be prohibitively expensive. Simulations verified that the use of galvanised steel does not affect the field uniformity as compared with using aluminium, but the loss factor of the chamber may increase.

The structures were intended to be placed on the ceiling but this was not feasible in the US chamber. It was therefore decided to place these passive pyramid structures underneath the horizontal stirrer as this space was not being utilised, and did not interfere with the original working volume of the RC. The placement of the pyramidal PFUE structures in relation to the existing mode stirrers is shown in Figures 6 and 7.

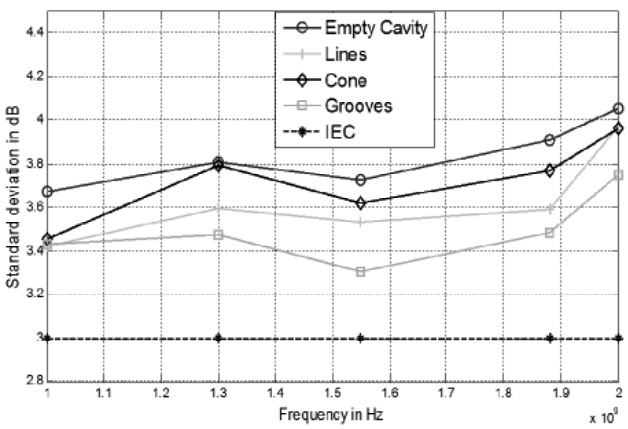

Figure 5: Simulated standard deviation of the electric field distribution within the CPUT chamber for the empty cavity, and the inclusion of the PFUE structures (cone, line and groove) for a vertically positioned dipole antenna.

The measured results indicating field uniformity are presented in Figures 8 and 9, showing the standard deviation of the two scenarios, compared to the IEC limit. Figure 10 shows the chamber calibration factor (CCF) which compares the induced losses for the two scenarios.

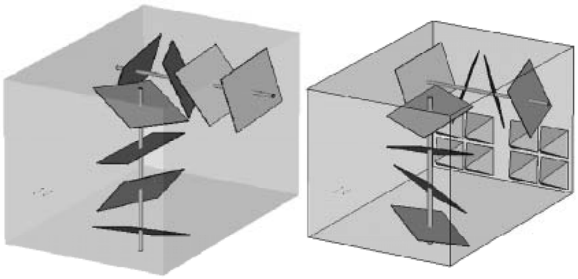

Figure 6: US RC fitted with stirrers only and with eight pyramid structures with dimensions: 0.47 x 047 x 0.47 m.

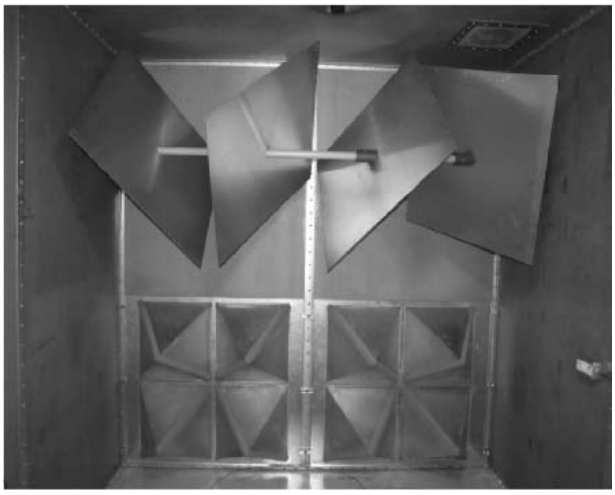

Figure 7: Photograph of the US RC fitted with eight pyramidal PFUE structures below the horizontal stirrer.

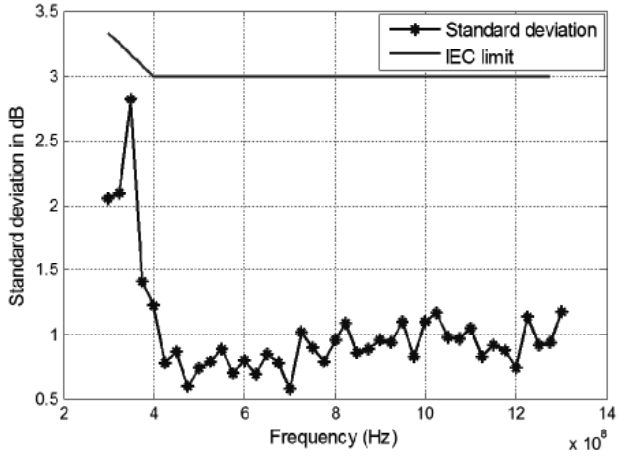

Figure 8: Measured standard deviation of the electric field for the US RC fitted with stirrers only for 3 independent data samples.

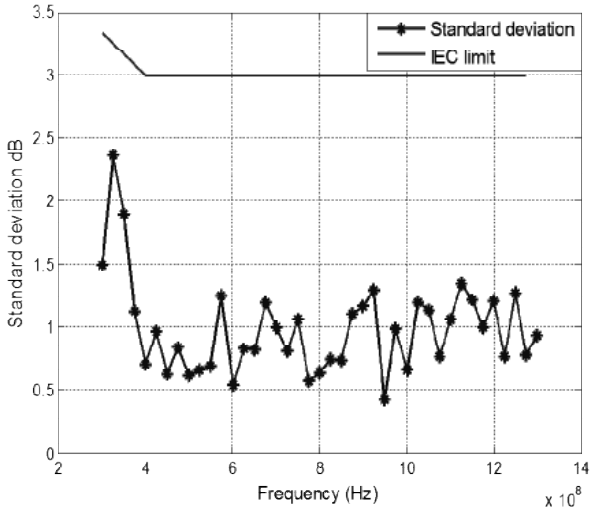

Figure 9: Measured standard deviation of the electric field for the US RC fitted with stirrers and pyramid structures.

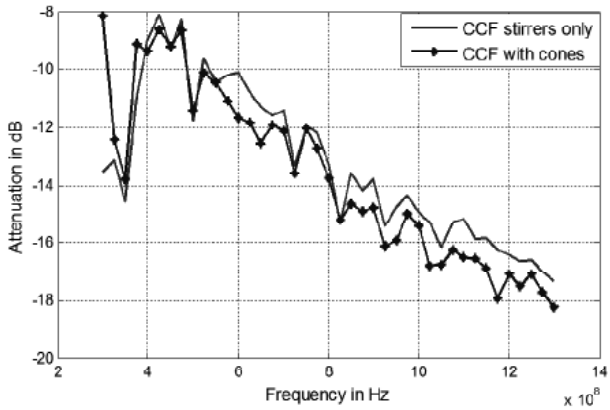

Figure 10: Comparing the measured chamber calibration factor of the RC with stirrers only against the RC with stirrers and pyramid structures.

From the measured results in Figures 8 and 9 it is clear that the combination of passive and active stirring mechanisms improves the field uniformity by up to 0.93 dB over the frequency range of 300 - 400 MHz. Figure 10 shows that for the worst case, there is up to 2 dB additional loss at high frequencies when compared to the stirrers only case. Loss is expected due to the loading effect of RCs. This loss will, however, not adversely affect the RC's performance as it can be incorporated in the calibration of the chamber.

7. CONCLUSION

This paper principally investigated the addition of PFUE techniques in active RCs through simulation and measurement. The PFUE structures are shown to yield better field uniformity at the lower end of the chamber frequency range. Dawson et al. [7] achieved similar field uniformity with optimised stirrer geometry. It would be of interest to combine both stirrer geometry optimisation and PFUE inclusion to push the lower usable band limit of reverberation chambers.

Based on our measured results, with a limited PFUE inclusion, a valuable improvement of up to 0.93 dB in standard deviation was achieved in the low frequency range of 300 - 400 MHz. However, no improvement in field uniformity was noticed at higher frequency ranges. These structures are also cost-effective. We expect further gains by incorporating these PFUE structures on the ceiling and other available wall space.

8. REFERENCES

[1] R. De Leo, & V. Primiani. "Radiated immunity tests: reverberation chamber versus anechoic chamber results". *IEEE Transactions on Instrumentation and Measurement*, vol. 55, no. 4, pp. 1169–1174, August 2006.

[2] H. Streitwolf, R. Heinrich, H. Behnke, L. Dallwitz & U Karsten. "Comparison of radiated immunity tests in different EMC test facilities". *18th International. Zurich Symposium on EMC*, pp. 229-232, September 2007.

[3] P.G. Wiid. "Investigating Cost-Effective EMC Methods". University of Stellenbosch. 2005.

[4] E. Voges & T. Eisenburger. "Electrical Mode Stirring in Reverberation Chambers by Reactively Loaded Antennas". *IEEE Transactions on Electromagnetic Compatibility*, vol. 49, no. 4, pp. 756-761, November 2007,

[5] D.A. Hill. "Boundary Fields in Reverberation Chambers" *IEEE Transactions on Electromagnetic Compatibility*, vol. 47, no. 2, pp. 281-290, May 2005.

[6] J. Sanchez-Heredia, M. Garcia-Fernandez, M. Gruden, P. Hallbjorner, A. Rydberg, & D. Sanchez-Hernandez. "Arbitrary fading emulation using mode-stirred reverberation chambers with stochastic sample handling". *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)*, pp. 152–154, April 2011.

[7] J. F. Dawson, M. O. Hatfield, L. Arnaut, N. Eulig. " *Reverberation (Mode-stirred) chambers for electromagnetic compatibility*". www.compliance-club.com/archive/old_archive/030530.htm.

[8] *IEC 61000-4-21*, Electromagnetic Compatibility (EMC)—Part 4-21: Testing and measurement techniques—Reverberation chamber test methods, 2003.

[9] J. Skrzypczynski. "On Shielding Effectiveness Measurements Using Dual Vibrating Intrinsic Reverberation Chamber". *2010 International Conference on Software, Telecommunications and Computer Networks (SoftCOM)* , pp. 112 – 116, September 2010.

[10] C. Bruns. "Three dimensional simulation and experimental verification of a reverberation chamber". Zurich: Universitat Frediriciana Karlsruhe. 2005.

[11] L. Xiaoqiang, W. Guanghui, Z. Yongqiang & Z. Chenghuai. "Effects of Stirrer on the field uniformity at Low Frequency in a Reverberation Chamber and its Simulation". *International Symposium on Computer Science and Computational Technology* (ISCSCT '08), vol. 2, pp. 517 - 519. December 2008.

[12] CST Computer Simulation Technology. CST MICROWAVE STUDIO – Transient Solver. http://www.cst.com/Content/Products/MWS/TransientSolver.aspx.