Reverberation chambers – design and application for EMC

Ralf Heinrich[1], Uwe Karsten[2]

[1]Schaffner Electrotest GmbH, Landsberger Str. 255, 12623 Berlin, Germany, RHeinrich@Schaffner.com
[2]Schaffner Electrotest GmbH, Landsberger Str. 255, 12623 Berlin, Germany, UKarsten@Schaffner.com

***Abstract* — Reverberation chambers are a promising EMC test environment which has several advantages. The set-up and design of reverberation chambers are discussed in the first part of the paper. The second part deals with their application for EMC. Several performance and comparison tests are presented and discussed which show a good reliability and reproducibility of the reverberation chamber as a test environment for radiated emissions.**

I. Introduction

Reverberation chambers are a modern EMC test environment in addition to the established methods, like semi or fully anechoic rooms, open area test sites or (G)TEM cells.

A reverberation chamber basically consists of a shielded room and a stirrer which changes ("stirs") the electromagnetic field inside the chamber [1]. The chamber itself behaves like a multi mode resonator. Thus a high field strength can be achieved with relatively low input power requirements [2]. The stirrer has the task to move the natural resonances of the chamber in such a way, that a time-averaged spatially homogenous field distribution inside the chamber is achieved. This principle works quite well in the higher frequency range of several 100 MHz and above. However, in the lower frequency range a larger number of independent stirrer steps is needed in order to achieve a homogenous field distribution and there is a lowest usable frequency (LUF) where this method starts to work. The lowest usable frequency according to IEC 61000-4-21 is determined by statistical analysis of the calibration data of the chamber and can be estimated by different methods, e.g. the presence of the 60th mode in the chamber or 3 times of the first resonance frequency [3].

Reverberation chambers can be used for emission and immunity tests [1,4,5,6]. Several standards already support the use of reverberation chambers, e.g. RTCA DO160, MIL461e, some automotive standards and the basic standard IEC 61000-4-21 which defines the use of reverberation chambers.

Especially for immunity tests reverberation chambers have several advantages. The most important ones are probably the low input power requirements to achieve a high field strength and the lack of absorbers which provides a significant cost reduction.

The electromagnetic interference of the DUT is done by a random field coming from all directions in any orientation and polarization, therefore no turning of the DUT is necessary. This becomes especially important in the high frequency range for larger DUT's if the uniform field area is smaller than the DUT and a partial illumination of the DUT is required.

The mechanical set-up of a reverberation chamber seems to be very simple at first glance, however several aspects have to be considered to ensure a successful operation of the reverberation chamber. A selection of important design parameters will be discussed in the next section.

II. Design considerations for reverberation chambers

The IEC standard IEC 61000-4-21 gives general recommendations for the chamber design [1].

A very basic requirement is that the chamber should be big enough to maintain a multi-mode electromagnetic environment with respect to the lowest test frequency (LUF). However, a larger chamber would be favorable regarding the testing efficiency since less stirrer steps are required in the upper frequency range, e.g. only 12 steps above the sextuple lowest usable frequency.

Furthermore the chamber should not have equal dimensions, i.e. the length, width and height of the chamber should not have the same length. Same sized chamber walls would lead to resonances at the same frequencies which would not contribute to a homogenous field distribution [4]. The chamber resonances can be calculated by the following formula:

$$f_{l,m,n} = \frac{c}{2}\sqrt{\left(\frac{l}{L}\right)^2 + \left(\frac{m}{W}\right)^2 + \left(\frac{n}{H}\right)^2} \qquad (1)$$

where

l,m,n are mode indices and

L,W,H are the chamber dimensions length, width and height

A high screening effectiveness is a very important parameter in order to achieve a high quality factor of the resonant cavity which ensures low input power requirements for high field strengths. Leakages in the chamber can reduce the chamber quality factor significantly [7]. Dissipative elements inside the chamber, e.g. a wooden floor etc., also reduce the quality factor and should therefore be avoided. The conductivity of the chamber walls contributes directly to the quality factor of the chamber. Therefore a high conductivity is favorable, however if the quality factor becomes too high it becomes more and more difficult to achieve a homogenous field distribution, especially in the low frequency range.

Another disadvantage of a very high quality factor is an increase of the chamber time constant which leads to longer relaxation times for pulse excitation. Hence the above discussed parameters should be optimized in order to achieve an acceptable compromise between input power requirements and chamber performance.

The stirrer is an essential part of the chamber design. The stirrer changes the boundary conditions of the electromagnetic field in order to achieve a time averaged spatially homogenous field distribution inside the working volume of the chamber. This can either be done by a continuous rotation of the stirrer (stirred mode) or by stepping the stirrer through 360° in discrete steps (tuned mode).

The size of the stirrer is directly related to its ability to change the electromagnetic field inside the chamber. The stirrer should therefore be as large as possible with respect to the chamber size. At least one quarter wavelength of the lowest frequency or at least three quarter of the smallest chamber dimension is recommended in the standard IEC 61000-4-21 [1].

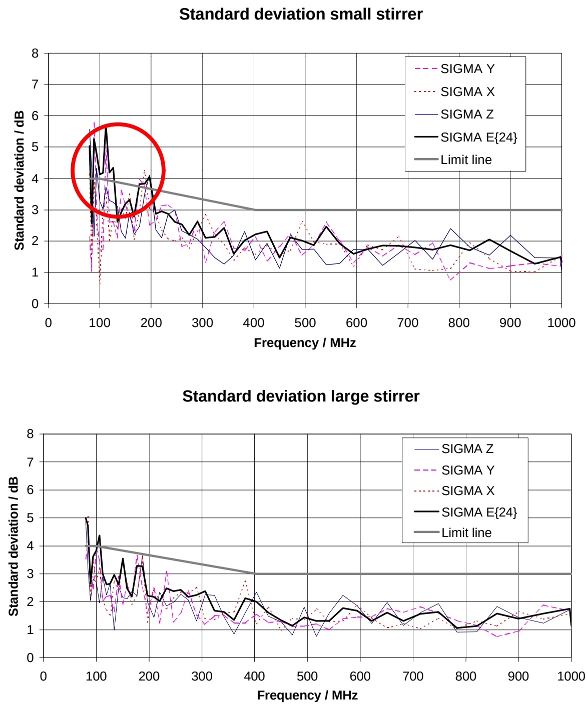

Fig. 1. Standard deviation σ_x, σ_y, σ_z and σ_{24} as a result from the empty chamber calibration using a small stirrer (figure above) and a large stirrer (figure below).

Fig. 1 shows the calculated standard deviations of the electric field strength along all three orthogonal axes for a small stirrer and a large stirrer. The straight line which ranges from 4 dB down to 3 dB up to 400 MHz and remains at 3 dB above 400 MHz indicates the limit given by the IEC-standard IEC 61000-4-21. It can be seen that the large stirrer is very well suited to enable a chamber operation down to approx. 120 MHz whereas the small stirrer cannot be used below 200 MHz as indicated with the circle.

The stirrer design is not only important in the low frequency range to achieve a low LUF but also in the high frequency range.

The standard IEC 61000-4-21 recommends to perform a cross check between the expected E-field measured by the probes and the expected E-field estimate based on the eight antenna measurements. The results of the cross check of a suboptimal stirrer design are displayed in fig. 2. It can be seen that the deviation of the E-field based on the probe measurements and the E-field based on the antenna measurements exceeds a limit of +/- 3 dB (indicated with a dotted line). A redesign of the stirrer solved this problem and reduced the deviations well below 3 dB.

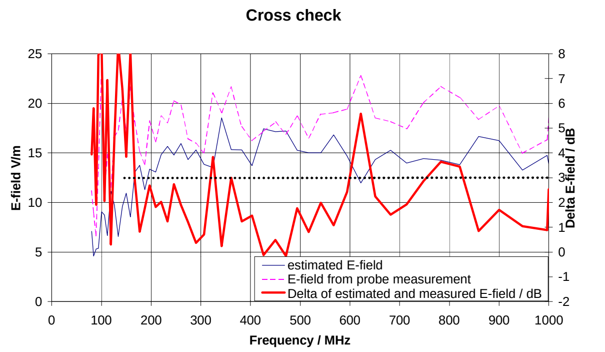

Fig. 2. Cross check between the expected E-field measured by the probes and the expected E-field estimate based on the eight antenna measurements.

The shape of the stirrer is also important to achieve a non repetitive field pattern which is one criterion to get independent stirrer positions. A symmetric stirrer would lead to a behavior as shown in Fig. 3.

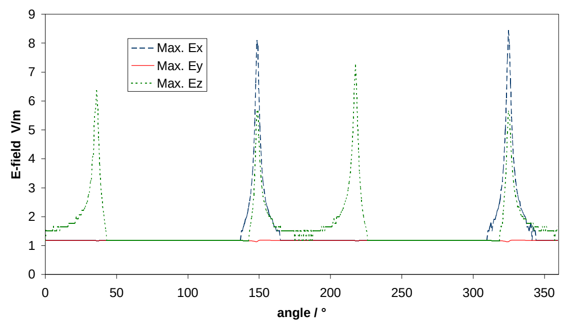

Fig. 3. Maximum E-field components E_x, E_y, E_z for one stirrer revolution.

This behavior can especially be seen in the low frequency range close to the LUF. The maximum E_x in this example occurs at 150° and at approx. 150°+180°=330° which shows a 180° symmetry. A similar behavior can be observed for the E_z component.

III. APPLICATION OF REVERBERATION CHAMBERS

The application of a reverberation chamber requires a calibration. Based on statistical analysis the calibration proves the field homogeneity in the working volume (as shown in fig. 1 for an empty chamber) and provides the necessary data for the test, e.g. input power for the desired test field strength.

The calibration consists of 2 parts, field strength and power measurements of the empty chamber and the same measurements for a maximum loading of the chamber. This kind of calibration has to be done only once in the lifetime of the chamber, unless changes in the chamber, e.g. set-up, stirrer design or similar, are introduced.

Prior to each test a “quick check” has to be performed in order to prove that the chamber is not adversely loaded, i.e. the loading by the DUT is somewhere between the empty chamber and the maximum loading of the chamber which was determined during the calibration. Fig. 4 shows, as an example, the maximum loading of our small chamber as determined during the calibration. The chamber could have been loaded more than about 7 dB (suggested nominal loading is 12 dB [1]), however this initially determined loading turned out to be sufficient for our investigations, i.e. the loading introduced by the reference source (DUT) was much less.

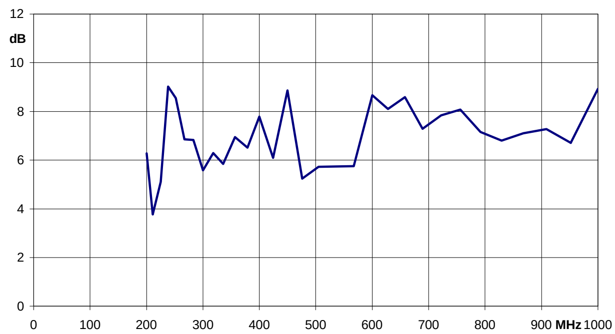

Fig. 4. Maximum loading of the small chamber as determined during the calibration.

Reverberation chambers can be used for emission and immunity testing. For immunity testing the desired test field strength can be calculated from the formula:

$$P_{input} = \left[\frac{E_{test}}{\left\langle \overleftrightarrow{E} \right\rangle_{24 or 9} * \sqrt{CLF(f)}} \right]^2 \quad (2)$$

where

P_{input}	is the forward power in W into the chamber
E_{test}	is the desired test field strength in V/m
$CLF(f)$	is the chamber loading factor derived from the calibration and the “quick check”
E	is the average of the normalized E-field from the empty chamber calibration

For emission testing the radiated power from the DUT is measured. It can be calculated from the formula:

$$P_{Radiated} = \frac{P_{AveRec} * h_{TX}}{CCF} \quad (3)$$

where

$P_{Radiated}$	is the radiated power from the DUT
P_{AveRec}	is the maximum power received over the number of stirrer steps
CCF	is the chamber calibration factor
h_{TX}	is the antenna efficiency factor for the Tx antenna used in calibrating the chamber

The radiated emission performance of reverberation chambers can be easily and reliably investigated using a reference source based on a comb generator. Fig. 5 shows the radiated emission of a reference source placed at different locations inside the working volume of the chamber. The measured radiated emission is almost independent from the location of the DUT inside the working volume. Only close to the LUF there are some deviations.

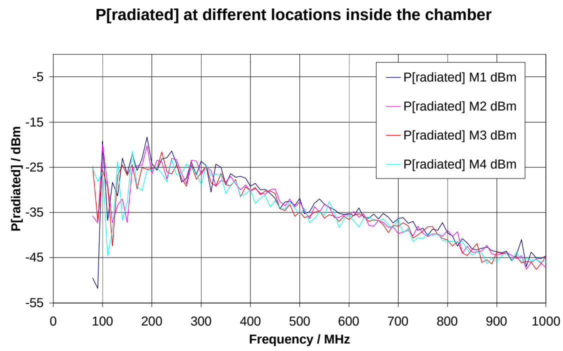

Fig. 5. Radiated emission of a reference source placed at different locations M1 to M4 inside the working volume of the chamber.

The same reference source was used to compare the emission measurement results of 2 different reverberation chambers:

- Chamber 1: approx. 2.5 x 4 x 2.4 m (small chamber)
- Chamber 2: approx. 3.1 x 7 x 2.4 m (large chamber)

Fig. 6 shows the test results of the radiated emission in a small and a large reverberation chamber. It can be seen that the difference between the chambers is very small although the chambers and the stirrer are entirely different. The deviations below 250 MHz are due to the higher LUF of the small chamber.

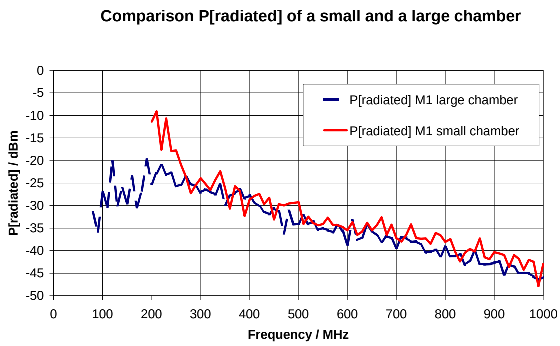

Fig. 6. Comparison of the radiated emission measurements in a small and a large reverberation chamber.

Above 1 GHz similar results were achieved as shown in fig. 7.

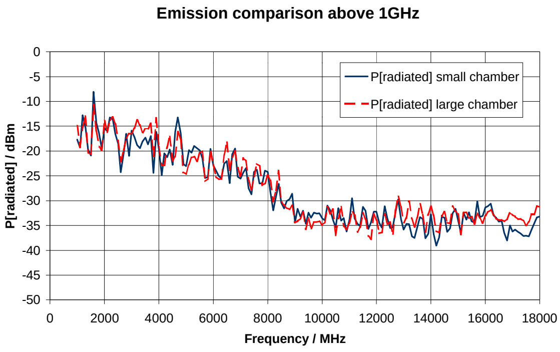

Fig. 7. Comparison of the radiated emission measurements in a small and a large reverberation chamber above 1 GHz.

The radiated emission has also been compared with an established method. Fig. 8 and 9 show the radiated electric field strength (3 m distance in free space) measured in a reverberation chamber compared to the measurement in a GTEM cell.

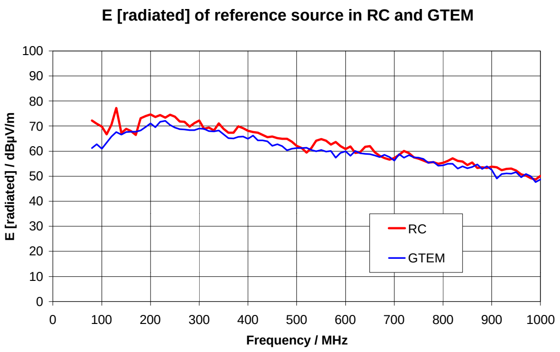

Fig. 8. Comparison of the radiated emission measured in a reverberation chamber and in a GTEM cell.

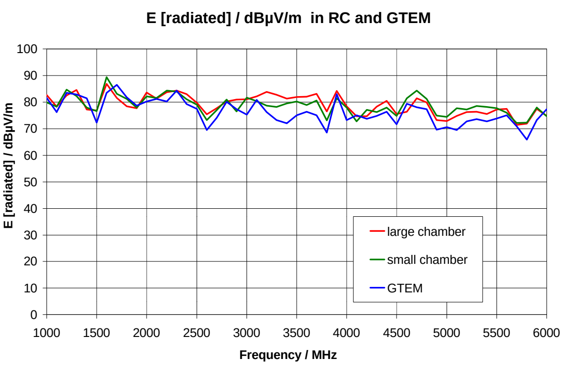

Fig. 9. Comparison of the radiated emission measured in reverberation chambers and in a GTEM cell above 1 GHz.

Generally a reasonably good agreement between the emission measurements in the reverberation chamber and the GTEM cell can be seen, however the measured emission in the reverberation chamber is slightly higher than in the GTEM cell. Possible reasons for this behavior could be that the reverberation chamber better determines the radiated power from the DUT or that the antenna efficiency factor for the antenna in the RC is not as high as assumed (0.75 for log per antenna and 0.9 for horn antenna).

IV. Conclusions

Reverberation chambers have a relatively easy set-up. Several important design parameters were discussed in the paper. The presented investigations for radiated emissions show a good reproducibility and reliability of the measurement results.

The emission measurement results are almost independent from the location of the DUT in the test volume, turning of the DUT is not necessary.

The comparison between two different reverberation chambers shows a very good reproducibility of the test results.

Similar measurement results were achieved in the reverberation chamber and in the GTEM cell.

These results of the investigations and its advantages make the reverberation chamber an attractive test environment in addition to the established methods.

Acknowledgement

The authors wish to thank Mr. Andreas Lange for his assistance in doing the measurements in the reverberation chamber.

References

[1] IEC 61000-4-21, Electromagnetic compatibility (EMC) – Part 4-21:Testing and measurement techniques – Reverberation Chamber Test Methods, 2003-08.

[2] N. Eulig, A. Enders, H.G. Krauthäuser and J. Nitsch, “Achievable field strength in reverberation chambers” in Advances in Radio Science (2003), pp. 53–56.

[3] J. Clegg , A.C. Marvin, J.F.Dawson, S.J. Porter and M. Bruenger-Koch. “Optimisation of stirrer designs in a mode stirred chamber using TLM”. XXVIIth General Assembly of the International Union of Radio Science (URSI), Maastricht. Paper No. AE.P.3. 17-24 August, 2002.

[4] M. Bäckström, O. Lundén and P-S. Kildal “Reverberation Chambers for EMC Susceptibility and Emission Analyses“, Review of Radio Science 1999-2002, pp. 429–452, 2002

[5] M. Petirsch, I. Sotriffer and A. Schwab “Electromagnetic Susceptibility Measurements in a Mode-stirred Chamber”, EMC Zurich 1999

[6] J F Dawson, M O Hatfield, L Arnaut and N Eulig “Reverberation (Mode-Stirred) Chambers for Electromagnetic Compatibility”, EMC and Compliance, ISSN 1464-7559 Issue 46, May 2003, pp30-38

[7] M. Hillgärtner and D. Peier “Einflussgrößen bei der Gütebestimmung von Modenverwirbelungskammern”, HF-Report 1/2005