Field Statistics in a One-Dimensional Reverberation Chamber Model

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Abstract — This work focuses on the study of the statistical properties of the fields within a One-Dimensional Reverberation Chamber model presented previously. The aim here is to show the excellent agreement between this simple model and real RCs. A One-Dimensional Radiated Emission test setup is defined and shows reliable matching with reality. The variation of the field performance near the conducting walls is also investigated.

1 INTRODUCTION

Reverberation Chambers (RC) are gaining significant confidence in their use for radiated emissions and immunity measurements. RC users need to fully understand its working principles in order to correctly interpret the measurement results and to optimize the performance for various measurement tasks.

Reverberation Chambers’ extensive knowledge up to now, results from a somehow partial juxtaposition of four different approaches:

1. the deterministic models (i.e. [1], [2]),
2. the statistical models (i.e. [3], [4]),
3. the empirical techniques (i.e. [5], [6]), and
4. the computer/numerical methods (i.e. [7]).

It is not possible to leave one of these approaches behind, as each one of them behaves as a non-exhaustive, non-excluding part of RCs’ description. Furthermore, they mutually collaborate to give fairly successful answers in fields where the other one fails, and vice versa. Therefore, there is an obvious gap which makes us change our methodology depending on what kind of result we seek. In this sense it is to point out that statistical description is meaningful only if the chamber is working in an overmoded regime and only on special chamber geometries (for example, the Plane Wave Integral Representation [8] has its rigorous validity only in spherical volumes). On the other hand, the success of deterministic models is intimately linked to the specificity of the chamber geometry and it compels us to pay no attention to the mode stirring process, which is an essential constituent of the RC performance. Consequently, a call for filling this gap and linking the two approximations is needed. This necessity is supported by the aim of having a better understanding, to manage a simpler yet complete model and to reduce up to a reasonable minimum the empirical techniques.

An attempt of filling this gap was presented in [9], where a one-dimensional reverberation chamber model (see fig. 1 for a schematic diagram) was shown to have a statistical behavior equal to real RCs. It simulates the electromagnetic field distribution inside a theoretical vacuum-filled one dimensional segment of length $a$, with the presence of a one dimensional “stirrer” (a perturbing lossless dielectric layer) of length $t = x_2 - x_1$ and relative dielectric constant $\kappa$, and with losses in the walls. A continuous-wave point source of frequency $f_0$ is located at $x_0$. In this model, the statistically uniform field can be obtained by means of different stirring processes, each one of them finding a strong analogy with real reverberation chambers. In the following we will extend the analogy of the one dimensional reverberation chamber model not only to investigate the probability distributions but also to assess other characteristics reported for real reverberation chambers, in order to gain even more confidence in this model.

Figure 1: Definition of the one-dimensional cavity under study. The length of the cavity is $a$, the one dimensional "stirrer" is of length $t = x_2 - x_1$ and of relative dielectric constant $\kappa$. A CW point source of frequency $f_0$ is located at $x_0$.

Section 2 will compare the performance of the one dimensional reverberation chamber model with real RCs, in the case of radiated emission test measurements. In section 3 the field statistics near the cavity walls will be studied.

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2 RADIATED EMISSION (RE) MEASUREMENTS

In this section, the measurement of the total radiated power of an equipment under test (EUT) in a reverberation chamber will be addressed. Reference [10], Annex E (and references therein) report how to determine the total radiated power. The main findings in radiated emission tests within reverberation chambers, are (not exhaustively) summed up to be:

- The radiated emission measurement is independent of the equipment under test and receiving antenna position, orientation and radiation pattern.

- The averaged and/or maximum power received by an antenna is directly proportional to the averaged and/or power radiated by an equipment under test.

- The main factors influencing this proportionality are: the chamber quality factor $Q$, the antenna efficiency, the loading and the cavity losses.

The aim of this paper is about the assessment of our one dimensional model to reproduce the main literature findings regarding reverberation chambers knowledge.

2.1 Modeling of a test setup

Firstly, we will place a one dimensional equipment under test inside the chamber, and study the statistical characteristics when the mode-stirring process is acting. The one dimensional equipment under test is modeled as a set of point sources, each one of them as shown in fig. 1 but with a (discrete) current distribution following that of a dipole. The choice of a dipole as an equipment under test is supported by the fact that the latter is the most representative of the standard EUT behavior. In fact, [10] recommends to use a directivity of $D = 1.7$ (that is to say, a dipole) in the case of emission testing, if the actual directivity of the equipment under test is unknown.

The electric field is then calculated as in [9] and superimposing the set of sources. Figure 2 shows the real part of the electric field for 15 different stirrer sizes. The largest size and the position of the stirrer is depicted by the thick line ($x_1 = 5.5$ m, $x_2 = 7.5$ m), while the distribution of the current sources is represented by the vertical red arrows (the scale of current is not provided).

Table 1: Factorial Plan

<table>
<thead>
<tr>
<th>Factors</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>1 m</td>
<td>2 m</td>
</tr>
<tr>
<td>$P_t$</td>
<td>1 W</td>
<td>4 W</td>
</tr>
<tr>
<td>$Q$</td>
<td>100</td>
<td>1000</td>
</tr>
</tbody>
</table>

GHz (resulting in a wavelength of $\lambda = 30$ cm, approximately). The chamber’s length $a = 10$ m. The process of mode stirring is analogously revealed as in [9] and it is confirmed that the correct statistical behavior is again reproduced.

2.2 Radiated Emissions test procedures

In order to verify the overall performance of this test setup, we will firstly make use of a proper factorial design. We will assess the influence and main effects of three factors: the length of the EUT ($L$), the power delivered to the EUT ($P_t$) and the RC’s quality factor ($Q$) over two widespread known outputs, viz.: the average and the maximum received power. Secondly, the existing relation between transmitted and received power is discussed.

2.2.1 Assessment of the effect of $L$, $P_t$ and $Q$ in RE tests.

A factorial design was defined, outlining two levels of variation for every factor. Each level was chosen guided by the empirical experience and they are all summed up and presented in Table 1.
The average and maximum of $|E|^2$ (which is proportional to the received power) within the test volume were calculated for the resulting 8 experiments. For each configuration of the factors levels, 500 independent calculations were realized as in [9]. The other factors, such as the chamber length, and the frequency of operation were taken to be the same as those of figure 2.

A complete analysis of the factors indicates a total agreement with the behavior found in practice for RCs and with the literature. The following considerations represent a summary of our observations:

1) it is seen that the radiated emission tests are independent of the EUT size;
2) the effect of $Q$ is largely greater in the case of maximum received power (evidencing the higher uncertainty of this method with respect to the average received power);
3) the effect of $P_t$ is significantly lower in the case of average received power (supporting the fact that this method needs a more sensitive measurement system to get an accurate result).

The above properties are in agreement with the published RC theories and with measured results on real RCs (in particular, see [10]).

### 2.2.2 Determining Radiated Power

Reference [10] Annex E, reports how to determine the power radiated from a device using either the average or the maximum received power. In both cases, $P_t$ is calculated to be proportional to the measured average ($P_{AvgRec}$) or maximum power ($P_{MaxRec}$) with a constant of proportionality found during a necessary calibration campaign.

The following equations (1) and (2), given in [10], are used for the mentioned estimation.

\[
P_{Radiated} = \frac{P_{AvgRec} \cdot \eta_T}{CCF} \quad (1)
\]

\[
P_{Radiated} = \frac{P_{MaxRec} \cdot \eta_T}{CLF \cdot IL} \quad (2)
\]

where $CCF$ is the chamber calibration factor, $CLF$ is the chamber loading factor, $IL$ is the chamber insertion loss, $P_{AvgRec}$ is the received power averaged over the number of stirrer steps, $P_{MaxRec}$ is the maximum power received over the number of stirrer steps and $\eta_T$ is the antenna efficiency factor.

We can reproduce the same test setup using the experiments described in section 2.2.1, and pretend that the experiments for $P_t = 1W$ are the ones for calibration. Also, we assume the EUT length $L = 1$ m. We computed $|E|^2$ for two different positions within the test volume and for 500 variations of the stirrer. By this process, we are able to determine $CCF$, whose value is $7.8644 \times 10^{-5}$. Afterwards, we apply equation (1) to the data of the same experiment but with $P_t = 4$ W. For the resulting $P_{Radiated}$ values at two different measurement positions, we obtained 4.35 W and 3.64 W (a value of $\eta_T = 1$ was assumed for the receiving antenna efficiency). The same procedure was repeated for the maximum received power for all the 8 experiments of Table 1 and for two different positions inside the test volume. The complete list of all the exact results is omitted here for brevity, but they were found to lay between $\sim 3.5$ W and $\sim 4.5$ W, except for the cases with $Q = 100$ and with the maximum received power method. These results are reasonably close to the actual $P_t = 4$ W of our forged "unknown" EUT.

Hence, we can conclude once more that our 1D model (although simplistic) provides a good representation of reality.

### 3 FIELD STATISTICS NEAR THE CAVITY WALLS

Observations of mode-stirred chambers has suggested that proper statistics apply, provided that the distance from the walls (or any other conducting structure) is greater than one quarter of the free-space wavelength [10]. To show the coherence of this "quarter wave rule" between real RCs and our 1D RC model, we solved many one-dimensional chambers to investigate the variation of statistical distribution with position in a cavity. The chamber length $a = 10$ m, the frequency of operation $f_0 = 1$ GHz (with the corresponding wavelength of approximately $\lambda = 30$ cm) and the number of independent stirrer sizes $n = 500$ were chosen as the conditions of the experiments.

Initially, some fixed positions were chosen to be $x = 6.5$ m (mid-way across the test volume), $x = 9.85$ m (a half wavelength from the wall), $x = 9.925$ m (quarter wavelength) and $x = 9.9625$ m (eighth of a wavelength): the resulting field distributions of the real part of the electric field are compared in Figure 3. Note that the distributions still resemble a Gaussian curve when the distance is less than a quarter wavelength, but that the variance is dramatically reduced in value.

To deepen into this phenomenon, we calculated the field statistics for a large number of positions and plotted the value of the variance of the real and the imaginary part of the electric field against the distance from the left wall $d = a - x$. The results are shown in Figure (4) on a logarithmic scale.
It can be seen that this result gives good reason to the “quarter wavelength rule”. An explanation of the fall of the variance when $d < \lambda/4$ is that the boundary conditions compel the total electric field (and each one of its contributing modes) to be zero at the side walls.

4 CONCLUSIONS.

This paper discusses the field statistics within a 1D RC model that presents a strong behavioral analogy with 3D RCs. Besides recognizing in it the same statistical behavior (as done in [9]), further characteristics of real RCs were compared with our 1D RC model. These are: radiated emission measurements (section 2) and the field statistics near the cavity walls. The main convenience of this model consists on giving a complete understanding of RCs, without leaving any gap on its theoretical development. Future work (currently under way) involves both the development of a correlation between the real stirrer and its 1D parameters, and a 3D extension of this model.

References


