Experimental Observations of the Minimum Dwell Time for Radiated Immunity Tests in a Vibrating Intrinsic Reverberation Chamber

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***Abstract*—Reverberation environments permit creating a statistically homogenous and isotropic electromagnetic field for testing electronic devices. Vibrating intrinsic reverberation chambers are one of the possible reverberation environments where successive, independent samples of the electromagnetic field values are generated through the vibrations of the flexible walls. In this paper, we investigate the test time (the dwell time) necessary for creating dataset of independent field sample values with homogenous statistics in a 1.5 m x 1.2 m x 1.0 m vibrating cavity. In particular, we present the results of an experimental study conducted at frequencies close the lowest usable frequency. We have compared empirical to simulated datasets showing that a prediction, based only on a theoretical approach, of the minimum dwell time could lead to large errors when non-idealities in the stirring process appear.**

Keywords—VIRC; reverberation chamber; minimum number of independent samples; dwell time.

I. INTRODUCTION

In the context of the electromagnetic compatibility (EMC) for electronic components or devices, a reverberation chamber (RC) is a test environment that permits a reliable assessment of the susceptibility thresholds to radiated electromagnetic fields [1]. The RC provides a test environment where it is possible to generate an electromagnetic field with statistical properties uniformly and isotopically distributed into the cavity´s working volume (WV). The reference standard for RCs [2] describes how to validate such statistical field and gives a criterion based on the standard deviation of the field strength maximum levels for fixing a lowest usable frequency (LUF) for the particular cavity used. The uniformity of the field strength maxima is assessed through datasets of electric field strength samples measured at the eight corners of the WV and along three mutual orthogonal directions. Thus, a total of 24 dataset shall be collected for the analysis and the number of independent samples present in each dataset is one of the factors determining the accuracy of the estimation. The reference standard IEC 61000-4-21 indicates to use at least 12 uncorrelated samples for each dataset, generated during the stirring action of a mechanical rotating tuner to reach good field uniformity in the WV. At the frequencies close to the LUF, where non-idealities appear in the stirring process, could be necessary increasing the number of samples, for example, from 12 to 50 [2]. In a vibrating intrinsic reverberation chamber (VIRC) [3], the occurrence of uncorrelated field samples is determined by the outline of the flexible, vibrating walls. In fact, the boundary conditions that must be satisfied by the field distribution within the cavity are determined by the instantaneous positions and dimensions of the folds in the flexible fabric. In [4], it has been measured that the typical temporal distance between uncorrelated boundary conditions (i.e., a substantial change in the VIRC´s outline happened) for a very large VIRC (26 m x 8 m x 6m) is, at 300 MHz, about 250 ms. This results in a minimum dwell time of 3 s (for 12 samples) or 12.5 s (for 50 samples) to be used for that specific frequency. Therefore, it becomes beneficial, for the user, the *a priori* knowledge of the minimum size of field sample datasets (i.e., the minimum dwell time). This can help in optimizing the scheduling and costs of the test. In this document, we have used both a numerical and empirical approach: First, we have used a Monte-Carlo (MC) program based on a Weibull model [5] to generate simulated data and make some prediction on the minimum dwell time. Then, we have compared numerical and empirical datasets to determine the accuracy of the predictions. It has been concluded that the estimation of the field uniformity based on the number of samples and their statistical distribution, is not particularly accurate at lower frequencies. At those frequencies, only the empirical analysis can help significantly in finding the minimum dwell time.

The document is organized as follows: The Section II describes the measurement setup used for the experiments. The performance criterion used to assess the field uniformity is discussed in Section III and the MC model in Section IV. Actual measurements at the LUF are described in Section V. Finally, the Section VI comments the outcomes of the previous sections.

II. MEASUREMENT SETUP

All experiments were carried out in a VIRC installed at the University of Twente [6]. The VIRC is a 1.5 m x 1.2 m x 1.0 m rectangular structure and the electric field is stirred by the vibrations of its flexible surfaces. According to a simple criterion, the LUF could be found at three times the fundamental cavity resonance, i.e. 450 MHz [2]. The receiving antenna is a double-ridged horn type directed to a moving wall in a non-line-of-sight configuration with the transmitting discone antenna. The receiving antenna has been located, vertically polarized (formally, the *z* direction), in eight different positions of the WV separated by a minimum distance of $\lambda/2$ (calculated at the lowest frequency of operation).

III. THE STATISTICAL DISTRIBUTION OF THE STANDARD DEVIATION VALUE

The field uniformity value is based on the standard deviation of the maximum values extracted by different datasets of electrical field samples taken by a field probe or antenna at the eight corners of the WV and along three orthogonal mutual directions [2]. Consequently, the standard deviation is calculated according to the IEC normative equation:

$$\sigma(dB) = 20\log_{10}\left(\frac{\sigma + \langle E\mathrm{max}\rangle}{\langle E\mathrm{max}\rangle}\right) \qquad (1)$$

where $\langle E\mathrm{max}\rangle$ is an averaged value of the local maxima appeared into the WV during the stirring process and σ their linear standard deviation. Without loss of generality, the measurements and simulations described in the next sections refer only to eight datasets (i.e., (1) is given only in the *z* direction).

In the RC context, (1) is not a deterministic number, but a random variable with a probability distribution function. The expected value of (1) and its variance are determined by the number of uncorrelated field samples present in each dataset, but also by the actual physical imperfections of the stirring action. Simulation models based on the underlying Rayleigh distribution (valid only for an ideal stirring action of the cavity´s field) for the Cartesian components of the field, show that dataset of 12 uncorrelated samples can guarantee the homogeneity of the test field ((1) < 3 dB) with a 95% confidence [7] and [2]. However, this condition holds only for ideal chamber and in overmoded conditions. Fig. 1 shows the empirical histogram plot of 250 iterations of calculating (1) at 500 MHz into the VIRC described in the previous section and keeping the test setup unvaried. The two curves refer to the calculation of (1) made through datasets of 12 and 100 samples

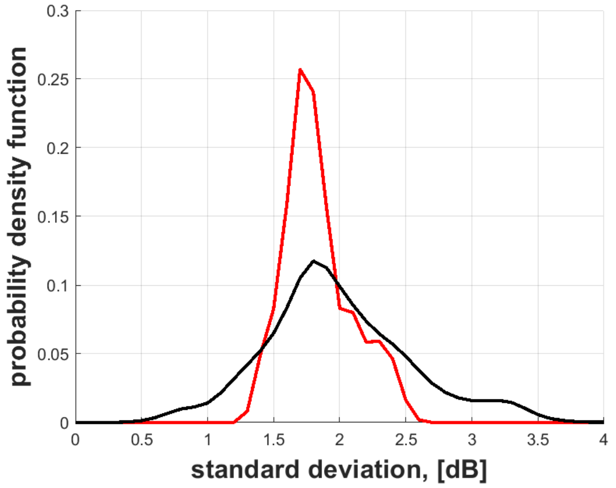


Fig. 1. The histogram plot indicates the rate for each value of (1) obtained through repeated test with datasets made of 12 (black) and 100 (red) uncorrelated electric field samples at 500 MHz.

Datasets of 12 samples generate a field with good uniformity (i.e., (1) is on average 2 dB) yet a non-null probability to obtain values of (1) above 3 dB, exists. However, the uniformity of the field, as well as the accuracy of the estimates of (1), can be improved by enlarging the size of each dataset, i.e., using larger dwell times for the analysis. The number of uncorrelated samples has been determined (the VIRC is not mentioned in the IEC 61000-4-21) according to the same approach indicated in [4]. Here, the number of uncorrelated samples was derived from the coherence time of the stirring action, which is the period of a coherent, stable geometric configuration of the boundaries imposed by the cavity´s walls to the internal field. It can be assumed, in fact, that if boundaries do not change, the electric field remains unaltered within the WV. For the VIRC used for the test, the total number of uncorrelated samples in a 2 s dataset is about 100 at 2 GHz (Table I).

TABLE I. AVERAGED (AMONG THE MEASURING POSITIONS) COHERENCE TIME VALUES

Frequency [MHz]	***Coherence time [ms]***
495	120
500	120
505	125
510	110
2000	20

IV. THE MONTE CARLO SIMULATION

The assumption that the statistical distribution of the field strength samples is, in a resonant cavity, Weibull-like well describes the electromagnetic field at the working frequencies close to the LUF, but it can be extended to the entire usable frequency spectrum. In fact, the expected underlying Rayleigh distribution can be considered as a special case of the general two-parameter Weibull model [5]. Before analyzing the field statistics close to the LUF, a single frequency in the overmoded region of the VIRC (at 2 GHz) is presented as reference. Here, the parameters of the Weibull distributions have been assessed for dataset of 2 s (about 100 independent samples) and for each measuring point. The empirical couples (A, B) of the Weibull distribution function have been estimated through the maximum likelihood estimation method implemented by the *wblfit* function in MATLAB. The 95% confidence interval (95% CI) of both parameters, A and B is presented in the Fig. 2.

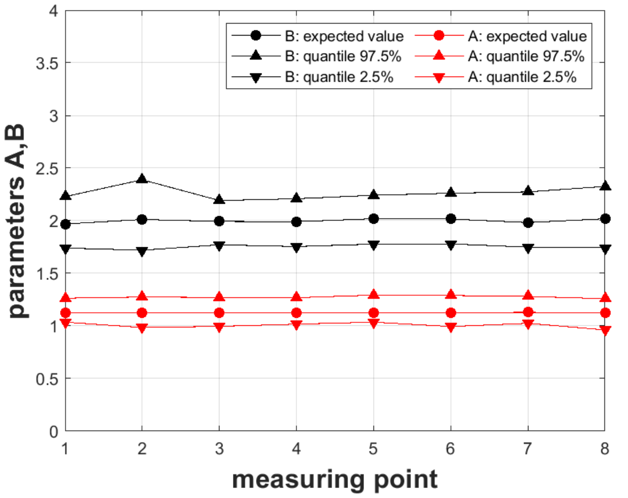


Fig. 2. 95% CI of the parameters A and B at 2 GHz and for each measuring point. The dataset length is 2 s (about 100 independent samples).

The MC program used for the estimation of (1) is now briefly described: Each loop of the program is performed with an adequate number of iterations (10000). During the loop process, a set of N samples is generated using the Weibull random number generator implemented in MATLAB. All the elements are divided into eight dataset and the standard deviation of the maxima from each dataset, calculated according to (1). At each iteration, parameters A and B are generated using a uniform random number generator in a range from 1.0 to 1.2 for A, and 1.8 to 2.2 for B. The simulated quantiles together with the results of 250 empirical estimations of (1) are reported in the Fig. 3.

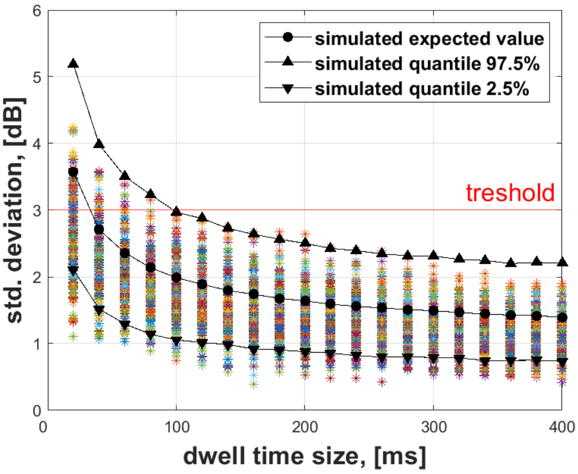


Fig. 3. The simulated quantiles (2.5%, 50%, 97.5%) of (1) are compared with 250 empirical, independent observations of (1) at 2 GHz.

Fig. 3 shows that good agreement can be observed between simulation and measurement results. The empirical statistics of the standard deviation agrees with the prevision of the simulated Weibull model and after 100 ms (about five independent samples) the worst-case estimation of (1) remains below 3 dB. In this case, the 12 uncorrelated samples, equivalent to a dwell time of 240 ms, required by the reference standard does not elongate the minimum dwell time too much.

Fig. 4 shows the statistics of parameters A and B at 500 MHz, where the modal density of the cavity is lower.

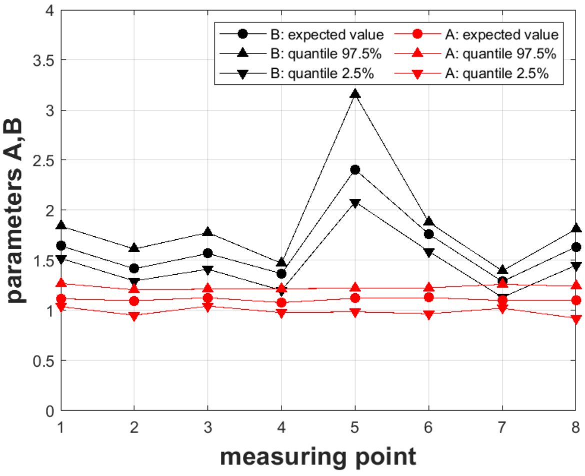


Fig. 4. 95% CI of parameter A and B at 500 MHz and for each measuring point. The dataset length is 11 s (about 100 independent samples).

It can be observed, that the statistical distributions of the electric field are not homogeneous across the positions of the measuring antenna and a clear outlier is present in the position five. At 510 MHz, the statistics of (1) change again and the Weibull´s parameters range in different intervals (Fig. 6).

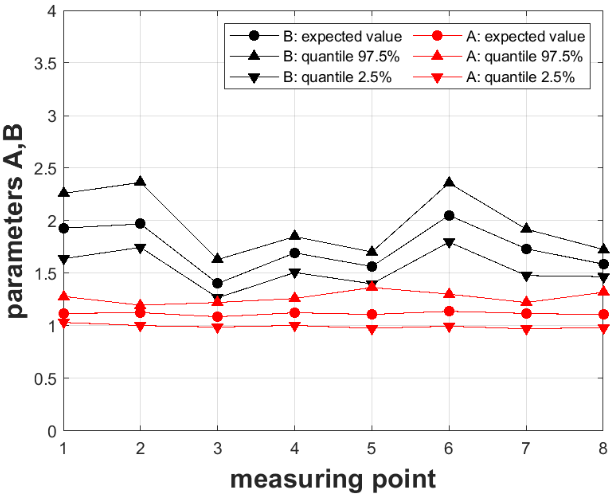


Fig. 5. 95% CI of parameter A and B at 510 MHz and for each measuring point. The dataset length is 11 s (about 100 independent samples).

The statistics of the parameters A and B indicated in Fig. 2 can be associated to a good stirring action and can be found also for other working frequencies in the overmoded region (not indicated in the paper for brevity). This means also that they are independent from the cavity, the working frequency or the stirring mechanism considered. This is a very important conclusion, because it permits to define a performance criterion valid for the evaluation of a well-working resonant environment, independently from the cavity used.

However, in the lowest part of the usable frequency spectrum, where the stirring mechanism of the electromagnetic field is not working properly and non-idealities appear in the field sequences, this condition of generality is violated and the field statistics are generally not predictable. This prevents, in our opinion, the use of numerical simulations for the assessment of the minimum number of samples and suggests the empirical approach described in the next section. In practice, Weibull parameters cannot be related, at the lower frequencies, to a particular frequency or physical parameter of the cavity.

V. Evaluation of the Field Homogeneity through Empirical Measurements

In this section, the uniformity of the cavity field levels has been assessed as a function of the dwell time size, not the number of uncorrelated samples contained in each dataset. Although the two approaches are equivalent, it has been preferred using a time basis approach because, for VIRCs, it is only necessary measuring the time necessary to reach the uniformity condition of the electromagnetic field during the wall´s vibration, not counting the number of step positions for the rotating stirrer.

Reliable statistical observation of (1) as a function of the dwell time size, have been obtained by repeated (250 times) calculations over dataset of the same size. Since we are only interested in the LUF position, the investigation is conducted at 400 MHz and 500 MHz (Figs. 6 and 7).

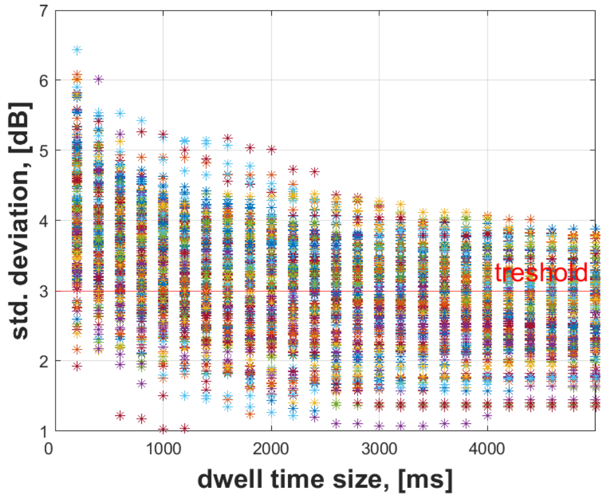
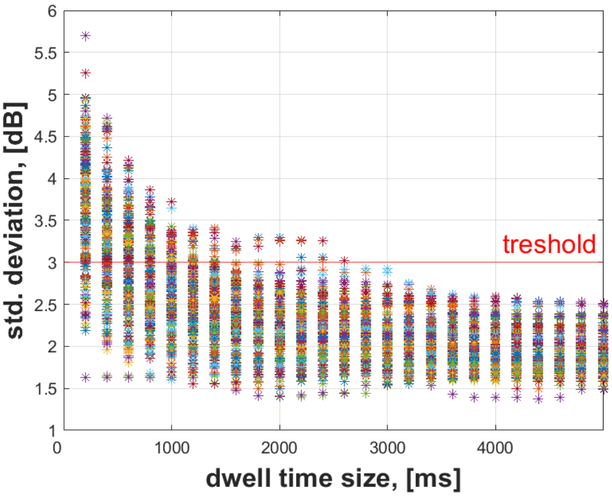


Fig 6. Estimations of (1) at 400 MHz. In the plot are indicated the results of 250 empirical, independent observations for each dwell time size.



(b)

Fig 7. Estimations of (1) at 500 MHz. In the plot are indicated the results of 250 empirical, independent observations for each dwell time size.

At 400 MHz, several estimates of (1) remain above 3 dB. Moreover, the Fig. 6 shows that the field is quasi-static in the sense that, after some time, the size of the dwell time does not improve the value of (1) further. This means that the boundary conditions imposed to the cavity field through the vibrations of the flexible surface do not change effectively the electromagnetic field distribution. On the contrary, at 500 MHz, we are allowed to use a minimum dwell time of 2.8 s (Fig. 7). The same analysis reported in Figs. 6 and 7 is repeated for four frequencies close to 500 MHz (Table II). One can observe that the number of samples rapidly decreases from 495 MHz to 505 MHz. This follow the fact that the number of active modes in a cavity is not uniformly distributed and large deviation can be expected [1].

TABLE II. MIN. DWELL TIME AND NUMBER OF SAMPLES FOR ACHIEVING THE FIELD HOMOGENEITY

Frequency [MHz]	***Min. dwell time [ms]***	***Min. number of independent samples***
495	4600	38
500	2800	23
505	600	5
510	800	7

VI DISCUSSION OF THE RESULTS AND CONCLUSIONS

The shortest temporal interval, necessary for making the stirring of the electromagnetic field in a VIRC effective, has been investigated through simulations and measurements. It has been shown that a MC simulation can predict very well the 95% CI of (1) as a function of the dataset size used for its calculation. However, this holds only in the upper part of the usable frequency range, where the statistical distributions are generated in conditions close to the ideal ones. At relative low frequencies (low modal density), the indication of a minimum number of independent samples could lead to large errors and useless extensions of the test time. For example, we have observed through empirical test that only five samples (not 50, as suggested by the reference standard) make the uniformity of the electromagnetic field good at 500 MHz.

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