Analysis and improvement of reverberation chamber method for characterization of small and terminal antennas

Analysis and Improvement of Reverberation Chamber Method for Characterization of Small and Terminal Antennas

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***Abstract*— In this paper the uncertainty of reverberation chamber measurements is determined by a procedure proposed for a possible CTIA standard. The different contributions to the measurement uncertainty are analyzed. By improving the mode stirring based on this knowledge, it was possible to reduce the standard deviation of the measurements from about 0.5 dB to 0.3 dB for frequencies above 600 MHz.**

Keywords - accuracy; measurement uncertainty; reverberation chamber; standard deviation; validation procedure;

I. Introduction

A reverberation chamber (RC) is a metal cavity with electromagnetic reflective walls. By injecting an electromagnetic field in the chamber, and by stirring that field, the chamber can be used to generate a 3-dimensional Rayleigh fading environment [1] with an exponential decaying power delay profile. The signal received by a device placed in the chamber is similar to the faded signal received by the end-user equipment in a real multipath propagation environment, like urban and indoor environments [2]. In contrast to the real world, the chamber will be a repeatable facility. Because of these favourable properties, the reverberation chamber has become an established tool for analysis and characterization of various antenna parameters, such as radiation efficiency, impedance mismatch, diversity gain, MIMO antenna capacity, total radiated power (TRP), and total isotropic sensitivity (TIS). The measurement setups for measuring these parameters are well described in previous publications [3-6].

As the RC becomes more and more popular for over the air (OTA) measurements of wireless devices [3], [6]-[7], it is of interest to quantify and improve the accuracy of the measurements. According to [8], the typical figure of merit for the measurement uncertainty is the standard deviation (STD). A simple method for determining the standard deviation in a reverberation chamber is proposed in [9]. Some studies of measurement uncertainty using this method was reported in [10] together with a new improved uncertainty model. The conclusion was that the direct coupling is a source of error.

In this contribution, the system validation procedure is described in detail, together with examples of how to optimize the mode-stirrer configuration of a reverberation chamber. The paper will show the reduction of uncertainty obtained by mechanical improvements of a traditional reverberation chamber configuration in terms of stirrer size and introduction of a shielding plate. The chamber used in this study is shown in Fig. 1.

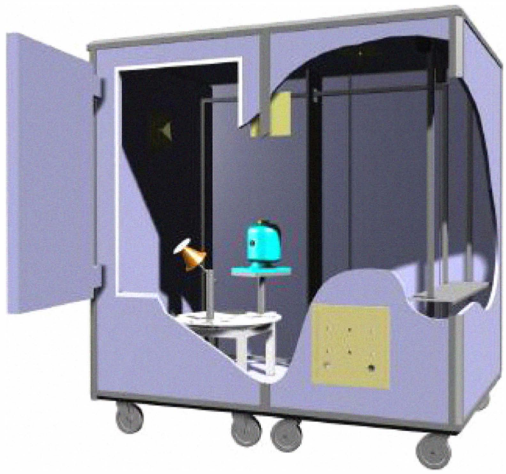

Fig. 1 The Bluetest reverberation chamber used in the measurements. The cavity size is 1.75m x 1.8m x 1.2m.

II. Measurements in a Reverberation Chamber

The traditional RC used in the present paper has a cavity size of 1.75m x 1.8m x 1.2m. It is equipped with two metallic plates that move along the chamber walls, continuously or in a stepwise manner. The plates stir the electromagnetic field by changing the boundary conditions in the chamber. By stirring the field a different distribution of complex values of the chamber transfer function (1_{11}) is achieved for every position of the plates. The distribution in every point in the chamber, as well as the distribution throughout the chamber, will be Gaussian, which means that the amplitude values at every point in the chamber will have a Rayleigh distribution. Thus, a DUT placed in one position in the chamber will experience a Rayleigh faded signal.

The chamber is further equipped with a turntable, on which the DUT is placed. This table is rotating during the measurement. In addition, the chamber is equipped with three transmitting antennas, mounted on the walls orthogonally to each other.

A. Reference Measurement

For all RC measurements it is essential to know the loss of signal power between the test equipment (vector network analyser or base station simulator) and the DUT. This path loss is found from a reference measurement, where the chamber transfer function is measured with a reference antenna with known efficiency.

The reference measurement is performed by transmitting a signal from a vector network analyser (VNA), which is received by the reference antenna. The reference antenna is further connected to the VNA, which samples the received signal for different stirrer positions. The samples of the received complex filed are then used to calculate the chamber transfer function according to the following equation.

$$G_{ref}^{ant_i} = \frac{\overline{\left|S_{21}^{ant_i}\right|^2}}{\left(1-\left|\overline{S_{11}^{ant_i}}\right|^2\right)\left(1-\left|\overline{S_{22}}\right|^2\right)\cdot e_{rad,ref}} \tag{1}$$

where ı ııı ııı is the corrected transfer function for the *i*:th transmitting antenna, ı ııı ıı the transfer function for the *i*:th transmitting antenna, ı ııı ıı the reflection coefficient for the *i*:th transmitting antenna, ı ıı the reflection coefficient for the reference antenna and ı ııı ,ııı is the radiation efficiency (internal losses only, reflection loss excluded) of the reference antenna. The mean is taken over the samples collected at the different stirrer and turntable positions. The total chamber transfer function is then calculated as

$$G_{ref} = \frac{1}{N}\sum_{i=1}^{N} G_{ref}^{ant_i} \tag{2}$$

where N is the total number of transmitting antennas. The reference measurement setup is given in Fig. 2. Important to note is that the VNA must be calibrated in order to remove the cable losses. The VNA calibration points are given in Fig. 2.

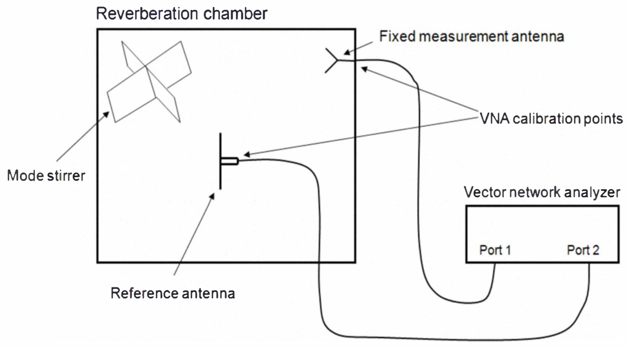

Fig. 2 The measurements setup for the reference measurement.

III. Contributions to the Measurement Uncertainty

The uncertainty of parameter estimations from Gaussian distributed complex values will be dependent on the number of independent samples collected during the measurement [11]. A requirement for ensuring high accuracy is to collect a large number of samples during the measurement. The possibility to generate a large amount of independent samples is thus an important characteristic of a reverberation chamber. However, a large number of samples will not ensure independent samples.

There are a number of things affecting the independence of the samples collected during a measurement sequence in the RC. The samples need to be uncorrelated, that is the received signal must be unique for every sample position. This is achieved by changing the environment in the chamber, i.e. by stirring the field, or by moving the DUT around in the chamber. It is reasonable to assume that the more the environment is instantaneously changed, the more the received signal will change. This means that the larger the stirred volume, the more independent samples can be collected. This reasoning is supported by the theory presented in [12], where the number of independent samples is said to increase with increased stirred volume.

Another contribution to the number of independent samples is the amount of unstirred field relative to the stirred field. The unstirred field consist of the line of sight (LOS) component between the transmitting and receiving antennas, as well as wall reflections that have not interacted with the stirrers. A measure of the unstirred component relative to the stirred component is the K-factor. It is calculated from reverberation chamber data as [13]

$$K = \frac{\left|\langle S_{21}\rangle\right|^2}{\left\langle \left|S_{21} - \langle S_{21}\rangle\right|^2\right\rangle} \tag{3}$$

where ı ıı is the transfer function for one combination of transmitting antenna and turntable position. Equation 3 is basically the ratio between the unstirred and the stirred component.

In [14] a simple model describing the relationship between the K-factor and the STD ∑ of the mean chamber transfer function is proposed. This relationship is given by the following equation

$$\Sigma = \sqrt{\frac{\frac{1}{N_{stirred}} + K^2\frac{1}{N_{unstirred}}}{1+K^2}} \tag{4}$$

where ı ıııııı is the number of stirrer positions and ı ıııııııı is the number of turntable positions times the number of transmitting antennas. According to equation 4, the STD will be low when the K-factor is small. This means that the accuracy increases when there is a small unstirred component relative to the stirred component in the received field. This is reasonable, since the more of an unstirred component that is present, the more similar the collected samples. It can be compared to the extreme case with only an unstirred component, which makes all the samples identical.

IV. Standardized Procedure for Determine the Reverberation Chamber Measurement Accuracy

The procedure for determination of the accuracy in a reverberation chamber is given in [8] and is based on measuring the average chamber transfer function (equation 2) for nine different receiver antenna locations and orientations (see Fig. 3). The standard deviation of the transfer function measured at these nine positions is then calculated, using the mean over the nine positions as a reference. This reference value is given as

$$G_{ref}^{mean} = \frac{1}{M}\sum_{j=1}^{M} G_{ref}^{j} \tag{5}$$

where G_{ref}^{j} is the transfer function for the j:th receiving antenna position and M is the total number of receiving antenna positions. The variance of the transfer function is then given as

$$\sigma^2 = \frac{1}{M}\sum_{j=1}^{M}(G_j - G_{ref}^{mean})^2 \tag{6}$$

and the normalized STD as

$$\Sigma_{measured} = \frac{\sqrt{\sigma^2}}{G_{ref}^{mean}} \tag{7}$$

In this paper the normalized STD is translated to a corresponding decibel value using the following equation.

$$\Sigma_{measured}^{dB} = 5\log\frac{1+\Sigma_{measured}}{1-\Sigma_{measured}} \tag{8}$$

The STD calculated from equation 7 will give a measure of how much the orientation of the DUT affects the measurement result. In [9] and [10] it is proposed that the relative STD should be 0.5 dB or better in a well stirred RC without any load.

Fig. 3 The three different orientations (horizontal, 45 degree and vertical) of the receiver antenna used for the system validation procedure. These orientations are repeated for three different heights over the turntable, 30, 38 and 46 cm, giving a total of nine different receiving antenna positions.

V. Accuracy of Reverberation Chamber Measurements

The RC is equipped with metallic plates, a turntable and three transmitting antennas in order to mitigate the contributions to the measurement uncertainties described in section III and thus increase the accuracy of the measurements. The plates enable a Rayleigh distribution of amplitude values and independent samples in every position in the chamber and the turntable is introduced in order to sample the field at independent positions and to average out the unstirred component [15]. The three orthogonal transmitting antennas will further create polarization balance of the electromagnetic field [16]. All of these modifications will make the measurements less independent of the orientation of the DUT and thus decrease the STD of the mean chamber transfer function.

In order to verify that the accuracy is acceptable with the stirring configuration described above, the system validation procedure described in section IV was applied to the RC. The results from this measurement can be studied in Fig. 4. This figure shows the STD for the frequency interval 0.6 – 1.2 GHz. The STD is seen to have statistical fluctuations around a mean value of 0.5 dB at 650 MHz and about 0.3 dB at 1.2 GHz. It has been verified that for higher frequencies the STD is also about 0.3 dB. For the specified operating frequency range, 0.7 – 6 GHz, the mean STD is within the proposed limit.

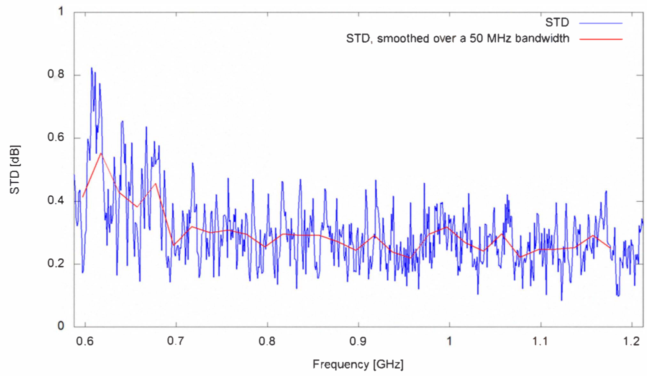

Fig. 4 The STD calculated for 9 receiver antenna positions for a traditional reverberation chamber. The red curve shows the STD smoothed over a 50 MHz bandwidth.

VI. Improved Accuracy of Reverberation Chamber Measurements

So far it has been shown that the mean STD of traditional RC measurements is below the proposed limits for the operating frequencies of the chamber. However, at the lower frequencies there are statistical fluctuations above 0.5 dB. Using the knowledge in section III, the traditional reverberation chamber was modified in order to improve the accuracy even further.

The first modification of the chamber addresses the stirred volume and the premise that the number of independent samples increases if the stirred volume increases. Thus, the size of the metallic plates was increased. This will have largest impact for the lower frequencies. The stirred volume in the traditional chamber is 13.8 % of the total chamber volume, whereas the chamber with improved stirring configuration has a stirred volume of 22.4 % of the total chamber volume.

The second modification addresses the premise that the K-factor affects the accuracy of the measurements. In order to decrease this parameter further, the transmitting antennas were placed behind a shielding plate, which completely removes the LOS signal between the transmitting and the receiving antenna.

The system validation procedure was repeated for the reverberation chamber with the improved stirring configuration. The result can be studied in Fig. 5. This figure shows that the mean STD has been decreased to 0.2 – 0.3 dB for the entire frequency range of interest. It is also seen that the statistical fluctuations are decreased and there are no peaks above 0.5 dB. For the specified operating frequency range of this chamber, 0.65 – 6 GHz, the mean STD, as well as the statistical fluctuations, are thus seen to be well within the proposed limit (the chamber is even seen to have high accuracy at 0.6 GHz). Hence, the stirrer size is seen to be significant for the stirring efficiency, just as the effect of decreasing the direct coupling between the transmitting antennas and the receiving antenna.

In table I a comparison of the STD between the traditional RC and the RC with the improved stirring configuration can be studied. The maximum STD in a given frequency interval is also given in Table II. These tables show clearly the improvement of the measurement accuracy.

Concerning the STD at the higher frequencies, the limiting factor is the number of samples collected. The STD can be decreased even further by increasing the number of samples. An STD of 0.1 dB has been achieved for the higher frequencies in the chamber with the improved stirring sequence. However, the increase in measurements time is not motivated by the small increase in accuracy.

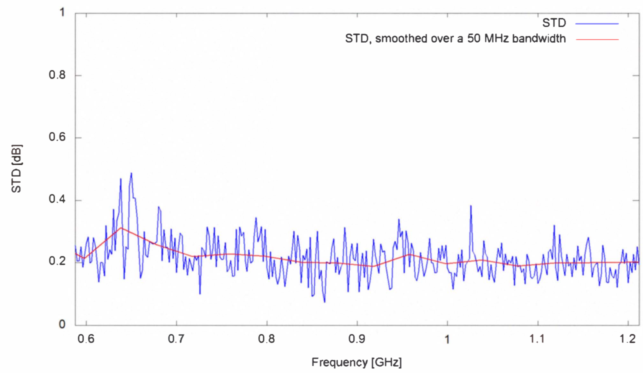

Fig. 5 The STD calculated for 9 receiver antenna positions for a reverberation chamber with improved stirring configuration. The red curve shows the STD smoothed over a 50 MHz bandwidth.

TABLE I
Comparison of the maximum mean standard deviation in different frequency intervals between a traditional reverberation chamber and a reverberation chamber with improved stirring configuration.

Frequency interval [GHz]	**STD, traditional chamber [dB]**	**STD, chamber with improved stirring configuration [dB]**
0.6 – 0.7	0.55	0.31
0.7 – 1.0	0.35	0.25
1.2 – 6.0	0.30	0.20

TABLE II
Comparison of the maximum standard deviation in different frequency intervals between a traditional reverberation chamber and a reverberation chamber with improved stirring configuration.

Frequency interval [GHz]	**STD, traditional chamber [dB]**	**STD, chamber with improved stirring configuration [dB]**
0.6 – 0.7	0.82	0.49
0.7 – 1.2	0.55	0.38

VII. CONCLUSIONS

In this paper different contributions to the measurement uncertainty in reverberation chamber measurements have been analyzed. This knowledge has been used to improve the stirring configuration in the chamber, which has been shown to increase the accuracy of the measurements. The largest improvement is achieved for the lower frequencies around 600 - 700 MHz, where a standard deviation of 0.3 dB has been measured. For higher frequencies a standard deviation of 0.2 dB is achieved. The latter value can be improved further by increasing the number of samples collected, but this will also increase the measurement time.

Furthermore, the system validation procedure for evaluation of the reverberation chamber measurement accuracy has been described in detailed. This procedure is based on finding the standard deviation of the mean chamber transfer function for different positions of the receiving antenna.

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