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9th European Conference on Antennas and Propagation, EuCAP 2015, Lisbon, Portugal, 13-17 May 2015

Citation for the published paper:
Schilliger Kildal, M. ; Chen, X. ; Kildal, P. et al. (2015) "Investigation of mode stirring with plate on platform in a reverberation chamber". 9th European Conference on Antennas and Propagation, EuCAP 2015, Lisbon, Portugal, 13-17 May 2015

(article starts on next page)

Investigation of mode stirring with plate on platform in a reverberation chamber

Madeleine Schilliger Kildal[1], Xiaoming Chen[2], Per-Simon Kildal[3], Jan Carlsson[4]

[1]Bluetest AB, Gothenburg, Sweden (industrial PhD student at Chalmers University of Technology)
[2]Qamcom Research & Technology, Gothenburg, Sweden
[3]Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden
[4]Electronics department, SP Technical Research Institute of Sweden, Boras, Sweden

***Abstract*—The accuracy of the reverberation chamber has been investigated when mode stirring is performed with a plate placed on a rotatable platform, i.e., plate-on-platform stirring. The accuracy and scanning volume of the platform plate are then compared to the original mode stirring plates that are moving alongside two walls. The results are also compared to physical theoretical models. The mode stirring with a plate on the platform provides STD of the measurements that are a factor 2 worse than with the original plate and platform stirring of the chamber. Still, this is good enough for accurate measurements above 2 GHz, provided the AUT is also located on the platform.**

***Index Terms*—reverberation chamber, mode stirring, platform.**

I. INTRODUCTION

The reverberation chamber (RC) has been used for more than 10 years to test small multi-port antennas [1] and active wireless devices [2]. The RC exhibits a Rayleigh fading environment [3], which is created through mode stirring. The calibration is done by measuring the average power transfer function. This is according to Hill's transmission formula proportional to the radiation efficiencies of the transmitting and receiving antennas, see [4] and [5, Eq. (6)]. The mode stirring presented in [1] and [5] are done in three ways; two plate stirrers moving along two of the chamber walls (referred to as original plate mode stirring), polarization stirring by the use of three orthogonal chamber antennas, and platform stirring. The platform stirring was introduced in [6]. It is based on a movement of the antenna under test (AUT), by mounting it on a rotating platform. This platform stirring improves actually the standard deviation (STD) by two physical processes that are different from the normal mode stirring used in EMC RCs. We can generally call them position stirring (introduced in [7]) and K-factor randomization (according to the accuracy models in [5]). Above, we have mentioned four different physical stirring processes. These processes and how they are related to their practical implementation are summarized in row 1, 2, and 3 in Table I.

Reference [5] presented a model for the STD of the measured average power transfer function. The model is based on an estimation of the average Rician K-factor due to direct coupling between the transmitting and receiving antenna, or any other unstirred component. The STD model was validated by using 9 wideband measurements of the average power transfer function, with the calibration antenna in 9 different positions and orientations, respectively, referred to here as the 9-measurement method.

It is natural that the accuracy of a RC must relate to the number of excited modes during a stirring sequence. Further this must be equal to the mode density times a bandwidth. Therefore, we presented in [5] the following physical equation for the maximum number of independent samples, $N_{\rm ind}$, due to mode stirring:

$$N_{\rm ind} = 8\frac{dN}{df}(B_{\rm mech} + \Delta f) = 8\frac{8\pi V f^2}{c^3}(B_{\rm mech} + \Delta f)\ . \quad (1)$$

Here, the mode density, dN/df is obtained by differentiation of the classical Weyl's formula for the cumulative number of modes inside a cavity of volume, V. The reason for the factor 8 is that there are 8 times more plane waves than modes in the chamber [5]. Δf in the formula is the average mode bandwidth. This is included, because with stationary stirrers we can only excite the modes for which the frequency of operation appears within their resonance bandwidths. In addition, it is reasonable to believe that when the mechanical mode stirrers move, the resonance frequencies of the cavity modes will change, so that the number of excited modes during a complete stirring sequence will increase. This effect is included in (1) by means of a mechanical stirring bandwidth $B_{\rm mech}$. Thus, $B_{\rm mech}$ is an equivalent bandwidth that describes the quality of mechanical mode stirrers.

Reference [8] derives some relations for the number of "coherence cells" traversed by mechanical mode stirrers, and of the complete chamber volume. The latter is used to introduce an equation for the number of excited modes in the chamber at at given frequency. This is equal to the mode density times the average mode bandwidth, corresponding to Eq. (1) with $B_{\rm mech} = 0$. However, [8] does not show how the "coherence cell" quantities can be used to find neither the number of independent samples nor the STD.

The plate-on-platform mode stirring introduced in the present paper is a type of mode stirring, where a large metal plate is placed on the rotatable platform. It is therefore NOT like the original platform stirring in [6] representing only a movement of the AUT and no mode stirring, see Table I. If the AUT is located on the floor we will only get mode stirring,

TABLE I
DESCRIPTION OF DIFFERENT PHYSICAL STIRRING APPROACHES IN REVERBERATION CHAMBERS AND THEIR PRACTICAL IMPLEMENTATION.

	Description of implemented practical stirring methods	Physical stirring process: Mode stirring	Polarization stirring	Position stirring	K-factor randomization
1	Moving or rotating mechanical stirrers like plates, fans or other objects	Yes	No	No	No (unless stirrers block LOS)
2	Platform stirring (the AUT is located on a rotatable platform)	Almost none	Can be if antenna is located in the center	Yes in 2D	Yes in 2D
3	Switching between fixed chamber antennas	No, not really but it may appear as such. The excited modes are different	Yes, with collocated orthogonal chamber antennas	No	Yes
4	"Plate-on-platform" mode stirring, with AUT on platform	Yes	No	Yes	To some degree
5	"Plate-on-platform" mode stirring, with AUT on floor	Yes	No	No	No

whereas if it is located on the platform together with the plate, the platform will in addition randomize the Rician K-factor, in the same way as the original platform stirring. The goal of this work is to find out if we can achieve the same accuracy with this plate-on-platform mode stirring, as with the original plate mode stirring in the same chamber. We also want to see if any of the available theoretical models can predict the experimental results, or be extended to predict them.

II. EXPERIMENTAL DATA

The accuracy of the RC is obtained by using the 9-measurement method and calculating the STD of the chamber transfer function, like in [5]. The Bluetest RTS60 RC, with the dimensions $1.8\,\mathrm{m} \times 1.7\,\mathrm{m} \times 1.2\,\mathrm{m}$, is used for the measurements. The measurements are performed in the frequency range $f = 0.5 - 3\,\mathrm{GHz}$, where the measurements are performed with a frequency step of 2 MHz. The AUT used is a disk-cone antenna, see Fig. 1. Frequency smoothing with a $50\,\mathrm{MHz}$ window is performed on the STD values, before converting them to dB through [5, Eq. (19)].

Three sets of measurements are performed. Two with the AUT fixture located on the floor of the chamber, where one measurement set is done with an unfolded metal plate and one with a folded metal plate (with a fold angle of $9°$) positioned on the rotatable platform. The third measurement set is done with the AUT located on the platform together with the folded metal plate, see Fig. 1. Each measured with the 9-measurement method. The mode stirring was performed in a stepwise manner with 1000 platform positions. The STD calculated for the three sets of measurements can be seen in Fig. 2a.

We see in Fig. 2a that the STD for the unfolded plate is better than for the folded plate. We can try to explain this by the shape and scanning volume of the mode stirrers. Table II shows the dimensions for the different stirrers. The stirring volumes of the folded plate and the unfolded plate are almost identical, but the results in Fig. 2a are different for the two

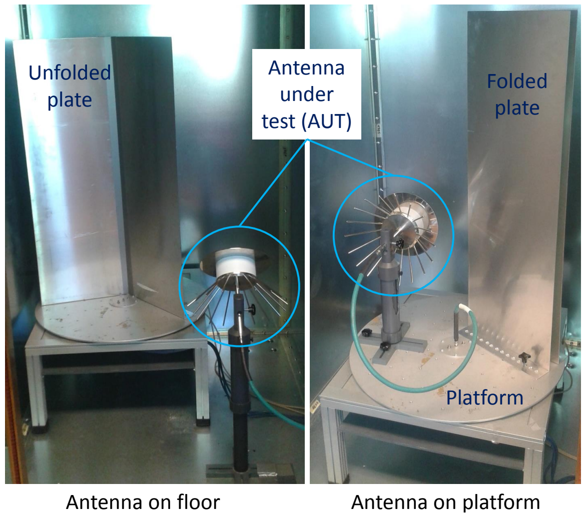
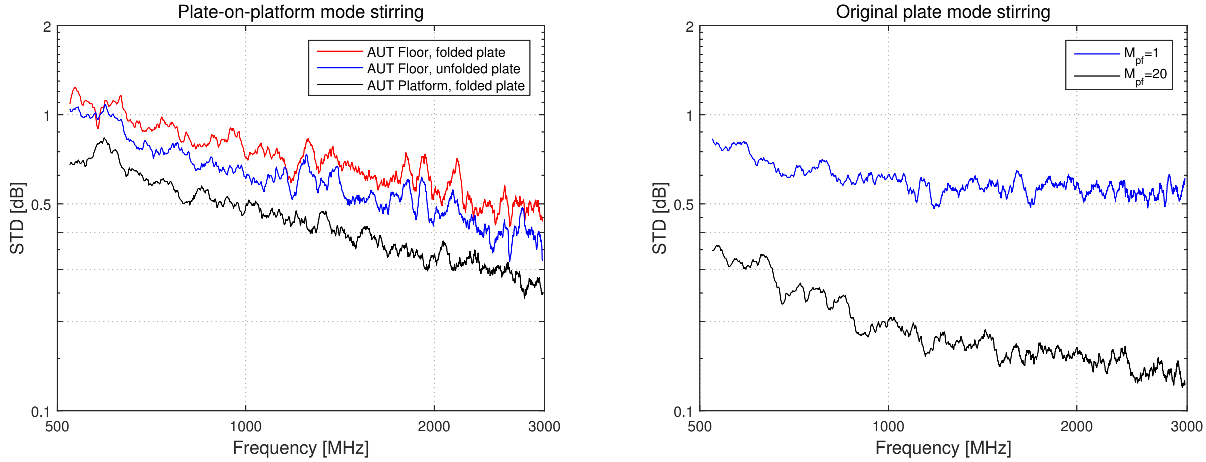


Fig. 1. Measurement setup in the RC. The picture on the left shows the AUT on the floor with the unfolded plate on the platform. The right picture shows the AUT placed on the platform together with the folded plate.

cases. This indicates that the relationship between different quality of stirrers is not the scanning volume itself.

The STD becomes better when the AUT is placed on the platform, see the black curve in Fig. 2a. This is due to some randomization of the direct coupling (the Rician K-factor) between the AUT and the chamber antennas (or of another unstirred contribution), as noted in Table I. The STD is good for $f > 1\,\mathrm{GHz}$, with an STD of below $0.5\,\mathrm{dB}$. This is a very good result taken into account that the scanning volume relative to the total chamber volume is only $6\,\%$, see Table II. The original plate mode stirrers had in comparison a relative scan volume of $23\,\%$, which is four times larger.

The blue and black curves in Fig. 2a are comparable to the blue curve in Fig. 2b (that comes from [5]), which show the STD with the original plate mode stirrers (25 positions) and no platform stirring. The black curve in Fig. 2b shows the best obtained STD with both the original plate mode stirring (25



(a) (b)

Fig. 2. STD comparison for (a) plate-on-platform mode stirring and (b) original plate mode stirring. The curves representing the original plate mode stirring are shown with different number of platform positions, M_{pf}. The results shown in (b) is taken from [5].

TABLE II
DIMENSIONS FOR MODE STIRRERS.

	Original plate stirrer		Plate on platform	
	Roof	Wall	Folded	Unfolded
Plate width/radius [m]	0.97	0.88	0.28	0.28
Plate depth [m]	0.40	0.30	-	-
Plate height [m]	0.37	0.05	0.90	0.90
Scan length	1.25 m	1.45 m	341°	360°
Scan volume [m^3]	0.44	0.38	0.21	0.22
Total scan volume [m^3]	0.83		0.21	0.22
Relative scan volume [%]	23		6	6

positions) and platform stirring (20 positions). Here we see an improvement of the STD with a factor 2 or more, when the platform stirring is added.

We use in the present work 1000 platform positions. All these do not give rise to independent samples. By reducing the number of platform positions, M_{pf}, we will see when the STD starts increasing. The increase of the STD means that there is a reduction of the number of independent samples, see Section III. In the case with the AUT located on the platform, there will also be a decrease of the STD due to the randomization of the Rician K-factor. This means that it is expected that the reduction of M_{pf} has a greater effect in Fig. 3b (belonging to the AUT on the platform), than in Fig. 3a (belonging to the antenna on the floor). We see a clear effect on the STD curves for the higher frequencies when the number of platform positions is reduced to 50 and lower.

III. COMPARISON WITH PHYSICAL MODELS

According to [3] the theoretical STD is given by

$$\sigma = \frac{1}{\sqrt{N_{\mathrm{ind}}}} , \qquad (2)$$

where N_{ind} is the number of independent samples, which we assume can be described by (1). The condition for (2) is that there is no unstirred component, i.e., the Rician K-factor is zero.

The theoretical model introduced in [5, Eq. (18)] contains also the contribution to the accuracy from a stochastic Rician K-factor during the measurements. This is characterized by an average K-factor, and we refer therefore to the whole model as an average K-factor model. The STD according to this is

$$\sigma = \frac{\sqrt{(\sigma_{\mathrm{NLOS}})^2 + K_{\mathrm{av}}^2(\sigma_{\mathrm{LOS}})^2}}{\sqrt{1+K_{\mathrm{av}}^2}} , \qquad (3)$$

with σ_{LOS} the STD for the unstirred (referred to as a line-of-sight (LOS) component), and σ_{NLOS} the STD for the stirred non-line-of-sight (NLOS) component.

We have used the K-factor measured in [5] for an unloaded chamber to determine the STD when the AUT is located on the floor. Then, the K-factor is not reduced by any randomization, so $\sigma_{\mathrm{LOS}} = 1$, which makes the K-factor term in (3) dominant. We see that the theoretical STD curves in Fig. 4a have the right shape, but they predict a factor 2 worse STD than we have in reality.

When the AUT is located on the platform, we have a large effect of the K-factor randomization. Therefore we will try to see if we can model everything by only using (1)-(2). We achieve the average mode bandwidth from the measured average power transfer function by using Hill's transmission formula (see [4] and [5]), as explained in [9, Eq. (2)]. We do not have any theoretical expression for B_{mech} yet. Therefore, we simply try some different values to see if the model looks reasonable. The results are presented as the dotted lines in Fig. 4b.

The best result is achieved when B_{mech} is between 0 and 1 MHz. The slope of the curves are quite good, but it indicates that B_{mech} is slightly frequency dependent and smaller for higher frequencies.

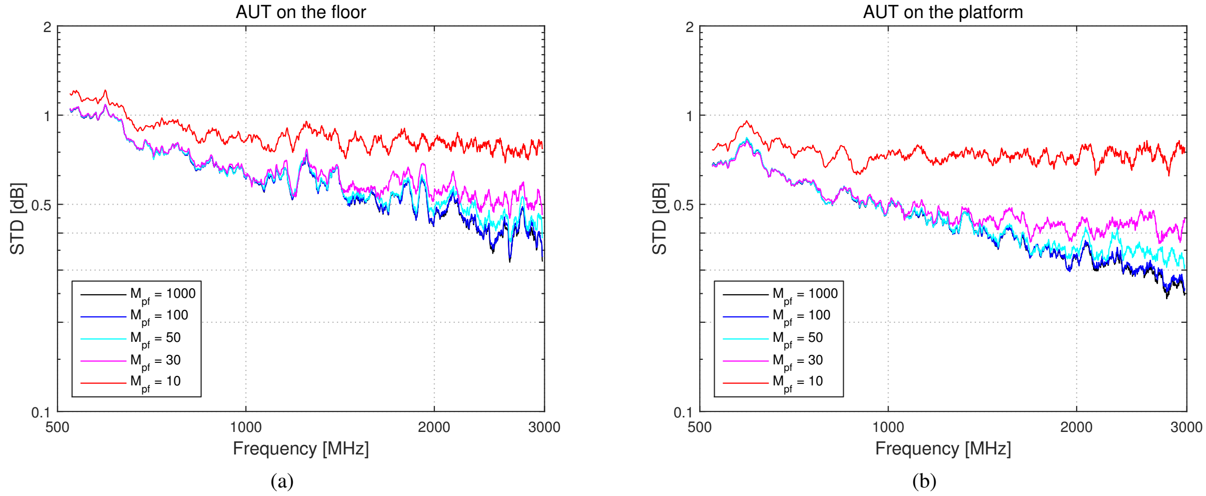


Fig. 3. STD for plate-on-platform mode stirring with different number of platform positions, M_{pf}. The data comes from the case with; (a) the AUT on the floor and an unfolded plate on the platform, (b) the AUT on the platform together with a folded plate.

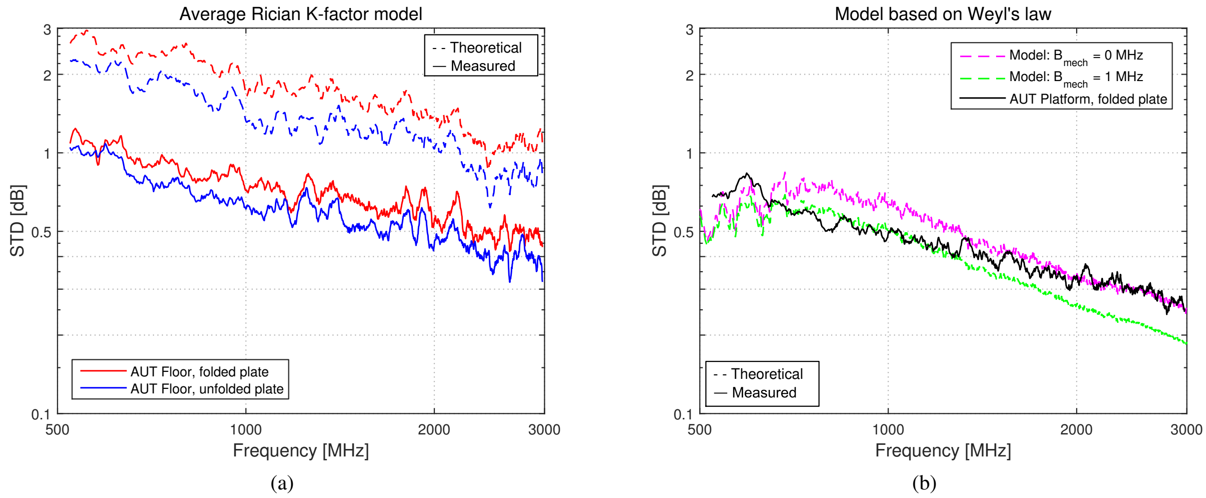


Fig. 4. Comparison between the measured STD (plate-on-platform mode stirring) and physical models. The dashed and solid curves are the theoretical and measured curves, respectively. (a) The theoretical values comes from using Eq. (3). (b) The theoretical values comes from Eq. (1), with different values of B_{mech}.

IV. Conclusions

It is possible to get fairly good accuracy by using plate-on-platform mode stirring, although it is worse by a factor 2 relative to the original plate mode stirring in the same chamber, for the chosen plate-on-platform size. This factor 2 could be caused by the scan volume of the original plates being 4 times larger than of the plate on the platform, see Table II, so the accuracy should improve with larger plate sizes. Still, satisfactory accuracy is achieved above $2.5\,\mathrm{GHz}$ with STD better than $0.3\,\mathrm{dB}$.

The investigated physical models do not explain the measurement results satisfactorily. A new model is needed, where the B_{mech}-model should be a good starting point. Different sizes of the plate on the platform should be tried out, to get a connection between B_{mech} and the shape or scanned volume of the stirrers.

Acknowledgment

This work has been partly supported by the Swedish Research Council over the industrial PhD project D0571801.

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