Statistical estimation of antenna gain from measurements carried out in a mode-stirred reverberation chamber

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Abstract

This paper proposes for the first time a method for estimating the gain of an antenna in a mode-stirred reverberation chamber. The method is based on the estimation of the Ricean K-factor which provides the relative transmitting power level of the line-of-sight path. Experimental results are compared with anechoic chamber measurements using a set of different antennas.

1   Introduction

Reverberation chambers (RC) have been studying for many years for electromagnetic compatibility (EMC) purposes, and they are now widely used for immunity and emissivity tests [1]. In the last decade, many other research activities have been performed to extend the use of RC for other topics *e.g.* antenna efficiency measurement [2], diversity gain [3], or to simulate a controllable Rician radio environment for testing wireless devices [4]. The detection of the directivity of an equipment under test (EUT) is more complex since directivity has usually no influence any more in RC [5]. With regards to real illumination conditions, in RC we need to take into account the bias due to the absence of the impact of directivity in the susceptibility level evaluation [1]. Up to now, we have not found any method for evaluating the directivity of an EUT directly in RC on an experimental basis. Usually we evaluate directivity in an anechoic chamber or using simplified analytical models [1, 6]. Here we propose a first method for estimating the gain of an antenna directly from RC measurements. With the knowledge of radiation efficiency [2], then we can have access to directivity. Section 2 is devoted to the analytical formulation of an appropriate gain estimator in RC and section 3 presents significant experimental results.

2   Evaluating gain from K-factor estimation

For a multi-path electromagnetic environment, we define the Ricean K-factor as the ratio of the coherent component over the scattered component of a transmitted signal [7]. Here we are mainly interested in the evaluation of the coherent component since it is related to gain in the case of a line-of-sight transmission between a transmitter and a receiver (see Friis' formula in [8]). A rough estimation of the Ricean K-factor from S-parameters measurements in RC have been proposed in [4], and has recently been improved in [9] as follows:

$$\langle \widehat{K} \rangle_{\Delta f} = \frac{N-2}{N-1} \left\langle \frac{|S_{21}^{\mathrm{dir}}|^2}{\langle |S_{21}^{\mathrm{sti}}|^2 \rangle} \right\rangle_{\Delta f} - \frac{1}{N} \quad , \tag{1}$$

with N the number of independent stirrer positions, S_{21}^{dir} and S_{21}^{sti} denoting respectively the unstirred and the stirred components of the transmitting S-parameter, $\langle \cdot \rangle$ and $\langle \cdot \rangle_{\Delta f}$ meaning the arithmetic average over respectively the mechanical stirring process and the electronic stirring process in a small Δf bandwidth [9]. This estimator has no significant bias and is well controlled as shown by the small width of the 95% confidence interval (CI) in Fig. 1.

Using [10], we can formulate an estimate for the gain of the antenna under test (AUT) in a small Δf

bandwidth, as a function of a reference antenna, as follows:

$$\widehat{G}_{\text{AUT}} = G_{\text{ref}} \times \frac{\left\langle \widehat{K}_{\text{AUT}} \right\rangle_{\Delta f}}{\left\langle \widehat{K}_{\text{ref}} \right\rangle_{\Delta f}} \times \frac{d_{\text{AUT}}^2}{d_{\text{ref}}^2}, \tag{2}$$

with "ref" and "AUT" referring respectively to the reference antenna and the AUT, d the distance between the transmitter (position 1) and the receiving antenna (position 2) in line-of-sight configuration (see Fig. 2). Next we perform measurements respecting $d_{\text{AUT}} = d_{\text{ref}}$ in order to simplify the analysis.
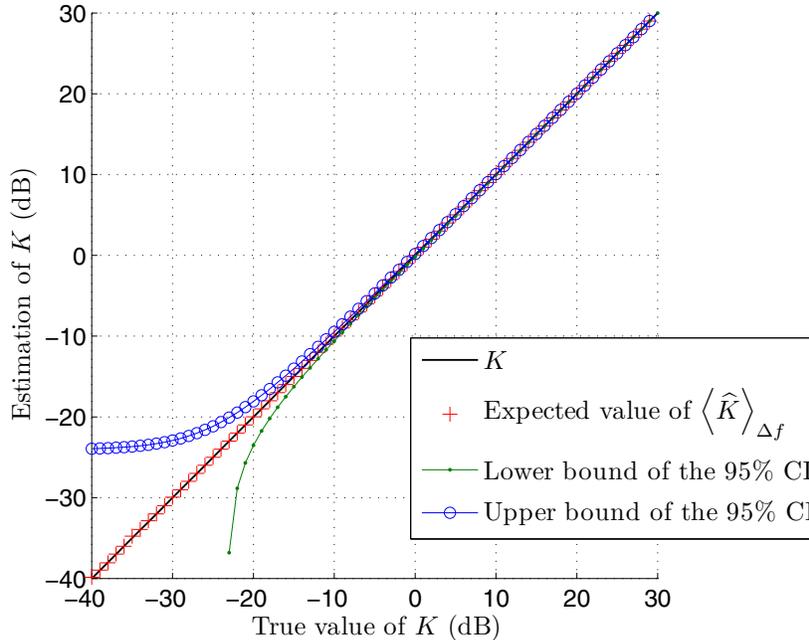

Figure 1: Expected value and 95% confidence interval associated with the estimation $\langle \widehat{K} \rangle_{\Delta f}$ using 50 independent stirrer positions and 100 independent frequencies in the small Δf bandwidth. This figure is the result of a Monte-Carlo simulation using 100 000 trials.

3   Experimental results

The experimental setup consists in two similar steps which differ only with the use of either the reference antenna or the AUT as the antenna located in position 1 in Fig. 2. The 1st step uses the reference antenna and leads to the estimation of $\left\langle \widehat{K}_{\text{ref}} \right\rangle_{\Delta f}$, whereas for the 2nd step we replace the reference antenna by the AUT leading to the estimation of $\left\langle \widehat{K}_{\text{AUT}} \right\rangle_{\Delta f}$, and therefore to the estimation of its gain (eq. 2). For both steps the power injected into the chamber remains constant. In order to validate the proposed method, we use several Yagi printed antennas as AUT which differ only with the number of directors (Fig. 3), thus changing the gain.

We performed measurements in the frequency range [2.5 GHz - 3.5 GHz], using a vector network analyzer with 5000 independent frequency points. We consider $\Delta f = 10$ MHz leading to an electronic stirring process with 50 independent frequency points. Moreover, we use 100 independent stirrer positions for the mechanical stirring process. Therefore, each K-factor is estimated using 5000 independent data leading to a significant statistical estimation of the gain. The experimental results are presented in Fig. 4, for three different distances d, and five different antennas under test. Moreover, a comparison with anechoic
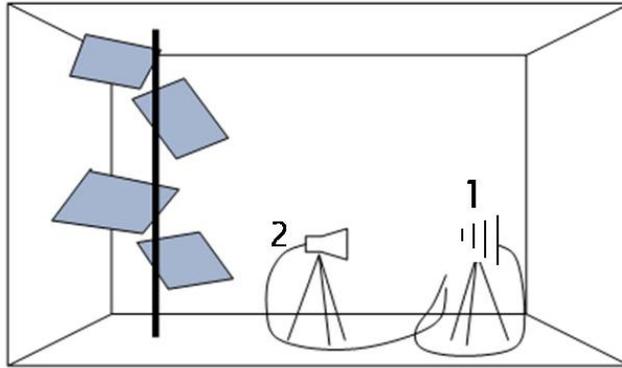
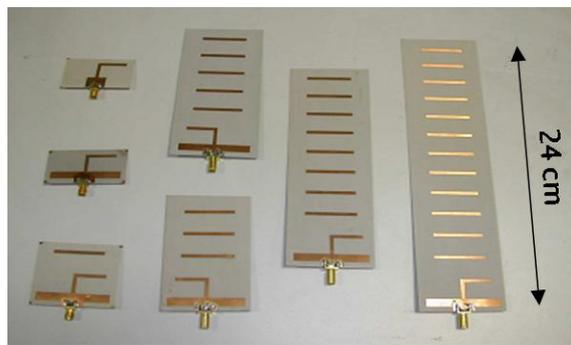Figure 2: Experimental configuration in the IETR reverberation chamber (2.9m × 3.7m × 8.7m).

Figure 3: Yagi printed antennas with variable gain.

chamber measurements and simulation results are provided. It is reasonable to say that using this method a reverberation chamber can provide a satisfying estimation of the gain of an AUT, especially for EMC testing for which we can accept more or less 3 dB of estimation uncertainty.
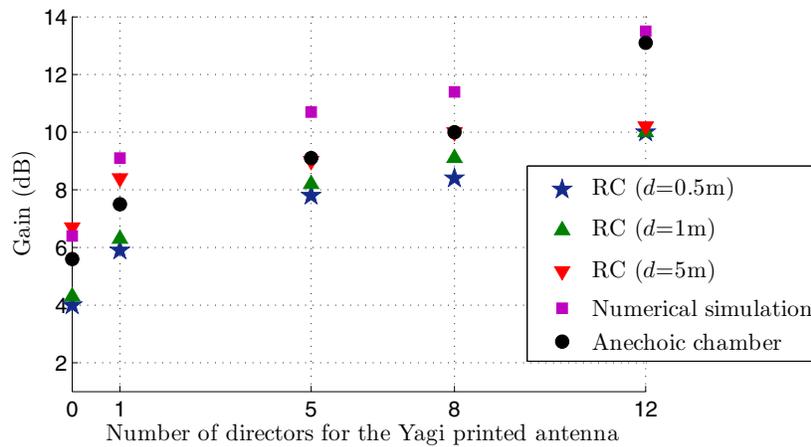

Figure 4: Experimental results of the estimation of antennas gain in RC, in comparison with anechoic chamber measurements and simulation results.

4   Conclusion

This paper proposes for the first time a method for estimating antenna gain in a mode-stirred reverberation chamber. The original method is based on the accurate estimation of the Ricean K-factor which provides the relative transmitting power level of the line-of-sight path. Although we used to consider that RC washes out the directivity [5], experimental results with a comparison with anechoic chamber measurements show that it is actually possible to have access to the gain of an antenna in RC. Using a third antenna in steps 1 and 2 of the proposed method, we can also estimate the AUT radiation efficiency [2], giving access to the directivity of the AUT. We will next focus our research activity on the directivity estimation of more complex systems than a single intentional emitter. The same method could be extended to large complex systems, locating the AUT inside the equipment under test with a control of the power injected into the chamber.

5   Aknowledgement

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