Reviews of Electromagnetics
Vision paper

A Vision on the Future of Reverberation Chamber Measurement Techniques

Anouk Hubrechsen* and Teun van den Biggelaar

Abstract
The increasing integration of antennas in electronic devices, combined with the adoption of advanced architectures such as phased arrays, has led to a substantial growth in over-the-air testing requirements. Reverberation chambers can take over a significant load of over-the-air testing, due to their potential to speed up testing with several orders of magnitude while maintaining a high accuracy. We envision that new measurement methods will enable even faster and more accurate measurements of existing test metrics, but also ones traditionally not performed in reverberation chambers such as antenna directivity or error vector magnitude. We present a vision on the future of reverberation chamber measurement techniques, highlighting some of the technological directions we believe to be most beneficial.

Key terms
Antenna Measurements; Over-the-Air Testing; Reverberation Chamber

Antennex B.V., Eindhoven, The Netherlands
***Corresponding author**: anouk.hubrechsen@antennex.tech

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1. A New Starting Point

Let us start with stating the obvious. Reverberation chambers (RCs) are inherently deterministic [1]. However, well-stirred RCs behave as chaotic systems [2]. That means that if mode-stirring is applied, the electromagnetic fields inside the RC are seemingly randomized, and we can start to observe the law of large numbers [3, 4]. This allows us to use stochastic methods for the evaluation of measurements critical to antenna performance such as antenna efficiency, total radiated or received power (TRP), adjacent channel leakage ratio (ACLR), and even noise figure [5, 6, 7]. Significant benefits are that no antenna alignment is necessary, no far-field conditions need to be adhered to (allowing for smaller form-factor chambers), and RCs are much faster in testing power-based metrics than anechoic chambers [8]. There have been many works and summaries describing these concepts and we are not about to give you another one.

Here, we would like to discuss where we can go next. Our vision is that all anechoic-chamber measurements are possible in a reverberation chamber. Whether that's realistic or practical is a different discussion, but it sure is a good motivation for disruptive research topics. For example, how can we retrieve phase information and can we use it to test error vector magnitude (EVM) and radiation patterns? Do we really need to assume the law of large numbers to perform an accurate measurement? Can we use its deterministic properties in ways we have not seen before to obtain more information on our device under test in a faster time? Or can we combine deterministic and stochastic approaches to test even faster?

Here's why you should care about that: wireless tests take a long time and companies now need to perform many more of them every day because antennas are becoming more complex and more integrated into many different products [9, 10]. And of course, an antenna can only be tested wirelessly. Think of a phased array with thousands of settings (e.g. scan angles, tapering, digital predistortion, bias and/or filter settings) [11, 12]: there is no way you are going to book up your anechoic chamber(s) for months on end only to test a limited subset, especially not in production. With this ongoing industry shift, the test and measurement industry needs to develop new techniques and technologies to enable industries such as wireless, automotive, and aerospace & defense to build reliable products at a reasonable cost per test. We believe that RCs are part of the solution, with tight integration with existing and new RF instrumentation.

2. Leverage Determinism and Correlation

When using stochastic methods in RCs, correlation and determinism are usually the enemy. They are an indicator of systematic biases in the measurements results and are often introduced by unstirred energy or poorly sampled measurement data [13, 5]. Physical aspects like chamber design and antenna placement are typically chosen to minimize unstirred energy, and a low correlation between samples is often an aspect of having a good mode-stirring sequence [13].

We see it differently: correlation and determinism can be very advantageous for extracting key information[1]. In fact, several RC researchers have entertained these ideas too. One of them is A. Cozza, who used deterministic time-reversal methods to characterize the time characteristics of the chamber by using a short excitation pulse [15]. He then traces the fields back to their source which could potentially be used to test a radiation pattern of the device under test (DUT) in under a second. Another work achieved pattern measurements by linking the correlation measured over antenna orientations to the spherical mode coefficients of the antenna[2] [16]. It is these types of correlation or deterministic techniques that enable the extraction of information that is typically lost in an RC such as phase, polarization, or directionality.

Correlation can be found anywhere where there is some type of stirring. For example, in mechanical mode stirring using a rotating stirrer or turntable it is often described using coherence angle, in position stirring it can be coherence distance, and in frequency stirring it is coherence bandwidth [5]. Many other stirring methods exist, such as polarization stirring, stirring with walls made of metal-laced fabric, electronic stirring with metasurfaces, etc., and they all have their own way of creating correlation [17, 18, 19, 20]. It seems that we have well figured out the usage of independent samples, but in our opinion the greatest future opportunities lie in the usage of correlation and dependent samples to gain back information that is traditionally lost.

3. The Areas of Greatest Potential

3.1. Radiation Patterns and Directional Information

Dependent samples can be used to isolate direct line-of-sight (LoS) paths in RCs by filtering out random or stirred components using various forms of averaging. Several works have used such isolated LoS paths to extract metrics such as radiation patterns or radar cross sections [21, 22]. In [23], a similar example is shown in which we extract a radiation pattern in an RC that intentionally includes a scatterer that would normally create systematic errors due to a strong multipath component. By taking a deterministic approach and applying phase correlation, any strong multipath component can be mitigated.

Methods like that are interesting from a technology perspective, but do not provide a time advantage compared to the anechoic chamber since they still rely on sequential field sampling. We believe that parallel field sampling in RCs using correlative techniques could be a solution to this issue. Here's one way to imagine that: since an RC has a metallic interior, all radiated information about the DUT stays inside and there must be a way to extract it. In contrast, the walls of an anechoic chamber absorb almost all radiated waves, and therefore the information carried by them is lost. What a waste!

3.2. Modulation as a Processing Benefit

Sample dependency can also be found in modulated signals. There are standardized methods for demodulating signals in reverberation chambers which have been used for many years to test metrics such as Total Isotropic Sensitivity of communication devices [5]. They work by maintaining an active connection between a DUT such as a phone and a base-station emulator that equalizes the channel. We will not go in depth about those here but they are well described in [5].

An interesting idea is to use the modulation scheme as a stirring mechanism. This would be the case with Orthogonal Frequency Division Multiplexing (OFDM), which inherently averages per frequency bin (over a bandwidth of 15 kHz or more) when equalizing and could remove the need for physical mode-stirring. This can be observed in the results shown in [24]. Another modulation scheme that can replace physical mode-stirring is a Frequency Modulated Continuous Wave (FMCW) signal emitted by a radar [17]. An FMCW radar transmits a time-varying signal having a large bandwidth. Since an RC can create a time- and frequency-dependent output, a significant amount of information can be retrieved from just a single chirp using time-domain acquisition and applying frequency stirring. Compared to minutes or hours in a (multiprobe) anechoic chamber, a TRP measurement can now be made within the time of a single chirp, which is on the order of tens of microseconds [17].

This shows that modulated signals can enable faster retrieval of information in comparison to continuous-wave measurements typically used in antenna measurements. This begs the questions: why don't we apply artificial modulation schemes to measurements, for the sole purpose of speeding them up [25]?

3.3. DUT-Model-Assisted Measurements

All stochastic or deterministic methods used in RC measurements rely on some type of model. Most of them use averaging the measured power over all mode-stirring states (e.g. total radiated power, efficiency, chamber loss, material absorption). This works well for transmitters. It also works for receivers that operate in the linear domain.

Things get more complicated when the receiver is brought into non-linear operation. This can happen due to the mode-stirring process because the power arriving at the DUT varies per mode-stirring state. The DUT's behavior now changes over mode-stirring states. If we were to not take that into account and use a simple averaging operation, we would likely get a false estimate of the gain.

This is where different models come in to solve it. A transistor or an amplifier has a distinct behavior. For example, if we test an antenna-amplifier combination in the chamber, the input power to the antenna has to be determined by another reference antenna in a statistical manner. However, the individual samples can be mapped to the amplifier's output power since it is very unlikely (if not impossible) that the lowest powers arriving at the antenna aperture correspond to the highest amplifier output powers. Using such assumptions on correlation or models on

[1]This idea is not new. It is one of the key principles in communication protocols such as CDMA used in GPS or 3G [14].

[2]Both of these approaches have drawbacks. The time-reversal approach has challenges in calibration and repeatability (especially with shorter wavelengths and higher antenna directivity), and the decomposition approach may not have a unique solution and has a long measurement time.

the compression curves of typical amplifiers, we can even use the effect that the DUT's behavior changes per mode-stirring state to our advantage to speed up testing. Instead of changing input-power levels with a tuner, we can simply mode-stir to do the same so we can obtain the entire compression curve. A similar idea was presented for TIS measurements in [26].

The trend of (transistor-)model-supported measurements is also occurring in the conducted domain, so why not take it over the air? And while we are at the topic of models, why is it still so difficult to model an electrically large reverberation chamber? There must be a way.

4. Limitations and Future Perspectives

The areas of greatest potential identified in this vision paper are considered as such because they would address the largest limitations that reverberation chambers currently have. Inherent to the technology is that retrieving spatially dependent or phase information is challenging and may even be impossible without complex hardware additions. This information is needed to measure important spatial metrics such as directivity, Effective Isotropic Radiated Power (EIRP), and EVM, or to accurately evaluate complex waveforms. We showed ideas that could potentially solve some of those issues, but they have yet to be rigorously evaluated in terms of accuracy and typical uncertainty. Given the current state of the art, it is not surprising that these tests still occur mainly in anechoic chambers.

Another limitation that reverberation chambers will always have is related to the uniform field that inherently exists inside them. This contribution serves as a challenge since it could load the DUT in a way that is not representative of it's final environment. Although this is not an issue for most devices, some systems may be sensitive to loading by the uniform field, especially in high-output-power scenarios. This may be a limitation that cannot easily be overcome.

That said, the potential for reverberation chambers to further disrupt the test and measurement industry remains enormous. Just in the past few years, several new methods have been introduced that significantly reduced testing time and even enabled new metrics to be measured. Reverberation chambers are a complementary solution to this day, but we believe that this may change when we manage to expand their functionalities by overcoming the mentioned limitations.

To close off, it is no secret that antennas are no longer standalone elements. Engineers are more often fully integrating them into the design of their system, making over-the-air testing no longer optional, but rather the default methodology. To match testing time with the increasing number of antennas used, we need to think differently. Marginal reductions of 10–30 % in measurement time won't get us where we need to go. We need improvements of orders of magnitude. If we set the bar high enough, it may just be the reason we reach it.

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