# Overview of Antenna and Over The Air (OTA) Measurements in Reverberation Chambers

***K.S Lee[1], M. Andersson[2]***

*[1]ST Electronics (Info-Comm Systems) Pte Ltd , Singapore, leekis@stee.stengg.com*
*[2]Bluetest AB, Götaverksgatan 1, SE-417 55 Gothenburg, Sweden, mats.andersson@bluetest.se*

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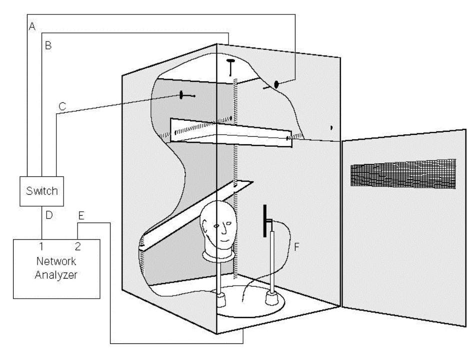
## Abstract

Antennas have traditionally been measured in anechoic chambers. An anechoic chamber is a suitable and necessary reference environment to measure large antennas that are used in a Line-Of-Sight (LOS) environment, but it is an unsuitable environment to measure devices with small antennas. Devices with small antennas are normally used in a Non-LOS environment, which is typically characterised by a lot of reflections as e.g indoors or in an urban environment, and not at all by an anechoic environment. A rich scattering environment is much easier to simulate in a reverberation chamber. The reverberation chamber is a reference environment with a Rayleigh distribution suitable for tests of small antennas and devices with small antennas such as mobile phones, laptops, PDAs, etc. The reverberation chamber has the advantage that it can be made much smaller and that the measurements can be performed much faster than in an anechoic chamber. The accuracy of a small reverberation chamber is similar or better to large anechoic chambers and the measurement times for antenna efficiency, TRP and TIS are between 3 - 15 times faster depending on type of test and communication protocol. For multi-antenna tests the measurement time in reverberation chambers is very fast. Antenna diversity gain can for example be measured in just 1 minute.

## 1 Introduction

Researchers at Chalmers have in collaboration with Bluetest during the last 9 years pioneered the use of reverberation chambers for direct tests of antenna efficiency, TRP, TIS, antenna diversity gain, and MIMO capacity [1, 2, 3, 4, 5, 6]. The reverberation chamber has the advantage that it can be made much smaller and that the measurements are performed much faster than in a traditional anechoic chamber, usually with better repeatability and accuracy. For small antennas in either Single Input Single Output (SISO) or Multiple Input Multiple Output (MIMO) systems, the most important parameter to optimize is the antenna efficiency. The antenna efficiency directly influences how much of the transmitter power is radiated into space, or how much of the radiation incident on the antenna reaches the receiver. The Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) are thus directly related to the antenna efficiency and have a direct influence on such important parameters as coverage, battery life time and bit rate in the up and down link. The antenna efficiency and hence the TRP and TIS performance, can be measured with good accuracy although it is very hard to estimate accurately with software. The antenna efficiency is also the most important parameter for diversity and MIMO antennas, much more important than antenna correlation [5]. This paper will give an overview of how different types of passive and active measurements can be performed in reverberation chambers, such as antenna efficiency, Total Radiated Power (TRP), Total Isotropic Sensitivity (TIS), and antenna diversity gain. The typical test times will be compared to f standard anechoic chambers.

Figure 1.Sketch Bluetest's standard chamber. The network analyzer is connected via switch to the three fixed orthogonal monopole antennas, and to a dipole in the chamber. The dipole is mounted in a holder on a rotating platform.




## 2 The Reverberation Chamber

The reverberation chamber is a metallic cavity resonator of high-Q factor, which is large enough to support several cavity modes at the frequency of operation. Hence, the spatial distribution is strongly inhomogeneous (standing waves). However, the modes can be stirred to create a Rayleigh distributed transfer function between a fixed wall mounted antenna and the antenna under test, inside the chamber. The reverberation chamber used in most of the measurements reported in this paper is shown in Figure 2. It has the dimensions 1.2m x 1.75m x 1.8m. The chamber makes use of frequency stirring, platform stirring [2], and polarization stirring [8] to improve accuracy. This size allows accurate measurements with a standard deviation of less than 0.5 dB down to 700 MHz. Note: The LUF of this size is 450 MHz.

Besides being the only direct measurement instrument for diversity gain as well MIMO capacity [4], it is also a very fast and cost effective instrument for measuring TIS (Total Isotropic Sensitivity) [9] and TRP (Total Radiated Power) of mobile terminals [10]. TRP can be measured within one minute. Receiver sensitivity improvements taken over the complete sphere can also be measured within one minute. The full TIS value can be estimated by measuring the Average Fading Sensitivity (AFS) [11], which takes 5 – 10 minutes. The reverberation chamber is also a very efficient tool for measuring radiation efficiency of small antennas [12] and to determine the performance of all kinds of wireless terminals with small antennas, i.e. Bluetooth modules [13], DECT phones [14], RFID chips, wireless sensors etc. Measurements of the parameters above can be performed up to 10 times faster than in traditional anechoic chambers and with the same or better accuracy. The cost and space compared to an anechoic chamber is much smaller and the chamber is very easy to move from one room to another within the same building or between buildings.

## 3 Measuring Antenna Efficiency

One always start with a reference measurement using an antenna with a known radiation efficiency. It can be known with the help of calculations or measured in another measurement chamber. This procedure is similar to the use of a standard gain horn in anechoic chambers. By first measuring the reference antenna we get an estimate of the total losses in the chamber. It is therefore a necessary requirement that objects that can contribute to losses are not moved from or into the chamber between the reference measurement and the measurement of antenna efficiency, radiated power, etc. The reference antenna is positioned at least 0.5 wavelenghts from the walls or mode stirrers in the chamber and at least 0.7 wavelengths from absorbing materials, for example a head phantom. A network analyzer is used and the average received power from each of the 3 fixed antennas to the reference antenna is measured during continuous mode-stirring. In the Bluetest High Performance (HP) chamber, see Figure 2, it takes 1 minute to measure a value with less than 0.5 dB standard deviation. Since we know the efficiency of the reference antenna and the received power from the reference measurement, we can normalize the received power to what it would have been if the reference antenna had an efficiency of 100 %. We call this power $P_{ref}$.

When the reference measurement is done, it is possible to take an antenna where the efficiency is unknown and measure it. This is done in a similar manner as described above and the present measured power from the antenna (i.e. Antenna Under Test), we call $P_{AUT}$. It is now possible to calculate the antenna efficiency of the unknown antenna with the following formula:

$$e_{rad} = P_{AUT}/P_{ref}$$

Measuring antenna efficiency takes 1 minute in the Bluetest HP chamber. This is about 5 - 15 times faster than in most standard anechoic chambers.

## 4 Measuring Total Radiated Power (TRP)

The Total Radiated Power (TRP) is the power that is transmitted, from for example a mobile phone, integrated over all directions. This power is affected by the output power of the amplifier, missmatch between amplifier and antenna, the antenna efficiency, objects in the vicinity to the antenna that contribute with losses, for example mobile phone chassis, hand, head, etc. To measure the total radiated power in a reverberation chamber, the DUT, for example a mobile phone, is positioned on the turntable at least 0.5 wave lengths from any wall and at least 0.7 wavelenghts from any absorbing material. A base station simulator is connected to the 3 fixed antennas. It is now possible to initiate communication between terminal and basestation simulator or vice versa. If a mobile phone is measured, a special SIM card is normally used and after a call has been set up, the base station simulator orders the terminal to send at full power. The power between the mobile phone and fixed antennas is then measured. Since the base station simulator measures the received power and we know how large the chamber losses are from the reference measurement, it is easy to calculate the total radiated power. Just as in the case when you measure antenna efficiency it takes only 1 minute with the Bluetest HP chamber to reach a TRP result with a standard deviation less than 0.5 dB. This is 5 - 15 times faster than in most standard anechoic chambers.

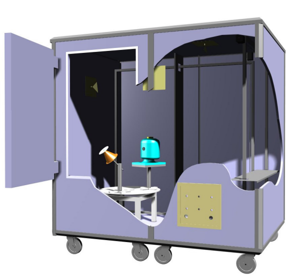


Figure 2.Drawing of the Bluetest High Performance (HP) chamber.

## 5 Measuring Total Isotropic Sensitivity (TIS)

The Total Isotropic Sensitivity (TIS) is the the power that reaches the receiver through the antenna integrated over all directions. This sensitivity is affected by the sensitivity of the receiver, missmatch between receiver and antenna, the efficiency of the antenna, objects in the vicinity to the antenna that contribute with losses, for example mobile phone chassis, hand, head, etc. To measure the total isotropic sensitivity in a Bluetest chamber, the test object is positioned in the same way as described above. After the call has been set-up, the base station simulator sends a bit stream at a given low power to the mobile phone and orders the mobile phone, after it has received the bit stream, to send it back at full power when it assumed that no further bit errors will occur on the up link. The base station simulator compares the received bit stream with the sent one. If the bit error rate is less than 2.4 % (example for GSM) the power from the base station simulator is successively lowered in steps until the power that corresponds to a bit error rate of 2.4 % is found. This power minus the losses in the chamber is the received power at a bit error rate of 2.4 %. This procedure is repeated for each mode stirrer position. By averaging all the measurements it is possible to calculate the TIS value. TIS measurements shall by definition be made in a non-fading or static environment. This is probably due to the tradition to use anechoic chambers. It is possible also to use a static measurement environment in the Bluetest chambers. The bit error rate is then measured when all mode stirrer mechanisms are in a fixed position. This makes a TIS measurement take a relatively long time also in a reverberation chamber, about 10 minutes per channel. This is, however, about 6 times faster than in traditional anechoic chamber.

## 6 Measuring Antenna Diversity Gain

Antenna diversity gain can be used to combat fading and hence to increase the bit rate of new (HSPA and WiMAX) and future (LTE) mobile wireless services [16]. By using more than one antenna connected to the receiver, i.e. diversity, it is possible to increase the received SNR by selection combining, switch combining or maximum ratio combining (MRC). Improvements of more than 10 dB have been reported [17]. Diversity gain can be measured in a real environment, i.e. drive tests, estimated from measured 3D patterns, or measured in a reverberation chamber. In a rich scattering environment these methods have been shown to give similar results [18]. Drive tests are often unreliable since you can never be sure to drive exactly the same route and through the same environment more than once. Measurements of full 3D patterns in an anechoic chamber, followed by software simulation of the channel are usually time-consuming. The reverberation chamber on the other hand is a very fast and convenient instrument for direct measurements of antenna diversity gain in a rich scattering environment. The diversity gain improvement depends on both the correlation and the mutual coupling where mutual coupling may be a dominant factor in a rich scattering environment [5]. The test procedure for measuring antenna diversity gain in a reverberation chamber with a two-port network analyzer is described in detail in [5]. If possible, a multi-port network analyser, to minimize measurement time, should be used to simultaneously measure amplitude and phase of the different antennas in the multi-antenna configuration and the 3 fixed antennas in the reverberation chamber. The measurements described were made on two dipoles, each of which was connected to 2 different ports of a multi-port network analyser [7]. The mode stirrers and platform moved continuously. This movement creates a Rayleigh distribution at each of the antennas. The complex S parameter values are sampled every 200 ms until a sufficient number of samples for high accuracy have been collected. This takes about 1 - 2 minutes for a standard deviation of < 0.5 dB depending on bandwidth and frequency used. For diversity antenna with 2 branches both S12 and S13 are measured simultaneously. Both these antenna branches will show a certain probability to have fading below a certain level, usually referred to as the cumulative distribution function (CDF). By choosing the best of the measured S12 and S13 at every point in time, one can get a CDF that is called selection combining. It is of course possible to use the S12 and S13 to get the CDF of any diversity scheme, e.g. maximum ratio combining (MRC), since both amplitude and phase have been measured. However, in this example we use selection combining. By taking the difference between the CDF for either S12 or S13 and the CDF for selection combining, it is possible to estimate the ”apparent” diversity gain, i.e. how much it is possible to gain in the deepest fading dips, normally at a probability level of 1 %, by choosing the best antenna. The most relevant value though should be how much you gain in comparison to using an ideal antenna, i.e. to compare the CDF for a single antenna with 100 % antenna efficiency with the CDF for selection combining. This is the “effective” diversity gain [4]. The terms “apparent” and “effective” diversity gain as mentioned in [4], had already been introduced in 2002 using measurements in a Bluetest standard reverberation chamber. If you compare with the CDF for a real antenna, i.e. with losses, this is the “actual” diversity gain. For antenna configurations with large mutual coupling, as for example 2 dipoles that are moved very close to each other, their antenna efficiency will become very low which means that what may look like a very good diversity gain, i.e. ”apparent” diversity gain is, in reality compared to using just a single antenna, not at all very good.

In Figure 3 one can see that at 15 mm distance between two 900 MHz dipoles the ”effective” diversity gain is only 3 dB at the 1 % probability level. For most of the time, in the example in more than 90 % of the time one will loose signal strength compared to just using a single antenna. In the case of using dipoles the ”effective” and ”actual” diversity gains are very similar since a dipole typically has an antenna efficiency of about 95 %.

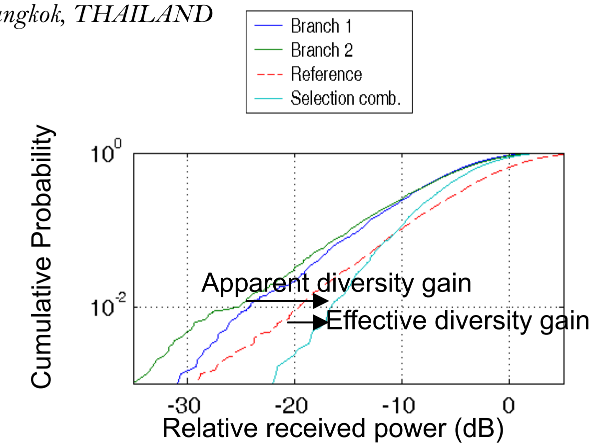



Figure 3.Cumulative probability distribution functions of reference dipole (red curve), each of 2 dipoles at a distance of 15 mm and parallel to each other (green and blue curves), and the selection combined curve (light blue curve). The effective diversity and apparent diversity gain at 1% cumulative probability level is marked by the arrowed lines. The frequency is 900 MHz.

## Conclusions

Reverberation chambers can be used for fast, repeatable and cost effective passive and active tests of devices with small antennas. The test time is about 5 - 15 times faster than in anechoic chambers. Accuracy and repeatability is very good since reverberation chambers have no problems with reflections in turntables, motors, positioners etc. The positioning of the test object is very easy since there is no quiet zone to consider, all positions in the chamber at least 0.5 wavelengths from metal walls give the same results within the statistical uncertainty of the chamber. Reverberation chambers are easy to calibrate and maintain since they use no active electronics in the measurement path.

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