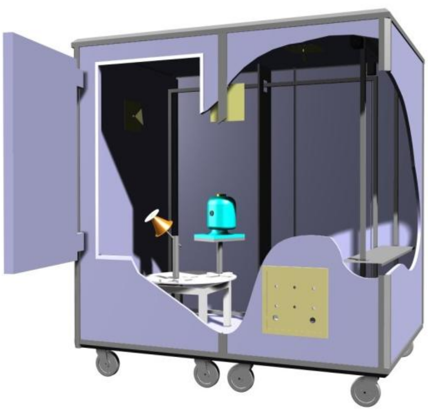
Testing Communication System Performance in Reverberation Chamber

White Paper

Fast, Repeatable and Cost Effective System Measurements Using Single or Dual Reverberation Chambers

Keywords: Reverberation chamber, antenna diversity gain, MIMO capacity, MIMO channel modelling, system test

Base stations and/or terminals with multi-antenna configurations are expected to significantly contribute to much higher bit rates in mobile broadband systems. Higher bit rates using multi-antenna systems can, when there is rich scattering in the communication channel, be achieved 1) by increasing the modulation rate and/or reducing the coding rate as the Signal to Noise Ratio (SNR) is increased through the use of diversity combining, or 2) through the use of simultaneous partially uncorrelated communication channels (Multiple Input Multiple Output, MIMO). It is not possible to do direct tests to find the best multi-antenna configuration for optimizing diversity gain or MIMO capacity with the traditional antenna measurement method, i.e. anechoic chambers. Of the two alternatives for making direct measurements, i.e. drive tests and the reverberation chamber, the reverberation chamber offers many advantages. It creates an artificial, fully controlled and repeatable Rayleigh environment in which measurements are simple, fast and cost effective. The results are reliable and in very good agreement with simulations.



Introduction

The traditional way of measuring antennas in anechoic chambers, i.e. without any reflections, is an unsuitable way to measure devices with small antennas, especially for multi-antenna systems, that normally are used in an environment with a lot of reflections, i.e. indoors or in an urban environment. Such an environment is much easier to simulate in a reverberation chamber. Bluetest has since 10 years been the pioneer in the use of reverberation chambers for direct tests of antenna efficiency, TRP, TIS, antenna diversity gain, MIMO capacity [1, 2, 3, 4, 5, 6]. The reverberation chamber also have the advantage that it can be made much smaller and that the measurements are performed much faster than in a traditional anechoic chamber. For small antennas in either Single Input Single Output (SISO) or MIMO systems the most important parameter to optimize is the antenna efficiency. Antenna efficiency is much more important than antenna correlation for multi-antenna systems [5, 7]. The traditional antenna metric for large antennas, i.e. the antenna pattern, is on the other hand, for small antennas in SISO or MIMO systems, of little or no importance during design and evaluation. The requirement of measuring antenna patterns in standards is just a tradition and cause unnecessary delays for market introduction of products with small antennas. This is because for small antennas 1) the patterns are more or less omni-directional, 2) most devices are used in a multipath environment and in random positions and 3) the antenna pattern is just an (unnecessary) step on the way to calculate antenna efficiency and hence TRP, TIS, diversity gain and MIMO capacity, but of little or no use in itself. This paper will focus on fast, repeatable and cost effective multi-antenna system measurements using single or dual reverberation chambers.

The Reverberation Chamber

The reverberation chamber is a metal cavity which is large enough to support several cavity modes at the frequency of operation.

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 1. 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.

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 ten times faster than in a traditional anechoic chamber 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.

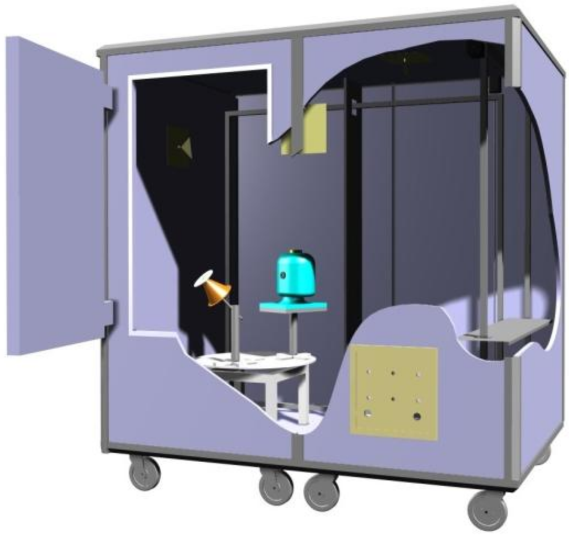


Figure 1. Drawing of the Bluetest HP700 reverberation chamber

Measuring MIMO System Throughput

There are no accepted or well-known standards today to measure system throughput of multi-antenna solutions. One of the reasons for this is that established standards use measurements in anechoic chambers where the effect of multi-antenna solutions is not directly measurable. There is thus a need for a repeatable testing methodology to check the throughput of multi-antenna devices in an environment with rich scattering. This environment should preferably have rich scattering that is repeatable as well as isolated from outside interference that may affect the measurements. The reverberation chamber fulfils these requirements. To test that this works in praxis Bluetest has together with Sony Ericsson performed a project [15] during 2008 within the Swedish Chase (Chalmers Antenna Systems VINN Excellence Center) program, where a MIMO WLAN router and MIMO laptop where used to test throughput in the Bluetest HP chamber. Both MIMO router and laptop were placed within the chamber. The laptop on the turntable and the router at a fixed location and the TCP as well as UDP throughput was measured in the repeatable Rayleigh environment. The measurements were performed over a 90 seconds continuous stirring sequence with a sampling frequency of 2 samples/second.

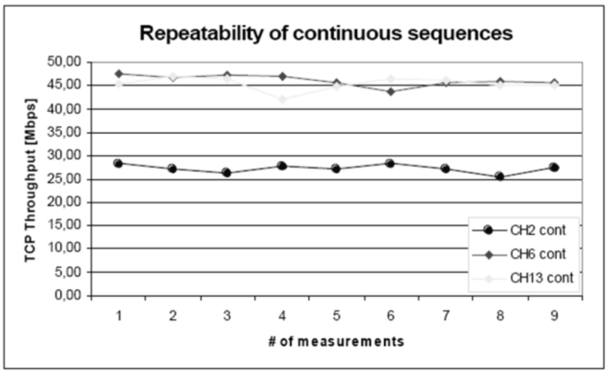


Figure 2. Nine consecutive measurements at 3 different days showing good repeatability

This was found to be long enough for 95% confidence interval for the sample average smaller than 2 Mbps. Figure 2 shows 9 measurements of 3 channels with good repeatability. For more information of how different numbers or types of MIMO antennas affected the throughput, see [15].

Using the Reverberation Chamber to Optimize Scheduling Algorithms

By using multiple terminals in the chamber in conjunction with one base-station connected to the chamber or placed inside the chamber it will be possible to optimize system throughput in a repeatable Rayleigh environment. With such a setup, multiple access technologies such as OFDMA or MU-MIMO including the associated scheduling can be evaluated and the performance of different scheduling algorithms can be measured. OFDMA and SDMA/MU-MIMO rely on a space and frequency-selective channel, respectively, which can be provided by the reverberation chamber.

Since scheduling algorithms generally also need a channel, which evolves over time, it can be desirable to move the stirrers in the chamber as well as the platform during the measurements. This channel evolution over time however needs to be sufficiently slow to allow SDMA/MU-MIMO to function. Note, that in a chamber of reasonable size, it might be possible to place numerous mobile terminals, since they already experience independent fading, if the distance between them is larger than lambda-half.

For the single-cell measurements a base-station is connected to the chamber (or if small potentially placed inside the chamber). In addition mobile terminals are added, with spacing between them of at least half a wavelength to ensure independent fading. In a next step communication is established between the mobile terminals and the base-station and throughput measurements of all terminals in parallel are started. Then the platform and stirrers are moved slowly.

Depending on the objective of the measurements, a different number of terminals may be required. For the investigation of SDMA or MU-MIMO it can be sufficient to use only two terminals and force them to operate on the same frequency-time resource block such that they need to be separated in space using MIMO techniques. If, however, scheduling algorithms are to be evaluated, the number of mobile terminals needs to be large in comparison to the number of available frequency-time slots, since the quality of a scheduling algorithms shows best at a high system load. The results of these measurements are the individual throughputs of each terminal. They can be used to analyze not only sum-throughput in this artificial cell, but also to investigate for example the fairness characteristics of the scheduling algorithm.

Multi-Cell System-Level Measurements

Rather than connecting only a single base-station to a reverberation chamber, it is also possible to connect more than one base-station. This setup can be used to investigate the performance of the system, when the terminal is moving in the handover area, as indicated in Figure 3. In the hand-over area the average power received by a mobile from two different base-stations is approximately the same. This corresponds to the uniform average power distribution over area in the reverberation chamber. Note, that the handover area or cell-edge in a communication system is not defined by geometry but rather by signal power levels.

If two base-stations with identical output powers are connected to a reverberation chamber, the average received power from the two base-stations at the terminal is also identical. The chamber environment in the chamber therefore corresponds to exactly the handover region between two base-stations. To change this, attenuators can be used to adjust the powers of the base-stations connected to the chamber and by that “move” closer to one of the base-stations. In the extreme, these attenuators might even be made time-variant. Alternatively to using attenuators it would also be possible to use a cylinder, which is filled with lossy material, and move it over the terminal in order to create fading on a slower time-scale, which should trigger handover between two base-stations.

With such a setup it is possible to simulate handover scenarios from one base to another. Such a handover decision should not be made on the basis of short-term fading but rather average power levels. The short-term fading in this case would be created by the chamber. On top of the base-station/system algorithms, this setup will also allow for evaluating the performance of the interference rejection at the terminal. If connected to one base-station, the other base-station creates interference for the terminal, which it can combat using interference rejection based on multiple antenna schemes.

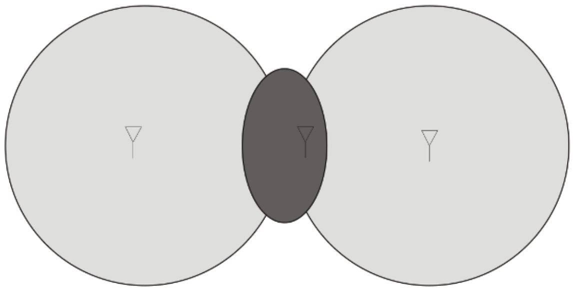


Figure 3: Two base-station setup with hand-over region. Note that cells are based on receiver power not on geometry.

Alternatively to the classical hand-over scenario, the two base-stations could also be used as cooperating base-stations serving the terminal(s) in the hand-over region jointly, as discussed in the context of IMT-advanced.

In Table 1 different potential measurement setups which parameters/properties of the system can be evaluated, are summarized.

	Single-Cell	*Multi-Cell*
Multi-Antenna	MU-MIMO SDMA Channel dependent scheduling	Cooperative base-stations Interference suppression at terminal Hand-over
OFDM(A)	Channel dependent scheduling	

Table 1. Different potential measurement setups.

System Measurements in Multi-Keyhole Channel

The so called keyhole effect [16] in MIMO communication systems is known as a situation where the rank of a wireless communication channel is limited, even though there is rich scattering both at the transmit and receive antenna sites. The available MIMO capacity in such a channel would be severely reduced not due to increased correlation between antenna branches, but due to the reduced rank of the channel. The perfect keyhole channel has only one mode of propagation between the transmit and receive sites, but in reality such a case would be rarely found. Instead, the case of a multi-keyhole channel would be more realistic, i.e. a case which have several modes of transmission between the environments surrounding each of the transmit and receive antenna sites. Reverberation chambers are ideally suited to simulate keyhole channels due to the very rich scattering inside the chamber, and the possibility to connect two reverberation chambers with various numbers of coaxial cables to resemble multi-keyhole channels.

Figure 4 shows measured capacities for a number of different connections between the two chambers, together with calculated values for a perfect keyhole channel, a multi-keyhole channel with six modes of transmission, and for an ideal Rayleigh channel (i.i.d.). The results confirms that the setup with two reverberation chamber behaves like theoretical multi-keyhole channels, i.e. the more connections there are between the two chambers, the closer the capacity will come to that of an ideal Rayleigh distributed channel. There is a close agreement between the measured case of a single connection and the calculated case for a perfect keyhole channel, as well as there is a close agreement between the measured and calculated cases with six connections between the chambers. This shows that the behavior of the measurement setup can be predicted theoretically.

It is interesting to note that the case with six connections between the chambers have a capacity relatively close to that of an ideal Rayleigh channel, although it seems to be many more connections needed to come really close due to the asymptotic behavior. It is also worth noting the relatively small effect of going from four to six connections. In the presented results, there is actually no significant difference between those two cases.

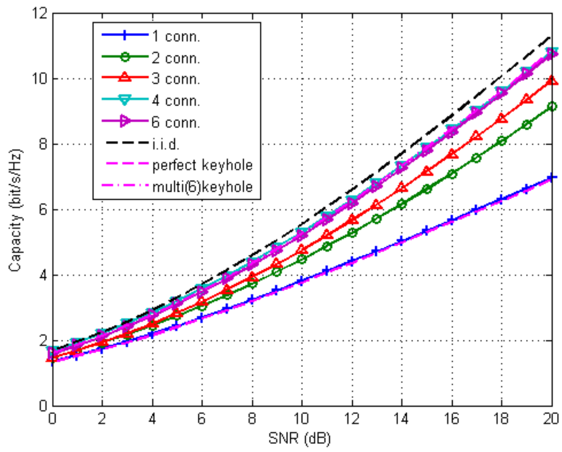


Figure 4. Measured and calculated capacities for a MIMO system in two connected reverberation chambers.

Conclusions

Reverberation chambers can be used for fast, repeatable and cost effective passive and active tests of devices with small multi-antenna configurations. By combining two chambers it is possible to very cost effectively emulate and control the transmission channel from base-station to terminal and vice versa.

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