

Reverberation Chamber for Mobile Phone Antenna Tests

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1. Introduction

Reverberation chambers (RC) [1] have been used in the EMC community for a long time – especially for immunity tests, for which standards exist. New applications for the RC are emerging, such as measuring antennas [2] and for air interface testing of mobile phones. The field distribution in the RC is statistically homogeneous and isotropic, so there is no sensitivity of the positioning of the device under test and there is a potential for performing tests in parallel. A scattered field chamber (SFC) is a general test chamber, used to simulate a scattered field environment, which can be different from the Rayleigh distribution environment in an RC. The SFC can be made smaller than the RC, and it can be excited in various ways to tune the chamber field statistics.

Reverberation chambers and scattered field chambers are being studied for production test applications at Flextronics International Sweden AB (previously Ericsson Mobile Communications AB) in Linköping, Sweden. The RC and SFC are also being studied at R&D sites within Ericsson, as a general antenna measurement tool and simulator for different scattered field environments. When testing antennas in the RC and SFC, the requirements on measurement accuracy are in general higher than for EMC measurements. Special attention is given to the measurement accuracy, measurement time and cost of implementation for an RC or SFC – both for a production test scenario as well as for R&D work. For production process control, it is interesting to be able to monitor the radiating performance of the phones from the production line. Several frequency bands are of interest and different types of antennas, including internal antennas, are to be tested today and in the future. 3D radiation patterns are time consuming to measure and it is of interest for R&D work to

have a quick alternative for measuring antenna radiation efficiency and total radiated power, both in free space and with a phantom head. RCs and SFCs have a number of advantages concerning measurement time, accuracy, and cost for implementing, and are therefore useful tools.

This paper gives an overview of work performed the last two years at Ericsson, including some work in progress. Experiments performed at the Swedish Defence Research Agency (FOI) in 1999 have given important experience on measurement methods and how a mobile phone antenna is affected by both a large and a small chamber for both an unloaded and a loaded chamber test case. A smaller SFC built at Ericsson is described, together with some examples of performed studies. The small SFC has been, and still is, very useful for antenna testing. Results and work in progress with a new SFC in Linköping is discussed. The SFC is designed to be operational from 800 MHz and it has dual stirrers and is EMC shielded. Finally, some general conclusions are drawn and a few open questions are discussed.

2. Mobile phone antenna tests at FOI

Experiments with mobile phones have been performed in a reverberation chamber at FOI in Linköping. The measurements were performed in the E3 chamber at FOI in October 1999. The size of the chamber E3 is 5.10x2.46x3.00 m and it is further described in [3]. The measurements were performed in the GSM 900/1800 MHz bands.

Before the actual measurements on the antenna under test (AUT), measurements were made to characterize the statistical distributions inside the RC. These characterization measurements were performed in the 890-915 MHz and 1710-1785 MHz bands, both with the chamber loaded by the TX/RX antennas and loaded by 1 and 2 sheets (0.60x0.60 m) of absorber of type Emerson and Cuming AN77. The average and variance of the transmission P_r/P_t between the two antennas over all stirrer positions were computed for three cases – no extra absorber, 1 sheet of AN77, and 2 sheets of AN77 absorber on the floor of the chamber. Fig 1 shows that the variance is close to one, which indicates that the statistical distribution of the fields inside the chamber complies with the theoretical distribution. The variance was found to be near one also in the 1710-1785 MHz band, for the unloaded and loaded RC.

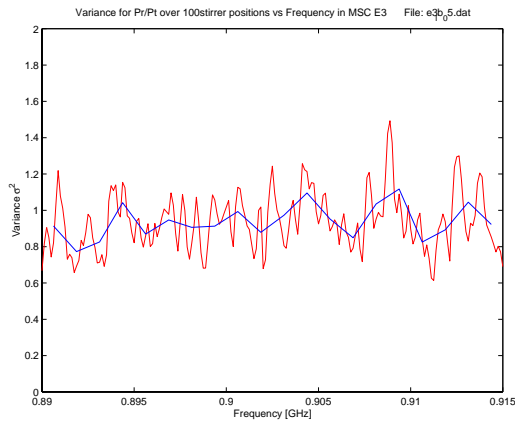


Fig 1: Variance of P_r/P_t normalized to its average at each frequency, 2 sheets of absorber.



Fig 2: AUT placed inside the E3 RC at FOI.

After checking the unloaded and loaded chamber performance, the actual measurements were performed. The effect of the reverberation chamber on the voltage standing wave ratio (VSWR) of the antenna under test has been investigated with and without the chamber loaded with absorber. The AUT was in this case a dual band antenna in the Ericsson phone A1018s, connected to a network analyzer by a coaxial cable soldered to the phone antenna. The measurements were performed with the AUT placed on a dielectric block placed inside the RC, as shown in Fig 2.

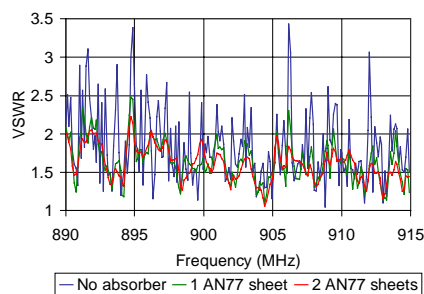


Fig 3: AUT VSWR in RC @ 890-915 MHz.

As shown in Fig 3 above, the peak VSWR values are reduced when 1 and 2 pieces of AN77 absorbers are placed in the chamber. This is important when active phones are tested in the chamber. The power amplifier sees a change in impedance, compared to free space, and if this change is too large, the output power and other characteristics of the RF power may be affected. It was encouraging to observe that the desired field distribution inside the reverberation chamber was maintained also with 2 pieces of AN77 absorber. A test was also made with 5 phones with terminated antennas near the AUT, cf Fig 4. It was found that placing the 5 phones near the AUT had a similar effect on the VSWR as that of placing absorber in the chamber. The conclusion was that by loading the RC with absorber or phones, it was possible to reduce the VSWR values, and still have good field statistics.



Fig 4: AUT surrounded by 5 phones.

It was also studied how the average P_r/P_t was reduced when 5 phones were placed in the chamber. It was found that the 5 phones with terminated antennas resulted in 1.0 dB extra loss in the P_r/P_t ratio at 890-915 MHz. At 1710-1785 MHz, the extra loss was 0.5 dB.

3. Antenna tests in the E0 chamber

After the tests in the large RC at FOI, a smaller chamber, with internal dimensions 0.87x1.05x1.19 m, was also tested as a reverberation chamber. The purpose of this test was to investigate how a small chamber would behave in the GSM 900/1800 MHz bands.



Fig 5: A small chamber (E0) at FOI.

The small shielded chamber, called E0, is used for measurements in the frequency range 0.5-2.0 GHz. The results of a goodness-of-fit test to the expected distribution, cf [4], are shown in Fig 6. Calculated statistics from the stirrer measurements show that this chamber starts to behave poorly below 1 GHz. There is not, however, a very sharp limit and it is always a question of desired measurement accuracy if the chamber is well behaved or not. The Q-value of the chamber was also measured and the result is shown in Fig 7.

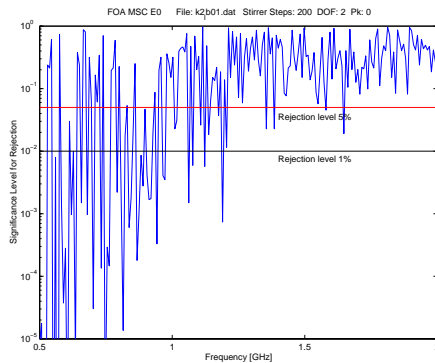


Fig 6: E0 goodness of fit test 0.5–2 GHz, cf [4].

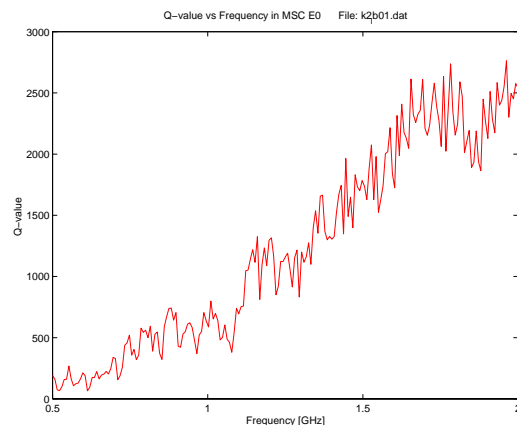


Fig 7: E0 Q-value in 0.5-2.0 GHz range.

The correlation between different stirrer steps was measured in the E0 chamber. From the autocorrelation of the measured signal, the number of independent samples can be calculated – which governs the measurement accuracy of an experiment. The variance of the average measured power is inversely proportional to the number of independent samples. Assuming an efficient stirrer design, the stirrer angle offset for uncorrelated field distribution decreases with increasing number of independent samples. It was found that a stirrer step of 3.6 degrees resulted in the 1/e correlation at about 900 MHz.

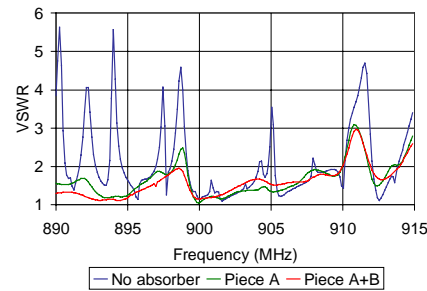


Fig 8: VSWR in E0 @ 890-915 MHz.

Measurements on the AUT VSWR similar to those in the large chamber were then performed in the small chamber in the 890-915 MHz and 1710-1785 MHz bands. This was done both with an empty chamber and with the chamber loaded by absorbers and other phones. Introducing small pieces of AN77 absorber inside the chamber influenced the peak VSWR values, cf Fig 8. Loading the E0 with 12 phones (A1018s) also had a significant effect on the VSWR of the A1018s under test, cf Fig 9.

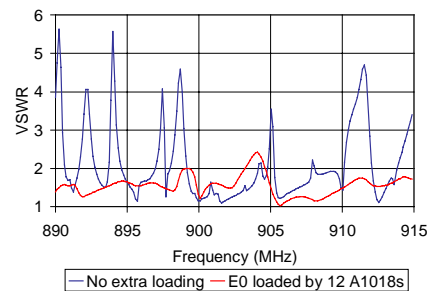


Fig 9: AUT VSWR for the E0 empty and loaded with 12 phones @ 890-915 MHz.

4. A small SFC for antenna test

A small SFC for testing antennas at frequencies above 2 GHz has been built at Ericsson in Kumla, Sweden. The size of the SFC is 1.00x0.50x0.50 m and it was later modified into a reverberation chamber. Even for a small chamber such as this, in the frequency band 2.40-2.50 GHz, we note that the accumulated number of modes at the lower end of this band is about 700 – well above 200 modes which is recommended according to a rule of thumb [5].



Fig 10: Small SFC (side wall removed).

A stirrer driven by a stepper motor was controlled by a PC, giving the possibility to rotate the stirrer in both mode-stirred and mode-tuned operation. The SFC as shown in Fig 10 is excited by a transmitting antenna, fed by a 0 dBm CW signal at 2.40 GHz. A spectrum analyzer is used to measure the power in the receiving antenna for a full stirrer revolution.

The received power distribution showed good agreement to the desired, cf Fig 11. The number of independent samples for the SFC at 2.40 GHz was 80. The small SFC has a shielded wall and a shielded access door.

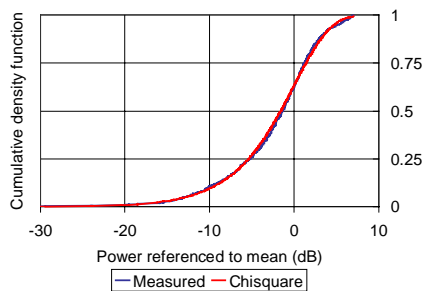


Fig 11: CDF of measured data and a chisquare distribution.

The small SFC is used for a number of studies – both fundamental studies of antenna measurements as well as for simulating various scattered field environments. Examples of the latter are adjusting the spatial field distribution, and creating line-of-sight field statistics. In an experiment performed according to the setup in Fig 12, two separate TX antennas were used. The TX1 antenna is the standard antenna giving only stirred power, corresponding to scattered waves. The TX2 antenna is positioned to excite resonances that are unaffected by the stirrer, thereby representing a direct wave.

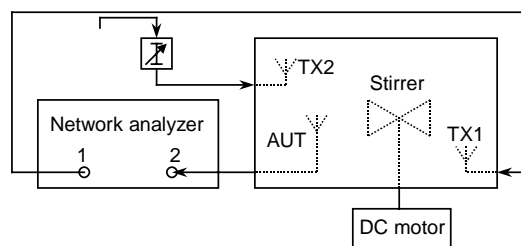


Fig 12: Setup for variable amplitude distribution experiment with scattered waves antenna TX1 and direct wave antenna TX2.

The ratio between the direct and scattered waves can be varied by an adjustable attenuator. Figs 13a-b clearly shows how the signal environment gradually changes from having a Gauss distribution to a Rayleigh distribution as the direct wave is attenuated.

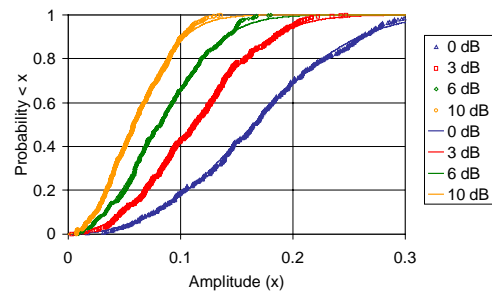


Fig 13a: Amplitude distributions for four values of the attenuation. Measured and best fit theoretical CDF.

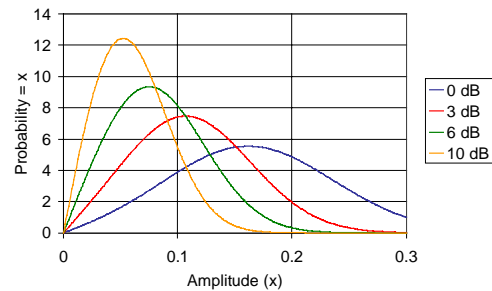


Fig 13b: Amplitude distributions for four values of the attenuation. Best fit PDF.

A study of the statistical isotropy in the small SFC has been made – including tests of how the placement of absorbers in the chamber can be used to deliberately destroy the isotropy. Measurements are performed with a directional horn antenna pointing in 6 directions along three perpendicular axes. Some results are shown in Fig 14. In the isotropy test, the chamber contained no absorber, whereas in the anisotropy test, a piece of absorber was placed on the wall in direction 5 in the chamber. As expected, a uniform angular distribution was confirmed for the empty chamber. With absorber, there is an increased loss in the received signal in direction 5, but also a reduction of the levels in all directions.

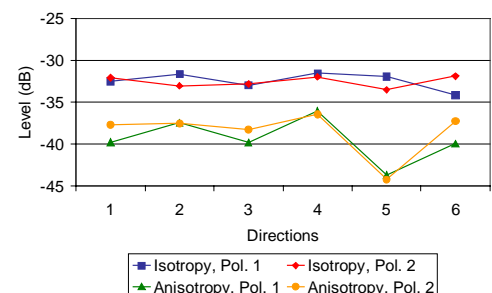


Fig 14: Measured average levels in 6 directions showing the isotropy in a standard RC, and a created anisotropy.

Measurements were performed at 2.5, 5, 7.5, and 10 GHz in the six directions for the unloaded and absorber loaded chamber and it was seen that the isotropy improved with increasing frequency.

Field quality aspects in an RC, like amplitude distribution, stir efficiency, and correlation, are unveiled in the complex plane. Ideally, the real and imaginary parts should be independent and Gauss distributed with zero mean. Fig 15a shows a distribution normally measured, whereas 15b shows the same case, but with a piece of absorber in the chamber. The individual points clearly follow a trace, which is the same as to say that there is a dependence between the points. The complex mean is also shifted from zero, indicating unstirred power.

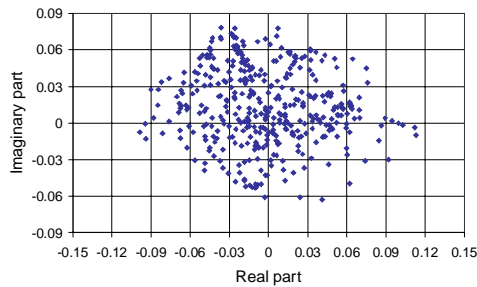


Fig 15a: Complex field distribution in an unloaded RC.

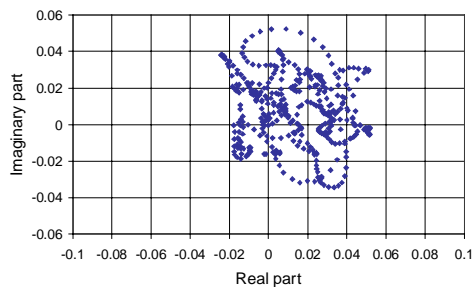


Fig 15b: Complex field distribution in an RC loaded with absorber.

The SFC as a controlled environment for the evaluation of antenna diversity performance has been shown to give repeatable results [6]. To this end, a phone model with two antennas has been tested in the SFC in the setup shown in Fig 16.

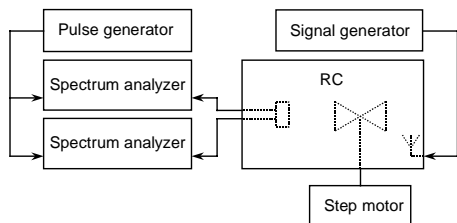


Fig 16: Terminal diversity experiment.

In the terminal diversity experiment, a signal generator was used to feed a horn antenna. The received power in the two antennas in the phone model was recorded simultaneously by means of two spectrum analyzers. A pulse generator was used for starting the analyzer sweeps at the same moment. A model similar to the Ericsson T10 phone was used, with an

element spacing of 10 cm between the two diversity antenna elements. The return loss was >10 dB for each antenna and the isolation between the antennas was >15 dB. Five tests were performed at 2.0 GHz and 2.5 GHz, with the terminal placed in different positions inside the chamber. The sweep time of the two spectrum analyzers was set at 10 seconds, which was the same as the stirrer period. The received power in the two antennas versus time along one stirrer period typically looked like Fig 17.

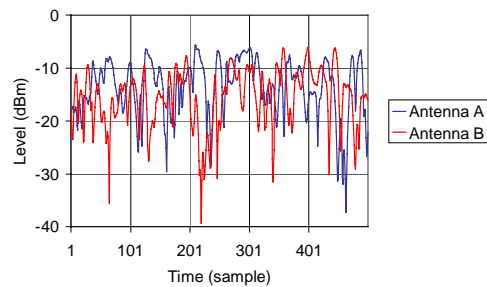


Fig 17: Received power in antenna A and B of the terminal diversity phone model.

Autocorrelations and amplitude distributions for the respective elements looked like in any single antenna measurement. The results from computing the amplitude and power correlations between the received signals in the two antennas are shown below.

Test No.	Amp. Corr.	Power Corr.
1	-0.18	-0.18
2	-0.18	-0.17
3	-0.09	-0.06
4	-0.10	-0.03
5	0.03	0.10

It was observed that the two correlation coefficients were about the same, and that the level followed the theory [7] for a scattered environment almost perfectly.

Experiments to determine the VSWR for internal Bluetooth antennas have been performed and the results have been compared to free space VSWR. Fig 18 shows a typical measurement for an antenna inside the SFC.

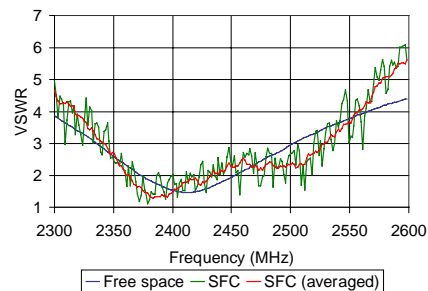


Fig 18: VSWR for a Bluetooth antenna.

5. Ongoing and future work

A new SFC designed to operate at frequencies above 800 MHz has recently been installed at Flextronics in Linköping, cf Fig 19 below.



Fig 19: SFC at Flextronics in Linköping.

The new SFC was designed by Ericsson Mobile Communications AB in Linköping and is a 2.00x1.45x0.85 m chamber with dual stirrers. The purpose of the chamber is to use it for measurements of antenna efficiency in the production of mobile phones. It will also be used for R&D. The new SFC has been designed using the experience gained from experiments performed since 1999 and also from simulations on the empty chamber which shows that more than 300 modes are available from cutoff to 890 MHz. It is possible to remove the right wall in Fig 19 for better access, e.g. for antenna placement and inserting wall diffusors. The dual stirrers and log periodic antennas are shown in Fig 20.



Fig 20: The new SFC with dual stirrers.

The initial measurements on the new SFC was to determine the Q-values of the chamber at different bands. The measurement of Q-value was made by measuring the 3 dB resonance width of the S_{11} for an antenna placed inside the SFC. Three different antennas were used, a log-periodic, a horn, and a circularly polarized antenna. A typical measurement for the circularly polarized antenna is shown in Fig 21.

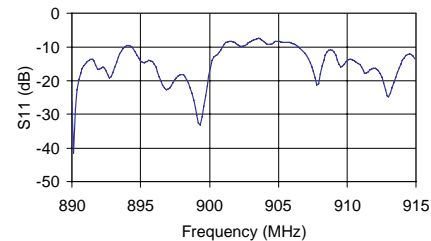


Fig 21: Circularly polarized antenna in SFC.

The 3 dB width of the resonance at 899 MHz above is about 1 MHz. The following results were obtained with the different antennas:

890-915 MHz:

Antenna	Q-value
Logperiodic	1085
Horn antenna	1016
Circular pol (EA no 2)	976

1710-1785 MHz:

Antenna	Q-value
Logperiodic	2075
Horn antenna	1500

2440-2450 MHz:

Antenna	Q-value
Logperiodic	2740

Some initial measurements of the shielding effectiveness of the new SFC have been made. This was done by injecting a CW signal at 2.4 GHz via a horn antenna inside the chamber and by measuring the power received by another horn antenna connected to a spectrum analyzer set in sweep mode around 2.4 GHz with max hold. A reference measurement was first made, by placing the receive antenna inside the chamber and then a measurement was made outside the chamber and the difference in max hold on the spectrum analyzer was recorded. Both stirrers were rotating for both the reference measurement and the measurement of field leakage outside the SFC. After some modifications, a shielding efficiency of 45 dB was measured at 2.4 GHz. We are currently working to replace the current type of EMC gasket in the large door with a better gasket, to reach the goal of 60 dB shielding.

When the mechanics for the stirrers was in operation, including the software to control the stirrers, the statistical distributions of the field inside the chamber was measured using methods described in [5]. Tuner sweep measurements were performed, by injecting a CW signal into a TX antenna and by sampling the received power with an RX antenna. The number of independent samples at different frequencies was then determined, by the $1/e$ criterion. The first measurements were taken by rotating both the horizontal and the vertical stirrer at the same speed – one revolution per 10 seconds. This was equal to the sweep time of the spectrum analyzer. The measurements were performed at frequencies from 800 to 3000 MHz, in steps of 100 MHz. A logperiodic antenna was used as RX antenna. As TX antenna was used either the logperiodic antenna or the horn antenna. The results are shown in Fig 22.

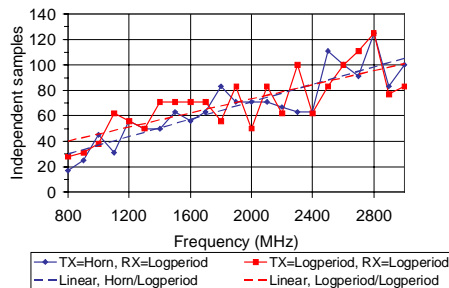


Fig 22: Independent samples in SFC.

Note that there seems to be a linear trend for the number of independent samples, with increasing frequency – but that the number of independent samples still is quite limited. In order to be able to measure antennas with a good accuracy, we need more independent samples. This way of measuring in the SFC, with both stirrers rotating with equal speed, does not give the best measurement accuracy. It is better to operate the stirrers independently. Experiments were made with varying speed ratio between the vertical and horizontal stirrers. Both a spectrum analyzer and a network analyzer (set in CW mode) were used to measure the tuner sweeps. The spectrum analyzer had 500 measurement points and the network analyzer had 1601 points. It was observed during the measurements that a large number of points is needed. This is the case especially when the speed ratio becomes large, something which is proved advantageous at high measurement frequencies.

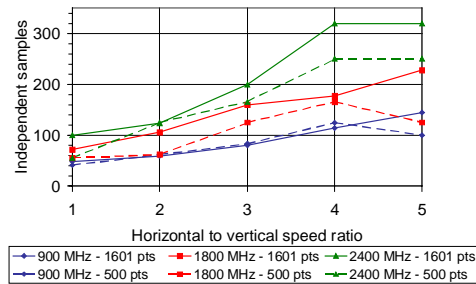


Fig 23: Independent samples vs horizontal to vertical stirrer speed ratio.

As is seen in Fig 23, the number of independent samples increases with speed ratio. In this measurement, the horizontal stirrer was rotated up to five times faster than the vertical stirrer. The frequency of the vertical stirrer was kept constant. At ratios of 4 or more, there is a saturation of the number of independent samples. Using a larger number of points results in a larger number of independent samples. A series of 29 test runs were performed to investigate the maximum to mean ratio in the SFC. This is an alternative way of measuring the number of independent samples. In the experiment, the vertical and horizontal stirrer periods were 5 and 20 seconds, respectively. The sweep time of the analyzer was 20 seconds and the test was performed at 900, 1800 and 2400 MHz. Two different horn antennas were used as TX and RX antennas in this experiment. Field diffusors had been installed in the chamber in this test. The results are shown in Fig 24.

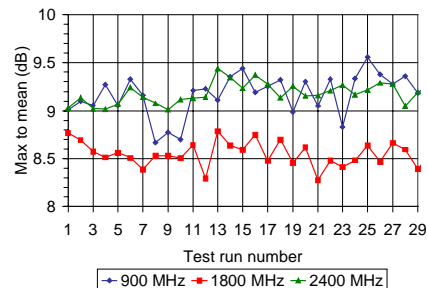


Fig 24: Max to mean ratios in the SFC.

Previous measurements have shown that running the two stirrers one at a time (while the other one is not moving) has resulted in the following number of independent samples:

900 MHz		
Vertical	Horizontal	Vert*Hor
32	28	900
1800 MHz		
Vertical	Horizontal	Vert*Hor
61	44	2680
2400 MHz		
Vertical	Horizontal	Vert*Hor
69	71	4900

By taking the product of the number of independent samples for each stirrer rotating on its own, we get the total number of independent samples that can be achieved with the two stirrers run independently.

Current work in progress includes putting the new chamber to the test in measurements of antenna efficiency and total radiated power. A test of the radiation from the internal Bluetooth transmitter in new Ericsson phone R520 was made at frequencies 2402, 2440, and 2480 MHz. First a calibration was made for the three test frequencies, by injecting a 0 dBm CW-signal into a horn antenna feeding the SFC. The average received power was recorded for the reference measurement. Then the phone under test was put in static TX transmission at 2402, 2440, and 2480 MHz and the average received power was recorded. The tests were performed at two different stirrer ratios and the phone was measured in 8 angles in steps of 45 degrees in the horizontal plane. By computing the average value for the 8 angles and adjusting for the calibration, we get the following result.

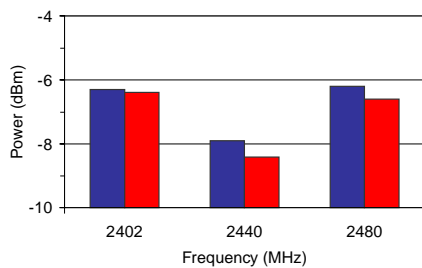


Fig 25: Total radiated power for the R520.

Work is currently in progress to check the correlation from the measurements of Bluetooth phones in cable feed mode and internal transmitter mode measurements in the SFC to measured data in anechoic chambers. More measurements need to be performed. A typical example of the variation of the measured received power as the phone under test was placed in 8 different angles on a dielectric table is shown in Fig 26. The phone was an R520 and the test frequency was 2440 MHz.

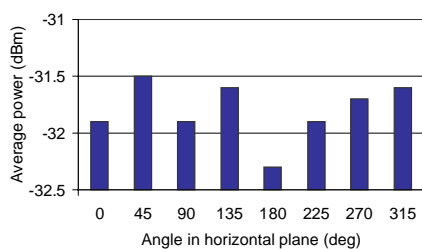


Fig 26: Received average power at 8 different angles in the horizontal plane.

6. Conclusions and further work

Reverberation chambers have some very interesting properties that render them useful tools in both the production and design phases. Growing experience in using RCs and SFCs as well as encouraging results from several research studies enhances our confidence in these techniques. Compared to traditional antenna radiation pattern measurements, the described methods represent improvements in both measurement accuracy and cost. Anechoic chambers are still needed in antenna design though, to fully characterize the radiation properties. Here the RC (or SFC) serves as a complement.

However, our knowledge of these methods is by no means complete. To give a better control of measurement accuracy, there is a need for a better understanding of the factors that affect the number of independent samples, e.g. the design and position of the stirrers. What happens to the field distributions in the chamber when it is loaded by various amount of absorber in different locations is studied, but some work still remains to be done for a full understanding.

When it comes to using an SFC as a tool for simulating realistic environments, this is a field waiting to be explored. The benefit of using an SFC instead of field tests is a much better repeatability. We have only just started with a few experiments here, with promising results. As an example, the temporal characteristics of the chamber is not investigated yet, something which can be of interest when testing parameters that depend on the delay spread. Further, measuring weighted average gain in an SFC should be possible, if the angular distribution and polarization distribution can be adjusted. The requirement is an anisotropical field distribution that corresponds to the weight function and that is independent of the AUT.

7. Acknowledgements

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