Using reverberation chambers for EM measurements

Frank B.J. Leferink

Thales Netherlands
Hengelo, The Netherlands
frank.leferink@nl.thalesgroup.com

University of Twente
Enschede, The Netherlands
frank.leferink@utwente.nl

Abstract - **Reverberation chambers (RC) are being used for several decades. The main advantage is the high field strength which can be generated, with only modest power. In the last few years the use of RCs became much popular, for testing multi-path propagation for communication links, or testing the coupling of complex fields into transmission lines, as well as testing coupling into objects, and measuring the shielding effectiveness of materials. The costs for setting up a conventional RC, with rotating mode stirrers, is low compared to the cost of anechoic chambers. Existing chambers are making use of a paddle wheel to change the resonant modes in the chamber. A transportable reverberation chamber with varying angles between wall, floor and ceiling and with vibrating walls has been used for testing of many systems. Inside this Vibrating Intrinsic Reverberation Chamber (VIRC) a diffuse, statistically uniform electromagnetic field is created without the use of a mechanical, rotating, mode stirrer. This chamber results in a better homogeneity and increased field strength compared to conventional mode stirred reverberation chambers. The use of flexible material to build the VIRC is making a test facility at even lower cost possible. Furthermore such a VIRC can be built around a test object, and the test object is not to be moved to an anechoic chamber. This can reduce test costs for complex systems. The basic principles of RC and VIRC are explained, and several applications shown.**

1. INTRODUCTION

A reverberation chamber generally consists of a rectangular test room with metal walls and one or two mode stirrer(s), usually in the form of a large paddle, near the ceiling of the chamber, as shown in Figure 1.
The equipment under test (EUT) is placed in the chamber and exposed to an electromagnetic field while the stirrer slowly revolves. The average response of the EUT to the field is found by integrating the response over the time period of one revolution of the stirrer. The metal walls of the chamber allow a large field to be built up inside the chamber. The EUT is therefore exposed to a high field level consisting of several different polarizations [1,2,3,4]. The most significant quality of a chamber is its ability to create very high electromagnetic field strength.
This provides an electromagnetic environment which is:

- Spatially uniform: the energy density in the chamber is everywhere the same:
- Randomly polarized: the phase, and thus polarization, between all the waves, is randomly distributed
- Isotropic: the energy flow in all directions is the same.

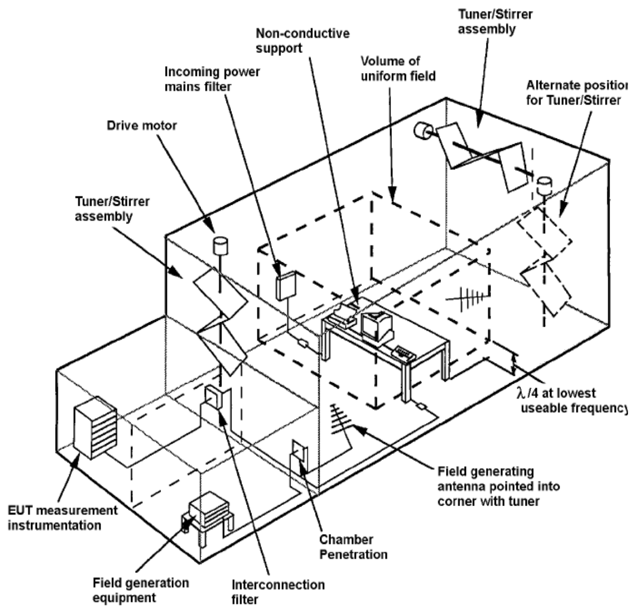

Figure 1: The reverberation chamber as described in IEC-61000-4-21

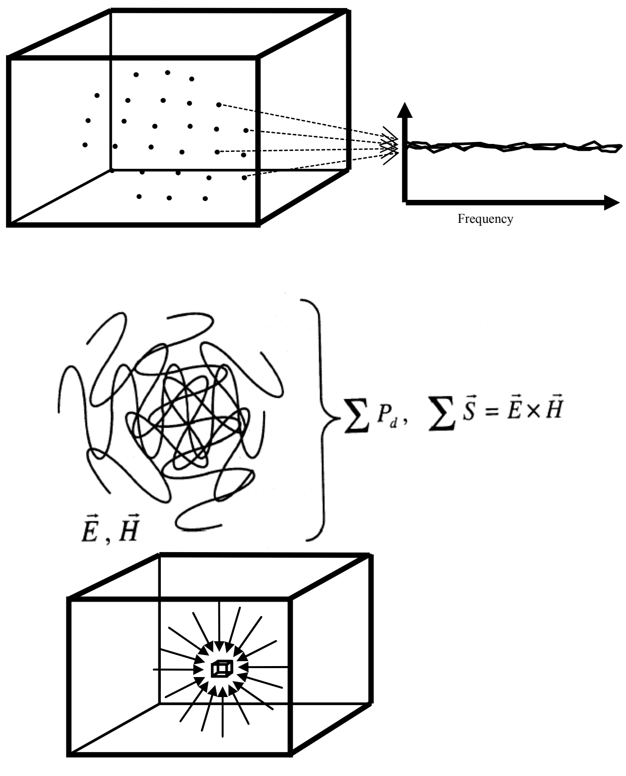

Figure 2: Uniform, randomly polarized and isotropic

In recent years the use of a reverberation chamber to mimic multiple reflections and propagation in enclosed environments gained interest.

It has been shown [5, 6, 9, 10, 11, 12, 13, 14] that the variation of the boundary conditions deviate the resonant behaviour of a reverberation room. For proper mode separation we need asymmetric structures. On the other hand, circular structures result in focussing of rays and thus degrade the spatial uniformity. Wall irregularities and wall-floor angle irregularities show that the spatial uniformity and isotropicity can be improved.

By changing all angles of the wall-floor-ceiling of a reverberation room in a high velocity compared to the classic mode stirrer in mode stirred reverberation chambers we can use all beneficial effects. This technique is called Vibrating Intrinsic Reverberation Chamber (VIRC). The VIRC is a reverberation chamber where the walls are made of flexible conducting material. It is mounted in a rigid structure and connected to that structure via flexible rubber strings, as shown in Figure 3.

Figure 3: The VIRC: a flexible tent with irregularly shaped walls. The field is stirred by moving the walls

By moving one or more ridges or one or more walls the modal structure inside the chamber is changed. Because the frequency shift is much larger compared to what is possible with a conventional mode stirrer, the frequency range of the chamber is extended to lower frequencies compared to conventional (mode stirred) reverberation chambers with equal dimensions. Note the natural corrugation of the flexible walls in Figure 3 which is beneficial for the spatial uniformity too. Another advantage is that the flexible chamber can be erected inside a standard anechoic chamber where the EUT has been installed for standard EMI tests. Furthermore the VIRC does not need extra space inside the laboratory: it can be folded and put away fast. The most important advantage of the flexible structure of the VIRC is that it can be installed in-situ. The technique has been described in [16, 17, 18 and 19].

2. IN-SITU TESTING USING A VIRC

A VIRC has been designed and built for in-situ testing of an active phased array antenna. Pictures of this VIRC are shown in Figure 4. The dimensions of this VIRC are 5x3x3m, resulting in a first resonance frequency of 58 MHz. The VIRC was fabricated by a tent manufacturer from the basic material we supplied. The walls were made from metallised (copper) fabric. The seams were overlapping, using double stitch. The interface with the EUT was made via a around electrical connection, as shown in Figures 4 and 5.

Figure 4: The VIRC as built for in-situ testing

Figure 5: Detail of interface with EUT

All cable feedthroughs are either a waveguide-beyond-cutoff penetration for non-conducting parts, or a circumferencial electrical connection for all conducting parts, such as cables. The vibration has been created by using automobile wiper motors with an excentric arm which is connected to the VIRC by means of an elastic rope.

The VIRC has been validated before actual EMI test were performed. Details can be found in the references. An important parameter is the spatial field uniformity (SFU). The SFU gives the ability to generate an isotropic, randomly polarised field, which is stochastic equal in the whole volume of the chamber, except near the walls. In Figure 6 the vectorial sum of the magnitude of the field strength in the three orthogonal directions, with respect to the mean field strength, per measuring position has been drawn as function of the frequency. From this figure we can conclude that the field strength is within the 0-6dB range for frequencies higher than 150 MHz.

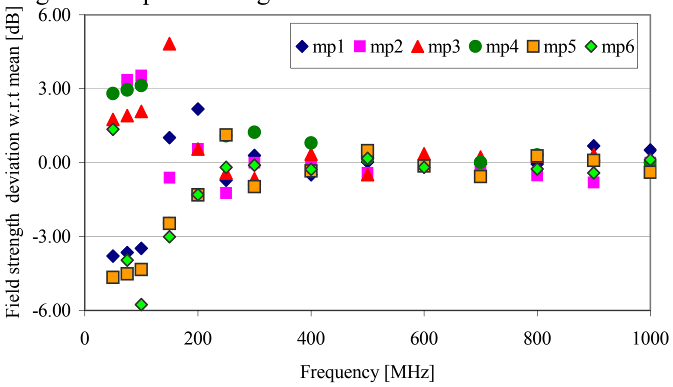

Figure 6: Field uniformity, 6 measuring positions

The Equipment Under Test (EUT) is the multifunctional Active Phased Array Radar (APAR). A picture taken in front of the EUT is presented in Figure 7. Note that the EUT is part of the wall of the VIRC. The VIRC was attached in front of the radar antenna making an electrical connection over the whole circumference, as shown in Figure 7.

Figure 7: Test set-up: EUT in the VIRC, with an antenna placed in foreground

Radiated emission measurements and radiated immunity measurements have been performed. The field strength has been measured as function of frequency. Average and peak detectors were used simultaneously. The measured field strength was corrected by means of the experimentally obtained Chamber Factor:

$$E = E_{measured} - CF$$

For frequencies below 10 MHz the CF equals 0. The radiated emission measurements performed in this frequency range therefore result in the same field strength as would be obtained in an anechoic chamber or free space environment. For frequencies above 10 MHz, the chamber factor is positively valued. Therefore the CF corrected field strength in the VIRC is much lower compared to the field strength which could have been measured in a free space environment!

Ambient measurements have been carried out to determine if the VIRC shielding effectiveness was retained. Only EMI receiver noise has been measured. This was also the case with the EUT activated. This means that the radiated emission was below the receiver noise upto 1 MHz, and even 20dB below receiver noise for frequencies higher than 10 MHz.

Inside the VIRC the maximum power, as available in our laboratories, was generated, for immunity testing. This includes for instance 2500 W in the frequency band 10kHz-200MHz, 500 W 200 MHz- 1 GHz, and 200 W in the frequency band 1-18 GHz.

The generated field strength can be calculated via the chamber gain, or obtained via measurements. The measured maximum average field strength was beyond 1000 V/m, while the maximum peak field strength was nearly 10.000 V/m. The EUT did not show degradation of performance.

3. IN-SITU TESTING USING A VIRC, SOME OTHER EQUIPMENT

Many other equipment has been tested using several versions of the VIRC, often made particularly for the test campaign. Some products are shown in the pictures below.

Figure 8: Radar system tested with the VIRC (with CEO of Thales, Denis Ranque)

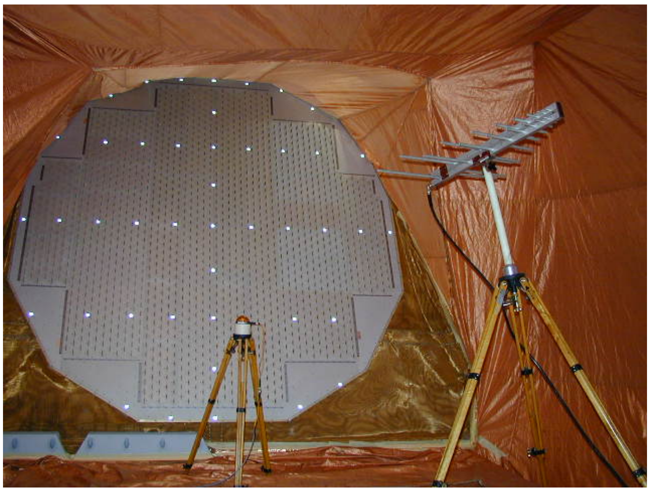

Figure 9: Radar system tested with the VIRC

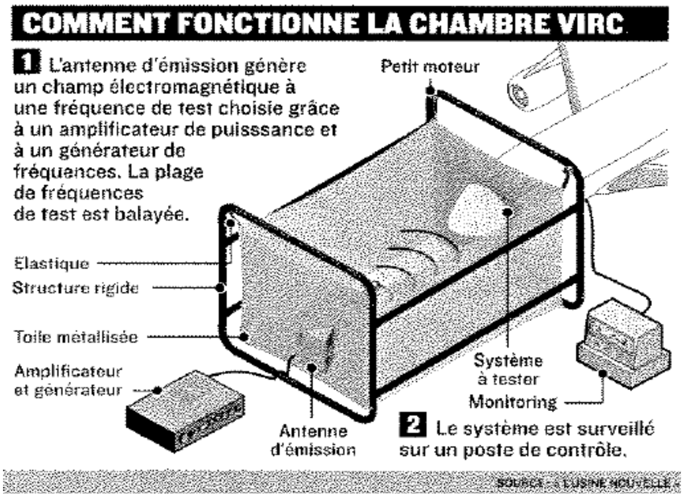

Figure 10: Cockpit tested with the VIRC

4. DUAL VIRC FOR SHIELDING EFFECTIVENESS TESTING

Two Vibrating Intrinsic Reverberation Chambers (VIRCs) with a common wall is shown in Figure 11. A Device Under Test (DUT) can be mounted in this common wall, by means of standard hatches. The electromagnetic fields are stirred by moving the walls of both VIRCs. The walls can be moved by means of a simple motor with a crankshaft and rubber strings. The VIRC has a major advantage over conventional mode stirred chambers, because the modes are changed much better at lower frequencies, and they are changed faster. The two small VIRCs are made of copper cladded cloth that is sewn together, creating two boxes. These two boxes are mounted in two metal frames by means of spiral springs. On one end, both boxes are ending on a metal plate. One of the metal plates contains a standard hatch that normally is used in the wall between the control room and anechoic room of the EMC measurement facility. The other plate contains a knife-edge that fits the hatch of the first VIRC. The hatch is used to mount the DUT.

The Q-factor of both VIRCs is this high that only a moderate input power level is needed to create high level field strengths inside VIRC 1, using a broadband microwave horn antenna. The shielding of both VIRCs is high and therefore small signal levels can be detected in VIRC2. This means that high dynamic range shielding effectiveness (SE) measurements can be carried out by means of this setup. As an example, only the output power of a (scalar) network analyzer is sufficient for achieving over 100dB dynamic range.

Figure 11: Dual VIRC test setup

The shielding effectiveness of many samples has been measured , including composite boxes with metallic loading and several metalized fabrics. Also the SE of panels with gaskets have been measured.

4. BUILDING A VIRC

A reverberation chamber can be built easily. The basic material can be bought from several suppliers. We used Shieldex Kassel from Statex in Germany. The costs are approximately €35,- per square meter. The VIRC (we often say 'tent') is sewed together by a regular tent manufacturer. The best ratio for length, width and depth is 5x4x3 m (or 9x8x7 m). These figures are less dividable which results in a better field homogeneity at low frequencies. Considering a 5x4x3 m tent, you need 94 m^2. Total costs will be approximately € 5000,-.

The tent is hung via elastic ropes in a construction. This can be basic construction worker scaffolding. Experience showed that only 2 corners have to be moved. And if the experiments are performed outside, the wind (in The Netherlands) is sufficient to create sufficient movements of the tent.

The VIRC is calibrated according the basic procedures described in the IEC 61000-4-21 standard. This means performing a lot of measurements and combining the results in such a way that a probability density curve can be created.

In practice you are interested in the differences with respect to a conventional test setup. Therefore two antennas are placed in front of each other in a free space environment (open area, or full anechoic room), and a two-port measurement is performed. Then the same setup is moved to the VIRC and the measurement is repeated. Then the test equipment should be in max-hold with a measurement time larger than the movement of the VIRC. This is in practice less than several 10ms. The difference between the two measurements is the chamber gain. When performing emission measurements this chamber gain should be subtracted from the measured level in order to obtain the free space values.

The VIRC has been used to test several complex systems. The VIRC is in daily use for performing transfer ratio measurements on gaskets, seals, hatches, feedthroughs etc. Other interesting applications of reverberation chamber technique are the coverage of wireless systems (used for video streaming), and understanding and simulating multiple reflections, by using the RC technique, or the effect on MIMO systems in these semi-enclosed environments

5. Conclusion

A transportable reverberation chamber to create a spatial uniform and isotropic electromagnetic field is the Vibrating Intrinsic Reverberation Chamber (VIRC). The major benefits of the VIRC are the high field strength which can be generated for immunity testing. The increased dynamic range for emission testing is also beneficial, as well as the lower useable frequency compared to conventional fixed wall reverberation chamber testing. Several VIRCs have been developed for in-situ measurements on many systems, and every VIRC has been validated prior to use. Examples have been shown in this paper. Other applications involve shielding effectiveness testing, coupling testing and applications for multipath propagation.

ACKNOWLEDGEMENTS

This research project has been supported by a Marie Curie Transfer of Knowledge Fellowship under the Sixth Framework Programme of the European Union, contract number 042707.

References

[1] H.A. Mendes, A New Approach to Electromagnetic Field Strength Measurements in Shielded Enclosures, Wescon Technical Papers, Western Electronic Show and Convention, Aug. 20-23, 1968, LA

[2] P. Corona, G. Latmiral, E. Paolini, L. Piccioli, Use of a reverberating enclosure for measurements of radiated power in the microwave range, IEEE Transactions on Electromagnetic Compatibility, May 1976, p.54-59.

[3] M.L. Crawford, G.H. Koepke, Operational Considerations of a Reverberation Chamber for EMC immunity Measurements - Some Experimental Results, IEEE Symposium on EMC, 1984.

[4] M.L. Crawford, G.H. Koepke, Design, Evaluation and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/ Vulnerability Measurements, NBS Nt 1092, 1986.

[5] F.B.J. Leferink, J.C. Boudenot, W. van Etten, The Vibrating Intrinsic Reverberation Chamber: an Optimal Use of Geometrical Change in Boundary Conditions, Report University of Twente, EL-TEL, sept. 1999.

[6] Y. Huang, Conducting triangular chambers for EMC measurements, Meas.Sci.Technol, 10, 1999, L21-L24

[7] D.A. Hill, Electromagnetic theory of reverberation chambers, NIST Technical note 1506, dec. 1998.

[8] J.M. Dunn, Local, High-Frequency Analysis of the Fields in a Mode-Stirred Chamber, IEEE Transactions on Electromagnetic Compatibility, Febr. 1990, pp. 53-58.

[9] F.B.J. Leferink, High field strength in a large volume: the intrinsic reverberation chamber, IEEE Symp. on EMC, 1998, pp. 25-27.

[10] A.C. Marvin, J.A.S. Angus, J.F. Dawson, J. Clegg, 'Enhancements to Stirred Mode Chambers by the Use of Pseudo-Random Phase reflection Gratings', Int. Symposium on EMC, Rome, Italy, 1994, pp. 218-221.

[11] J. Clegg, A.C. Marvin, J.A.S. Angus, J.F. Dawson, 'Optimal Phase Reflection gratings and the Effect on Fields in a Mode Stirred Chamber', Int. Symposium on EMC, Rome, Italy, 1996.

[12] M. Petirsch, A. Schwab, 'Optimizing Shielded Chambers Utilizing Acoustic Analogies', IEEE Symposium on EMC, 1997, pp. 154-158.

[13] E.A. Godfrey, Effects of corrugated walls on the field uniformity of reverberation chambers at low frequencies, IEEE Symposium on EMC, 1999, pp. 23-28.

[14] Y. Huang, D.J. Edwards, An investigation of electromagnetic fields inside a moving wall mode-stirred chamber, IEE Conference on EMC, Edinburgh, 1992.

[15] M. Hatfield, Visualisation of Electromagnetis Fields in a Rev. Chamber, Experiments Session IEEE EMC Symposium 1998.

[16] F.B.J. Leferink, W.C. van Etten, The Vibrating Intrinsic Reverberation Chamber, IEEE Tr. on EMC, 2001.

[17] F.B.J. Leferink, J.C. Boudenot, W.C. van Etten, Experimental Results Obtained in the Vibrating Intrinsic Reverberation Chamber, IEEE Symposium on EMC, Washington D.C. 2000.

[18] F.B.J. Leferink, W.C. van Etten, Optimal Utilization of a Reverberation Chamber, 4th European Symposium on Electromagnetic Compatibility, Brugge, 2000.

[19] Patent WO34795, NL1010745, AU18605 etc, Test Chamber, Hollandse Signaalapparaten B.V., Netherlands.