High Field Strength in a Large Volume:
The Intrinsic Reverberation Chamber

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Abstract: An intrinsic reverberation chamber with non-parallel walls, ceiling not parallel to the floor, at most two walls placed perpendicular and with fixed field diffusers is presented. Inside this room no eigenmodes exist and a diffuse, statistically uniform field is created without the use of a mechanical mode stirrer. As a result, test time can be reduced drastically compared to mode stirred reverberation chambers.

INTRODUCTION

One of the main issues of EMI testing is the establishment of a high field strength in a large volume at reasonable cost. The creation of a field strength of more than 600V/m (HIRF) is extremely difficult and costly. The reverberation chamber is one of the possible test techniques capable of creating high field strengths.

The reverberation chamber generally consists of a rectangular test room with metal walls and a stirrer, usually in the form of a large paddle, near the ceiling of the chamber. The equipment under test (EUT) is placed in the chamber and exposed to an electromagnetic field during which time 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 cavity allow a large field to be built up inside the chamber. At the same time, the stirrer smooths out the sharp nulls of the field; these nulls are usually present in such a resonant structure. The EUT is therefore exposed to a high field level consisting of several different polarisations [NBS Note 1092, Crawford, Hatfield].

REVERBERATION ROOM BASICS

When electromagnetic energy is fed into a (rectangular) chamber a number of different chamber resonances, sometimes referred to as normal modes or eigenmodes, are activated. The type of mode excited depends on how the initial wave is reflected and returns to the point of excitation in the same phase and direction as the initial wave. In a rectangular chamber the simplest eigenmode is the axial mode in which the component waves travels along one axis, one dimensional, parallel to two wall pairs as shown in Figure 1. The power density in the chamber varies as shown by the curve.

Figure 1: Electric field pattern, axial mode (4,0,0)

Another type of eigenmode is one in which the component waves are parallel to one pair of walls but are oblique to the other two pairs, two dimensional, and is termed a tangential mode. Figure 2 shows this type of eigenmode.

Figure 2: Electric field pattern, tangential mode (2,1,0)

The third type of an eigenmode is one in which the component waves are parallel to none of the three wall pairs and is termed oblique mode, as shown in Figure 3.

Figure 3: Electric field pattern, oblique mode (2,1,1)
The resonant frequency $f$ of each eigenmode in a rectangular chamber can be calculated from

$$ f = \frac{c}{2} \sqrt{\left(\frac{n_a}{l}\right)^2 + \left(\frac{n_b}{w}\right)^2 + \left(\frac{n_c}{h}\right)^2} \quad [\text{MHz}] \quad (1) $$

where

- $f$ is the frequency [Hz]
- $c$ is the speed of the electromagnetic wave [m/s]
- $l$ is the length of the chamber [m]
- $w$ is the width of the chamber [m]
- $h$ is the height of the chamber [m]
- $n_a, n_b, n_c$ are integer numbers

To evaluate the frequencies for axial modes, two of the integers are set to zero while for the tangential and oblique modes, one of the integers and none of the integers are set to zero respectively. It can be shown that the axial and tangential modes dominate at low frequencies while the oblique modes dominate at high frequencies.

The total number of chamber resonances $N$ occurring in a rectangular chamber in the frequency range $\theta$ to $f$ is [Bruel & Kjaer]:

$$ N = \frac{4\pi}{3} V + \frac{\pi}{4} S + \frac{L}{2} f - \frac{f^3}{c^3} + \frac{f^2}{c^2} + L $$

where

- $V$ is the volume [m$^3$]
- $S$ is the surface area [m$^2$]
- $L$ is the length of the room edges [m]

In statistical treatment of electromagnetics it is assumed that the power density is diffuse, i.e.:

- the energy density in the chamber is uniform everywhere,
- the energy flow in all directions is the same,
- the polarisation between all waves is random and
- the phase between all waves is random.

These requirements are fulfilled if there are a large number of eigenmodes in the room, which is the case above a certain frequency [NBS Note 1092, Crawford, Hatfield].

In order to improve the uniformity a mode stirrer is commonly applied for the following reasons:

- the stirrer reduces the spatial variance of the field strength in the chamber which improves the accuracy of estimates of the space-averaged field strength;
- the rotating stirrer produces a modulation of the power flow from the source into the chamber which usually makes the field strength of the source (at low frequencies) somewhat less dependent of source position in the reverberation chamber.

The effectiveness of mode stirrers depends primarily on their size. The stirrer should, therefore, be as large as the chamber dimensions permit [Bruel & Kjaer, ISO 354, Wu].

ANALOGY ACOUSTICS AND ELECTROMAGNETICS

The reverberation chamber modal theory as presented is completely equal to that used in acoustics by replacing the words

- room with chamber (more common in electromagnetics)
- diffuser with mode stirrer.

Both worlds are similar, despite the vector nature of electromagnetic waves compared to scalar acoustic waves. Reverberation rooms for acoustics were investigated by Sazinc (1922), Knudsen (1932) and Briël (1951) among others.

THE INTRINSIC REVERBERATION CHAMBER

The response of an EUT to the field inside the conventional reverberation chamber is found by integrating the response over the time period of one revolution of the stirrer. In a large reverberation chamber a large stirrer has to be applied in order to guarantee a sufficiently uniform field. The rotation time of this large and slow stirrer will determine the test time completely.

A rectangular reverberation chamber without and with a stirrer is drawn in Figure 4 and 5 respectively. A tangential mode has been drawn in these figures.

![Figure 4: Tangential mode in reverberation room without mode stirrer](image)

![Figure 5: Tangential mode in reverberation room with mode stirrer](image)
Instead of using a rectangular chamber with a mechanical mode stirrer a chamber with
- no walls parallel,
- at most one wall placed perpendicular to another wall,
- dimensions not being a multiple of each other (i.e. \( l=3 \), \( w=4 \) and \( h=5 \)) and
- fitted with curved, fixed diffusers with a surface area of at least 25% of the total chamber area,

results \textit{instantaneously} in a uniformly distributed field. Note: for wall, read wall, ceiling or floor. As a result, the test time decreases drastically: instead of a dwell time equal to at least one rotation of the mode stirrer in a conventional reverberation chamber, the dwell time in the intrinsic reverberation chamber is equal to the dwell time of the EUT.

An intrinsic reverberation chamber has been drawn in Figure 6, side view, and Figure 7, top view.

The intrinsic reverberation room has been used by our laboratory over a long period for \textit{acoustic} investigations. The dimensions of the room are approximately 5.5x6x4.8m, with a volume \( V=164\,\text{m}^3 \) and a surface \( S=180\,\text{m}^2 \). The chamber is constructed out of concrete. The walls will be lined with copper foil in order to upgrade the chamber from acoustic to electromagnetic test chamber. Test results were not available before the publication date of this paper.

**QUALITY FACTOR, ANALOGY ACOUSTICS**

The most common figure of merit when discussing reverberation chambers is the \( Q \) of the chamber, which is defined as the stored energy in the chamber divided by the power that must be injected into the chamber, multiplied by the angular frequency, \( \omega=2\pi f \), of operation. It is desirable to make a chamber with a \( Q \) as large as possible in order to give a high field strength. The theoretical expression for the first-order \( Q' \) of a rectangular chamber is:

\[
Q' = \frac{3V}{2\delta_s \mu_r S}
\]

(3)

where:
- \( V \) volume [\( \text{m}^3 \)]
- \( S \) surface [\( \text{m}^2 \)]
- \( \delta_s \) skindepth [\( \text{m} \)]
- \( \mu_r \) relative permeability of wall

This was derived by writing the fields inside the chamber as a series of cavity modes and then averaging over the ensemble of all such modes after assuming that an equal amount of energy was in each mode. The modal method cannot be applied to shapes other than those with separable geometries [Dunn]. The no-parallel walls of the intrinsic reverberation chamber increase the modal density but restrict the use of modal theory.

Dunn and Hill [Dunn, Hill 96] showed that for arbitrarily shaped cavities an ensemble of plane waves can be used for calculating the \( Q \), resulting in the same equation. The suggestion on the use of non-parallel walls for reverberation chambers for electromagnetic tests is therefore also implicit in [Dunn, Hill 96].

In analogy with acoustics, where the reverberation time \( T_{60} \) is the figure of merit for a reverberation chamber, using Sabine’s Equation:

\[
T_{60 \, \text{dB}} = \frac{0.161 V}{\alpha S} [\text{s}]
\]

(4)

where
- \( T_{60} \) time wherein the acoustic noise pressure decreases 60dB, after stopping the noise source
- \( \alpha \) absorption coefficient of the walls

we can also use the reverberation time of an electromagnetic reverberation chamber:

\[
\tau = \frac{Q}{\omega} = \frac{3}{2\delta_s \mu_r \omega} \frac{V}{S}
\]

(5)

electromagnetics

as shown by [Richardson, Hill 96]
This relationship implies that one can determine the power density in a reverberation chamber simply by measuring the reverberation time and then measuring the net power injected into the chamber. It is not necessary to use a calibrated reference antenna or field probes.

CONCLUSION

A test technique for high power electromagnetic immunity/susceptibility testing has been described which makes it possible to decrease test time drastically: instead of a dwell time equal to at least one rotation of the mode stirrer in a conventional reverberation chamber, the dwell time in the novel chamber is equal to the dwell time of the EUT.

REFERENCES/BIBLIOGRAPHY

In this short bibliography publications on reverberation rooms as used in acoustics and reverberation chambers as used in electromagnetics are included.

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