

Stadium Reverberation Chamber for High-Intensity Isotropic Field EMC Testing at Microwave Frequencies

Luk R Arnaut

luk.arnaut@npl.co.uk

National Physical Laboratory — Center for Electromagnetic Metrology
Teddington, Middlesex TW11 0LW, United Kingdom

Abstract

Measurement results, statistical data analysis and chamber characteristics are reported for the *NPL* untuned 3D stadium reverberation chamber at 2.5, 8.2 and 18GHz. Coefficients for field anisotropy and field inhomogeneity enable the quality of the reverberant field to be quantified. Spectral analysis is used to calculate the normalized spectral bandwidth and the characteristics of the underlying stochastic model for the stirring process. Statistics of level crossings and excursion lengths show reasonable agreement with theoretically predicted values.

INTRODUCTION

Conventional EM reverberation chambers are typically rectangular or cubic cavities in which one or more rotating paddle wheel(s) produce(s) changes in the EM boundary conditions (mechanical stirring) so as to generate a statistically isotropic and homogeneous field of high intensity ($> 100\text{V/m}$). Alternatively, a CW source can be swept in phase or frequency to the same effect (electronic stirring). In contrast, the *NPL* untuned 3D stadium reverberation chamber has been designed around an intrinsically ergodic stadium cavity, with supporting untuning wave diffractors. It thus combines properties of well-known untuned cavity resonators with characteristics of regular ergodic ('chaotic') cavities, as recently studied in the theory of quantum chaos ('quantum billiards').

CONFIGURATION

The chamber consists of two aluminium concave hemispheres of average radius 350mm, connected by a central octagonal cylindrical section of height 175mm (Fig 1). On the inner wall, smaller convex hemispherical corrugations of various sizes exist with radii ranging between 5mm and 40mm. These corrugations es-

tablish the inner radius of the cavity as a spatially random variable ('untuned cavity'). By making the lower hemisphere rotatable, the corrugations provide a mechanical stirring capability ('wall stirring'). As convex diffractors, the corrugations also reduce the field inhomogeneity. Their wave dispersing properties enhance the ergodic properties of the chamber considerably because their randomized positions and sizes help to preserve the ergodicity in three dimensions.

The central cylindrical section transforms the otherwise integrable (spherical) cavity into a nonintegrable 3D Bunimovich stadium [1, 2]. The value of the stadium parameter, i.e. the ratio of the height of the cylindrical section to the cavity diameter, can be increased at will and optimized by inserting an extra cylindrical section at the equator. The upper hemisphere, the coupling plates in the cylindrical section and the positions of the horns remain fixed at all times during a scan by the lower hemisphere with respect to an inertial frame of reference. Reverberation is achieved by spinning the lower hemisphere around a vertical axis. The present set-up allows for this in both discrete ('mode tuned') or continuous ('mode stirred') mode. Here we report on results for discrete (mode tuned) operation only. For frequencies in excess of 2.5GHz, wall stirring has been found to produce an efficient change in the EM boundary conditions. It also provides a comparatively large usable volume relative to the physical volume because obstructive paddle wheels are no longer required.

AUTOCORRELATION STATISTICS

A total of $M = mN = 1,500$ samples at angular equidistant wall steps of 2.60mrad were taken at 8.2GHz in mode tuned operation. The autocorrelation function (acf) $\rho(\tau)$ for wall stirrer positions τ is typically used to analyze tuner sweep data for linear

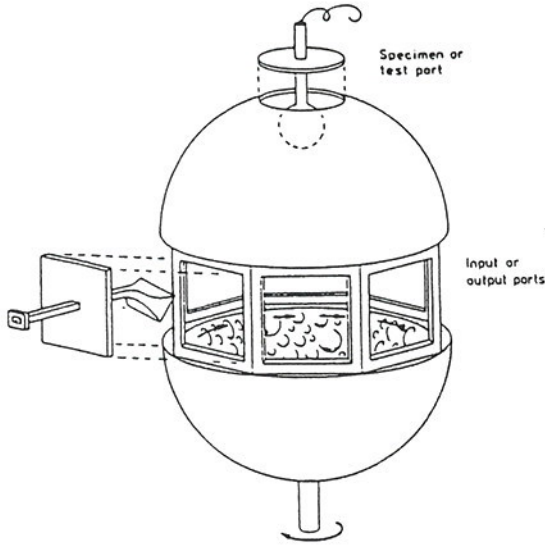


Figure 1: The NPL untuned 3D stadium reverberation chamber

dependence and correlation length. In addition, the statistical properties of the acf itself can be used to express data correlation in a more rigorous manner, by considering the distribution function of the standardized correlation coefficient $r(\tau) = [\rho - \langle \rho \rangle] / \sigma_\rho$ for $\tau \neq 0$ [4, 5]. This has the advantage of enabling confidence and tolerance limits for the correlation coefficient and correlation length to be established, together with the use of tests for goodness-of-fit, and to provide a direct link with spectral properties. Provided the number of data points remains sufficiently large, the cumulative distribution function (cdf) of the acf tends to the distribution of the acf of white noise, i.e. a Gauss normal distribution, as the subsampling rate $1/m$ is reduced where m ($m \geq 1$) represents the decimation factor obtained from the acf itself.

FIELD ISOTROPY

Various 'quick tests' applied to the stirrer data suggest that the cavity is reverberating well at 2.5, 8.2 and 18GHz (Tbl 1). However, more detailed study shows that such tests are not always reliable. Even visual inspection of the match between the measured and theoretical cdf of normalized received power can be deceptive in certain cases. Moreover, these criteria are only *indirect* measures for field isotropy, which hamper a proper identification and intercomparison of true reverberation performance between different rooms. Hence the need for more universal measures of field isotropy and field homogeneity. In [3], a coef-

ficient of planar field anisotropy:

$$A_{xy} \triangleq \frac{|E_x|^2 - |E_y|^2}{|E_x|^2 + |E_y|^2} = \frac{(P_x/P_{in}) - (P_y/P_{in})}{(P_x/P_{in}) + (P_y/P_{in})}, \quad (1)$$

was introduced, which is a self-normalized dimensionless measure. It makes the quantification of field anisotropy independent of the level of the local power density and field inhomogeneity, which can be studied separately. For an arbitrary stirrer position, the sign of A_{xy} indicates the dominant direction of the field in the oxy plane for each position of the stirrer. It can be shown [3] that A_{xy} exhibits a uniform pdf $f_{A_{xy}}(a_{xy}) = 1/2$, ranging between -1 and $+1$ if perfect field isotropy, i.e. ideal reverberation, holds. The total mean field anisotropy A can subsequently be defined from three planar field anisotropy measurements as an rms value of the individual planar field anisotropies. For an ideal reverberation chamber, the values of all $\langle A_{\alpha\beta} \rangle$ and $\langle A \rangle$ decreases to zero as $N \rightarrow \infty$: the phasor sum approaches null, in the mean, with each additional field phasor. Close agreement has been demonstrated between measured and ideal cdf $F_{A_{xy}}(a_{xy})$ [4]. The dependence of the measured $\langle A_{xy} \rangle$ on the number of stirrer positions N shows the reverberation process at work (Fig 2): as the sample size N increases, $|\langle A_{xy} \rangle|$ decreases in the mean, i.e. the mean planar field isotropy increases. The stirring process can be terminated as soon as some a priori chosen (low) mean level for $|\langle A_{xy} \rangle|$ has been reached with confidence. In our chamber for $N = 600$ at 8.2GHz, $|\langle A_{xy} \rangle| = 0.0046 \pm 0.048$, corresponding to $[(-23.42) \pm (-13.16)]$ dB, at the 95% confidence level.

The parameter $\langle A_{xy} \rangle$ has been found to be a more sensitive and consistent quality measure for statistical field isotropy than e.g. cdf residuals or cdf mismatch coefficients between theoretical χ^2_2 and measured cdfs of the insertion loss p [4]. Further analysis of additional sets of stirrer data has shown that 'good' stirring corresponds to $|\langle A_{\alpha\beta} \rangle| < -20$ dB, as an indicative figure.

FIELD HOMOGENEITY

Similar to A_{xy} , a field inhomogeneity coefficient $I_{\alpha i}$ can be defined for E_α ($\alpha = x, y, z$ or *total*) at two different measurement locations $\underline{r}_1$ and $\underline{r}_2$ defining a direction $\underline{i}$ parallel to $\underline{r}_2 - \underline{r}_1$ [3]:

$$I_{\alpha i}(\underline{r}_1, \underline{r}_2) \triangleq \frac{|E_\alpha(\underline{r}_1)|^2 - |E_\alpha(\underline{r}_2)|^2}{|E_\alpha(\underline{r}_1)|^2 + |E_\alpha(\underline{r}_2)|^2}$$

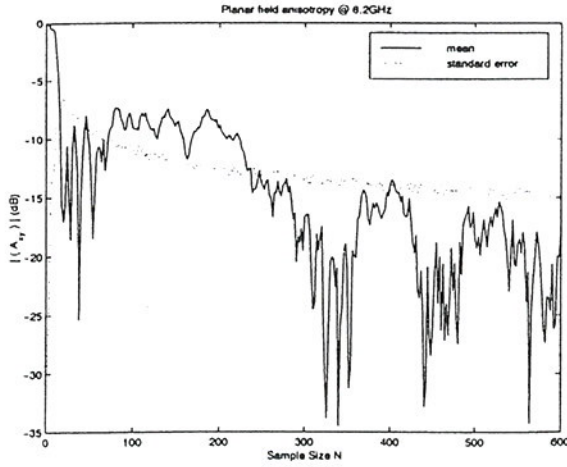


Figure 2: Planar field anisotropy for wall stirring

$$= \frac{[P_{\alpha}(r_1)/P_{in}] - [P_{\alpha}(r_2)/P_{in}]}{[P_{\alpha}(r_1)/P_{in}] + [P_{\alpha}(r_2)/P_{in}]} \quad (2)$$

The total field inhomogeneity I_i along $\underline{l}_i$ can be defined similar to A and then averaged over all directions $\underline{l}_i$ to yield the total field inhomogeneity I [4]. A very similar dependence of $\langle I_{\alpha i} \rangle$ on N is found as compared to $\langle A_{\alpha \beta} \rangle$. In fact, it can be shown that field isotropy and field homogeneity are statistically highly correlated quantities [4].

In addition, we made measurements at various locations parallel to the equatorial plane, by shifting the receiving horn antenna in radial direction through different coupling plates. Fig 3 shows the radial dependence of $\langle p \rangle$, with and without wall stirring, demonstrating that mode tuned stirring assists in reducing the field inhomogeneity. Results are based on 600-sample data sets per location. The average insertion loss $\langle p \rangle = \langle P_{Rx}/P_{Tx} \rangle = -21.22\text{dB}$ was found to have a spatial variation of only 2.2dB (i.e. $\pm 1.1\text{dB}$) across all measurement locations. The spatially averaged measured max-to-mean ratio is 7.42 ± 0.31 and the theoretical max-to-mean ratio is 7.25 ± 0.05 , all at the 95% confidence level.

Mechanical and electronic source stirring have equally been investigated. While showing a stirring capability in principle, their performance at 8.2GHz was found to be inferior to wall stirring, with the present set-up. Nevertheless, these techniques certainly show potential, at least, for increasing stirring performance when used in a hybrid stirring method [4].

TIME DOMAIN ANALYSIS

Pulse excitation has been used with mode stirred and mode tuned operation to analyze the reverberation

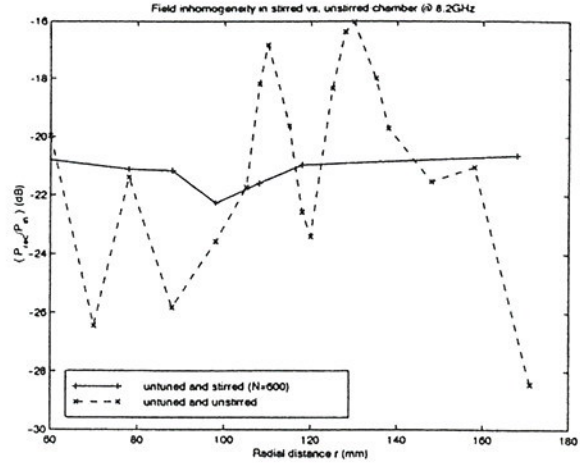


Figure 3: Radial dependence of mean insertion loss

process and quantify the quality factor. Whereas the early and intermediate pulse decay show the familiar exponential decrease with time, the late decay is found to be characterized by a t^{-1} time dependence, as a result of the intrinsic cavity ergodicity. Such a late time dependence has been confirmed by theory and can be attributed to the 'bouncing ball' modes [2].

SPECTRAL CHARACTERISTICS

Spectral analysis of the stirrer data shows that the normalized power spectral density, radial spectrum and radial spectral density for the stirrer data all show Gamma distributions. The power spectral density is found to conform to good approximation to a 1st order autoregressive (exponential) process: $g(\omega) = g_0 \exp(\alpha\omega)$ with $\alpha < 0$. The measured values of the spectral bandwidths δ and ϵ were found to increase, in the mean, with increasing N (Fig 4), but to decrease somewhat towards the center of the cavity for arbitrary N (Fig 5). Cross spectra associated with stirrer data for two mutually orthogonal directions of polarization are found to be real and to conform to the same exponential process.

THRESHOLD CROSSINGS. EXCURSIONS

Statistics of upward level crossing frequency, threshold exceedance frequency and excursion length for uninterrupted high field strength exposure are all found to be in good agreement with predicted values [4], particularly for relatively high threshold values, which are of greatest practical interest. This correspondence serves as an indirect confirmation that the measured pdf is indeed close to that for a 3D homo-

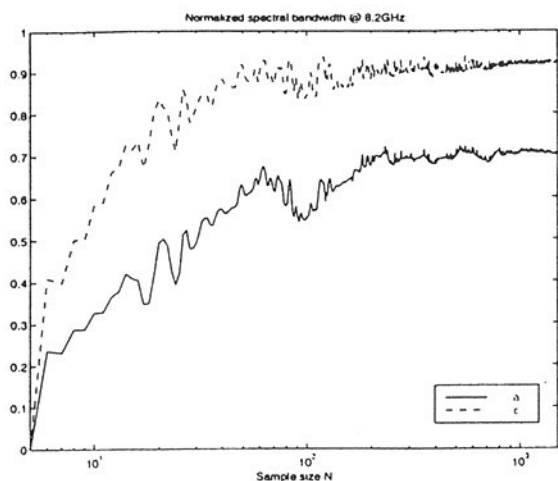


Figure 4: Dependence of δ and ϵ on N

geneous isotropic field.

MAXIMUM FIELD STRENGTH

At 8.2GHz, the maximum rectilinear field strength for 50mW nominal input power was estimated at 70V/m. Maximum values w of the mean normalized field strength can be reasonably well predicted. Fig 6 compares our result, $w = \sqrt{(4/\pi) \ln(N)}$ [4], with other expressions earlier suggested in the literature, showing somewhat better correspondence with measured values for $50 < N < 200$. When additional information is available on the actual spectral bandwidth of the stirring process, it may be expected that still more accurate predictions can be made.

CONCLUSION

The NPL untuned stadium reverberation chamber is found to provide a compact and efficiently stirred cavity for EMC testing at microwave and millimeter-wave frequencies. Various statistical tests suggest that the chamber is reverberating well at 2.5GHz, 8.2GHz and 18GHz, even for small subsets of the maximum number of independent samples available.

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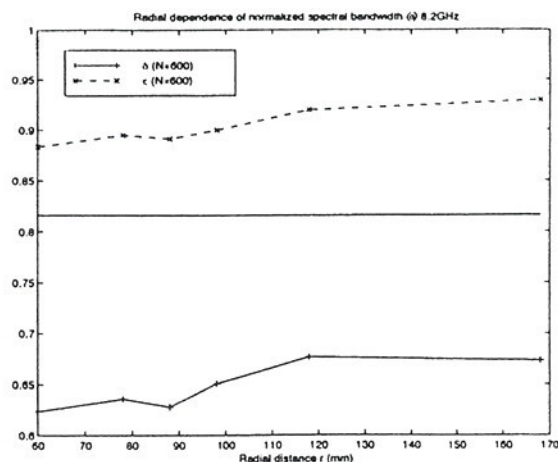


Figure 5: Radial dependence of δ and ϵ

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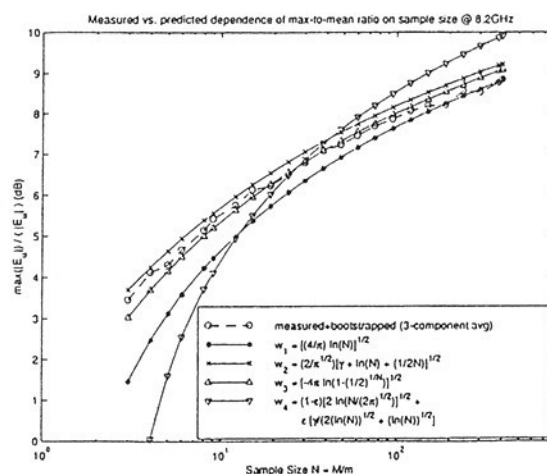


Figure 6: Maximum-to-mean field ratio