Source Stirring Reverberation Chamber Design and Experimental Investigation

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Abstract — According to the source stirring reverberation chamber (SSRC) theory, the key factors influencing its performance is analyzed and a source stirring scheme is proposed. Through the experiment, the valuable data for SSRC design and performance evaluation is provided. In the 800MHz-1000MHz frequency range, with the smallest sample number of the request, a better field uniformity is obtained. Meanwhile, the statistical characteristics of the electric field magnitude obeys Rayleigh distribution, which performed by the Kolmogorov - Smirnov (K-S) fitting method.

Index Terms — Reverberation Chamber, Source stirring, Field uniformity, statistical characteristics.

I. INTRODUCTION

In 1992, Y.Huang firstly issued the source stirring reverberation chamber (SSRC) concept [1]. The SSRC, which changes the excitation source to create an evenly homogeneous and isotropic field, is different from the traditional mechanics stirring reverberation chamber (MSRC) which changes the boundary to achieve the same field. Y.Huang adopted Dyadic Green’s function to describe electromagnetic field in the rectangle conductive cavity, illuminated the effect of the source stirring design in chamber through comparing the field distribution with and without stirring, and predicted the SSRC solution.

Because Dyadic Green’s function is complicated, Dr. Ding jian-jin started with the Helmholtz equation, use of superposition of eigen functions and method of constant variation, deduced a analytic expression in the rectangular cavity [2] of clear physical meaning and convenient application, and adopted symmetric mode and anti-symmetric mode of the source to improve the performance of the SSRC.

Dr Shen Yuan-mao made use of the Dyadic Green’s function to obtain the electric field expression in the two-dimensional and three-dimensional models of the SSRC; and elaborated its working principle on this basis deeply [3].

The idea of SSRC has been advanced long before. But most ideas only rest on the theoretical analysis, and only few of those concern experimental precept and testing data. Basing on a lot of theory research and computer simulation, this paper puts forward a source stirring scheme, and we carried out a series of test, analyzed the testing data and proved some important conclusion for reverberation chamber.

II. THEORY ANALYSIS

The SSRC does not need to equip the electrically large dimension tuners, which makes the reverberating boundary condition more simple and the stirring principal more clear. Reverberation chamber field strength formula is [4]:

\[
\hat{E} = \sum_{m,n,p} \left( c_{\text{mnp}} A_{\text{mnp}} \hat{e}_x + c_{\text{imn}} A_{\text{imn}} \hat{e}_y + c_{\text{imp}} A_{\text{imp}} \hat{e}_z \right)
\]

(1)

Where, the symbols \( A_{\text{mnp}} \), \( A_{\text{imn}} \), \( A_{\text{imp}} \), are eigen functions, coefficient \( c_{\text{mnp}}, c_{\text{imn}}, c_{\text{imp}} \) can be calculated by the second equation as (2):

\[
c_{\text{mnp}} = \frac{c^2}{4\pi^2 (f^2 - f_{mnp}^2)^2} \frac{8}{LWH} \int \int \int_{D} j_{\text{mnp}} A_{\text{mnp}} dxdydz
\]

\[
c_{\text{imn}} = \frac{c^2}{4\pi^2 (f^2 - f_{imn}^2)^2} \frac{8}{LWH} \int \int \int_{D} j_{\text{imn}} A_{\text{imn}} dxdydz
\]

\[
c_{\text{imp}} = \frac{c^2}{4\pi^2 (f^2 - f_{imp}^2)^2} \frac{8}{LWH} \int \int \int_{D} j_{\text{imp}} A_{\text{imp}} dxdydz
\]

(2)

Where, \( f_{\text{mnp}} \) is the resonance frequency, \( m, n \) and \( p \) is the nonnegative integer, \( L, W, H \) is the length, width and height of the reverberation chamber respectively, and they meet the relationship:

\[
f_{\text{mnp}} = \frac{c}{2} \sqrt{\left( \frac{m}{L} \right)^2 + \left( \frac{n}{W} \right)^2 + \left( \frac{p}{H} \right)^2}
\]

(3)

And, \( J_x, J_y, J_z \) is the rectangular component of the current density vector \( \vec{J} \):

\[
\vec{J} = \hat{e}_x J_x + \hat{e}_y J_y + \hat{e}_z J_z
\]

(4)

From equations (1) and (2), we can find that, the traditional MSRC uses the tuners rotation to change the integral boundary condition and the eigen function, while the exciting current distribution remains unchanged.

In the SSRC, mainly by changing the antennas position and polarization to change the exciting current distribution, in
other words, the key factors influencing the electromagnetic
strength are the weighted coefficient of eigen mode in the
chamber.

In a stirring cycle of the MSRC, the field uniformity (FU)
is calculated through a certain number of independent
sampling points. Comparing with the SSRC, each exciting
source position or polarization corresponds one sampling
point, and through those sampling points we can calculate the
reverberation chamber FU as well as the MSRC. The field
uniformity and the field distribution of the SSRC are the
same as the MSRC, but the only difference is the principle of
stirring.

III. EXPERIMENT VERIFICATION

Chamber dimension is 8.2m×5.6m×3.5m, the shielding
panel is galvanized steel panel. The testing frequency range
is 800MHz-1000MHz.

A. Experimental Setup

Figure 1 shows the source stirring testing system layout. The
transmit antenna is log-periodical antenna, which works
from 30MHz to 2.6GHz. The amplifier drives antenna to
transmit a high power radio waves. The field strength
monitoring device is a field probe which has respective x, y,
z direction probe. The receiving antenna is also
log-periodical antenna. The major equipments connect to the
control computer through the GPIB interface, and form an
automatic measurement system.

![Figure 1 Reverberation chamber testing system layout](image)

The operational mode of SSRC is the same as the mode
tuning which described in the standard IEC61000-4-21 [5].

B. Experimental Approach

Source stirring is mainly realized through changing
position or polarization of the exciting antenna, which is
identical to the mode tuning MSRC. So, the SSRC cavity
 calibration is carried out with the mode tuning approach
described in IEC61000-4-21, and the related data is
measured.

First of all, empty the working volume and place the
receive antenna at a location within the working volume of
the chamber as outlined in Figure 3. Place the E-field probe
at a location on the perimeter of the chamber working
volume as shown in Figure 3. Set the receiver to monitor the
receive antenna on the correct frequency, adjust signal
generation in the lowest frequency source, inject appropriate
input power to the transmitting antenna for making the probe
readings be reliable.

Change the operating frequency by step 40MHz, record the
input power of the reverberation chamber and the field
strength for each axis of E-field probe. At each position,
firstly change the transmit antenna polarization, then change
its position, as shown in Figure 2; meantime, the field
samples are achieved to meet IEC61000-4-21 minimum
sampling points requirement. Field uniformity region (that is,
the work volume) of MSRC is usually at a distance of 1m to
the wall. So we suppose a test region of 2m×2m×1m to
carry out our verification in SSRC, as shown in Figure 2.

![Figure 2 Antenna position and the field uniformity region layout](image)

![Figure 3 Chamber work volume](image)
strength at the eight positions shown in Figure 3 has been detected.

C. Experimental Results

1) Field Uniformity

Reverberation chamber work volume is a region that the electromagnetic field distribution is statistically uniform and statistically isotropic. EUT is tested just in this volume, the test data can be reliable, and the test result will be traceable. Here, only the final data of the work volume is processed, the specific data processing method is described in reference [5]. The standard deviation of the E-field measured value is expressed in terms of dB relative to the mean:

\[
\sigma_{dB} = 20 \log_{10} \left( \frac{\sigma + \langle \vec{E}_{xyz} \rangle}{\langle \vec{E}_{xyz} \rangle} \right)
\] (5)

Where, \( \langle \vec{E}_{xyz} \rangle \) is the arithmetic mean of normalized vector \( \vec{E}_{xyz} \) from all eight measurement locations, \( \sigma \) is the standard deviation of all vectors.

\[
\sigma = \sqrt{\sum (\vec{E}_{xyz} - \langle \vec{E}_{xyz} \rangle)^2 / (n-1)}
\] (6)

Reverberation chamber field uniformity requirements follow IEC61000-4-21, and above 400Hz the standard deviation is less than 3dB. The actual field uniformity test result is shown in Figure 4.

![Figure 4](image)

From Figure 4, field uniformity of the SSRC meets the standards requirements. We can get that the source stirring and mechanical stirring reverberation chamber achieve the same field uniformity through the statistics of different field structure. Their difference is only stirring ways, MSRC changes the reverberation chamber field structure by the mechanical stirrer rotation, but the SSRC by changing antenna locations and polarizations.

2) Field Statistics

In the reverberation chamber, the electric field can be described with three rectangular components, and each component includes both real and imaginary parts, which indicates that the E-field needs six components to describe[10],[11].

Because each E-field component is a sum of corresponding components from resonant modes, so it is a sum of lots of random variables. According to the central limit theorem, the sum of a lot of positive variance of independent random variables which distribution is normal distribution and each component is normal distribution [6]. So, the magnitude of electric field is Raleigh distribution [7], [8].

Here, the experimental data is checked by the Kolmogorov-Smirnov (K-S) test. K-S test is a non-parameter goodness-of-fit hypothesis test method, which determines if a random sample X could have the hypothesized, continuous cumulative distribution function (CDF). K-S test can be used for large sample size, but more suitable for small cases (sample size less than 20) [9].

Due to smaller sample size of the source stirring, K-S test method is used to analyze whether the distribution function with the source stirring test data complies with the theoretical distribution function., that is, whether the test data comes from the collectivity of the theoretical distribution. K-S test is based on the experience cumulative distribution functions (ECDF), applicable to a variety of distribution. Assumed number N samples, orderly sorted as \( Y_1, Y_2, \ldots, Y_N \), then the ECDF is defined as:

\[
F(Y_i) = n(Y_i) / N
\] (7)

Where, \( n(Y_i) \) is the quantity of data less than \( Y_i \), and \( Y_i \) is sorted ascendingly.

The definition of F is the theoretical continuous distribution function. K-S test is based on the maximum difference of the ECDF and the theoretical distribution function, that is,

\[
D = \max_{1 \leq i \leq N} |F(Y_i) - F(Y_i)|
\] (8)

Where, F(Y_i) is CDF theory value corresponding to Y_i. According to sample size N and a significant level \( \alpha \), the critical value \( D_{\alpha/2} \) can be found in the K-S test table.

| TABLE 1 CRITICAL VALUE (D) OF THE TEST |
|-----------------|-----------------|-----------------|
| Frequency (MHz) | D of the rectangular component | D of the rectangular component |
| 800             | 0.1442 0.1525 0.1783 | 840 0.1472 0.1565 0.1681 |
| 880             | 0.1696 0.1235 0.1375 | 920 0.1641 0.1783 0.2803 |
| 960             | 0.1357 0.2258 0.2400 | 1000 0.2308 0.1641 0.1950 |

From Table 1, the all testing results of D are less than \( D_{0.025} = 0.3754 \), that is, in the 800M-1000MHz frequency range, the measured data is consistent with the theoretical distribution.
range, the ECDF of electric field magnitude is subordinate to the theoretical cumulative distribution function.

Figure 5 - Figure 7 show the distribution function diagram of the Ez, Ey and Ez, which are field strength of probe 1 in the 800MHz frequency.

As shown in Figure 5 - Figure 7, it can be directly observed that the experimental measurements coincide with the theoretical values.

And, as a result of few sampling points of the measurement, curves are not smooth enough, which can be improved by increasing the number of samples.

IV. CONCLUSION

From the theoretical analysis and the experimental verification, the reverberation chamber field uniformity can be achieved effectively through antenna suitable layout, and the field distribution conforms to a certain statistical rule. Therefore, it’s confirmed that the SSRC and MSRC are equivalent. But at the same time there are still many issues which need further study. For example, in this paper, the test frequency is much higher than the minimum resonant frequency f110 (32.4MHz), which eliminates the frequency affection on the reverberation chamber performance.

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