# Test Quantities When Performing a Radiated Susceptibility Test in the Reverberation Chamber

Magnus Höijer<sup>#1</sup>, Olof Lundén<sup>#2</sup>

<sup>#</sup>Swedish Defence Research Agency FOI Olaus Magnus väg 42, Box 1165, SE-581 11 Linköping, Sweden, EU

<sup>1</sup>magnus@foi.se

<sup>2</sup>ololun@foi.se

*Abstract*— We present a method on how the strength of the reverberation chamber (RC) as test facility is easily measured. We do also present expressions of how the strength of the stress onto the equipment under test (EUT) is easily calculated outgoing from the strength of the RC. Expressions for the strength onto the EUT are given in the quantities power, rectangular component of the electric field and total electric field.

Key words: electromagnetic statistics, high power electromagnetics, maximum value statistics, radiated susceptibility tests (RST), reverberation chamber (RC).

### I. INTRODUCTION

Electronic equipments immunity against electromagnetic irradiation needs to be tested. Such a test, often called radiated susceptibility test (RST), can be performed in many different test facilities, e.g., at an open area test site (OATS), in an anechoic chamber (AC), in a gigahertz transverse electromagnetic (GTEM) cell or in a reverberation chamber (RC).

The different test facilities do all have their special properties and advantages. The OATS, the AC and the GTEM cell all have one principal property in common, one irradiate the EUT with a plane electromagnetic wave. It is well known by the EMC community that the susceptibility of the EUT varies with from which direction the EUT is irradiated, as well as the polarization used to irradiate the EUT, see e.g. [1,2,3]. It is most often neither affordable nor practicable to irradiate the EUT from a sufficient number of directions [1]. Not to surprising, round robin tests have shown very different results between the participating test facilities. The RC has different properties. The EUT is in the RC simultaneously stressed from many directions and with many different polarizations. All the susceptible components in the EUT are stressed with electromagnetic power values which equal the average stresses taken over all incident directions and all polarizations when the test is performed at an OATS, or in an AC or GTEM cell. The result from a test in the RC gives a fast and reliable immunity value, though it gives no information on the directional and polarizational properties of the EUT [4].

An advantage with the RC is that high electromagnetic field and energy test levels can be reached. An RC is a room with walls, ceiling and floor completely in metal, see Fig. 1. The EUT is placed inside the RC and electromagnetic energy is pumped into the RC through an antenna. The energy

pumped into the RC is not lost out into space, but at the walls reflected back into the chamber. Hence, the electromagnetic energy is reused. The total electromagnetic energy inside the chamber will not reach infinity; it is limited by that conductivity in the walls are not infinite, imperfections in the walls, energy absorbed by antennas, the EUT and other possible objects inside the RC. In practice it is often the limited conductivity of the walls which (at the higher frequencies) is the main absorber of electromagnetic energy. Still, the reuse of electromagnetic energy implies that when the RC is used, substantially smaller electromagnetic sources can be used to generate the same stress onto the EUT as in the case when the OATS/AC/GTEM is used.



Fig. 1 A typical radiated susceptibility test (RST) in a reverberation chamber (RC). Electromagnetic power is pumped into the reverberation chamber through a transmitting antenna. Thereby the equipment under test (EUT) is stressed. The strength of the stress is measured by a reference antenna. It is concluded whether the EUT can withstand a certain test level or not. (The author is not to be in the chamber during the test.)

A drawback of using the RC is that there is always an inherent uncertainty in quantifying the strength of the stress we put onto the EUT. An electromagnetic standing wave is built up inside the EUT, and the electromagnetic energy inside the RC is inhomogeneously distributed. As a consequence the strength of the stress we impose on the EUT will differ from the stress we measure in a reference antenna inside the chamber, see Fig. 1.

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We will in this paper see how we can quantify this uncertainty. We will also be able to somewhat disarm the debate on which test quantity is the best to quantify the stress which we put onto the EUT.

### II. STRENGTH OF TEST FACILITY

In the complex electromagnetic environment inside the RC, the strength of the stress we put onto the EUT is changed every time the electromagnetic boundary conditions are changed in the RC. The electromagnetic boundary conditions can be changed by rotating a stirrer inside the RC. An example of a stirrer can be seen in the ceiling of the RC in Fig. 1. The electromagnetic stress onto the EUT will differ among different stirrer positions. The more stirrer positions we stress our EUT for, the higher the expected stress onto the EUT will be. The maximum stress onto the EUT, and the maximum received power in the reference antenna are not received for the same stirrer position, and they will also differ in magnitude. Both are just random samples taken from the same process.

To straighten things out, we introduce two important concepts,

- Strength of test facility
- Strength of stress onto the EUT

By the reference antenna we measure the strength of our test facility (or process) as accurate as possible. We measure the power received in the reference antenna  $(P_n)$  for  $\mathbb{N}$  independent stirrer positions. As a measure of the strength of our test facility we take the average value<sup>1</sup>,

$$\langle P \rangle = \frac{1}{\mathbb{N}} \sum_{n=1}^{\mathbb{N}} P_n$$
 (1)

For a discussion concerning the choice of  $\langle P \rangle$  as strength of our test facility, see [5]. For large N, in practice for N >10,  $\langle P \rangle$  will converge toward a number completely describing the strength of our test facility [4].

We now know the strength of our test facility, but we do not know the exact strength of the stress onto our EUT. We have stressed the EUT for  $\mathbb{N}$  stirrer positions, but the magnitude of the stress is a random number. In this paper we present expressions for the magnitude of the stress imposed onto the EUT. The derivation of the expressions can be found in [4,5],

### III. STRENGTH OF THE STRESS ONTO EUT

### A. Power as Measure of Stress

Let us assume that we have stress the EUT for  $\mathbb N$  stirrer positions, we measure the received power in the reference

antenna for every stirrer position and calculate the average received power according to (1), then the maximum power stressed onto the EUT is [4],

$$P_{max} = T < P > , \qquad (2)$$

where T is a random variable with probability distribution function (pdf) [4],

$$f_T(t) = \int_0^\infty q f_Z(qt) f_Q(q) \mathrm{d}q \quad , \tag{3}$$

and cumulative distribution function (cdf) [4],

$$F_T(t) = \int_0^\infty F_Z(qt) f_Q(q) \mathrm{d}q \quad . \tag{4}$$

The help functions in (3) and (4) are,

$$f_Z(z) = \mathbb{N} \left( 1 - e^{-z} \right)^{\mathbb{N}^{-1}} e^{-z} , \qquad (5)$$

$$F_{Z}(z) = (1 - e^{-z})^{\mathbb{N}}$$
, (6)

$$f_{\mathcal{Q}}(q) = \gamma(q, \mathbb{N}, \frac{1}{\mathbb{N}}) = \frac{\mathbb{N}^{\mathbb{N}}}{(\mathbb{N}-1)!} q^{\mathbb{N}-1} e^{-\mathbb{N}q} .$$
(7)

The gamma probability distribution function  $(\gamma)$  is implemented in many numerical mathematical tools.

### B. The Electric Field as Measure of Stress

The maximum power stressed onto the EUT, we think is a very good measure of the stress we put onto the EUT. Part of our community prefers to have an electric field value as measure of the stress we put onto the EUT. However, as the electromagnetic field inside the RC is complex, with field components in all directions, there is no unequivocal definition of the field inside the EUT. Some suggest that a rectangular component of the electric field is the best measure of the stress imposed upon the EUT. Others suggest that the resultant of the electric field, often called the total electric field, is the best measure.

Now a nice feature of distinguishing between *strength of test facility* and *strength of stress onto the EUT* will be obvious. The strength of our test facility is defined by the average power value in (1), and, in complete similarity with (2), an expression for the maximum value of the rectangular electric field component can be derived [5],

$$E_{r,max} = \sqrt{\frac{8\pi}{\lambda^2} \frac{Z_0}{3}} M \sqrt{\langle P \rangle} , \qquad (8)$$

<sup>&</sup>lt;sup>1</sup> We assume that the reference antenna is impedance matched and lossless. If that is not the case, we can easily compensate for that.

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as well as an expression for the maximum value of the total electric field [5],

$$E_{t,max} = \sqrt{\frac{8\pi}{\lambda^2} \frac{Z_0}{3}} N\sqrt{\langle P \rangle} . \tag{9}$$

In (8) and (9),  $Z_0$  is the free space wave impedance,  $\lambda$  the wavelength of the electromagnetic field, M is a random variables with pdf and cdf [5],

$$f_M(m) = \int_0^\infty of_G(om) f_O(o) \mathrm{d}o \quad , \tag{10}$$

$$F_M(m) = \int_0^\infty F_G(om) f_O(o) \mathrm{d}o \quad , \tag{11}$$

respectively, and N is a random variables with pdf and cdf [5],

$$f_N(n) = \int_0^\infty o f_H(on) f_O(o) \mathrm{d}o , \qquad (12)$$

$$F_N(n) = \int_0^\infty F_H(on) f_O(o) \mathrm{d}o , \qquad (13)$$

respectively. The help functions in (10), (11), (12) and (13) are,

$$f_G(g) = 2\mathbb{N}ge^{-g^2} \left(1 - e^{-g^2}\right)^{\mathbb{N}-1}, \qquad (14)$$

$$F_G(g) = \left(1 - e^{-g^2}\right)^{\mathbb{N}}$$
, (15)

$$f_{H}(h) = \mathbb{N}h^{5}e^{-h^{2}} \left[ 1 - e^{-h^{2}} \left( 1 + h^{2} + \frac{h^{4}}{2} \right) \right]^{\mathbb{N}-1}, \quad (16)$$

$$F_{H}(h) = \left[1 - e^{-h^{2}} \left(1 + h^{2} + \frac{h^{4}}{2}\right)\right]^{\mathbb{N}} , \quad (17)$$

$$f_o(o) = 2o\gamma(o^2, \mathbb{N}, \frac{1}{\mathbb{N}}) .$$
<sup>(18)</sup>

Hence, once we measured the strength of our test facility via (1), all three measures in (2), (8) and (9) of the stress onto the EUT is known. Three plots of the pdf of the random variables M, N and T can be seen in Fig. 2. The three plots show the pdf for 12, 35 and 100 independent stirrer positions, respectively.

### IV. TEST VALUES

Equations (2), (8) and (9) give us three measures of the stress onto the EUT. All three depend on the strength of our

test facility via the average received power in the test facility  $(\langle P \rangle)$ . However, there is no exact value of the measures, because the expressions include the random variables *T*, *M* and *N*, respectively. That is a fundamental property of performing a radiated susceptibility test (RST) in the RC; there is uncertainty about the true stress onto the EUT. It is an inherent property of the RC as test facility and not a measurement error in normal sense.



Fig. 2 The probability density functions (pdf) for the random variables M, N and T. The blue curve to the left is the pdf for M, the green curve in the middle is the pdf for N and the red curve to the right is the pdf for T. The random variables are shown for 12, 35 and 100 independent stirrer positions ( $\mathbb{N}$ ).

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One could be mislead to think that by actually measuring the quantities on the left hand side of (2), (8) and (9), the uncertainty should be smaller, but that is not the case. Though true that the quantities in (2), (8) and (9) certainly can be measured with a high accuracy, much higher than the uncertainty in T, M and N, it is irrelevant. The key point is that the EUT and measurement antenna and/or probe will always face different stresses. That is an inherent property of using the RC as a test facility; the actual stress is a random variable. The best thing we can do is to measure the strength of our test facility. That we do by measuring the average received power in the test facility ( $\langle P \rangle$ ). The actual stress onto the EUT is just one random sample of many possible outcomes.

With that taken into consideration, how do we show our test results in a practical manner? We probably want to say that we have tested our EUT up to a certain level, and that level we want to be a number, not a random variable. One way to do that is to introduce confidence bounds. Let us define the bound  $t_{\alpha}$  so that with  $\alpha$  probability, the random variable *M* is larger than  $t_{\alpha}$ ,

$$F_T(t_\alpha) = 1 - \alpha \ . \tag{19}$$

Often  $t_{\alpha}$  is called the  $1-\alpha$  percentile. By introducing the inverse function  $F_T^{-1}$  we get,

$$t_{\alpha} = F_T^{-1}(1-\alpha) , \qquad (20)$$

$$m_{\alpha} = F_M^{-1}(1-\alpha),$$
 (21)

$$n_{\alpha} = F_N^{-1}(1-\alpha),$$
 (22)

where we also introduced the similar bounds for the M and N random variables. By using the bounds in (20), (21) and (22) in (2), (8) and (9), respectively, we can easily introduce the test values,

$$P_{maxT} = t_{\alpha} < P > \tag{23}$$

$$E_{r,maxT} = \sqrt{\frac{8\pi}{\lambda^2} \frac{Z_0}{3}} m_\alpha < P >$$
(24)

$$E_{t,maxT} = \sqrt{\frac{8\pi}{\lambda^2} \frac{Z_0}{3}} n_{\alpha} < P >$$
<sup>(25)</sup>

The three test values above are typical values to be specified in a test protocol. The choice of  $\alpha$  depends on the actual test being performed, but is also a matter of convenience. To get a high confidence that the true stress onto the test object is higher than the one specified in the test protocol the 5 % percentile may be used. On the other hand, if one is afraid of overtesting, the 95 % percentile may be used. If one wants a typical value, the 50 % percentile may be used. In Fig. 3, the 5 %, 50 % and 95 % percentiles are shown as function of the number of stirrer positions, for the *T*, *M* and *N* 

random variables. The percentiles for the T and M are identical in the dB-scale [5].



Fig. 3 The 5 %, 50 % and 95 % percentiles as function of the number of stirrer positions for the T, M and N random variables. The blue solid lines show the percentiles for M, and the red dashed lines show the percentiles for N. The percentiles for T and M are identical in a dB-scale.

### V. MEASUREMENT VERIFICATION

At the symposium we will also show the results from measurements that we have performed to verify the validity of the expressions presented.

### VI. CONCLUSION

A radiated susceptibility test (RST) in a reverberation chamber (RC) can easily be performed by placing the EUT and a reference antenna inside the RC. The EUT is stressed for  $\mathbb{N}$  stirrer positions and the average value of the power received in the reference antenna is monitored. The test values to which we stress our EUT are easily calculated with the (23), (24) and (25). The test values are specified in a measurement protocol.

#### ACKNOWLEDGMENTS

This work was financially supported by the Swedish Armed Forces.

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