

Considerations about Radiated Emission Tests in Anechoic Chambers that do not fulfil the NSA Requirements

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Abstract- In this paper, some critical issues concerning the measurement of radiated emissions of products in an electromagnetic compatibility test stage are dealt with. In particular, an approach is proposed to evaluate the adequacy of anechoic enclosures that do not fulfil the requirements regarding the normalized site attenuation (NSA) factor. The purpose is to suggest a test method that can be used in order to define a way to know the limits of the chamber in terms of the frequency response over some critical radiations. To this aim, a number of simulation analyses and experiments have been performed for two different elementary types of radiating circuits (electric dipole, magnetic loop). Investigations have also been made by varying the physical size of the antennas.

I. Introduction

Radiated emission tests of electronic products are performed in the electromagnetic compatibility (EMC) area in accordance with some suitable standards, i.e. [1]. They consist of electromagnetic field measurements, to be executed at a given distance from the equipment under test (EUT) and under suitable conditions of the test site. The test site is commonly a semi-anechoic chamber that must be validated through estimates the measurement of the normalized site attenuation (NSA) according to the standard [2]. The standard requires NSA values within the range of ± 4 dB from the theoretical NSA, and over the whole radiated emission frequency range 30 MHz to 1 GHz.

In a semi-anechoic chamber (SAC), electromagnetic field absorbers are placed at the chamber walls and ceiling to avoid reflections of the radiated waves and echoes at the receiver input of the measurement apparatus. The only exception is for the ground plane, which must be a conducting metal plane, without absorbers. In order to reduce the costs due to the expensive absorbing materials and the large dimensions of the chamber required by the standard, pre-compliance test sites are often realized and frequently used. Due to the fact that such chambers usually do not satisfy the above recalled criteria in terms of NSA (especially in the lowest range of frequency), it is important to investigate the accuracy obtained from the measurements.

In the past, several scientific researches have studied the correlation between measurements performed in an ideal test site and measurements carried out in some non-compliance sites. In [3], Garn introduced the concept of 'chamber factors', through which the E field estimates obtained in a non-compliance site can be corrected in order to achieve values that can be used to directly verify the compliance of the product to the emission limits. The chamber factor was also introduced in [4] along with the concept of 'grey factor'. Despite its effectiveness, the use of correction factors has non-negligible practical drawbacks: it requires a complex handling of the general measurement results, and moreover a number of preliminary reference measurements are always needed to be performed in an open area test site (OATS).

In this paper, the use of the correction chamber factors in anechoic chambers that do not satisfy the above recalled criteria in terms of NSA is analysed and some of its drawbacks are pointed out. A test with a large radiating device is reported to explain the limits of the chamber and an approach is then presented, mainly considering the different conditions for a chamber frequency response. The aim of the paper is to suggest a practical way to evaluate the limits of radiated emission tests when performed within chambers that do not fulfil the NSA requirements. To this aim, a number of simulation analyses and experiments have been performed for two different elementary types of radiating circuits (electric dipole, magnetic loop). Investigations have also been made by varying the physical sizes of electric antennas.

II. Chamber Factors

The characterization of a test enclosure in terms of chamber factors requires to perform several measurements at different test configurations, *i.e.* for different transmit antenna (dipole or loop), antenna positions and polarizations. For each of the configurations, the correction factor can be determined as follows:

$$C_F [dB] = E_{REF} [dB\mu V/m] - E_{ENC} [dB\mu V/m], \quad (1)$$

where C_F is the correction factor, E_{REF} is the field strength measured at the reference site, and E_{ENC} is the field strength measured in the enclosure, *i.e.* the semi-anechoic chamber. The reference site is a good OATS, *i.e.* with only very small deviations from the ideal values of NSA. The OATS consists of a conducting ground metal plane with gaps dimensions not larger than $\lambda/10$ at the highest frequency of operation, being λ the wavelength. A dipole and a loop antenna are used as a transmit antenna to provide fields with different wave impedance. A biconical antenna is used as a receive antenna. When plotted in a graph, the values of C_F typically appear with a superimposed spread. The upper envelope curve obtained is the worst-case chamber factor, while the mean between the upper and lower curve is the mean chamber factor. The spread of the correction factors is the grey factor.

Once determined, chamber factors can be used to adjust the field strength estimates obtained in the radiated emission tests of the EUT. In particular, the chamber factors (in dB) are to be added to the field strength estimates (in dB μ V/m) measured in the semi-anechoic chamber in order to obtain the open-site equivalent values (in dB μ V/m).

Chamber factors are function of frequency and polarization, and depend on EUT physical features, such as dimensions and radiating circuit type (loop or dipole-like). Indeed, the absorbers used in the chamber have properties that depend on the wave impedance, which is constant in the far field region, and may vary considerably in the near field one. On the other hand, the extension of near and far field regions is strongly related to the wave frequency and EUT dimensions. Approximately, the near field region includes the points whose distance from the EUT is lower than λ , while the far field region includes the points located far away from the EUT, by more than $2D^2/\lambda$, being D the largest dimension of the EUT. Therefore, upon the varying of the frequency and D , the properties of the absorbers may considerably change, and, consequently, the chamber response too.

In a pre-compliance analysis of radiated emissions, the measurement of the chamber response upon the varying of the frequency and the EUT dimensions is essential. To this aim, [2] requires to apply the so-called "volume method", which consists of measurements to be performed with the transmit antenna placed at different locations within the volume that a EUT may occupy. A limit of this method is that it does not consider the real effects of the EUT emissions, hence the effects of its possible large dimensions, *i.e.* the parameter D . This fact could lead to even relevant inaccuracy in the estimate of radiated emissions.

III. Characterization of the Investigated Test Site

A first set of preliminary experiments has been performed with the aim of characterizing a semi-anechoic chamber 7.94 m (L) x 3.74 m (W) x 3.34 m (H).

NSA has been measured according to the approach defined in [2], in the frequency range 30 MHz to 1 GHz and with variable step size (1 MHz for 30-100 MHz, 5 MHz for 100-500 MHz, and 10 MHz for 500-1000 MHz). In particular, a couple of biconical and log periodic antennas (one for transmit and another for receive) have been used in the range 30 - 200 MHz and 200 - 1000 MHz, respectively. The antennas have been positioned in the chamber according to the volume method and with the transmit antenna located within a cylindrical test volume of 2 m diameter. For each considered frequency and transmit antenna position, a number of measurements have been repeated for the two polarizations. The worst-case values obtained are summarized in Fig. 1, where the difference between the measured and theoretical NSA is plotted versus frequency. The plot clearly shows that the employed chamber does not satisfy the above recalled ± 4 dB requirement. In particular, the highest differences are observed in the range 30 - 200 MHz.

Chamber factors have been determined as described in Section II. In particular, E_{ENC} has been assessed in the semi-anechoic chamber under test, while E_{REF} has been evaluated in the open field site of Seibersdorf at the Austrian Research Centre. A calibrated RefRad reference radiator has been used to generate the signal. Three antennas have been then connected: a dipole of 65 cm length and a square loop of 30 cm side length, in the range 30 - 200 MHz, and a dipole of 20 cm length, in the range 200 - 1000 MHz. The measurement of the field strength has been carried out by using a biconical antenna in

the range 30 – 200 MHz, and a log periodic antenna in the range 200 – 1000 MHz. For the measurement in the semi-anechoic chamber the receive antenna has been moved at a scan range of 1 to 2 m above the floor and with a measurement distance of 3 m. For each considered frequency, transmit antenna type and position, a number of measurements have been repeated for the two polarizations. The magnitude of worst-case values obtained are summarized in Fig. 2, where the chamber factors are plotted for both horizontal and vertical polarization. The plot shows once again the limits of the chamber response, for which remarkable correction factors are needed.

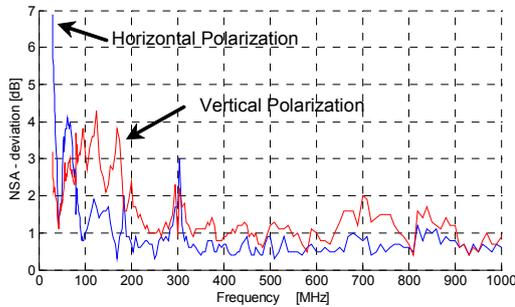


Figure 1. Estimated NSA versus frequency.

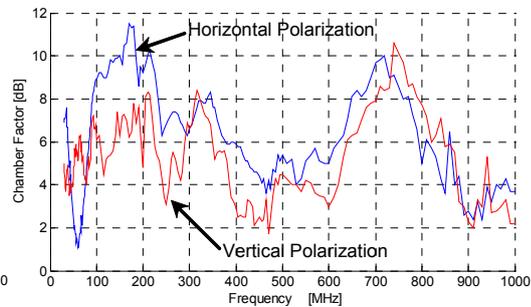


Figure 2. Estimated Chamber Factor versus frequency.

Further NSA measurements have been conducted in an OATS reference site. The OATS consisted of a 6 m x 7 m conducting ground plane, positioned over a flat concrete ground plane free of obstacles. A picture of the used OATS is shown in Fig. 3. The conducting ground plane has been realized by using two metallic layers, each consisting of 30 cm width aluminium stripes placed side by side with overlaps of about 3 cm. The stripes have been positioned orthogonally in the two layers in order to emulate as well as possible the properties of an ideal ground plane. From a set of measurements, NSA has been measured and found to be in good agreement with the theoretical values, over the whole frequency range 30 MHz – 1 GHz.



Figure 3. The employed OATS.

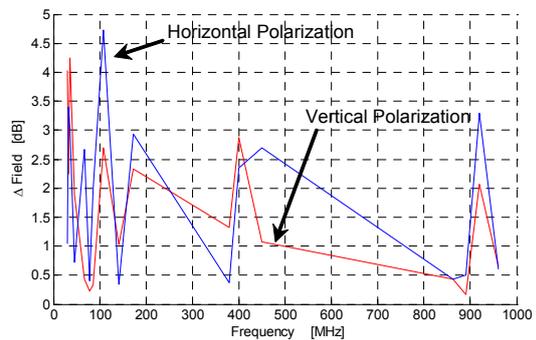


Figure 4. Difference between field estimates in the OATS and in the chamber.

NSA results of the anechoic chamber have been compared with the same measurements performed in the OATS. The mean values obtained, in terms of field deviations between OATS and chamber estimates, Δ_{FIELD} , are summarized in Fig. 4. As can be seen, the obtained Δ_{FIELD} is always lower than 3 dB, with the exception of the following cases: horizontal polarization and frequencies 108.2 MHz and 920 MHz, for which $\Delta_{FIELD} = 4.7$ and 3.3 dB, respectively.

IV. Considerations about Radiated Emission Test in Anechoic Chambers

As above-mentioned, the behaviour of the absorbers in the chamber depends on the wave impedance Z_W [4], which is constant in the far field region, and may vary considerably in the near field one. The anechoic material on walls and ceiling is called to face the values of Z_W in the near field region (at low frequencies and next to the EUT). Therefore the absorber effectiveness may be affected, depending on both the EUT nature (electric or magnetic source of noise) and dimensions (larger EUTs are giving smaller distance between the EUT and anechoic material).

Secondly, in case of large equipment, the EUT radiating structure may couple with the walls and ceiling of the chamber. This can produce modifications in the EUT radiating property, compared to the radiation obtained in an OATS, where no walls and ceiling are present. Both effects can lead to variations in the radiation characteristics of the EUT, and consequently to inaccuracy in the radiated

emission measurements.

These situations are only partially taken into account with the NSA parameter of the anechoic chamber. NSA measurements are performed using “electrical” antennas to generate the field: the anechoic material (near the transmitting antenna) can face only wave impedance values higher than Z_0 . Moreover, the “volume method” is studying the behaviour of the chamber when the source of noise is at the border of the volume, but no information is given concerning the problems of real equipment that may have physical dimensions significantly larger than the used transmitting antenna.

For these reasons, the deviation of the normalized site attenuation from the theoretical value is suitable to describe the situation of EUTs radiating in the near field with high values of Z_W (electric field), with physical dimensions similar to the antenna used for NSA measurements.

In the proposed approach, both electric and magnetic field sources (e.g. dipoles and loops) are used. Moreover, large antennas are considered in order to evaluate the coupling effects of large apparatus with the chamber.

V. Simulation Analysis

The EUT nature is here intended as the presence of internal circuits that can be modelled, in terms of field radiation, as electric dipoles or magnetic loops. In particular, Z_W will assume values lower or higher than $Z_0 = 120 \pi$, *i.e.* the wave impedance in the far field region, and proportional or inversely proportional to the distance d between the interested point and the EUT, depending on the predominating source of field, *i.e.* loop or dipole, respectively.

Theoretical analysis and specific simulations to estimate the radiation of a magnetic field (using a loop antenna) are now proposed. A convenient geometrical arrangement for the field analysis of a loop antenna is to position the antenna symmetrically on the x - y plane, at $z=0$, as shown in Fig. 5 [5]. With the assumption of constant current distribution (I_0) in a thin wire, the generic equations for far field propagation are eq. (2) reported below, where a is the radius of the loop antenna in meters, r the distance from the centre of the loop in meters, η the wave impedance, and $k=2\pi/\lambda$. Following the classical NSA formulation [6] for far field region, it is possible to obtain the following equation (3), valid for field propagation in the test set-up sketched in Fig. 6:

$$H_\theta \cong \frac{-(ak)^2 I_0 e^{-jkr}}{4r} \sin \theta \quad (2)$$

$$E_\phi = -\eta \cdot H_\theta$$

$$H_{Tot} = \frac{-(ak)^2}{4} I_0 D \left(\frac{e^{-jk d_1}}{d_1^2} + \frac{|\rho g| e^{-j(k d_2 - \phi g)}}{d_2^2} \right) \quad (3)$$

where ρg is the reflection coefficient of the ground plane, ϕg is the reflection coefficient phase angle, $d_1 = \sqrt{D^2 + (h_1 - h_2)^2}$ is the length of the direct ray, $d_2 = \sqrt{D^2 + (h_1 + h_2)^2}$ the length of the reflected ray, h_1 and h_2 are the heights of the transmitting and receive antennas, and D the separation distance.

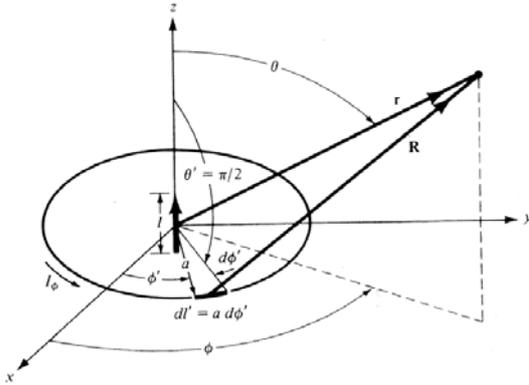


Figure 5. Geometry for circular loop.

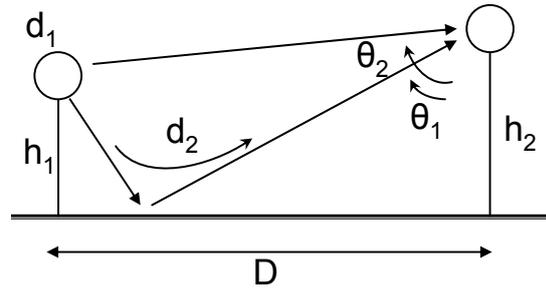


Figure 6. Propagation geometry for loop antenna.

The magnitude of (3) is:

$$|H_{Tot}| = \frac{-(ak)^2}{4} I_0 D \frac{\sqrt{d_1^4 + d_2^4 + 2(d_1 d_2)^2 |\rho g| \cos(\phi g - \lambda(d_2 - d_1))}}{(d_1 d_2)^2} \quad (4)$$

To maintain a good ‘match’ between the circumference of the loop and its working frequency range, two different antennas’ radii have been used [5]: $a_1=16$ cm for the frequency range 30 MHz to 80 MHz and $a_2=6$ cm for the frequency range 80 MHz to 140 MHz. Predictions of H field radiation with $I_0 =$

500 μ A, $D = 3$ m, $h_1 = h_2 = 1$ m, are shown in Fig. 7 for the two loops.

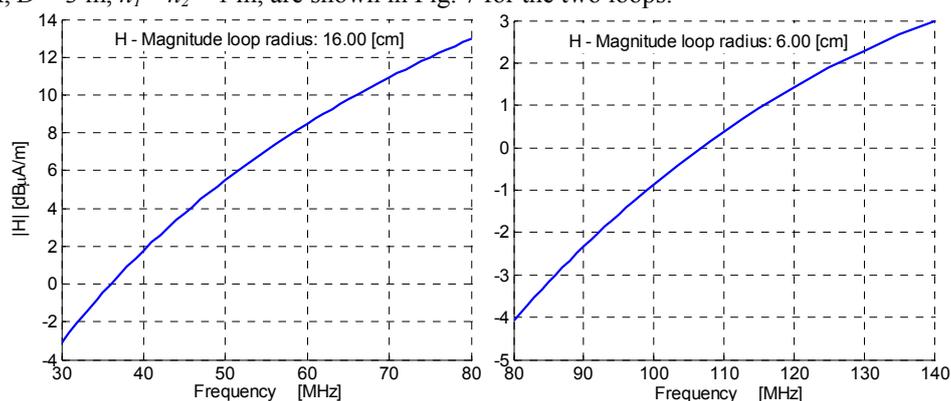


Figure 7. Loop antenna: H-Magnitude predictions.

In a similar way an estimation of the electric field radiated by a “large” source (a folded dipole having length $l = 1.5$ m) has been made starting from the basic equations given in [5] and taking into account the ground reflection (see Figure 8, continuous line).

VI. Experimental Results

A number of experiments have been performed in order to evaluate the critical points mentioned in this work. As a practical example, an industrial washing machine (dimensions: 1.20 m x 1.33 m x 1.90 m height) has been used as EUT, occupying a large portion of the calibrated volume of the chamber. The EUT external enclosure was a box with metallic conductive sides. The radiating sources were the electronic devices embedded in the equipment. Radiated emission measurements have been performed according to the standardized procedure in [1], namely both in the semi-anechoic chamber (SAC) and on an OATS. Some of the obtained results are summarized in Table 1, for different frequencies, polarization and antenna height.

Frequency MHz	Antenna		SAC dBμV/m	OATS dBμV/m
	Pol	H (cm)		
34.33	H	137	52.83	58.70
35.71	H	168	53.80	59.60
40.73	H	157	39.72	39.00
50.91	H	102	42.76	39.90
78.81	H	100	33.94	34.80
35.97	V	175	39.98	27.30
36.42	V	131	38.79	35.80
36.43	V	127	41.95	35.80

Table 1

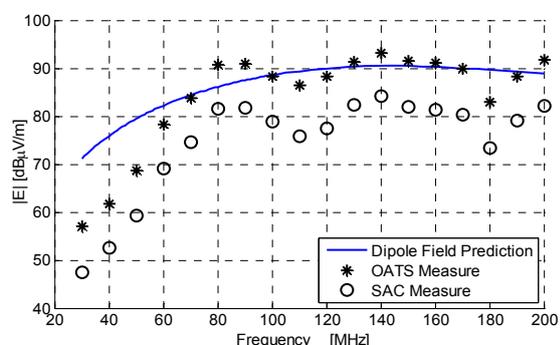


Figure 8. Folded Dipole: Measure and Prediction

With reference to an apparatus of significant dimensions compared to the employed chamber, considerable differences of the electric field values measured in the semi-anechoic chamber can be observed.

In order to investigate the origin of these differences and the effects of the EUT nature and dimensions on the radiated emission tests, a proposal is suggested below, which aims to compare the theoretical propagation formulas and the measurements performed both in a semi-anechoic chamber and on an OATS.

The proposal takes into account both the possible low-impedance radiating field and the coupling of large EUTs with the chamber structure. Aim of this approach is to find the critical conditions of the EUT (nature and dimensions) and then to establish the limits (or the correction) to be able to use the chamber for radiated emission tests.

To this purpose the effects of a large dimension field source are examined by means of a folded dipole. The first step consists in doing the measurements in the same OATS used in Section III with a folded dipole, having $l = 1.50$ m, in the range 30 MHz – 200 MHz ($D = 3$ m, $h_1 = h_2 = 1$ m). The measurement of the field strength has been carried out by using a calibrated biconical antenna. The second step consists in repeating the measurements with the same set-up within the anechoic chamber. Results are summarized in Fig. 8 (continuous line represents the electric field prediction, star dots the OATS

measurements, circle dots the SAC measurements). The results show some “attenuation” introduced by the chamber response and, of course, a better prediction in the far field region.

To investigate the effect of a magnetic field source, the loop antennas described in Section V are then used as transmitting devices in their respective working frequency ranges. Again, the tests (repeated in the OATS and inside the chamber) are compared with the theoretical propagation formula. Results are presented in Fig. 9 in terms of equivalent electric field (continuous line = field prediction, star dots = OATS measurements, circle dots = SAC measurements).

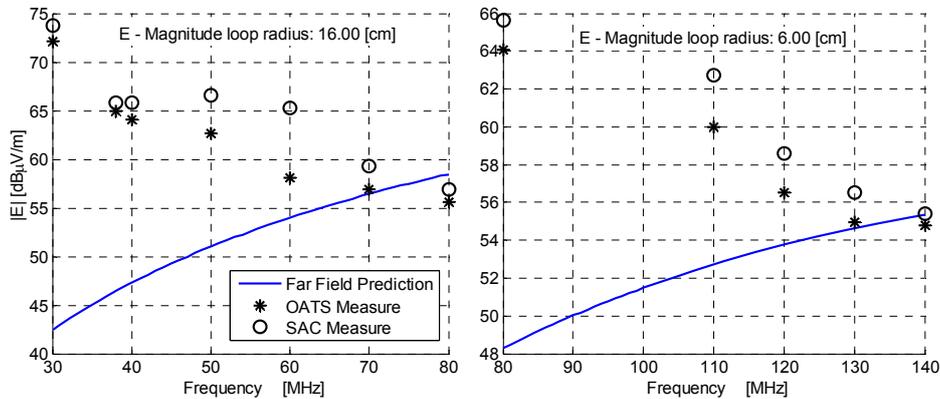


Figure 9. Loop Antennas: Measurement results.

OATS and SAC behaviour is similar, with some greater ‘attenuation’ in the OATS measurements. Both trends are closer to the field prediction only at higher frequencies, while in the lower frequency range the measured field values are very high compared to the theoretical ones.

The obtained results are only preliminary results: they highlight the need of a deeper study, aimed at understanding the gap between the theoretical predictions and experimental measurements. Some remarks can already be expressed. For instance, the radius of an antenna plays a key role in the ideal condition and hypothesis, like the constant current in the loop. To solve this problem, different ‘magnetic’ antennas can be used for predictions and measurements. Moreover, the theoretical radiated field has been calculated by adopting the same hypothesis made for NSA prediction, i.e. the near field contribution has been neglected and only far field radiation considered. A deeper investigation, both theoretical and experimental, is necessary to better analyze this aspect.

Finally, to evaluate the effects of the antenna coupling with the anechoic chamber walls and ceiling, further measurements with ‘large’ dipoles are planned in the near future: a few folded dipoles will be used having different dimensions, e.g. from the size of a typical biconical antenna up to the maximum size allowed by the test volume of the chamber.

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