From NSA to Site-Reference Method for EMC Test Site Validation

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Abstract: Electromagnetic compatibility compliance testing of electronic apparatus includes the measurement of radiated-emissions in the frequency range of 30 MHz to 1 GHz. To achieve equivalent test results from different testing laboratories, test sites must be of validated, standard performance. This paper suggests a substantial improvement to the standard site validation procedure: A new "site-reference method" for site validation is suggested. It avoids the determination of the antenna factors of transmit and receive antenna, gives full traceability and thus minimizes uncertainties in the measurement result. This improves the reliability of judgements upon site performance and helps to economize the design of test facilities, e. g. anechoic chambers.

INTRODUCTION

Electromagnetic Compatibility compliance testing of electronic products includes the measurement of radiated-emissions in the frequency range of 30 - 1000 MHz. The field-strength measured at a certain distance from a device strongly depends on the wave propagation conditions of the test site. To achieve equivalent test results from different testing laboratories, requirements regarding the quality of the site have been introduced by CISPR 16-1 [1]. These requirements are defined in terms of the so-called "site attenuation". A large, flat, obstruction-free field with reflecting ground fulfills these requirements. Such an "open-area test site" (OATS) is normally equipped with a metal groundplane. Furthermore alternative test sites such as OATS with all-weather cover and semi-anechoic chambers are acceptable, if additional requirements regarding site attenuation are fulfilled. In CISPR these test sites are called COMTS (compliance test site).

Site validation is done by site attenuation measurements with either tuned dipoles or broadband antennas. This is a very critical and responsible task, because the investment for an anechoic chamber with a 10 m – test range including the necessary installations is 2 million US-$ or more. Antenna factors (AF) of broadband antennas play a key role in the determination of normalized site attenuation. In this paper, we describe our high-precision "site-reference measurement method" which helps to minimize uncertainties in the test results. Thus, maximum confidence in the judgement upon the acceptability of the site is gained.

Figure 1: Picture of the CALTS (Calibration Test Site) in Seibersdorf

DEFINITION OF SITE ATTENUATION AND NORMALIZED SITE ATTENUATION

Site attenuation (SA), and 'normalized' site attenuation (NSA), have become the standard methods for determining the adequacy of EMC test sites dedicated to perform radiated emission measurements. They represent a frequency response characteristic of a test site, acquired via measurements in accordance with various standards, e.g. [1]: Two antennas are set up on the test site in an appropriate geometry. The SA procedure requires two different measurements of the voltage received. The first reading V_{Direct} is with the two coaxial cables disconnected from the two antennas and connected to each other. The second reading V_{Site} is taken with the coaxial cables reconnected to the antennas and the maximum signal measured with the receive antenna scanned in height. The SA that includes the antenna performance is calculated according to Eq. 1. To describe the performance of the test site the antenna factors of transmit and receive antenna (AF_T, AF_R) have to be subtracted. The result is defined as NSA, Eq. 2. Therefore special care has to be taken on the appropriate calibration of the antennas involved.

$$SA = V_{Direct} - V_{Site} \quad (1)$$

$$NSA = SA - AF_T - AF_R \quad (2)$$

Thus, the NSA should basically be a characteristic of the site itself. Unfortunately, standard NSA reference values are only valid for a particular type and construction of antennas used, which is not adequately specified in the standard. The reasons are described below.

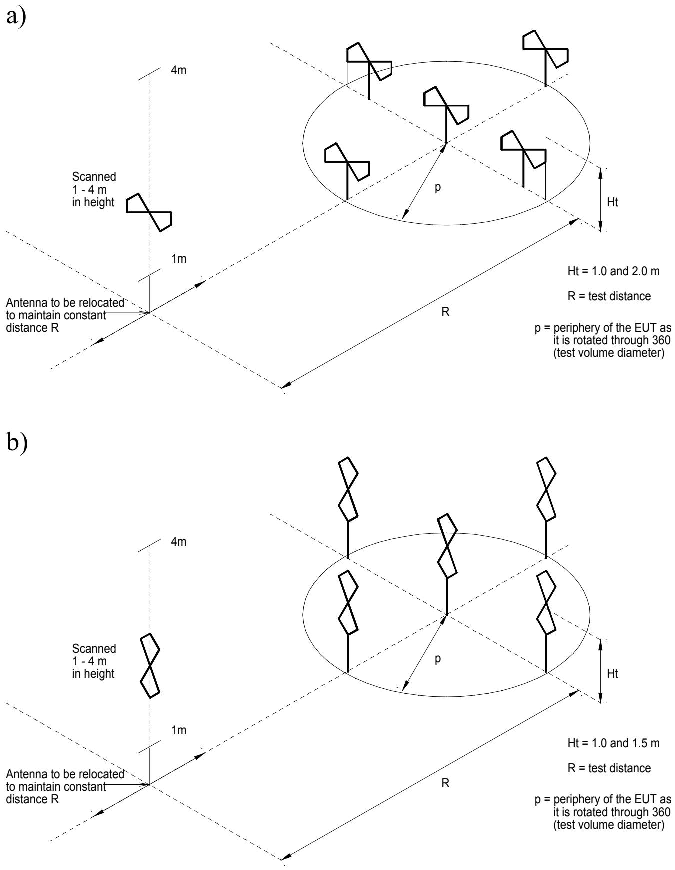


Figure 2: Volume Method for site attenuation measurements on alternative test sites with reflecting groundplane
a) Horizontal polarization
b) Vertical polarization

Using the swept frequency method, broadband antennas are applied. With biconical antennas in the frequency range of 30 - 200 (300) MHz, the impedance of the balun is the reason for different ground coupling of different antenna types. The input impedance of the antenna changes with frequency, height above ground and polarization [2]. Clearly, this affects the antenna factor and, thus, the NSA. Logarithmic-periodic dipole antennas of different construction show different directivity. During height scanning, the directions of direct and ground-reflected wave impinging on the receive antenna change. This results in different NSA values for different antennas.

SITE ACCEPTABILITY

The normalized site attenuation measured on a particular site is compared to theoretically calculated reference values of an ideal site. Deviations between test results and theoretical reference values have to be less than $\pm$ 4 dB at any frequency, otherwise the site is not acceptable. Measurements are to be made at a minimum of 24 frequencies, if tuned dipoles are used. Certain room resonances can be very narrowband and might be overlooked with the large frequency step specified as minimum requirement by CISPR. Therefore, swept-frequency techniques using broadband antennas should be preferred. Transmit antenna heights are 1 m and 2 m for horizontal polarization, and 1 m and 1.5 m for vertical polarization.

For standard open-area test sites, the transmit antenna is placed in the center of the turntable. A single NSA measurement is sufficient to determine the conformity.

For alternative test sites with groundplane, e.g. OATS with all-weather cover or semi-anechoic chambers, a "volume method" as shown in Fig. 2 must be applied. The tests are performed at five different locations (one after the other), depending on the size of the turntable. The transmit antenna is relocated to maintain a constant horizontal test distance. The antennas are always oriented to face each other.

DESCRIPTION OF METHODS AND IMPROVEMENTS

The majority of all site validations are made with broadband antennas. The swept-frequency technique is much faster than the measurement with precision dipoles. Moreover, it provides quasi-continuous data over the whole frequency range. For these measurements, site attenuation reference values for broadband antennas are required.

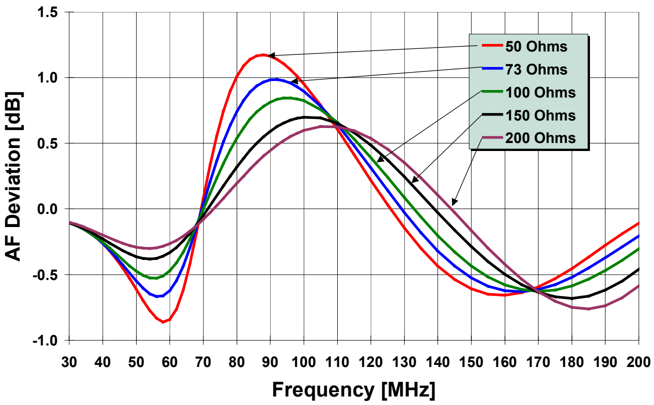
NSA Method

The standard site validation procedure described in CISPR [1] foresees two steps:

1. The antennas have to be calibrated to determine the antenna factors AF_T and AF_R of transmit and receive antenna. Unfortunately the calibration procedure is still under consideration and no guidelines are given at present. The common method for antenna calibration is the standard-site three-antenna method according to ANSI C63.5 [3].

2. SA measurement and calculation of NSA using AF_T and AF_R.

a)



b)

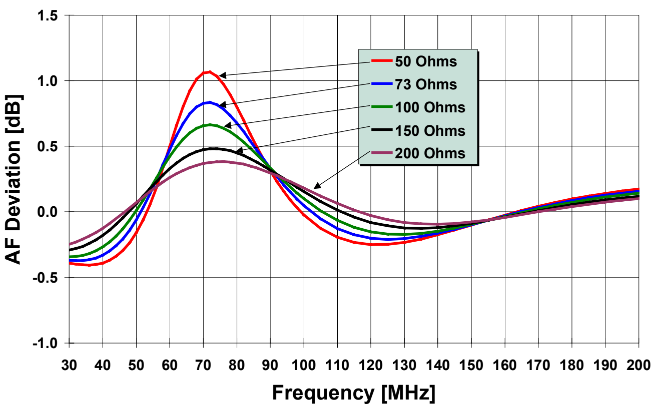


Figure 3: Influence of the proximity of the groundplane in 1 m on the antenna factor compared to free space, depending on the impedance of the antenna balun;
a) Horizontal polarization
b) Vertical polarisation

The standard site validation procedure [1] has the following disadvantages:

- The antenna factors of biconical antennas are functions of polarization and height above ground. Standard antenna calibration procedures that are frequently applied worldwide do not take that into account [3]. Furthermore free-space antenna factors are not appropriate for NSA-measurements above groundplane. In Figure 3 the deviation between the simulated (NEC) free-space antenna factor and the antenna factor in 1 m height above ground-plane is shown [2]. The parameter is the balun impedance. For commercially available biconical antennas the impedance of the balun and therefore the AF deviation is unknown. A correction of free space antenna factors is only possible for antennas with specially designed baluns with known and stable impedance.
- Standard NSA reference data [1] can never be unique for all kinds of broadband antennas. Therefore, evaluations of a particular site based on these data will always contain a systematic error.

Dual Antenna Factor Method

To overcome the above mentioned disadvantages and to enhance the overall measurement accuracy, the dual-antenna factor method has been introduced [4]. This method has been used already many years successfully for site validations.

To calculate the normalized site attenuation NSA_{Site} from SA_{Site}, only the sum of the two antenna factors AF_T and AF_R (in dB) has to be known. Therefore, the dual-antenna factor method employs a standard-site, two-antenna method for antenna calibration: A site attenuation measurement is made on a reference site with validated performance [1]. (This performance evaluation should have been done with precision dipoles [5]). The setup, antenna heights above ground, horizontal measurement distance and polarization, is exactly the same as for the site validation measurements. The result of the calibration is the dual-antenna factor (DAF), which is defined as

$$DAF\ [dB(1/m)] = AF_T + AF_R =$$
$$20*\log f_{MHz} - 48.92 + SA_{RefSite} + E_D^{max} \qquad (3)$$

where E_D^{max} is the theoretically calculated reference value that accounts for the geometry of the test setup with direct and ground-reflected wave and the maximum received field [3, 6, 7].

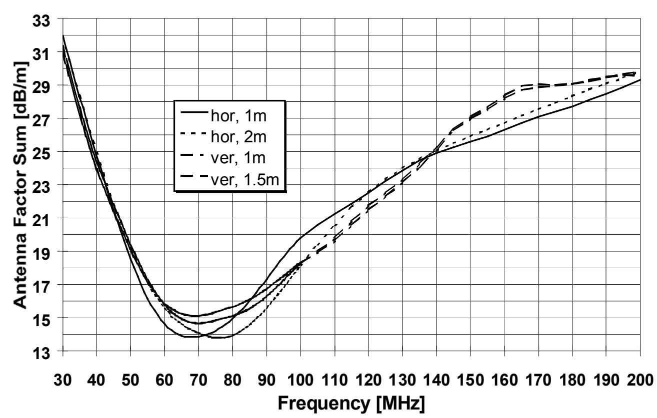


Figure 4: Dual-antenna factor of a pair of biconical antennas PBA320 calibrated at 10 m distance on a reference open-area test site

Figure 4 shows the DAF of a pair of biconical antennas calibrated at the OATS in Seibersdorf. The measurement distance is 10 m. The figure depicts the strong height- and polarization-dependence of the DAF of biconical antennas.

The major advantage of this method is that only ***one*** measurement is necessary to determine the calibration result. Other methods need more measurements: In the standard-site three-antenna method [3], 3 measurements are required (this procedure has other disadvantages as well, [2]). In the reference antenna method [8], also 3 measurements are necessary. In any case, each measurement contributes to the total uncertainty of the result. Therefore, the DAF method provides lower uncertainty methods used for single AF calibration.

Site Reference Method

The following considerations allow us to further optimize the procedure of validating test sites. In the DAF antenna calibration procedure, SA is measured on a reference site. The DAF is determined assuming ideal wave propagation conditions and a perfectly reflecting groundplane. In a site validation measurement, SA_{Site} of the site to be evaluated is measured. To obtain NSA_{Site}, the DAF is subtracted:

$$NSA_{Site} = SA_{Site} - DAF \qquad (4)$$

Substituting (3) in (4) gives

$$NSA_{Site} = SA_{Site} - 20*\log f_M + 48.92 - SA_{RefSite} - E_D^{max} \qquad (5)$$

The terms $20*\log f_M$, 48.92 and E_D^{max} represent fixed standard values. Therefore, the relevant result of the site validation measurement is the term $SA_{Site} - SA_{RefSite}$. Adding fixed terms gives no substantial, additional information. This shows that, in fact, a **direct comparison** between the site attenuations measured on the reference site and on the site under evaluation is made.
We define the Site Attenuation Deviation (DSA) as difference between measured SA of a real test site to be validated and the corresponding measured Reference Site Attenuation of the CALTS (calibration test site).

$$DSA = SA_{Site} - SA_{RefSite} \qquad (6)$$

At time of writing this paper the requirements for CALTS [1] validation are specified for horizontal polarization only. The reference values of theoretical site attenuation for tuned dipoles have been re-calculated using numerical simulations (NEC). Precise SA-values are given in [1, 9]. These values should be used to validate CALTS. The acceptance criterion for a CALTS is a deviation of less than ± 1 dB from theoretical SA values. The DSA, as defined in Eq. 6. becomes:

$$DSA_{CALTS} = SA_{Site} - SA_{Calculated} \leq \pm 1 \text{ dB} \qquad (7)$$

Practical validations have shown an agreement between numerical calculations and measurement within 0.25 dB at any frequency [5]. On such sites, reference site attenuation can be determined for pairs of broadband antennas. Work is in progress for defining the vertical polarization validation procedure in CISPR.

Figure 5 and 6 show measured results of a site validation measurement in a semi-anechoic chamber of excellent performance. The DSA is less than 2.5 dB at any frequency.
Applying the site-reference method antenna factors, theoretical reference values and non traceable mutual coupling factors play no role in site validation any more. The quality of the reference site is of the same importance as for determining the antenna factors and measuring the NSA the 'classical' way.

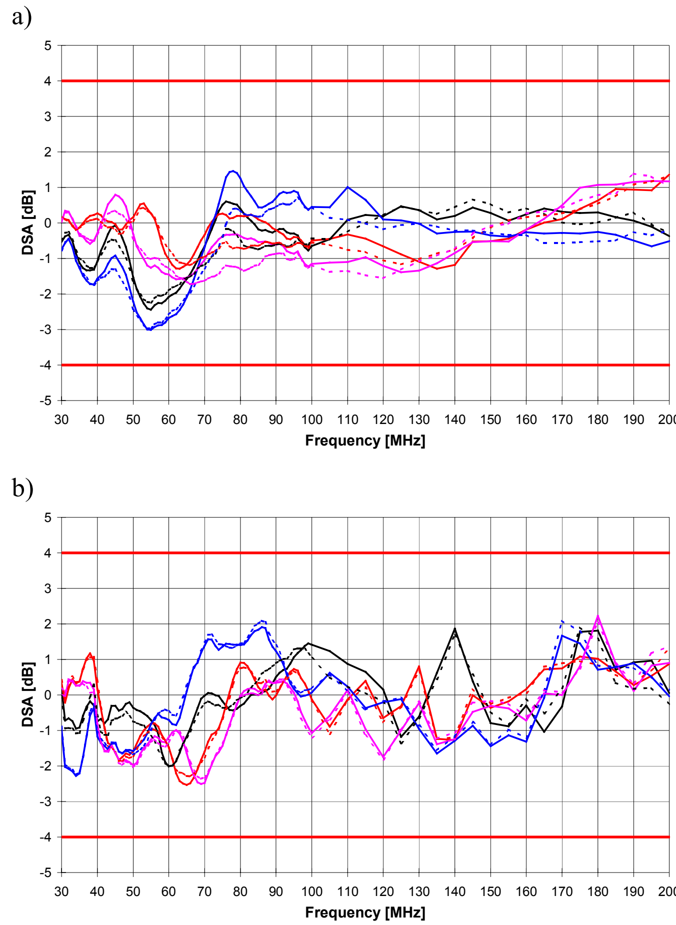


Figure 5: Results of a site validation measurement in a semi-anechoic chamber, 10 m test distance, 2 m test volume diameter
a) Horizontal polarization, biconical antennas
b) Vertical polarization, biconical antennas

Judgements upon the performance and acceptability of a site should be based on the direct comparison between the site attenuation measured on a (validated, high-performance) reference site and the site attenuation measured on the site under evaluation. Uncertainties in the site validation procedure can thus be minimized.

a)

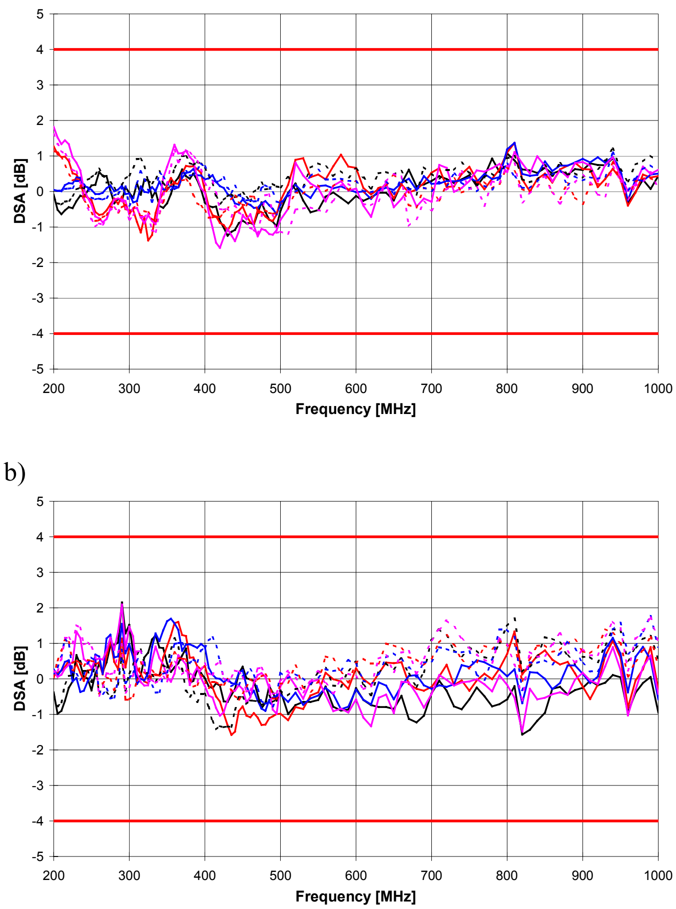


Figure 6: Results of a site validation measurement in a semi-anechoic chamber, 10 m test distance, 2 m test volume diameter
a) Horizontal polarization, logarithmic-periodic dipole antennas
b) Vertical polarization, logarithmic-periodic dipole antennas

Suppliers of absorber-lined chambers have to validate a number of sites per year. For maximum economy, we suggest the following solution: First, a high-performance open-area reference test site (CALTS) is validated by site attenuation measurements with half-wave dipoles. This has to be done only once. Then, all chamber validations are made by direct comparison of the site attenuation measured with broadband antennas to the reference site attenuation of the open-area reference test site.

Summary and Conclusions

Reference values of normalized site attenuation for broadband antennas can never be independent of the type of antenna. Therefore, the standard values given in [1] are not absolutely correct, but are rather estimates.

The common method for antenna calibration is the standard-site three-antenna method according to ANSI C63.5 [3]. This method is not suitable for calibrating pairs of broadband antennas intended for use in site validations [2].

In this paper, various issues concerning antenna calibration for high performance site validation have been clarified and several improvements have been proposed:

Reference values of normalized site attenuation play no role in a site validation following the site-reference method described in this paper. Judgements upon the performance and acceptability of a site should be based on the direct comparison between the site attenuation measured on a (validated, high-performance) reference site and the site attenuation measured on the site under evaluation.

Suppliers of absorber-lined chambers have to validate a number of sites per year. Site validations with half-wave dipoles provide optimum accuracy, but are inefficient as they are very time consuming and thus, raise the price unnecessarily. Site validations with broadband antennas are efficient, but inaccurate, if standard NSA reference values are used. Therefore, the site-reference method is the most economic solution: First, a high-performance open-area reference test site is validated by site attenuation measurements with half-wave dipoles. This has to be done only once. Then, all validations are made by direct comparison of the site attenuation measured with broadband antennas to the reference site attenuation of the open-area reference test site. It has been shown that a reference site can be constructed with anomalies of less than 0.25 dB in site attenuation [5].
By using the recommendations given in this paper, uncertainties in the site validation procedure can be minimized. This offers two major advantages:

Optimum (maximum) reliability of the test result is assured. This provides legal security for both the customer and the supplier of EMC test sites such as an anechoic chamber.
Minimum measurement uncertainty in the site validation leaves maximum tolerance for the performance of the site, which must comply with the ± 4 dB – limit of CISPR and CENELEC.

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