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Site-Reference Method for EMC Test Site Validation

Referenzgelände-Methode für die EMV-Meßgeländeüberprüfung

Abstract
Electromagnetic compatibility (EMC) compliance testing for the CE-certification of electronic apparatus involves 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 two substantial improvements to the standard site validation procedure: (i) Precise, numerically calculated reference values of site attenuation for tuned dipoles are given. (ii) The new "site-reference method" for site validation is suggested. It avoids the determination of the antenna factors of transmit and receive antenna and 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.

Übersicht
Überprüfungen der elektromagnetischen Verträglichkeit (EMV) zur CE-Zertifizierung elektronischer Geräte beinhalten Störfeldstärkemessungen im Frequenzbereich von 30 MHz bis 1 GHz. Um von verschiedenen Prüflaboratorien gleichwertige Testergebnisse zu erhalten, benötigt man normgerechte, überprüfte Meßstrecken. Diese Arbeit schlägt zwei substantielle Verbesserungen des genormten Validierungsverfahrens für Meßstrecken vor: (i) Präzise, numerisch berechnete Referenzwerte der Felddämpfung für abgestimmte Halbwellendipole; (ii) Die neue "Referenzgelände-Methode" zur Meßgeländeüberprüfung. Diese vermeidet die Bestimmung der Antennenfaktoren von Sende- und Empfangsantenne und minimiert die Unsicherheiten im Meßergebnis. Das erhöht die Zuverlässigkeit bei der Beurteilung der Eignung eines Meßgeländes und gestattet ein wirtschaftlicheres Design von Meßeinrichtungen wie z. B. Absorberhallen.

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Für die Dokumentation
Absorberhalle, echoarmer Raum, elektromagnetische Verträglichkeit, EMV, Störfeldstärkemessung, Felddämpfung, Freifeld-Meßgelände, Referenzgelände.

1. Introduction

Electromagnetic Compatibility (EMC) compliance testing for the CE-certification of electronic products involves 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, a requirement regarding the quality of the site has been introduced by CISPR [1]. This requirement is given in terms of the so-called " site attenuation". It is fulfilled by a large, flat, obstruction-free field with reflecting ground. Such an "open-area test site" (OATS) is normally equipped with a metal groundplane. Alternative test sites such as OATS with all-weather cover, semi-anechoic chambers or fully anechoic chambers are acceptable, if extended requirements on site attenuation are fulfilled [2, 3].

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 value of 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. It helps to minimize uncertainties in the test results. Thus, maximum confidence in the judgement upon the acceptability of the site is gained.

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 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. Chapter 3 deals with the precise calculation of site attenuation. Measurements methods for broadband antenna are described in Section 4.

2. Standard Specifications

2.1 Definition of site attenuation and normalized site attenuation

Site attenuation (SA) is the minimum transmission loss between a transmit and a receive antenna operated in a standard setup on the site. The height above ground of the transmit antenna is fixed at 1 m, 1.5 m or 2 m, depending on the procedure. The height of the receive antenna is scanned between 1 m and 4 m above ground to search for the field-strength maximum in the interference pattern.

The input impedances of the antennas change with frequency, height above ground and polarization. Mismatch losses between the feedpoints of each antenna and the 50 Ω reference impedance shall be part of the site attenuation. The attenuation of cables, matching attenuators and baluns shall not be part of the site attenuation. To avoid standing waves on the cable, good match at the antenna feedpoints is necessary. Measurements are made with both horizontal and vertical polarization of the antennas. The test distance is specified in the product standard to be applied. Usual values are 3 m and 10 m.

Normalized site attenuation (NSA) is the site attenuation with the antenna factors of transmit and receive antenna subtracted, (1). Thus, the NSA should basically be a characteristic of the site itself. Unfortunately, standard NSA reference values are only valid for a particular kind and construction of antennas, which is not adequately specified in the standard. The reasons are described below.

$$NSA = SA - AF_T - AF_R \quad dB \qquad (1)$$

2.2 Antennas

In the *discrete frequency method*, tuned half-wave dipoles are to be used. In vertical polarization, there are some restrictions on antenna movement at frequencies below 80 MHz. The most important disadvantage of this method is that a measurement using one particular dipole length can only be performed over a very narrow frequency band (usually, just one frequency is used). Therefore, it is very time-consuming to investigate the whole frequency range of 30 - 1000 MHz by this method. Moreover, narrowband room resonances in absorber-lined chambers are easily overlooked. The basic requirements for dipoles are

- the balun must be able to be calibrated separately
- the antenna must be shaped such that it allows exact modelling:
  - the dipole elements must be cylindrical (extensible dipoles are not appropriate) with minimum sag in horizontal orientation
  - there must not be any parts of metal or material with high permittivity in the vicinity of the radiating elements (use selected plastic).

Dipole antennas shall be tuned for zero reactance of the input impedance in free-space. This means that the antenna is detuned in proximity to ground. This must be taken into account in the calculated reference values of site attenuation.

In 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. 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 means different NSA for different antennas.

According to [1], broadband antennas are acceptable, if the following conditions are met:

- The antenna must be substantially linear polarized.
- The main lobe of the radiation pattern of the antena shall be such that the response in the direction of the direct ray and that in the direction of the ray reflected from the ground do not differ by more than 1 dB.
- The voltage standing-wave ration of the antenna with the antenna feeder connected and measured from the receiver end shall not exceed 2:1. In practise, matching attenuators are needed at their feedpoints to avoid standing waves on the cables.

According to [1], "the antenna factors of broadband antennas used to make site attenuation measurements should be traceable to a national standard."

2.3 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 result and theoretical reference values have to be less than ± 4 dB at each frequency, otherwise the site is not acceptable. Measurements are to be made at a minimum of 24 frequencies, if tuned dipoles are used. Unfortunately, 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.

For *alternative test sites with groundplane* (OATS with all-weather cover, semi-anechoic chambers), a "volume method" as shown in **Fig. 1** must be applied: Tests are done 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. Antennas are always oriented to face each other.

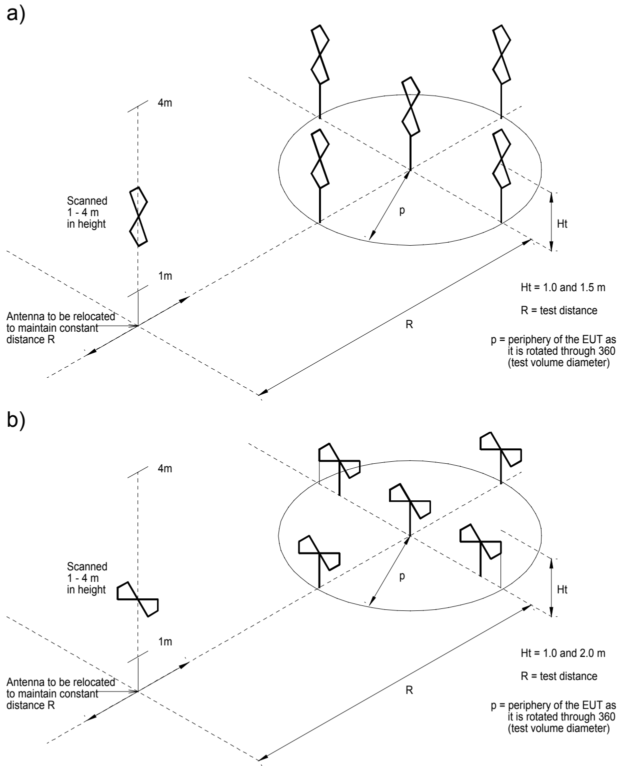

Fig. 1: Volume Method for site attenuation measurements on alternative test sites with reflecting groundplane [2]
(EUT: Equipment under test)
a) Vertical polarization
b) Horizontal polarization

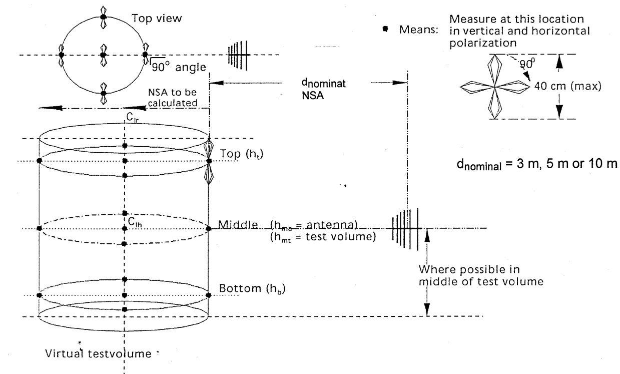

Fig. 2: Volume method for site attenuation measurements in fully anechoic chambers [3]

In *fully anechoic chambers*, fifteen points on the turntable shall be used (5 positions in 3 horizontal planes), see **Fig. 2** [3]. The receive antenna is kept in a fixed position, the antennas are not adjusted to face each other in the side positions and in the top and bottom plane. The transmit antenna shall be a biconical antenna with a maximum length of 40 cm.

3. Numerical Calculation of Theoretical Site Attenuation for Dipoles

A complete analytical model for the description of transmission loss between a transmit and a receive antenna above groundplane has been given in [4]. Site attenuation values were calculated using this so-called "induced emf method" [5, 6]. The model yields accurate results for far-field conditions. In the range of 30 - 50 MHz, where the distance between antenna and groundplane is less than $\lambda/10$, deviations to practical measurements up to about 1.8 dB had occured. In this paper, numerical methods are applied.

We use NEC2D, a double precision version of the Numerical Electromagnetics Code NEC [7]. For input to and output from NEC we use our program ANTENNA, which is based on ANTCAD, a program developed at the Institut für Nachrichtentechnik und Hochfrequenztechnik of the Technical University of Vienna. The dipoles were modelled as uniformly segmented straight wires with the same diameter as the real antennas. The number of segments was chosen between 29 and 125, depending on the frequency. The conductivity of the elements was assumed to be infinite.

We have investigated the convergence of the results as we increased the number of segments up to 125. As soon as more than 15 segments are used (all of equal length), the calculated site attenuation is stable to within less than 0.01 dB.

NEC can be used both in the far-field and in the radiating near-field. Therefore, the transmission loss can be reliably calculated even at, e. g., 300 MHz at a distance of one meter. We used this in the experimental validation procedure for our dipoles.

NEC impresses a voltage of 1 V in the feed (center) element of the transmit antenna. In the receive antenna, the center element represents the load resistor, where the "structure loss" occurs. Thus, the "power budget" of NEC (power transmitted, P_T, and power absorbed in the load, P_R) contains the effect of mismatch at the receive antenna, but does not contain the insertion loss between the generator (impedance $\underline{Z}_G$) and the transmit antenna (impedance $\underline{Z}_{i1}$). As NEC calculates the input impedance of the transmit antenna, we can calculate the site attenuation SA (including all mismatches between signal generator and receiver) from (2).

$$SA[dB] = 10 * \log\left[\frac{P_T}{P_R}\right] + 10 * \log\left[\frac{1}{1-\left|\frac{\underline{Z}_{i1}-\underline{Z}_G}{\underline{Z}_{i1}+\underline{Z}_G}\right|^2}\right] \qquad (2)$$

All calculations were made for the geometry of our precision reference dipoles PRD. They have a miniaturized, resistive matching network between antenna elements and balun. The balun is a 180° hybrid coupler. Therefore, the reference impedance is 100 Ω [8, 9]. **Fig. 3** shows values of calculated transmission loss versus height at several frequencies. We observe strong interference that causes deep nulls at frequencies above about 400 MHz. This emphasizes the necessity for exact antenna positioning in the relative field-strength maximum (minimum of transmission loss). **Table 1** gives an overview of calculated results for site attenuation (minimum transmission loss at each frequency) on an open-area test site.

The agreement between NEC-calculations and practical measurements done on the high-performance reference OATS in Seibersdorf was 0.15 dB for two standard deviations [10]. Therefore, these NEC-calculated values should be used as the standard reference.

The SA-values listed in **Tables 1** and **2** are valid for dipoles of certain geometry. For an other thickness of the dipole elements as well as for other reference impedance values the results are somewhat different. The same is true for the antenna factors. For high-precision measurements with dipoles, NEC-calculated site attenuation data should be used as the reference. **Fig. 4** shows that the standard NSA reference values given by CISPR [1] deviate from NEC-calculated values.

For *free-space*, the typical test distance is 3 – 5 m. Table 2 lists NEC-calculated reference values of free-space site attenuation for pairs of tuned precision dipoles at 3 m distance. These values can be used to validate quasi free-space test sites. The simple free-space transmission loss formula (3) given by CENELEC [3] yields very inaccurate results under near-field conditions, see **Fig. 5**

Table 1: NEC-calculated values of site attenuation on an open-area test site, tuned precision dipoles, 10 m distance, hT = 2 m, hR = 1 - 4 m, reference impedance 100 Ω

Frequency [MHz]	Element length [mm]	Element diameter [mm]	NEC SA horiz. [dB]	NEC SA vert. [dB]
30	2358.0	25	21.0	16.5
35	2021.0	25	20.9	17.0
40	1765.0	25	20.6	17.9
45	1561.0	25	20.7	18.6
50	1405.0	25	21.1	19.2
60	1167.0	25	22.2	20.9
70	996.0	25	21.8	22.4
80	870.0	25	21.0	23.5
80	890.5	6	20.9	23.6
90	791.0	6	21.3	24.6
100	710.5	6	22.3	25.4
120	591.0	6	24.7	27.2
140	505.5	6	25.8	28.3
160	441.5	6	26.2	28.9
180	391.0	6	27.4	29.7
200	351.0	6	28.8	30.4
250	280.0	6	30.1	32.0
300	232.0	6	31.9	33.5
300	235.5	3	31.9	33.5
400	175.8	3	34.7	36.4
500	140.0	3	36.9	37.7
600	116.2	3	38.4	39.5
700	99.3	3	39.6	40.7
800	86.6	3	40.9	41.9
900	76.8	3	41.8	42.9
1000	68.9	3	42.6	43.7

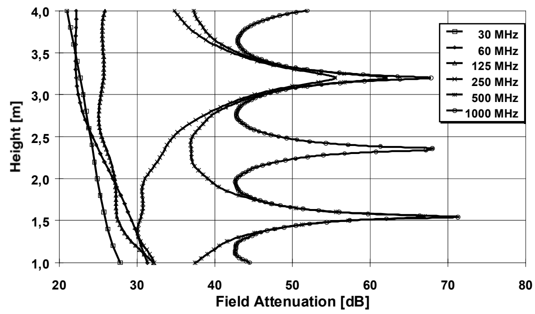

Fig. 3: Calculated transmission loss between horizontally polarized linear antennas on an open-area test site
Parameter: Frequency in MHz
Transmit antenna height above ground: 1 m
Measurement distance: 10 m

$$NSA_{CENELEC} = 20\log_{10}\left[\left(\frac{5Z_0}{2\pi}\right)\left(\frac{d}{\sqrt{1-\frac{1}{(\beta d)^2}+\frac{1}{(\beta d)^4}}}\right)\right] - 20\log_{10} f_m \quad [dB] \qquad (3)$$

Table 2: NEC-calculated values of free-space site attenuation, tuned precision dipoles,
3 m distance, reference impedance 100 Ω

Frequency [MHz]	Element length [mm]	Element diameter [mm]	NEC SA [dB]
30	2358.0	25	10.5
35	2021.0	25	11.5
40	1765.0	25	12.3
45	1561.0	25	13.0
50	1405.0	25	13.6
60	1167.0	25	14.5
70	996.0	25	15.5
80	870.0	25	16.6
80	890.5	6	16.6
90	791.0	6	17.6
100	710.5	6	18.5
120	591.0	6	19.8
140	505.5	6	21.1
160	441.5	6	22.2
180	391.0	6	23.2
200	351.0	6	24.1
250	280.0	6	26.0
300	232.0	6	27.6
300	235.5	3	27.6
400	175.8	3	30.0
500	140.0	3	32.0
600	116.2	3	33.5
700	99.3	3	34.9
800	86.6	3	36.0
900	76.8	3	37.1
1000	68.9	3	38.0

where
Z_0 reference impedance [Ω]
d measurement distance [m]
f_m frequency [MHz]
β $\beta = 2\pi/\lambda$, λ ... wavelength [m]

4. Site Attenuation Measurements with Broadband Antennas

4.1. Standard Swept-Frequency Method

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.

The standard site validation procedure forsees two steps:

1. Calibration of the antenna factors AF_T, AF_R of transmit and receive antenna
2. SA measurement and calculation of NSA using AF_T and AF_R.

This procedure 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 [11]. Also, free-space antenna factors are not appropriate for NSA-measurements above groundplane.

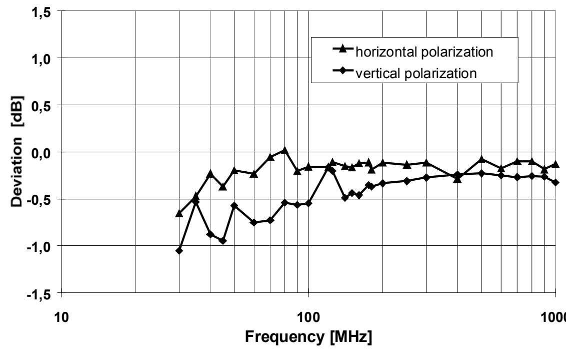

Fig. 4: Difference between standard NSA (1) reference values for tuned dipoles [1] and our NEC-calculated values (NSA_{CISPR} - NSA_{NEC})
Horizontal measurement distance: 10 m
Reference impedance: 50 Ω
Height of the transmit antenna: 2 m (horizontal) / 2.75 m (vertical)
Height of the receive antenna: 1 - 4 m (scanned)

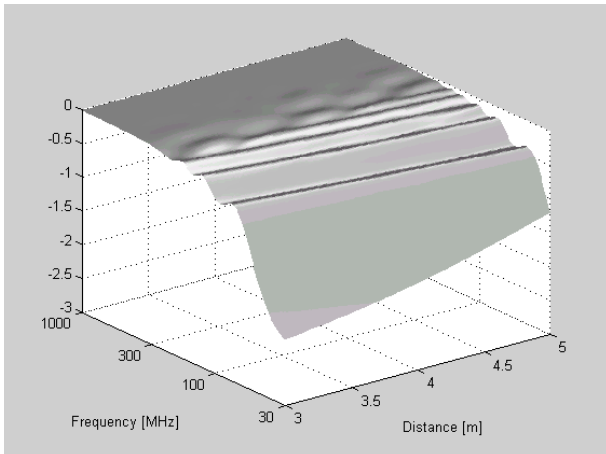

Fig. 5: Near-field error of a simple free-space transmission loss formula (3) applied to tuned dipoles in comparison to precise, numerically calculated values
Ordinate: $NSA_{CENELEC [3]}$ - NSA_{NEC} [dB]
Reference impedance: 50 Ω

- 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.

To overcome the above mentioned disadvantages and to enhance the overall measurement accuracy, the dual-antenna factor method described below has been introduced.

4.2. Dual-Antenna Factor Method

In the standard site validation procedure, site attenuation SA_{Site} has to be measured using a transmit and a receive antenna with known antenna factors. 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 [10]). The setup (antenna heights above ground, horizontal measurement distance, polarization) is exactly the same as for the site validation measurements. The result of the calibration is the dual-antenna factor (DAF):

$$DAF = AF_T + AF_R = 20*\log f_{MHz} - 48.92 + SA_{RefSite} + E_D^{max} \quad [dB(1/m)] \qquad (4)$$

where

E_D^{max}. Theoretically calculated reference value that accounts for the geometry of the test setup with direct and ground-reflected wave and the maximum received field [11, 12, 13]

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 [11], 3 measurements are required (this procedure has other disadvantages as well, [14]). In the reference antenna method [15], 2 x 2 = 4 measurements are necessary (2 substitution procedures for the two different heights of transmit and receive antenna). In any case, each measurement contributes to the total uncertainty of the result. Therefore, the DAF method provides lower uncertainty than previous methods.

4.3 Site-Reference Method

The following consideration allows us to further optimize the procedure. 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. Reference values of E_D^{max} have been theoretically calculated using simple geometrical relations and are given in the standard [11, 12, 13].

In a site validation measurement, SA_{Site} of the site to be evaluated is measured. To obtain NSA_{Site}, the DAF is subtracted:

$$NSA_{Site} = SA_{Site} - DAF \qquad (5)$$

Substituting (4) in (5) gives

$$NSA_{Site} = SA_{Site} - 20*\log f_M + 48.92 - SA_{RefSite} - E_D^{max} \qquad (6)$$

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 that is to be evaluated is made. Antenna factors play no role. Nevertheless, the standard documentation of a site validation requires the calculation and presentation of NSA_{Site} and the comparison to standard reference values. In our automatic measurement system, we can do all the above arithmetic operations.

If highly precise results are desired, some optimized measurement practises regarding unwanted secondary effects of feed cables are recommended:

- The transmit antenna cable can be omitted, if a stable, battery-operated comb generator is connected directly to the antenna feed point. We use our well-tried product RefRad® [17].
- The layout of the cable to the antenna that is operated at fixed height can be standardized. The position of the cable can be exactly reproduced by using mechanical fixes.
  Furthermore, ferrite-loaded coax attenuates surface currents and thus minimizes secondary effects.
- Use antennas with a very well balanced balun.
- Time-domain gating should be used to determine site reference data, provided that the antennas utilized have a smooth antenna factor versus frequency. This criterion is usually fulfilled by biconical antennas. Gating is particularly useful in vertical polarization to eliminate groundplane egde effects. The criterion is not fulfilled for logarithmic-periodic dipole antennas. However, gating is not necessary with these antennas because of their directivity. It should be noted that gating may not be used in site evaluations!

By applying these techniques, optimum measurement accuracy can be achieved. A prerequisite is that the reference calibration ($SA_{RefSite}$ measurement) is done on a site with only minimum site anomalies. On our OATS in Seibersdorf, we have achieved deviations of less than 0.25 dB between theoretically calculated values and measurement results at all frequencies between 30 and 1000 MHz. Therefore, this site is excellently suited to serve as reference site [10, 16].

4.4 Results

Fig. 6 shows a DAF of a pair of biconical antennas calibrated at the OATS in Seibersdorf. The measurement distance is 10 m. We observe the strong height- and polarization-dependence of this kind of antenna.

Fig. 7 shows measured results of a site validation measurement in a semi-anechoic chamber of excellent performance. The devation $SA_{Site} - SA_{RefSite}$ is less than 2.5 dB at any frequency and for any of the 20 antenna positions.

5. Summary and Conclusions

The concept of normalized site attenuation has become a well-recognized method for site validations worldwide. However, it suffers from a number of severe problems that have not been solved by current standards:

- Reference values of site attenuation and normalized site attenuation for dipoles have formerly been calculated using the so-called "induced emf" method [4, 8, 9]. Precise measurements and NEC-calculations have shown that standard reference values are in error by more than 1 dB at frequencies between 30 and 50 MHz [10], depending on measurement distance and polarization.
- Antenna factors of tuned dipoles have formerly been calculated using a simple formula that is based on the effective length of the dipole elements [17]. Precise measurements and NEC-calculations have shown that these values are in error by up to 1.3 dB, especially in horizontal polarization and at lower frequencies [10].
- Reference values of normalized site attenuation for broadband antennas can never be independent of the kind of antenna. Therefore, the standard values given in [1] are not absolutely correct, but rather mean values.

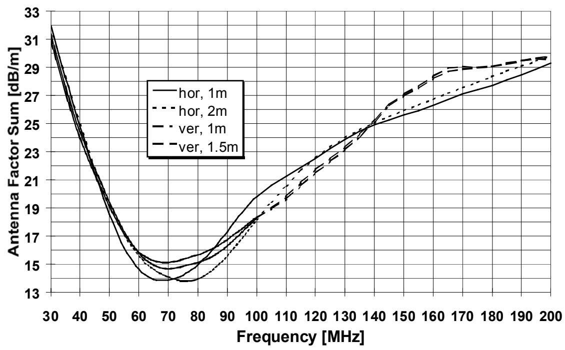

Fig. 6: Dual-antenna factor of a pair of biconical antennas PBA320 measured at 10 m distance on a reference open-area test site

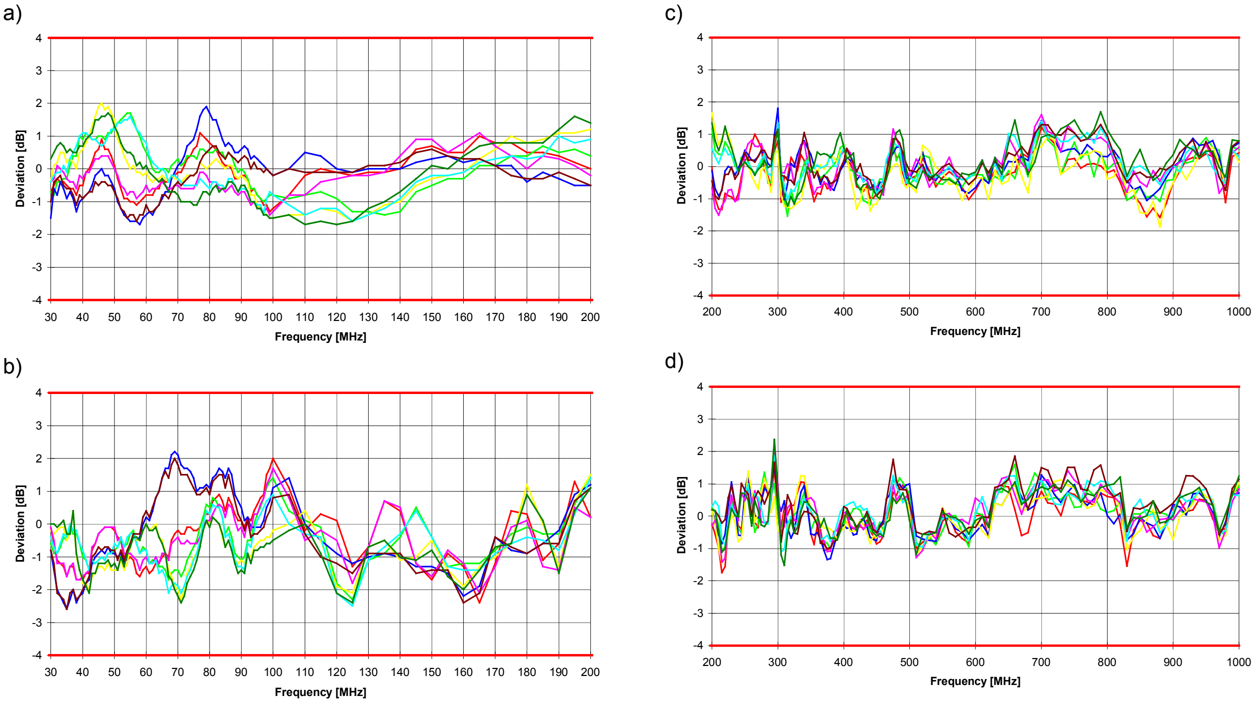

Fig. 7: Results of a site validation measurement in a semi-anechoic chamber, 10 m test distance, 2 m test volume diameter
a) Horizontal polarization, biconical antennas
b) Vertical polarization, biconical antennas
c) Horizontal polarization, logarithmic-periodic dipole antennas
d) Vertical polarization, logarithmic-periodic dipole antennas

- The usual method for antenna calibration is the standard-site three-antenna method according to [11]. This method is not suitable for calibrating pairs of broadband antennas that shall be used for site validations [14].

In this paper, all above issues have been clarified and improvements have been proposed:

1) The reference values of theoretical site attenuation for tuned dipoles have been re-calculated using NEC. Precise SA-values are given in the tables of this paper. Practical validations have shown an agreement between numerical calulation and measurement within 0.25 dB at any frequency [10]. These values should be used to validate reference open-area test sites. On such sites, reference site attenuation can be determined for pairs of broadband antennas.
2) 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 to be evaluated.

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 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 on the basis of the reference values given in this paper. 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. It has been shown that a reference site can be constructed with anomalies of less than 0.25 dB in site attenuation [10].

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 an EMC test site 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. This helps to economize chamber design and makes test sites more affordeable.

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