SITE ATTENUATION OF LIMITED - SIZE GROUND PLANES FOR VERTICAL POLARISATION

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Abstract: We have investigated the site attenuation performance of open area test sites for vertical polarization in the frequency range from 30 MHz up to 200 MHz. The results have been obtained by numerical simulation using FDTD. Practical measurements and NEC, an other numerical simulation method, have been used for verification. We have found that the site attenuation in vertical polarization depends in contrary to horizontal polarization strongly on the size of the ground plane. Edge effects influence the accuracy of all field strength and site attenuation measurements. The site attenuation shows a deviation of up to ± 2 dB on a perfect, but limited-size ground plane. Measurements with the receive antenna not positioned in the height scan maximum should be avoided as errors up to 15 dB may arise. When calibrating an antenna according to the reference antenna method in vertical polarization an identical antenna type has to be used as reference antenna to avoid edge effect errors.

1. Introduction

Radiated emission testing and calibration of EMC test antennas is based on the wave propagation characteristic between EUT and antenna or between two antennas. For test sites with a metallic ground plane of infinite size and conductivity the wave propagation is described in ANSI [1] and CISPR [2]. The design of open area test sites (OATS) is given in e.g. ANSI C63.7 [4], where the recommended size of the ground plane is defined as 20 m length by 17.3 m width for a 10 m test distance.

To check the appropriate performance regarding wave propagation on the test site the normalized site attenuation has to be measured. We have performed measurements of different OATS all over the world. The results show the same characteristics: the normalized site attenuation in vertical polarization deviates much more from the theoretical value than in horizontal polarization. This effect is in the magnitude of up to 2 dB.

To better understand this phenomenon we started investigations by numerical simulations of limited-size ground planes and by comparative measurements. We wanted to find the reasons, the consequences to existing measurement procedures and propose possible solutions. In this paper we present the first results of our work.

2. Site Attenuation Simulation for Vertical Polarization

2.1. Site Attenuation

Site attenuation (SA), and 'normalized' site attenuation (NSA), have become the standard method for determining the adequacy of EMC test sites to perform EMI emission measurements. It is a frequency response characteristic of a test site that is acquired via measurement on the test site in accordance with various standards, e.g. [2], [3]. 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.

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

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

2.2. Description of the Simulation Method

For our simulations of finite ground planes we have chosen FDTD [6], [7]. This simulation method works in the time domain, and the frequency domain is obtained by the discrete Fourier transformation. The advantage of this is that one gets results in a fine frequency step over a wide band in one simulation run.

The ratio of minimum wavelength and cell size should be about 10. We have chosen a cell size of 5 cm to allow simulation on a standard personal computer with 512 Mbytes of system memory. The maximum frequency we can look at is 600 MHz in our case. The problem space of our simulation is 440 x 380 x 120 cells.

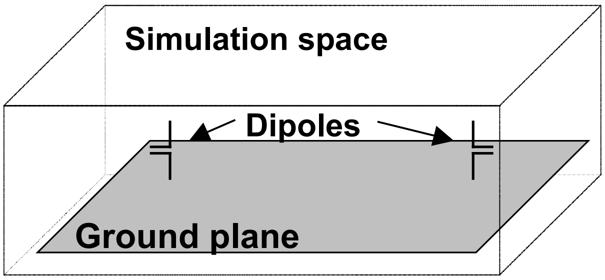


Fig. 1: Setup of SA determination on OATS.

The ground plane is modeled by using a rectangular plate of a perfect electrical conductor (PEC). In the case of an infinite ground plane the plate fills the whole XY-plane, for a finite ground plane we let enough space to the boundary. Absorbing boundary condition (ABC) is used for all outer planes of the simulation space, see Fig. 1.

We use dipole antennas to simulate the transmission loss. They are modeled with thin wire elements of a diameter of 18 mm, the same diameter like the precision reference dipole PRD [5]. The thin wire technique is used for the modeling of wire antennas, where the wire radii are much smaller than the cell size. It provides better accuracy for antenna impedance and coupling than simple PEC elements.

The signal fed into the transmit antenna is a Gaussian pulse. It is necessary to wait for the direct signal and all reflections from the edge of the ground plane to arrive at the receive antenna. 200 ns after the stimulation pulse all echoes are accounted which have a maximum path of 60 m. Further echoes have not enough energy to influence the received signal.

An example of the simulated SA for a certain geometry on finite and infinite ground plane is given in Fig. 2a. There one can see the 'smooth' behavior of the SA on the infinite ground plane and the 'distorted' SA on the limited-size ground plane.

2.3. Site Attenuation Deviation

We define the Site Attenuation Deviation (DSA) as difference between measured (or simulated) NSA of a real test site and the corresponding theoretical NSA (TNSA) of the ideal test site.

$$DSA = NSA - TNSA \qquad (3)$$

For different antenna setups (distance, height, polarization) individual TNSA values exist. The TNSA can be calculated according to the formulas in the Annex of ANSI C63.4 [3]. The DSA describes the site performance in terms of ± x dB, where the limit for an acceptable site is ± 4 dB for radiated emission test sites.

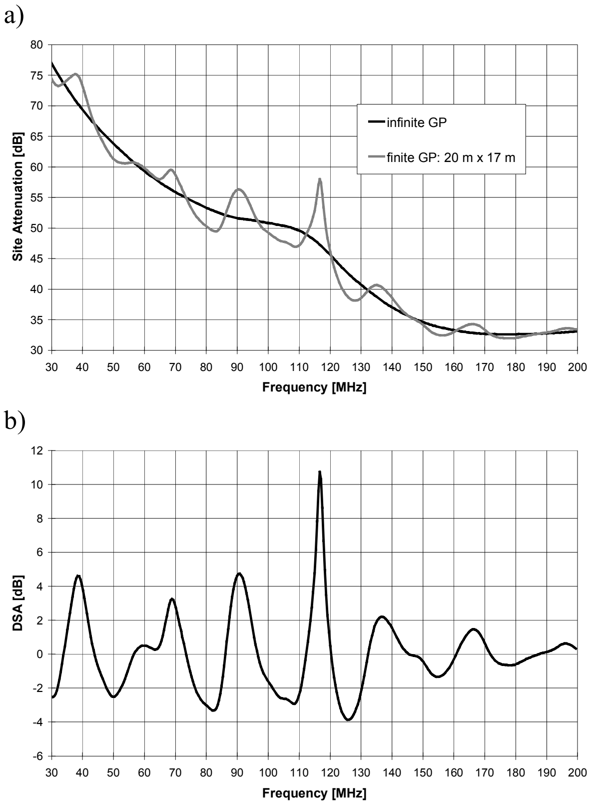


Fig. 2: DSA example: a) site attenuation on finite and infinite ground plane; b) deviation of the site attenuation DSA.

The DSA concept is also perfectly suited for evaluating simulation results of imperfect sites. In the first step we simulate the SA with particular antennas in a specified geometry on an infinite, ideal site. This acts as reference and with Eq. 2 we can write:

$$SA_{infinite} = AF_T + AF_R + TNSA \qquad (4)$$

In the second step we simulate the SA on the imperfect site (e.g. finite ground plane) using the identical setup geometry and the identical antennas as used for the reference simulation in the first step:

$$SA_{finite} = AF_T + AF_R + NSA \qquad (5)$$

Substituting Eq. 4 and 5 in Eq. 3 we obtain:

$$DSA = NSA - TNSA = SA_{finite} - SA_{infinite} \qquad (6)$$

With this definition we are able to compare our DSA simulation results directly with NSA measurement results.

To illustrate the special behavior of the limited-size ground plane we calculate the site attenuation deviation (DSA) according Eq. 6. This is shown in Fig. 2b.

2.4. Verification of the Simulation

We have done broadband SA measurements in the frequency range of 30 MHz up to 200 MHz using two PRD precision reference dipole antennas with a half-wave resonance frequency of 150 MHz. The test distance was 10 m and the height of the antenna above ground plane was 1 m. The antennas were set up in vertical polarization. The measurements were done at a fixed height of the receive antenna (no scan with max-hold).

Simulations of the transmission loss of the same setup as for the measurements have been done with FDTD. The ground plane was chosen to be 20 m x 17 m.

The reference data for the ideal infinite ground plane have been simulated with the NEC-based software ANTENNA [5]. NEC (Numerical Electromagnetic Code) is a well accepted tool for the simulation of SA on infinite ground planes and for antenna factor simulation [2].

From the measured and simulated site attenuations we have calculated three examples to verify our simulation model:

1. Difference of the measured SA to the simulated SA on the infinite ground plane by NEC, given in Fig 3.
2. Difference of the FDTD simulated SA on the limited-size ground plane to the simulated SA on the infinite ground plane by NEC, given in Fig 4.
3. Difference of the FDTD simulated SA on the infinite ground plane to the simulated SA on the infinite ground plane by NEC, given in Fig 5.

The results show a good matching between the measurements and the simulation of the limited-size ground plane.

There is an agreement in the SA for the infinite ground plane between the two simulation methods better than 0.7 dB.

3. Simulation Results

3.1. Influence of Material Below the Ground Plane

We have investigated three different scenarios:

a) The material in the whole simulation space below the ground plane level was chosen $\sigma = 0$ S/m and $\varepsilon_r = 1$. This gives the worst case results for the simulation. All simulation results in this paper use this scenario.

b) A little better result is obtained, in the 'roof-top' scenario when the material below the ground plane has $\varepsilon_r = 4$, like concrete.

c) The smoothest behavior shows the scenario, where the whole simulation space below the ground plane level was chosen $\sigma = 0.04$ S/m and $\varepsilon_r = 4$, like a finite ground plane on the infinite soil. The practical realization of such a site is quite difficult because any foundations from gravel or concrete act as isolator.

The results of these simulations are presented in Figure 6. To demonstrate the worst case situation that might happen on an OATS with limited-size ground plane all simulations are done with scenario a).

The simulation parameters are:

site dimensions: 20 m x 17 m

test distance: 10 m

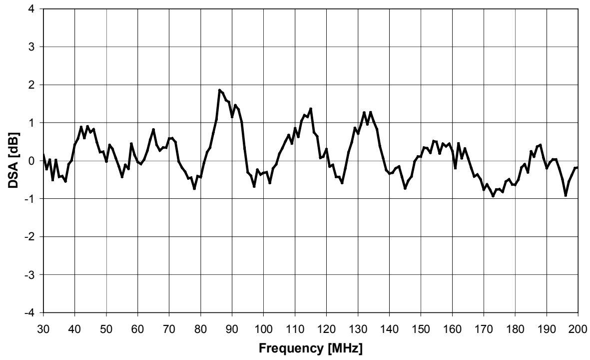


Fig. 3: DSA: measurement for a limited-size ground plane related to a simulated infinite ground plane (NEC).

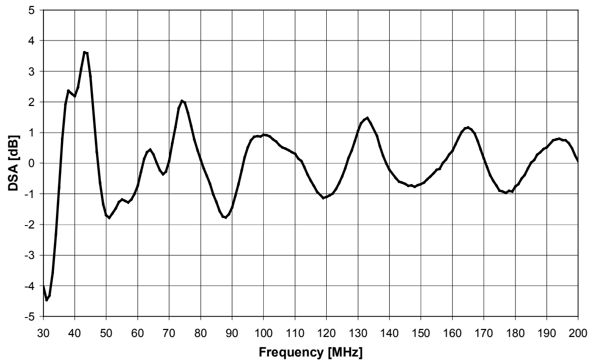


Fig. 4: DSA: FDTD simulation for a limited-size ground plane related to a simulated infinite ground plane (NEC).

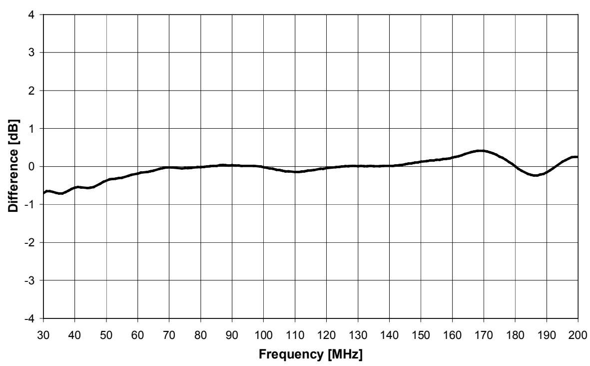


Fig. 5: Deviation of the SA results for an infinite ground plane, simulated with FDTD and NEC.

antennas: half-wave dipoles with a resonance frequency of 150 MHz

height of transmit antenna: $h_{TX} = 2$ m

height receive antenna: $h_{RX} = 1 \ldots 4$ m, with maxhold

3.2. Site Attenuation at Fixed Height

The site attenuation on a limited-size ground plane for a certain geometry is compared with the SA on an infinite ground plane and the same geometry. The variation-parameter is the height of the receive antenna. The result

is given in Fig. 7.
The simulation parameters are:
site dimensions: 20 m x 17 m
test distance: 10 m
antennas: half-wave dipoles with a resonance frequency of 150 MHz
height of transmit antenna: h_{TX} = 2 m
height receive antenna: h_{RX} = 1 ... 4 m, no maxhold

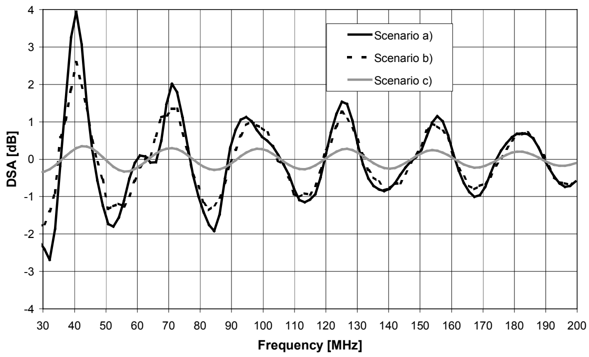


Fig. 6: Influence of the limited-size ground plane on the SA. Scenarios as described in Section 3.1.

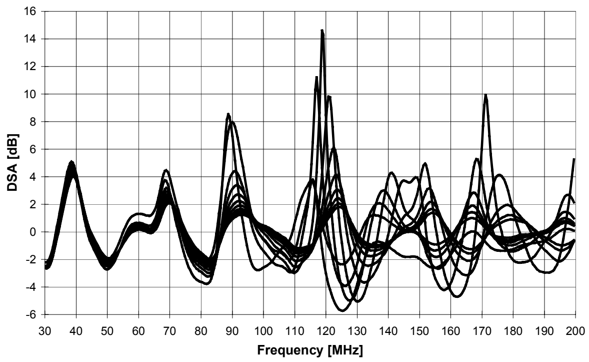


Fig. 7: Influence of the limited-size ground plane on the SA dependent on the antenna height. The receive antenna is moved from 1 to 4 m in 30 cm steps

3.3. Site Attenuation with Height Scan

The site attenuation on a limited-size ground plane is compared with the SA on an infinite ground plane using the same setup. For both simulations a height scan of the receive antenna is performed in the range of 1 m to 4 m in order to find the maximum signal (= minimum SA). The result is shown in Fig. 8. The deviation of ± 2 dB from 45 MHz up to 200 MHz corresponds very well with results from practical measurements. The dominance of the peak at 40 MHz results from the missing material below the ground plane (see 3.1, scenario a).
The simulation parameters are:
site dimensions: 20 m x 17 m
test distance: 10 m
antennas: half-wave dipoles with a resonance frequency of 150 MHz
height of transmit antenna: h_{TX} = 2 m
height receive antenna: h_{RX} = 1 ... 4 m, with maxhold

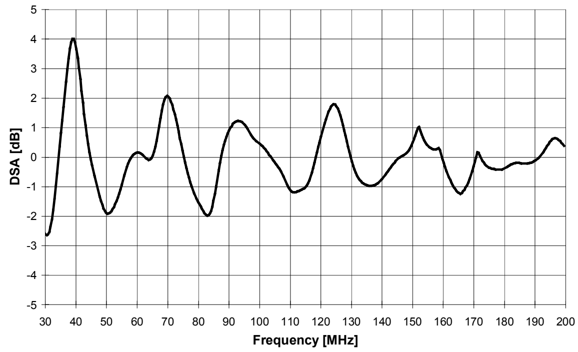


Fig. 8: Influence of the limited-size ground plane on the SA when the usual height scan (1-4 m) of the receive antenna is applied to find the maximum received signal.

3.4. Influence of Different Ground Plane Sizes

A simulation run according to 3.2 (fixed height) on sites with different sized ground planes shows that the ripple that distorts the performance depends on the ground plane size. Figure 9 shows the DSA for ground plane sizes of 10 m x 10 m, 20 m x 10 m and 20 m x 17 m.
height of transmit antenna: h_{TX} = 2.75 m
height receive antenna: h_{RX} = 2.75 m

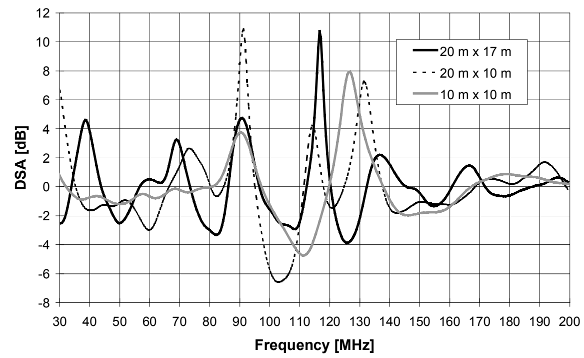


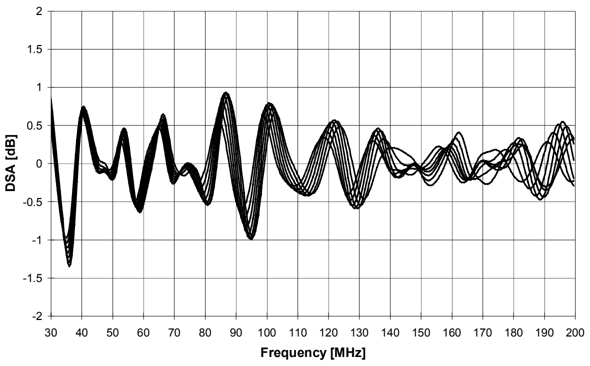
Fig. 9: Influence of the ground plane size on the site attenuation.

3.5. Influence of Different Test Distances

The site attenuation on a limited-size ground plane is compared with the SA on an infinite ground plane using the same setup. The variation parameter is the distance between the antennas. A slight variation in distance was chosen to simulate the reference antenna calibration of large antennas. With such antennas the phase center changes with frequency and therefore the 'effective distance' varies. On an infinite ground plane this effect causes a slight change in site attenuation only. On a limited-size ground plane the effect is much more dramatic, especially in 10 m distance in the frequency range above 100 MHz (see Fig. 10b).
The simulation parameters are:
Test distance: 2.55 m – 3.45 m and 9.1 m – 10.9m
Height of transmit antenna: h_{TX} = 2 m

Height of receive antenna: h_{RX} = 2 m, no maxhold scan

a)



b)

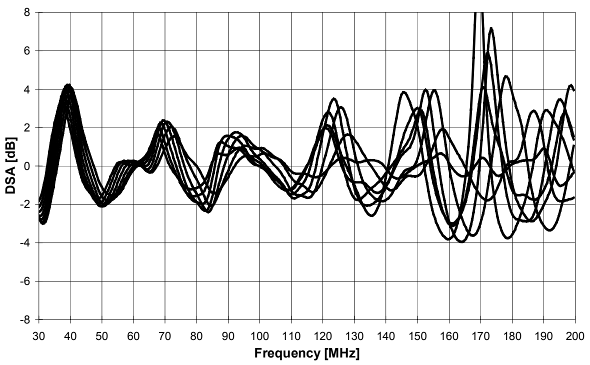


Fig. 10: Influence of slight distance variations on the site attenuation: a) d=3m ± 45 cm, 15 cm steps; b) d=10m ± 90 cm, 30 cm steps

4. Consequences

The results presented in chapter 3 have consequences on radiated emission measurements and antenna calibration procedures in vertical polarization above limited-size ground planes. Some types of measurement are listed here and the influence is explained:

4.1. SA Measurement with Height-scan of Receive Antenna

From the simulation results in Chapter 3.3 an error of less than ± 2 dB in the site attenuation for the given geometry can be found. This deviation corresponds very well with the practical experience that the SA in vertical polarization 'always' shows a worse performance than in horizontal. The site attenuation in horizontal polarization is practically independent of the ground plane size [5]. Of course a certain minimum size is also required for horizontal polarization.

For different ground plane sizes, materials and setups the error contributions may vary in magnitude.

4.2. SA Measurement with Fixed Height of Receive Antenna

A very convenient and time saving method for site validation measurements is the SA measurement at a fixed height of the antennas. The heights of the antennas have to be chosen so that there is no destructive interference due to the direct and the ground reflected wave at the location of the receive antenna. The measured SA is then compared to the calculated SA for the specific geometry. This works well for horizontal polarization of the antennas. In vertical polarization the ground plane size must be 'infinite'. If the ground plane has a limited size, errors of up to 15 dB can be observed in the worst case, see Figure 7.

The interference pattern of the incident field at the receive antenna is determined by the direct wave, the ground reflected wave, the reflections from nearby objects and for vertical polarization by ground plane effects (edge diffraction/reflection). The last component has of course a significant influence (2 dB) at the height of the field strength maximum. There the energy of direct and ground reflected field are added and represent a rather large value. The influence of the site imperfections is rather small. At heights off the maximum the result of the superposition of direct and ground reflected field is rather small and the site imperfections become dominant. An influence of several 10 dB can be observed.

Measuring the field strength means always an integration over the volume of the antenna. In horizontal polarization the antenna is exposed to a horizontally homogeneous field. In the contrary in vertical polarization the antenna is illuminated by a vertically inhomogeneous field. Therefore the field strength measurement result depends on the antenna length ($\propto$ integration volume) and on the inhomogeneous field distribution. For an infinite ground plane the distribution can be considered, for a finite ground plane it is impossible in practical realizations and large errors result.

4.3. Antenna Calibration with Reference Antenna Method

We assume that the reference antenna is a dipole antenna. Then we have to distinguish between two situations:

1. The antenna to be calibrated has the same dimensions and electrical properties as the reference antenna (e.g. dipole antennas)
2. The antenna to be calibrated has different dimensions as the reference antenna (e.g. log.-periodic dipole array antenna).

For case 1 there arise no additional problems due to limited-size ground planes. The method is well established for horizontal polarization and it works also pretty good in vertical polarization. Special attention has to be given to the antenna positioning, as these errors can be significantly larger in vertical polarization.

In case 2 we have to consider a combination of the effects of chapter 3.2, fixed height of the antennas and 3.5, influence of different test distance. The calibration requires two measurements: first with the reference antenna and second with the antenna under calibration. The reference measurement determines the field strength at the location of the reference antenna. This field strength depends on the transmitted field and the NSA of the test site. For the measurement with the antenna under calibration the transmitted field remains constant, the NSA changes and induces an error in the calibration procedure.

In Fig 11 the variation in the DSA on a limited-size ground plane from Fig. 10b is shown. The results are normalized to the nominal test distance of 10 m.

For practical calibrations of antennas where the location of the phase center depends on the frequency this dramatic effect of more than ± 8 dB is reduced due to the fact that these antennas have a certain directivity. The directivity improves the NSA ostensible, because the sides of the ground plane are less illuminated.

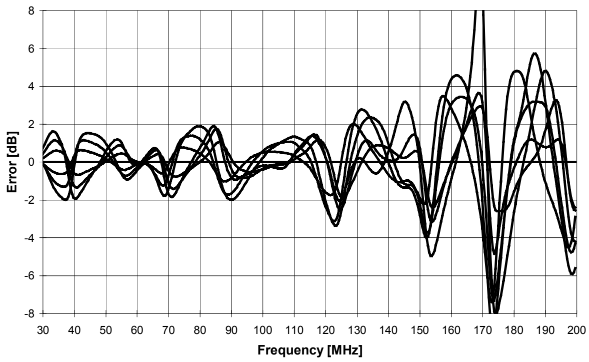


Fig. 11: DSA variation when the distance varies in the range 9.1 m to 10.9 m, normalized to 10 m distance on a limited-size ground plane.

5. Conclusion

In this paper we are highlighting several aspects of open area test sites with limited-size ground planes. The results have been obtained by numerical simulations using FDTD and verified by practical measurements.

We have found that the site attenuation in vertical polarization depends in contrary to horizontal polarization strongly on the size of the ground plane. Edge effects influence the uncertainty of radiated emission measurements and antenna calibration procedures in vertical polarization. The site attenuation shows a deviation of up to ± 2 dB on a perfect, but limited-size ground plane. Measurements with the receive antenna not positioned in the height scan maximum should be avoided as errors up to 15 dB may arise. When calibrating an antenna according to the reference antenna method in vertical polarization an identical antenna type has to be used as reference antenna to avoid edge effect errors.

Methods how to reduce these uncertainties on open area test sites are currently under investigation.

6. Acknowledgements

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