SLOVENSKI STANDARD
SIST R210-010:2003

01-december-2003

Electromagnetic compatibility - Emission measurements in fully anechoic chambers

Electromagnetic compatibility - Emission measurements in fully anechoic chambers

Elektromagnetische Verträglichkeit - Störaussendung in Absorberräumen

Compatibilité électromagnétique - Émission en chambres anéchoïques entiers

Ta slovenski standard je istoveten z: R210-010:2002

ICS:

33.100.10 Emisija Emission

SIST R210-010:2003 en

CENELEC **R210-010**

REPORT June 2002

English Version

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This CENELEC Report has been prepared by TC 210, Electromagnetic compatibility (EMC). It was approved by TC 210 on 2001-11-13 and was endorsed by the CENELEC Technical Board on 2002-03-05.

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CENELEC
European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. R210-010:2002 E

Foreword

This Technical Report has been prepared by the joint WG 4 of CENELEC TC 210, Electromagnetic compatibility, and SC 210A, EMC Products.

It was approved for publication by the CENELEC Technical Board on 2002-03-05.

Contents

1 Scope

This technical report applies to emission measurements of radiated electromagnetic fields in Fully Anechoic Rooms in the frequency range from 30 MHz to 18 GHz. This report covers the frequency range from 30 MHz – 1000 MHz. The frequency range above 1 GHz is under consideration, due to the absence of practical experience.

This report describes the validation procedure for the Fully Anechoic Room (FAR) for radiated emission tests and the procedures to carry out the tests (e.g. test set up, EUT position, cable layout and termination, test procedures). Recommendations for the relation between FAR emission limits and common Open Area Test Site (OATS) emission limits given in standards such as EN 55011 and EN 55022 are given in Annex B.

This FAR emission method may be chosen by product committees as an alternative method to emission measurement on an Open Area Test Site (OATS) as described in CISPR 16. In such cases, the product committee should also define the appropriate limits. Typical measurement uncertainty values for FARs and OATS are given in Annex C.

2 References

This technical report incorporates by dated or undated reference, provisions from other publications. These references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

Publication	Title
CISPR 16-1	Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus
CISPR 16-2	Specification for radio disturbance and immunity measuring apparatus and methods – Part 2: Methods of measurement of disturbance and immunity
CISPR 16-3	Reports and recommendations of CISPR
EN 50147-1	Anechoic chambers – Part 1: Shield attenuation measurement
EN 55011	Industrial, scientific and medical (ISM) radio-frequency equipment – Radio disturbance characteristics – Limits and methods of measurement (CISPR 11, mod.)
EN 55022	Information technology equipment – Radio disturbance characteristics - Limits and methods of measurement (CISPR 22, mod.)
IEC 60050-161	International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility
ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories
ANSI C 63.4/	American national standard for methods of measurement of radio-noise emissions from low voltage electrical and electronic equipment in the range of 9 kHz – 40 GHz
ANSI C 63.5	Electromagnetic compatibility – Radiated emission measurements in Electromagnetic Interference (EMI) control – Calibration of antennas

3 Definitions and abbreviations

3.1 Definitions

For the purpose of this technical report, the following definitions and the definitions contained in IEC 60050-161 apply.

3.1.1
Fully Anechoic Room (FAR)
shielded enclosure whose internal surfaces are lined with radio frequency absorbing material (i.e. RAM), that absorbs electromagnetic energy in the frequency range of interest.

NOTE The fully Absorber-Lined Room is intended to simulate free space environment.

3.1.2
Equipment Under Test (EUT)
test sample including connected cables.

NOTE The EUT may consist of one or several pieces of equipment.

3.1.3
test volume
region of the Room that meets the NSA requirements of this technical report and which contains the EUT as fully set up

3.1.4
free space antenna factor (AF_{FS})
antenna factor of an antenna which is not affected by mutual coupling to conducting bodies in the environment of the antenna

NOTE It is also the antenna factor measured when the antenna under test is illuminated by a plane wave, which implies that the source antenna is in the far-field of the antenna under test. Antenna factor is defined as the ratio of the magnitude of the E-field in which the antenna is immersed to the voltage at the antenna output of a given transmission line impedance, usually 50 Ω.

3.1.5
antenna reference point
physical position on the antenna from which the separation distance to the defined reference plane on the EUT is measured

NOTE For dipole and biconical antennas this will be the centre of the antenna in line with the central antenna elements. For an LPDA antenna and a hybrid antenna, the reference point is the mark on the antenna provided by the manufacturer for this purpose. The reference point is approximately at the mid-way point between the array elements that are active at the top and bottom frequencies at which the measurements are being made. Hybrid antenna is here defined as a combination of a biconical and LPDA antenna which has a frequency range including 30 MHz to 1 GHz.

3.1.6
Normalised Site Attenuation (*NSA*)
site attenuation obtained from the ratio of the source voltage connected to a transmitting antenna and the received voltage as measured on the receiving antenna terminals

NOTE Normalised site attenuation is site attenuation in decibels minus the antenna factors of the transmit and receive antenna factors. *NSA* was first introduced for evaluation of open area test sites with ground planes and was measured by height scanning the receive antenna. In this technical report, *NSA* is measured in a quasi-free space environment, and because there is no deliberate ground plane height scanning is not required.

3.1.7
test distance (d_t)
distance measured from the reference point of the antenna to the front of the boundary of the EUT

3.2 Abbreviations

EUT	Equipment Under Test
FAR	Fully Anechoic Room
NSA	Normalised Site Attenuation
AF_{FS}	antenna factor (free space)
LPDA	Log-Periodic Dipole Array
OATS	Open Area Test Site
RS	reference site
SA	site attenuation
SA_R	measurement of SA made on RS
NEC	Numerical Electromagnetic Code

4 Test and measurement equipment

Equipment in accordance with CISPR 16 shall be used.

4.1 Fully Anechoic Rooms (FARs)

A Fully Anechoic Room is required for the emission testing in which the radiated electromagnetic waves propagate as in free space and only the direct ray from the transmitting antenna reaches the receiving antenna. All indirect and reflected waves shall be minimised with the use of proper absorbing material on all walls, the ceiling and the floor of the FAR.

The screening of the FAR shall have an adequate attenuation level to avoid outside electromagnetic radiation entering the Room and influencing the measurement results. The shield attenuation is measured in accordance with EN 50147-1. Shielding recommendations are given in the technical report 'recommendation on shielded enclosures'.

4.2 Antenna

Linear polarised antennas shall be used to measure the emitted electromagnetic field of the EUT. Biconical or log-periodic antennas and hybrid antennas are typical antennas used. The free space antenna factor shall be used. CISPR 16-3 clause 4.7 gives parameters of broadband antennas. However no length limitation on LPDA or hybrid antennas is given. Subclauses 5.5.4 and 5.5.5 of CISPR 16-1 give information on antennas. Subclause 5.5.5.2 states “it is essential that the variation of the effective distance of the antenna from the source and its gain with frequency be taken into account”. Antennas over 1,5 m in length could increase the uncertainties of emission testing using a separation of 3 m between the reference point of the antenna and the front of the EUT.

5 Anechoic Room performance

5.1 Theoretical normalised site attenuation

The Site Attenuation (*SA*) is the loss measured between the connectors of two antennas on a particular site. For a free space environment the *SA* (in dB) can be defined by Equation 1 (see Annex D):

$$SA = 20\log_{10}\left[\left(\frac{5Z_O}{2\pi}\right)\left(\frac{d}{\sqrt{1-\frac{1}{(\beta d)^2}+\frac{1}{(\beta d)^4}}}\right)\right] - 20\log_{10} f_m + AF_R + AF_T \quad [\text{dB}] \tag{1}$$

where AF_R and AF_T are the antenna factors of the receive and transmit antenna in dB/m, *d* is the distance between the reference points of both antennas in meters, Z_0 is the reference impedance (i.e. 50 Ω), *ß* is defined as $2\pi/\lambda$ and f_m is the frequency in MHz.

The theoretical Normalised Site Attenuation (NSA) in dB is defined as site attenuation with respective antenna factors subtracted, thus:

$$NSA_{calc} = 20\log_{10}\left[\left(\frac{5Z_O}{2\pi}\right)\left(\frac{d}{\sqrt{1-\frac{1}{(\beta d)^2}+\frac{1}{(\beta d)^4}}}\right)\right] - 20\log_{10} f_m \tag{2}$$

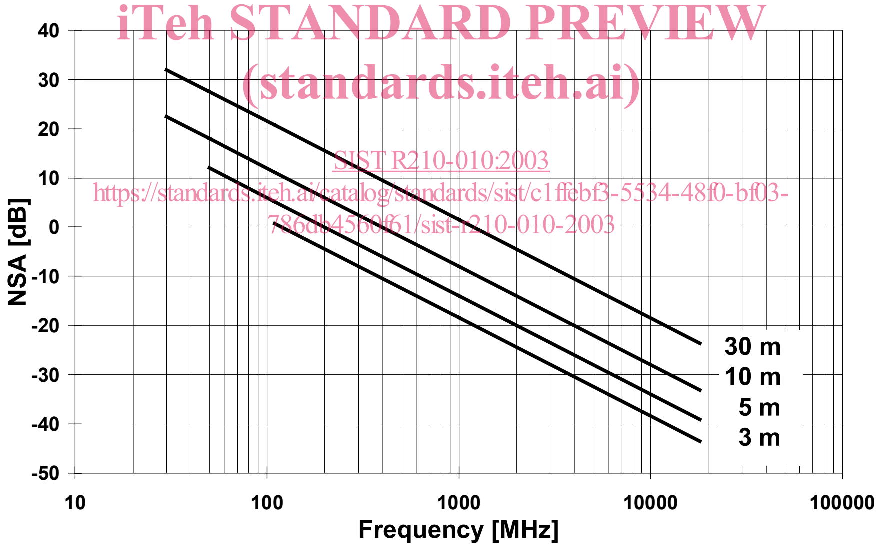

Figure 1a - Plot of theoretical *NSA* values in free space for far field conditions (Equation 3)

In far-field conditions Equation 2 simplifies to Equation 3 by omitting the near field terms:

$$NSA_{calc} = 20\log_{10}\left[\frac{5Z_O d}{2\pi}\right] - 20\log_{10} f_m \tag{3}$$

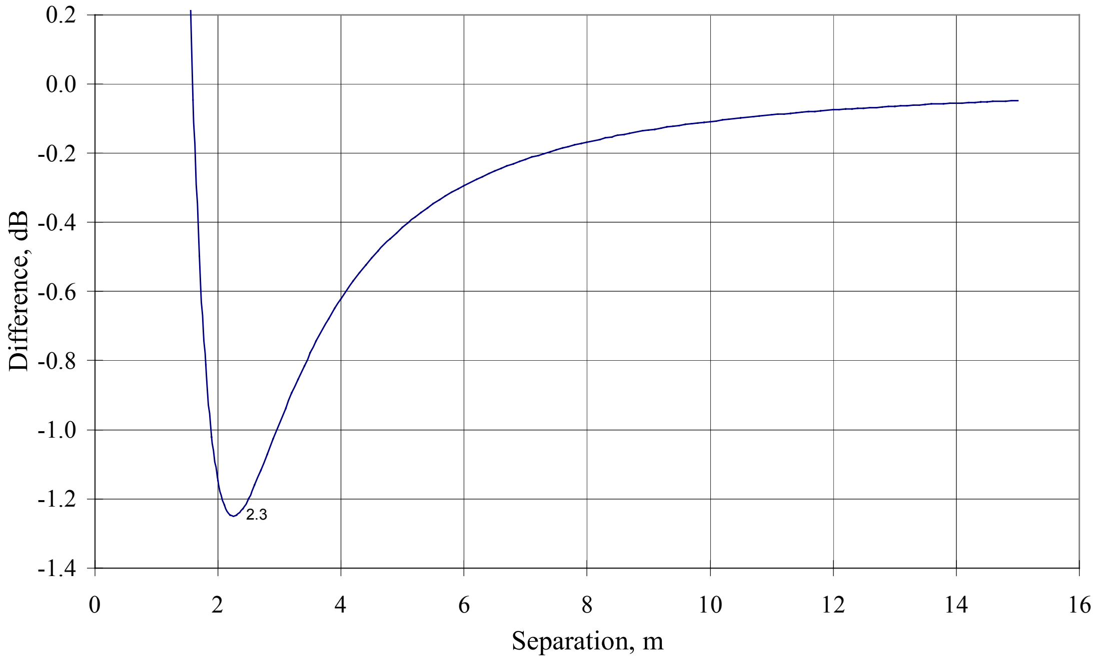

Figure 1b - Difference in theoretical *NSA* between Equation 2 and Equation 3 Distances relate to a frequency of 30 MHz

Using the simplified equation (Equation 3) the error is less than 0,1 dB at frequencies above 60 MHz for 5 m distance and above 110 MHz for 3 m distance. Figure 1b shows the worst case near-field error which is at 30 MHz. However at higher frequencies there are Fresnel zone errors for large antennas which is treated in Annex F.

Equation 1 and Equation 2 account for near field effects of small antennas. In this context, using a transmit antenna less than 40 cm long, near-field effects become significant (> 0,2 dB) where the receive antenna length is greater than a quarter of the separation distance. This assumes the use of a 1,4 m long biconical antenna at 300 MHz. The graph in Annex F shows that the error is less than 0,2 dB for a separation of 3 m and a maximum frequency of 200 MHz (it is common to change to a log antenna above 200 MHz). To cater for the general use of antennas (biconicals up to 300 MHz, or bilogs), the site reference method (6.2.1 and Annex A) shall be used for chamber validation at distances up to 5 m. In this method the site attenuation measured in the FAR are compared to those measured on a free space reference site.

5.2 Room validation procedure

The test volume must meet the Room requirements given in 5.3. The shape of the test volume will be a cylinder, due to the rotation of the EUT on a turntable. The minimum height and diameter of the test volume shall be 1 m. The height and diameter do not have to be equal between the maximum and minimum values.

A single *SA* measurement is insufficient to pick up possible reflections from the construction and/or absorbing material comprising the walls, the floor and the ceiling of the Fully Anechoic Room.

In validating the Fully Anechoic Room *SA* measurements shall be performed at 15 measurement points for horizontal and vertical polarisation of the antennas:

1) at three heights of the test volume: bottom, middle and top of test volume
2) at five positions in all three horizontal planes: the centre, left, right, front and back position of the horizontal plane

For *SA* measurements, two broadband antennas shall be used: one transmit antenna at the measurement points of the test volume and one receive antenna outside this test volume at a prescribed orientation and position. The transmit antenna shall approximate an omnidirectional antenna pattern and shall have a maximum dimension of 40 cm. Typical antennas are biconical antennas. The receive antenna used during the Room validation shall be of the same type as the receive antenna used during radiated emission testing of the EUT.

The frequency range 30 MHz to 1 GHz can be covered with one antenna, a hybrid antenna. The measurement results may be different if separate biconical and LPDA antennas are used.

For FAR validation the receive antenna shall be in the position of the middle level of the test volume as shown in Figure 2 and operated in horizontal and vertical polarisation. The distance between reference points of the receive and transmit antenna shall be $d_{nominal}$. The height of the measurement volume is less than the height of the test volume by the height of the transmit antenna. This is in order that the tip of the vertically polarised transmit antenna does not protrude above the top plane or below the top plane of the test volume. This treatment has not been applied, by reducing the diameter, to the horizontally aligned antenna, because it is room height rather than width which is at issue.

When varying the transmit antenna to the other positions of the test volume the receive antenna shall be moved to $d_{nominal}$. In all positions and polarisation the antennas shall face each other (receive antenna tilted). When the transmit antenna is placed in the upper and bottom level, the receive antenna remains in the middle level. The transmit antenna is moved to all 15 positions, the 30 site validation measurements are performed. Tilting of the antennas implies that only one site reference measurement is needed to cover all 15 positions.

The back-position does not need to be taken into account if the distance between the boundary of the test volume and tips of the absorber is more than 1 m. Experiments and modelling have shown that this distance could be reduced to 0,5 m and further work may be needed to confirm this.

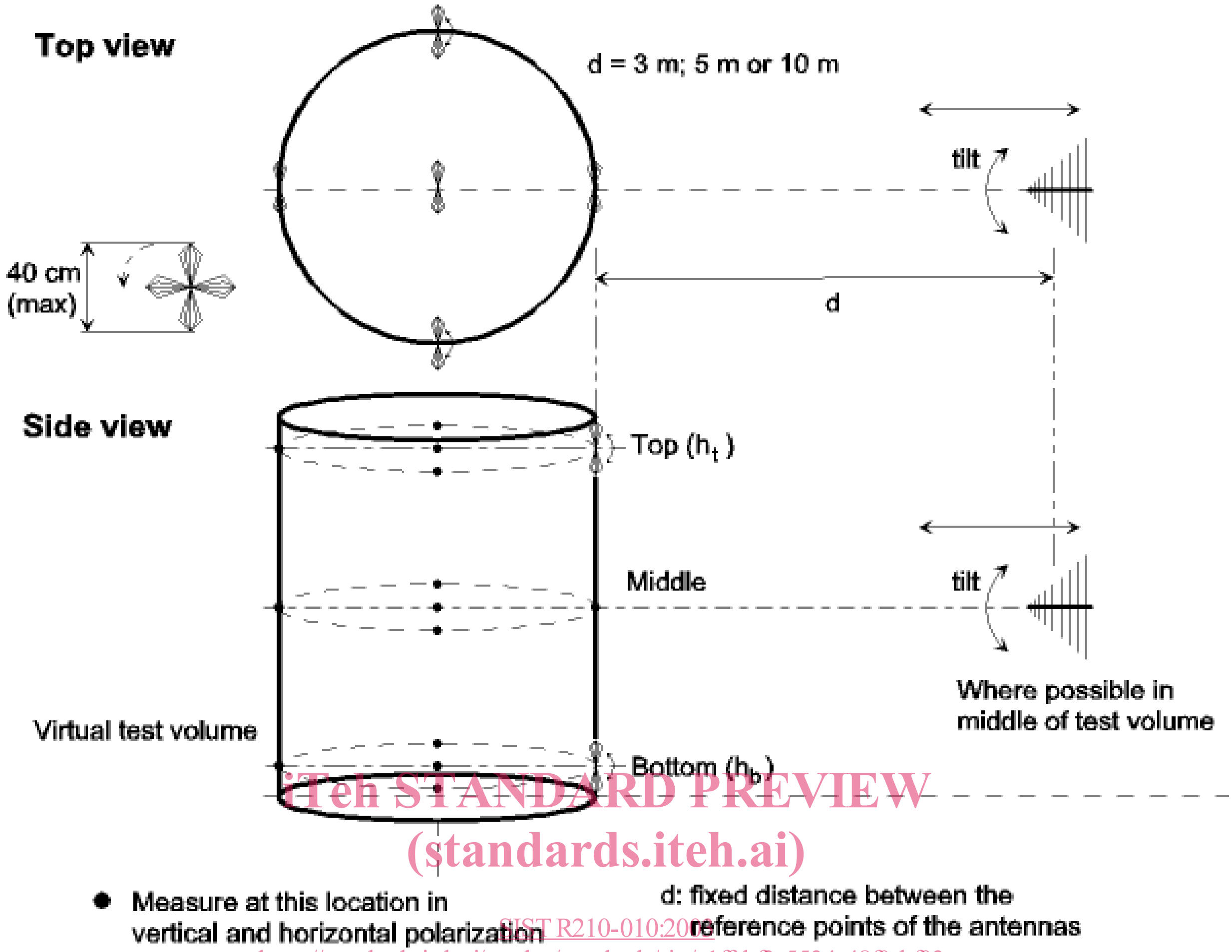

Figure 2 – Measurement points in room validation procedure

For each measurement the frequency range is incrementally swept. The frequency step size shall not exceed 1% and need not be less than 1 MHz as given in Table 1.

Table 1 - Frequency ranges and step sizes

Frequency range MHz	Maximum Frequency step MHz
30 – 100	1
100 – 500	5
500 – 1000	10

For validating the Room performance, two methods exist:

1) the site-reference method, preferred for a test distance up to 5 m
2) the *NSA*-method, preferred for test distances larger than 5 m

NOTE With reference to the site reference method, achieving quasi-free space conditions requires expertise. The problem is in sufficiently eliminating reflections from the ground. In practice this probably confines the site reference method as described in Annex A to distances of less than 5m. On the other hand there are also limitations with the *NSA* method in that the free space antenna factor is used. At 3 m distance the antenna coupling is not negligible and expertise is required to correct the free space antenna factor for coupling. A practical solution is to confine the *NSA* method to distances greater than 5 m. Corrections, such as to phase centre, are required, but this can be done precisely.

The intention of the *SA* measurement is to give "0 dB" deviation on an ideal site. Any measure can be taken to improve the measurement accuracy as long as it is not contradictory to the described setup and procedure and does not hide any bad Room performance (e.g. smoothing).

The accuracy in the validation procedure can be improved by the following measures:

1) The cables are extended by at least 2 m behind each antenna before dropping the cable to the ground for a vertically polarised antenna. The cables will - if possible - extend straight back to the bulkhead connectors in the wall of the room. Additional possibilities are ferrite rings around cables.
2) Any bad match of the antennas is padded out by use of attenuators at the antenna connectors (e.g. 6 dB or 10 dB).
3) Antennas with a good balance of the balun shall be used, giving a change in receiver reading of less than ± 0,5 dB when the illuminated antenna is inverted with respect to its input cable (see Annex G).
4) The directional pattern of the receive antenna can be accounted for on site validations with the *NSA* method.

The Room validation procedure shall be applied at a regular interval (to detect long-term changes in Room characteristics) and when changes in the Fully Anechoic Room are implemented or occurred, that might influence the electromagnetic wave transmission characteristics of the Room.

5.2.1 The site reference method

The *SA* measurement of the antenna pair (transmit and receive antenna) on a quasi free space test site is required as reference. The antenna pair that is used for site validation is calibrated as a pair on a reference site. In Annex A the procedure of determining this Site Reference (*SR*) is described. This method accounts for coupling of the antennas and near field effects which can have a significant influence at a 3 m test distance, reducing as the distance increases to 5 m.

The site validation for each measurement point is performed in three steps:

1) The insertion loss (M_0) is measured in dB with the cables connected together.
2) The transmission loss (M_1) is measured in dB with the cables connected to the antennas.
3) The deviation of the measured site attenuation from site reference is calculated according Equation 4:

$$\text{Dev} = M_0 - M_1 - SR(d) \tag{4}$$

5.2.2 The *NSA* method

The *NSA* method is recommended for distances equal to or greater than 5 m. The free space antenna factors of the transmit and receive antenna are required for this procedure. The theoretical *NSA* is a simple calculation between point sources, and therefore does not account for the radiation patterns of the actual antennas used. As the transmit antenna is moved throughout the volume it will be slightly off the boresight direction of the receive antenna. The effects of the radiation pattern are small and can be corrected for assuming the pattern is that of a Hertzian dipole, or cos θ. The phase-centre variation of log.-periodic and bicon.-log.-periodic antennas have also to be taken into account – see 6.1.

The site validation for each measurement point is performed in four steps:

1) The insertion loss (M_0) is measured in dB with the cables connected together.
2) The transmission loss (M_1) is measured in dB with the cables connected to the antennas.

3) The measured NSA (NSA_m) is calculated in dB according to Equation 5:

$$NSA_m = M_0 - M_1 - AF_T - AF_R \text{ in dB} \quad (5)$$

AF_T and AF_R are free space antenna factors in dB/m.

4) The deviation of the measured *NSA* (Equation 5) from the theoretical *NSA* (Equation 2) is calculated according to Equation 6. NSA_{calc} is given by equation 2 in 5.1.

NOTE The real distance *d* between the reference points of the transmit and receive antenna has to be used in Equation 2, not the nominal test distance $d_{nominal}$. i.e. if the LPDA antenna has been calibrated at its true phase centre at each frequency, a phase centre correction must be included if a fixed distance (to the reference point on the LPDA) is used.

$$Dev = NSA_{calc} - NSA_m \text{ in dB} \quad (6)$$

5.3 Anechoic room requirements

A measurement site shall comply with the two following requirements:

1) the Room validation procedure shall provide deviations which are within ± 4 dB of the site reference values (or the theoretical *NSA* values for the *NSA* method) for both horizontal and vertical polarisation and for the test volume intended to be occupied by the EUT.

2) the maximum diameter and height of the EUT is equal or less than the test distance divided by 2. This requirement ensures acceptable uncertainties in EUT emission testing. These include distance variation to the emission source, antenna directivity and near field effects. The maximum diameter as a function of 3 test distances is given in Table 2.

Table 2 - Relation between maximum diameter of EUT and test distance

Maximum diameter and height of EUT	Test distance
1,5 m	3,0 m
2,5 m	5,0 m
5,0 m	10,0 m

The uncertainty budget of the site evaluation measurement shall be available.

6 Emission measurement

6.1 Test set up

The same type of antenna shall be used for EUT emission testing as the receive antenna used for Room validation testing. The antenna height is fixed at the geometrical centre height of the test volume. The test distance is measured from the reference point of the antenna to the boundary of the EUT. In the case of a difference between the reference point on an antenna and the phase centre, a correction factor, C_R dB, shall be applied to obtain the field strength at the test distance (see Annex E).

$$C_R = 20 \log\left[\left(d + P_f - R\right)/d\right] \quad (6.1a)$$

E-field strength is given by Equation 6.1b:

$$E_f = V_f + AF_{FS(f)} + C_R \quad (6.1b)$$