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AMENDMENT 2
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Amendment 2

Methods of measurement for radio equipment used in the mobile services –

Part 1:
General definitions and standard conditions of measurement

Amendement 2

Méthodes de mesure applicables au matériel de radiocommunication utilisé dans les services mobiles –

Partie 1:
Définitions générales et conditions normales de mesure

International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http://www.iec.ch

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

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FOREWORD

This amendment has been prepared by IEC technical committee 102: Equipment used in radio communications for mobile services and for satellite communication systems.

The text of this amendment is based on

FDIS	Report on voting
102/41/FDIS	102/49/RVD

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

A bilingual version of this amendment may be issued at a later date.

Add the following reference to the list of "Other IEC publications quoted in this standard":

IEC 60489-8:1984, *Methods of measurement for radio equipment used in the mobile services – Part 8: Antennas*

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Add the following Annex A after figure 3.

Annex A
(normative)

Guide for the use of test sites and radio-frequency coupling devices (RFCDs)

A.1 General

Test sites are basic means to perform radiation measurements. Radio-frequency coupling devices (RFCDs) are means generally designed to perform many equipment radiation measurements economically, using the same measuring method as equipment with antenna terminals.

This annex describes low reflection test sites (LRTS) and anechoic chambers (AC) for upper frequency limit extension and interference-free measurements, as well as random field measurement sites for measurements similar in the real field and for measurement equipment with a diversity antenna. TEM cells and GTEM cells are also described for wideband upper-frequency limit extension and interference-free measurements.

The evaluation measurement of a test site is the method to judge whether a test site construction satisfies the required conditions and is introduced for LRTS, AC and RFM sites in this annex. The evaluation measurement for OATS was studied, but not introduced because the available evaluation measurement required important measurement condition changes.

The calibration method for a test site is the process for determining the numerical relationship between equipment radiation power and the observed output of a radio-frequency signal generator which replaces the EUT during the substitution measurement, or the numerical relationship between the field strength where the EUT is placed and the indication of the selective measuring device with the calibration antenna.

RFCDs were originally used only for ratio measurement of equipment receiving radio-frequency electromagnetic energy. The radiation sensitivity measured in the RFCD was called "the reference sensitivity (RFCD)" and defined as the level of RFCD input signal in microvolts (µV).

This annex also describes calibration methods. Calibration is the procedure for determining the numerical relationship between RFCD input or output voltage and the equivalent field strength where the EUT is placed, or the radiated power of the EUT. RFCDs should be principally calibrated. Therefore, RFCDs need no evaluation measurement.

Test site overview and overview of RFCDs are shown in tables A.1 and A.2 respectively.

Table A.1 – Test site overview

Test sites	Advantages	Disadvantages
OATS: Open area test site	Low construction cost Available for large size EUT Includes ground reflection effects	Needs a lot of space Interference from others Weather dependency Measurement fluctuation is relatively high at frequencies higher than 1 GHz
LRTS: Low reflection test site	Clear and flexible evaluation criterion Possible to reduce error Wide frequency range Available for large size EUT No influence of ground reflections	Does not reflect reality Is affected by absorber size Interference from others
AC: Anechoic chamber	No interference No weather dependency No influence of ground reflections	Limited lower frequency Limited EUT size Expensive, especially for low frequency
RFM: Random field measurement site	Few construction site requirements (anywhere) Evaluation of real world antenna efficiency Clear and flexible evaluation criterion Available for the evaluation of diversity antenna	Needs many measurement values and their calculation

Table A.2 – Overview of radio-frequency coupling devices (RFCDs)

RFCDs	Maximum size of EUT [mm]	Features
Narrowband RFCD Test fixture	---------- (Only for specific EUT)	Available in small size Not expensive Only for specific EUT Only for specific or approximate frequency
Wideband RFCDs		More than twice frequency range
Stripline arrangement	200 l × 200 b × 250 h for maximum frequency of 200 MHz 400 l × 400 b × 500 h for maximum frequency of 100 MHz	Can be constructed with detailed information Influence of surroundings Limited frequency range
TEM cell	100 l × 150 b × 50 h for maximum frequency of 500 MHz 200 l × 300 b × 100 h for maximum frequency of 250 MHz	No influence from surroundings Limited frequency range
GTEM cell	300 l × 300 b × 200 h to greater than 5 GHz or 1 000 l × 1 000 b × 500 h to greater than 5 GHz	No influence from surroundings Wide frequency range
NOTE – A certain manufacturer specifies d.c. to 17 GHz for the frequency range of a GTEM cell.		

A.1.1 Abbreviations:

AC Anechoic chamber
ETSI European Telecommunication Standards Institute
EUT Equipment under test
GTEM GHz TEM
LRTS Low reflection test site
OATS Open area test site
RFCD Radio-frequency coupling device
RFM Random field measurement
TEM Transverse electromagnetic mode

A.2 Test sites

A.2.1 Introduction, outline and selection of test sites

The radiation characteristics of equipment are measured at test sites. Both equipment emitting radio-frequency electromagnetic energy and equipment receiving it can be measured. Emission measurements can be made for all radio-frequency parameters pertaining to radiated radio-frequency electromagnetic energy, for example, transmitter radiated power, transmitter radiated spurious power, receiver radiated spurious power. Receiver measurements can be made for all radio-frequency parameters pertaining to received radio-frequency electro-magnetic energy, for example, receiver radiation sensitivity.

OATSs are the classic test sites and have been left as before. ACs are already widely used, and the new evaluation measurement has been introduced. LRTS and RFM site are newly introduced test sites. Both LRTS and RFM sites have clear and flexible evaluation criteria which allow for easy appraisal of conformity to construction requirements.

All test sites use the substitution method for emission measurements and this reduces measurement error. The EUT is to be substituted with a half-wave dipole antenna and a radio-frequency signal generator. The field strength in receiver measurements is to be measured by the calibration antenna and the selective measuring device.

A guide for the selection of test sites is shown in table A.1.

A.2.2 Open area test site (OATS)

A.2.2.1 General

Open area test sites are applicable to all kinds of measurements on mobile radio equipment in areas where no interfering radio services are operating, and no other radio services may interfere with the propagation of the measuring frequencies power used on the test site. In other cases indoor test sites are recommended.

On an OATS, the measuring antenna or the calibration antenna receives the combination of a direct wave and a ground reflected wave. By contrast, the measuring antenna or the calibration antenna on the LRTS receives only a direct wave, while the ground reflection is suppressed.

Measuring distances of 3 m and 30 m are applied for OATS.

Emission measurements can be made on any measuring distance for all radio parameters concerning radiated electromagnetic energy, for example, transmitter radiated power, transmitter radiated spurious power, receiver radiated spurious power. The shorter measuring distance test site can measure low power. The longer one can measure a large size of EUT and lower frequency.

Receiver measurements can be made only on 30 m test site for all radio parameters concerning received electromagnetic energy, for example, receiver radiation sensitivity. The 3 m test site has great field gradient in higher frequencies.

A.2.2.2 Test site characteristics

Characteristics	Limits for a 3 m test site
Useful frequency range	100 MHz to 1 000 MHz
Nominal site attenuation	12 dB to 38 dB for 100 MHz
Nominal site attenuation	32 dB to 58 dB for 1 000 MHz
Equipment size limits	0,6 m maximum, including the antenna
NOTE - The nominal attenuation of the test site for a half-wave dipole is 18 dB for 100 MHz and 38 dB for 1 000 MHz. The actual attenuation may vary due to ground reflections.	

Characteristics	Limits for a 30 m test site
Useful frequency range	25 MHz to 1 000 MHz
Nominal site attenuation	20 dB to 46 dB for 25 MHz
Nominal site attenuation	52 dB to 78 dB for 1 000 MHz
Equipment size limits	6 m, including the antenna
NOTE - The nominal attenuation of the test site for a half-wave dipole is 26 dB for 25 MHz and 58 dB for 1 000 MHz. The actual attenuation may vary due to ground reflections.	

A.2.2.3 Basic measuring procedure

A.2.2.3.1 Transmitter emission measurements

a) Place the transmitter under test on the platform. Orientate the measuring antenna so that it has the same polarization as the transmitter. Orientate the transmitter so that an intended direction is perpendicular to the direction of the measuring antenna and operate the transmitter.

b) Tune the selective measuring device to the radiated power component.

c) Raise and lower the measuring antenna to obtain the maximum indication on the selective measuring device. Note the maximum indication.

d) Substitute the auxiliary antenna and the radio-frequency signal generator for the transmitter under test. Adjust the measuring antenna height to the maximum point where reading in the selective measuring device can be obtained.

e) Adjust or calculate the radio-frequency signal generator output level to the level obtained in step c). This level is the radiated power of the transmitter under test for an intended direction.

NOTE 1 – The selection of the measuring distance and the connection of the equipment in the test site are not included in the above steps.

NOTE 2 – The measuring antenna height in step c) and step d) may vary. The measuring antenna height in step c) for another intended direction may differ from the original.

A.2.2.3.2 Receiver measurement receiving radio-frequency electromagnetic energy

a) Calibrate the radio-frequency signal generator level to the electromagnetic field strength received by the calibration antenna and the selective measuring device. It should be confirmed that the transmitting antenna is less dependent upon small changes in antenna height before the calibration.

b) Replace the calibration antenna and the selective measuring device by a receiver under test. Orientate the receiver so that an intended direction is perpendicular to the direction of the transmitting antenna and operate the receiver.

c) Adjust the signal generator level to the level which just satisfies the receiver radiation sensitivity according to the sensitivity measurement procedure.

d) Read or calculate the average of signal generator level and convert it to the calibrated level. This level is the radiation sensitivity of the receiver in an intended direction.

NOTE – Connection of the equipment in the test site is not included in the above steps. The measuring distance is 30 m.

A.2.2.4 Construction of a radiation test site

The measuring arrangement for equipment emitting radio-frequency electromagnetic energy is shown in figure A.1. The measuring arrangement for equipment receiving electromagnetic energy is shown in figure A.2.

The radiation test site shall be on ground level having uniform electrical characteristics and being free from reflecting objects over an area as wide as possible, to ensure that the extraneous electromagnetic fields do not affect the accuracy and repeatability of the test results.

A.2.2.4.1 3 m test site

A continuous ground screen (either sheet metal or wire mesh having openings no greater than 10 mm, which should maintain good electrical contact between the wire) shall be used to establish a uniformly conducting earth over part of the test site. The turntable shall be metallic and shall be flush with the ground screen. The minimum ground screen area is shown in figure A.3.

A.2.2.4.2 30 m test site

The minimum boundary of the test site shall be an ellipse having a major axis equal to 60 m and a minor axis equal to 52 m. The EUT and the measuring antenna or the transmitting antenna shall be located at the foci.

No extraneous conducting objects having any dimensions in excess of 50 mm shall be in the immediate vicinity of either the EUT or the antennas.

The test site shall have a turntable and a support for the measuring antenna. The measuring distance is the distance in the horizontal plane between the central vertical axis of the turntable and the central vertical axis of the measuring antenna. A shelter may be provided for the whole or a part of the test site. All such constructions having any dimensions greater than 50 mm should be of wood, plastic, or other non-conducting material. Wood shall be impregnated to ensure minimum water absorption.

All test equipment, if located above ground, shall be powered preferably by batteries. If the equipment is powered by mains, each of the supply cables shall be provided with a suitable radio-frequency filter. The cable connecting the filter and the measuring equipment shall be as short as possible and shielded. The cable connecting the filter and mains shall either be shielded and grounded, or buried to a depth of approximately 300 mm.

A.2.2.5 Position of the EUT

The equipment with its cabinet or housing in which it is normally operated shall be placed on a horizontal platform, the upper side of which is 1,50 m above the ground. The platform and its support shall be made of non-conductive material.

For equipment with an integral antenna, the equipment shall be placed on the platform in a position which is closest to that in normal use.

Equipment having a rigid external antenna shall be mounted so that the antenna is in a vertical position. Equipment having a non-rigid external antenna shall be mounted vertically, using a non-conducting support.

It shall be possible to rotate the equipment around the central vertical axis of its antenna. It is recommended that a turntable, preferably remotely controlled, be used for this purpose. If the equipment has a power cord, it should extend down to the turntable, and any excess should be coiled on it.

For information on the use of alternative test mounting arrangements for equipment which is hand-carried or carried on a person in normal operation, see clause A.4.

A.2.2.6 Measuring antenna

The measuring antenna shall be suitable for the reception of linearly polarized waves. It may consist of a half-wave dipole, the length of which is adjusted for the frequency concerned. For practical reasons, however, to increase the sensitivity and to attenuate remaining reflections, a more complex antenna, having high directivity and broad bandwidth, is preferred. For low frequencies short dipoles are recommended.

The measuring antenna shall be mounted at the end of a horizontal boom supported by a vertical pole, both made of non-conducting materials. The boom shall project at least 1 m from the pole in the direction to the EUT and shall be arranged so that it may be raised and lowered from 1 m to 4 m. The mounting shall permit the antenna to be positioned for measuring both horizontal and vertical components of the electric field. The mount shall permit the antenna to be tilted so as to permit simultaneous inclusion of both the direct and reflected rays. The lower end of the antenna, when oriented for vertical polarization and placed at its lowest position, shall be at least 0,3 m above the ground.

The antenna cable shall be routed along the horizontal boom for at least 2 m, preferably at ground level. Suitable antenna clearance is recommended. Alternatively, the cable may be routed underground.

A.2.2.7 Transmitting antenna

The transmitting antenna shall be suitable for the radiation of linearly polarized waves. It may consist of a half-wave dipole, the length of which is adjusted for the frequency concerned. For practical reasons, however, to increase the sensitivity and to attenuate remaining reflections, a more complex antenna having high directivity and broad bandwidth is preferred. For low frequencies short dipoles are recommended.

The transmitting antenna shall be mounted at the end of a horizontal boom supported by a vertical pole, both made of non-conducting material. The boom shall project at least 1 m from the pole in the direction of the equipment under test and shall be arranged so that the centre of the antenna is 3 m ± 0,2 m above the ground. The mounting shall permit the antenna to be positioned for the same polarization as that of the receiver antenna.

The antenna cable shall be routed along the horizontal boom for at least 2 m, preferably at ground level. Suitable antenna clearance is recommended. Alternatively, the cable may be routed underground.

At some frequencies, an appreciable variation of signal level occurs for a small change in antenna height due to ground reflections. Where this occurs, the transmitting antenna should be moved up or down by an amount that will place the antenna in a region of small height sensitivity and make the test site calibration less dependent upon small changes in antenna position.

A.2.2.8 Auxiliary antenna

The auxiliary antenna substitutes for the equipment under test during calibration. The auxiliary antenna shall be a half-wave dipole and shall be arranged in a manner similar to that of the measuring antenna, except that the centre of the auxiliary antenna should coincide approximately with the normal position of the centre of radiation of the equipment under test. A broadband antenna also may be used as the substitution antenna.

At frequencies below about 60 MHz, the above condition may be impossible to achieve for vertical polarization. In this case, the lower end of the antenna should be placed 0,3 m above the ground, and the EUT shall be positioned to satisfy the above listed conditions.

A.2.2.9 Calibration antenna

The calibration antenna replaces the EUT during calibration of the receiver receiving electromagnetic energy measurement. The calibration antenna shall be an antenna for which the available power output has been calibrated in field strength. The centre of the calibration antenna is located so that this point coincides with the centre of the radiation centre of the EUT.

The antenna, including the cable, shall be matched to the input impedance of the selective measuring device.

At frequencies below about 60 MHz, the above condition may be impossible to achieve when the antenna is arranged for vertical polarization. In this case, the lower end of the antenna should be placed 0,3 m above the ground and the EUT shall be positioned to satisfy the above conditions.

A.2.2.10 Radio-frequency signal generator

A well-shielded radio-frequency signal generator, with a matching or combining network (if required) and its associated output cable, shall be placed so that it will not affect the accuracy of the results, and shall be connected to and matched to the auxiliary antenna.

A.2.2.11 Selective measuring device

The selective measuring device should be a calibrated field strength meter or a spectrum analyzer (with preselector), and shall be placed, together with its associated input cable, in a position where it will not affect the accuracy of the test results.

A.2.2.12 Calibration method for OATS

A.2.2.12.1 General

The test site calibration is the procedure for determining the numerical relationship between the EUT radiated power and the selective measuring device indication in an emission measurement site, or the field strength where the EUT is placed, and the radio-frequency signal generator equivalent output voltage in a receiver measurement site.

Measurement distance is not so important for the substitution method. Only the adjustment of the radiation centre of the EUT at the measurement distance to that of the auxiliary antenna for substitution is meaningful.

The radiation centre of the receivers is not recognized and the radiation centre of the calibration antenna may differ from that of the receivers. This means that the field strength measured by the calibration antenna might be different from the field strength at the radiation centre of the receivers.

A.2.2.12.2 Calibration for measurement of equipment emitting radio-frequency electromagnetic energy

This method is applicable to the radiated radio-frequency power of transmitters and the radiated spurious components of receivers.

a) Connect the equipment as illustrated in the chosen test site with the auxiliary antenna and the measurement antenna oriented to provide the polarization intended for the measurement.
b) Adjust the auxiliary antenna (if applicable) to the correct length for the frequency to be measured and adjust the frequency of the radio-frequency signal generator to the same frequency.
c) Adjust the measurement antenna (if applicable) to the correct length for the frequency to be measured and tune the selective measuring device to the operating frequency of the radio-frequency signal generator.
d) Adjust the output level of the radio-frequency signal generator to –10 dBm (103 dBµV).
e) Raise and lower the measuring antenna to obtain the maximum indication on the selective measuring device. Record the indication level of the selective measuring device.
f) The radiated radio-frequency power for other values of the selective measuring device indication is given by:

   radiated power = (new indication level in decibels (dB)) – (indication level in step e) in decibels (dB)) – 10 dBm

NOTE – The calibration is only valid for the frequency, antennas, polarization, and antenna position used in the calibration procedure. If any of these change, the site should be recalibrated.

A.2.2.12.3 Calibration for measurement of equipment receiving radio-frequency electromagnetic energy in a 30 m test site

a) Connect the equipment as illustrated in the chosen test site with the transmitting antenna and the calibration antenna oriented to provide the polarization intended for the receiver under test.

b) Adjust the frequency of the radio-frequency signal generator to the operating frequency of the receiver.

c) Adjust the calibration antenna (if applicable) to the correct length for the frequency to be measured and tune the selective measuring device to the operating frequency of the radio-frequency signal generator.

d) Adjust the output level of the radio-frequency signal generator to produce a reading of 100 µV/m (40 dBµV/m) on the selective measuring device. Record the output of the radio-frequency signal generator in microvolts.

e) The field strength for other values of the radio-frequency signal generator output is given by:

$$\text{field strength} = \frac{\text{new output level}}{\text{output level recorded in step d)}} \times 100\ \mu\text{V/m}$$

or

field strength in dBµV/m = 40 + 20 lg (new output level in microvolts)
–20 lg (output level in microvolts recorded in step d).

NOTE 1 – The calibration is only valid for the frequency, antennas, polarization, and antenna position used in the calibration procedure. If any of these change, the site should be recalibrated.

NOTE 2 – Measurement distance is not so important for the substitution method, but the radiation centre coincidence between calibration antenna and the receiver under test is very important because the radiation centre difference between them means a calibration error. To reduce this error, a longer measurement distance is recommended because it has a lesser degree of field strength variation than a shorter measurement distance. Especially at high frequency, this becomes severe, for example an 8 dB variation with 100 mm height difference is observed at 900 MHz at a measurement distance of 3 m. Therefore, a 3 m test site for equipment receiving radio-frequency electromagnetic energy is not recommended.

A.2.3 Low reflection test sites (LRTS, reduced ground reflections)

A.2.3.1 Introduction

The open area test sites (OATS) are widely used and popular test sites. Recently, upper frequency limitation improvement became necessary and some studies were made. One of the effective improvement methods is to suppress the ground-reflected waves. It also improves the measurement repeatability.

On an OATS, the measuring antenna or the calibration antenna receives the combination of a direct wave and a ground reflected wave. By contrast, the measuring antenna or the calibration antenna on the LRTS receives only a direct wave, while the ground reflection is suppressed.

The suppression of ground-reflected waves makes the characteristics of the test site similar to those of anechoic chambers and not to those of OATS.

LRTS have simple and clear evaluation criteria which can be adapted to any level of measuring error or repeatability requirements. LRTS require no specific construction requirements and can be applied to any measuring distance, for example, 3 m, 5 m, 10 m or 30 m.

For suppression of ground-reflected waves, use of a high directivity antenna and any other means are recommended. However, the quality of the construction is to be judged only by the evaluation criterion. (see A.2.3.4 and A.2.3.5)

NOTE – ETSI indoor test site is involved in LRTS. It requires a specific construction and a specific evaluation criterion.

A.2.3.2 Test site characteristics

Measuring distances of 3 m to 30 m can be used in combination with ground-reflected wave suppression described in A.2.3.4. Longer distance sites are unusual. Only the lowest frequency to be used and the largest dimension of the equipment under test require a longer measuring distance. LRTS characteristics are very similar to those of an anechoic chamber. The anechoic chamber can be used as an LRTS. The useful frequency range is extended to 18 GHz (depending on site performance).

As an example, a measuring distance of 3 m is shown below.

Characteristics	Limits for a distance of 3 m
Useful frequency range	100 MHz to 18 GHz
Nominal site attenuation	32 dB to 44 dB for 1 000 MHz
Equipment size limits	0,6 m maximum

A.2.3.3 Basic measuring procedure

A.2.3.3.1 Transmitter emission measurements

a) Place the transmitter under test on the platform. Orientate the measuring antenna so that it has the same polarization as the transmitter. Orientate the transmitter so that an intended direction is perpendicular to the direction of the measuring antenna and operate the transmitter.

b) Tune the selective measuring device to the radiated power component.

c) Raise and lower the measuring antenna around the same height as the transmitter under test, to obtain the maximum indication on the selective measuring device. Note the maximum indication.

d) Substitute the auxiliary antenna and the radio-frequency signal generator for the transmitter under test. Adjust the auxiliary antenna height to the maximum reading point in the selective measuring device.

e) Adjust or calculate the radio-frequency signal generator output level to the level obtained in step c). This level is the radiated power of the transmitter under test for an intended direction.

NOTE 1 – Selection of the measuring distance, connection of the equipment in the test site and the evaluation measurements are not included in the above steps.

NOTE 2 – The measuring antenna height, the transmitter radiation centre and the auxiliary antenna will be the same.

A.2.3.3.2 Receiver measurement receiving radio-frequency electromagnetic energy

a) Calibrate the radio-frequency signal generator level to the electromagnetic field strength received by the calibration antenna and the selective measuring device.

b) Replace the calibration antenna and the selective measuring device by a receiver under test. Orientate the receiver so that an intended direction is perpendicular to the direction of the transmitting antenna and operate the receiver.

c) Adjust the signal generator level to the level which just satisfies the receiver radiation sensitivity according to the sensitivity measurement procedure.

d) Read or calculate the average of the signal generator level and convert it to the calibrated level. This level is the radiation sensitivity of the receiver in an intended direction.

NOTE – Selection of the measuring distance, connection of the equipment in the test site and the evaluation measurements are not included in the above steps.

A.2.3.4 Construction of a radiation test site

The measuring arrangement for equipment emitting radio-frequency electromagnetic energy is shown in figure A.4. The measuring arrangement for equipment receiving electromagnetic energy is shown in figure A.5.

For the ground reflected wave suppression, use of a high directivity antenna and any of the measures in figure A.6 are suggested.

If a radio-wave screening curtain is used for the suppression of ground-reflected waves, the height of the curtain should be adjusted to be the optimum clearance as shown in figure A.6a. The optimum clearance will be 80 % to 100 % of the first Fresnel zone, which is calculated by the following formula. The output of the measuring antenna or the calibration antenna becomes a maximum at the optimum clearance.

$$H_0 = \sqrt{\frac{d_1 d_2}{d_1 + d_2}}$$

If a radio-wave absorber is used for the suppression of the ground-reflected wave, the width of the absorber area projected circle on the perpendicular plane to the ground-reflected wave path should be more than the circle with the same radius as the first Fresnel zone (see figure A.6d).

The other side area of the high directive measuring antenna or transmitting antenna should be as wide as possible to avoid extraneous reflected waves.

No extraneous conducting objects shall be in the immediate vicinity of either the equipment under test or antennas. It is also not recommended to use high permittivity dielectric in the immediate vicinity of either the equipment under test or the antennas. It may affect field distribution in the 800 MHz band or a higher frequency band.

The extraneous reflected waves increase the standing wave ratio in the evaluation measurement and this means an increase of the measurement error.

The test site shall have a turntable. The measuring distance is not critical in substituting a measurement if the centre of the equipment under test and the centre of the measuring antenna are placed in the same position.

A.2.3.5 Evaluation measurements

The evaluation measurement is the procedure to judge whether the test site construction satisfies the required conditions.

The reflected waves cause standing waves. The ratio value in decibels (dB) between a peak and an adjacent valley measured field strength means the maximum measuring value variation in decibels (dB). The maximum value measured in the volume of EUT is to be the maximum measuring error or the repeatability of the test site. The standing waves should be measured at least in two directions, in the three perpendicular directions of the measuring antenna or the calibration antenna. Measurement should be made by moving the measuring antenna or the calibration antenna continuously.

The length of the standing-wave measurement should be greater than the size of the EUT or a half-wave length, whichever is longer. The centre of the standing-wave measurement should be almost the same point to the radiation centre of the EUT.

Any value of the evaluation criterion could be used if both the purchaser and the manufacturer agree. However, ±1 dB to ±3 dB would be realistic.

A.2.3.6 Position of the EUT

The position of the EUT is recommended to be as high as possible because the higher position makes larger incident angle difference between the ground-reflected wave and the direct wave. Consequently, the received power of the ground-reflected wave is reduced by the increased directivity of the measuring antenna. The higher position also increases the propagation loss of the ground-reflected wave which reduces the power of the reflected wave.

Some examples of higher positions are shown in figure A.7.

The equipment in the cabinet or housing in which it normally operates shall be placed on a platform. The platform and its support shall be made of non-conducting materials. Equipment having an integral antenna shall be placed on the platform in a position which is closest to its normal use. If dielectric material is used for supporting the stand position of the equipment, low permittivity material is recommended.

It shall be possible to rotate the equipment about the vertical axis through the centre of the antenna of the EUT. It is recommended that a platform in the form of a turntable, preferably remotely controlled, should be used for this purpose. If the equipment has a power cable, it should extend down the turntable.

For information on the use of alternative test mounting arrangements on this test site for equipment which is hand-carried or carried on a person while in normal operation, see clause A.4.

A.2.3.7 Measuring antenna

The measuring antenna shall be suitable for the reception of linearly polarized waves and shall be a high directive antenna for suppressing the receiving power of the ground-reflected wave and other extraneous reflected waves.

The mounting shall permit the antenna to be positioned for measuring both horizontal and vertical components of the electric field.

NOTE – EUT is generally designed for vertical polarization. However, it may have other stronger polarizations in higher frequency spurious components.

A.2.3.8 Transmitting antenna

The transmitting antenna shall be the same as the measuring antenna except that the transmitting antenna height and direction shall be adjusted so that the received power of the calibration antenna becomes maximum.

A.2.3.9 Auxiliary antenna

The auxiliary antenna replaces the EUT during part of the emission measurement. The auxiliary antenna shall be a half-wave dipole (see A.7.1).

The auxiliary antenna height shall be adjusted so that the received power of the measuring antenna becomes maximum after the measuring antenna height has been adjusted to the maximum point of the received power from the EUT. This procedure makes the radiation centre of the auxiliary antenna coincide with the radiation centre of the equipment under test.

A.2.3.10 Calibration antenna

The calibration antenna replaces the equipment under test during calibration of the receiver receiving electromagnetic energy measurement. The calibration antenna shall be an antenna for which the available power output has been calibrated in field strength. The centre of the calibration antenna shall be located so that this point coincides with the centre of the radiation centre of the EUT. The antenna, including the cable, shall be matched to the input impedance of the selective measuring device.

A.2.3.11 Calibration method for LRTS

A.2.3.11.1 General

The test site calibration is the procedure for determining the numerical relationship between EUT radiated power and the selective measuring device indication in an emission measurement site, or the field strength where the EUT is placed and the radio-frequency signal generator equivalent output voltage in a receiver measurement site.

The measurement distance is not so important for the substitution method. Only the adjustment of the radiation centre of the EUT at the measurement distance to that of the calibration antenna for substitution is meaningful.

Radiation measurement directions in a vertical plane are almost always horizontal and may differ from that of an OATS or an AC with ground plane.

A.2.3.11.2 Calibration for measurement of equipment emitting radio-frequency electromagnetic energy

This method is applicable to the radiated radio-frequency power of transmitters and the radiated spurious components of receivers.

a) Connect the equipment as illustrated in the chosen test site with the auxiliary antenna and the measurement antenna oriented to provide the polarization intended for the measurement.

b) Adjust the auxiliary antenna (if applicable) to the correct length for the frequency to be measured and adjust the frequency of the radio-frequency signal generator to the same frequency.

c) Adjust the measurement antenna (if applicable) to the correct length for the frequency to be measured and tune the selective measuring device to the operating frequency of the radio-frequency signal generator.

d) Adjust the output level of the radio-frequency signal generator to –10 dBm (103 dBμV).

e) Raise and lower, for example ±0,3 m, the measuring antenna to obtain the maximum indication on the selective measuring device. Record the indication level of the selective measuring device. The same height to the auxiliary antenna may be acceptable if the above indication shows flatness or very little variation.

f) The radiated radio-frequency power for other values of the selective measuring device indication is given by:

   radiated power = (new indication level in decibels (dB)) – (indication level in step e) in decibels (dB)) – 10 dBm

NOTE – Calibration is only valid for frequency, antennas, polarization, and the antenna position used in the calibration procedure. If any of these change, the site should be recalibrated.

A.2.3.11.3 Calibration for measurement of equipment receiving radio-frequency electromagnetic energy

a) Connect the equipment as illustrated in the chosen test site with the transmitting antenna and the calibration antenna oriented to provide the polarization intended for the receiver under test.

b) Adjust the frequency of the radio-frequency signal generator to the operating frequency of the receiver.

c) Adjust the calibration antenna (if applicable) to the correct length for the frequency to be measured and tune the selective measuring device to the operating frequency of the radio-frequency signal generator.

d) Raise and lower, for example ±0,3 m, the calibration antenna to obtain the maximum indication on the selective measuring device. The same height to the auxiliary antenna may be acceptable if the indication shows flatness or very little variation.

e) Adjust the output level of the radio-frequency signal generator to produce a reading of 100 µV/m (40 dBµV/m) on the selective measuring device. Record the output of the radio-frequency signal generator in microvolts (µV).

f) The field strength for other values of the radio-frequency signal generator output is given by

$$\text{field strength} = \frac{\text{new output level}}{\text{output level recorded in step e)}} \times 100 \ \mu\text{V/m}$$

or

field strength in dBµV/m = 40 + 20 lg (new output level in microvolts (µV))
–20 lg (output level in microvolts (µV) recorded in step e))

NOTE – Calibration is only valid for frequency, antennas, polarization, and the antenna position used in the calibration procedure. If any of these change, the site should be recalibrated.

A.2.4 Anechoic chamber

A.2.4.1 General

The anechoic chamber is a well-shielded chamber which allows disturbing influences on the measurements from outside to be avoided.

All inside surfaces are covered by electromagnetic absorption material which suppresses reflections and simulates free-space conditions. However, the suppressing of reflections is limited in reality by the frequency or the room to be used.

A.2.4.2 Characteristics of an anechoic chamber

Example of an anechoic chamber with the dimensions of 5 m × 5 m × 10 m.

Characteristics	Limits for a 10 m chamber
Useful frequency range	100 MHz to above 1 000 MHz
Useful measuring distance	3 m to 5 m
Nominal site attenuation	5 m distance and 100 MHz 26 dB
Nominal site attenuation	5 m distance and 1 000 MHz 46 dB
Minimum shielding attenuation	100 dB
Minimum return loss of absorbers	10 dB
Maximum equipment size	1 m

A.2.4.3 Basic measuring procedure

The basic measuring procedure of the anechoic chamber is the same as that of the LRTSs (see A.2.3.3).

A.2.4.4 Example of the construction of an anechoic chamber

An example of a chamber with dimensions of 5 m × 5 m × 10 m, which is shown in figure A.8, has internal room dimensions of 3 m × 3 m × 8 m, so that a maximum measuring distance of 5 m in the middle axis of the room is available. The chamber consists of shielded walls, ceiling and floor. The ceiling and walls of the chamber are coated with about 1 m high pyramid absorbers. The floor can be covered with floor absorbers which can be walked on. The ground reflections need not be considered and the antenna height has basically no influence on the results.

All measuring results therefore can be checked by simple calculations and the measuring tolerances are as small as possible. When planning an anechoic chamber, two parameters are very important: shielding loss and return loss. Shielding loss is the capability of the chamber to attenuate radiated r.f. energy. The attenuation depends on the material and the construction of the chamber and is normally specified by the manufacturer.

The return loss is a measure of its ability to suppress reflections and standing waves. The value of the return loss depends on the material, the geometrical shape and the dimensions of the absorbers applied.

Typical values of pyramid-shaped absorbers with a base of 600 mm × 600 mm and a height of 600 mm are 5 dB to 8 dB return loss. The attenuation varies, for example, with the height and material of the absorber and the frequencies, as well as the installation practice.

The measuring arrangement for equipment emitting radio-frequency electromagnetic energy and for equipment receiving electromagnetic energy are the same as those of the LRTSs shown in figure A.4 and figure A.5 respectively.

A.2.4.5 Evaluation measurements

To meet the proposed specification, it is necessary to measure the quality of the anechoic chamber which depends especially on the wall influences of the mounted chamber. The evaluation measurement is the procedure to judge whether the test site construction satisfies the required conditions.

The reflected waves cause standing waves. The ratio value in decibels between a peak and an adjacent valley measured field strength means the maximum measuring value variation in decibels. The maximum value measured in the volume of the equipment under test (EUT) is to be the maximum measuring error or the repeatability of the test site. The standing waves should be measured at least in two directions, in the three perpendicular directions of the measuring antenna or the calibration antenna. The measurement should be made by moving the measuring antenna or the calibration antenna continuously. The length of the standing wave measurement should be greater than the size of the EUT or a half-wave length, whichever is longer. The centre of the standing wave measurement should be almost the same point to the radiation centre of the EUT.

Any value of the evaluation criterion may be used if both the purchaser and the manufacturer agree. However, ±1 dB to ±3 dB would be realistic.

A.2.4.6 Position of the equipment under test

The EUT shall be placed on a horizontal platform, the upper side of which is 1,5 m above the floor. Other heights may be used. However, the position of the EUT should be separated as long as possible from the walls, the ceiling and the floor to reduce the reflected waves. The platform and its support shall be made of non-conducting material. Equipment having an integral antenna shall be placed on the platform in a position which is closest to its normal use. Equipment having a rigid antenna shall be mounted so that the antenna is in the vertical position.

Equipment having a non-rigid external integral antenna shall be mounted vertically with a non-conducting support. It shall be possible to rotate the equipment around the vertical axis through the centre of the antenna. It is recommended that a turntable, preferably remotely controlled, shall be used for this purpose. If the equipment has a power cord, it should extend down to the turntable, and any excess should be coiled onto the turntable.

For information about the use of alternative test mounting arrangements for equipment which is hand carried or carried on a person while in normal operation, see clause A.4.

A.2.4.7 Measuring antenna support

The measuring antenna shall consist of a horizontal boom supported by a vertical mast, both made of non-conducting materials. The boom shall be placed at least 1 m from the vertical mast in the direction of the EUT. The mounting shall permit the antenna to be positioned for measuring both horizontal and vertical components of the electrical field. The height of the antenna shall be adjustable.

A.2.4.8 Measuring antenna

The measuring antenna shall be suitable for the reception of linear polarized waves. It normally may consist of a half-wave dipole, which is adjusted for the frequency concerned. To increase the sensitivity of the measurements and to attenuate possible wall reflections, it may be preferable to use a number of separate fixed broadband dipoles or more complex antennas.

The measuring antenna shall be mounted at the end of a horizontal boom. The lower end of the antenna, when oriented for vertical polarization and placed in its lowest position, shall be at least 0,25 m above the floor.

The cable from the antenna shall be routed along the horizontal boom and preferably preferably leave the chamber in the same direction through the wall, before it is connected to the selective measuring device, placed in a separate shielded cabinet. Alternatively, the cable may be routed beneath the ground absorbers.

A.2.4.9 Transmitting antenna

The transmitting antenna shall be the same as the measuring antenna, except that the transmitting antenna height and direction shall be adjusted so that the received power of the calibration antenna becomes maximum.

A.2.4.10 Auxiliary antenna

The auxiliary antenna replaces the EUT during calibration. It shall be a half-wave dipole arranged in a manner similar to that of the measuring antenna, except that the centre of the auxiliary antenna should coincide approximately with the normal position of the centre of the EUT. At frequencies below about 100 MHz, the above condition may be impossible to achieve when the antenna is arranged for vertical polarization. In this case, the lower end of the antenna should be placed 0,25 m above the ground and the equipment under test shall be positioned to satisfy the above conditions.

A.2.4.11 Calibration antenna

The calibration antenna replaces the EUT during calibration of the receiver receiving electromagnetic energy measurement. The calibration antenna shall be an antenna for which the available power output has been calibrated in field strength. The centre of the calibration antenna will be located so that this point coincides with the centre of the radiation centre of the EUT. The antenna, including the cable, shall be matched to the input impedance of the selective measuring device.

A.2.4.12 Radio-frequency signal generator

A radio-frequency signal generator, with a matching or combining network (if required) and its associated output cable, shall be placed in a position so that it will not affect the accuracy of the results, and shall be connected to and matched to the auxiliary antenna.

A.2.4.13 Selective measuring device

The selective measuring device may be either a calibrated field strength meter or a spectrum analyzer and shall be placed, together with its associated input cable, in a position so that it shall not affect the accuracy of the test results.

A.2.4.14 Calibration method for an anechoic chamber

The calibration method for an anechoic chamber is the same as that for the LRTSs (see A.2.3.11).

A.2.5 Random field measurement (RFM) site

A.2.5.1 General

RFM came from the measurement of relative antenna efficiency in urban surroundings. The relative antenna efficiency can be obtained by averaging the signal levels received while an operator with a transmitter walks along a selected route (random path). When the mean level obtained from a reference antenna on the same route is known, the relative efficiency of the unknown antenna will then be equal to the ratio between the mean levels. Instead of measuring the mean levels directly, it is also possible to measure the percentage of the time a given signal level had been exceeded and find the relative efficiency by the number of decibels by which the system loss shall be increased or reduced in order to obtain the same probability of coverage with the two antennas.

The RFM site would be normally installed in a room with radio wave scatters, obstacles and measuring arrangement or transmitting arrangement so that an antenna moves along the random path.

Radio waves from a transmitter under test, for example, would be scattered to all directions so that the measuring antenna receives not only one direction but many directions from the transmitter.

A.2.5.2 Characteristics of the RFM site

Useful frequency range	30 MHz to 3 000 MHz

Only the size of the test site limits the lower useful frequency range.

Site attenuation	40 dB to 90 dB

NOTE – On this test site the actual value of the attenuation depends on the distance of the two antennas and the arrangement of the scattering materials and obstacles. The nominal site attenuation is based on the use of a half-wave dipole.

Size of equipment limits	None

NOTE – The equipment to be tested must be surrounded with the radio wave scatterers. The distance between the two antennas needs to be great enough considering the size of the equipment.

Use of simulated hand	Allowed
Site environment	Either indoor or outdoor operation.

NOTE 1 – No special precautions are necessary to eliminate reflections from outside the test site, if they are constant.

NOTE 2 – Receiver characteristics measurement for data, for example radiation sensitivity (random field), in this test site become the measurement under multipath propagation conditions induced by random path movement. Only available random path movement velocity can be measured.

A.2.5.3 Basic measuring procedure

A.2.5.3.1 Transmitter emission measurements

a) Place the auxiliary antenna in a first horizontal direction and adjust the output level of the radio-frequency signal generator to *D* dBm (about –10 dBm, but may be changed according to the received level distribution in the dynamic range of the selective measuring device).

b) Move the measuring antenna from the beginning to the end of the random path in 360 or more approximately equally spaced positions and record the output values of the selective measuring device in dBμV for each position. Determine the median of the above values.

c) Place the auxiliary antenna in a second horizontal direction, which is perpendicular to the first direction, and repeat step b).

d) Place the auxiliary antenna in a third vertical direction, which is perpendicular to the first and second direction, and repeat step b).

e) Replace the auxiliary antenna and the radio-frequency signal generator with a transmitter under test and operate the transmitter with an antenna. Repeat step b).

f) The radiated radio-frequency power (random field: P_{RFD}) of the transmitter is given by:

$P_{RFD} = D + A - B$ (dBm)

where

D is the output level of the signal generator in step a);

A is the median value of step e);

B is the averaged median value of steps b), c) and d).

NOTE 1 – Location and connection of the equipment in the test site are not included in the above steps.

NOTE 2 – The radiated radio-frequency power (random field: P_{RFD}) would be the integration of all direction radiated power and not the same as the radiated power measured in other test sites.

A.2.5.3.2 Receiver measurement receiving radio-frequency electromagnetic energy

a) Place the calibration antenna in a first horizontal direction and adjust the output level of the radio-frequency signal generator to D dBm (about –10 dBm, but this may be changed according to the received level distribution in the dynamic range of the selective measuring device).

b) Move the transmitting antenna from the beginning to the end of the random path in 360 or more approximately equally spaced positions and record the output values of the selective measuring device in dBμV for each position. Determine the median of the above measured values.

c) Place the calibration antenna in a second horizontal direction, which is perpendicular to the first direction, and repeat step b).

d) Place the calibration antenna in a third vertical direction, which is perpendicular to the first and second direction, and repeat step b).

e) Replace the calibration antenna and the selective measuring device with a receiver under test and operate the receiver.

f) Move the transmitting antenna from the beginning to the end of the random path in 360 or more approximately equally spaced positions and measure the receiver output signal-to-noise ratio in each position. Record the number of times N that the signal-to-noise ratio exceeds the standard signal-to-noise ratio (12 dB SINAD).

NOTE 1 – The receiver output could be connected directly to measuring equipment using carbon impregnated polytetrafluoroethylene (PTFE) wires or connected acoustically, using an acoustic coupling device. The squelch circuits output or the received signal strength indicator signal may be used instead of the receiver output. The data duplex equipment could retransmit the receiver output to measuring equipment through the transmitting part.

NOTE 2 – The sensitivity of some receivers as data receivers will require the measurement to be carried out under specified maximum Doppler frequencies or the specified velocities. The measuring antenna moving speed in the random path corresponds to the maximum Doppler frequency or the velocities. The antenna moving speed may not cover all of them.

NOTE 3 – SINAD is defined as $\frac{S+N+D}{N+D}$

g) If N is less than 72 increase the field strength level, record the output level of the radio-frequency signal generator, and repeat step f).

If N is greater than 252 decrease the field strength level, record the output level of the radio-frequency signal generator, and repeat step f).

h) Using the value of N recorded in step f), calculate C as follows:

$$C = 10 \lg \frac{\lg(0{,}5)}{\lg(N\ /\ 360)} \ \text{dB}$$

NOTE – If a number other than 360 is used, 72, 252 and N should be changed proportionally to the number.

j) Record the radiation sensitivity (random field: R_{RFD}) in dB(µV/m) as given by:

$R_{RFD} = C + E – D + F$

where

D is the output level of the signal generator in step a);

E is the signal generator output level in step f);

F is the averaged median value of step b), c) and d).

NOTE 1 – Location and connection of the equipment in the test site are not included in the above steps.

NOTE 2 – Steps a) to d) can be omitted if the test site has been calibrated in the same frequency and the same conditions.

NOTE 3 – The radiation sensitivity (random field: R_{RFD}) is similar to the radiation sensitivity in the real world and not the same as the radiation sensitivity measured in other test sites.

A.2.5.4 Construction of an RFM site

The measuring arrangement for equipment emitting radio-frequency electromagnetic energy is shown in figure A.9. The measuring arrangement for equipment receiving electromagnetic energy is shown in figure A.10.

The radiation test site may be situated in any convenient location that will allow the movement of the measuring or transmitting antenna along the random path.

On this test site the r.f. signal of the EUT or the auxiliary antenna, coming from any direction, should be scattered and reflected on the route to the measuring antenna.

For equipment receiving radio-frequency electromagnetic energy, the same test site construction and the opposite propagation condition should be used.

A.2.5.4.1 Random path

The random path is a predetermined path that has a minimum path length of the value listed in the following table according to the aimed measuring error or repeatability. The random path should not have much difference of distance between the EUT and any point of the path.

A rotator assisted arrangement can realise a random path with good repeatability. The rotator assisted arrangement is built by a rotator, an arm and an arm rotator and is able to support the measuring antenna. The arrangement operates as follows: during the first rotation the arm is settled so that the measuring antenna is in a vertical position; in the second rotation the arm is rotated 15°; and during the next rotation a further 15°. Thus the inclination of the measuring antenna increases by steps of 15°. M rotations can increase the path length M times 3,1 m if the arm has a radius of 1 m.

The measuring antenna or the transmitting antenna could be moved by hand or carried by a person; however, in this case, the repeatability of the movement should be confirmed sometimes by an evaluation measurement.

The aimed error in the following table means 90 % possibility and the path lengths are introduced from the study of the relationship between the estimation error of cumulative probability distribution of received signal strength and the measurement time in a Rayleigh fading signal environment.

Aimed error (dB)	1	2	3
Path length (wavelength)	44	8,7	3,3

A.2.5.4.2 Radio-wave scatterers

The radio-wave scatterers should be composed of several hundred or more scatterers, which are electrically separated from each other. The scatterers should be made from metallic material and it would be preferable to form curved boards of slightly differing shapes. The size of the scatterers should be about a quarter of the wavelength of the centre frequency of the frequency range of the test site.

The auxiliary antenna or the equipment under test should be surrounded by the scatterers.

NOTE – An example of 1 000 scatters of A4 size and obstacles gave an average of 1 dB DDD values in the frequency range of 470 MHz to 2,6 GHz. DDD stands for the Deviation of receiving level Dependent on the antenna Directions.

A.2.5.4.3 Obstacles

The obstacles, using metallic walls or radio-wave screening curtains or something similar, should be arranged so that the radio-wave passed scatters cannot reach the measuring antenna without being reflected more than twice.

A.2.5.5 Evaluation measurement

After the installation of the RFM test site, it is necessary to make an evaluation measurement to confirm whether the test site satisfies the required measuring error or repeatability. The measurement should confirm the DDD value.

Any value of the evaluation criterion could be used if both the purchaser and the manufacturer agree.

A.2.5.5.1 Method of measurement to confirm the DDD value

a) Locate the measuring antenna on the random path and arrange the other equipment as illustrated in figure A.9.

b) Place the auxiliary antenna in a first horizontal direction.

c) Move the measuring antenna from the beginning to the end of the random path in 360 or more approximately equally spaced positions and record the output values of the selective measuring device in dBµV for each position.

d) Place the auxiliary antenna in a second horizontal direction, which is perpendicular to the first direction.

e) Repeat step c).

f) Place the auxiliary antenna in a third vertical direction, which is perpendicular to the first and second direction.

g) Repeat step c).

NOTE – The same procedure can be applied for figure A.10.

A.2.5.5.2 Representation of results

a) Record the input power of the auxiliary antenna.

b) Determine and record the mean of the values recorded in A 2.5.5.1 steps c), e) and g).

c) The maximum difference of the three means is the DDD value. It is the maximum measurement error of the test site at this frequency.

A.2.5.6 Measuring antenna

The measuring antenna may be any antenna that can receive linearly polarized waves. It may consist of a half-wave dipole, the length of which is adjusted to the frequency concerned.

A.2.5.7 Transmitting antenna

The transmitting antenna shall be the same type as the measuring antenna.

A.2.5.8 Auxiliary antenna

The auxiliary antenna is used for the evaluation measurement and replaces the EUT during part of the emission measurement. The auxiliary antenna shall be a half-wave dipole and shall be arranged so that the centre of the auxiliary antenna approximately coincides with the centre of radiation of the EUT.

A.2.5.9 Calibration antenna

The calibration antenna replaces the equipment under test during calibration of the receiver receiving electromagnetic energy measurement. The calibration antenna shall be an antenna for which the available power output has been calibrated in field strength. The centre of the calibration antenna shall be located so that this point coincides with the centre of the radiation centre of the equipment under test. The antenna, including the cable, shall be matched to the input impedance of the selective measuring device.

A.2.5.10 Radio-frequency signal generator

The generator shall be matched to the antenna, if necessary by use of a matching network (balun).

A.2.5.11 Selective measuring device

The selective measuring device may be a field strength meter or a selective voltmeter or a spectrum analyzer with an output proportional to the field strength, or the logarithm of the field strength over a range of 50 dB.

NOTE – Since the measurement requires that many measurements should be recorded, it will be more practical to have an electrical output from the selective measuring device that can automatically be recorded and processed by a computer.

A.2.5.12 Calibration method for RFM site

A.2.5.12.1 General

The RFM site calibration is the procedure for determining the numerical relationship between EUT effective radiated power and the selective measuring device indication mean value in an emission measurement site, or the field strength mean value where the EUT is placed and the radio-frequency signal generator equivalent output voltage in a receiver measurement site.

The calibration method contains the evaluation measurement because the calibration needs the averaged indication of three perpendicular directions of the auxiliary antenna or the calibration antenna.

A.2.5.12.2 Calibration for measurement of equipment emitting radio-frequency electromagnetic energy

This method is applicable to the radiated radio-frequency power of transmitters and the radiated spurious components of receivers.

a) Locate the measuring antenna on the random path and arrange the other equipment as illustrated in figure A.9.

b) Place the auxiliary antenna in a first horizontal direction.

c) Adjust the output level of the radio-frequency signal generator to D dBm (about –10 dBm, but may be changed according to the received level distribution in the dynamic range of the selective measuring device).

d) Move the measuring antenna from the beginning to the end of the random path in 360 or more approximately equally spaced positions and record the output values of the selective measuring device in dBµV for each position. Determine the median of the above values.

e) Place the auxiliary antenna in a second horizontal direction which is perpendicular to the first direction.

f) Repeat step d).

g) Place the auxiliary antenna in a third vertical direction which is perpendicular to the first and second direction.

h) Repeat step d).

i) The radiated radio-frequency power (random field: P_{RFD}) for other median values is given by:

$$P_{RFD} = D + A - B \text{ (dBm)}$$

where

D is the output level of the signal generator in step c);

A is the new median value;

B is the average median value of steps d), f) and h).

NOTE – Calibration is only valid for frequency, antennas, polarization and the antenna position used in the calibration procedure. If any of these change, the site should be recalibrated.

A.2.5.12.3 Calibration for measurement of equipment receiving radio-frequency electromagnetic energy

a) Locate the transmitting antenna on the random path and arrange the other equipment as illustrated in figure A.10.

b) Place the calibration antenna in a first horizontal direction.

c) Adjust the output level of the radio-frequency signal generator to *D* dBm (about –10 dBm, but may be changed according to the received level distribution in the dynamic range of the selective measuring device).

d) Move the transmitting antenna from the beginning to the end of the random path in 360 or more approximately equally spaced positions and record the output values of the selective measuring device in dBµV for each position. Determine the median of the above measured values.

e) Place the calibration antenna in a second horizontal direction which is perpendicular to the first direction.

f) Repeat step d).

g) Place the calibration antenna in a third vertical direction which is perpendicular to the first and second direction.

h) Repeat step d).

i) The median field strength for other values of the radio-frequency signal generator output is given by

median field strength = $E - D + F$

where

D is the output level of the signal generator in step c);

E is the new signal generator output level;

F is the average median value of steps d), f) and h).

NOTE – Calibration is only valid for frequency, antennas, polarization and the antenna position used in the calibration procedure. If any of these change, the site should be recalibrated.

A.3 Radio-frequency coupling devices (RFCDs)

A.3.1 Introduction, outline and selection of RFCDs

The object of using RFCDs is the realization of convenient radiation measurements. The signal level at the input or output of an RFCD can be measured by the same procedure for receivers or transmitters equipped with suitable antenna terminals and the level can be replaced by the field strength or the radiated power. The field strength or the radiated power can be calibrated by the calibration procedure.

There are two principles for constructing RFCDs. One is near-field coupling between an antenna and the EUT in a shielded box. The other is electromagnetic coupling between an enlarged transmission line and the EUT in it. The former would have narrowband characteristics and would be supplied by the manufacturer of the EUT. The latter would have wideband characteristics and would be supplied by another manufacturer. The test fixture is a narrowband RFCD. Stripline arrangement, TEM cell and GTEM cell are wideband RFCDs.

The coupling of RFCDs can be calibrated by test site measurements. The coupling will differ with equipment size and internal construction. Therefore, the calibration is effective only for the same equipment and for the frequency calibrated.

The guide for the selection of RFCDs is shown in table A.2.

A.3.2 Test fixture (narrowband RFCD)

The test fixture is a device for coupling a given equipment with an internal antenna to an input socket and classified into a narrowband RFCD. It is generally designed and provided by the manufacturer of EUT.

A test fixture input radio-frequency signal can be calibrated to the field strength in a test site using EUT. A test fixture allows the performance of relative measurements at the same frequency or around the same frequency. Therefore, the measurements and compliance tests of spurious response immunity and radiated spurious components are excluded.

A.3.2.1 Guide for the construction and measurement of a test fixture

To ensure measurement repeatability, a test fixture which includes the following should be used in the measurement arrangement:

– a radiating element;

– a radio-frequency input terminal connected to the radiating element through a transmission line;

– a means to ensure that the input impedance of the test fixture be the same as the impedance of the transmission line from the radio-frequency signal generator;

– a means for positioning the receiver being measured in a precise, repeatable and stable manner;

– a means to ensure that the presence of the person making the measurement does not affect the results.

It shall also have the following characteristics:

– a coupling loss between the radio-frequency input terminal and the receiver being measured of less than 30 dB;

– a coupling loss variation over the frequency range used in the measurement which does not exceed 2 dB;

– no non-linear elements which can affect the measurement results.

The coupling loss shall be sufficiently low so that the output power requirements at the signal generators used in this standard will not exceed the power output capability of commercially available signal generators.

When making these measurements, precautions shall be taken to ensure that:

– the receiver is adequately shielded from electromagnetic disturbance;

– the attenuation of the coupling between the radiation source and the receiver being measured is sufficiently low, stable and constant throughout the measuring frequency range.

The coupling loss depends on the particular measuring arrangement, the frequency being used, and the receiver being measured. Normally it is not precisely measured, as it will only be useful for a particular measuring arrangement and frequency.

A.3.2.2 Calibration method for a test fixture

a) Measure the receiver radiation sensitivity of the same n ($n \geq 1$) EUT for receiver specific direction in a test site and calculate the average. An LRTS or an anechoic chamber are recommended for this purpose.

b) Measure the receiver sensitivity of all the above EUT in a test fixture at a determined position and direction. The sensitivity is the signal level at the input of the test fixture. Calculate the average of the sensitivity.

c) The calibration is the averaged value of step b) in microvolts (µV) which is replaced by the average value of step a) in microvolts per metre (µV/m).

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The sensitivity measurement of data also has dispersion. The average of n measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of n measured values reduces calibration error by $1/n^{1/2}$.

NOTE 2 – The calibration is only valid for the frequency, the same EUT, EUT position and direction. If any of these change, it should be recalibrated.

A.3.3 Wideband RFCDs

A.3.3.1 Stripline arrangement

A.3.3.1.1 General

Previously (see IEC 60489 series), the equipment parameter measurements applicable to this RFCD were all ratio measurements pertaining to receiver radio-frequency energy, for example, receiver selectivity, spurious response immunity and intermodulation immunity. However, if a stripline arrangement input radio-frequency signal is calibrated to the field strength in a test site for EUT, it becomes available for the measurements and compliance tests of radiated measured usable sensitivity for the same EUT at the same frequency.

The calibrations for emission measurements are also possible. If the stripline output voltage is calibrated to the radiated power of EUT in a test site, it becomes available for the measurement of the same EUT at the same frequency.

The stripline is especially suitable for measurements on small equipment. To avoid environmental influences, such as interfering radio services and man-made noise, it is recommended to operate the stripline in a shielded room. With the stripline, it is possible to generate very high field strengths.

NOTE – The above radiation sensitivity corresponding to the first introduction was the RFCD reference sensitivity (selective calling) and defined as the level of the RFCD input signal in microvolts (µV).

A.3.3.1.2 Stripline characteristics

Characteristics	Limits	
	Size I	Size II
Useful frequency range	1 MHz to 200 MHz	1 MHz to 100 MHz
Available field strength	See A.3.3.1.5	
Equipment size limits	Length = 200 mm	400 mm
(antenna included)	Width = 200 mm	400 mm
	Height = 250 mm	500 mm

A.3.3.1.3 Construction of the stripline

The stripline is made of three pieces of a highly conductive metal (e.g. copper sheet) that are sufficiently rigid (e.g. strengthened by wood) to support the EUT mounted in the stripline.

The shape and size of the stripline are shown in figure A.11. It is open on both sides, has an impedance of 100 Ω and shall be terminated with the impedance by resistors having less than 5 Ω of reactance at any frequency from 1 MHz to 200 MHz (see figure A.12). Both outer conductors are connected by the shielding of the transmission line.

The stripline shall be matched to the transmission line impedance with matching networks (see figure A.13) with resistors having less than 5 % reactance at any frequency from 1 MHz to 200 MHz (e.g. for a 50 Ω transmission line, a shunt and a series resistance of 70,7 Ω should be used).

Resistors with very low inductance and capacitance are needed (e.g. surface-mounted resistors) because the size and the material of the resistors have a great influence on reactance, especially at frequencies above 100 MHz.

A.3.3.1.4 Position of the EUT

The EUT shall be mounted on a pedestal, made of a material with a dielectric constant less than 2, so that it is placed at least 10 mm above the lower conductor. The equipment shall be centred in the horizontal plane of the stripline in the following positions.

a) Equipment having an integral antenna is mounted in such a way that the antenna is in a vertical position, with that axis vertical which is closest to vertical in normal use.

b) Equipment having a rigid external antenna is mounted in such a way that the antenna is in a vertical position.

c) Equipment with a non-rigid external antenna: the antenna is mounted vertically with a non-conducting support.

d) Or as agreed with the manufacturer.

A.3.3.1.5 Explication of the term "available field strength in a radiation stripline"

The available field strength is nearly equal to the voltage on the centre conductor divided by the distance from the centre conductor to the outer conductor in meters. The relationship of the field strength in the stripline to the input voltage is given by the following formula:

$$E = V_i \times C \times A \times 1/H \ (\mu V/m)$$

where

E is the field strength;

H is the distance, in metres, between the outer conductor and the centre conductor, and is equal to 0,3 m for size I and 0,6 m for size II;

V_i is the voltage in microvolts (µV) at the input to the stripline;

A is the voltage ratio of the voltage on the centre conductor to V_i, and in this stripline it is equal to 100/170,1 or 0,5858;

C is a constant.

V_i is determined in the same way that the input voltage to a receiver is determined (e.g. the radio-frequency signal generator output reduced by any loss due to attenuators, cables, combining or matching networks). V_i should be determined for each measuring device and frequency used in the measurement.

If the radio-frequency signal generator output is calibrated in microvolts (µV) (e.m.f.) then C is 0,5.

If the radio-frequency signal generator output is calibrated in microvolts (µV) (matched load, ml) then C is 1.

A.3.3.1.6 Radio-frequency signal generator

For susceptibility measurements, a well-shielded radio-frequency generator and a matching network (if required) shall be connected to the input terminal of the stripline.

A.3.3.1.7 Selective measuring device

For emission measurements, a selective measuring device shall be connected to the input of the stripline. The device may be either a frequency selective voltmeter or a spectrum analyzer.

A.3.3.1.8 Calibration method for a stripline

The calibration is the procedure for determining the numerical relationship between RFCD input or output voltage and the equivalent field strength where EUT is placed, or the radiated power of EUT.

A.3.3.1.8.1 Calibration for measurement of equipment receiving radio-frequency electromagnetic energy

a) Measure the receiver radiation sensitivity of the same n ($n \geq 1$) EUT for receiver specific direction in a test site and calculate the average. An LRTS or an anechoic chamber is recommended for this purpose.

b) Measure the receiver sensitivity of all the above EUT in a stripline at a determined position and direction. The sensitivity is the signal level at the input of the stripline. Calculate the average of the sensitivity.

c) The calibration is the average value of step b) in microvolts (µV) which is replaced by the average value of step a) in microvolts per metre (µV/m).

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The sensitivity measurement of data also has a dispersion. The average of *n* measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of *n* measured values reduces the calibration error by $1/n^{1/2}$.

NOTE 2 – Calibration is only valid for the frequency, the same EUT, and the EUT position and direction. If any of these change, it should be recalibrated.

A.3.3.1.8.2 Calibration for measurement of equipment emitting radio-frequency electromagnetic energy

a) Measure the transmitter radiated power of the same *n* ($n \geq 1$) EUT for transmitter specific direction in a test site and calculate the average. An LRTS or an anechoic chamber are recommended for this purpose.

b) Measure the transmitter radiated power of all the above EUT in a stripline at a determined position and direction. The radiated power is the signal level at the output of the stripline. Calculate the average of the power.

c) The calibration is the average value of step b) in microvolts (µV) which is replaced by the average value of step a) in watts.

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The average of *n* measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of *n* measured values reduces the calibration error by $1/n^{1/2}$.

NOTE 2 – Calibration is only valid for the frequency, the same EUT, and EUT position and direction. If any of these change, it should be recalibrated.

A.3.3.2 TEM cell

A.3.3.2.1 General

TEM (transverse electromagnetic mode) cell is a special kind of shielded symmetrical waveguide arrangement. TEM cells are designed for fast and precise radiated susceptibility and emission measurements of mobile radio equipment. The TEM cell needs no measuring antenna and no auxiliary antenna.

TEM cells are applicable to all kinds of radiation measurements on mobile radio equipment. TEM cells are especially suitable for measurements on small equipment. They are independent of environmental influences such as interfering radio services and man-made noise. With TEM cells, it is possible to generate very high field strengths.

A.3.3.2.2 TEM cell characteristics (examples)

Characteristics	Size I	Size II
Frequency range	DC to 250 MHz	DC to 500 MHz
Maximum power input	500 W	500 W
Impedance of cell	50 Ω	50 Ω
SWR_{max}	1,2:1	1,2:1 to 250 MHz 1,4:1 to 500 MHz
Cell total breadth	2 000 mm	1 000 mm
Cell total height	600 mm	300 mm
Cell total depth	1 000 mm	500 mm
Septum depth	740 mm	370 mm
Maximum dimensions of EUT ($b \times h \times d$)	300 mm × 100 mm × 200 mm	150 mm × 50 mm × 100 mm

(concluded)

Access ports	Size I	Size II
Top round outer diameter	110 mm	110 mm
inner diameter	30 mm	30 mm
Side round outer diameter	110 mm	110 mm
inner diameter	30 mm	30 mm
Side rectangular $b \times h$	600 mm × 200 mm	300 mm × 130 mm

A.3.3.2.3 Construction of the TEM cell

The construction of a TEM cell is illustrated in figure A.14. It consists of a tube with a rectangular cross-section and a flat inner conductor. The input and the output connectors are matched to the stripline by tapers. The output terminal of the TEM cell shall be terminated with an equivalent resistive load.

The dimensions of the TEM cell and the tapers provide an impedance of 50 Ω from end to end. When terminated with 50 Ω, a uniform high impedance field approaching that of free space is produced throughout the test sample location. The test location is accessible through a door.

The primary limitation to standard TEM cell usage is the size of the test volume, which is inversely proportional to the upper frequency limit. The upper frequency limit is determined by the appearance of high-order wave modes which perturb the desired TEM mode field distribution. This occurs when the cell width is of the order of half a wavelength. Thus the test chamber size in a standard TEM cell is limited to approximately one-quarter of the lowest operating wavelength. If testing up to 1 GHz (300 mm wavelength) is required, the chamber size would be limited to 75 mm, which is too small for most practical applications.

A.3.3.2.4 Position of the EUT

The EUT shall be placed in the middle of the test volume which is specified by the manufacturer.

a) Equipment having an integral antenna shall be mounted so that the antenna is in a vertical position, with the axis vertical which is closest to vertical in normal use.

b) Equipment having a rigid external antenna is mounted so that the antenna is in a vertical position.

c) For equipment with a non-rigid external antenna, the antenna shall be mounted vertically with a non-conducting and low permittivity material support.

   If the EUT has a power cable or other connections, it shall be led out of the TEM cell horizontally and be as short as possible.

A.3.3.2.5 Radio-frequency signal generator

For susceptibility measurements, a radio-frequency generator, with a power amplifier and a matching network (if required), has to be connected to the input terminal of the TEM cell.

The output terminal of the TEM cell shall be terminated with a resistive load of the nominal value to achieve the specified SWR.

A.3.3.2.6 Selective measuring device

For relative emission measurements, a selective measuring device shall be connected to the input of the TEM cell. The device may be either a frequency selective voltmeter, or a spectrum analyzer. The output terminal of the TEM cell should be loaded with a load with the same impedance as the TEM cell, for example 50 Ω.

A.3.3.2.7 Calibration method for the TEM cell

A.3.3.2.7.1 Calibration for measurement of equipment receiving radio-frequency electromagnetic energy

a) Measure the receiver radiation sensitivity of the same n ($n \geq 1$) EUT for receiver specific direction in a test site and calculate the average. An LRTS or an anechoic chamber are recommended for this purpose.

b) Measure the receiver sensitivity of all the above EUT in a TEM cell at a determined position and direction. The sensitivity is the signal level at the input of the TEM cell. Calculate the average of the sensitivity.

c) The calibration is the average value of step d) in microvolts (µV) which is replaced by the average value of step a) in microvolts per metre (µV/m).

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The sensitivity measurement of data also has dispersion. The average of n measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of n measured values reduces calibration error by $1/n^{1/2}$.

NOTE 2 – The calibration is only valid for the frequency, the same EUT, the EUT position and direction. If any of these change, it should be recalibrated.

NOTE 3 – The above calibration procedure may be omitted, if the manufacturer of the TEM cell guarantees the field strength maximum error for equipment which has lesser dimension than that specified and which is placed in the specified volume with the specified direction.

A.3.3.2.7.2 Calibration for measurement of equipment emitting radio-frequency electromagnetic energy

a) Measure the transmitter radiated power of the same n ($n \geq 1$) EUT for transmitter specific direction in a test site and calculate the average. An LRTS or an anechoic chamber are recommended for this purpose.

b) Measure the transmitter radiated power of all the above EUT in a TEM cell at a determined position and direction. The radiated power is the signal level at the output of the TEM cell. Calculate the average of the power.

c) The calibration is the average value of step b) in microvolts which (µV) is replaced by the averaged value of step a) in watts.

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The average of n measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of n measured values reduces calibration error by $1/n^{1/2}$.

NOTE 2 – Calibration is only valid for the frequency, the same EUT, EUT position and direction. If any of these change, it should be recalibrated.

NOTE 3 – The above calibration procedure may be omitted if the manufacturer of the TEM cell guarantees the field strength maximum error for the equipment which has lesser dimension than that specified and which is placed in the specified volume with the specified direction.

A.3.3.3 GHz TEM cell (GTEM)

A.3.3.3.1 General

The GTEM cell is a test facility applicable to both susceptibility and emission measurements on mobile radio equipment for frequencies from d.c. to much above 1 GHz. The facility is a hybrid between a TEM cell and an anechoic chamber (see figures A.8, A.14 and A.15).

The name GTEM emphasizes its gigahertz capability. The GTEM cell permits overcoming the frequency and size limitations inherent in a standard TEM cell, while retaining its basic advantages.

They are independent of environmental influences and man-made noise and do not interfere with radio services. With GTEM cells it is possible to generate very high field strengths.

A.3.3.3.2 Characteristics of a GTEM cell (examples)

Characteristics	Size I	Size II
Maximum height of test volume	500 mm	1 500 mm
Maximum size of object	300 mm × 300 mm x 200 mm	1 000 mm × 1 000 mm × 500 mm
Approximate outer cell dimensions	2 500 mm × 1 000 mm x 670 mm	6 500 mm × 3 000 mm × 2 000 mm
Maximum input power	100 W to 400 W	1 kW to 2 kW
Maximum c.w. field strength	135 V/m	450 V/m
Maximum pulse voltage	15 kV	>80 kV
Maximum pulse field	30 kV/m to 90 kV/m	>50 kV/m to 150 kV/m
Frequency range	d.c. to > 5 GHz	d.c. to > 5 GHz
Field uniformity	± 4 dB	± 4 dB
Typical impedance	50 Ω	50 Ω
SWR	< 2	< 2,5

NOTE 1 – GTEM cells have various sizes from 500 mm to more than 1 750 mm in height between the inner conductor (septum) and the bottom. The typical upper test object dimensions are roughly 30 % to 50 % of the above-mentioned space, depending on the shape of the EUT.

NOTE 2 – A certain manufacturer specifies the maximum input power of 400 W for size 1 and 2 kW for size 2.

NOTE 3 – A certain manufacturer specifies d.c. to 17 GHz for the frequency range of a GTEM cell.

A.3.3.3.3 Example of the construction of a GTEM cell

The GTEM cell is an alternative design for a TEM cell. It consists of a section of a gently flared rectangular coaxial transmission line terminated with a matched load. The end termination of the cell is a wall with absorbing material (see figures A.15 and A.16). At low frequencies it operates as a circuit element 50 Ω load. At high frequencies the absorbers attenuate the incident waves as in an anechoic chamber. The cross-over between these two regions depends on the cell size and the absorber length. The broadband match provided by the termination suppresses the creation of higher order modes. The absorbing material significantly reduces the *Q* of the chamber; thus, the resonance effects tend to be small. The field uniformity is better than ±4 dB versus frequency (d.c. to 1 GHz) in the test chamber of an empty cell.

A.3.3.3.4 Position of the EUT

The EUT and its associated cabling shall be placed in the middle of the test volume which is specified by the manufacturer.

a) Equipment having an integral antenna shall be mounted so that the antenna is in a vertical position, with the axis vertical which is closest to vertical in normal use.

b) Equipment having a rigid external antenna is mounted so that the antenna is in a vertical position.

c) For equipment with a non-rigid external antenna the antenna, shall be mounted vertically with a non-conducting and low permittivity material support.

If the EUT has a power cable or other connections, it shall be led out of the GTEM cell horizontally, or led out via the manufacturer's interface panel, and be as short as possible.

A.3.3.3.5 Radio-frequency signal generator

For susceptibility measurements a radio-frequency generator, with a power amplifier and a matching network (if required), shall be connected to the input terminal of the GTEM cell.

A.3.3.3.6 Selective measuring device

For emission measurements, a selective measuring device shall be connected to the input of the GTEM cell. The device may be either a frequency selective voltmeter or a spectrum analyzer.

A.3.3.3.7 Calibration method for a GTEM cell

A.3.3.3.7.1 Calibration for measurement of equipment receiving radio-frequency electromagnetic energy

a) Measure the receiver radiation sensitivity of the same n ($n \geq 1$) EUT for receiver specific direction in a test site and calculate the average. An LRTS or an anechoic chamber are recommended for this purpose.

b) Measure the receiver sensitivity of all the above EUT in a GTEM cell at a determined position and direction. The sensitivity is the signal level at the input of the GTEM cell. Calculate the average of the sensitivity.

c) The calibration is the average value of step b) in microvolts (µV) which is replaced by the average value of step a) in microvolts per metre (µV/m).

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The sensitivity measurement of data also has dispersion. The average of n measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of n measured values reduces calibration error by $1/n^{1/2}$.

NOTE 2 – The calibration is only valid for the frequency, the same EUT, EUT position and direction. If any of these change, it should be recalibrated. If the EUT is small enough compared to the gap of the inner conductor and the outer conductor of the RFCD, the construction difference of the EUT may cause very little coupling difference and a calibrated value may be used for another EUT construction or other EUT which has smaller size.

NOTE 3 – The above calibration procedure may be omitted if the manufacturer of the GTEM cell guarantees the field strength maximum error for the equipment which has a lesser dimension than that specified and which is placed in the specified volume with the specified direction.

A.3.3.3.7.2 Calibration for measurement of equipment emitting radio-frequency electromagnetic energy

a) Measure the transmitter radiated power of the same n ($n \geq 1$) EUT for transmitter specific direction in a test site and calculate the average. LRTS or anechoic chamber are recommended for this purpose.

b) Measure the transmitter radiated power of all the above EUT in a GTEM cell at determined position and direction. The radiated power is the signal level at the output of the GTEM cell. Calculate the average of the power.

c) The calibration is the average value of step b) in microvolts (µV) is replaced by the average value of step a) in watts.

NOTE 1 – The measurement values of steps a) and b) generally have a dispersion. The average of n measured values has a dispersion of $1/n^{1/2}$ of the original dispersion value. Therefore, the average of n measured values reduces calibration error by $1/n^{1/2}$.

NOTE 2 – The calibration is only valid for the frequency, the same EUT, EUT position and direction. If any of these change, it should be recalibrated. If the EUT is small enough compared to the gap of the inner conductor and the outer conductor of the RFCD, the construction difference of the EUT may cause very little coupling difference and a calibrated value may be used to another EUT construction or other EUT which has smaller size.

NOTE 3 – The above calibration procedure may be omitted if the manufacturer of the GTEM cell guarantees the field strength maximum error for the equipment which has a lesser dimension than that specified and which is placed in the specified volume with the specified direction.

A.4 Alternative test mounting arrangement

A.4.1 Simulated man (for belt-mounted radios)

A.4.1.1 General

Most radio paging receivers have an integral antenna. In normal operation, the radio pager is worn on the person and most often is clipped to the clothing at the person's waist. Radio paging antennas are designed for optimum performance when worn on the person. Therefore, to standardize the radio paging radiation sensitivity measurements, a test device is used to simulate the human body. This test device consists of a standard container filled with salt water, and is referred to in this clause as the simulated man (see figure A.17).

The simulated man is used to measure the reference radiation sensitivity (selective calling) and/or average radiation sensitivity (selective calling) of radio pagers.

A.4.1.2 Characteristics of the simulated man

Material	Cast acrylic tube closed at both ends
Height	1 700 mm ± 100 mm
Outside diameter	305 mm ± 2 mm
Sidewall thickness	4,8 mm ± 0,2 mm
Top and bottom thickness	30 mm ± 2 mm.

It is filled with salt (NaCl) solution of 1,5 g per litre of water (H_2O).

A.4.1.3 Characteristics of a light-weight simulated man

The following are the dimensions of "Salty-Lite". The space between the inner and outer tubes is filled with 41,5 l of salt water. The salt (NaCl) concentration is 4,0 g/l. Total "Salty-Lite" weight is 61,5 kg.

1) Outer tube

Material	Acrylic plastic
Outer diameter	303 mm
Height	1 356 mm
Wall thickness	4,3 mm
Top lid	48 mm
Bottom lid	30 mm
Water height	1 315 mm
Water layer thickness:	39 mm

2) Inner tube

Material	Acrylic plastic
Outer diameter	216 mm
Height	1 520 mm (may be shorter)
Wall thickness	6,4 mm
Top lid	not used

It should be noted that the water layer thickness and the tube diameters may be particularly critical dimensions in that they determine the fine structure of the frequency response. All other dimensions are typical.

A.4.1.4 Position of the EUT

The top of the radio pager should be 1,0 m ± 0,1 m from the ground. The radio pager should be fixed on the surface of the simulated man without a gap between them.

A.4.2 Simulated arm

The simulated arm is a test mounting arrangement for radiation measurements on mobile radio equipment, which is arm-mounted while in normal operation (e.g. wrist-watch pager).

Under consideration

A.4.3 Simulated head

The simulated head is a test mounting arrangement for radiation measurements on mobile radio equipment, which is head-mounted while in normal operation (e.g. headset).

Under consideration

A.4.4 Combination of simulated man, arm and head

The combination of simulated man, simulated arm and simulated head is an alternative test mounting arrangement provided for mobile radio equipment which is hand-held or carried on the body of a person while in normal operation (e.g. cordless telephone).

Under consideration

A.5 Baseband signal connection arrangement

A.5.1 General

The radiation measurement on a test site or in an RFCD may need baseband signal connection, for example receiver output to a SINAD meter or an audio frequency signal generator to transmitter input. These connections should not affect radiation measurement results. The following connection arrangement, which needs no connection wire for electromagnetic radio wave, is recommended.

NOTE – SINAD is defined as $\frac{S+N+D}{N+D}$.

A.5.2 Direct electrical connection measuring arrangement

A.5.2.1 General considerations

When a receiver is being measured on a radiation test site or in a radio-frequency coupling device (RFCD), the audio-output voltage should be conducted from the receiver to the remote indicator by a means that will not perturb the field near the receiver. This should be done by making direct electrical connection to the audio-output terminals if they are available, or by making direct electrical connection to the speaker terminals.

A.5.2.2 Field perturbation from the measuring arrangement

When objects having high electrical conductivity such as copper wire are present on a radiation test site or in an RFCD, the field will be perturbed. This perturbation can be minimized by making the wires that are used to make the electrical connection between the remote indicator and the receiver from material which has high resistivity. The re-radiated fields from these connecting wires will be too weak to noticeably affect the radiation measurement results.

The wires should be long enough to ensure that the remote indicator can be located either beyond the edge of the radiation test site, or below the ground surface. If an RFCD is used, the wires should be long enough so that the presence of the remote indicator will not affect the measurement results.

A.5.2.3 Wire characteristics

A flexible material having a resistivity of at least 0,28 Ωm (280 000 Ωmm^2/m) should be used for the wires. A suitable wire can be made of carbon-impregnated polytetrafluoroethylene (PTFE).

A.5.2.4 Measurement arrangement considerations

Even large diameter wire fabricated from this material will have a very high resistance. For example, 30 m of 3 mm diameter wire will have a resistance of 1 MΩ. This does not present a problem for test equipment having a high input impedance (for example, greater than 1 MΩ), because SINAD is a ratio.

Due to the high input impedance of the test equipment and the high resistance of the wires, the capacitance between the wires should be minimal to avoid the effect of audio frequency sensitivity of the measuring arrangement. The wires should be spaced over 100 mm apart for most of their length.

Carbon impregnated PTFE wire will generate considerable noise when it is moved. Care should be taken, therefore, to ensure that there is no movement of the wire while the SINAD is being measured.

NOTE – SINAD is defined as $\frac{S+N+D}{N+D}$.

A.5.2.5 Precautions to be taken when using direct connections

When the receiver has audio output terminals, a specified test load shall be connected across them. The test load should be as small as possible, and the leads should be as short as possible. When connections are made to the speaker, the conducting material used to make the connection should have the smallest possible mass.

A.5.3 Measuring arrangement using an acoustic coupling device to obtain the signal-to-noise ratio

A.5.3.1 General considerations

When a direct electrical connection to either the audio output terminals or the speaker terminals cannot be made, the signal-to-noise ratio may be measured by using an acoustic coupling device.

It is not intended that measurements of audio-frequency response, harmonic distortion, or audio intermodulation distortion be made by using the acoustic coupling device.

In such an arrangement, the measured signal-to-noise ratio is a function of the response characteristics of the audio frequency amplifier, of the internal loud speaker, and of the acoustic coupling device. In this standard, radio-frequency parameter measurements that are made by using the acoustic coupling device should give the same results as though direct electrical connections were made across the speaker terminals. This is accomplished by using the acoustic SINAD instead of the standard SINAD in the methods of measurements.

In this standard the standard signal-to-noise ratio is 12 dB SINAD.

Acoustic SINAD is the signal-to-noise ratio of an acoustic signal which is produced by an acoustic transducer (speaker) when the SINAD measured by direct electrical connection is 12 dB. The acoustic SINAD may be several decibels greater or less than 12 dB.

The manufacturer should open the receiver to make a direct electrical connection across the speaker (or output of the audio amplifier), and determine in the laboratory the acoustic SINAD, which is equivalent to the 12 dB SINAD measured with direct connection to the transducer by using an acoustic coupling device, a microphone, and a correcting network identical to those used on the test site (figure A.18). For the purpose of this standard, the acoustic coupling device shall be understood to mean the combination of the plastic funnel covering the loudspeaker, the 2 m acoustic tube, and the fixture for positioning and supporting the EUT.

After the acoustic SINAD has been determined, all measurements made on the receiver in an RFCD or on a radiation test site will use the acoustic SINAD value whenever the standard signal-to-noise ratio is required.

Measurements of the output signal-to-noise ratio of a receiver shall be made by means of acoustic coupling to a microphone. On a radiation test site, all conducting materials used in the test equipment shall be placed below the surface and the acoustic energy conveyed from the receiver to the microphone by means of a non-conducting acoustic pipe.

When an RFCD is used, the same measuring arrangement may be used without placing the microphone below the ground surface.

The manufacturer shall establish the acoustic signal-to-noise ratio for the receiver and the test arrangement. The acoustic signal-to-noise ratio shall be used in all measurements that require measuring at the standard signal-to-noise ratio (12 dB SINAD).

The manufacturer shall supply or specify the acoustic coupling device and frequency correcting network.

If it is intended that the receiver be worn on a person, the acoustic coupling device shall be constructed to secure the receiver to the surface of the simulated man at the position specified.

NOTE – SINAD is defined as $\frac{S+N+D}{N+D}$.

A.5.3.2 Acoustic coupling device

The acoustic pipe shall be long enough (for example 2 m) to reach from the equipment under test to the underground surface where the microphone is located (see figure A.19). The acoustic pipe shall have an inner diameter of about 6 mm and a wall thickness of about 1,5 mm. A plastic funnel having a diameter appropriate to the size of the loudspeaker in the equipment under test, with soft foam rubber glued to its edge, shall be fitted to one end of the acoustic pipe, and the microphone shall be fitted to the other end. The acoustic pipe should be sufficiently flexible to allow the platform to rotate. The microphone shall have a response characteristic that is flat within 1,0 dB over a frequency range of 50 Hz to 20 000 Hz, a linear dynamic range of at least 50 dB, and a sensitivity sufficient to measure a signal-to-noise ratio of 40 dB. Its size should be sufficiently small (for example 7,5 mm) to couple to the acoustic pipe (see figure A.19).

The influence of the relatively large funnel volume feeding the small diameter pipe causes a de-emphasis of about 6 dB per octave for frequencies above 1 000 Hz. The resulting frequency response has a high peak at 1 000 Hz which could cause a high SINAD at the microphone output. A frequency correcting network should be placed between the microphone output and the SINAD meter input. The corrected frequency response of the acoustic coupling device shall not deviate by more than 3 dB from 400 Hz to 2 600 Hz.

It is very important to fix the centre of the funnel in a reproducible position relative to the receiver under test, as the position of the centre has a strong influence on the frequency response that will be measured. This can be achieved by positioning the equipment in a close-fitting fixture, supplied or specified by the manufacturer, of which the plastic funnel acoustic coupler is an integral part. Care should be taken to avoid varying the acoustic tube cross-section as the fixture is rotated.

NOTE – SINAD is defined as $\frac{S+N+D}{N+D}$.

A.5.3.3 Determination of the acoustic signal-to-noise ratio (manufacturer's action)

a) Place the receiver in the acoustic coupling device and connect the equipment as illustrated in figure A.18. Make direct electrical connection to the terminals of the output transducer so that they can be connected to the SINAD meter.

b) Measure the frequency response of the combination of loudspeaker and acoustic coupling device at the microphone amplifier output.

c) If the frequency response varies by more than 3 dB between 400 Hz and 2 600 Hz, insert a correcting network between the microphone amplifier output and the input to the SINAD meter that will reduce the response variation to less than 3 dB.

   NOTE – It may be necessary to limit the output level to a value which reduces the loudspeaker distortion to a maximum of 5 %.

d) With the correcting network inserted, make sure that at high radio-frequency input levels there is at least a 20 dB SINAD.

e) Adjust the input radio-frequency signal level to produce a 12 dB SINAD measured by direct electrical connection to the transducer. Measure the acoustic signal-to-noise ratio on the SINAD meter connected to the output of the correcting network. Record this as the acoustic signal-to-noise ratio for this receiver and acoustic coupling device.

NOTE 1 – The correcting network may have to contain a high-input impedance and a low-output impedance amplifier to ensure that the impedance of the SINAD meter does not change the frequency correcting network characteristics.

NOTE 2 – SINAD is defined as $\frac{S+N+D}{N+D}$.

A.5.3.4 Using the acoustic coupling device

When the measurement of the receiver output signal-to-noise ratio is required using an acoustic coupling device, connect the equipment, as illustrated in figure A.18, with the receiver placed in the acoustic coupling device. Insert the correcting network supplied or specified by the manufacturer. Whenever the measurement requires that the output of the receiver be the standard signal-to-noise ratio, the output of the receiver should be set so as to obtain an acoustic signal-to-noise ratio of 12 dB.

A.5.4 Loop-back arrangement from receiver output to transmitter input in duplex operation equipment

A.5.4.1 General consideration

The audio frequency output of a receiver and/or the received signal strength indication signal can be transmitted using a transmitter part of a duplex transceiver.

For the receiver radiation measurement, the received signal strength is near to the radiation sensitivity level and the received signal quality and/or the received signal strength information are transmitted from the transmitter part to the measuring arrangement. The transmitted signal should be received by the measuring arrangement without signal quality degradation. However, this measuring arrangement should not perturb the electromagnetic field between the EUT and the transmitting antenna. The measuring antenna should be constructed by an antenna, a receiver and the SINAD meter or the comparator. The receiver in the measuring arrangement is the same one as the EUT and receiving characteristics are known. The measuring arrangement can measure the receiver signal quality and/or the received signal strength information without wire connection.

For the transmitter radiation measurement, the radio-frequency signal generator high-level output which is modulated by an audio frequency signal or encoder output is connected to an antenna and transmitted to the receiving part of the EUT. The receiving part of the EUT demodulates the modulation signal and modulates the transmitter in the duplex transceiver. The path loss between the antenna connected to the radio-frequency signal generator and the receiver should be kept minimum so as not to degrade the signal quality. However, the antenna, the radio-frequency signal generator and the audio frequency signal generator or the encoder should not perturb the electromagnetic field between the EUT and the measuring antenna. The transmitter can be modulated by the audio frequency signal generator or the encoder without wire connection.

The loop-back arrangement would help equipment size reduction because it needs no mechanical interface. It would also help computer controlled measuring and complex protocol tests.

NOTE – SINAD is defined as $\frac{S+N+D}{N+D}$.

A.5.4.2 Loop-back circuit in duplex mobile equipment

Figure A.20 gives an idea of how the loop-back circuit for analogue and digital modulation equipment can be made.

The digital modulation equipment would be able to transmit more than two signals simultaneously. Figure A.20b shows the information channel loop-back. The other information, for example the received signal strength indication, can be transmitted accordingly. The information channel loop-back can realize measurement for the bit stream. The measurement for character string or the message can be realized using the other information channel or the information channel.

A.6 Correlation of test sites, methods of measurement

A.6.1 Correlation of test sites, between test sites and a RFCD

Test sites are classified into three types, for example OATS, LRTS/AC and RFM sites. Each test site measures in different radio-wave conditions.

OATS measures the composite of a direct wave and a ground-reflected wave. The direct wave does not necessarily reach only in a horizontal direction. The EUT is 1,5 m high on the ground. The angle between the horizontal plane and the direct wave may change between $\tan^{-1}(2,5/3)$ and $-\tan^{-1}(0,5/3)$ in a 3 m test site because the measuring antenna is raised and lowered from 1 m to 4 m. The same angle is reduced between $\tan^{-1}(2,5/30)$ and $-\tan^{-1}(0,5/30)$ in a 30 m test site. The ground-reflected wave is reflected at the area where the incident angle and the deflected angle become equal.

LRTS including AC measure only a direct wave in a horizontal direction in any measurement distance.

RFM sites measure the composite of all directions of radiated electromagnetic energy.

Different EUT would have different radiation directivity in a vertical plane. Therefore, the measurement results in these three types of test site are not necessarily the same, and correlation of different test sites would have no meaning.

In an RFCD measurement, coupling between an RFCD and an EUT will differ with the size and/or construction of the EUT. This means the radio wave in an RFCD will not be the same as in any test site. Very small size equipment, compared to the gap between inner conductor and outer conductor of a wideband RFCD, may have the same condition in LRTS. If the condition differs, the calibration coefficient dispersion will be increased and correlation will not be good.

A.6.2 Methods of measurement

The basic methods of measurement which measure only one direction of the EUT in each test site are described in each test site subclause. Table A.3 gives an overview of methods of measurement for integral antenna mobile radio equipment. These methods of measurement will be assembled from the basic method of measurement. Table A.3 indicates measurement methods to be used for different parameters of objects to be measured.

NOTE – All methods of measurement will be described in a future step-by-step procedure. See note 3 in table A.3.

Table A.3 - Overview of methods of measurement for integral antenna mobile radio equipment

Measurement items	OATS	LRTS/AC	RFM	RFCD
Transmitters				
– Average radiated power	A	B		
– Maximum radiated power		C		
– RFM radiated power			D	
– RFCD radiated power				E
Receivers				
– Average radiation sensitivity				
• Average radiation sensitivity (MUS)	H	I		
• Compliance test method	J	K		
• Average radiation sensitivity (SUS)				
– Reference radiation sensitivity	L			
– Normal radiation sensitivity	M	N		
– RFM radiation sensitivity			O	
– Diversity radiation sensitivity			P	
– RFCD radiation sensitivity				Q

NOTE 1 – A to E and H to O in the above table show different methods of measurement to be described.

NOTE 2 – Q is not the same as the original definition. The original definition uses RFCD input voltage in microvolts (μV). O uses equivalent field strength in RFCD in microvolts per metre (μV/m).

NOTE 3 – A to E and H to Q will be described for the case of A3, F3 continuous wave. Other modulation or access methods could be the combination of these methods and the difference between A3. F3 continuous wave and other modulation or access method in the terminal measurement method.

NOTE 4 – The spurious radiation power can be measured with the same procedure as the radiation power except that it may be necessary to reduce the carrier power by a band-eliminating filter because the carrier power may affect measurement result.

A.6.2.1 Electromagnetic energy emission measurement

The average radiation power means an average of eight directions. Both OATS and LRTS/AC measure eight direction averages. However, A and B mean these methods of measurement differ from each other in certain details.

The maximum radiation power means the maximum of the direct radiated power in 4π steradian globe directions.

The RFM radiation power is the integration power of all directions.

The RFCD radiation power means power measured at specific direction and place in RFCD. The calibration of RFCD would be made with specific direction in OATS or LRTS/AC. The average of eight directions in RFCD may be measured.

A.6.2.2 Electromagnetic energy receiving measurement

The average radiation sensitivity means the average of eight direction sensitivities. The compliance test method of average radiation sensitivity means that if for five or more directions, a compliance with the specification has been recorded, the equipment does comply; otherwise it does not comply.

The reference radiation sensitivity means the radiation sensitivity in a minimum radiation sensitivity direction. It may be other than eight directions.

The normal radiation sensitivity means the sensitivity in a normal direction, which the manufacturer has specified. M and N are the same as the basic method of measurement respectively.

The RFM radiation sensitivity is similar to the real sensitivity. Care should be taken if a digital modulation receiver is measured because the demodulation circuit will be affected by a fading signal which has arisen from the random path moving. The random path moving speed may not cover all speed required.

The diversity radiation sensitivity means the similar sensitivity to the real sensitivity of equipment which has diversity antenna. The same care as for the above RFM radiation sensitivity is necessary.

The RFCD radiation sensitivity means sensitivity measured at a specific direction and place in the RFCD. The calibration of the RFCD would be made with specific direction in OATS or LRTS/AC. The average of eight directions in the RFCD can be measured.

A.7 Antennas

This clause gives additional information for an antenna used in test site measurements. The antenna characteristics will be supplied by the manufacturer. If an antenna calibration is necessary, see IEC 60489-8. It shall be performed by the manufacturer or nationally recognized antenna calibration laboratory.

A.7.1 Half-wave dipole antenna

The half-wave dipole antenna is used as the auxiliary antenna which replaces the EUT during part of the measurement. It may also be used as the measuring antenna and the transmitting antenna for some test sites.

The antenna shall be a balanced dipole and resonant in length. It shall be matched to the feeder by a suitable transforming device. Connection to the feeder and the input of the measuring apparatus shall be made through a symmetric-asymmetric transformer arrangement. The antenna shall be rotatable so that all polarization of incident radiation may be measured.

The balance of the antenna shall be such that when the antenna is rotated in a uniform field, the level in the cross-olarization direction shall be at least 20 dB below that in the parallel polarization direction.

The preferred fixed frequency dipoles between 1,7 GHz and 6 GHz should be as follows:

a) the total radiation element length is nearly half-wave;

b) the bandwidth in which the SWR is less than 1,5 is 1 % to 2,5 % of the centre frequency;

c) input impedance is 50 Ω;

d) the radiation coefficient is 0,5 dB ± 1 dB.

In frequencies of more than 6 GHz, the half-wave dipole antenna will not be commercially available and the pyramidal horn antenna is recommended instead.

A.7.2 Pyramidal horn antenna

It is recommended to use the pyramidal horn antenna as the measuring antenna and the transmitting antenna at frequencies higher than 1 GHz. It is used as the calibrated antenna and the auxiliary antenna at higher frequencies than 6 GHz and may also be used at frequencies between 0,7 GHz and 18 GHz.

The pyramidal horn antenna should have waveguide-to-coaxial transition and the input impedance should be 50 Ω. The antenna shall be rotatable so that all polarization of incident radiation may be measured.

The balance of the antenna shall be such that when the antenna is rotated in a uniform field, the level in the cross-polarization direction shall be at least 20 dB below that in the parallel polarization direction.

The preferred pyramidal horn antenna should be as follows:

a) the radiation gain is 10 dBi to 20 dBi considering the directivity and the gain variation is ±0,5 dB;

b) input impedance is 50 Ω and the SWR is less than 1,5;

c) the radiation gain variation is ±0,5 dB of specified or measured value;

d) the radiation coefficient is ±0,5 dB of specified or measured value.

A.7.3 Log-periodic antenna

The log-periodic antenna is one of the wire antenna arrays, designed so that its characteristic dimensions are periodic with the logarithm of the frequency. The antenna will be essentially frequency independent. The frequency range for the log-periodic antenna is roughly given by the frequencies at which the longest and shortest dipoles in the array are half-wave resonant. Ten times wideband characteristics can be obtained.

An example of the log-periodic antenna is as follows:

a) the frequency range is 200 MHz to 2 000 MHz;

b) the average gain in the frequency range is 5 dB to a half-wave dipole;

c) the front to back gain ratio is more than 15 dB;

d) the input impedance is 50 Ω and the SWR is less than 2.

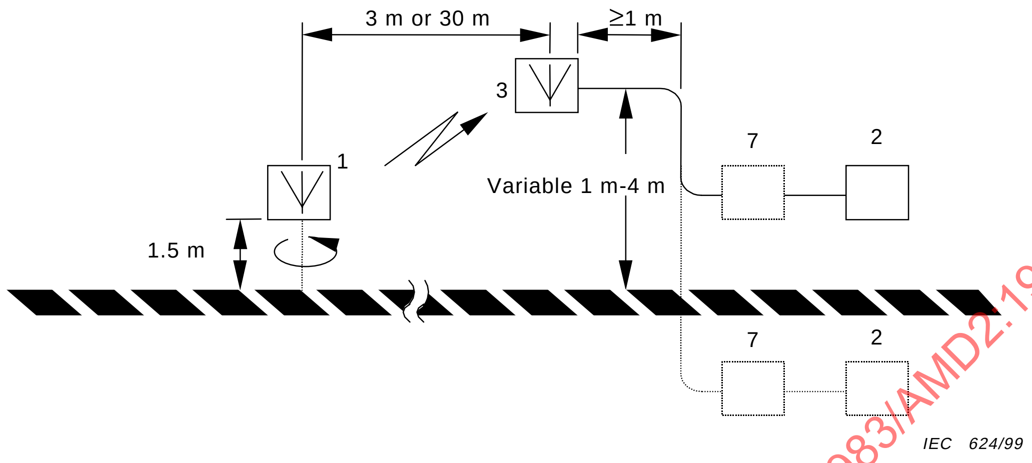

Figure A.1a – Measuring arrangement for the EUT

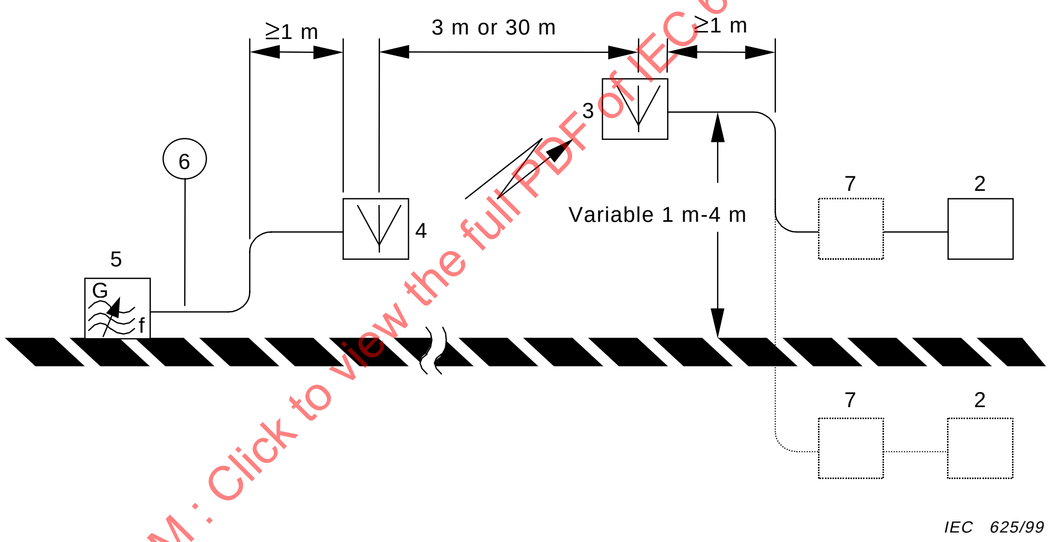

Figure A.1b – Measuring arrangement for substitution measurement

Key

1 Transmitter under test

2 Selective measuring device

3 Measuring antenna

4 Auxiliary antenna

5 Radio-frequency signal generator

6 Selective measuring device

7 Optional calibration attenuator for measuring the effective radiated power or fundamental oscillation rejection filter for measuring non-essential emissions

Figure A.1 – Measuring arrangement for radio-frequency emission on an OATS

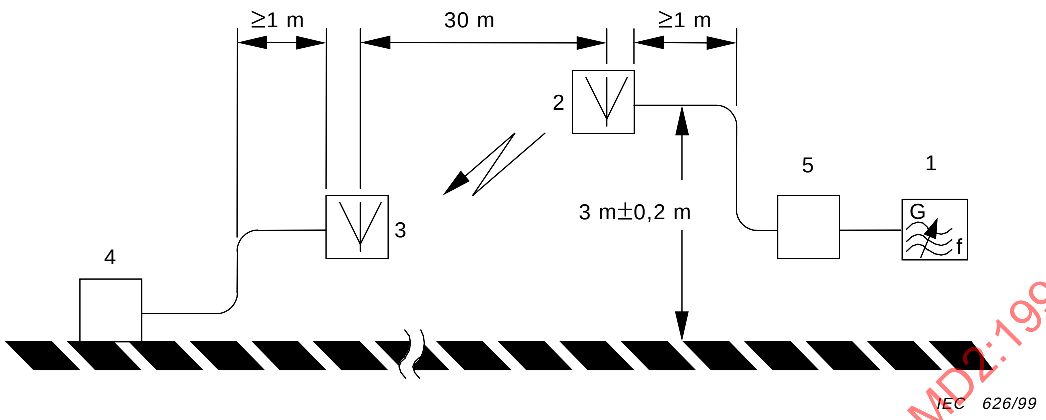

Figure A.2a – Measuring arrangement for calibration measurement

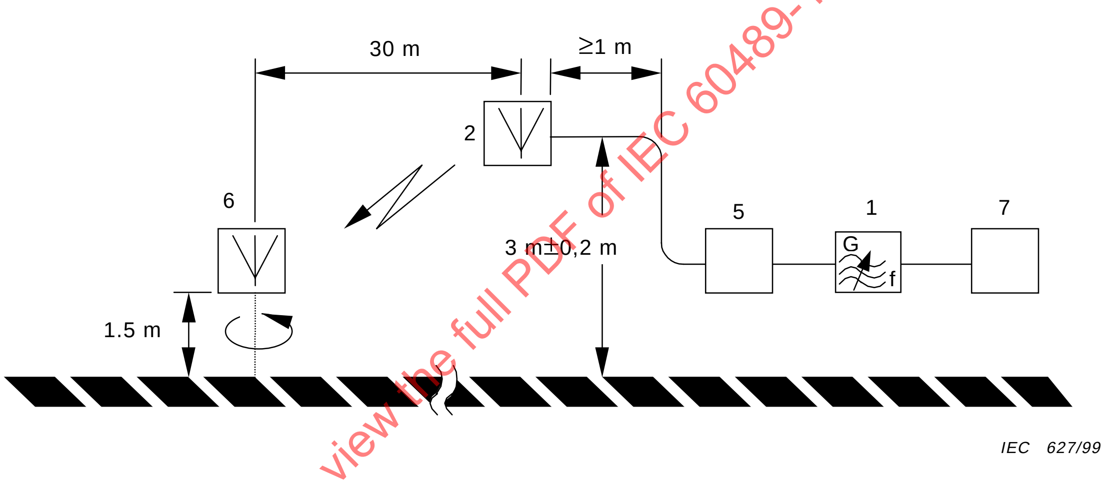

Figure A.2b – Measuring arrangement for the EUT

Key

1 Radio-frequency signal generator

2 Transmitting antenna

3 Calibration antenna

4 Selective measuring device

5 80 dB step attenuator, 1 dB steps

6 Receiver under test

7 Audio frequency signal generator or encoder

Care should be taken to ensure that the field in the vicinity of the receiver under test is not disturbed by the test equipment.

Figure A.2 – Measuring arrangement for radio-frequency receiving on an OATS

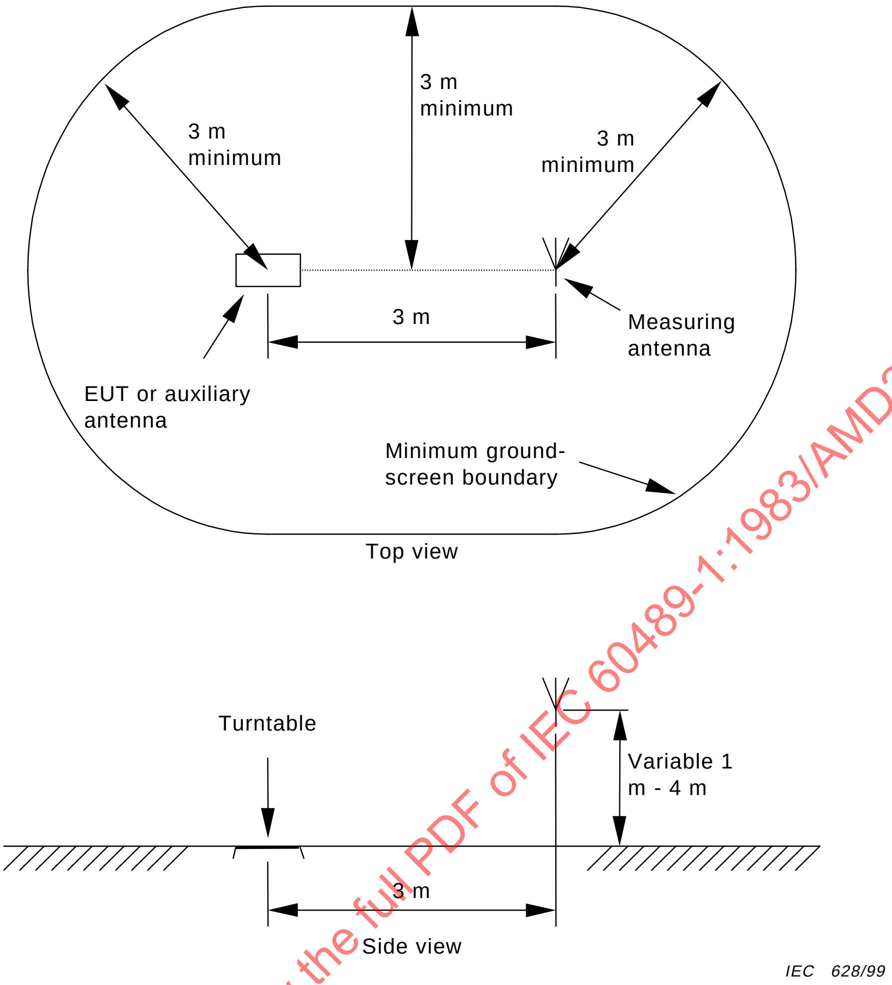

Figure A.3 – 3 m site dimensions inside the ground-screen boundary

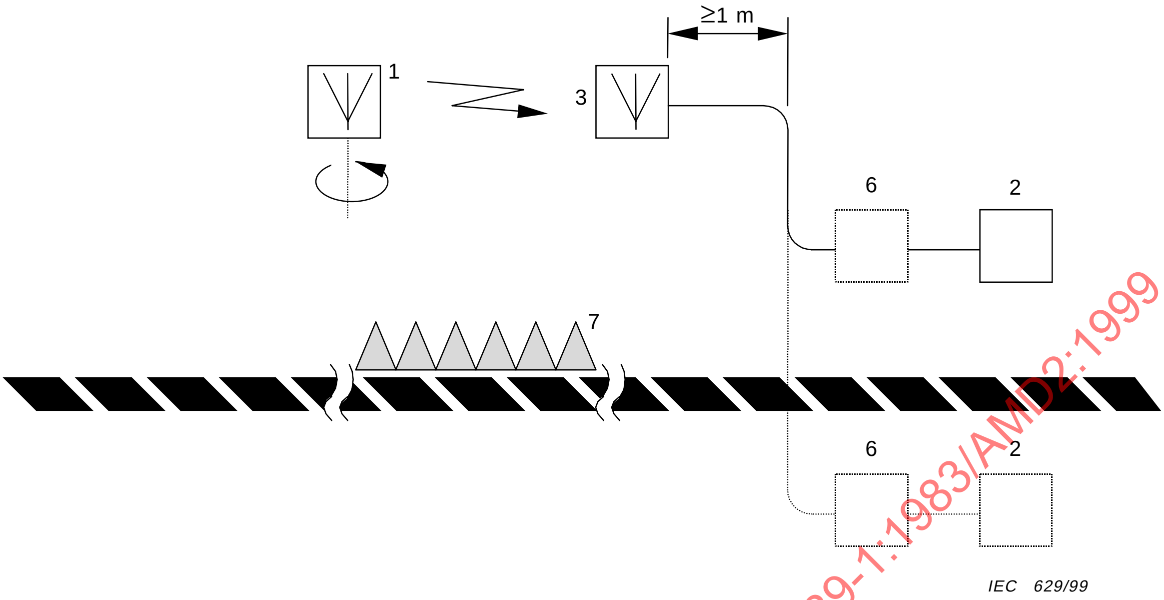

Figure A.4a – Measuring arrangement for the EUT

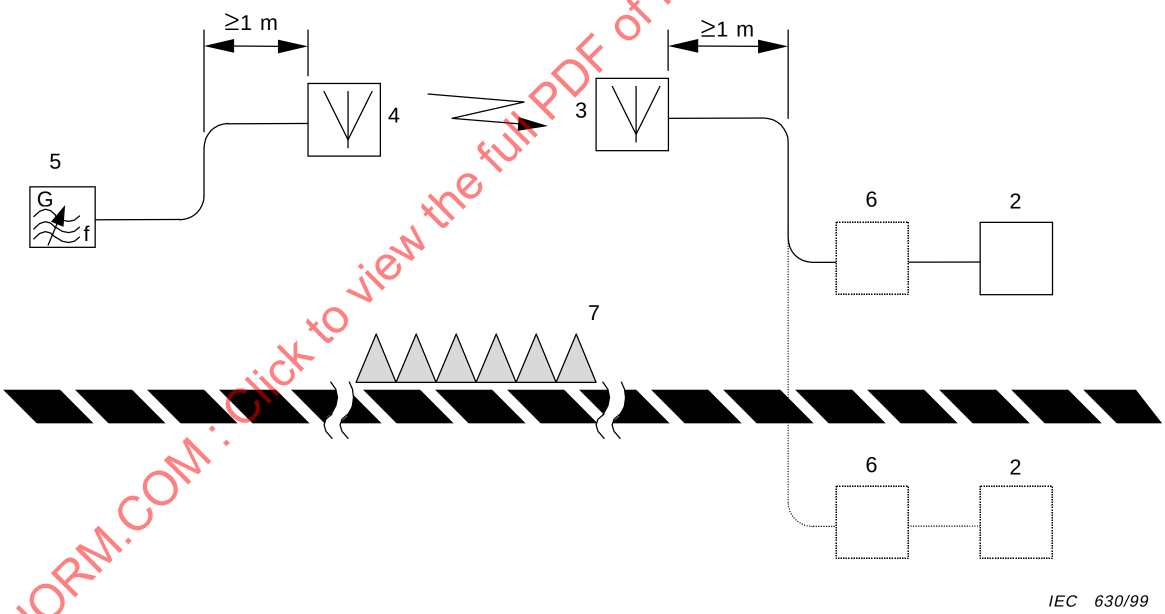

Figure A.4b – Measuring arrangement for substitution measurement

Key

1 Transmitter under test

2 Selective measuring device

3 Measuring antenna

4 Auxiliary antenna

5 Radio-frequency signal generator

6 Optional calibrated attenuator for measuring the effective radiated power, or fundamental oscillation rejection filter for measuring non-essential emissions

7 Radio wave absorber

Figure A.4 – Measuring arrangement for radio-frequency emission on an LRTS using radio-wave absorber

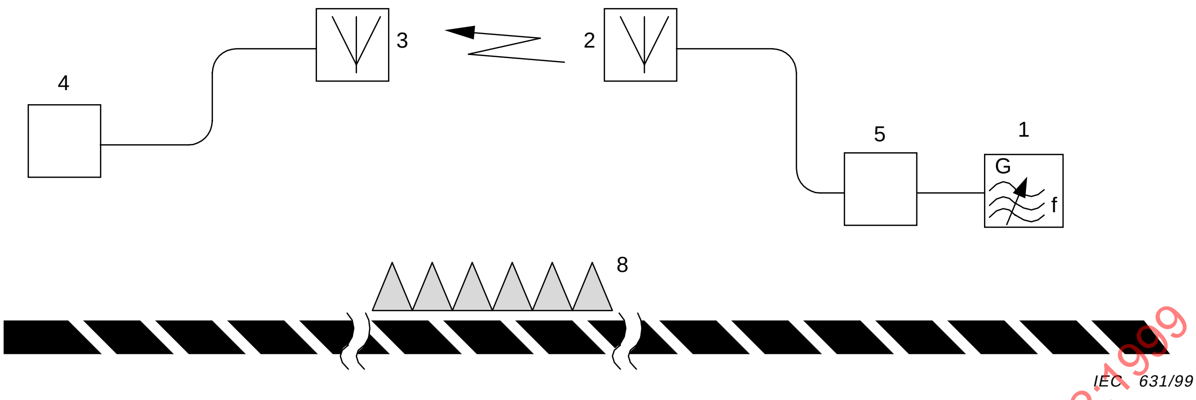

Figure A.5a – Measuring arrangement for calibration measurement

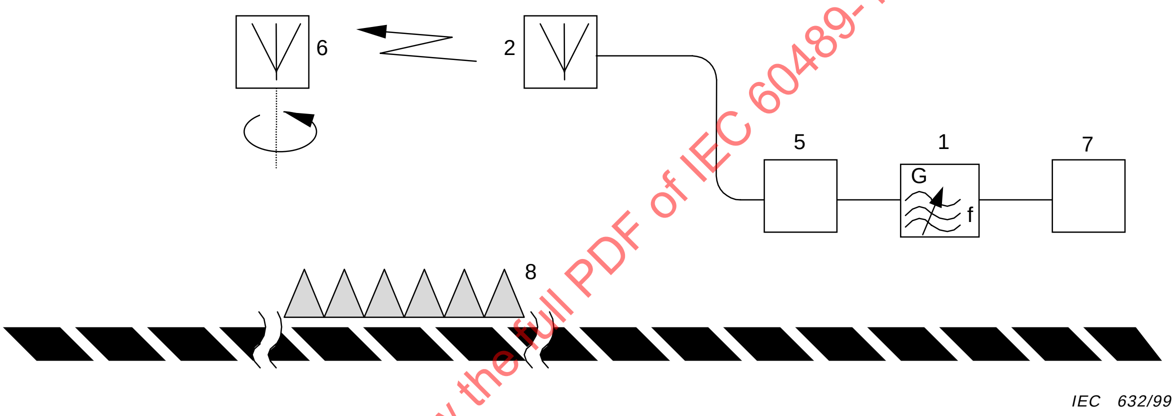

Figure A.5b – Measuring arrangement for the EUT

Key

1 Radio-frequency signal generator

2 Transmitting antenna

3 Calibration antenna

4 Selective measuring device

5 80 dB step attenuator, 1 dB steps

6 Receiver under test

7 Encoder

8 Radio-wave absorber

Care should be taken to ensure that the field in the vicinity of the receiver under test is not disturbed by the test equipment.

Figure A.5 – Measuring arrangement for radio-frequency receiving on an LRTS using radio-wave absorber

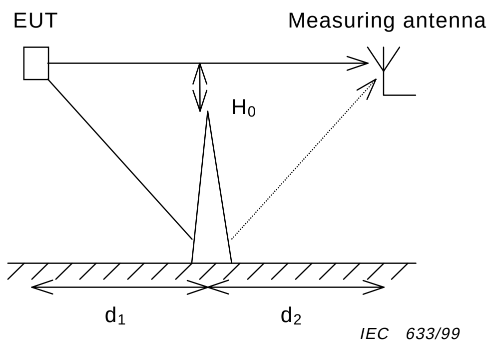

Figure A.6a – Radio-wave screening curtain

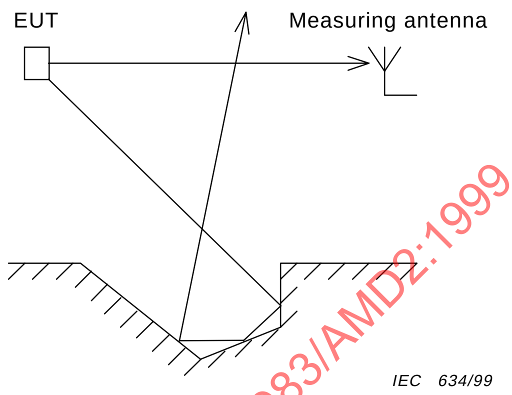

Figure A.6b – Mazed gap

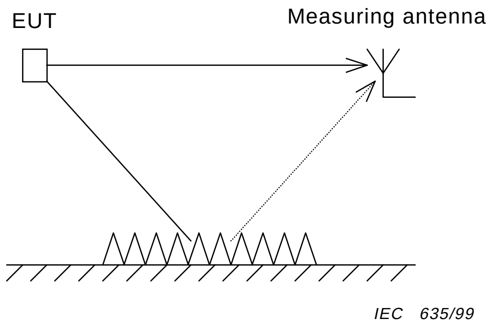

Figure A.6c – Radio-wave absorber

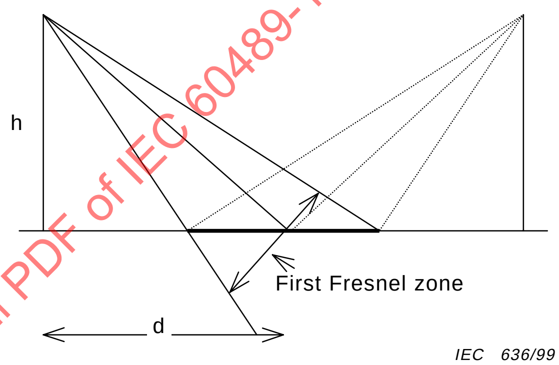

Figure A.6d – Width of absorber

Figure A.6 – Ground-reflected wave suppression

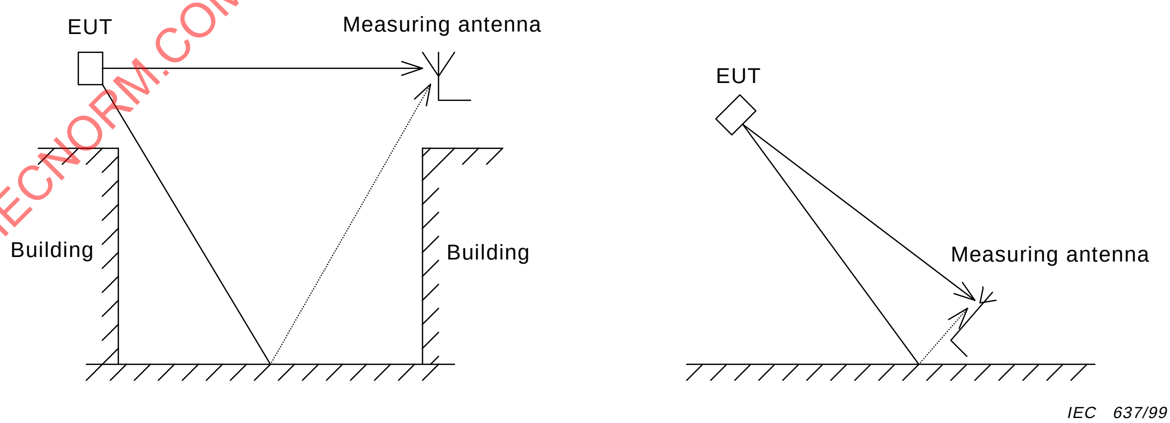

Figure A.7 – Higher position to reduce ground-reflected wave

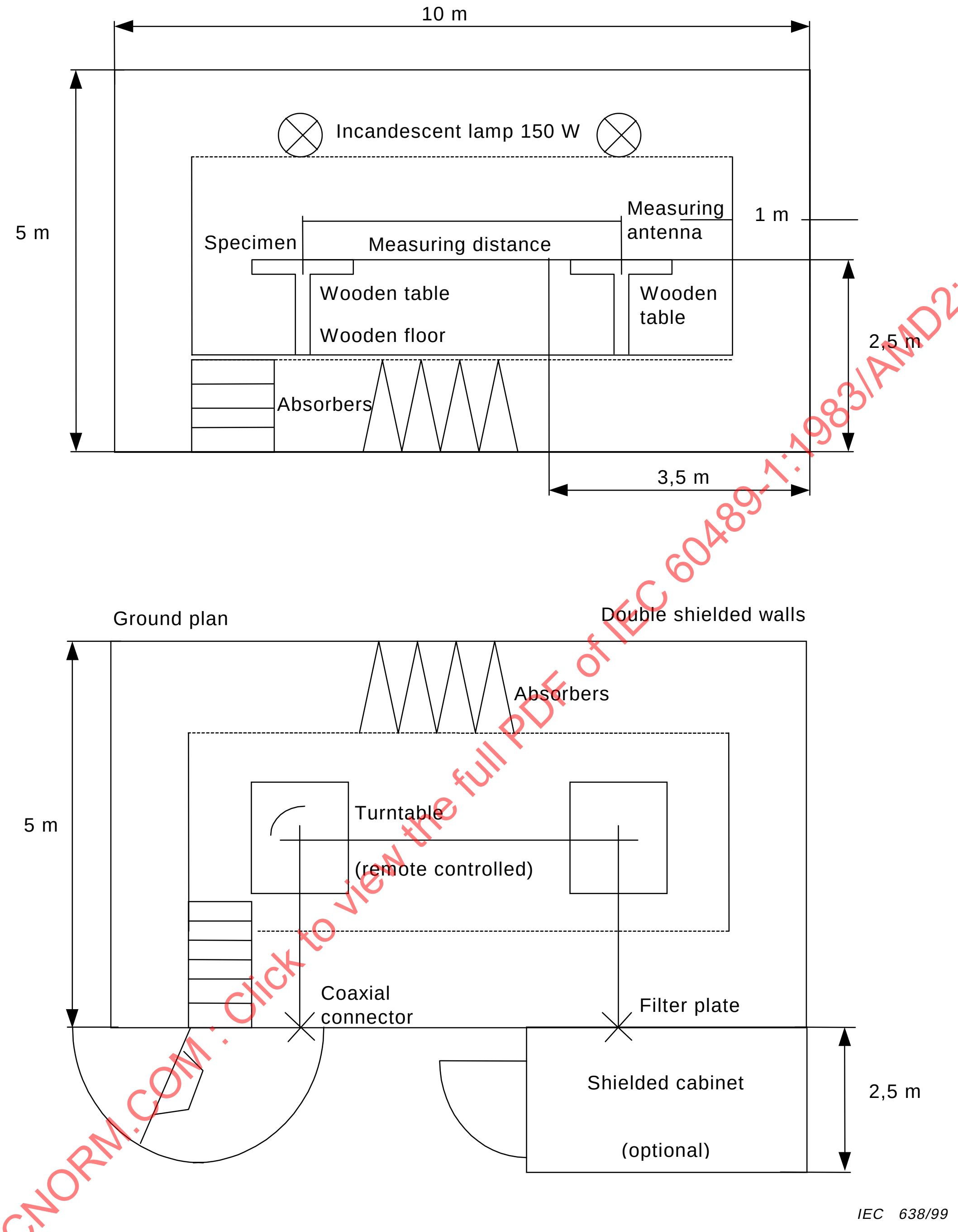

Figure A.8 – Example of an anechoic chamber