

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Evaluation of human exposure to electromagnetic fields from short range devices (SRDs) in various applications over the frequency range 0 GHz to 300 GHz –

Part 1: Fields produced by devices used for electronic article surveillance, radio frequency identification and similar systems

Evaluation de l'exposition humaine aux champs électromagnétiques produits par les dispositifs radio à courte portée dans la plage de fréquence 0 GHz à 300 GHz –

Partie 1: Champs produits par les dispositifs utilisés pour la surveillance électronique des objets, l'identification par radiofréquence et les systèmes similaires



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Partie 1: Champs produits par les dispositifs utilisés pour la surveillance électronique des objets, l'identification par radiofréquence et les systèmes similaires

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**EVALUATION OF HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS
FROM SHORT RANGE DEVICES (SRDS) IN VARIOUS APPLICATIONS
OVER THE FREQUENCY RANGE 0 GHz to 300 GHz –****Part 1: Fields produced by devices used for electronic article
surveillance, radio frequency identification and similar systems**

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International Standard IEC 62369-1 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

The text of this standard is based on the following documents:

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106/156/FDIS	106/159/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The list of all parts of IEC 62369 series, published under the title *Evaluation of human exposure to electromagnetic fields from short range devices (SRDs) in various applications over the frequency range 0 GHz to 300 GHz*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

Electromagnetic fields interact with the human body and other biological systems through a number of physical mechanisms. The main mechanisms of interaction are based on nervous system effects and heating. These effects are dependent on frequency and are defined by biologically relevant quantities. Based on these scientifically established health effects, there are international, regional and sometimes national exposure requirements. These are set as basic restrictions on quantities, which are not necessarily directly measurable, and contain high safety factors to ensure a high level of protection. These quantities may be determined either by calculation for each case, or by measuring a reference value that has a pre-derived relationship to them, usually under worst-case, far-field conditions. Respect of the reference value will ensure respect of the relevant basic restriction, except in some specific near field situations which would normally be identified or highlighted within the applicable exposure guidelines. If the measured quantity exceeds the reference value, it does not necessarily follow that the basic restriction is also exceeded. Under those circumstances, more detailed evaluation techniques will be necessary which are specific to that type of equipment and exposure.

This document is part of a multi-part standard covering the evaluation of human exposure to electromagnetic fields from short range devices (SRDs) in various applications over the frequency range from 0 GHz to 300 GHz.

EVALUATION OF HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS FROM SHORT RANGE DEVICES (SRDS) IN VARIOUS APPLICATIONS OVER THE FREQUENCY RANGE 0 GHz to 300 GHz –

Part 1: Fields produced by devices used for electronic article surveillance, radio frequency identification and similar systems

1 Scope

This part of IEC 62369 presents procedures for the evaluation of human exposure to electromagnetic fields (EMFs) from devices used in electronic article surveillance (EAS), radio frequency identification (RFID) and similar applications. It adopts a staged approach to facilitate compliance assessment. The first stage (Stage 1) is a simple measurement against the appropriate derived reference values. Stage 2 is a more complex series of measurements or calculations, coupled with analysis techniques. Stage 3 requires detailed modelling and analysis for comparison with the basic restrictions. When assessing any device, the most appropriate method for the exposure situation may be used.

At the time of writing this International Standard, electronic article surveillance, radio frequency identification and similar systems do not normally operate at frequencies below 1 Hz or above 10 GHz. EMF exposure guidelines and standards can cover a wider range of frequencies, so clarification on the required range is included as part of the evaluation procedures.

The devices covered by this document normally have non-uniform field patterns. Often these devices have a very rapid reduction of field strength with distance and operate under near-field conditions where the relationship between electric and magnetic fields is not constant. This, together with typical exposure conditions for different device types, is detailed in Annex A.

Annex B contains comprehensive information to assist with numerical modelling of the exposure situation. It includes both homogeneous and anatomical models as well as the electrical properties of tissue.

This International Standard does not include limits. Limits can be obtained from separately published human exposure guidelines. Different guidelines and limit values may apply in different regions. Linked into the guidelines are usually methods for summation across wider frequency ranges and for multiple exposure sources. These shall be used. A simplified method for summation of multiple sources is contained in Annex C. This has to be used with care as it is simplistic and will overestimate the exposure; however it is useful as a guide, when the results of different evaluations are in different units of measure which are not compatible.

Different countries and regions have different guidelines for handling the uncertainties from the evaluation. Annex D provides information on the two most common methods.

A bibliography at the end of this standard provides general information as well as useful information for the measurement of electromagnetic fields. See [1],[2],[3],[4],[5],[6]¹⁾.

Similar national or international standards may be used as an alternative.

1) Figures between brackets refer to the bibliography.

2 Normative references

None.

3 Terms, definitions, and abbreviations

The internationally accepted SI units are used throughout this document.

3.1 Quantities

Quantity	Symbol	Unit	Dimension
Magnetic flux density	B	tesla (Vs/m ²)	T
Electric flux density	D	coulomb per square metre	Cm ⁻²
Electric field strength	E	volt per metre	Vm ⁻¹
Frequency	f	hertz	Hz
Magnetic field strength	H	ampere per metre	Am ⁻¹
Current density	J	ampere per square metre	Am ⁻²
Power density	S	watt per square metre	Wm ⁻²
Specific absorption rate	SAR	watt per kilogram	Wkg ⁻¹
Temperature	T	kelvin	K
Permittivity	ϵ	farad per metre	Fm ⁻¹
Wavelength	λ	metre	m
Permeability	μ	henry per metre	Hm ⁻¹
Mass density	ρ	kilogram per cubic metre	kgm ⁻³
Electric conductivity	σ	siemens per metre	Sm ⁻¹

3.2 Constants

Physical constant	Symbol	Magnitude
Velocity of light in free space	c	$2,998 \times 10^8 \text{ ms}^{-1}$
Permittivity of free space	ϵ_0	$8,854 \times 10^{-12} \text{ Fm}^{-1}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ Hm}^{-1}$
Impedance of free space	Z_0	$120\pi \text{ (or } 377) \Omega$

3.3 Terms and definitions

3.3.1

antenna

antennas are conductive elements that radiate, and/or receive energy in the radio frequency spectrum

3.3.2

average (temporal) absorbed power

P_{avg}

time – averaged rate of energy transfer defined by:

$$P_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t) dt$$

where t_1 and t_2 are the start and stop time of the exposure (the period $t_2 - t_1$ is the exposure duration)

3.3.3

averaging time

t_{avg}

appropriate time over which exposure is averaged for purposes of determining compliance

3.3.4

bandwidth

range or band of frequencies in the electromagnetic spectrum within which a system is capable of receiving and transmitting

3.3.5

basic restrictions (or basic limits)

values for human exposure to time-varying electric, magnetic, and electromagnetic fields that are based on levels for which there are established health effects, with a high level of safety included. These values may be defined in terms of induced current density, in-situ electric field, specific absorption rate or similar dosimetric quantity

3.3.6

carrier

frequency used to carry data by appropriate modulation of the carrier waveform

3.3.7

conductivity

σ

ratio of the conduction–current density in a medium to the electric field strength in the medium

$$J = \sigma E$$

3.3.8

current density

J

electromagnetic field-induced current per unit area inside the body

3.3.9

deactivator

device which changes transponders so that they no longer respond

**3.3.10
dielectric constant** ϵ

See permittivity.

**3.3.11
electric field strength** E

magnitude of a field vector at a point that represents the force (F) on an infinitely small charge (q) divided by the charge

$$E = \frac{F}{q}$$

**3.3.12
electric flux density** D

magnitude of a field vector that is equal to the electric field strength (E) multiplied by the permittivity (ϵ)

$$D = \epsilon E$$

**3.3.13
electronic article surveillance****EAS**

system which detects the presence of transponders, which is often used for anti-theft purposes

**3.3.14
exposure**

exposure occurs whenever and wherever a person is subjected to electric, magnetic or electromagnetic fields or to touch currents other than those originating from physiological processes in the body and other natural phenomena

**3.3.15
exposure level**

value of the quantity under analysis when a person is exposed to electromagnetic fields or touch currents

**3.3.16
exposure requirements**

standard, recommendation, set of guidelines or limits or other document that defines exposure levels for guidance, assessment or compliance purposes

**3.3.17
far-field**

that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free space region), the field has a predominantly plane-wave character, i.e. locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation

**3.3.18
harmonics**

multiples of a principal frequency, invariably exhibiting lower amplitudes

3.3.19

induced current

current induced inside the body as a result of direct exposure to electromagnetic fields

3.3.20

interrogator

module in which all the basic processing of the data protocol takes place and there is an interface to the transponder (for communicating and facilitating data transfer). An interrogator is often also known as a reader.

3.3.21

magnetic flux density

B

magnitude of a field vector that is equal to the magnetic field H multiplied by the permeability (μ) of the medium

$$B = \mu H$$

3.3.22

magnetic field strength

H

magnitude of a field vector in a point that results in a force (F) on a charge (q) moving with velocity (v)

$$F = q(v \times \mu H)$$

[or magnetic flux density divided by permeability of the medium, see “magnetic flux density”]

3.3.23

near-field

region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into two sub-regions. The **reactive near-field region** is closest to the radiating structure and contains most or nearly all of the stored energy. The **radiating near-field region** is where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure

3.3.24

permeability

μ

property of a material which defines the relationship between magnetic flux density B and magnetic field strength H . It is commonly used as the combination of the permeability of free space and the relative permeability for specific dielectric materials

$$\mu = \mu_R \mu_0 = B/H$$

where

μ is the permeability of the medium expressed in henrys per metre (Hm^{-1})

μ_0 is the permeability of a vacuum

μ_R is the relative permeability

3.3.25

permittivity

ϵ

property of a dielectric material (e.g. biological tissue) which defines the relationship between electrical flux density D and electrical field strength E . It is commonly used as the combination

of the permittivity of free space and the relative permittivity (or dielectric constant) for specific dielectric materials

$$\varepsilon = \varepsilon_R \varepsilon_0 = D/E$$

where

ε is the permittivity of the medium expressed in farads per metre (Fm^{-1})

ε_0 is the permittivity of a vacuum

ε_R is the relative permittivity

3.3.26

power density

S

power per unit area normal to the direction of electromagnetic wave propagation. For plane waves the power density (S), electric field strength (E) and magnetic field strength (H) are related by the impedance of free space, i.e. 377Ω

$$S = \frac{E^2}{377} = 377H^2 = EH$$

where E and H are expressed in units of Vm^{-1} and Am^{-1} , respectively, and S in Wm^{-2} .

NOTE Although many survey instruments indicate power density units, the actual quantities measured are E or H , or the square of those quantities. It should be further noted that the value of 377Ω is only valid for free space, far field measurement conditions (and does not apply for inductive devices operating in the reactive near field).

3.3.27

radio frequency identification

RFID

system which reads the data stored in transponders, using electromagnetic fields. Some system/transponder combinations also allow new or updated data to be transferred to the transponders (read/write)

3.3.28

read

decoding, extraction and presentation of data from formatting, control and error management bits sent from a transponder

3.3.29

read/write transponder

transponders that are capable of having their data repeatedly modified are called read/write transponders

3.3.30

reference value

reference level

maximum permissible exposure

action value

value of exposure in a measurable quantity that has been conservatively derived from basic restrictions or basic limits in such a way that compliance with the value ensures that there is also compliance with the basic restrictions it is derived from. Non-compliance with the reference value does not imply non-compliance with the basic restrictions it is derived from, only that additional evaluations or actions are required to show such compliance.

3.3.31

root-mean-square (rms)

effective value or the value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function

$$X = \sqrt{\frac{1}{N} \int_0^N [f(x)]^2 dx}$$

Or in its equivalent form for a series of discrete parts

$$X = \sqrt{\frac{1}{N} \sum_{n=1}^N (X_n)^2}$$

NOTE Although many survey instruments indicate rms, the actual quantity measured is root-sum-square (rss) (equivalent field strength). The value rss is obtained from three individual rms field strength values, measured in three orthogonal directions combined disregarding the phases.

3.3.32

root-sum-square

rss

effective value or the value associated with joule heating, of a periodic electromagnetic wave. The rss value is obtained by taking the square root of the sum of the squared value of a function

$$X = \sqrt{\int_0^N [f(x)]^2 dx}$$

Or in its equivalent form for a series of discrete parts

$$X = \sqrt{\sum_{n=1}^N (X_n)^2}$$

3.3.33

specific absorption rate

SAR

time derivative of the incremental electromagnetic energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ)

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left(\frac{dW}{\rho dV} \right)$$

SAR is expressed in units of watts per kilogram (Wkg^{-1}).

NOTE SAR can be calculated by:

$$SAR = \frac{\sigma E_i^2}{\rho}$$

$$SAR = c_i \left. \frac{dT}{dt} \right|_{\text{at } t^0}$$

where

E_i : rms value of the electric field strength in the tissue in V/m

σ : conductivity of body tissue in S/m

ρ : density of body tissue in kg/m³

c_i : specific heat capacity of body tissue in J kg⁻¹ K⁻¹

$\frac{dT}{dt}$: initial time derivative of temperature in body tissue in K/s

3.3.34

touch current

contact current

electric current passing through a human body or when it touches one or more accessible parts of an installation or of equipment transponder

3.3.35

transponder

transmitter/receiver pair contained within a single package designed to respond to an external interrogating signal. This is often also referred to as a tag, electronic tag, electronic label, electronic bar-code, RFID chip, code plate and various other similar terms

3.3.36

wavelength

wavelength (λ) of an electromagnetic wave is related to the frequency (f) and velocity (v) of the wave by the expression

$$\lambda = \frac{v}{f}$$

where v is the velocity of the wave in ms⁻¹

NOTE In free space the wave velocity is the velocity of light in free space, c .

4 Measurements and calculations for equipment evaluation

4.1 Introduction

This clause provides a three-stage method of exposure evaluation. The stages vary in complexity and the one most suitable for the equipment and the exposure situation should be used.

Evaluations are made either against basic restrictions or against derived reference values. Reference value parameters are directly measurable and so are used for the simplest evaluation method in 4.2. Basic restriction parameters provide a more fundamental evaluation of exposure but are difficult or impossible to measure directly, so calculation, and numerical modelling techniques are required. Evaluations against basic restrictions are provided in 4.4 and 4.5, with increasing levels of sophistication and complexity. In 4.4, the modelling takes account of the non-uniformity of the fields, but not of human tissue. In 4.5, the modelling also takes account of the non-uniformity of the human tissue and its properties.

Subclause 4.6 contains a method to demonstrate compliance for contact and limb currents. This shall be used in all cases.

4.2 Evaluation against reference values

4.2.1 General

This subclause describes the method for determining compliance of a system to field strength reference values.

The measuring instrumentation must be suitable for purpose and must cover the frequency range of emissions from the unit under test. In the event that broadband instruments are used the bandwidth of the instrumentation must cover the range of frequencies emitted. The measuring instrumentation may have a frequency dependent response that correlates with the limits. All measurement equipment used for the purposes of this standard shall be calibrated, with traceable results, via a suitable accredited laboratory. The test site or facility used for product compliance evaluations shall also be suitably calibrated; however this may not be possible for measurements made at equipment installation sites. In the case of an uncalibrated test site or facility, care must be taken to avoid, or take into account, external influences which could affect the results. All such effects and remedies should be noted in the evaluation report, together with any uncertainties, which are created from them.

Instrumentation used to measure exposure levels may be commercially available or specifically designed for purpose. IEC 61786 and IEC 61566 provide information about such measurements and equipment.

In order to fully characterise the exposure conditions it may be necessary to use several instruments, including broadband meters, oscilloscope or spectrum analyser. If more than one instrument is used, some overlap of frequency range of the instrument may not be avoidable however. In this case, unnecessary overevaluation of the levels should be minimized. Spectral information is required to determine compliance with frequency dependent levels. Measurements shall be performed using instrumentation capable of measuring relevant frequency domain and time domain characteristics of the signal. In the case of time domain measurements, it may be necessary to determine the frequency content to compare with the reference values.

It is necessary to consider the frequency range of the emissions and any time varying modulation. In addition, the duration of the exposure should be noted. These must be considered where time averaging of exposure is allowed. It may be necessary to calculate the instantaneous maximum field strength for comparison with limits for pulsed sources. It may also be necessary to sum the field level at each frequency in accordance with the appropriate exposure requirements.

It is important to consider the wavelength of the emissions with respect to the position of the person to determine whether separate electric and magnetic field measurements are necessary. In the near field, for example, it may only be necessary to measure magnetic fields.

The measurements shall be carried out to determine the unperturbed field strengths. For electric field measurements, the presence of the human body can significantly affect the field and the instrumentation should be mounted on a non-conductive support. It may also be appropriate to use a fibre-optic coupled remote read-out unit (or similar means of distancing the body of the operator) for some electric field measurements.

If a power adjustment is available on the unit under test then this should be set to maximum or adjusted according to the manufacturer's setting up instructions. The unit under test should be located at sufficient distance from nearby objects to ensure that the field is not perturbed.

4.2.2 Direct measurement for comparison against reference values

The field strengths shall be measured all around the unit under test at a distance X, as defined in Table 1. A preliminary scan may be performed to determine the positions of maximum electromagnetic field at this distance. The field strength shall be determined either

by a vector sum over three orthogonal measurement axes or by measuring the magnitude from a single measurement aligned to give the maximum value. The electromagnetic field at the maximum field positions shall be recorded.

If the emissions from the unit under test comply with reference values at all positions then the equipment is compliant and no further evaluations are necessary, other than those in 4.5.

4.2.3 Spatial measurements for comparison against reference values

The methods described in this subclause are an option to be used instead of 4.2.1. It allows the use of a measurement grid pattern over the typical exposed volume, to minimise the measurements necessary.

For the types of equipment covered by this document (e.g., see Annex A), the torso is the most appropriate area of the body to be assessed and the grid in Figure 1 shall be used. The position of the grid in relation to the unit under test can vary according to the typical usage of the unit. The layout and dimensions of the grid shall remain identical. In the exceptional cases where the exposure is predominately to the head, then the grid in Figure 2 must be used. This ensures that a more conservative result is obtained.

The measurement methods as described in the previous subclause shall apply and measurements taken over the grid patterns defined in Figures 1 to 11 and Table 1. The actual grid position used, in relation to the unit under test, depends on the typical equipment configuration. Other grid positions than those described can be used provided that the position used is representative of the normal use of the unit.

The measured values at each of the grid points shall be recorded and compared with the appropriate derived reference values. This result shall be recorded.

In some exposure requirements, the reference values are based on spatially averaged values over the entire body of the exposed individual. In such cases the appropriate linear or quadratic average (rms) of the measured values should be calculated and compared with the appropriate derived reference values. This result shall be recorded also.

It is important to note that while spatially averaged results may be applicable for whole body exposure, substantial differences between individual values near to, or above the reference values could indicate that localised basic restrictions might not be met. In such cases more complex methods from other subclauses should be used to confirm that basic restrictions are met.

For frequencies above 300 MHz and when the measurement is substantially in the far field, measurements can be taken of *E*-field as above.

4.2.4 Modelling and analysis including field non-uniformity

The methods described in this subclause are an option to be used instead of 4.2.1 and 4.2.2.

For both near and far field evaluations, it is acceptable to use calculated fields for comparison to reference values. Several suitable commercial packages are available for modelling field patterns. The model should initially be validated by one or more comparative field measurements and the comparison should be within reasonable measurement and modelling uncertainties (see Clause 8).

This subclause also takes account of the non-uniform fields that are normal for the types of equipment covered by this document at these frequencies. The near field extends for some metres away from the unit, so all evaluations are made in the near field.

The fields may be measured using a finer grid than that used in 4.2. The grid size should be commensurate with the spatial variation of the field, thus allowing realistic interpolation between measurement points.

Field modelling is also an acceptable way to determine complex field patterns. Several suitable commercial packages are available for this. The model should initially be validated by one or more comparative field measurements and the comparison should be within reasonable measurement and modelling uncertainties (see Clause 8).

Table 1 – Dimensions and distances for Figures 1 to 11

	Figure ^g	Normative dimensions cm ^e			Informative dimensions cm ^{a,h}		
		a/b/c	X	Z	Height	Width	Depth
General torso grid	1	15	-	85	-	-	-
General head grid ^b	2	10	-	145	-	-	-
Single floor standing unit	3	15	20	85	120-160	-	40-80
Dual floor standing units	4	15	20	85	120-160	70-200	40-80
Single unit in the floor ^f	5	15	-	85	-	60-100	40-80
Single unit in the ceiling	6	15	-	85	210-300	60-100	40-80
Dual floor/ceiling units ^f	7	15	-	85	210-300	60-100	40-80
“Walk- through” unit ^f	8	15	20	85	210-300	70-300	0,5-50
Counter mounted unit ^c	9	15	30	85	70-90	20-40	20-40
Wall mounted unit	10	15	20	-	60-160	20-100	20-50
Hand-held unit ^d	11	15	10	-	70-140	Area: 100-200 cm ²	
^a These dimensions represent the range over which the majority of equipment falls. Some may fall outside the range.							
^b The total sum of the size of the head grid and Z dimension is 175 cm, which corresponds with the height used for a standard person.							
^c The X distance represents a typical distance when mounted in a counter top. If operated at closer distances, occupational levels are most likely to apply.							
^d If the hand-held device is to be used to scan the human body, then an appropriate X distance should be used. For close scanning devices an X distance of no more than 3 cm is appropriate.							
^e In the case of equipment not falling into the above categories, it is permissible to use the nearest appropriate category or use a new configuration using similar principles to those above.							
^f Some units are buried a minimum distance below the top surface of the floor. This distance can be added to the Z dimension, provided the requirement is clearly stated in the installation documentation.							
^g The grid positions and dimensions reflect the position of the centre of the probe. The grey circle shows an example of the probe position with respect to the grid.							
^h Some units are circular or oval but approximate dimensions would reflect the rectangular sizes given.							

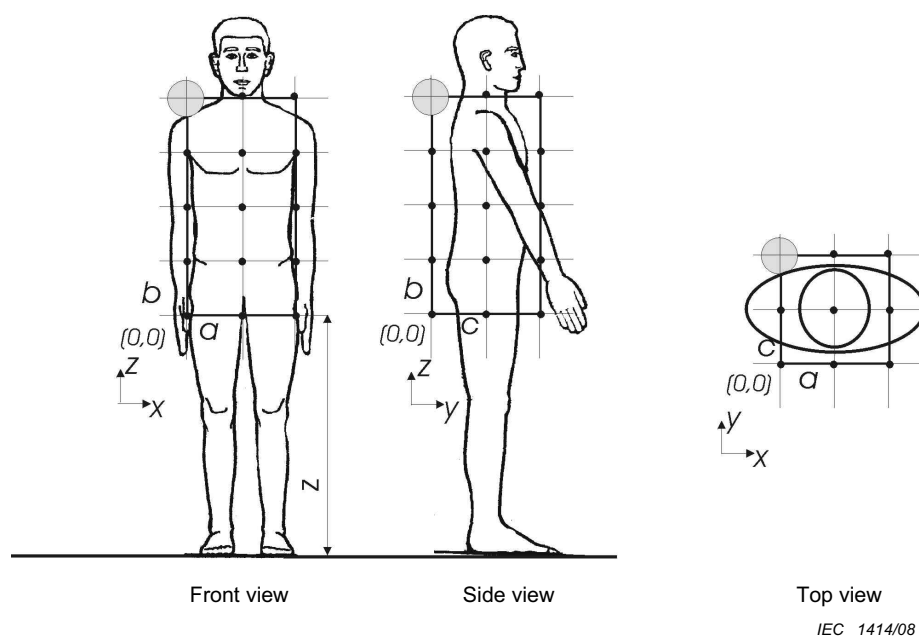


Figure 1 – General torso grid

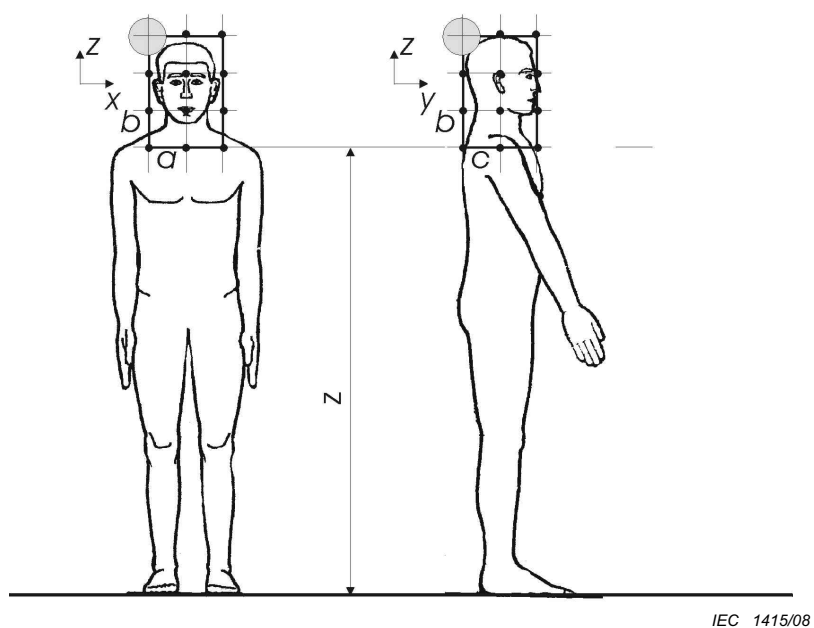


Figure 2 – General head grid

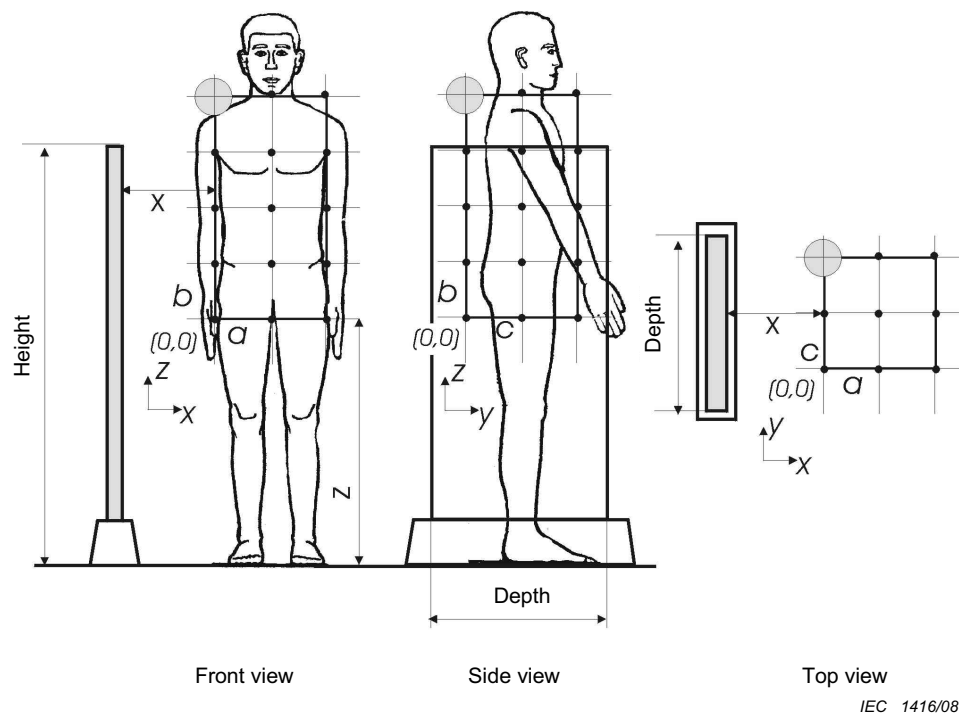


Figure 3 – Single floor standing antenna

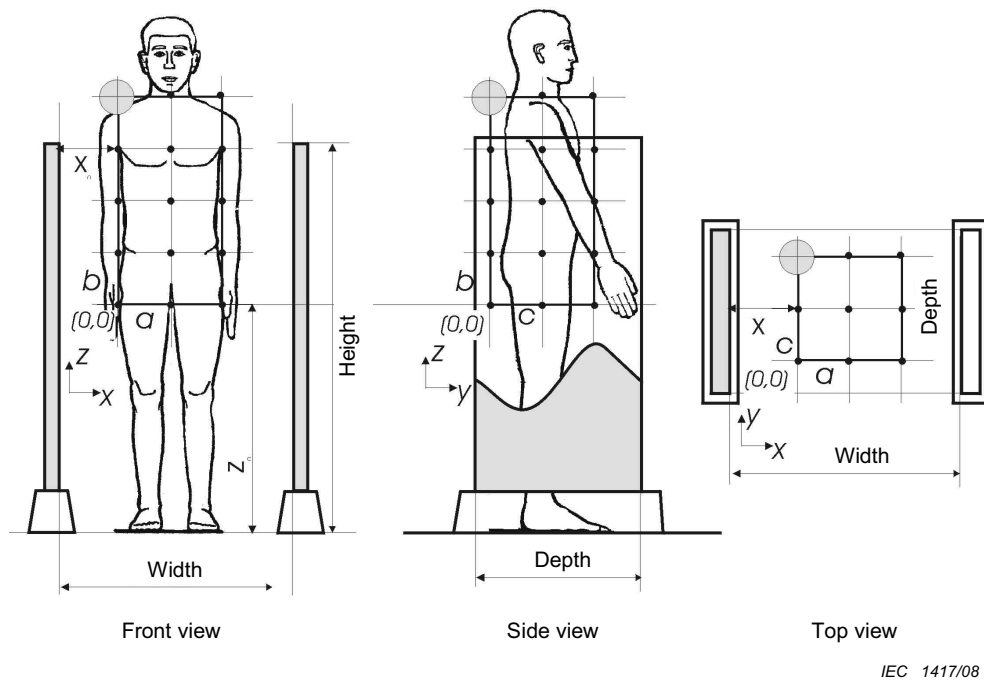


Figure 4 – Dual floor standing antenna

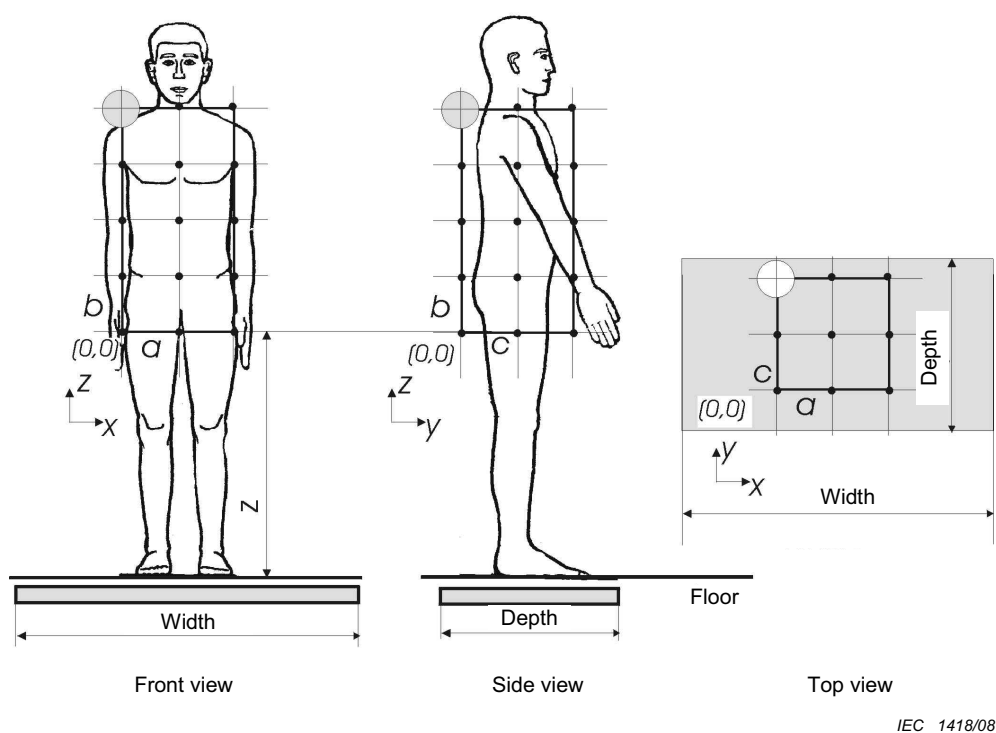


Figure 5 – Single floor antenna

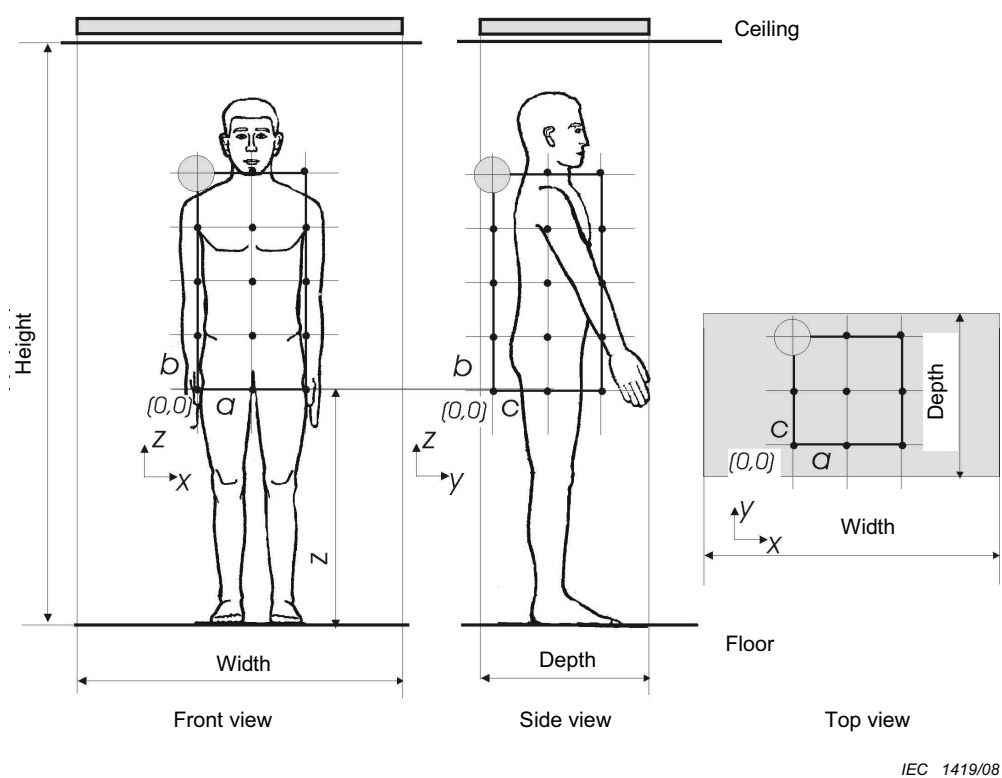


Figure 6 – Single ceiling antenna

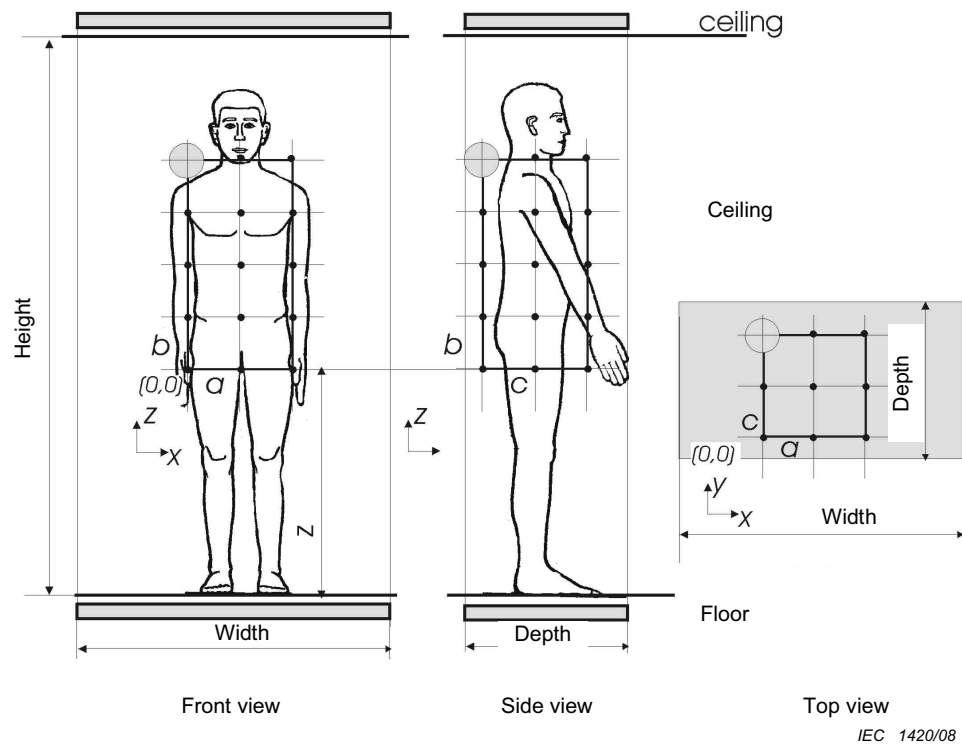


Figure 7 – Combined floor and ceiling antennas

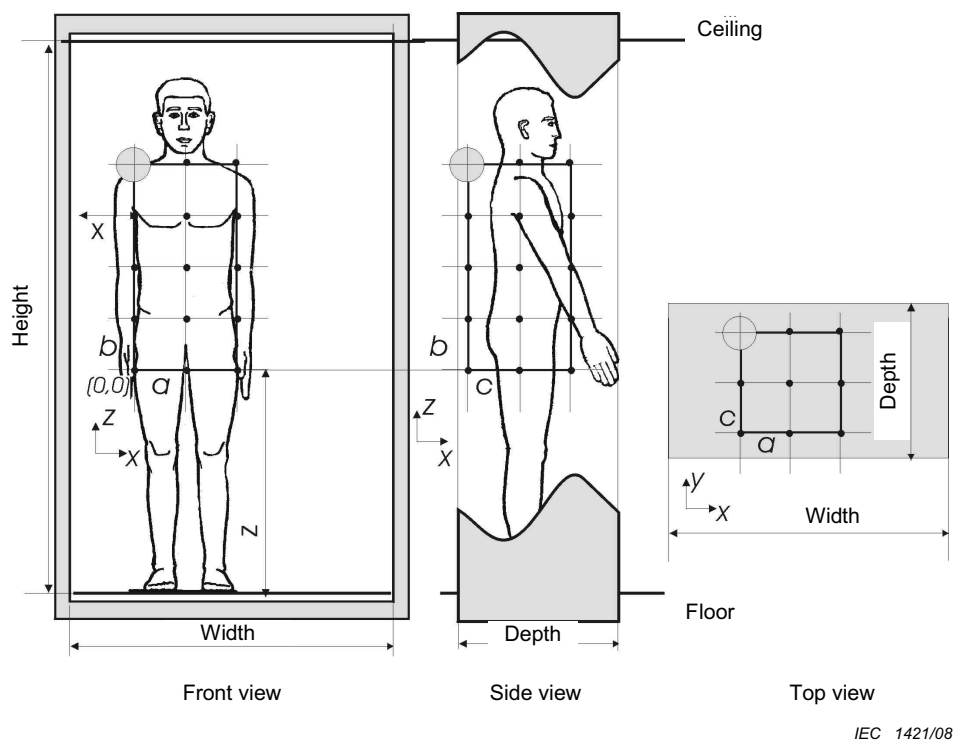


Figure 8 – “Walk-through” loop antenna

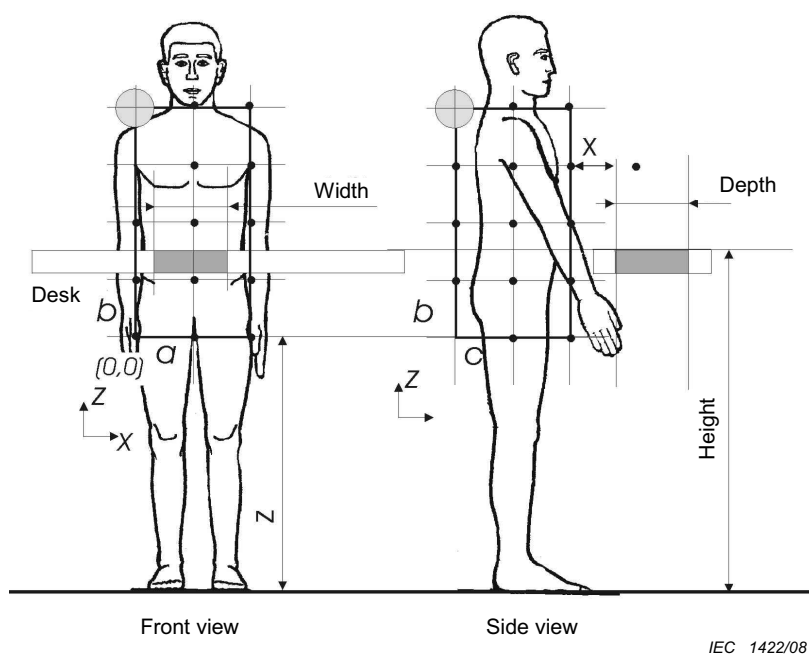


Figure 9 – Counter or desk mounted antenna

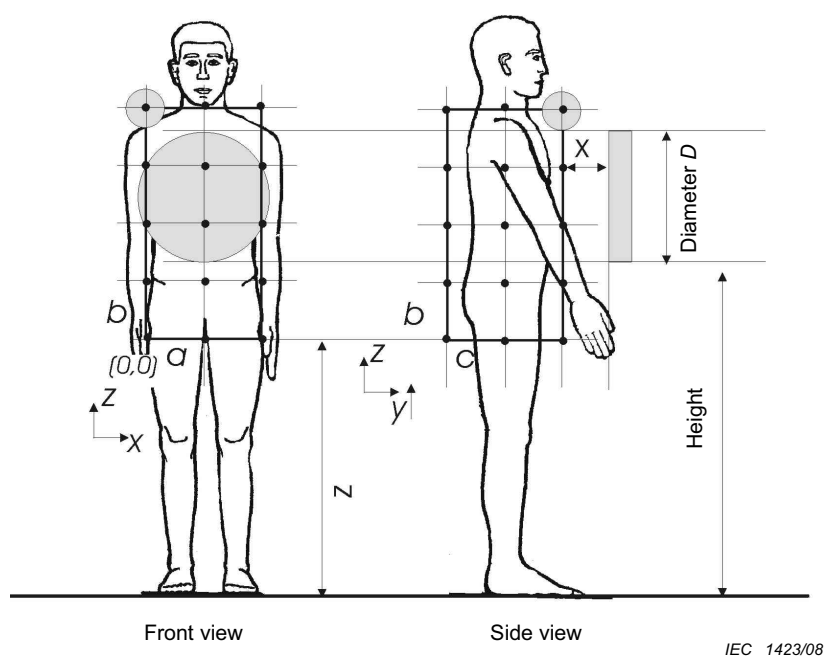


Figure 10 – Vertical, wall or frame mounted antenna

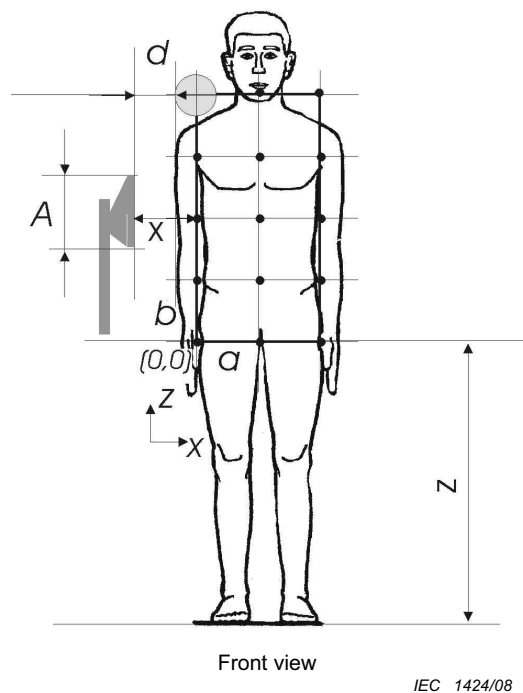


Figure 11 – Hand-held antenna

4.3 Specific absorption rate (SAR) measurements

4.3.1 General

There are three main methods to directly measure SAR in human body phantoms:

- internal electric field strength measurements for evaluation of localised SAR;
- internal temperature measurement for evaluation of localized SAR;
- calorimetric measurement of heat transfer for evaluation of whole-body-averaged SAR.

IEC 62209-1 and IEC 62209-2 contain considerable information on SAR measurement procedures. The detailed procedures from those standards may be used as the basis for evaluation of the devices, provided the method used is documented and provides results with a known uncertainty (see Clause 8), or which inherently overestimate the exposure.

The following subclauses provide some general information and some specific information relevant for SAR evaluation of devices covered by this standard, to assist when using IEC 62209

4.3.2 Internal electric field strength measurements

Evaluation of SAR via *E*-field measurement is performed using a miniature probe that is automatically positioned in a liquid-filled phantom model of the human body or a part of it (for example: the head), which is exposed to an electromagnetic field. From the measured *E*-field values, the SAR distribution and the maximum mass averaged SAR value can be calculated according to

$$SAR = \frac{\sigma}{\rho} E_i^2 \quad (1)$$

The *E*-field probe should have an isotropic response (within ± 1 dB). Because of the short wavelength in tissue and since the field may have large spatial gradients, the probe size should be as small as possible (for example: dipole length 2 mm to 4 mm). The probe should affect the field as little as possible. Care has to be taken to avoid significant influence on SAR measurements by any reflection from the environment (such as floor, positioner, etc) or from unknown sources.

NOTE To obtain 3-dimensional SAR distributions in exposed human phantoms by the *E*-field-probe technique, it is preferable to use an automatic probe positioning system, for example an industrial robot.

The measurement equipment shall be calibrated as a complete system. Sensitivity, linearity and isotropy of the probe system shall be determined in the tissue equivalent liquid. Measurements in close vicinity to media interfaces result in errors due to boundary effects. These effects depend on the probe size and can be quantified as a function of distance from the surface using a waveguide calibration set-up. Having been quantified, these effects can be compensated for in order to minimize errors.

4.3.3 Internal temperature measurements

Evaluation of SAR via temperature measurement is performed using a temperature probe that is positioned in a liquid-filled phantom model of the human body or a part of it (for example: the head), which is exposed to an electromagnetic field. From the measured temperature increase, the local SAR distribution can be calculated using the formula

$$SAR = c_i \frac{\Delta T}{\Delta t} \quad (2)$$

where ΔT is the temperature rise during the small time interval Δt and c_i is the specific heat capacity of the body tissue in $\text{J kg}^{-1} \text{K}^{-1}$. The temperature-rise measurement has to start at a thermal balance. This equation is applicable under the condition that the heat diffusion effect can be disregarded. If the diffusion effect cannot be disregarded, an integral equation including the heat-diffusion factor has to be employed.

Common types of available equipment for temperature measurements in exposed body models use probes consisting of a high-resistance thermistor or optical probes. Temperature probes have very small tips; this allows high spatial resolution. The temperature resolution of these probes is typically 0,005 K to 0,1 K, which limits the sensitivity of SAR to about 0,03 W/kg. In order that the probe does not perturb the electromagnetic field, it is constructed using high-resistance thermistors connected to high-resistance leads or by using fibre optics.

NOTE To determine the three-dimensional SAR distribution or local peak SAR in a phantom model, the temperature probe has to be moved inside the phantom using a similar positioning system as for *E*-field probes.

Temperature rise in a phantom model (or even at the surface of a real human being) can also be assessed by infrared imaging devices. Hence, a thermographic camera may be used to determine the 2-dimensional temperature-rise and SAR distribution in solid phantom cross-sections or at surfaces. First the phantom has to reach uniform temperature. Directly after the exposure of a few seconds the phantom is placed in front of the thermographic camera and a thermographic image is immediately taken to map the temperature-rise profile. Temperature profiles inside the phantom may be taken by separating the phantom at specially prepared cuts.

The sensitivity of temperature sensors is relatively low in comparison to *E*-field probes. In order to achieve a reasonable sensitivity in SAR evaluation via temperature measurement, in general, high-power exposure sources have to be applied to get a sufficient temperature increase in a short time interval. Some devices have to be fed in the test with an additional (external) source.

Calibration of temperature-measurement equipment includes, beside the general probe calibration, a careful evaluation of heat diffusion processes.

4.3.4 Calorimetric measurements of heat transfer

Calorimeters allow the measurement of the whole-body averaged or partial-body averaged SAR for human body models exposed to electromagnetic fields. Averaged SAR is derived according to the equation below by measuring the total energy absorbed in a body, ΔW , with mass, m , during an exposure time Δt :

$$SAR = \frac{\Delta W}{m \Delta t} \quad (3)$$

Starting at thermal equilibrium with the environment, the exposure time is typically about several minutes. Heat diffusion inside the phantom is no problem to the resulting averaged value. However, thermal radiation and convection losses have to be avoided by controlling the environmental conditions and restricting the exposure time.

For whole-body averaged SAR measurements, human-size calorimeters are used, while small calorimeters may be used for measurements of partial-body averaged SAR or for measurements in scaled-down whole-body phantoms. After exposure the phantom is quickly put into the calorimeter container where it is allowed to reach thermal equilibrium in a known mass of water over a period of typically up to several hours. The calorimetric twin-well technique uses two calorimeters and two identical body models. This means that the measurement can be performed under less-well-controlled thermal conditions than a normal calorimetric measurement. Calorimeters can give very accurate averaged SAR values, but do not give any information on the three-dimensional SAR distribution within the body.

4.3.5 Phantom models and fluid

The size of the phantom model needs to be large enough to allow evaluation of the SAR effect from the device. The maximum size of phantom is a real human sized model, for a whole body or the part of the body for which the evaluation is being made.

The fluid used in the evaluation should have characteristics representative of the body for the frequency of operation of the device being evaluated. Such fluids are normally created for the purpose. Differences from the expected body characteristics should be noted and included in the uncertainty evaluation.

4.4 Numerical evaluations for comparison against basic restrictions

4.4.1 General

In cases where measured values exceed derived reference values, compliance may be demonstrated by comparison against basic restrictions. This can be achieved by simple analytical or numerical modelling as outlined in the following subclauses. It is not necessary to assess the exposure using all of the subclauses in 4.4

4.4.2 Evaluations using homogeneous models

In order to model dosimetric quantities for comparison against basic restrictions, a simplified body shape of uniform conductivity is used. Suitable body models are disks, cubes, prolate spheroids or simplified homogeneous human body shapes (Figures 12, 13 and 14). For further details of the shapes see Annex B. The dimensions should be as in Table 2, unless specified in the exposure requirements being used for the limits.

It is possible that for the normal method of use of a piece of equipment, those dimensions are not appropriate. In that case, other dimensions may be used provided they are justifiable. The field values used with the model can be either the measured ones or modelled (as above). The tissue conductivity used should be as described in Annex B, Table B.6.

For modelling with non-uniform fields, a computational software package is likely to be required which is capable of some form of physical modelling, using finite difference, finite element or boundary element methods. Again suitable software models are commercially available; often these enable both the fields and the induced current to be modelled in the same package. Such commercially available software should be suitable for checking compliance with basic restrictions. The package, and its method of use, can be tested by comparison against an analytical solution in a simple case, such as a disk of uniform conductivity, or a layered cylinder or sphere with uniform conductivity for each of the layers, in a uniform magnetic field. After averaging over relevant cells of the model, the numerically calculated current density should agree with the analytically-derived value to within 20 %: this serves as a validation check on the software being used for the computations.

It is usually only necessary to validate the model once. It is not necessary to revalidate the model every time it is used. Such validation could be provided by the software supplier.

In certain very simple cases, such as circularly symmetrical fields, numerical integration of an analytical expression may be possible using less complex and lower cost software packages.

The results of the modelling may be specified as induced current density, in-situ electric field or SAR, defined over the appropriate averaging size, for localised or whole body evaluation. The maximum value over the modelled space (averaged according to the exposure requirements being used) should be compared with the appropriate basic restriction.

If the relevant basic restrictions are exceeded using this comparison, it may be possible to demonstrate compliance by taking account of tissue non-uniformity and shape, using computational dosimetry, as outlined in 4.5.

Table 2 – Dimensions and distances for simplified body shapes

	Body/Torso (cm)			Head (cm)		
	h	w	d	h	w	d
Disk	60	4	-	30	4	-
Cube	60	30	30	30	20	20
Spheroid	60	30	-	30	20	-
Human	See Annex B.					
The distances for X and Z should correspond with those specified in Table 1.						

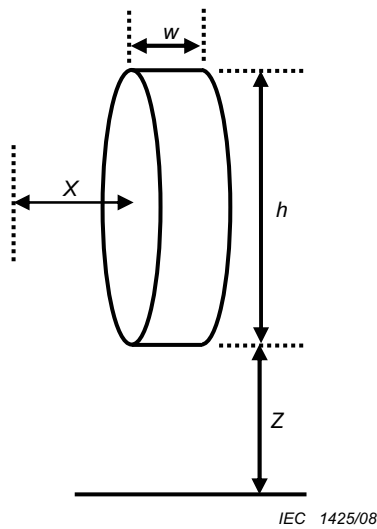


Figure 12 – Disk model

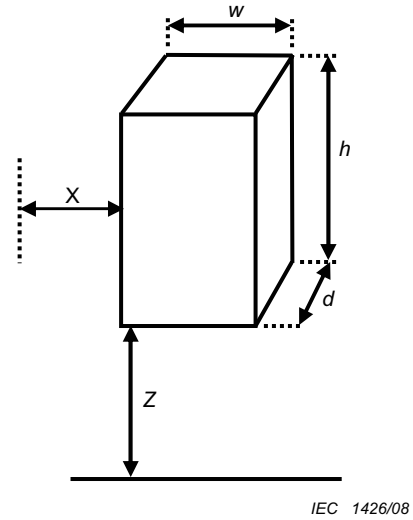


Figure 13 – Cubic model

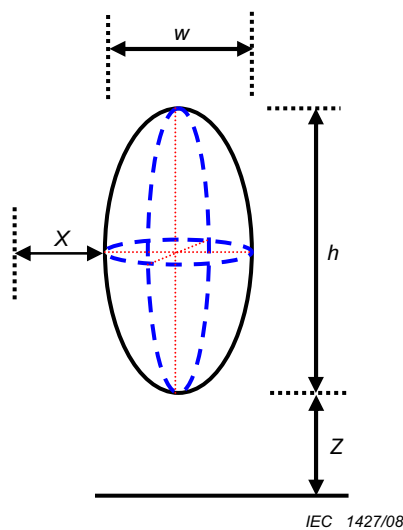


Figure 14 – Spheroid model

4.4.3 Special case of inductive near-field exposure 100 kHz to 50 MHz

This is a special case for near-field exposure (even under the assumption of uniform field) for sources at 100 kHz to 50 MHz.

At frequencies below 100 kHz, induced current density or in-situ magnetic field are the dosimetric quantities. Some exposure guidelines extend these low frequency dosimetric quantities up to 10 MHz. At frequencies above 100 kHz, the dosimetric quantity is SAR, and the magnetic field is generally considered in its interaction with the body as if it were a component of a plane electromagnetic wave. When non-uniform exposure occurs in the inductive near field of a source above 100 kHz, this approach may overestimate SAR, since the electric field component is much smaller than assumed for a plane propagating electromagnetic wave.

It is more appropriate in circumstances of inductive near-field exposure to assess compliance with the basic restriction using a dosimetric model based on the interaction of just the magnetic field with the human body. The model for dosimetric quantities used below 100 kHz can be extended to frequencies up to 50 MHz. At 50 MHz, the near field extends out to about 1 m, and within this distance, the magnetic field is the predominant field component.

SAR can still be used as a dosimetric quantity, so that conformance is tested against basic restrictions in *SAR* as well as induced current density. Even at frequencies where there is no basic restriction on induced current density, the induced current density can still be used to calculate the localised *SAR* from the relationship

$$SAR = \frac{|J|^2}{\sigma\rho} = \frac{\sigma|E|^2}{\rho} \quad (4)$$

where *J* is the rms value of the induced current density, *E* is the rms value of the in-situ electric field, σ is the electric conductivity and ρ is the density of body tissue (see B.2.3).

The relationship between *SAR* and *H*-field can be calculated using a simple uniform-field-in-a-ring model linking *J* and *H* (see Annex B.2.1). It is an extension of the reference values upward in frequency for the special case of near-field magnetic exposure.

Because there is a basic restriction, in some standards or guidelines, on the induced current density, *J*, at frequencies up to 10 MHz, it is important that when *SAR* time-averaging is applied, the instantaneous field is not sufficient to cause *J* to exceed the relevant basic restriction on current density.

4.4.4 Frequencies > 50 MHz

In the near field, there is no simplistic modelling technique currently available. For far fields, commercially available modelling software can be used to determine fields, which may be compared against reference values.

If the reference values are exceeded in the far-field, then analytical techniques may be employed to calculate localised *SAR*. If the reference values are exceeded in the near-field, then compliance with basic restrictions should be assessed directly. There may be simple analytical approaches to this, but it is likely that the presence of a person or a part of the body (i.e. head) will affect the radiation characteristics of the antenna. It is usual in this situation to use numerical modelling in which the antenna and body are treated as part of a coupled system.

4.4.5 Localised *SAR* (100 kHz to 10 GHz)

Some exposure requirements specify localised values of maximum *SAR*. For example, many exposure requirements define localised *SAR* averaged over 10 g or 1 g of contiguous tissue, either as a cube or with its shape undefined. Calculations can be made of the effective power into localised tissue volumes. The simplest form of this is to assume that all the transmitted power goes into the averaging mass of tissue.

$$P_{\text{Max}} = SAR_{\text{Max}} \times M_{\text{Tissue}} \quad (5)$$

where

SAR_{Max} is the basic restriction or limit for localised exposure

M_{Tissue} is the mass of contiguous tissue, used for the averaging

P_{Max} is the maximum power delivered to the antenna, assuming all power is absorbed by the mass of contiguous tissue, independent of its shape.

As an example, for an SAR_{Max} of 2 W/kg (0,002 W/g), averaged over 0,01 kg (10 g) of tissue: any device that supplies less than 20 mW ($= 2 \times 0,01$ W or $0,002 \times 10$ W) from its antenna port, will not exceed the 2 W/kg SAR level.

Modelling the maximum proportion of the power that is absorbed by the tissue can extend this, but care must be taken to include any refractions or reflections in the environment. As in previous subclauses, the proportioning model should be validated by comparative measurement.

4.5 Evaluations using non-homogeneous models for comparison against basic restrictions

4.5.1 General

It is acceptable to show compliance using computational dosimetry. Such evaluation involves the use of sophisticated millimetre resolution body models (with voxel² resolutions of the order of 2 mm to 6 mm). These models are often derived from MRI data or from photographs of the anatomical sectional diagrams, and include accurate tissue conductivities, including those for the heart or Central Nervous System (CNS) tissues, such as the brain and the spinal cord. This subclause does not specify any one individual method, model or technique, as several are equally applicable and accurate. Research is continuing in this area and new methods and information will become available. These can be used, provided the criteria set out in this subclause are met.

Induced currents, in-situ electric fields and SAR and power density distributions are calculated at the resolution of the model used. Because the models that are used are anatomically based, it is possible to obtain results specifically for particular tissue types, for example in the CNS tissues (the brain and/or the spinal cord), or other types as appropriate for the type of exposure under consideration and the exposure requirements being used.

If such modelling techniques are used, appropriate validation is required. This can be provided by peer review, appropriate published reference citations or comparison against other reviewed or referenced models.

4.5.2 Anatomical body models

The International Commission for Radiological Protection has defined a "standard man" [7] as 1,76 m tall. Based around this, models that fulfil the following criteria are suitable for use:

- height (from top of head to base of heel): $1,76 \text{ m} \pm 8 \%$;
- representative human shape;
- representative of the inhomogeneous structure of the human body;
- realistic dielectric properties of tissues;
- data resolution better than or equal to 10 mm steps.

There are a number of anatomical body models in use. These are based on medical imaging data or anatomical cross sectional diagrams/pictures and are representative of a human man. The actual data sets may be scaled to fit the above criteria. For localised exposure situations it is also acceptable to model using just the part or parts of the body specifically affected.

Example body models are described in Annex B and in many of the references contained in the bibliography. Many of them are specific to the institution or author concerned, but are still suitable for use if the above criteria are met. A more publicly available example is the Visible Human Project from the National Library of Medicine, Bethesda, MD, USA. There are commercially available data sets based on the Visible Human information.

²) A voxel is a volume unit corresponding to the smallest element of a tridimensional space to which individual characteristics such as colour or intensity can be attributed.

Another important part of the modelling process is the characterisation of the electrical properties of the various tissue types. Each of the tissue types in the body model must have the electrical/dielectric properties associated with it, included in the overall model. The electrical properties are often frequency dependent, so this must also be taken into account. More details are available in Annex B.

When there are several tissue types within the same voxel, it is normal practice to use an average of the tissue properties for modelling purposes. It is also acceptable to use the worst-case tissue type (the one providing the highest value of induced current densities, in-situ electric fields or SAR distributions as appropriate for that voxel) or the tissue type of concern, instead of calculating an average. If a voxel or averaging area contains the required tissue type, it is acceptable to assume that it contains only that tissue type for the purposes of the model.

4.5.3 Calculation/modelling method

Over the years, several computational methods have been proposed for calculations of induced current densities, in-situ electric fields and SAR distributions in heterogeneous anatomically based models of the human body. These are the finite element method (FEM), finite integration technique (FIT), impedance method, the scaled frequency finite-difference time-domain (FDTD) method, and the scalar potential finite difference (SPFD) method. Additional details of these are provided in Annex B.

All the methods can be used for uniform field exposure conditions. Quasi-static methods (where it is assumed that the phase of the incident field is constant across the body being modelled) are suitable at lower frequencies, where the body dimensions are small in comparison with the wavelength (up to about 30 MHz). Methods based on the solutions of Maxwell's equations (e.g. the FDTD method) are preferred at higher frequencies.

Specific care must be taken when modelling the non-uniform vector magnetic fields characteristic of dominant magnetic field lower frequency EAS/RFID devices, that the methods adequately cover the non-uniformity of the fields.

Typical resolutions are on the order of 6 mm to 10 mm for a coarse representation of the whole body model and 2 mm to 4 mm for finer modelling of the specific regions involving the specific tissue types required. It is also then possible to use these results to calculate an average value at a lower resolution, if necessary. For example, some exposure requirements have specified averages over 1 cm². Unless specifically defined in the exposure requirements being used, the averaging area should not extend outside the outer boundary of the body being evaluated, when the average is calculated.

4.5.4 Position of the body in relation to the unit under evaluation

The position of the body in relation to the unit under evaluation should reflect the principles defined in 4.2.3. Because there are differences in the body models available, an exact location match may not be possible, however dimensions provided in Table 1 should be respected to within $\pm 10\%$. It is possible to use positions other than this but the use of these must be representative of actual use of the unit and this must be clearly stated in the evaluation report.

4.6 Measurement of limb and touch currents

Both limb currents and touch currents can be measured by using a clamp on current transformer on an arm or leg. For currents passing through the legs, stand-on current meters may also be used in lieu of a clamp-on current transformer.

As an alternative to measurement, it is possible to directly model some of the currents using the techniques given in 4.4 and 4.5.

5 Measurements for field monitoring

5.1 General

This clause provides methods to evaluate the emitted field on installed equipment. When performing this type of evaluation it is necessary to take account of the following points.

- The equipment being assessed can produce fields in excess of the reference values from the relevant exposure requirements, provided it meets the basic restrictions. It is usually not possible to measure the basic restrictions directly.
- There are significant effects due to background noise and other sources in the environment.
- There may be several pieces of equipment (not all of which would be covered by this standard) contributing to the overall measured value. This could cause the overall exposure to be above levels in the appropriate exposure requirements, while the exposure due to the equipment covered by this standard is below those levels.

5.2 Field measurements

5.2.1 Measurement where persons spend significant periods of time

This subclause should be used where the exposure requirements are specified for areas where the general public spends significant periods of time. The exposure from equipment covered by this standard is of a transitory nature and so the general public would normally only be exposed for short periods. This subclause is for exposure evaluation when not directly using the system. If this is not specified, 5.2.2 should be used.

The level shall be evaluated using the method in 4.2.1, but at a distance of 2 m around the equipment (see also A.2.4). If the position of the equipment is such that the distance to the normal position where people spend significant periods of time is different from 2 m, this distance shall be used and noted with the results. Separate measurements, at a different distance, may be needed if workers are exposed at a different distance than the general public. If the measured value is in excess of the reference values used for comparison, additional evaluation may be necessary. Many exposure guidelines and standards have different reference values for workers than those for the general public so the appropriate comparison values should be used for worker or general public exposure evaluations.

5.2.2 Detailed measurements for non-transitory exposure

The level shall be measured using the method and distance as defined in 4.2, as appropriate for the equipment and exposure guidelines being used. If the measured value is in excess of the reference values used for comparison, additional evaluation may be necessary.

5.3 Additional evaluation

Should the reference values be exceeded, it may not be due to any one piece of equipment but may be due to the overall combination of sources at that location. Alternatively, it may be due to one piece of equipment, which is still compliant with the basic restrictions. In these cases additional evaluation can be made for all equipment contributing to the exposure, as detailed below:

- adjusting the position of some pieces of equipment, where possible, to minimise the overall exposure;
- tests repeated on individual pieces of equipment (or similar equipment) in a controlled test environment;
- comparison of equipment settings (currents, voltages etc.) with information provided in the user guide or installation guide for the equipment;
- comparison of the equipment against the Technical Documentation, including any evaluation results covered by this standard;

- evaluation of equipment according to 4.3, 4.4 or 4.5, for comparison against the appropriate basic restrictions.

Because of the technical detail required in the evaluation, the manufacturer or original equipment supplier would have to be consulted whilst performing the evaluation. The total exposure shall comply with the basic restrictions.

6 Exposure from sources with multiple frequencies or complex waveforms

The operating nature of devices covered by this document is such that they operate on one or more discrete frequencies with other frequencies suppressed by more than 30 dB. Where this is the case, the exposure evaluation can be made at the declared operating frequency or frequencies without requiring all other frequencies to be assessed. If this is not the case, then an exposure evaluation must be made at all frequencies to which this does not apply.

Devices that operate at multiple frequencies may not use all the frequencies simultaneously. The effects of non-simultaneous operation are not additive so separate evaluation can be made for each frequency or frequencies not used simultaneously. If time averaging is being used then all frequencies transmitted during the averaging period should be considered.

In situations where simultaneous exposure to fields of different frequencies does occur, the possibility that these exposures will be additive in their effects must be considered. It may also not be possible to effectively assess devices emitting a complex, non-sinusoidal, waveform. If that is the case, the waveform may be considered as a Fourier type series of related frequencies which are additive in effect.

The biological and health effects are different at low frequencies from those at higher frequencies. At lower frequencies the biological effects are due to electrical stimulation and at higher frequencies they are based on thermal considerations. Calculations based on such additivity should be performed separately for each effect; thus, separate evaluations should be made for thermal and electrical stimulation effects on the body. Different exposure requirements have slightly different calculation methods for adding multiple fields. The methods described in them should be used when assessing compliance against them.

Various exposure requirements adopt different, specific approaches to short duration pulses. Such approaches include calculation of an effective frequency using Fourier techniques, or a weighted peak approach [8]. For waveforms consisting of a sinusoidal carrier frequency contained within an envelope of short duration bursts (provided at least 5 carrier cycles are included), the evaluation can be made by comparing the maximum peak amplitude against the peak value of the limit obtained from the appropriate guidelines. This is in addition to showing compliance of the rms amplitude of the waveform with the rms limit from the appropriate guidelines. The technique appropriate to the exposure requirements being used for compliance evaluation should be used.

7 Exposure from multiple sources

To determine the total exposure from multiple sources, the summation formulae for simultaneous exposure to multiple frequencies applicable to the exposure requirements under consideration should be used.

Some exposure requirements use induced current or in-situ electric fields as a basic restriction up to 100 kHz (or 10 MHz) and SAR from 100 kHz. In such cases, the exposure from 0 kHz to 100 kHz (or 0 MHz to 10 MHz) and from 100 kHz to 300 GHz should be assessed independently. Any values at frequencies that overlap the two ranges should be included in both exposure evaluations.

If there is a time relationship between the exposures from different sources, this can be taken into account. For example several sources may be synchronised so they cannot emit

simultaneously such as with a “listen before talk” spectrum management system, where only one would transmit at any time. For exposures using time averaging, all sources should be considered which are emitting during the averaging time.

When combining the exposure from multiple sources it is necessary to also take account of the spatial relationship of the sources to the exposure position. Most equipment is assessed at a set distance but the exposure position may be further away in the case of multiple sources. The exposure from a source reduces as the distance from the source increases, in many cases quite dramatically (inverse second or third order relationship).

The simultaneous exposure formulae in currently published exposure guidelines do not include a means of specifically combining basic restriction proportions with those from reference values. It can be difficult to directly add the exposure due to more than one source if some of the sources are assessed against basic restrictions and some are assessed against reference values.

Annex C (informative) contains a method which may be used to combine the exposure from multiple sources when some of the sources are assessed against basic restrictions and others against reference values. The method is simplistic and conservative and so cannot be used to show non-compliance.

8 Uncertainty

8.1 General

Uncertainty is a statistical evaluation of the quality of the results of the evaluation being performed. The actual value of the item under evaluation may be above or below the assessed value by any amount up to the determined uncertainty (to a confidence level of 95 %). In itself uncertainty is not an error value that must be added or subtracted, however some guidelines or standards may require it to be included in the overall evaluation of a product or exposure situation. Annex D provides information on possible ways to include uncertainty, if required.

Different regions, countries and even agencies treat the inclusion of uncertainty in different ways. Also different methods and assessors will have different uncertainties.

This clause provides a guide to the uncertainty of the different methods of evaluation. It also provides an overall level of uncertainty which can be considered reasonable when assessing equipment. In all cases, the evaluation shall be made based on a representative sample of the equipment. Production variations are not included in the evaluation.

8.2 Evaluating uncertainties

The uncertainties in the evaluation method should be evaluated according to the methods described in the ISO *Guide to the expression of uncertainty in measurement* [9]. A good overall interpretation of this, in a context of somewhat similar electromagnetic compatibility measurements, is provided by LAB 34 [10], and the basic principles therein can be used for both measurement and numerical modelling uncertainties. A similar document for mobile radio equipment is ETSI TR 100 028-1 [11] and any small differences obtained by using the two documents is not considered significant. CISPR 16-4-2 [12] also provides information on uncertainties and handling them.

8.2.1 Individual uncertainties

The individual uncertainties shall be evaluated and stated as equivalent standard deviations to the result. A judgment must be made on how individual uncertainty values would affect the final result (not all of these would be directly proportional) and the effective uncertainty caused to the result should be used wherever possible.

8.2.2 Combining uncertainties

Calculating the accumulated standard deviation is achieved by combining the standard deviations of the individual contributors to the overall uncertainty. The calculation of the accumulated uncertainty is achieved by combining the individual, uncorrelated, standard deviations by the root-sum-of-the-squares (RSS) method.

The uncertainty shall be evaluated based on the accumulated standard deviation expanded by a factor of 1,96, to obtain a 95 % confidence level.

8.3 Examples of typical uncertainty components

The following typical uncertainty components are only examples. There may be other components, which are not listed, and some of the listed examples may not be present or may not be significant in the overall evaluation.

8.3.1 Measurement

- Size and shape of the measurement probe (including the relative coil positions)
- The actual position of the probe in relation to the planned measurement point
- Calibration or stated accuracy of the measurement instrument
- Interaction between the equipment under evaluation and the measurement system
- Repeatability
- Effect of the environment during the measurement

8.3.2 Numerical calculation

- Variation in the anatomical model size and weight from the standard man
- Uncertainty in the values of tissue electrical properties
- Voxel size and shape
- Calculation method uncertainties
- Accuracy of the modelled parameters of the equipment being assessed

8.4 Overall uncertainties

The overall maximum uncertainties as given in Table 3 are reasonable.

Table 3 – Maximum total evaluation uncertainties

Frequency	Measurement	Numerical modelling
< 10 kHz	+58 %, -37 % (+/- 4 dB)	+/- 50 %
10 kHz to 1 MHz	+41 %, -30 % (+/- 3 dB)	+/- 50 %
1 MHz to 30 MHz	+41 %, -30 % (+/- 3 dB)	+/- 40 %
30 MHz to 1 GHz	+100 %, -50 % (+/- 6 dB)	+/- 40 %
1 GHz to 30 GHz	+100 %, -50 % (+/- 6 dB)	+/- 50 %

9 Evaluation report

The evaluation report shall contain or have appended to it, the following minimum information:

- trade name or product reference of the unit under evaluation;
- contact details for the submitting organisation or person;
- contact details for the evaluating expert and/or organisation;

- identification of the subclauses of this standard used;
- description of the unit under evaluation, including emission type, power adjustment, output levels and any modulation effects;
- description of the spatial positioning of the unit under evaluation and the exposure position(s), including evaluation points;
- detailed description of the method used (including, where appropriate, published references and clauses from other international standards used);
- uncertainty;
- summary and explanation of the results.

In the case of evaluations made by measurement the following shall also be included

- power adjustment on the unit under evaluation (if applicable);
- details of the measurement equipment, instrumentation and any special fixtures and ancillary equipment used;
- description of the measurement environment, ambient temperature, humidity, and any background levels which could affect the results;
- diagram of the measurement points;
- measured levels and frequencies at each measurement point.

In the case of evaluations done by numerical modelling, the following shall also be included:

- explanation of the model representing the shape and emission of the unit under evaluation and, if appropriate, the results of any validation;
- summary of the body model and tissue parameters used (including published references or data sources where appropriate);
- summary of the body model position and the position of the specific tissues under consideration, in relation to the unit under evaluation;
- explanation of the modelling/calculation method used (including published references where appropriate).

Annex A (informative)

Characteristics of equipment

A.1 Introduction

EAS and RFID systems are intended for only brief, transitory use by members of the public. If a person lingers within the system then they will usually block a passageway, so they will be moved on by other users or by security guards. Normal walking pace through a system is approximately 1 ms^{-1} (about $3,6 \text{ km h}^{-1}$), and the detection zone is at most 1 m long (along the path through the system). Exposure duration is thus normally approximately 1 s.

If a customer or user is slow or hesitant in passing through the system, then exposure duration could extend to approximately 10 s. In exceptional circumstances a customer or user may become caught in a queue inside a system. In such cases, exposure duration could be no more than a few minutes, so the longest exposure in such systems is generally regarded as brief.

A.2 EAS Equipment

A.2.1 General description

Electronic article surveillance (EAS) systems use electromagnetic fields to prevent unauthorised removal of items. They are most commonly used in shops, supermarkets, and boutiques to prevent theft. They are also used to monitor the removal of books in libraries and also in hospitals to stop kidnapping of babies.

EAS systems are composed of two main parts; the detection system, and the detected transponders. The detection system usually consists of two sub-elements: the current-generation and processing electronics, the field-generation and detection antennas. The detection system antennas are the most significant source of electromagnetic fields.

The antennas are usually visible and recognisable as flat panels, loops, or pillars at or near the store exit. The main magnetic fields exist between the panels, in the “detection zone”. The detection electronics are usually concealed in a cupboard or behind a fascia in the store or the checkout, or they may be integrated into the panels. The transponders are always distributed throughout the store, attached to articles.

The transponders are in the form of detachable tags or labels and cause a slight perturbation of the fields in the detection systems. They are usually “passive” in the sense that they do not contain any power source, although they may contain a small number of electronic components such as diodes. Most transponders are disposable; i.e. they leave the store together with the goods that they protect. These types of transponders are more or less like paper labels. Some transponders are of a higher-cost, more durable nature; they are encased in a bulky protective plastic capsule that is attached to the goods by a pin, and removed by the checkout personnel at purchase.

The magnetic field disturbances produced by the transponders are both minuscule (four or five orders of magnitude lower than those of the main detection field) and also similar in magnitude to those produced by common objects such as keys, spectacle frames, belt buckles, and tin cans.

A small number of the re-useable transponders have a battery on-board, and do produce an “active” signal; however their magnetic fields are still typically two or three orders of

magnitude lower than those of the main detection field. The active transponders are designed so that there is no output from the transponders when they are outside the area of the detection zone or deactivation zone.

There are normally no user-changeable settings on any systems. Normally the system fields are set during manufacture or by a trained installation technician at the time of installation and servicing, at nominal magnitude (using a meter to measure magnetic field, or electrical current or voltage into the drive coil). Some systems have electronics which automatically re-optimises the fields in systems if they are upset due to de-tuning by large metal objects being placed close to the panels. Some systems can change the field pattern during the detection cycle.

Since EAS systems rely on field perturbations for their detection principles, out-of band emissions are strongly controlled by design. Accordingly, it is not necessary to measure field values outside the frequency operation bands specified by the manufacturers, as they make very little contribution to the exposure.

EAS systems differ from their close relative, identification systems (e.g. entry-permit systems); mainly in that EAS systems only work with one “bit” of data (i.e. presence or absence of signal). Otherwise, the base technologies are often related.

A.2.2 Types of EAS system and operating principles

There are four main types of EAS system, with characteristically different field types:

System type	Dominant field	Typical frequencies
Non-linear magnetic	Magnetic (H)	10 Hz to 20 kHz
Resonant inductive (electronic or magnetic)	Magnetic (H)	20 kHz to 135 kHz
Resonant radio frequency inductive	Magnetic (H)	1 MHz to 20 MHz
Non-linear microwave	Electromagnetic	0,8 GHz to 2,5 GHz

The first three types of system listed above use inductive fields: i.e. the operating zone is much smaller than the wavelength of EM radiation, so the field is almost completely magnetic in nature, and there is negligible propagating field. The field-generation element is a current-carrying loop embedded in the detection panel.

Microwave systems use predominantly a short-range propagating microwave field, and the field-generation element is a helical coil antenna or similar field generator. The field power levels are low and, although they do propagate, they are constrained in area by the antenna directivity.

In brief, the four types of system operate as described below.

A.2.2.1 Non-linear magnetic

The transponder contains a magnetic element that is very “soft” magnetically (i.e. easily saturated). When it is magnetised by the AC field in the detection zone, its resulting magnetisation cannot linearly follow the magnetising field (because of saturation effects). So it magnetisation produces harmonics of the drive field. These harmonics are picked up and recognised by the detection system.

A.2.2.2 Resonant inductive

The transponder contains an element that resonates in the presence of the specific frequency of the detection zone’s magnetic field. The detection field is at a precise frequency and has a very short “on” pulse duration, and the “ringing” of the transponder’s magnetic field is detected during the subsequent “off” period. The resonance can be a mechanical vibration of

the transponder, because the transponder has a magnetostrictive element, or an electronic tuned circuit: however, in both cases it is the magnetic field of the resonator, which is detected.

A.2.2.3 Resonant radio frequency inductive

The principle is similar to that above in that an inductive resonator at a specific frequency is detected. However, the implementation and detection are different. The resonator is an inductor-capacitor circuit on the transponder, and detection is typically carried out by detecting a phase perturbation in the field. The field is swept through the resonant frequency.

A.2.2.4 Non-linear microwave

The transponder has a microwave antenna with a small diode incorporated. This produces super or sub-harmonics, or mixing, of the drive frequency due to non-linearity.

A.2.3 EAS detector systems used for entrance or exit protection

These detectors are configured to protect an entrance to or exit from an area.

The types of system that use inductive fields are first described together, because these have fields that are similar in some characteristics. Current-carrying coils drive the fields and the coil dimensions are typically as follows:

Height:	0,5 m to 2 m
Width:	0,3 m to 1 m for inductive systems; 0,5 m to 1 m for non-linear magnetic systems
Depth:	1 cm to 3 cm
Orientation:	coil in a vertical plane parallel to the line walked on exit from store

There are usually two panels facing each other at a separation of 0,7 m to 3 m (see examples in Figures A.1 and A.2).

In some installations, there may be more than two panels, placed at regular intervals to cover a very broad exit. Sometimes both (all) of the panels contain current-generating coils (transmitting coils, as well as receiving coils), although sometimes only one panel is a field transmitter.

When both panels produce magnetic fields, they are usually in a Helmholtz-type configuration, so that the fields between the panels add together in direction, rather than being opposing in direction. Because of this, the major magnetic field component is approximately in a direction that is perpendicular to the customers' path through the system.

There are a few installations where the field-generating coil is a large, walk-through coil with a height of over 2 m and width of several metres. In these installations, the main field component is along the path of exit from the store.

Because of the method of use of EAS products, members of the public and workers will receive exposure in characteristic ways. Members of the public will receive transient exposure to the main identification field, while workers will receive longer-term exposure to the lower-amplitude field located at the rear and the side of the systems.

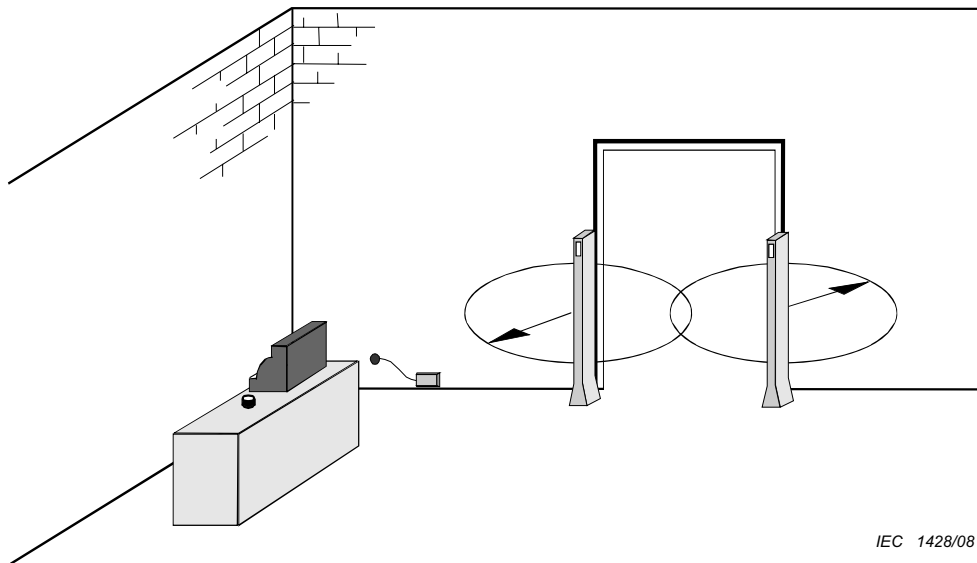


Figure A.1 – Example of exit mounted equipment showing detection range

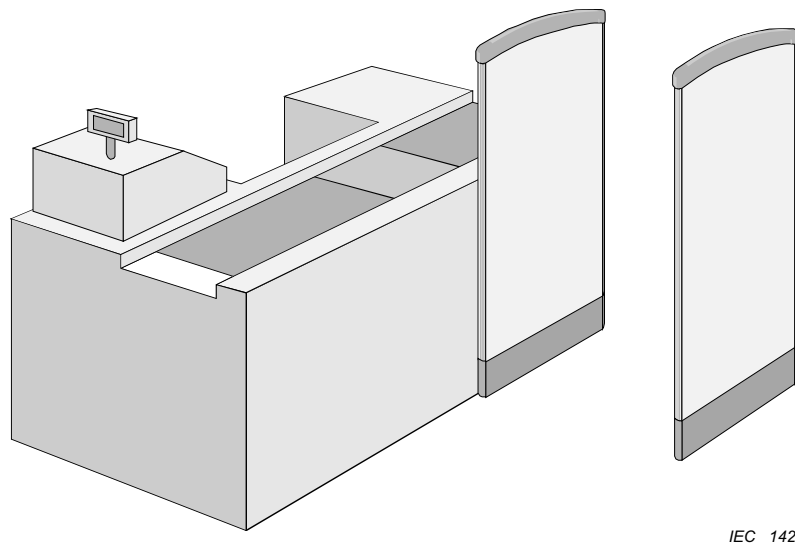


Figure A.2 – Example of aisle mounted equipment

A.2.4 Exposure of the public

EAS systems are intended for only transitory use by members of the public. If a person lingers within the system than they will usually block a passageway, so they will be moved on by other users or by security guards. Normal walking pace through a system is approximately 1 m/s (about 3,6 km/h or 2 mph), and the detection zone is at most 1 m long (along the path through the system).

Additionally, the magnetic field in the system is not homogeneous in magnitude or direction. Typically, it is strongest at a very small region, on the panel, close to the current-carrying coil, and weakest at the point furthest from the panels (e.g. midway between panels). Most of the field experienced by customers is similar to the weakest field and will be essentially whole-

body exposure in a relatively uniform field (this can be effectively measured at distances greater than 2 m from the detectors).

A.2.5 Exposure of workers

Operators are located outside of the main detection zone. They are not sited close behind the panels because usually the panels are opaque and tall, so they would be unable to see and transact with members of the public.

The presence of metal from the operator's desk and chair can disrupt the operation of the system.

At EAS installations close to checkouts, the checkout personnel sit behind and to the side of the systems, usually about 0,5 m behind and 1 m from the centre axis (see Figure A.2). By this distance the field fall-off has reached approximately an inverse power law of 2 to 2,5 in amplitude fall-off, and the amplitude is between 0,1 and 0,5 of the system-centre amplitude. and more uniform over the body. In many cases, the systems have shields installed on the check out side of the detection panels and this reduces the field still further.

A.2.6 EAS desktop and activation/deactivation equipment

Another component of EAS systems is for activation and deactivation of transponders at the point of purchase. The majority of deactivators use either permanent magnets (DC field), or time-varying fields. The fields are usually higher in absolute amplitude than the main detection fields, though they are necessarily confined to a small region near the deactivator (and usually for a very short duration). The fields are spatially confined by design, because otherwise they would deactivate concealed transponders on stolen goods, so allowing the goods to be stolen.

Generally the deactivators are mounted at reasonable distances from the general public (30 cm and over). Occupational exposure might be closer but normally would be a similar distance (arm's reach). Desk or countertop heights are usually in the range 70 cm to 90 cm.

A.2.7 Description of magnetic fields from deactivators

Deactivators are of two main types: permanent magnets and electromagnets. Some systems (mostly microwave) use a third type, which does not involve a field (contact-current blowing of a "fuse" on the transponder).

Permanent-magnet deactivators normally use an array of polymer, metal, or ceramic magnets housed in a pad or other holder. Electromagnets are used where it is required that the deactivation field is not continuously present. The field from the electromagnet is necessarily contained in a small space (usually 2 cm to 5 cm in height) close to the checkout surface. These units generate one or more short magnetic pulses sufficient to modify the magnetic pole structure of the transponder or label.

The operator pressing a button or automatically by linking to a bar code scanner or similar device performs this "on demand". Some of the deactivators have a transponder sensing circuit built in (essentially a lower powered version of a detector panel) which automatically starts the deactivation signal.

RF deactivators operate similarly to the electromagnetic versions but the deactivation pulse is at the transponder frequency. These can be "on demand" as above or can be short pulses but operating regardless of transponder presence.

A.3 RFID equipment

A.3.1.1 Introduction

An RFID (radio frequency identification) system consists of an interrogator (usually including a transmitter and receiver), an antenna and a transponder. The transmitter sends out a radio signal on a certain frequency by means of an antenna. This signal is recognised by the transponder if within the transmitter's reading range. The transponder then responds with a signal that is recognised by the receiver. Data within a transponder may provide identification for an item in manufacture, goods in transit, a location, the identity of a vehicle, an animal, an individual, etc. By including additional data, it is possible to support applications by item-specific information or instructions immediately available on reading the transponder. A certain protocol takes care of the communication between interrogator and the host computer.

To understand the capabilities of RFID it is necessary to consider the system components and their function within the data flow chain. However, it is useful to begin by considering briefly the manner in which wireless communication is achieved, as the techniques involved have an important bearing upon the design of the system components.

A.3.2 Wireless communication

A.3.2.1 The air interface

The communication of data between interrogators and transponder is by wireless communication. The three techniques most frequently used are:

- inductive coupling by magnetic fields (see Figure A.3);
- propagating electromagnetic waves (see Figure A.4);
- electrostatic (capacitive) coupling by electric fields (see Figure A.5).

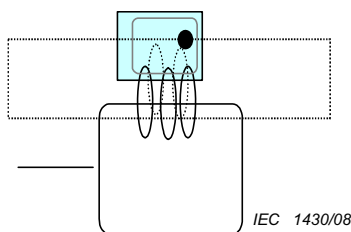


**Figure A.3 –
Inductive coupling**

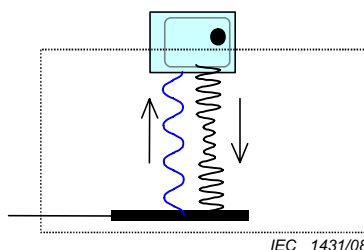


**Figure A.4 –
Electromagnetic coupling**

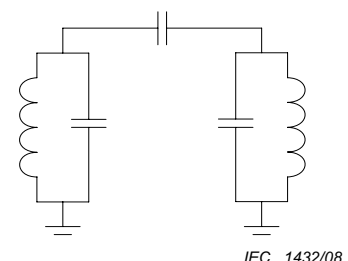


**Figure A.5 –
Capacitive coupling**

Coupling is via antenna structures forming an integral feature in both interrogators and transponders. While the term antenna is generally considered more appropriate for propagating systems, it is also loosely applied to inductive systems.

The transfer of data efficiently via the space (air interface) that separates the two communicating components requires the data to be superimposed upon a carrier wave. This process of superimposition is referred to as modulation. Various schemes are available for this purpose, each having particular attributes that favour their use. They are essentially based upon changing the value of one of the primary features of an alternating sinusoidal source, its amplitude, frequency or phase in accordance with the data-carrying bit stream. On this basis one can distinguish amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK).

A.3.2.2 Carrier frequencies

The approach that is generally adopted for radio frequency communication channels is to separate on the basis of frequency allocation. This requires different parts of the

electromagnetic spectrum being assigned to different purposes, and is generally covered by government legislation. Allocations may differ depending on the governments concerned, requiring care in considering RFID applications in different countries.

Three frequency ranges are generally distinguished for RFID systems: low, intermediate and high. Table A.1 summarises these three frequency ranges, along with the typical system characteristics.

A degree of uniformity is being sought for carrier frequency usage through co-ordination by the ITU (International Telecommunication Union). The ITU divides the world into three regulatory regions, Europe and Africa (Region 1), North and South America (Region 2) and Far East and Australasia (Region 3). Each country manages their frequency allocations within the guidelines published by the ITU.

Table A.1 – Frequency ranges and typical system characteristics

Frequency band	Characteristics
Low 1 Hz to 500 kHz	Short to medium read range low reading speed
Intermediate 2 MHz to 30 MHz	Short to medium read range potentially, medium reading speed
High, above 400 MHz	Long read range, high reading speed line of sight required

Four carrier frequencies receiving early attention as representative of the low, intermediate and high ranges are: below 135 kHz, 13,56 MHz, varied bands in the 900 MHz region and 2,45 GHz. However, there are a number of other frequency bands in use around the world, for RFID applications. Examples of the applications using these frequency bands are listed in Table A.2. As countries review their RFID frequency needs, this list may change or be added to. Thus it is non-exclusive and for general guidance only.

Table A.2 – Example frequency bands and their applications

Frequency range	Applications and comments
Below 135 kHz	EAS and a wide range of RFID products available to suit a range of applications, including animal tagging, access control and track and traceability.
6,78 MHz to 13,56 MHz	EAS and RFID systems and ISM (Industrial, Scientific and Medical)
27,12 MHz	ISM applications and RFID
433 MHz to 459 MHz	ISM and RFID applications specifically in Region 1
864 MHz to 956 MHz	UHF RFID and some EAS (the actual frequencies used within the range is dependant on country and region of operation)
2 400 MHz to 2 500 MHz	RFID and World-wide ISM band
5 400 MHz to 6 800 MHz	Band allocated for future use (including for RFID)

A.3.2.3 Data transfer rate and bandwidth

The choice of carrier wave frequency is of primary importance in determining data transfer rates. Generally speaking the higher the frequency the higher the data transfer or throughput rates that can be achieved. This is intimately linked to bandwidth (or space occupied within the frequency spectrum for the communication process).

A.3.2.4 Range and power levels

The range that can be achieved in an RFID system is essentially determined by:

- the power available at the interrogator to communicate with the transponder(s);
- the power available within the transponder to respond;
- the environmental conditions and structures.

Although the level of available power is the primary determinant of range, the manner and efficiency in which that power is deployed also influences the range. The field or wave delivered from an antenna extends into the space surrounding it and its strength diminishes with respect to distance. The antenna design will determine the shape of the field or propagation wave delivered, so that range will also be influenced by the angle subtended between the transponder and antenna.

The response from the transponder is at a much lower level than the field generated by the interrogator. This may require the inclusion of sensitive detection circuits within the interrogator to handle the received signals.

A.3.3 The RFID system

A.3.3.1 RFID system components

As mentioned above, an RFID system (see Figure A.6) consists of an interrogator (sometimes also called a reader), and a transponder (sometimes also called a tag). In the following subclauses, these components will be described in detail.

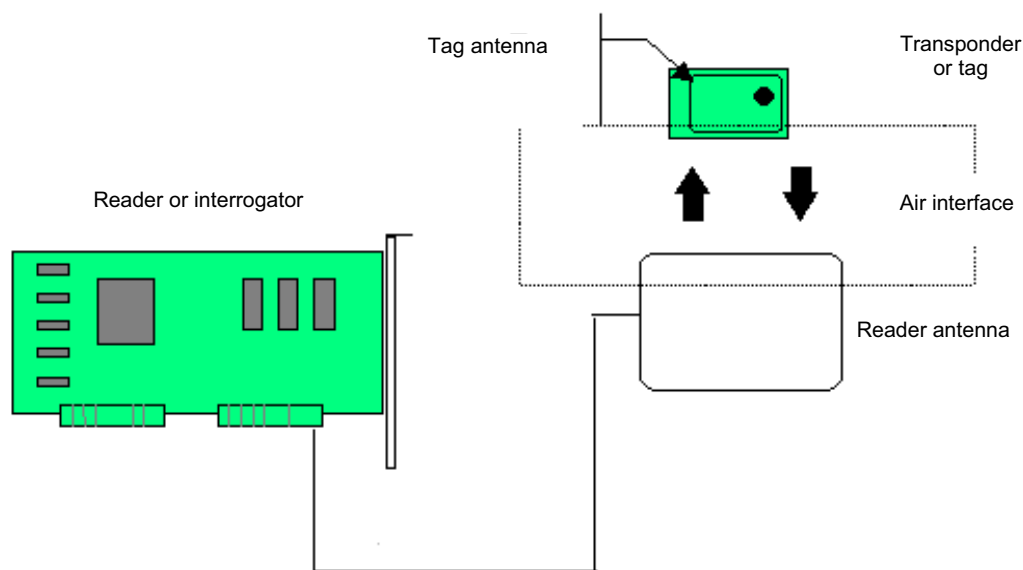


Figure A.6 – Overview of an RFID system

A.3.3.2 The interrogator

The interrogator can differ quite considerably in complexity, depending upon the type of transponders being supported and the functions to be fulfilled. However, the overall function is to provide the means of communicating with the transponders and facilitating data transfer. Functions performed by the interrogator may include quite sophisticated signal conditioning, parity error checking and correction. Once the signal from a transponder has been correctly received and decoded, algorithms may be applied to decide whether the signal is a repeat transmission. The interrogator may then instruct the transponder to cease transmitting.

A.3.3.3 The antenna

For the frequency range below 30 MHz the antennas are mostly coils, flat in shape, (round or rectangular) and consisting of one or more metal windings. These antennas typically may have dimensions of e.g. 20 cm by 20 cm, 1 m by 2 m (walk through), maybe 2 m by 10 m or maybe even bigger.

For frequencies above 400 MHz, antennas are mostly a dipole or patch shaped antenna.

A.3.3.4 The transponder

The word transponder, derived from TRANSmitter/resPONDER, reveals the function of the device. The transponder responds to a transmitted or communicated request for the data that it carries. For transponders to work, they require power, although the levels are invariably very small (μ W to mW).

Transponders can be divided into two categories, either passive or active.

- Active battery-powered transponders are typically read/write devices, i.e. it is possible for the interrogator to write new data, as well as reading the existing data stored in the transponder. Using a long life battery, a sealed active transponder can function for as long as ten or more years, depending upon the operating temperatures, read/write cycles and usage. Active battery-powered transponders allow greater communication range than can be expected for passive devices.
- Passive transponders operate without an internal battery source, deriving power from the field generated by the interrogator. Passive transponders have shorter read ranges than active transponders. Also, they are constrained in their capacity to store data and in their ability to perform well in noisy electromagnetic environments. In addition, it is generally only possible to write to a passive transponder at very close range. They have an almost indefinite electrical lifetime.

RFID transponders come in a wide variety of physical forms, shapes, sizes and protective housings. Animal tracking transponders, inserted beneath the skin, can be as small as a pencil lead in diameter and ten millimetres in length. Transponders can be screw-shaped to identify trees or wooden items, or credit card shaped for use in access applications. There are heavy-duty 120 mm by 100 mm by 50 mm rectangular transponders used to track inter-modal containers, heavy machinery, trucks, and railroad cars for maintenance and tracking applications.

A.3.4 RFID functionality

A.3.4.1 RFID system categories

RFID systems may be roughly grouped into three categories:

A.3.4.1.1 Portable data capture systems

Portable data capture systems are characterized by the use of portable data terminals with integral RFID interrogators and are used in applications where information is required from tagged items (mostly not moving), tagged animals etc. The hand-held interrogators/portable data terminals capture data which is then either transmitted directly to a host information management system via a radio frequency data communication (RFDC) link or held for delivery by line-linkage to the host on a batch processing basis.

A.3.4.1.2 Networked systems

Networked systems applications can generally be characterized by fixed position interrogators deployed within a given site and connected directly to a networked information management system. The transponders are fixed to moving or moveable items, or people, depending upon the application.