BS IEC 61786-2:2014

BSI Standards Publication

Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings

Part 2: Basic standard for measurements

bsi.

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of IEC 61786-2:2014.

The UK participation in its preparation was entrusted to Technical Committee GEL/106, Human exposure to low frequency and high frequency electromagnetic radiation.

A list of organizations represented on this committee can be obtained on request to its secretary.

Published by BSI Standards Limited 2015.

ISBN 978 0 580 79787 3

ICS 17.220.20

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2015.

Amendments/corrigenda issued since publication

Date	Text affected

Edition 1.0 2014-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour
inside

Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings –
Part 2: Basic standard for measurements

Mesure de champs magnétiques continus et de champs magnétiques et électriques alternatifs dans la plage de fréquences de 1 Hz a 100 kHz dans leur rapport à l'exposition humaine –
Partie 2: Norme de base pour les mesures

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX W

ICS 17.220.20

ISBN 978-2-8322-1970-6

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

MEASUREMENT OF DC MAGNETIC, AC MAGNETIC AND AC ELECTRIC FIELDS FROM 1 Hz TO 100 kHz WITH REGARD TO EXPOSURE OF HUMAN BEINGS –

Part 2: Basic standard for measurements

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61786-2 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:

FDIS	Report on voting
106/322/FDIS	106/326/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 committee has decided that the contents of this publication will remain unchanged until the stability 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

MEASUREMENT OF DC MAGNETIC, AC MAGNETIC AND AC ELECTRIC FIELDS FROM 1 Hz TO 100 kHz WITH REGARD TO EXPOSURE OF HUMAN BEINGS –

Part 2: Basic standard for measurements

1 Scope

This part of IEC 61786 provides requirements for the measurement of quasi-static magnetic and electric fields that have a frequency content in the range 1 Hz to 100 kHz, and DC magnetic fields, to evaluate the exposure levels of the human body to these fields.

Specifically, this standard gives requirements for establishing measurement procedures that achieve defined goals pertaining to human exposure.

NOTE Requirements on field meters and calibration are described in IEC 61786-1

Because of differences in the characteristics of the fields from sources in the various environments, e.g. frequency content, temporal and spatial variations, polarization, and magnitude, and differences in the goals of the measurements, the specific measurement procedures will be different in the various environments.

Sources of fields include devices that operate at power frequencies and produce power frequency and power-frequency harmonic fields, as well as devices that produce fields independent of the power frequency, and DC power transmission, and the geomagnetic field. The magnitude ranges covered by this standard are 0,1 μT to 200 mT for AC (1 μT to 10 T for DC) for magnetic fields, and 1 V/m to 50 kV/m for electric fields.

When measurements outside this range are performed, most of the provisions of this standard will still apply, but special attention should be paid to the specified uncertainty and calibration procedures.

Examples of sources of fields that can be measured with this standard include:

- devices that operate at power frequencies (50/60 Hz) and produce power frequency and power-frequency harmonic fields (examples: power lines, electric appliances…)
- devices that produce fields that are independent of the power frequency. (Examples: electric railway (DC to 20 kHz), commercial aeroplanes (400 Hz), induction heaters (up to 100 kHz), and electric vehicles.)
- devices that produces static magnetic fields: MRI, DC power lines, DC welding, electrolysis, magnets, electric furnaces, etc. DC currents are often generated by converters, which also create AC components (power frequency harmonics), which should be assessed.

When EMF products standards are available, these products standards should be used.

With regard to electric field measurements, this standard considers only the measurement of the unperturbed electric field strength at a point in space (i.e. the electric field prior to the introduction of the field meter and operator) or on conducting surfaces.

Sources of uncertainty during measurements are also identified and guidance is provided on how they should be combined to determine total measurement uncertainty.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61786-1:2013, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 1: Requirements for measuring instruments*

ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Throughout this standard, the words "magnetic flux density" and "magnetic field" will be considered synonymous.

3.1
average exposure level
spatial average over the entire human body of fields to which the individual is exposed

3.2
correction factor
numerical factor by which the uncorrected result of a measurement is multiplied to compensate for a known error

Note 1 to entry: Since the known error cannot be determined perfectly, the compensation cannot be complete.

3.3
coverage factor
numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

Note 1 to entry: For a quantity z described by a normal distribution with expectation μ_z and standard deviation σ, the interval $\mu_z \pm k\sigma$ encompasses 68,27 %, 95,45 %, and 99,73 % of the distribution for a coverage factor k = 1, 2, and 3, respectively.

3.4
repeatability (of results of measurements)
closeness of agreement between the results of successive measurements of the same measurand, carried out under the same conditions of measurement, i.e.:

- by the same measurement procedure,
- by the same observer,
- with the same measuring instruments, used under the same conditions,
- in the same laboratory,
- at relatively short intervals of time.

[SOURCE: IEC 60050-311:2001, 311-06-06, modified –The note to entry has been deleted.]

3.5
reproducibility (of measurements)
closeness of agreement between the results of measurements of the same value of a quantity, when the individual measurements are made under different conditions of measurement:

- principle of measurement,
- method of measurement,
- observer,
- measuring instruments,
- reference standards,
- laboratory,
- under conditions of use of the instruments, different from those customarily used,
- after intervals of time relatively long compared with the duration of a single measurement

[SOURCE: IEC 60050-311:2001, 311-06-07, modified –The notes to entry have been deleted.]

3.6
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

3.7
uncertainty of measurement
parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand

Note 1 to entry: Uncertainty of measurement generally comprises many components. Some of these components may be estimated on the basis of the statistical distribution of the results of series of measurements, and can be characterised by experimental standard deviations. Estimates of other components can be based on experience or other information.

4 General considerations

4.1 Different goals of measurement

4.1.1 General

Magnetic and electric fields can be characterised according to a number of parameters, i.e. magnitude, frequency, polarization, etc. (see IEC 61786-1:2013, Annex C). Characterisation of one or more of these parameters and how they might relate to human exposure may serve as possible goals of a measurement programme. As an aid for readers interested in developing a field measurement protocol, this subclause provides a list of such possible measurement goals and possible methods for their accomplishment.

Except in the vicinity of high voltage sources, there is no need to measure the power frequency electric field, because the electric field will be, at most, a few tens of volts per metre [3; 22][1].

Annex A gives examples of typical field characteristics in different environments.

The goals of a measurement programme, such as those considered below, shall be clearly defined. A clear definition of goals is required for the determination of instrumentation and calibration requirements, e.g. instrumentation pass-band, magnitude range, frequency calibration points, etc. Once the goals have been identified and appropriate instrumentation has been acquired, a pilot study in the measurement environment of interest may be desirable

---

[1] Numbers in square brackets refer to the Bibliography.

before decisions are made as to the final measurement methods and associated protocol. The protocol will describe the step-by-step procedure to follow, using the possible methods indicated, to accomplish the measurement goals. The protocol may explicitly indicate such things as instrument requirements (e.g. pass-band, probe size, magnitude range), location of measurements and duration of measurements. It should then be possible, using the same protocol, to compare with confidence measurement results obtained in similar electrical environments.

Possible measurement goals and possible methods for their accomplishment are given in 4.1.2 to 4.1.6.

4.1.2 Characterisation of field levels for compliance with safety standards

Limits on permissible electric or magnetic field levels expressed as resultant values and as a function of frequency have been indicated in a number of documents, such as [17-19; 21] necessitating the determination of field levels with the maximum value or spatial value in specified areas. The choice of measurement location shall be done in consideration of the possible location of people.

Method: Three-axis meters shall be used to make such measurements of the resultant magnetic and electric fields. Standards and guidance exist for such measurements near power lines [4; 9; 15] and electric appliances [10] .

Measurements of magnetic fields near power lines should be correlated with load currents. Load currents for appliances are either constant or, typically, periodic through a fixed range in a relatively short time, enabling the determination of the largest resultant magnetic field with relatively few measurements.

4.1.3 Characterisation of spatial variations

Magnetic and electric fields are not constant around sources. For example, variations of magnetic or electric fields below power lines are typical (Figures 1 and 2) and can be calculated.

In Figure 1, non-uniformity is defined by [4; 9] as the maximum value of

$$\left(\left|B_{\mathrm{h}} - B_{\mathrm{avg}}\right|\right) / B_{\mathrm{avg}} \times 100\ (\%)$$

Where

B_{h} is the magnetic field level at heights of 0,5 m, 1,0 m and 1,5 m above ground;

B_{avg} is the arithmetic mean of the three levels.

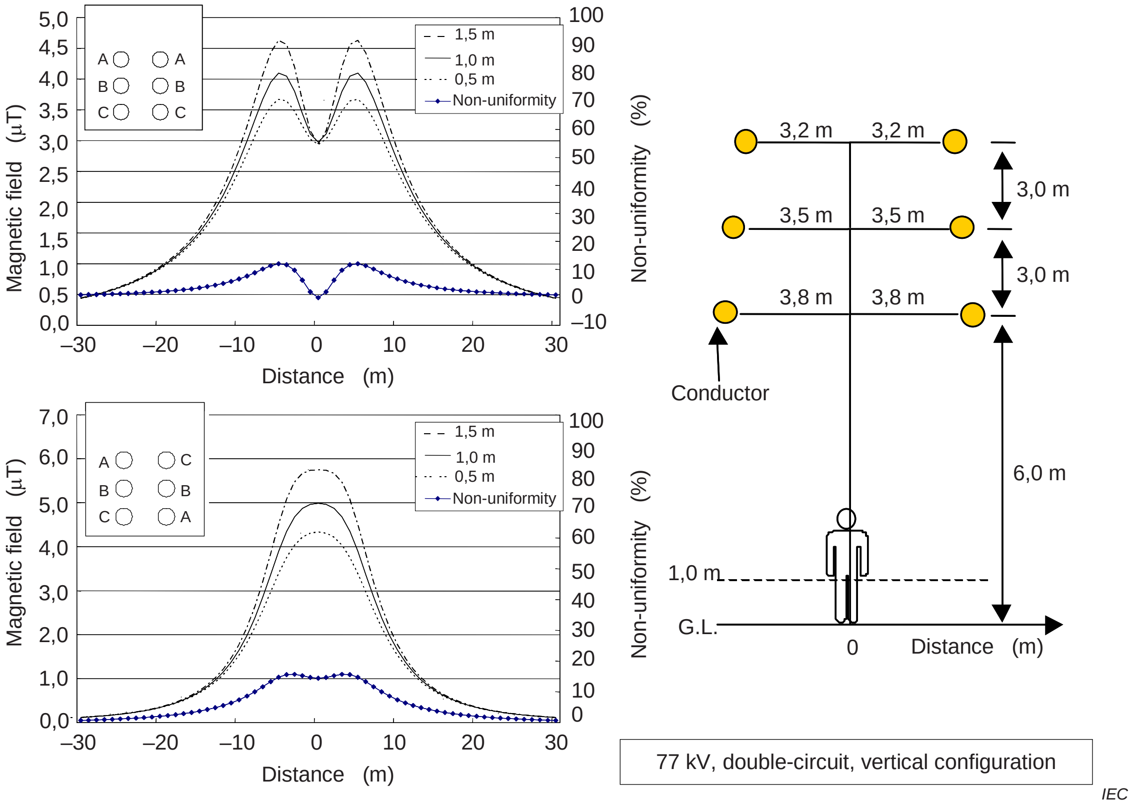


Figure 1 – Magnetic field levels under a 77 kV overhead transmission line (from [9])

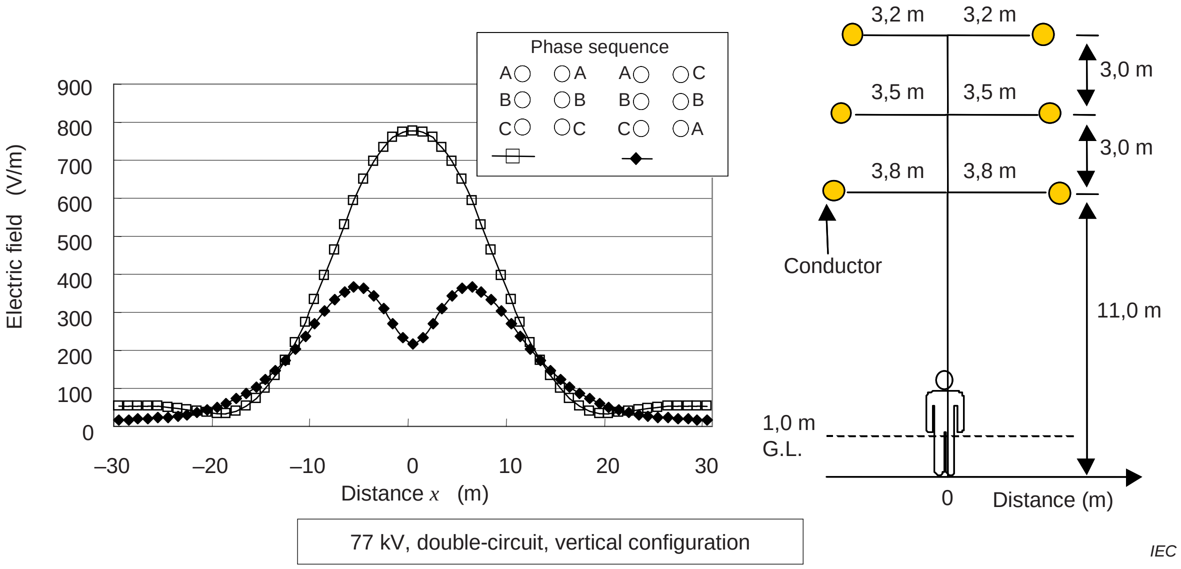


Figure 2 – Electric field levels under an overhead transmission line (from [9])

The spatial distribution of magnetic fields away from power lines or single identifiable sources is typically unknown.

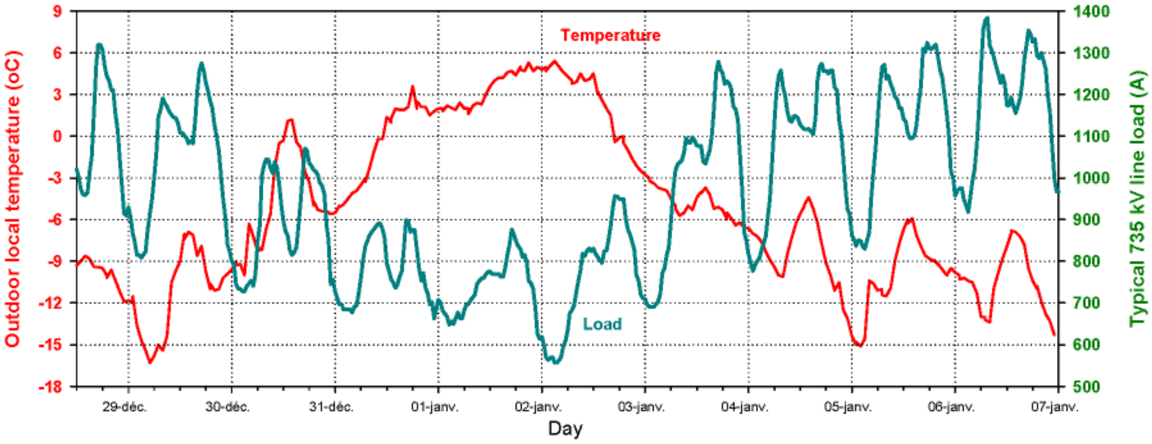
Alternating magnetic fields in most environments will be non-uniform because of the spatial dependence of the fields from the source currents. It is noteworthy that static magnetic fields also show considerable spatial variability in residences [29].

Method: The magnetic field components shall be recorded as a function of coordinate position when characterising spatial variation. Standards exist for carrying out such measurements near power lines [4; 9; 15] and electric appliances [[9]]. While such measurements can be made with survey meters, instrumentation incorporating "measurement wheels" is available for characterising spatial distributions of magnetic fields in environments where physical obstructions do not hinder the movement of the wheel. As the wheel rotates, it periodically triggers a three-axis magnetic field meter to record the resultant magnetic field. Software provided with such instrumentation permits the generation of plots of magnetic field profiles, equifield contours, statistical analyses of the field levels, etc [2; 26]. As for characterisation of field levels for compliance with safety limits, such data will not take the temporal variations of the field profiles into account without repeated measurements.

4.1.4 Characterisation of temporal variation

Because magnetic fields are produced by load currents and ground return currents that can vary greatly with time, the temporal variations of magnetic fields can easily exceed a factor of 2.

Under a power line, the magnetic field depends on the load of the line. For single circuit lines or double circuit lines operated in parallel, the magnetic field is directly proportional to the load of the line. Figure 3 gives an example of the load of a 735 kV line and the outdoor temperature. In this case, the load is influenced by human activities (daily cycle) and by outdoor temperature (season cycle) and by the place of the line in the network. Moreover, the magnetic field level can vary with the sagging of the conductors because of heating due to large current loads and environmental conditions [16] .



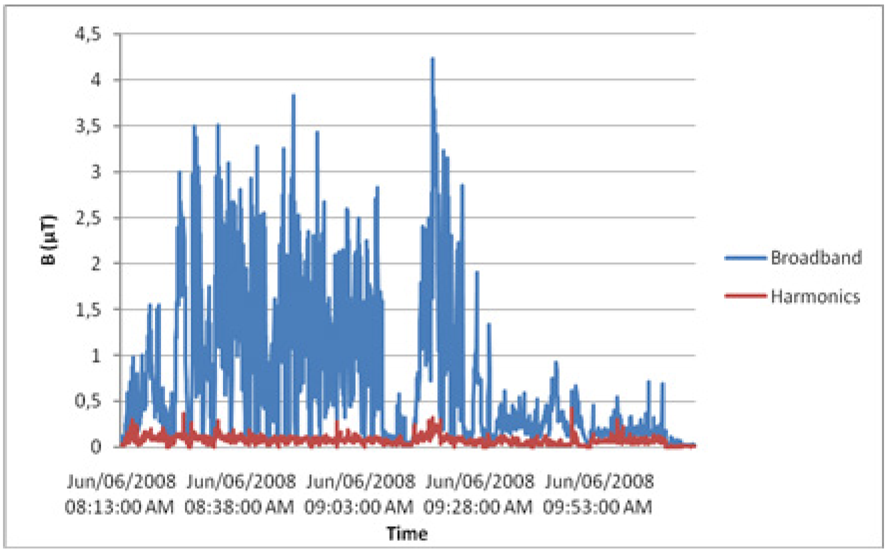
IEC

Figure 3 – Example of load variation of 735kV line due to the human activities (daily) and outdoor temperature (seasonal)

Method: Three-axis and single-axis magnetic field meters are available with output connections that can be used in combination with commercially available data loggers to record the variation of magnetic field levels at one or more locations, as a function of time. Three-axis exposure meters and magnetic field waveform capturing instrumentation can also be used to periodically record field levels. Because of the dependence of magnetic field levels on load currents, which can vary daily, weekly, seasonally (Figure 3), etc., the challenge is to determine a time interval for recording measurements that will capture enough variations of the field to obtain a valid statistical description. Conducting an initial pilot study in the measurement environment of interest can be useful for addressing the question of measurement sampling time.

Finding the temporal maximum of the magnetic field by measurement is not easy. For some simple situations, such as under single circuit power lines, this may be estimated by recording the current during the magnetic field measurement and extrapolation to the maximum load.

An additional consideration should be taken into account when measurements are performed in electric mass transportation systems or other areas where there are variable speed motors. For example, in trains, the magnetic field can be a function of the speed of the train (see Figure 4).



IEC

NOTE Broadband = 40 Hz – 800 Hz, harmonics = 100 Hz – 800 Hz.

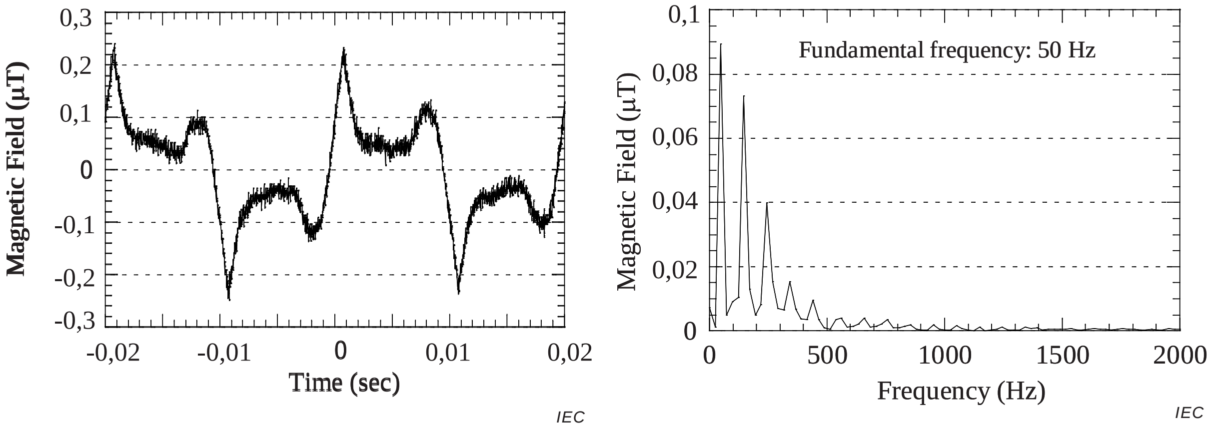
Figure 4 – 50 Hz magnetic field in a high speed train in France

For the electric fields, unlike spot measurements of magnetic fields from power lines, the measured values will not change greatly because the voltages remain nearly constant. However, the electric field level can vary with the sagging of the conductors because of heating due to large current loads [16] .

4.1.5 Characterisation of frequency content in magnetic field or electric field

Since (1) electric and magnetic fields from electrical equipment often contain power-frequency harmonics or frequencies unrelated to the power frequency, and (2) electric and magnetic field limits have been set as a function of frequency [17-19; 21], characterisation of the frequency content can be an important goal.

An example of a magnetic field that is rich in harmonics and that is produced by a common electrical appliance is shown in Figure 5. Figure 5a shows a waveform of the horizontal component of the magnetic field 10 cm away from the surface of the front-centre of an operating 66,04 cm (26 inches) flat-screen LCD television. The harmonic components in the field are indicated in Figure 5b, which shows a frequency spectrum for the waveform in Figure 5a. It is shown that the fundamental frequency is 50 Hz and significant levels of 3rd and 5th harmonics are included.



(a) (b)

Figure 5 – Waveform (a) and frequency spectrum (b) of magnetic field generated by a 66,04 cm (26 inches) flat-screen LCD television

Method: Commercially available single-axis and three-axis magnetic field meters are sometimes provided with output connections that give an output voltage proportional to the magnetic field strength.

Such instrumentation, in combination with commercially available spectrum analysers, can be used to characterise the frequency components in the magnetic field. Alternatively, wave-capturing instrumentation has software that enables the determination of the frequency content from the recorded data. Magnetic field meters which can be switched to indicate rms field values of the power frequency and one or more harmonic frequencies are also available. More modern electric and magnetic field meters include a spectrum analyser.

It should be noted that the frequency content of magnetic fields produced by variable speed electrical equipment, e.g. electric mass transportation systems, can change as a function of speed [5].

The electric field of AC power systems has low total harmonic distortion.Therefore the harmonics of power frequency electric field are negligible [9].

4.1.6 Characterisation of population exposure to magnetic field and definition of metric

A number of epidemiological studies on occupational or residential exposure, that have examined the possibility of health effects from exposure to power frequency magnetic fields, have been conducted. From the magnetic field measurements, different statistic indicators can be defined.

Method: A more precise assessment of exposure is determined by wearing a small three-axis exposure meter that periodically records the field at a location of interest on the body.

Estimates of human exposure shall be made from a combination of spatial and temporal variation measurements and information which describes patterns of human activity [31].

Commercially available three-axis exposure meters that can be worn on the body can be used. Such instrumentation periodically records the resultant magnetic field value for periods of time extending to several days, depending on the frequency of sampling of the magnetic field, memory storage capacity and battery life. The sampling rate will depend in part on the model assumed for the interaction between the field and subject. The data collected can be downloaded to a computer, and software provided with the instrumentation or specially developed, is used to determine exposure to the parameters such as TWA (time weighted average), geometric mean, and several percentile values.

Past human exposures in specified areas should be estimated by having surrogates wearing exposure meters perform activities that were conducted in the past in the specified areas [27-28; 30]. This approach assumes that the magnetic field sources have not changed significantly over time.

4.2 Sources with multiple frequencies

4.2.1 General

If a source is not producing a single sinusoidal field, the field produced can be described as a superposition of sinusoidal fields with different frequencies. The spectrum of the field may consist of discrete spectral components or it may be continuous. Examples of sources producing a discrete spectrum are distribution power lines and AC/DC converters. These examples also have a harmonic spectrum, which means that spectral components occur only at integer multiples of one fundamental frequency. A non-harmonic discrete spectrum may be produced by two or more independent generators. In a continuous spectrum there are no discrete spectral components visible because it consists of an infinite number of spectral lines with infinite small spaces. The spectrum of a single impulse or burst is an example of a continuous spectrum. Also thermal noise produces a continuous spectrum. Of course discrete and continuous spectra may be superposed in a real spectrum.

The goal of this subclause 4.2 is to show how non-sinusoidal fields can be compared with the reference levels of existing guidelines or standards.

In the frequency range up to 100 kHz, the guidelines are based on short term effects such as stimulation of the nervous system [17-19; 21]. The other known biological effect is the thermal effect which can be neglected below 100 kHz. Reference [25] gives a very good summary of the literature dealing with neurophysiological effects of electromagnetic fields.

The guidelines define basic restrictions to characterise neurophysiological effects. As these basic restrictions are not measurable quantities, the guidelines introduce reference levels for external fields. Basic restrictions and reference levels are frequency dependant.

With the reference level we have a practical model which is valid for external sinusoidal fields. The reciprocal of the reference level curve can be seen as a transfer function from the external fields to the biological effect. If the spectrum of the external field strength multiplied with this transfer function results in value below one, we assume that the external field is in compliance with the corresponding safety standard.

The concept of transfer function can also be applied to non-sinusoidal fields. The multiplication of the spectrum of the external field with the transfer function results in a spectrum which is relevant for the exposure and which can be called the weighted spectrum. For a discrete spectrum this means that the field strength of each spectral component is divided by the reference level at the frequency of the spectral line. The question is now how to add the weighted spectral lines. The following methods are published.

4.2.2 Sum of weighted magnitudes

In references [19], [21] and [18] it is proposed to add the magnitudes of the weighted spectral lines.

For example, reference [21] proposes the following criteria for magnetic field:

$$\sum_{j=1}^{10MHz} \frac{H_j}{H_{\mathrm{R},j}} \leq 1$$

where

H_j is the magnetic field strength at frequency j

$H_{\mathrm{R},j}$ is the reference level at frequency j defined in reference [21]

This method usually overestimates the exposure because it does not use the phase information of the spectrum.

4.2.3 Weighted peak value

An ICNIRP statement [20] showed clearly that the sum of weighted magnitudes method is only a worst case estimation because the phase of the weighted spectral lines is not taken into account. It is proposed to take the phase of the source spectrum into account and transform the weighted spectrum into the time domain. The peak value of the resulting weighted time domain signal is finally the relevant exposure measure. For the magnitude of the transfer function the reciprocal of the reference level curve is used. The phase of the transfer function is derived from the steepness of the reference level curve.

A method which works completely in the time domain is also proposed in reference [20]: in this method the time domain signal of the field is convolved with the impulse response of a weighting filter. The transfer function of this weighting filter is identical to the transfer function already described for the frequency domain method. Again the peak value of the weighted time domain signal is the relevant exposure measure.

Mathematically there is no difference between the two proposed methods because multiplication in the frequency domain is exactly the same as convolution in the time domain. In Clause 8 of IEC 62311:2007 [11] the weighted peak method is also described in detail. The weighted peak method using the convolution approach is already available in commercial measurement instruments. These instruments work in real time, are very easy to use and can be used for arbitrary signals. Especially pulses, bursts or noise-like signals can be evaluated in the sense of references [20] and [11].

4.2.4 Impulse separation

For signals with arbitrary temporal behaviour an evaluation of the time domain signal is proposed in 5.3.2 of reference [1] . It is described in detail for magnetic fields only. The time domain signal of the field is divided into a sequence of single impulses. From the duration of each impulse a corresponding frequency is calculated which is used to select the proper reference level for each impulse. In the general case the peak value of the time derivative of each magnetic field impulse must then be compared with the peak value of a sinusoidal signal at the reference level multiplied with its corresponding angular frequency.

In many cases this procedure gives the same results as the weighted peak method described in references [20] and [11] if the same reference levels are applied, if the impulses are separated correctly and if the corresponding frequencies of the impulses are extracted correctly. The reason for this similarity is that the same physical and neurophysiological effects are the basis of both methods. The interpretation of these effects is however somewhat different. The task to separate the time domain signal into single impulses and to extract the relevant parameters is not an easy one and not well defined. Therefore, the reproducibility of this method is not good.

4.2.5 Weighted RMS value

In [10] it is proposed to add the squares of the magnitudes of the weighted spectral components in a first step and then take the square root of this sum in a second step as a measure of the actual exposure. According to Parseval's theorem the RMS value of the weighted time domain signal is exactly the same. In reference [10] an averaging time of one second is proposed for the time domain method. This method was introduced to avoid the overestimation which could occur by summing the magnitudes directly. Also in reference [11] the frequency domain version of this method is proposed as a mean of avoiding overestimation. However there is no neurophysiological rationale for this approach. Therefore this procedure might underestimate the real situation.

4.2.6 Highest weighted spectral line

In reference [1] the absence of additive effects of different spectral components regarding the neurophysiological effects is assumed. According to 5.3.3 of reference [1] it is sufficient to show compliance of each spectral component separately if the spectrum consists of a limited number of harmonics and if the amplitudes of these harmonics decay with frequency. For the rationale of this approach reference [8] is cited in reference [1]. It is worth noting that [8] is only an abstract. It is also worth noting that the method described in 5.3.2 of Ref. [1] can give much more conservative results.

4.2.7 Conclusion and recommendation

We have seen that there is a broad range of methods to assess fields with multiple frequencies. From the current point of view the weighted peak method should be used because it has the lowest risk for overestimation as well as for underestimation. It also produces stable and predictable results with a minimum of work for the operator.

4.3 Considerations before measurements

Before carrying out measurements it is useful to have an idea of the distribution of the field that is to be measured. For this the following information is required (when possible):

- identification of the sources of the field;
- geometric characteristics of the source;
- load of the sources (defined in terms of current, power, etc.);
- pictures or maps to adequately describe the areas where measurements will be carried out;
- up-to-date electrical diagrams;
- atmospheric conditions;
- areas accessible to public or workers;
- presence of metallic objects.

NOTE While many sources of magnetic fields are visible (e.g. overhead lighting, electrical appliances), others are not (e.g. electrical equipment in adjacent rooms or on upper or lower floors).

It may be necessary to conduct a pilot study before the final measurements. The extent of this pilot study will depend on the context. It may be only a rapid scan of the area, in order to look for the maximum field. It may be more detailed in order to take decisions regarding spacing between measurements, measurement heights, sample size, formats of data sheets, questionnaires for job/task classification, etc.

In the pilot study, the presence of harmonics should be checked. If it can be demonstrated that harmonics are negligible, that is if the difference of exposure measured with and without harmonics is less than 5 %, then it is not necessary to measure them in the main study.

The measurement range of the instrumentation should also be checked in the pilot study. Some instruments are automatic ranging: this may be more convenient, for example if the levels of fields are very different in different places. Automatic range should not be used for transient signals.

When the goal of the measurement is an epidemiological study, a pilot study shall be done as part of the process for developing a final measurement protocol.

5 Measurement procedures and precaution

5.1 AC magnetic field

When developing a measurement method and protocol, the following sources of magnetic fields and items shall be considered when applicable:

- the electric sources serving the facility;
- types and locations of transformers;
- locations of main cables and circuit-breakers;
- magnitude of supply voltages and periods of peak power use;
- frequencies (including 0 Hz) of power supplies and electrical devices;
- location of people relative to known field sources;
- location of measurement relative to the human body, e.g. head, trunk,;
- presence of any motors and generators;
- presence of small heaters;
- presence of air-core coils used in air core compensation reactors and in filter coils
- earthing systems and connections.

Magnetic flux density measurements shall be made with three-axis instruments and shall be of the resultant magnetic field,

Using single-axis instruments is possible in some cases, e.g. to know the direction of the field and the maximum magnetic field, or in order to investigate the orientation and shape of the magnetic field ellipse, and in cases when the direction of a linearly polarized field is already known.

Some three-axis instrumentation can also determine the field parameters mentioned above.

The size of the probe or sensing elements shall be appropriate to the spatial variation of the field that is measured. The sensing elements should be of area 0,01 m^2 or smaller (5.8.2 of IEC 61786-1:2013).

The pass-band of the instrument shall be appropriate to the frequency content of the field being measured. Where the field is such that the pass-band of the instrument could significantly affect the reading (i.e. where more than one frequency is present in the field), the pass-band shall be recorded and included in the report.

When the magnetic field is produced by a power system, the frequencies present will usually be the fundamental (50 Hz or 60 Hz), plus the first few harmonics. The minimum pass-band used for measuring such fields shall extend from the fundamental frequency to 800 Hz. A narrower pass-band may be used only if it can be demonstrated that the harmonic content is sufficiently small for the measurement result to be negligibly different, e.g. near power lines, or if there is a specific reason for measuring a narrower range of frequencies.

When measuring the fields produced by sources other than the power system, the pass-band shall be chosen appropriately. Fields produced by some transportation systems have a lower fundamental frequency, while induction heaters, video display terminals, commercial airplanes, ships, and the harmonics produced by variable speed motors can produce fields with higher frequencies.

When extending the pass-band to lower frequencies, care shall be taken to avoid errors caused by the motion of coil probes in static fields. Such errors can generally be avoided by holding the coil stationary or by selecting an appropriate frequency range.

Measurements in an approximately uniform magnetic field correspond to exposure of the whole human body if present at the measurement location at the time of the measurements. This is the case under power lines [9] .

It is possible to use the concept of average exposure levels when the distance between the source and the body is greater than 20 cm. In order to determine the average exposure levels, the field shall be measured at different heights and positions, taking into account the position of the human body, and the results averaged. IEC 62110 gives a protocol for measuring public exposure to magnetic field emitted by electric installations, which defines 3 heights of measurements [9] .

Averaging in this way over the human body shall not be used when the distance is shorter than 20 cm.

The measurement protocol shall specify the measurement distances between the measurement point and the sources (or the walls or fences or surfaces). This distance should be by default 20 cm. Some standards define distances of measurement in specific situations (see Annex B).

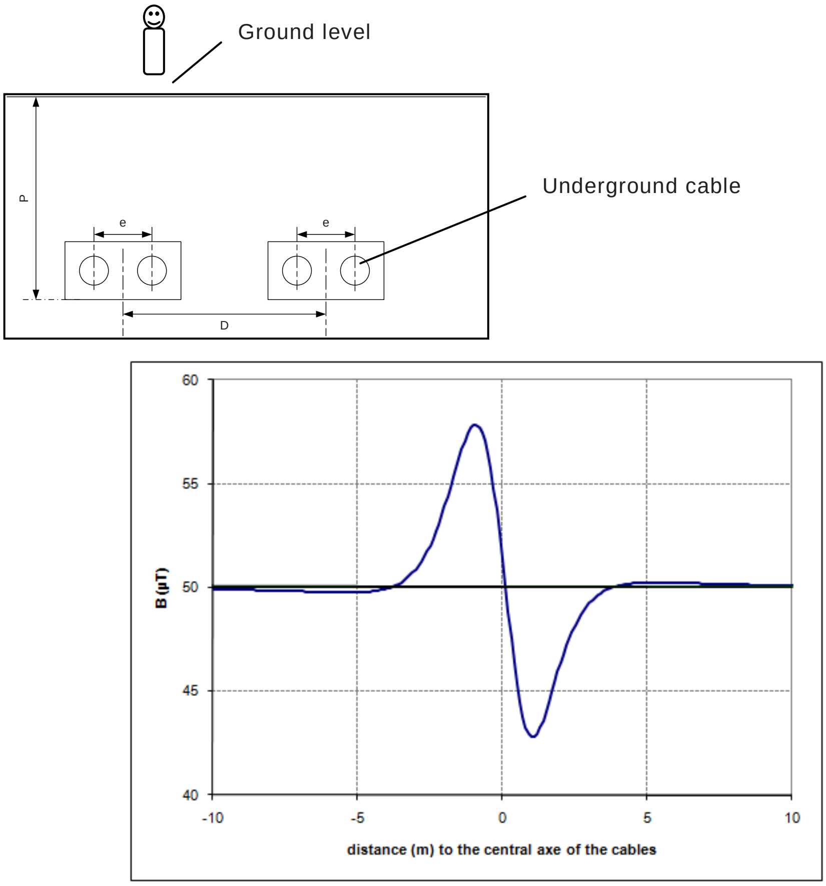
As part of the process for developing a measurement protocol for determining human exposure to magnetic fields, the measurement goals and methods for achieving them shall be clearly indicated. A clear definition of the goals is needed to determine instrumentation and calibration requirements, e.g. instrumentation pass-band, magnitude range, and frequency calibration points. The measurement protocol should indicate which field parameter(s) shall be measured, where the measurements shall be performed, and how the measurements shall be performed. It is important to note that, in general, a single measurement protocol will not be suitable for all measurement situations.

The magnetic field is proportional to the current and so may vary during the measurements. So, this variation shall be known in order to interpret the results. This could be done by recording the current in the load or by recording the magnetic field at a fixed place during the measurements.

5.2 DC magnetic field

The main difference between measuring AC and DC magnetic fields is the influence of the geomagnetic field.

In the case of DC electric networks, the protocol should be derived from IEC 62110. If the DC line is undergrounded, the DC field at the location of the body should be considered as uniform (in the sense of IEC 62110), so that a measurement at 1 m height should be sufficient. The uniformity of field can be a priori assessed by calculation (Figure 6).



IEC

P = 1,4 m D = 1,05 m e = 35 cm I =926 A

polarities of I in each cable = + – – +

geomagnetic field is 50 µT with angle of 60° to the bottom and aligned with the cable

Figure 6 – Example of DC magnetic field profile above DC underground cable (calculated at a height of 1 m)

The geomagnetic field shall be measured at the beginning and at the end of the measurements, on each side on the cable. As the geomagnetic field and the DC field emitted by the cables are vectors, it is not possible to simply subtract the geomagnetic field component. The measured magnetic field shall be reported, as it is. The geomagnetic field component shall also be reported.

5.3 AC electric field

Unperturbed field measurements shall be made with three-axis instruments and shall be of the resultant electric field.

Using single-axis instruments is possible in some case, e.g. when the direction of the field is already known

The pass-band of the instrument shall be appropriate to the frequency content of the field being measured. Where the field is such that the pass-band of the instrument could significantly affect the reading (i.e. where more than one frequency is present in the field), the pass-band shall be recorded and included in the report.

When electric fields are produced by electric power systems, i.e. power lines, transformers, and so forth, the predominant frequency is the power frequency 50 Hz or 60 Hz. An instrument with a narrow pass-band centred about the power frequency will be suitable in such cases for measuring the rms value of the electric field.

When measuring electric fields from other sources, e.g. on commercial aeroplanes, ships, and some electric trains, the fundamental frequency can differ significantly from 50 Hz/60 Hz, and the pass-band shall be chosen appropriately.

During electric field measurements, particular attention should be given to avoiding proximity effects of the observer as well as other people who may be in the vicinity of the field probe. Significant perturbation of the field can occur, capable of introducing unacceptable errors in the measurement.

Figure 7 shows the perturbation of the electric field measurement in percentage as a function of the observer distance from the probe and the field meter height above ground [7]. The data points represent measured perturbations beneath a 500 kV transmission line due to a 1,80 m tall grounded observer (arms at side). Proximity effects are shown for three heights of the field meter above the ground plane. The solid curves are theoretical predictions. Because the observer's potential is frequently close to ground potential due to leakage resistance and capacitance to ground, the proximity effects in Figure 7 can be regarded as typical.

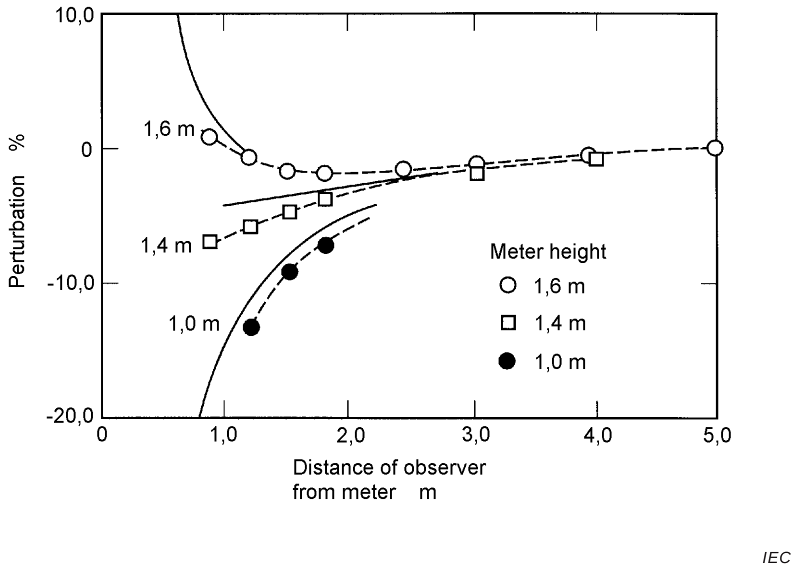


Figure 7 – Observer proximity effects during electric field measurements in vertical electric field

The observer proximity effects for free-body meters in other geometries, which may be greater or less than those shown in Figure 7, can be determined experimentally. The proximity effect may be determined by noting changes in the field value as a function of the observer distance from the centre of the probe.

So a minimum distance of 2 m shall be respected between operator and probe [4].

Electric fields are very easily perturbed by the presence of conductive objects, even if these objects are poor electrical conductors (trees, fences, vegetation, buildings… etc.) [4]. All movable objects should be removed whenever possible. If not, then the distance between the probe and the object should be equal to at least three times the height of the object (non-permanent object) or to 1 m (permanent object), if possible. Objects that cannot be removed shall be listed, indicating their dimensions and location [4].

The probe shall be put on an insulated tripod (see 5.8.4 of IEC 61786-1:2013).

Electric field measurements may be in error if the relative humidity is more than 70% (see 5.5 of IEC 61786-1:2013).

It should be recognized that measurements in an approximately uniform electric field correspond to exposure of the whole human body if present at the measurement location at the time of measurements. Electric field measurements in non-uniform fields have a more restrictive interpretation when determining human exposure, i.e. the field measurement represents human exposure only for that portion of the human anatomy which would coincide with the measurement location.

As part of the process for developing a measurement protocol to determine human exposure to electric fields, the measurement goals and methods for achieving them shall be clearly indicated. A clear definition of the goals is needed to determine instrumentation and calibration requirements, e.g. instrumentation pass-band, magnitude range and frequency calibration points. The measurement protocol shall indicate which field parameter(s) should be measured, where the measurements shall be performed, and how the measurements shall be performed. It is important to note that, in general, a single measurement protocol will not be suitable for all measurement situations.

6 Measurement uncertainty

Measurement uncertainty shall be assessed in compliance with ISO/IEC Guide 98-3. This standard requires that the standard deviation associated with each quantity influencing the measurement shall be determined on the basis of measurements performed (type A) or on the basis of experience (type B).

Decisions should be made regarding the total uncertainty permissible during measurements (instrumental uncertainty requirements are given in Clause 5 of IEC 61786-1:2013).

In order to determine the total uncertainty associated with rms measurements of the electric or magnetic field in different measurement environments, there should be an appropriate accounting of the various sources of uncertainty. Possible sources of uncertainty identified in Clause 6 of IEC 61786-1:2013 and in Annex C are as follows:

- **Uncertainty type A**
  - calibration uncertainty;
  - repeatability of the measurement;
  - reproducibility of the measurement;
- **Uncertainty type B**
  - correction factor;
  - averaging effects of coil probes during non-uniform field measurements;
  - errors in positioning the probe in non-uniform fields;
  - frequency response or pass-band limitations (choice of the filter);
  - instrument measurement time constant;
  - metrological drift;
  - resolution;
  - temperature;
  - proximity to objects or obstacles;
  - humidity (only for electric field);
  - hysteresis of scale in automatic range mode.

Some sources of uncertainty can be reduced to negligible levels. For example, stands fabricated from insulating materials may be used for precise positioning of the field meter probe.

Known correction factors should be applied to readings obtained when possible.

This may be complex due to the fact that the correction factors are defined for each axis.

Similarly, it should be recognized that uncertainties during the measurement of electric or magnetic fields from appliances or other electrical equipment, as a function of the distance from the source, can become very great (e.g. exceeding 100 %) as the field level from the source approaches the value of the background field.

The combined standard deviation u_c shall be obtained as the square root of the sum of the variances (i.e. the square root of the sum of the squares of the standard deviations):

$$u_\mathrm{c} = \sqrt{\sum_{1}^{m} c_i^2 . u_i^2}$$

where c_i is the sentitivity coefficient and u_i is the standard uncertainty

The expanded (total) uncertainty u_e shall be k times the combined standard deviation, where k is the coverage factor.

The coverage factor shall be taken as 2 which, for normal Gaussian distributions, will correspond to a confidence interval of approximately 95 %.

$$u_\mathrm{e} = 2u_\mathrm{c}$$

Annex D gives an example of assessment of measurement uncertainty.

7 Measurement report

The information that is required when recording and reporting the results of measurements can vary depending on the goals of the measurements. A clear indication of the measurement goals shall be provided at the outset. The following information pertaining to the instrumentation and measurements shall also be provided when appropriate:

- description of the measurement procedure;
- identification of manufacturer;
- identification of instrument model and probe;
- instrument bandwidth;
- date of last calibration/verification test;
- date of measurements;
- time of measurements;
- identification of personnel performing the measurements;
- weather conditions;
- humidity (for electric field only;)
- source description, for example frequency and signal characteristics;

- source conditions, i.e. current loading;
- frequency resolution of spectra for fields containing multiple frequencies;
- a clear indication of what field quantity is being reported, e.g. the maximum field, the resultant field, the vertical field component, time-weighted average (TWA), rms value, etc. (SI units should be used; common units may be expressed in parentheses);
- descriptions of human activity when human exposure data is presented;
- drawings which describe the area and locations where measurements are performed; with photos if possible;
- localisation of the reference measurement point, with GPS coordinates if possible;
- geomagnetic field when measuring DC magnetic field;
- statistical information, e.g. the largest and smallest field values, median, geometric mean, etc.;
- total measurement uncertainty;
- conclusion regarding the goals of measurement;
- distance to the source.

Annex A
(informative)

Examples of fields characteristics in typical environments

Knowledge of the field characteristics leads to the right choice of instrumentation and measurement procedure. In general, workers have access to environments where the electric and magnetic field intensities can be higher than those that are accessible to the public. In most cases, the two environments are naturally delimited by physical boundaries. For example, in substations or enclosures for medium voltage installations, there are areas where access is restricted to workers.

In general the public is exposed to higher fields close to the power line than far away from them.

The design of high voltage and high current equipment is optimized to reduce the field produced by electric installations.

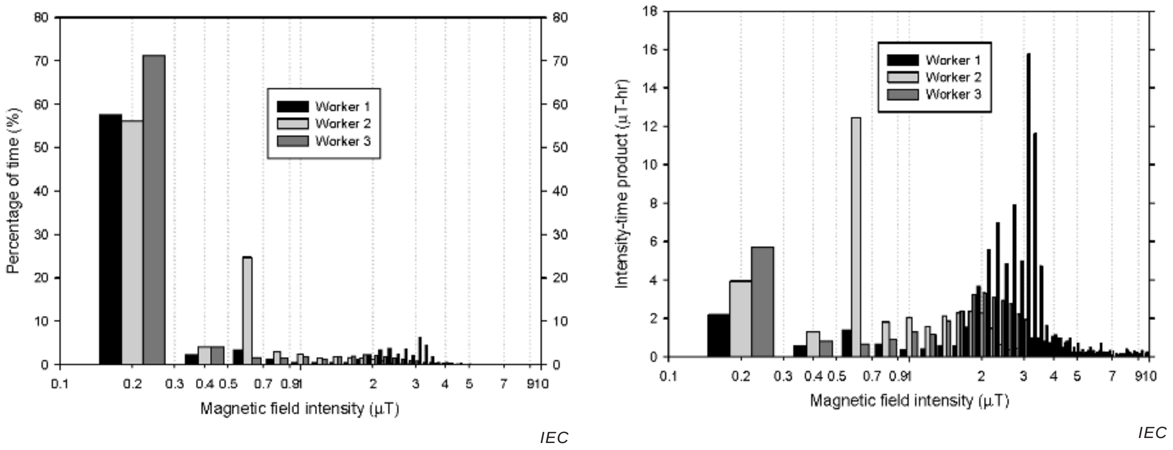
Due to the nature of the work, for example live line inspection or maintenance, workers may have access to areas where there are higher levels of field. The field intensities are relatively high at ground level in the substations beneath bus bars, close to the connections of alternators in the power stations and close to the phase conductors of overhead lines during live-line maintenance. Other examples of sources of high magnetic field at work include welding machines, electrolysis, induction heating, etc…

The order of magnitude of power frequency fields in areas accessible to workers and to the public in a North American utility substation installation and for the right of way (ROW) of power lines is summarized in Table A.1.

Table A.1 – Example of field characteristics inside (workers environment) and outside (public environment) electric substations in a North American utility

Electric field		**Magnetic field**		
Area accessible to workers	***Area accessible to public***	***Area accessible to workers***	***Area accessible to public***	
Maximum value at 2 m above ground under bus bar in substation 13,6 kV/m or higher	Maximum value between 1 m and 10 m from the substation fences, around 1 kV/m	1 000 µT in the vicinity of blocking inductance	4 µT outside the substation fence	**Different areas in a 735 kV substation**
Maximum value at 1 m above ground 10 kV/m		Maximum value at 1 m above ground 30 µT		**Beneath power line**
Computed value of electric field can reach 80 kV/m at the workplace, where workers are required to wear a conductive suit for reducing electric field at body level.		Computed value can reach 150 µT /kA load in a bundle of 4 sub-conductors (close intervention can be only done with a bucket roll over the bundle, current load is split between sub-conductors of the bundle)		**Live line maintenance at the phase conductor level**

The statistics of magnetic field exposure of 3 workers in a power plant are presented in Figure A.1. This illustrates the percentage of exposed time (Figure A.1a) and intensity-time product (Figure A.1b) of magnetic field during 3 work days. This example does not intend to be representative of all possible workers exposure in a power plant.



a) b)

Figure A.1 – Magnetic field exposure of typical worker (electrician) in North American power plant (based on 3 days recording)

Mass transit systems can produce field at higher frequency than power frequency. These field characteristics for public exposure are presented in Table A.2 [6]. The field in these systems can vary during the acceleration and deceleration of the vehicle.

Table A.2 – Field characteristics (µT) in different mass transportation system in US: average and (maximum)

Transportation system	**“Static” < 5 Hz**	**Extremely low frequencies 5 Hz to 3 000 Hz**	**Low extremely low frequency 5 Hz to 55 Hz**	**Power frequency 60 Hz**	**Power harmonics 65 Hz to 300 Hz**	**High extremely low Frequencies 305 Hz to 3 000 Hz**
Ferry	51,1 (76,0)	0,06 (0,33)	0,02 (0,10)	0,04 (0,31)	0,02 (0,12)	0,01 (0,03)
Escalator	55,7 (95,8)	0,15 (6,14)	0,13 (6,01)	0,04 (0,32)	0,02 (1,05)	0,01 (0,03)
Moving walkway	57,6 (121,8)	0,37 (20,0)	0,31 (19,54)	0,12 (1,24)	0,07 (3,72)	0,03 (1,90)
Conventional cars and light trucks	32,1 (96,8)	0,57 (12,45)	0,55 (12,45)	0,09 (1,94)	0,08 (1.36)	0,04 (0,78)
Electric cars and light trucks						
Dynamometer	40,8 (128,6)	0,57 (8,08)	0,34 (5,61)	0,09 (1,25)	0,36 (7,99)	0,1 (0,86)
Test track	38,8 (104,1)	0,57 (9,35)	0,48 (9,27)	0,08 (1,53)	0,19 (2,45)	0,07 (0,69)
Jetliner	55,2 (66,9)	1,35 (21,25)	0,06 (0,35)	0,00 (0,06)	0,02 (0,81)	1,35 21,24
Shuttle tram (AC electric)	47,0 (83,5)	1,37 (9,04)	1,07 (8,85)	0,55 (2,90)	0,30 (1,44)	0,12 (0,70)
Conventional bus	40,1 (112,4)	1,68 (14,57)	1,64 (14,42)	0,09 (1,42)	0,19 (2,13)	0,21 (2,48)
Electric shuttle bus	38,1 (80,8)	2,04 (48,78)	1,47 (48,67)	0,08 (3,88)	0,89 (22,05)	0,16 (1,07)
Commuter train	53,8 (196,9)	4,96 (79,93)	1,85 (45,35)	3,42 (73,88)	1,46 (34,03)	0,59 (4,87)

Depending on the environment, the electric or magnetic field may not be uniform in the area of interest. For example, IEC 62110 [9] explains that in the public environment field under power line can be considered as uniform, while the field above an underground line is not uniform.

Annex B
(informative)

Examples of measurement distances

B.1 IEC 62110:2009 [9]

h is the height of the measurement and d is the distance to the source.

- Single point: h =1 m
- Three-point: h = 0,5 m – 1 m – 1,5 m and d = 0,2 m
- Five-point: h = 0,2 m and d = 0,5 m from centre
- Around substations with overhead lines connected to the substation: h = 1 m and d = 0,2 m

B.2 IEC 62233: 2005 [10]

- Appliances used in contact with the relevant parts of the body: 0 cm
- Other: 30 cm
- Particular cases: Facial sauna appliances, hairdryers, water-bed heaters: 10 cm
- Induction hobs and hotplates: d = 30 cm, height h between 1 m above the cooking zone and 0,5 m below the cooking zone.

B.3 IEC 62311:2007 [11]

Distance (source to user): the distance used for the assessment shall be specified by the manufacturer and be consistent with the intended usage of the equipment.

B.4 IEC 62369-1:2008 [12]

The usual measurement distances from electronic article surveillance devices (EAS) are 20 cm / 30 cm. The measurement is based on a grid every 10 cm or 15 cm over the torso and the head (minimum height of 85 cm). More data are given in [12], describing the grid of measurement in function of the type of EAS systems.

B.5 IEC/TS 62597:2011 [14]

- Rolling stock:
  - Workers inside:
    - SURFACE METHOD →h = 0,5m – 1 m – 1,5 m
    - VOLUME METHOD → h = 1 m – 1,5 m and d = 0,3 m
  - Public inside:
    - SURFACE METHOD and VOLUME METHOD → h = 0,3 m – 1 m – 1,5 m and d = 0,3 m
  - Workers and public outside:
    - SURFACE METHOD and VOLUME METHOD → h = 0,5 m – 1,5 m – 2,5 and d = 0,3 m

- Fixed installation:
  h = 1 m or 1,5 m
  d =10 m (main line) d = 3 m (urban transport)
  AREAS CLOSED TO FIXED POWER SUPPLY INSTALLATIONS:
  Choose between two sets: h = 0,5 m – 1 m – 1,5 m or h = 0,3 m – 0,9 m – 1,5 m
  PLATFORMS: h = 0,5 m – 1 m – 1,5 m and d = 0,3 m

B.6 IEC 62493:2009 [13]

Figure B.1 – Lighting equipment and measurement distances (from [13])

Type of lighting equipment	**Measurement distance** (cm)
Hand lamps [a]	5[a]
Table lighting equipment	30
Wall lighting equipment	50
Up lighter	50
Suspended lighting equipment	50
Ceiling and/or recessed lighting equipment for fluorescent lamps with an input power[b] ≤180 W	50
Ceiling and/or recessed lighting equipment for fluorescent lamps with an input power[b] > 180 W	70
Ceiling and/or recessed lighting equipment for discharge lamps with an input power[b] ≤180 W	70
Ceiling and/or recessed lighting equipment for discharge lamps with an input power[b] > 180 W	100
Portable lighting equipment	50
Flood lights	200
Lighting equipment for road and street lighting	200
Lighting chains	50
Lighting equipment for swimming-pools and similar applications	50
Lighting equipment for stage lighting, television and film studios (outdoor and indoor)	100
Lighting equipment for use in clinical areas of hospitals and health care buildings	50
Ground recessed lighting equipment	50
Aquarium lighting equipment	50
Plug- in night lights	50
Self ballasted lamps	30
UV and IR radiation equipment	50
Transport lighting (installed in the passenger compartment of buses and trains)	50
Other lighting equipment not mentioned in this table	50

[a] Measurement distance should be 30 cm and the measured value should be calculated to a distance of 5 cm (equation; $1/r^3$).

[b] Total nominal power of the lighting equipment.

Annex C
(normative)

Measurement uncertainty

C.1 Overview

Once a valid calibration of a field meter has been performed, the number of mechanisms that can cause measurement errors is small. Sources of uncertainty that should be considered and combined with calibration uncertainties, when appropriate, are given below.

NOTE In some cases in Clauses C.2 and C.3, quantitative estimates of uncertainty are provided (e.g. effects of non-uniform fields), while in others brief guidance is given for its determination (e.g. temperature effects). For other uncertainty sources, attention only is directed to their possible influences.

C.2 Assessment of type A uncertainty

Uncertainty of calibration: the value is available in the certificate of calibration

Repeatability of measurement (see 3.4). Conditions of repeatability include:

- the same protocol of measurement;
- the same observer;
- the same meter used in the same measuring conditions;
- the same location for measurement;
- a short delay between repetitions (few minutes).

Reproducibility of measurement (See 3.5). Conditions of reproducibility include:

- different field meters or meter types;
- different protocol of measurement;
- different observers;
- different conditions of measurement;
- different time of measurement.

The coefficient of reproducibility can be determined by participating to inter-laboratories comparisons.

C.3 Assessment of type B uncertainty

C.3.1 Non-uniform field

Possibly the greatest uncertainties occur when measurements of highly non-uniform magnetic fields are made manually close to such sources as electrical appliances. Three-axis probes that do not have a common centre, e.g. in exposure meters, will sample the field at different locations. In addition, the magnetic field meter probes are normally calibrated in a nearly uniform magnetic field and are being used to measure a field that can vary as $1/d^3$ with d the distance to the source. While the centre of the probe is usually considered to be the measurement location, the magnetic field reading is actually an average of the normal component of the magnetic field over the entire cross-sectional area of the probe. In some cases, the average field can differ significantly from the central field value.

Uncertainties related to positioning the magnetic field probe more precisely with well-defined orientations may be reduced with the use of adjustable stands fabricated with non-conducting materials.

Although electric field meters are calibrated in a nearly uniform field, they may normally be used with small uncertainty for measurements in non-uniform fields. Furthermore, a minimum distance to objects shall be maintained (see 5.3). Consequently, the uncertainty caused by the non-uniformity of the electric field will be negligible for many practical cases.

C.3.2 Pass-band limitations

A limited pass-band can contribute to measurement uncertainty and lead to differences in measurement results. For example, the measurement of magnetic fields from some video display terminals (VDTs), using a power frequency field meter (i.e. a field meter with a narrow pass-band centred about 50/60 Hz), can differ by more than 20 % compared with measurements performed using field meters with broader pass-bands [24] . This occurs because the VDT magnetic field is rich in harmonics that cannot be detected with a power frequency meter. If the magnetic field contains no power frequency component, the difference or error could be much larger.

To minimize signals from the probe due to motion of the probe in the earth's magnetic field, the high-pass corner frequency of the detector circuit's filter may be increased, provided that the higher frequency does not compromise the measurements, e.g. measurements of $16^{2/3}$ Hz and 25 Hz magnetic fields from some electric trains.

C.3.3 Temperature

The influence of temperature on the operation of the field meter is another possible source of uncertainty. If extreme differences in temperature are anticipated at a measurement site, compared to the temperature at the time of calibration, the effects of ambient temperature should be known or characterised. If the temperature is outside the range recommended by the manufacturer, the influence of temperature may be determined under calibration conditions (IEC 61768-1) while the field meter is in an environmental chamber. The influence of the temperature is characterised by a multiplication factor per °C or °K.

C.3.4 Humidity

The effect of humidity is negligible on magnetic field measurement.

Humidity can have an influence on electric field meters. Under high-humidity conditions, a layer of surface condensation may form on parts of an electric field meter. The major source of uncertainty comes from handle leakage through the mounting insulation to one of the electrodes. If significant, this leakage will greatly increase the currents induced in the probe and the resulting field meter reading. A much smaller uncertainty is associated with leakage between the two sensing electrodes, which would reduce the reading of the field meter. The field meter, its handle assembly, and its internal insulation should be kept clean and dry to minimize errors due to leakage currents.

The influence of ambient humidity on the performance of electric field meters may be determined by calibration with the field meter in an environmental chamber. Effect of humidity is negligible on electric field measurement when humidity is less than 70 % (IEC 61786-1, [23])

C.3.5 Location of measurement

Measurement uncertainties can occur during measurements of non-uniform magnetic and electric fields because of uncertainty in the measurement location. The variation of the measured field B in relation to distance r can be described according to the relation

$$B = K\left(\frac{1}{r^{\alpha}}\right) \qquad \text{(C.1)}$$

where

$1 \leq \alpha \leq 3$ for most cases,

K is a constant, i.e. the alternating field has a constant rms value.

Differentiating equation (C.1) with respect to r yields

$$\partial B = B\left(-\frac{\alpha}{r}\right)\partial r \qquad \text{(C.2)}$$

Assuming a rectangular distribution for the uncertainty in r, the standard deviation in the value of B, s_d, due to uncertainties in $r(\Delta r)$ can be shown to be

$$s_d = \pm\frac{\alpha}{\sqrt{3}}\frac{\Delta r}{r}B \qquad \text{(C.3)}$$

For example, assuming a dipole magnetic field source (α = 3), Δr = 2 mm, and r = 500 mm, $s_d = \pm 0{,}007B$.

C.3.6 Long-term drift

Because of gradual changes in instrument components over time, changes in the field meter response may occur. Periodic verification of the calibration (see IEC 61786-1:2013, Clause 6) provides a means of determining the extent of long-term drifts and correction factors.

C.3.7 Instrument time constant

Another source of uncertainty is that due to the time constant of the detector circuitry. For example, if a meter with a digital display is read too soon after being placed in a high field, an erroneous reading may occur. Erroneous readings may also occur for rapidly fluctuating fields because of inadequate signal processing time.

A distinction should be made between uncertainty of measurement, which can be made quite small with proper instrument design and careful calibration, and variability of the field because of temporal and spatial variations. Temporal and spatial variations of the field can far exceed uncertainties in a measurement, and are considered in Clause 5.1.

C.3.8 Proximity effect of observer (for electric field)

The proximity of an observer is negligible if the distance between the observer and the electric field probe is greater than 2 m.

C.3.9 Correction factor

This factor is given in the certificate of calibration. For a three axis meter, it could be 1 value or 3 values (1 value being a mean). So care should be taken in the use of correction factors.

An example of the use of a correction factor is given in Annex D.

C.3.10 Hysteresis between scales

When using a field meter in automatic scale, care should be taken at changes of scales. For example, when the measured field is close to the scale value, a small variation of the field could change the scale. The measured field would then be at the lower part of the upper scale, which could induce an additional uncertainty.

Annex D
(informative)

Example of measurement uncertainty

Table D.1 gives an example of an uncertainty calculation for the measurement of magnetic field in the public area under a 50 Hz very high voltage overhead line. The measuring equipment used is a NARDA EHP-50C probe connected to a PMM 8053B with the measurement scale of 100 µT. The measurements are performed at 1 m above the ground.

The sources of uncertainty taken into account for the analysis of the measurement system are described in Annex C.

Table D.1 – Example of measurement uncertainty

Uncertainty sources	**Reference**	**Value of the uncertainty** uv_i	**Probability distribution**	**Division factor** k_i	**Sensitivity coefficient** C_i	**Standard uncertainty** $u_i = uv_i / k_i$
Statistic	**Type A**					
Calibration of EHP-50C	A1	0,50 %	Normal	2	1	0,25 %
Repetability	A2	4,00 %	Normal	2	1	2,00 %
Reproducibility	A3	4,00 %	Normal	2	1	2,00 %
Equipment	**Type B**					
Non-uniform magnetic field	B1	1,00 %	Rectangular	3,464	1	0,29 %
Pass-bad limitation	B3	1,00 %	Rectangular	3,464	1	0,29 %
Instrument time constant	B7	0,20 %	Rectangular	3,464	1	0,06 %
Long-term drift	B8	4,00 %	Rectangular	3,464	1	1,15 %
Correction factor	B10	4,00 %	Rectangular	3,464	1	1,15 %
Resolution	B11	0,01 %	Rectangular	3,464	1	0,00 %
Hysteresis of caliber	B12	0,00 %	Rectangular	3,464	1	0,00 %
Temperature	B13	0,04 %	U	2,828	1	0,01 %
Humidity	B14	0,00 %	Rectangular	3,464	1	0,00 %
Combined standard uncertainty			$u_c = \sqrt{\sum_{1}^{m} c_i^2}$			3,09 %
Expanded uncertainty (95 % confidence interval)			Normal	$u_e = 2u_c$		6,19 %
Ambient temperature: between 0 °C and 40 °C, integration time: 1 s.						

Bibliography

[1] BÖRNER, F., et al. *Electromagnetic fields at workplaces – a new scientific approach to occupational health and safety*. Bonn: Bundesministerium für Arbeit und Soziales, 2011. ISBN FB400

[2] BOTTURA, V., et al. Urban exposure to ELF magnetic field due to high-, medium- and low-voltage electricity supply networks. *Radiation Protection Dosimetry*, 2009, vol. 137, no. 3-4, p. 214-217

[3] CAOLA, R.J., et al. Measurements of Electric and Magnetic Fields in and Around Homes Near a 500 KV Transmission Line. *Power Apparatus and Systems, IEEE Transactions on*, 1983, vol. PAS-102, no. 10, p. 3338-3347

[4] CIGRE WORKING GROUP C4.203 *Technical Guide for Measurement of Low Frequency Electric and Magnetic Fields near Overhead Power Lines*. Technical Brochure n°375, 2009

[5] DIETRICH, F.M., et al. *Comparison of magnetic and electric fields of conventional and advanced electrified transportation systems.* 1993

[6] DIETRICH, F.M. AND JACOBS, *W.L. Survey and Assessment of Electric and Magnetic Field (EMF) Public Exposure in the Transportation Environment.* 1999, no. Report No. PB99-130908.

[7] DIPLACIDO, J., et al. Analysis of the proximity effects in electric field measurements. *IEEE Transactions on Power Apparatus and Systems*, 1978, vol. PAS-97, p. 2167-2177

[8] HEINRICH, H. AND BÖRNER, F. *Summation Formulae – Facts and Fiction*. The Biolectromagnetics Society 30th Annual Meeting. San Diego, 2008, p. 33-34

[9] IEC 62110:2009, *Electric and magnetic field levels generated by AC power systems – Measurement procedures with regard to public exposure*

[10] IEC 62233:2005, *Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure*

[11] IEC 62311, *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz - 300 GHz)*

[12] IEC 62369-1:2008, *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*

[13] IEC 62493:2009, *Assessment of lighting equipment related to human exposure to electromagnetic fields*

[14] IEC TS 62597:2011, *Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure*

[15] IEEE STD 644-1994, *IEEE Standard Procedures for Measurements of Power Frequency Electric and Magnetic Fields from AC Power Lines*

[16] IEEE STD 738-2006, *IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors*

[17] IEEE STD C95.1:2005, *IEEE Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz*

[18] IEEE STD C95.6:2002, *IEEE Standard for Safety Levels with respect to human exposure to electromagnetic fields, 0-3 kHz*

[19] INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION, Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). *Health Phys*, 1998, vol. 74, no. 4, p. 494-522

[20] INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION, Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines. *Health Phys*, 2003, vol. 84, no. 3, p. 383-387

[21] INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION, Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). *Health Phys*, 2010, vol. 99, no. 6, p. 818-836

[22] KAUNE, W.T., et al. Residential magnetic and electric fields. *Bioelectromagnetics*, 1987, vol. 8, no. 4, p. 315-335

[23] KORPINEN, L.H., et al. Influence of relative humidity on analyzing electric field exposure using ELF electric field measurements. *Bioelectromagnetics*, 2013, vol. 34, no. 5, p. 414-418

[24] MISAKIAN, M., et al. Measurements of power frequency magnetic fields away from power lines. *Power Delivery, IEEE Transactions on*, 1991, vol. 6, no. 2, p. 901-911.

[25] REILLY, J.P. *Applied Biolelectricity – from electrical stimulation to electropathology.* New-York: Springer, 1998. ISBN 0-387-98407-0

[26] RENEW, D.C., et al. A method for assessing occupational exposure to power-frequency magnetic fields for electricity generation and transmission workers. *Journal of Radiological Protection*, 2003, vol. 23, no. 3, p. 279

[27] SAHL, J.D., et al. Cohort and nested case-control studies of hematopoietic cancers and brain cancer among electric utility workers. *Epidemiology*, 1993, vol. 4, no. 2, p. 104-114

[28] SAVITZ, D.A. AND LOOMIS, D.P. Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers. *Am J Epidemiol*, 1995, vol. 141, no. 2, p. 123-134

[29] SWANSON, J. Measurements of static magnetic fields in homes in the UK and their implication for epidemiological studies of exposure to alternating magnetic fields. *J. Radiol. Prot*., 1994, vol. 14, no. 1, p. 67-75

[30] THERIAULT, G., et al. Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada, and France: 1970-1989. *Am J Epidemiol*, 1994, vol. 139, no. 6, p. 550-572.

[31] UK CHILDHOOD CANCER STUDY INVESTIGATORS, Exposure to power-frequency magnetic fields and the risk of childhood cancer. UK Childhood Cancer Study Investigators. *Lancet*, 1999, vol. 354, no. 9194, p. 1925-1931.

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

All the data, software and documentation set out in all British Standards and other BSI publications are the property of and copyrighted by BSI, or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI. Details and advice can be obtained from the Copyright & Licensing Department.

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™