BS EN 50554:2010

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Basic standard for the in-situ assessment of a broadcast site related to general public exposure to radio frequency electromagnetic fields

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National foreword

This British Standard is the UK implementation of EN 50554:2010.

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.

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Basic standard for the in-situ assessment of a broadcast site related to general public exposure to radio frequency electromagnetic fields

Norme de base pour l'évaluation in-situ de l'exposition du public aux champs électromagnétiques de radiofréquence d'un site de radiodiffusion

Grundnorm für die Bewertung eines Rundfunkstandorts vor Ort in Bezug auf die Exposition der Allgemeinbevölkerung gegenüber hochfrequenten elektromagnetischen Feldern

This European Standard was approved by CENELEC on 2010-11-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

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

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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 106X, Electromagnetic fields in the human environment.

The text of the draft was submitted to the Unique Acceptance Procedure and was approved by CENELEC as EN 50554 on 2010-11-01.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-11-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2013-11-01

Contents

1 Scope **4**

2 Normative references **4**

3 Terms and definitions **4**

4 Assessment fundamentals **6**

4.1 Level of protection 6
4.2 Worker/public exposure 6
4.3 Stakeholders 7
4.4 Actions required 7
4.5 Simultaneous exposure to fields at different frequencies 7
4.6 Area to perform a detailed assessment 8

5 Assessment methodology in the relevant domain when the exposure situation changes **8**

5.1 Introduction 8
5.2 Determination of the Threshold Distance (*TD*) 8
5.3 Area definition 8
5.4 Assessment 9
5.5 How to take inaccuracy into account 10
5.6 Report of the assessment 11

Annex A (informative) **Example of a simple method for estimation of the safety distance from a broadcast site** **12**

Annex B (informative) **Assessment procedure in Germany and in Italy** **14**

B.1 Assessment procedure in Germany 14
B.2 Assessment procedure in Italy 15

Bibliography **17**

Figures

Figure 1 — Area definition 9

Figure A.1 — Pattern of antennas 12

Figure A.2 — Safety distances for two antennas on the left side and one antenna on the right side 13

1 Scope

This basic standard specifies the method for assessing overall exposure from all fixed radio frequency sources at a broadcast site. This assessment may be applied at any time but must be carried out when the exposure situation changes in or around this site.

It plays an essential role in the coordination of different stakeholders, with respect to ensuring EMF exposure compliance in and around a broadcast site especially for equipment installed within the site.

2 Normative references

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

EN 50383, *Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz – 40 GHz)*

EN 50413, *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)*

EN 50492, *Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations*

EN 50496, *Determination of workers' exposure to electromagnetic fields and assessment of risk at a broadcast site*

3 Terms and definitions

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

3.1
basic restriction
restriction on exposure to time-varying electric, magnetic, and electromagnetic fields that is based directly on established health effects

NOTE In the frequency range from 30 MHz to 10 GHz, the physical quantity used is the specific absorption rate. Between 10 GHz and 40 GHz, the physical quantity is the power density.

3.2
broadcasting service
radiocommunication services in which the transmissions are intended for direct reception by the general public

NOTE This service may include sound transmissions, television transmissions or other types of transmission.

3.3
broadcast site
site where one or more broadcast transmitters are operated

3.4
controlled area
area in which the operator may decide who is permitted to enter or remain or an area which, due to actual circumstances, the public is prohibited from entering

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3.5
employer
natural or legal person who has an employment relationship with the worker and has responsibility for the undertaking and/or establishment

[Directive 89/391/EEC [4]]

3.6
Exposure Ratio
ER
for an individual source, between 100 kHz to 10 GHz:

$$ER = MAX\left[\left(\frac{E}{EL}\right)^2, \left(\frac{H}{HL}\right)^2\right];$$

between 10 GHz and 40 GHz:

$$ER = \left(\frac{S}{SL}\right)$$

where

ER is the exposure ratio at frequency f for the source;

EL is the investigation E-field reference level at frequency f;

HL is the investigation H-field reference level at frequency f;

E is the assessed E-field at frequency f for the source;

H is the assessed H-field at frequency f for the source;

SL is the power flux density limit at frequency f;

S is the assessed power flux density at frequency f for the source;

f is the frequency of the source

3.7
Member States
European Community Member States

3.8
reference levels
reference levels of exposure are provided for comparison with measured values of physical quantities; compliance with all reference levels given in these guidelines (Council Recommendation 1999/519/EC [2]) will ensure compliance with basic restrictions

NOTE If measured values are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to assess compliance with the basic restrictions.

3.9
relevant domain
in the absence of a national or local definition, domain surrounding the site where the sum of the exposure ratios from all sources of the site shall be more than 5 % at some height

3.10
relevant source
the principle of relevance establishes the conditions under which a radio source is considered relevant such that account has to be taken of the contribution of that source when assessing RF exposure

NOTE In the absence of a national or local definition, the relevant source is a fixed radio source, in the frequency range 100 kHz to 40 GHz, which has an exposure ratio more than 5 % in the relevant domain.

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3.11
site operator
party controlling access to the controlled area

3.12
Stakeholder
SH
party involved in the process of this European Standard in accordance with the local or national legislation

NOTE More than one stakeholder can be concerned (national authority, licence holder, broadcaster, site operator, etc.).

3.13
Threshold Distance
TD
minimum distance in a given direction, beginning from the boundary of the controlled area, at which compliance with reference level is achieved at all heights when considering emissions from the site alone

3.14
worker
person employed by an employer, including trainees and apprentices but excluding domestic servants

[Directive 89/391/EEC [4]]

4 Assessment fundamentals

4.1 Level of protection

In Council Recommendation 1999/519/EC [2], it is stated:

"II. Member States, in order to provide for a high level of health protection against exposure to electromagnetic fields, should:

(a) adopt a framework of basic restrictions and reference levels using Annex I.B as the basis;

(b) ...

(c) aim to achieve respect of the basic restrictions given in Annex II for public exposure."

and

"(15) Member States may, in accordance with the Treaty, provide for a higher level of protection than that set out in this recommendation;"

In consequence, national or local relevant regulations define the level of protection for applying this European Standard, expressed in basic restrictions and/or reference levels.

4.2 Worker/public exposure

In [2], it is stated:

"(14) In accordance with the principle of proportionality, this recommendation provides general principles and methods for the protection of members of the public while leaving it to the Member States to provide for detailed rules as regards the sources and practices which give rise to exposure to electromagnetic fields and the classification, as work-related or not, of conditions of exposure of individuals, in accordance with Community provisions concerning the safety and health protection of workers;"

Worker exposure at broadcast sites is dealt with in EN 50496 in accordance with Directives 2004/40/EC and 2008/46/EC [3].

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4.3 Stakeholders

In [2], it is stated:

"II. Member States, in order to provide for a high level of health protection against exposure to electromagnetic fields, should:

(a) ...

(b) implement measures according to this framework,...;"

and

"III. Member States, in order to facilitate and promote respect of the basic restrictions given in Annex II:

(a) ...

(b) should evaluate situations involving sources of more than one frequency in accordance with the formulae set out in Annex IV, both in terms of basic restrictions and reference levels;"

In consequence, national or local relevant regulations define the stakeholders responsible for applying this European Standard.

Potentially involved stakeholders:

a) site owner;

b) licence holder;

c) national authority;

d) technical operator;

e) community representatives;

f) broadcaster;

g) local authority;

h) content provider;

i) party originating the change;

j) assessment manager;

k) measurement laboratory.

4.4 Actions required

In [2], it is stated:

"IV. Member States should consider both the risks and benefits in deciding whether action is required or not, pursuant to this recommendation, when deciding on policy or adopting measures on exposure of members of the public to electromagnetic fields."

4.5 Simultaneous exposure to fields at different frequencies

In Annex IV of [2], it is stated:

"In situations where simultaneous exposure to fields of different frequencies occurs, the possibility that these exposures will be additive in their effects must be considered."

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Simultaneous exposure to fields of different frequencies is the common case at broadcast sites and has to be taken into account during the public and worker exposure assessment.

If a national or local relevant regulation treating multiple sources is available then this regulation shall be applied. If not, a threshold level has to be set, linked with the level of protection: each relevant source needs to be included to evaluate its influence.

4.6 Area to perform a detailed assessment

In [2], it is stated:

"(9) This recommendation ... therefore applies, in particular, to relevant areas where members of the public spend significant time in relation to the effects covered by this recommendation;"

Every place where the public and/or workers can access needs to be assessed. The emissions from a broadcast site only need to be taken into account within its relevant domain.

5 Assessment methodology in the relevant domain when the exposure situation changes

5.1 Introduction

Change is defined as a variation in the exposure situation which has not been previously assessed.

5.2 Determination of the Threshold Distance (*TD*)

The *TD* is the minimum distance out from the boundary of the controlled area at which compliance with the basic standards (EN 50413 and EN 50383) is achieved at all heights when considering emissions from the site alone. EN 50413 and EN 50383 give the methodology for determining the threshold distance using the radiation pattern of the antennas.

The *TD* shall be determined by the broadcast operator of the highest authorized ERP value on the site.

In the absence of data to carry out the required calculation, the threshold distance can be defined by using a worst case configuration of the services.

An example of a simple method for estimation of the *TD* from a broadcast site is described in Annex A.

5.3 Area definition

Assessment of the overall exposure can be made by many stakeholders.

The analysis is split into three areas:

l) area A: inside the controlled area;

m) area B: outside the controlled area of the site but within the threshold distance;

n) area C: outside the threshold distance but inside the relevant domain.

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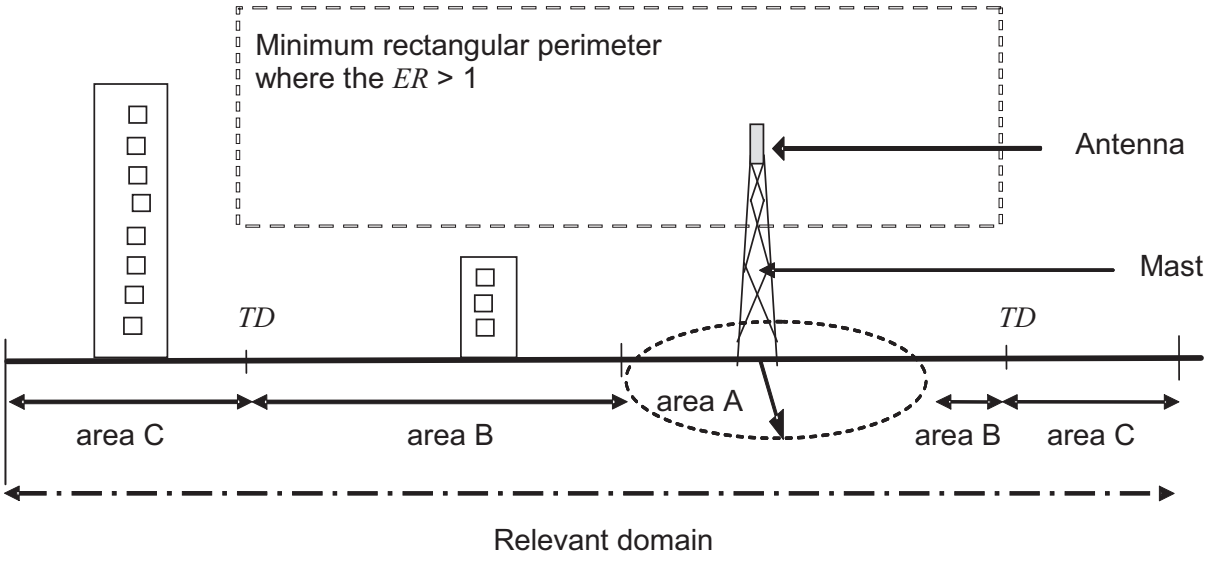

Figure 1 — Area definition

In the absence of national rules, these areas are used to define the parties responsible for collating the relevant data and also for carrying out the assessment.

5.4 Assessment

5.4.1 General

The stakeholder in charge of the assessment is defined in accordance with national rules (see Annex B for German and Italian examples). This responsible stakeholder may not be unique for all areas. As an example, the result of the assessment in area A, carried out by a site owner, could be an input to a telecom operator assessing areas A, B and C following a change in its equipment configuration.

5.4.2 For area A

In the absence of national rules the stakeholders in charge of the assessment will be the site operator or the broadcast operator.

The site operator is responsible for gathering the data required for the assessment within area A from:

o) characteristics of services from other stakeholders;

p) worst case characteristics of services.

In accordance with national regulations, the site operator has to inform people accessing the site.

The stakeholder in charge of the assessment will use the EN 50496.

The assessment will be carried out as often as this is deemed necessary.

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5.4.3 For area B

In the absence of national rules the stakeholders may be the service operator, the site operator, and local and/or national authorities.

In the absence of national rules, the site operator is responsible for gathering the data required for the assessment within area B including:

q) RF data from the site (similar to the data collected for area A);

r) RF data from signals originating outside the site (to collect from national or local authorities) or the worst case characteristics of these services;

s) environment information such as building planning applications, exclusion areas following local rules, etc.;

t) measurement data (according to EN 50492) if available or make a survey, testing the areas around installations with wideband or selective measurement equipments.

In the case where areas B of different sites overlap, site operators should share the information.

In the absence of national rules, the assessment will be carried out following the methodologies chosen from EN 50413 and EN 50492. In cases where there is more than one operator on the site:

u) if the exposure change results from a change in emission characteristics, then the operator responsible for the change will be responsible for gathering the data/carrying out the assessment;

v) if the exposure change results from an environmental change, then the broadcast operator giving rise to the highest contributions will be responsible.

Generally, theoretical exposure assessment should be performed before any environmental change authorization. If the assessment shows that exposure is over the limits, the operator doing the assessment alerts the other parties. Together, all parties will determine a way to comply.

The operator carrying out the assessment writes the report and communicates the result to the site operator.

The site operator keeps a record of the report until the next change.

5.4.4 For area C

Area C results in determination of ER and TD during assessment for area B.

The same approach as in area B should be used. However, in this case, the data collection does not include environmental information.

Assessment for areas B and C can be done together in only one report

5.5 How to take inaccuracy into account

This European Standard is written as a guideline based on data availability; the relevance of the data has to be evaluated in a risk assessment taking the accuracy of the data into account.

Where there are relevant National or Local regulations or guidance, then these must be complied with when taking uncertainty into account.

Additional information regarding methods for dealing with uncertainty is given in EN 50413.

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5.6 Report of the assessment

The results of each assessment and all information necessary for the interpretation of this assessment shall be reported accurately, clearly, unambiguously and objectively and in accordance with this European Standard.

The typical structure of the assessment report will be

a) generality;

b) reason for the assessment;

c) general situation of the site:

   1) data collection used for the assessment;
   2) local maps, excerpts from the local development or zoning plan, showing the land and buildings adjacent to the site);
   3) a building plan or sketch of the structure with dimensions (side view and top view), showing the mounting position of the radio equipments;
   4) diagrams of the antennas to be used;

d) limits and normative references used for the assessment;

e) results;

f) annex: photographic documentation.

In the case of measurements:

g) the measurement location shall be described in order to identify the points where measurements have been performed;

h) the environmental conditions (minimum information on weather, time & date and the name of the person responsible for the measurement, etc.), time and date shall be provided and the name of the person;

i) relevant information on the settings, characteristics of equipment and probes and their calibration shall be recorded;

j) the measurement protocol used shall be reported;

k) the uncertainty analysis and the uncertainty assessment shall be reported.

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Annex A
(informative)

Example of a simple method for estimation of the safety distance from a broadcast site

The described method allows a quick estimation of safety distances at a site with several antenna systems and transmitters. The result is a worst case, i.e. the more exact the method is or the more details you have the more realistic the result will be.

The idea is to assume that all antennas are concentrated at one point, at the height of the lowest antenna in the area of assessment. Thus we can sum the effect of the various contributions by determining the root sum of the squares (r.s.s.) of field strengths (and similarly for the safety distances, which have a similar relationship).

Data required for each frequency are

a) transmitter power P;
b) antenna gain G;
c) cable / other losses a;

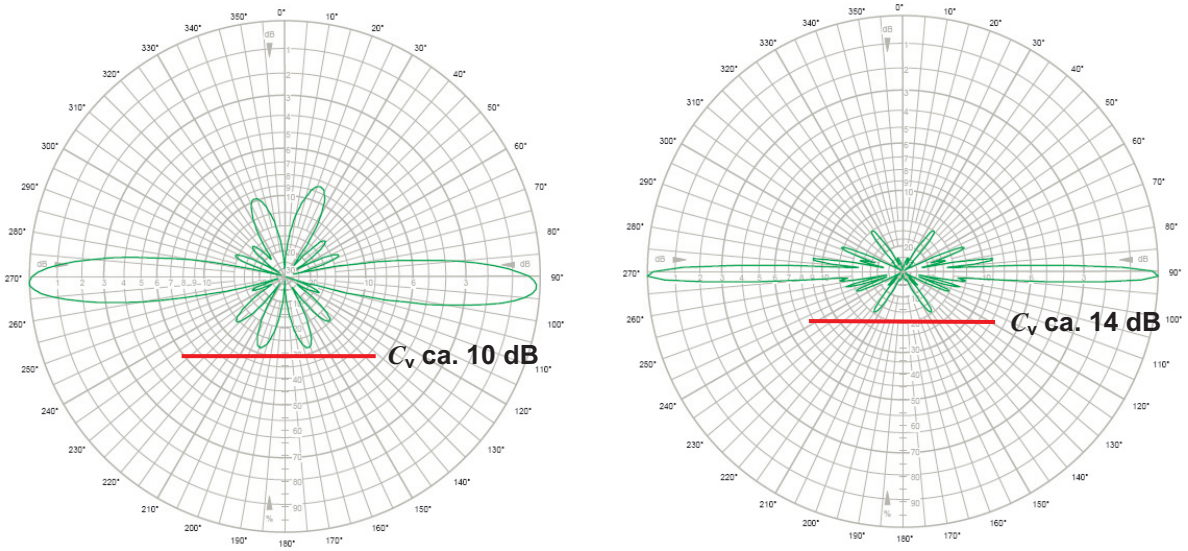
} or the Effective Radiated Power ERP of the antenna respectively

d) horizontal and/or vertical pattern to obtain C_h / C_v;
e) distance of the lowest and highest edge of the antenna above ground h_{ant};
f) reference field strength E_{ref}.

Determination of antenna factor C_h / C_v:

– C_h = 1 for omnidirectional antennas and if no horizontal pattern is available.
Otherwise, take C_h from the pattern in the direction of interest.

– C_v = 1 if no vertical pattern is available.
Otherwise, take C_v from the polar diagram of the radiation pattern, with linear scale as vertical distance from the lowest part of any lobe from the horizontal line (see examples in Figure A.1).



a) With directivity C_h = 1 & C_v = 0,31 (10 dB) **b) With directivity C_h = 1 & C_v = 0,2 (14 dB)**

Figure A.1 — Pattern of antennas

By using the general far field formulas

$$E = \sqrt{\frac{Z_0}{4\pi}} \cdot \frac{\sqrt{ERP}}{r} \cdot C$$

the horizontal and vertical distance for one emission (one frequency) can be calculated:

$$r_h = \sqrt{\frac{Z_0}{4\pi}} \cdot \frac{\sqrt{ERP}}{E_{ref}} \cdot C_h$$

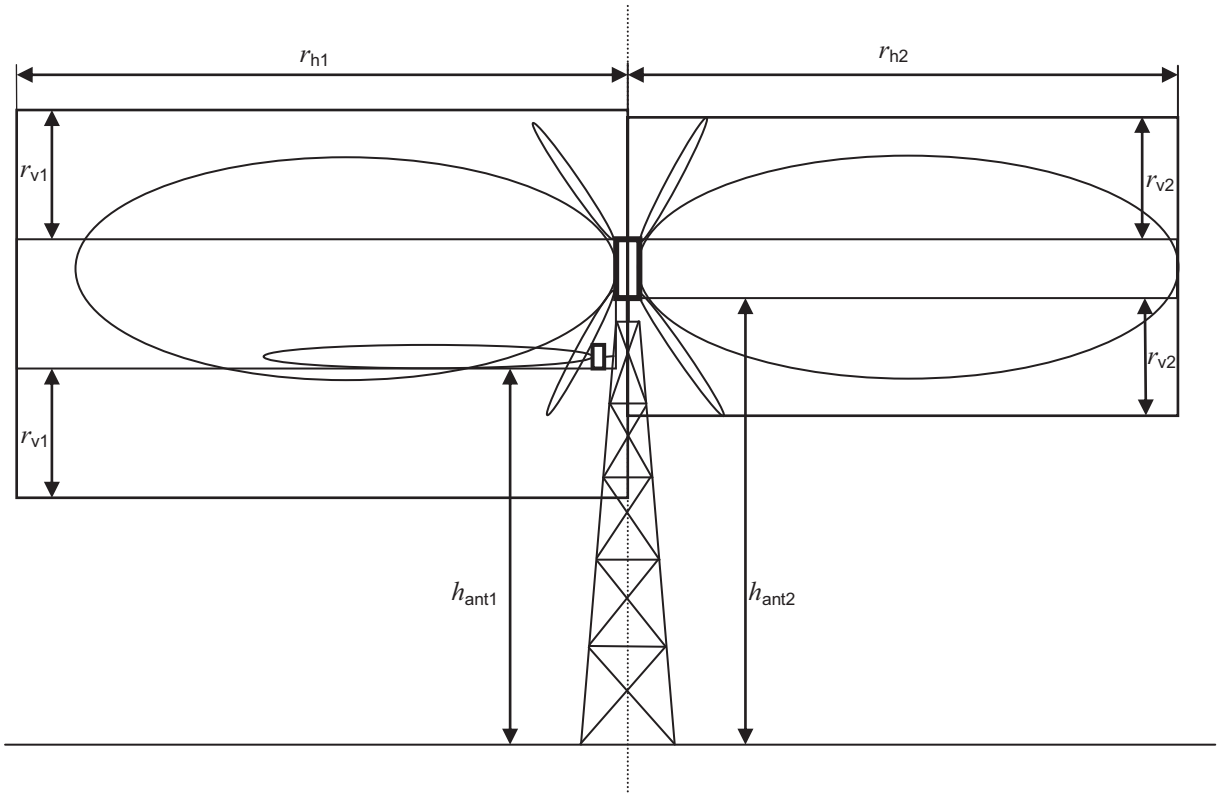
$$r_v = \sqrt{\frac{Z_0}{4\pi}} \cdot \frac{\sqrt{ERP}}{E_{ref}} \cdot C_v$$

Then, for n frequencies, the resulting safety distance from the lowest (highest) antenna is:

$$r_h = \sqrt{\sum_n (r_{hn}^2)} = \sqrt{\frac{Z_0}{4\pi}} \cdot \sqrt{\sum_n \left(\frac{ERP_n}{E_{refn}^2} \cdot C_{hn}^2\right)}$$

$$r_v = \sqrt{\sum_n (r_{vn}^2)} = \sqrt{\frac{Z_0}{4\pi}} \cdot \sqrt{\sum_n \left(\frac{ERP_n}{E_{refn}^2} \cdot C_{vn}^2\right)}$$

As an example, Figure A.2 shows the safety distances for two antennas on the left side and for one antenna on the right side.



EXAMPLE Resulting safety distances at a broadcast site. The horizontal safety distance r_h corresponds to the Threshold Distance TD.

Figure A.2 — Safety distances for two antennas on the left side and one antenna on the right side

Annex B
(informative)

Assessment procedure in Germany and in Italy

B.1 Assessment procedure in Germany

In Germany fixed radio equipment having an EIRP of 10 W or more is taken into service on the basis of the Radio Equipment and Telecommunications Terminal Equipment Act (FTEG). The authority issuing the site certificates and also doing the assessment is the German Federal Network Agency (BNetzA).

The Ordinance concerning the Controls for the Limitation of Electromagnetic Fields (BEMFV) issued by virtue of this Act on 20 August 2002 describes the procedure of taking fixed radio equipment into service and guarantees that the protection of the population exposed to electromagnetic fields is ensured.

Reference levels are shown below, as an excerpt from the EMF Controls Ordinance (BEMFV).

Section 3 of the Ordinance

For the limitation of electromagnetic fields from fixed radio transmitters, compliance with the following values, as limits, is required:

1. the limits set in the Electromagnetic Fields Ordinance – the 26th Ordinance Implementing the Federal Emission Control Act –; and

2. unless otherwise provided in the Federal Emission Control Act or detailed Ordinance, the reference levels in Table 2 of Annex III of Council Recommendation 1999/519/EC [2]; and

3. in addition, for the band 9 kHz to 50 MHz, the permissible values for active medical devices under the draft German standard DIN VDE 0848-3-1 [6].

The applicant for running a new transmitter site supplies BNetzA with all the required information (power, frequency, location, radiation pattern, antenna height, direction, etc.) for the site and applies for a site certificate.

BNetzA runs a database containing all sites with transmitters (with EIRP > 10 W) in Germany. The relevant data from the database, together with the applicant's information, are used to assess the site. Also, BNetzA consults primary users of the spectrum e.g. broadcasters and broadcast operators.

If the cumulated field values including the new transmitter and the incumbent services are below the limits according to national and international regulation and there are no objections from the primary users, BNetzA will issue the site certificate.

Otherwise, the applicant will be informed of a negative decision and is not authorized to run the transmitter.

For detailed information about the procedure, refer to the “Order on the procedure for providing proof as regards limiting exposure to electromagnetic fields [German designation: BEMFV]”.

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B.2 Assessment procedure in Italy

B.2.1 Assessment procedure in Italy: area A

The Italian regulation, which gives guidance on the evaluation of electromagnetic fields in the work place establishes that:

– measurements and assessments in work places have to be performed according to the guidelines of CENELEC standards;

– CEI (Comitato Elettrotecnico Italiano: the Italian National Committee) and ISPESL (the National Institute for Workplace Safety and Prevention) guidelines can be used as a reference in case the relevant CENELEC standard is missing;

– CEI will set a dedicated working group to develop its own guidance, based on existing national and international documents;

– ISPESL will collect data to produce a procedure for carrying out assessments in the work place, with the objective to evaluate all the physical agents considered dangerous for possible health effects in the work place, not just electromagnetic fields arising from broadcast fixed source.

B.2.2 Assessment procedure in Italy: areas B and C

In areas B and C, the national law L. 36/2001 and the decree DPCM 08/07/2003 are applied. These are both laws specifically tailored on the general public, thus in places where people can stay more than 4 h the applicable level is 6 V/m, otherwise the reference levels are 20 V/m from 3 MHz to 3 GHz or 60 V/m from 100 kHz to 3 MHz.

The responsibility for health and environmental surveillance, evaluating electromagnetic fields levels around installations, is held by the local Authorities (Town Council and Districts), through the technical local bodies of the Ministry of Environment (ARPA), as stated from the law L.36/2001, art. 14.

Generally ARPA makes its own tests, first assessing the field levels in the areas around the installations with wideband measurements. According to normative standard CEI 211-7 [7], where the measured value is above the 75 % of the reference level (i.e. above 4,5 V/m when the limit is set at 6 V/m), selective (narrow band) measurements shall be performed to verify the contribution of each single emission.

Then, if the applicable limit is exceeded, according to DPCM 08/07/2003, all parties involved (ARPA and the broadcaster) shall meet to perform simultaneous measurements and confirm the measured values. During these measurements the **Ministry of Economic Development – Communication Department** (through its local Departments: “Ispettorati”) verifies the compliance of transmitting conditions to the licence.

Eventually ARPA provides the so-called “reduction coefficients”, following the rules stated in Annex C of DPCM 08/07/2003: first of all, each contribution which, by itself, exceeds the reference level will be reduced to a value of 0,8 of the applicable exposure level. If this reduction is not sufficient to enable compliance with the limits established in the law, a further reduction is applied to all contributions exceeding the 10 % of the applicable level.

ARPA sends its official report to the local Authorities, and with reference to this report, the local Authority requires the involved subjects to reduce the electromagnetic field generated by them; where applicable, the Authority also imposes administrative sanctions.

At this point the broadcaster can decide either to comply or to appeal against the reduction order.

Whenever a new transmitter needs to be installed, the operators must first apply to **Ministry of Economic Development – Communication Department** for the frequency authorization, then they need to apply to local Authorities for the building and electromagnetic authorizations. The local authorities will seek the advice of ARPA, which will be delivered on the basis of the radioelectric project and on the basis of the results of the measurements of the existing environmental electromagnetic fields, either submitted by the operator or autonomously made by ARPA. In all cases when the installation is completed ARPA will verify if the real situation is compliant with the reference level.

For detailed information about the procedures, refer to the following:

– L.Q. 36/2001: is the outline law which establishes the reference frame for the general public exposure to electromagnetic fields. It defines the responsibilities of Italian State, Regions, Districts, Town Council and surveillance authorities like ARPA, APAT or ENEA. It also establishes general rules for compliance, economic sanctions and how to arrange long term improvement plans.

– Decree DPCM 08/07/2003: this is the decree containing specific rules to apply L.Q 36/2001. It defines the limits and the mathematical formula to establish the compliance when multiple sources are involved.

– Regional laws: Law L.Q. 36/2001 gives to the Regions the task to issue specific laws in which the competences of Districts and Town Councils are established, the areas where transmitting sites can be built are identified, the rules to set up and manage an “Electromagnetic Sources Registry” are defined.

– CEI 211/7 [7]: it is the reference guide, issued by CEI, and it contains measurement methods for the assessment of electromagnetic fields in the frequency range from 10 kHz to 300 GHz; it also includes many other useful information. This guide is referred to in the decree DPCM 08/07/2003, therefore its application is mandatory.

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Bibliography

[1] International Commission on Non-Ionizing Radiation Protection, *Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)*, Health Physics Vol. 74, No 4, pp. 494-522, 1998

[2] *Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), OJ L 199, 30/07/1999, pp. 59-70*

[3] *Directive 2008/46/EC of the European Parliament and of the Council of 23 April 2008 amending Directive 2004/40/EC on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)*, OJ L 114, 26.4.2008, pp. 88-89

[4] *Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work*, OJ L 183, 29.6.1989, pp. 1-8

[5] EN 50400, *Basic standard to demonstrate the compliance of fixed equipment for radio transmission (110 MHz – 40 GHz) intended for use in wireless telecommunication networks with the basic restrictions or the reference levels related to general public exposure to radio frequency electromagnetic fields, when put into service*

[6] DIN VDE 0848-3-1:1999/A1:2001, *Safety in electrical, magnetic and electromagnetic fields — Part 3-1: Protection of persons with active implants in the frequency range 0 Hz to 300 GHz*

[7] CEI 211-7, *Guide for electric and magnetic fields measurement and for valuation in the frequency range 10 kHz – 300 GHz, in reference to human exposure*

[8] ITU-R Recommendation BS.1698 (2005), *Evaluating fields from terrestrial broadcasting transmitting systems operating in any frequency band for assessing exposure to non-ionizing radiation*

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