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Standards for procedures for measuring and calculating electromagnetic fields that may affect human

Miljan Vasković[1], Goran Mrkaja[1]

1 Institute for Standardization of BiH, East Sarajevo, Bosnia and Herzegovina

E-mail address: miljan.vaskovic@isbih.gov.ba, goran.mrkaja@isbih.gov.ba

Abstract—**The paper presents the key features of the standards relating to measurements and calculations of electric and magnetic fields that may affect human health, with an emphasis on low-frequency radiation. Theoretical calculation methods and general knowledge related to levels and exposure to electromagnetic radiation in areas of the environment where human health may be affected are presented. Recommendations from European and international organizations for protection against non-ionizing radiation, as well as regulations at the national level, are given.**

Keywords-standard; electromagnetic field; electromagnetic radiation limits; law, regulations and recommendations; health protection;

I. Introduction

Electromagnetic radiation is a combination of oscillating electric and magnetic fields that propagate through space via electromagnetic waves. There is an electric field near every charged body, and a magnetic field is created around a conductor through which an electric current flows.

Electricity is present in all places where humans live, work and move, which means that humans, as well as other living beings, are exposed to the influence of electromagnetic radiation of varying intensity. Due to the emergence of an increasing number of sources of electromagnetic radiation, in recent decades, great attention has been paid to studying the influence of electromagnetic fields on living beings, primarily on humans. Based on the results of research, organizations such as the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNRP), the International Radiation Protection Association (IRPA) and others issue recommendations that, among other things, establish limit values for the intensity of electric and magnetic fields to which living beings can be exposed without this exposure affecting their health..

Electromagnetic fields can have direct and indirect effects on the human body. The effect of electromagnetic fields on the human body depends on the frequency, with low-frequency fields being able to affect the nervous system, while high-frequency fields can cause thermal effects on certain parts of the body. In addition to these direct effects, there are several indirect effects such as the occurrence of contact currents or the possible impact on the operation of active medical implants.

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Exposure assessments can be based either on reference levels (action levels) or on a basic restriction (exposure limit value) taking into account the specific characteristics of the particular field source or device being assessed.

The range for low-frequency measurements is from 1 Hz to 100 kHz, the range for intermediate-frequency measurements is from 100 kHz to 10 MHz, and the range for high-frequency measurements is from 10 MHz to 300 GHz. Note: The basic physiological effects of electromagnetic fields on the human body do not have a sharp frequency cut-off value to distinguish stimulation from thermal effects, which should be taken into account when choosing measuring equipment. [1]

II. Brief Overview and Basic Characteristics of the Standard for Measurement and Calculation of Electromagnetic Radiation

BAS EN 50413:2021 - *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz)* (EN 50413:2019, IDT - *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz)*)

The standard contains general methods for the measurement and calculation of quantities related to human exposure to electromagnetic fields in the frequency range from 0 Hz to 300 GHz. It is intended in particular for the assessment of emissions from various sources and comparison with the exposure limits for the general public given in Council Recommendation 1999/519/EC, as well as for the exposure of professionals at work, to determine compliance with the requirements of Directive 2013/35/EU, where appropriate. This standard deals with quantities that can be measured or calculated outside the human body, in particular electric and magnetic field strengths or power densities, and also includes the measurement and calculation of quantities inside the human body which form the basis for guidance on protection. The standard provides information on:

- definitions and terminology,
- characteristics of electromagnetic fields,
- measuring exposure amounts,
- instrument requirements,
- calibration methods,
- measurement techniques and procedures for exposure assessment,
- calculation methods for exposure assessment.

In case an applicable standard for the electromagnetic field exists, especially for a specific product or technology, it is expected to be used instead of this document. BAS EN IEC 62311:2021, Table 1 provides a list of relevant standards. [1]

BAS EN 61786-1:2015; prBAS EN 61786-1/A1:2025 - *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* (EN 61786-1:2014, IDT; IEC 61786-1:2013, IDT; EN 61786-1:2014/A1:2024, IDT; IEC 61786-1:2013/AMD1:2024, IDT - *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*)

This part of IEC 61786 gives guidelines for measuring instruments used for measuring field strength levels in quasi-static magnetic and electric fields with frequencies in the range of 1 Hz to 100 kHz, as well as DC magnetic fields, for the purpose of assessing the human body's exposure levels to these fields. The sources of the fields are devices operating at mains frequencies and generating power and supply frequency harmonic fields, as well as devices that generate fields in the frequency range specified in this document, including devices that produce static fields. The Earth's static magnetic field is also considered a source of the field.

The measurement range covered by this standard is 0.1 μT to 200 mT in AC (1 μT to 10 T in DC) for magnetic fields and 1 V/m to 50 kV/m for electric fields. For measurements outside this range, most of the provisions of the standard still apply, but with special attention to the determination of measurement uncertainty and calibration procedures. In particular, this standard:

- defines terminology;
- requests specifications for measuring devices;
- indicates calibration methods;
- defines requirements for instrumentation uncertainty;
- describes the general characteristics of the field;
- describes the principles of instrumentation.

Note: Measurement methods that achieve the defined objectives of human exposure assessment are described in IEC 61786-2.

The first editions of IEC 61786-1 and IEC 61786-2 replace IEC 61786 from 1998. Part 1 deals with measuring instruments and Part 2 deals with measurement procedures. The standard also identifies sources of uncertainty during calibration. With regard to electric field measurements, the standard only considers the measurement of undisturbed electric field strengths, at a point, in free space or above conductive surfaces. [12]

prBAS IEC 61786-2:2025 - *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* (IEC 61786-2:2014, IDT - *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*)

Part 2 of the IEC 61786 standard provides requirements for the establishment of measurement procedures that achieve defined measurement objectives, which relate to human exposure.

Note: Oil measurement and calibration requirements are described in IEC 61786-1.

Due to differences in the characteristics of the fields from sources in different environments, e.g. frequency range, temporal and spatial variations, polarization and magnitude, and differences in measurement objectives, the specific measurement procedures will be different in different environments.

Examples of measurable field sources covered by this standard:

- devices operating at mains frequencies (50/60 Hz), mains frequency plants and mains frequency harmonic fields (transmission lines, electrical devices, household appliances...);
- devices that generate fields that are independent of the mains supply frequency (electric railways (DC up to 20 kHz), commercial aircraft (400 Hz), induction heaters (up to 100 kHz) and electric vehicles);
- devices that produce static magnetic fields: MRI, DC power lines, DC welding, electrolysis, magnets, electric furnaces, etc. DC currents are often generated by converters, which also generate AC components (harmonics of the mains frequency), which should be taken into account.

Sources of uncertainty during measurement are also identified and instructions are given on how they should be combined to determine the total measurement uncertainty. [13]

BAS EN 62110:2010; BAS EN 62110/Cor1:2016 - *Electric and magnetic field levels generated by AC power systems - Measurement procedures with regard to public exposure* (EN 62110:2009, IDT; IEC 62110:2009, IDT; EN 62110:2009/AC:2015, IDT; IEC 62110:2009/COR1 :2015, IDT - *Electric and magnetic field levels generated by AC* *power systems - Measurement procedures with regard to public exposure*)

The standard establishes procedures for measuring the levels of electric and magnetic fields generated by AC power systems in order to assess the level of human exposure to these fields. This standard does not apply to portable DC systems. The standard applies to human exposure in both domestic and publicly accessible areas.

The standard specifies basic procedures for measuring fields, and in terms of human exposure, for obtaining a field value corresponding to a spatial average for the entire human body.

The standard is not applicable to professionals and their exposure related to, for example, the operation and/or maintenance of energy systems. Such exposure may be experienced by professionals working in a distribution or transmission substation, a power plant, in a shaft or tunnel with underground cables or on an overhead transmission line. The content of the 2016 correction has been incorporated into the standard. [14]

BAS EN IEC 62311:2021 - *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz – 300 GHz)* (EN IEC 62311:2020, IDT; IEC 62311:2019, IDT - *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300 GHz)*)

The standard applies to electronic and electrical equipment for which a dedicated product standard or product family standard relating to human exposure to electromagnetic fields does not apply. It covers equipment with intentional or unintentional radiation, as well as a combination thereof.

Provides assessment methods and criteria for the evaluation of equipment against human exposure limits associated with electric, magnetic and electromagnetic fields. The frequency range covered is from 0 Hz to 300 GHz.

The document does not list restrictions expressed in terms of baseline restrictions and/or reference levels. Such restrictions are subject to the assessment scheme applied, for example through regional restrictions.

This release includes the following significant technical changes compared to the previous release:

- a clear distinction was introduced between intentional and unintentional radiation;
- exposure to non-uniform fields is considered;
- improved handling of uncertainty for ratings;
- different addition modes are described in the Annex;
- data from the basic standards published in the meantime were used and therefore all informative annexes from the previous edition were removed. [15]

BAS ISO/IEC Guide 98-3:2015 - *Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)* (ISO/IEC Guide 98-3:2008, IDT - *Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*)

This Guide establishes general rules for estimating and expressing measurement uncertainty that can be monitored at different levels of accuracy in many aspects - from operational measurements to fundamental research. It is therefore intended that the principles of this Guide will be applicable to a wide range of measurements, including those required for:

- maintaining quality control and quality assurance in production;
- compliance with and enforcement of laws and regulations;
- conducting basic research and applied research and development in science and engineering;
- calibration of standards and instruments and performance of tests within the national measurement system, in order to achieve traceability to national standards;
- development, maintenance and comparison of international and national reference standards, including reference regulations.

This guide is primarily concerned with expressing the uncertainty in the measurement of previously defined physical quantities - measurands - that can be characterized by a single value. If the quantity of interest can only be represented as a distribution of values or is dependent on one or more parameters, such as time, then the measurand required for its description is a set of quantities that describe that distribution or that dependence.

The Guide provides general rules for the assessment and expression of measurement uncertainty and detailed guidance specific to the technology. Once the uncertainty of a particular measurement result has been assessed, it can be used for a variety of purposes, for example, to draw conclusions about the compatibility of that result with other similar results, to establish tolerance limits in a manufacturing process, or to decide whether a particular action can be safely taken. It may therefore be necessary to develop specific standards based on this Guide to deal with problems specific to particular areas of measurement or with different uses of quantitative expressions of uncertainty. These standards may be simplified versions of this Guide, but should contain details appropriate to the level of accuracy and complexity of the measurements and uses concerned. [16]

BAS EN IEC 62232:2024 - *Determination of RF field strength, power density and SAR in the vicinity of base stations for the purpose of evaluating human exposure* (EN IEC 62232:2022, IDT - *Determination of RF field strength, power density and SAR in the vicinity of base stations for the purpose of evaluating human exposure*)

The standard deals with the assessment of RF field strength, power density and specific absorption rate levels in the vicinity of base stations (BS), also called products or equipment under test (EUT), radiating in the radio frequency (RF) range from 110 MHz to 300 GHz in accordance with the scope, clause 1 of the standard. It does not deal with the assessment of current density.

The methods for assessing exposure to radiofrequency waves to be used for product compliance, product installation compliance and site exposure assessments are specified in this document. Exposure limits are not specified in this document. The assessment of exposure to radiofrequency waves, carried out by the entity, refers to the set of exposure limits that apply where the exposure occurs. Examples of applicable exposure limits considered in this document are given in the Bibliography of Standards, for example ICNIRP-2020, ICNIRP-1998, IEEE Std C95.1™-2019 and Safety Code 6. The standard supersedes BAS EN 50383 and BAS EN 50492. [17]

III. Low Frequency Electromagnetic Radiation

Low-frequency electromagnetic radiation is a topic of great public concern, given the presence of transmission and distribution facilities and their components in all environments. The group of low-frequency electromagnetic radiation with a frequency of 50 Hz includes radiation from household appliances, power distribution cables in buildings, distribution and transmission lines, substations and switchgear, underground electrical cables.

At low frequencies, the electric and magnetic fields are practically independent, so they can be observed separately, which makes their calculation and measurement easier. The electric field practically depends only on the voltage level of the conductor, which is constant thanks to voltage regulation in the power system, while the magnetic field depends on the current, which constantly changes over time due to changes in the load.

In households, in addition to electrical installations, there are a large number of appliances used every day, which are sources of radiation at a frequency of 50 Hz. As can be seen from Table 1, most of them induce magnetic fields in their immediate vicinity, the value of which is higher than that of high-voltage power lines. [6]

TABLE I. Values of electric field strength and magnetic induction for household appliances [6]

Device	Magnetic induction B (μT)			Elec. field E (kV/m)
	At a distance			
	3 cm	30 cm	1 m	30 cm
Hairdryer	**6 – 2000**	0.01 – 7	0.01 – 0.03	0.08
Electric shaver	**15 – 1500**	0.08 – 9	0.01 – 0.03	
Vacuum cleaner	200 – 800	**2 – 20**	0.13 – 2	0.05
Fluorescent bulbs	40 – 400	**0.5 – 2**	0.02 – 0.25	
Microwave	73 – 200	**4 – 8**	0.25 – 0.6	
Radio receiver	16 – 56	**1**	< 0.01	0.18
Electric oven	1 – 50	**0.15 – 0.5**	0.01 – 0.04	0.008
Washing machine	0.8 – 50	**0.15 – 3**	0.01 – 0.15	
Iron	8 – 30	**0.12 – 0.3**	0.01 – 0.03	0.12
Dishwasher	3.5 – 20	**0.6 – 3**	0.07 – 0.3	
Computer	0.5 – 30	**< 0.01**		
Refrigerator	0.5 – 1.7	**0.01 – 0.2**	< 0.01	0.12
Television	2.5 – 50	0.04 – 2	**0.01 – 0.15**	0.06

During the design phase of transmission lines and substations, electromagnetic fields are calculated to ensure that the electromagnetic radiation of the constructed facilities will be within the permitted limits. As confirmation of the above, the first measurements are carried out, after which the constructed facilities can receive an operating permit. Also, later, during the exploitation of the facilities, periodic measurements are carried out to check the levels of electromagnetic radiation. Measurements are carried out exclusively by an independent accredited institution according to the standards specified in Chapter IV..

A. *Example of analysis of magnetic induction levels near a transformer station*

A typical example that can be taken as a representative of electromagnetic radiation are distribution transformer stations located in or near facilities such as: residential buildings, schools, kindergartens or other public facilities that are characterized as zones of increased sensitivity.

As an example, 10/0.4 kV and 20/0.4 kV transformer stations were taken, where the dominant source of magnetic induction in the zone of increased sensitivity is represented by 0.4 kV busbars, which connect the transformer and the 0.4 kV distribution, Figure 1. Measurements obtain magnetic induction values that depend on the current load of the transformer, while calculations can also obtain maximum magnetic induction values that would occur when the transformer is loaded with the specified current. [7]

Figure 1. Transformer station in the basement of a residential building (10/0,4 kV, 1 × 1000 kVA) [10]

The level of magnetic induction in the zone of increased sensitivity primarily depends on the layout of the equipment in the transformer station, primarily on the position of the busbars connecting the transformer and the 0.4 kV distribution, but also on the power of the transformer, i.e. its rated current. Tests have shown that transformer stations in which the 0.4 kV busbar connections are located directly next to the ceiling or wall of the transformer station represent the most unfavorable configuration from the aspect of exposure to the magnetic field, if the area of the zone of increased sensitivity is located on the other wall.

However, in practice there are cases when the measurement gives a magnetic induction value that is lower than the reference limit value (40 μT[2]), and the calculation shows that when the transformer is loaded with the specified current, the magnetic induction value in the zone of increased sensitivity would exceed the reference limit value. In such cases, the application of the calculation methodology is of utmost importance, in order to make a reliable and final conclusion on compliance with the prescribed exposure limits and to take appropriate protective measures. In addition, there are cases when measurements in the zone of increased sensitivity yield values that exceed 10% of the limit reference level (4 μT), which is why the transformer station is categorized as a source of special interest, but the calculation shows that the limit reference value cannot be exceeded even when the transformer is loaded with the specified current, so the application of the calculation methodology is also important in such cases.

An example of the analysis of the influence of the distance between the rails on the values of magnetic induction is given.[8] The value of magnetic induction was calculated at a distance r = 0.5 m from the rails and at a current I = 1000 A through the rails. The distance between the rails (d) was varied in the range from 15 cm to 50 cm. The obtained results are shown in Figure 2. It is shown that with increasing the distance between the rails, the values of magnetic induction increase.

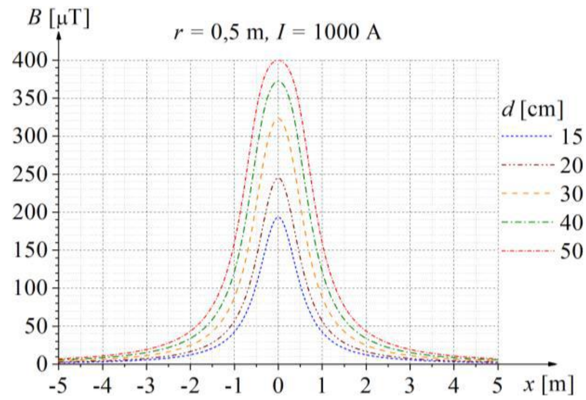

Figure 2. Calculated values of magnetic induction for different distances between rails (*d*) [8]

In the second case, the influence of the distance from the rails on the values of magnetic induction was analyzed. The calculation was carried out for the distance between the rails d = 0.3 m and the current I = 1000 A. The distance from the rails (r) was varied in the range from 0.5 m to 1 m. The obtained results are shown in Figure 3. The figure shows that with increasing distance from the rails, the values of magnetic induction decrease.

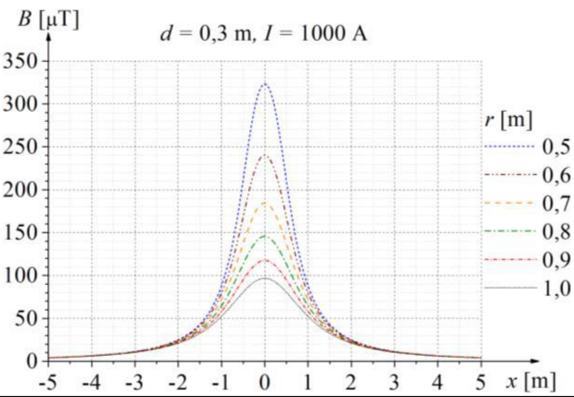

Figure 3. Calculated values of magnetic induction for different distances from the rails (*r*) [8]

A summary of the results obtained is given in Figure 4. The figure shows the values of the distances from the low-voltage rails, at which the calculated magnetic induction values are lower than the limit reference value (40 μT), for different distances between the rails (0.25 m and 0.5 m) and different values of the rated transformer power (400 kVA, 630 kVA and 1000 kVA). The values of the distance (r), for which the magnetic induction values do not exceed the limit reference level (40 μT), are higher at larger distances between the rails, as well as at higher rated powers, i.e. rated transformer currents..

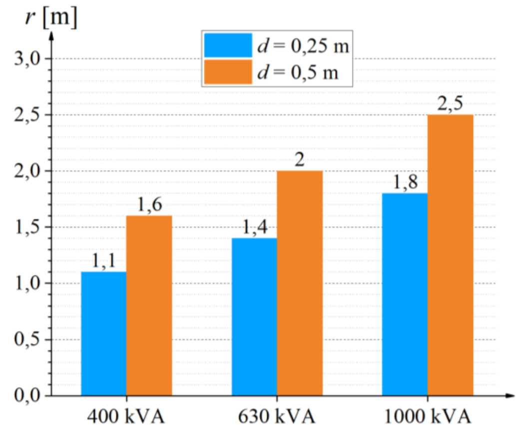

Figure 4. Distances from low voltage rails, r (m), at which the calculated values of magnetic induction are lower than 40 μT [8]

IV. Recommendations and Legal Regulations

Due to the emergence of an increasing number of sources of electromagnetic radiation, in the last few decades great attention has been paid to studying the impact of electromagnetic fields on living beings, primarily on humans. Taking into account previous epidemiological, laboratory and other studies, competent and world-renowned institutions have issued recommendations that, among other things, set the limit values for the intensity of electric and magnetic fields to which living beings can be exposed without this exposure affecting their health.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has issued recommendations:

• *"ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", Health Physics vol. 74, pp. 494 –522, 1998.* For fields with a frequency of 50 Hz, the limit values for electric field strength and magnetic induction are 5 kV/m and 100 μT, respectively, for the general population.

For the frequency range from 1 Hz to 100 kHz, new recommendations were published in 2010.

• *"ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz)", Health Physics vol.99(6), pp. 818-836, 2010.* For fields with a frequency of 50 Hz, the limit values for electric field strength and magnetic induction are 5 kV/m and 200 µT, respectively, for the general population. [3]

In 1999, the European Union published a recommendation in which the limits for exposure to electromagnetic fields for the general population were taken directly from the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) from 1998. *COUNCIL RECOMMENDATION of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC).* [4]

The World Health Organization (WHO), as part of its mandate to protect public health and in response to public concern about possible health effects from exposure to electromagnetic fields, established an international project in 1996 to assess the scientific evidence on the possible health effects of electromagnetic fields in the frequency range from 0 to 300 GHz. The project encourages focused research to fill gaps in knowledge and facilitate the development of internationally acceptable standards that limit exposure to electromagnetic fields. [5]

Table 2 provides an overview of European countries that have accepted a recommendation from relevant international organizations (ICNIRP recommendation or similar limit values determined so as not to cause adverse health effects) – Group I; countries that have prescribed much stricter limit values (either in addition to or instead of the EU Recommendations) – Group II; and countries that have also adopted additional recommendations (not expressed as numerical limits) – Group III.

TABLE II. OVERVIEW OF COUNTRIES THAT HAVE ACCEPTED THE RECOMMENDATIONS EУ [9]

Group I	Group II	Group III
Bulgaria	Austria	Denmark
Cyprus	Belgium	Great Britain
Czech Republic	Switzerland	Norway
Germany	Italy	Sweden
Estonia	Croatia	
Spain	Lithuania	
Finland	Luxembourg	
France	Netherlands	
Greece	Poland	
Hungary	Serbia	
Ireland	Slovenia	
Latvia	Montenegro	
Portugal		
Romania		
Slovakia		

The need to legally regulate this area in our country has been recognized, which has been implemented by adopting laws and accompanying bylaws. The *Law on Protection from Non-Ionizing Radiation*, adopted in 2019 ("Official Gazette of the Republika Srpska", No. 36/19), as well as the Regulation on Protection from Electromagnetic Fields up to 300 GHz ("Official Gazette of the Republika Srpska", No. 99/19) and the *Regulation on Professional Affairs in Protection from Electromagnetic Fields* ("Official Gazette of the Republika Srpska", No. 43/20). [11]

The values of characteristic quantities according to the *Regulations on protection against electromagnetic fields up to 300 GHz* ("Official Gazette of the Republic of Srpska" No. 99/19), for the network frequency, are given in Table 3. [2]

TABLE III. LIMIT VALUES OF REFERENCE QUANTITIES [2]

Limit values of reference quantities			
Frequency	Electric field strength E (V/m)	Magnetic flux strength H (A/m)	Magnetic flux density B (µT)
Limit values for areas of occupational exposure			
50 Hz	5000	80	100
Limit values for public areas			
50 Hz	5000	80	100
Limit values for areas of increased sensitivity			
50 Hz	2000	32	40

V. CONCLUSION

An overview of relevant standards related to the procedures for measuring and calculating electromagnetic radiation and their impact on health is given. Recommendations for limit values of international and European organizations are listed, as well as the legal regulations of our country. A characteristic example from practice is given of the calculation of electromagnetic radiation from a source near the zone of increased sensitivity, a distribution transformer station. In order for the obtained results to be on the safe side, the calculations were carried out for the case when the transformer would be loaded with the specified current. The obtained results show that the levels of magnetic induction in the zone of increased sensitivity are most affected by the transformer load current, the distance from the busbar connections to the zone of increased sensitivity, as well as the distance between the buses. When designing and constructing new transformer stations in buildings, it is necessary to take into account the layout of the equipment in the transformer station and adhere to the specified distances, so as to avoid the occurrence of high magnetic field values in zones of increased sensitivity.

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[3] Website - http://www.icnirp.org/

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[5] Website - https://www.who.int/health-topics/electromagnetic-fields#tab=tab_1

[6] Website - https://www.who.int/news-room/questions-and-answers/item/radiation-electromagnetic-fields

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[11] Website - https://rzsm.org/tehprop/mzsz

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[13] prBAS IEC 61786-2:2025 - 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 (identical IEC 61786-2:2014).

[14] BAS EN 62110:2010; BAS EN 62110/Cor1:2016 - Electric and magnetic field levels generated by AC power systems - Measurement procedures with regard to public exposure (identical EN 62110:2009).

[15] BAS EN IEC 62311:2021 - Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300 GHz) (identical EN IEC 62311:2020).

[16] BAS ISO/IEC Guide 98-3:2015 - Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) (identical ISO/IEC Guide 98-3:2008).

[17] BAS EN IEC 62232:2024 - Determination of RF field strength, power density and SAR in the vicinity of base stations for the purpose of evaluating human exposure (identical EN IEC 62232:2022).

Miljan Vasković graduated from the Faculty of Electrical Engineering, University of East Sarajevo, with the title of Bachelor of Electrical Engineering, majoring in Automation and Electronics. He has been employed at the Institute for Standardization of Bosnia and Herzegovina for eight years, as an expert associate for electrical standardization (standardization in the field of IEC/CLC/ETSI/ITU).

Goran Mrkaja is a graduate of electrical engineering, majoring in automation and electronics. He graduated from the Faculty of Electrical Engineering, University of East Sarajevo. He has been an employee of the Institute for Standardization of Bosnia and Herzegovina for more than 9 years, as an expert advisor in the EX Commission of Bosnia and Herzegovina (Commission for Testing and Certification of Explosion-Proof Devices in Bosnia and Herzegovina).